Distributed Intelligence in Critical Infrastructures for Sustainable Power
ENK5-CT-2002-00673

Distributed Generation as a means to increase system robustness

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References

[AMI-02]: Amin.M "Security Challenges for the Electricity Infrastructure". Computer, Pages: 8-10, Volume: 35, Issue: 4, April 2002.

[AMP-00]: Rapport final de la Commission Ampere, October 2000.
http://mineco.fgov.be/energy/ampere_commission/ampere_commission_fr.htm

[AND-77]: Paul.M.Anderson and A.A.Fouad, "Power System Control and Stability" The Iowa State University Press, 1977.

[BOE-98]: BOE num.197, Ministerio de Industria y Energia, Martes 18 Agosto 1998. (Spanish Energy and Industry department) **http://www.cne.es/**

[BON-01]: P.Bongrain, J.L.Fraise "Connection of Edf's remote control system to Dispersed Generation Units". CIRED. 16th International Conference and Exhibition on Electricity Distribution, 2001. Part 1: Contributions, Volume: Summaries;

[BRO1-02]: Brent Brobak et al "Real Time Data Acquisition from Wind Farms in Power System", IEEE Power Engineering Society Summer Meeting, 2002.Volume: 1, 21-25 July 2002 Pages:512 vol.1

[BRO2-02]: Brent Brobak et al "SCADA Systems for Large Wind Farms: Grid integration and Market Requirements", IEEE Power Engineering Society Summer Meeting, 2001.Volume: 1, 15-19 July 2001.Pages:20 – 21,vol.1.

[CAI-04]: The California ISO, "Load Voluntary Reduction Program". http://www.caiso.com/

[CAR-86]: Carpentier.J "The French National Control Center ". IEEE on Power Systems, Vol.PWRS-1,No.4, November 1986.

[CIG-03]: CIGRE B5.11, "The automation of new and existing substations: why and how". Draft. August 2003

[CIG2-03]: CIGRE Working Group 35.07, "The use of IP technology in the Power Utility environment". April 2000.

[CIG3-03]: CIGRE Joint Working Group 34/35.11, "Protection using telecommunications". August 2001.

[CIG4-03]: CIGRE Working Group 35.07, "Power System Communications in the High Speed environment". April 1996.

[COL-97]: "Dictionary of Information Technology", Ed. Peter Collin Publishing, 1997.

[CRA1-03]: Crappe, Michel et al, "Commande et régulation des réseaux electriques".Ed.Lavoisier. Paris, 2003.

[CRA2-03]: Crappe, Michel et al, "Stabilite et sauvegarde des reseaux electriques".Ed.Lavoisier. Paris, 2003.

[CRI-04]: C. Andrieu et al, "High Distributed network architectures and simulations", Deliverable D1.7 of ENK5-CT-2002-00673 CRISP-Project.

[EDF-01]: "Protection des installations de production raccordées à un réseau de distribution", EDF-GDF Guide Technique de la Distribution d'Electricité, Document public B.61.41.

[ETS-03]: "Report on Renewable Energy Sources (RES)", ETSO report, Brussels, December 2003.

[EXA-04]: EXaMINE project for the European Union, IST 2000 26116. "Deliverables 2.1 and 2.2 Needs Expression". **http://www.examine.ree.es/**

[FIN-00]: Donald.G. Fink and H.Wayne Beaty, "Standard Handbook for Electrical Engineers". Section 10, Supervisory Control and Data Acquisition, pp-10-147 to 10-168. Ed.Mc-Graw Hill, 2000.

[HAI-03]: Haibo You et al "Self-Healing in Power Systems: an approach using islanding and rate of frequency decline-based load shedding". IEEE Transactions on Power Systems, Volume: 18, No.1, February 2003.

[HAR-00]: James Harry Green, "The Irwin Handbook of Telecommunications", Fourth Edition , Ed. McGraw Hill, 2000.

[ICAI-04]: ICAI, Slides of Ph.D course about telecommunication system http://www.dea.icai.upco.es/sadot/doctorado/index.html

[JAM-96]: Jamniczky. L. "EMS Network Security Applications of the future". IEEE Computer Applications in Power, Pages: 42-46, Volume: 9, Issue: 2, April 1996.

[JON-99]: David.A.Jones, Ronald.L,Skelton. "The next threat to grid reliability-Data Security". IEEE Spectrum, Pages: 46-48 , Volume: 36 , Issue: 6 , June 1999.

[KHA1-02]: Abdel-Rahman Amin Khatib, "Internet-based Wide Area Measurement Applications in Deregulated Systems". Ph.D dissertation Virginia Tech, July 2002.

[KHA2-00]: Abdel-Rahman Amin Khatib et al, "Thoughts on Future Internet based Power System Information Network Architecture". IEEE Power Engineering Society Summer Meeting, 2000. Volume: 1, Pages:155 – 160, July 2000.

[KEZ-03]: Mladen Kezunovic "Data Integration and Information Exchange for Enhanced Control and Protection of Power Systems". Proceedings of the 36th Hawaii International Conference on System Sciences, 2003.

[KUN-94]: Prabha Kundur, "Power System Stability and Control", Ed.McGraw-Hill, 1994.

[LUQ1-94]: Jose Ignacio Escudero, Joaquin Luque, "Telecontrol de Redes Electricas", Universidad de Sevilla, Departamento de Tecnologia Electronica , Sevilla 1994.

[LUQ2-94]: Fernando Gonzalo, Joaquin Luque, "Redes de Comunicacion en Redes Electricas de Reparto y Distribucion", Congreso DECUS, Santander 1995.

[MAK-03]: Yuri Makarov et al "On risk-based Indices for Transmission Systems", IEEE Power Engineering Society General Meeting, 13-17 July 2003, Toronto, Canada.

[MAR-01]: Donald.J.Marihart "Communications Technology Guidelines for EMS/SCADA Systems", IEEE Transactions on Power Delivery, Vol.16, No.2, April 200.

[MCD-01]: John.D.McDonald "Managing the Data and choosing the right protocol", IEEE/PES Transmission and Distribution Conference and Exposition, 2001, Pages: 970 - 973 vol.2, 28 Oct.-2 Nov. 2001.

[MIT-99]: Jose Fernando Prada, "The Value of Reliability in Power Systems –Pricing Operating Reserves", Massachusetts Institute of Technology, June 1999.

[MOZ1-04]: Chuck Mozina. "Protecting generator sets using digital tecnology". Beckwith Electric. http://www.beckwithelectric.com/infoctr/protect.htm

[MOZ2-04]: Chuck Mozina. "Interconnection Protection of IPP Generators at Comercial/Industrial Facilities". IEEE Transactions on industry Applications, Vol.37,No.3, May/June 2001.

[NAD-02]: Biju Naduvathuparambil et al, "Communication Delays in Wide Area Measurement Systems", Proceedings of the Thirty-Fourth Southeastern Symposium on System Theory, 18-19 March 2002, Pages: 118 - 122

[PGE-04]: Pacific Gas and Electricity Company, "Load Management Programs", http://www.pge.com/

[QIU1-02]: Bin Qiu, "Next Generation Information Communication Infrastructure and Case Studies for Future Power Systems" Ph.D dissertation Virginia Tech, April 2002.

[QIU2-02]: Bin Qiu et al, "Web-based SCADA display systems (WSDS) for access via Internet". IEEE Transactions on Power Systems, Vol.15, No.2, May 2000.

[ROD-02]: Juan. M.Rodriguez et al, "Incidence on Power System Dynamics of High Penetration of Fixed Speed and doubly Fed Wind Energy Systems: Study of the Spanish Case". IEEE Transactions on Power Systems, Vol.17, No.4, November 2002.

[SCE-04]: Southern California Edison, "Demand Response Programs", http://www.sce.com/

[SHA-03]: Mohammad Shahidehpour and Yaoyu Wang, "Communication and Control in Electric Power Systems" IEEE Press, 2003.

[SUS1-03]: Soren Varming, Christian Gaardestruo and John Eli Nielsen, "Review of Technical Constraints for Integration of Distributed Generation in Electricity Networks". Deliverable version 1.1 of ENK5-CT-2001-00577 SUSTELNET-project.

[SUS2-03]: Soren Varming, Christian Gaardestruo and John Eli Nielsen , "Review of the role of ICT in Network Management and Market Operations". Deliverable version 1.1 of ENK5-CT-2001-00577 SUSTELNET-project.

[TOM-04]: Tomsovic.K et al "Designing the Next Generation of Real-Time Control, Communication and Computations for Large Power Systems", Submitted to IEEE Proceedings-Special Issue on Energy Infrastructure Systems 2004.

[TI-01]: J.P Clerfeuille et al, "Plan de Défense des réseaux contre les incidents majeurs", Techniques de l'Ingénieur, D4807.

[UCTE1-03]: UCTE Operation handbook, July 2003.

[UCTE2-03]: UCTE Operation handbook, December 2003.

[WEB01-04]: http://www.citris.berkeley.edu/defense/slides/Amin-Feb-04.PDF

[WEB02-04]: IEC/TR 62210 Standard, http://webstore.iec.ch/webstore/webstore.nsf/artnum/030578

[WEB03-04]: Project ExAMINE, http://www.examine.ree.es

[WEB04-04]: Siemens Spectrum, http://www.eci.siemens.com

[WEB05-04]: ICAI, Ph.D course about telecommunication system slides, http://www.dea.icai.upco.es/sadot/doctorado/index.html

[WEB06-04]: Webopedia, The online dictionary for Computer and Internet definitions, http://www.webopedia.com/

[WEB07-04]: Svenska kratnatt (Swedish TSO), http://www.svk.se/

Abbreviations

Acronym	Means
AC	Alternating Current
ACL	Agent Communication Langage
ADSL	Asymmetric Digital Suscriber Line
API	Application Programming Interfaces
APX	Amsterdam Power eXchange
ARP	Address Resolution Protocol
ASCII	American Standard Code for Information Interexchange
ATM	Asynchronous Transfer Mode
BT	Bluetooth
BO	Business Operations
BUSMOD	Business Modelling in a world of distributed generation
B2B	Business to Business
CCIT	Comite Consultatif International Telegraphique et Telephonique
CDI	Constrained Data Items
CHP	Combined Heat Power
CIM	Common Information Model
COMTRADE	Common Format for Transient Data
COP	Coefficient Of Performance
CPU	Central Processing Unit
CRISP	Distributed Intelligence in CRitical Infrastructures for Sustainable Power
DC	Direct Current
DG	Distributed Generation
DG	Dispersed Generation
DG-RES	Distributed generation based on renewable energy systems
DMS	Distribution Management System
DNO	Distribution Network Operator
DNP	Dictribution Network Protocol
DNS	Domain Name Server
DoS	Denial of Service (security study)
DR	Distributed Resources
DSM	Demand Side Management
EDI	Electronic Data Interchange
EDIFACT	EDI for administration, commerce and transport
ELF	Extremely Low Frequency
EMS	Energy Management System
EPS	Electric Power System
EHF	Extremely High Frequency
ESP	Encapsulating Security Protocol
FCI	Faulted Circuit Indicator
FDD	Fault Detection and Diagnostics
FPI	Fault Passage Indicator
FTP	File Transfer Protocol
GUI	Graphical User Interface
GIG	Global Information Grid
GPS	Global Positioning System
GW	Gateway
HF	High Frequency
HMI	Human Machine Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
HV	High Voltage

HVAC	Heating Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
ID	Identifier
IED	Intelligent Electronic Device
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISO	International Standards Organization
ICT	Information and Communication Technology
IED	Intelligent Electronic Devices
IEEE	Institute of Electrotechnical and Electronics Engineers
IEC	International Engineering Consortium
IP	Internet Protocol
IVP	Integrity Validation Procedures
LAN	Local Area Networks
LEO	Low Earth Orbit (satellite)
LF	Low Frequency
LN	Logical node
LPS	Lightweight Privilege Separation
LV	Low Voltage
MAS	Multi Agent Systems
MMS	Manufacturing Message Specification
MOM	Means, Opportunity and Motif
MV	Medium Voltage
NBW	Network-Based Warfare
NRU	No Read Up
NWD	No Write Down
OLTC	On Load Tap Changer
OSGi	Open Software Gateway initiative
OSI	Open Systems Interconnection
PAM	Pulse Amplitude Modulation
PCC	Point of Common Coupling
PDA	Personal Digital Assistant
PLC	Power Line Carrier
PMU	Phasor Measurement Unit
PNO	Power Net Operations
PPP	Point-to-Point Protocol
PQ	Power Quality
PS	Power System
PSTN	Public Switched Telephone Network
PV	Photovoltaic
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RES	Renewable Energy Systems
RF	Radio Frequency
SCADA	Supervisor Control and Data Acquisition
SCL	Substation Configuration Language
SDM	Supply and Demand Matching
SHF	Super High Frequency
SO	Services Operations
SONET	Synchronous Optical Network
SVC	Static Var Compensator
SVG	Static Var Generator
TBS	Time Based Security
TCBR	Thyristor Controlled Braking Resistor
TCP	Transmission Control Protocol
THF	Tremendously High Frequencies

TSO	Transmission System Operator
UCA	Utility Communication Architecture (EPRI)
UCTE	Union for the Co-ordination of Transmission of Electricity
UDP	User Datagram Protocol
UDI	Unconstrained Data Items
UHF	Ultra High Frequencies
UML	Unified Model Language
UPS	Uninterruptable Power Supply
UVLS	Under Voltage Load Shedding
VHF	Very High Frequency
VLAN	Virtual Local Area Network
VLF	Very Low Frequency
WAP	Wireless Application Protocol
WLAN	Wireless Local Area Network
WML	Wireless Markup Language
WWW	World Wide Web
WAN	Wide Area Networks

Summary

The present document is in some parts additional and complementary information to D.1.1. The need to share a common vocabulary with similar terms having different meanings leads us to give and define the usual technical words used in the power electric system and computer science (the reader will find a glossary of some terms). The direction of the works in WP 1.3 and also in other CRISP tasks leads to the definition of more concepts about the transmission and distribution system operation: ways to regulate frequency and voltage (ancillary services), benefits of distributed generation at the distribution level, current indices to qualify the system operation. These questions are defined and detailed to fix a baseline in order to define the robustness criteria which limit the DG insertion.

These robustness criteria and indices are proposed and they evaluate the system when faced to major contingencies. They take into account the static limits of the system, the amount of DG insertion, possible load shedding and the dynamic stability. Thus, the indices give an idea about the state of the system and warn the operator to take remedial in a preventive step in order to avoid catastrophic consequences.

One main goal of the work involved in WP 1.3 is to demonstrate the improvement of the system robustness when faced to major events, these major events are defined and some specific events caused by DG and susceptible to provoke a catastrophic event are specially detailed. This increase of the robustness is not always enabled by the DG because its dynamic characteristics. Therefore, different scenarios of DG performance are analysed in order to define an appropriate amount of insertion and the limiting factors. These scenarios of DG performance analyse the influence of different parameters such as: DG disconnection protection, intermittence, participation to the frequency control and to the voltage control.

The system robustness would be enhanced if DG stands the system in critcal situations, one possibility to increase the robustness it is the islanding operation at transmission and/ or distribution. The ability of islanding is commented and the new required distributed intelligence is detailed. On other side, one critical point to create islands is the protection system which is sited.

Finally, special attention is paid to communication and control aspects related to DG integration. A new architecture based on an IP network is proposed to integrate all the services of utilities in a unique network. Then other concepts such as observability, dispatchability, control and coordination are briefly commented e.g: it is necessary an increase of the observability of distribution networks which it is not today the common practice.

Glossary

The following list gives common vocabulary used in the fields of electrical power system, of information and communication technologies of computing science. Some similar terms are used by these fields but with different meanings: it is important to distinguish these differences to get as good as possible the information given by the experts and to avoid misunderstandings. The main references used to elaborate this glossary were: **[COL-97]**, **[CRI-04], [HAR-00], [UCTE1-03], [UCTE2-03], [WEB05-04], [WEB06-04].**

EPS: electrical power system
ICT: information and communication technologies
CS: computer science
MS: market system
IS: international system (given the international agreement for the physical units to use)

Active Power, EPS: average value of the real time variation of the product current by voltage, expressed in watt (W) in the IS, usually expressed in kilowatts (kW) or megawatts (MW), real component of the apparent power when expressed with imaginary numbers (see Apparent power, Reactive power)

Agent, CS:

(a) Servers that are designated to work with compatible client stubs known as user agent, which share the same server protocol. Agents are responsible for picking up and delivering messages between senders and receivers.(1)

(b) Series of command or actions that are carried out automatically on a particular file or data, the commands can be executed at a particular time in response to a signal (2)

American standard code for information interexchange (ASCII), CS: A 7-bit (plus 1 parity bit) coding system used for encoding characters for transmission over a data network

Analog, CS: A transmission mode in which information is transmitted by converting it to a continuously variable electric signal

Ancillary services, EPS : Ancillary services are interconnected operations services identified as necessary to effect a transfer of electricity between selling and purchasing entities and which a provider of transmission services must include in an open access transmission tariff (see primary control, secondary control).

Antenna, CS: Device for receiving or sending radio transmissions by converting electromagnetic impulses into electrical signals and vice versa.

Apparent Power, EPS: the product of voltage (in volts) and current (in amperes), expressed in volt-ampere (VA) in the IS. It may be given as a RMS value of the product, or as an imaginary number: the real component being the active power and the imaginary component being the reactive power. Usually it is expressed in kilo-volt-amps (kVA) or mega-volt-amps (MVA).

Architecture, CS: Layout and interconnection of a computer's internal hardware and the logical relationships between CPU, memory and I.O devices

Artifact, CS: A piece of information that is used or produced by a software development process. An artifact can be a model, a description or software.

Artificial intelligence, CS: The design and development of computer programs that imitate human intelligence, providing basic reasoning and other human characteristics

Asymmetric digital subscriber line (ADSL), CS: A technology for multiplexing a high-speed data or compressed video signal above the voice channel in a subscriber loop

Asynchronous transfer mode (ATM), CS: A broadband connection-oriented switching service that carries data, voice and video information in fixed-length 48-octet cells with a 5-octet header

Asynchronous transmission, CS: In data communications, a method of transmission in which sending and receiving of data is controlled by control characters rather than by a timing sequence

Audio frequency, CS: A range of frequencies, nominally 20 Hz to 20 kHz, that the human ear can hear

Availability of data, CS: State in which data are where the user needs them, and how the user needs them

Bandwidth, CS: The rate at which a communications link is capable of carrying data, usually measured in bits per second (bps)

Bit, CS: The smallest unit of binary information, a contraction from the words Binary Digit.

Blackout, EPS: a major event where a wide network area of the transmission network is unsupplied during a time period (may last several hours or days). In general this event leads to problem to recover the normal condition of supply (see restoration, black start capability)

Black start capability, EPS: the ability of generating unit to go from a shutdown condition to an operating condition and start delivering power without assistance from the electric system (see blackout).

Broadband, CS: A form of LAN modulation in which multiple channels are formed by dividing the transmission medium into discrete frequency segments. Also, a term used to describe high bandwidth transmission data signals.

Broadcast, CS: A transmission to all stations on a network

Byte, CS: A set of 8 bits of information equivalent to a character. Also called an octet.

Capacity, EPS: the rated continuous load-carrying ability, expressed in megawatts (MW) if active power or megavolt-amperes (MVA) if apparent power, of generation, transmission, or other electrical equipment.

Channel, CS: A path in a communications system between two or more points, furnished by a wire, radio, lightwave, satellite or a combination of media.

Coaxial cable, CS: A single-wire conductor surrounded by an insulating medium and a metallic shield that is used for carrying a telecommunications signal.

CODEC, CS: Coder/Decoder electronic device that converts an audio or video signal into a digital form (and vice versa) using various analogue to digital conversion techniques such as pulse code modulation

Communication association, CS: In a deployment diagram, an association between two nodes that implies a communication

Communication interface, CS: Serial interface of a device that allows exchange of (physical and logical) information among devices of the same or different functional levels in a hierarchical system. An interface specifies the connection as well as to the signal`s physical and functional characteristics.

Communication safety, CS: Measures and control to avoid any deterioration or losses of information (reliability)

Communication security, CS: Measures and control taken to deny unauthorized persons access to an information derived form communication facilities, and to ensure the authenticity of communication transactions.

Congestion (bottleneck), EPS: it is defined as the phenomenon that occurs when the limit of transmitted power is exceeded in a line or several lines of the electric power system.

Contingency, EPS: The unexpected failure of a system component, such as generator, transmission line, circuit breaker, switch, or other electrical element. A contingency also may include multiple components, which are related by situations leading to simultaneous component outages.

Connectionless, CS: A data transmission method in which packets are launched into the network with the sending and receiving address, but without a defined path.

Control unit, CS: Unit or equipment used to transmit orders from an alarm center to a remote site to perform operations by remote control

Consensus, CS: normal state of data and order exchanges without any incoherent situation

Curtailment, EPS: A reduction in the scheduled capacity or energy delivery

Data, CS: Digitized information in a form suitable for storage or communication over electronic means.

Datagram, CS: An unacknowledged packet sent over a network as an individual unit without regard to previous or subsequent packets.

Defence plan, EPS: The defence plan summarises all technical and organisational measures to prevent the propagation or deterioration of a power system incident in order to avoid a collapse (see blackout).

Delay, CS: The time required for a signal to transit the communications facility, also known as latency.

Demand (=Consumption) , EPS: The demand is the power consumed by a part of a system, it may be given as active power, or both active and reactive power at a given instant or averaged over any designated interval of time, demand should not be confused with load (a load is usually a device that induces a demand).

Device, CS: Physical entity connected to the communication network composed of at least on communication element (the network element), which may have a control element, and/or a monitoring element.

Digital, CS: A mode of transmission in which information is coded in binary form for the transmission on the network

Disturbance, EPS: an unplanned event that produces an abnormal system condition.

Domain name service (DNS) , CS: It translates hosts name to IP addresses

Droop of a generator, EPS: it is one of the parameters set on the primary speed controller of a generation set (generator and turbine). It is equal to the quotient of the relative variation in power output from the generator associated with the action of the primary controller. This ratio is generally expressed as a percentage. This kind of regulation is very important to share contribution of all generators to power fast variations in the system.

ELF, CS: Extremely low frequency, communication frequencies of less than 100 Hz

Electrical energy, EPS: the generation use of electric power by a device integrated over a period of time, expressed in kilowatt-hours (kWh), megawatt-hours (MWh), or gigawatt-hours (GWh) when dealing with the active power. The reactive energy may be also defined as the time integration of the reactive power.

Electrical power system, EPS: the power system comprises all the installations of generation, of transmission, of distribution, and of consumption that are interconnected together through a network. A distinction may be done between the transmissions EPS which is relative to the HV and VHV network including large production units, and the distribution EPS which is relative to MV and LV network including DG and DG-RES up to a few MVA.

Electric system losses, EPS: total electric losses in the electric system. The losses consist of transmission, transformation and distribution losses between supply sources and delivery points. Electric energy is mainly lost due to heating in the transmission and distribution components.

Electronic data interchange (EDI), CS: The intercompany exchange of legally biding trade documents over a telecommunication network

Error, CS: Any discrepancy between a received data signal from the signal as it was transmitted

Ethernet, CS: The Ethernet network is a local-area network (LAN) protocol developed by Xerox Corporation in cooperation with DEC and Intel in 1976. Ethernet uses a bus or star topology, and supports data transfer rates of 10 Mbps (standard) or 100 Mbps (using the newer 100Base-T version). The Ethernet specification served as the basis for the IEEE 802.3 standard, which specifies the physical and lower software layers. Ethernet uses the CSMA/CD access method to handle simultaneous demands. It is one of the most widely implemented LAN standards.

EHF, CS: Extremely high frequencies, radio frequencies from 30-300 GHz

Facility, CS: Any set of transmission paths that can be used to transport voice or data. Facilities can range from a cable to a carrier system or a microwave system.

Failure, EPS: The inability of a system or system component to perform a required function within specified limits. A failure may be observed when dealing with a fault: the protection may dysfunction, the circuit-breaker may dysfunction, and electrical components in the fault current passage may be broken for instance (see reliability).

Fault, EPS: unintentional connection or disconnection between conductors in the system, a major part of this event being the different types of short-circuits which can happen during the system operation. These faults can be caused by human errors, climatic conditions or natural events.

File transfer protocol (FTP), CS: A protocol use by TCP/IP networks to transfer files from one system to another system. It is a file sharing protocol that operates between layers 5,6 and 7 of an ISO model network

Firewall, CS: A device or combination of hardware and software used to enforce security. It protects the connection between a network and an untrusted connecting network such as internet. The firewall blocks unwanted traffic from entering the network and allows only authorized traffic to leave.

Frame relay, CS: A data communications service that transports frames of information across a network to one or more points.

Frequency control, EPS: primary control

Gateway, CS: Circuitry used to interconnect networks by converting the protocols of each network to that used by the other

Generation set, EPS: the set of machines consisting of a generator (and its driving apparatus) and a turbine of a generation unit.

HF, CS: High frequency, radio communications range of frequencies from 3-30 MHz

Hub, CS: A device connected to several other devices. It accepts a signal and distributes it from one point and redistributes it to more points within a network.

HTML, CS: Hypertext Transfer Protocol, this protocol is used to identify the address of www pages stores on the Internet

ICT component, ICT: object dedicated to a given application and whose algorithm is new enough to classify it as being ICT type.

Integrated services digital network, CS: A set of standards promulgated by ITU-T to prescribe standard interfaces to a switched digital network

Integrity, CS: Immunity requirements to the network data transfer errors due to accidental or intentional interference. Three levels are defined**:**

-High : where a vanishing small probability of undetected error must be achieved
-Medium : where inherent data redundancy provides adequate error immunity
-Low, where errors are merely a nuisance to the data recipient

Internet Protocol (IP), CS: A connectionless protocol used for delivering data packets from host to host across an internetwork

Island, EPS: a portion of a power system that is electrically separated from the main interconnected power system for which it is usually design to work. Intentional islanding means that the situation should be under control to maintain normal condition within the island: this ability may improve highly the restoration in large EPS. Unintentional islanding is generally a nuisance situation where the system is not able to deal with and that makes problem with protection detection (problem of safety and security).

Latency, CS: The delay between the time the data is sent from its origin and its received at its destination. Latency determines how responsive the link will be.

LF, CS: Low frequency, range of audio frequencies between 5-300 Hz or range of radio frequencies between 30-300 kHz

Link, CS: A circuit or path joining two communications channels in a network

Local area network, CS: A narrow-range data network using one of the non-switched multiple access technologies

Low earth orbiting satellite (LEOS), CS: A global personal communications service technology using a constellation of satellites orbiting the earth at a few hundred miles for communications with hand-held units.

Load, EPS: an end-use device or customer that receives power from the electric system. Load is commonly confused with demand, and so expressed in watt or in watt and var.

Load shedding, EPS: disconnection of load from the synchronous electrical system, usually fast and automatically, to limit a collapse of the frequency in critical situation. The frequency is a criterion of the balance between the global production and the global consumption. Under a threshold of frequency (a portion of 1 hertz for a large EPS in general) the risk of total collapse is clear, so the load shedding is a type of defence plan today.

Local intelligence, EPS: it is a decision block or tool that advises the operator (help to decision) or even in some cases takes automatically decisions related with the system configuration, protection, conversion and primary analysis of information.

Mainframe, CS: Large-scale high power computer system that can handle high capacity memory and backing storage devices as well as a number of operators simultaneously.

Master/Slave, CS: Communication management scheme called polling in which one IED (the master) requests one IED, or group of IEDs (Slaves), to deliver specified information. Only masters, not slaves, may issue unsolicited data pr commands. Used where data flows primarily between the slaves and the master

Microwave, CS: A high-frequency, high-capacity radio system, usually used to carry multiple voice channels.

Modem, CS: A contraction of Modulator/Demodulator. A modem is used to convert analog signals into digital form and vice versa

Multicast, CS: A transmission that includes selected stations on a network

Multiplexer, CS: A device used to combine several lower-speed channels into higher-speed channels

Network, CS: A set of communications nodes connected by channels

Node, EPS: point of the grid description connecting components of the network as conductors sections, switches and so on.

Node, CS: A major point in a network where lies from many sources meet and may be switched

Noise, CS: Any unwanted signal in a transmission path

Nuisance tripping, EPS: when a protection device makes trip a circuit-breaker, cutting the supply of a part of a network without a real need. It is an issue between the need of protection margin and also the need of reliability.

N-1 criterion, EPS: rule according to which, if a single network operating element fails (e.g. transmission line/ transformer or generation unit, or in the certain instances a bus-bar), the elements remaining in operation must be capable of accommodating the change of flows in the network caused by that single failure. This criterion is a major robustness criterion used today in the large EPS. It may be extrapolated in a N-2 criterion which means a right dynamical behaviour facing two important components loss in a short period of time.

Octet, CS: A group of 8 bits. Often used interchangeably with byte, although a byte can have other than 8 bits

Open systems interconnection (OSI) , CS: A seven layer data communications protocol model that specifies standard interfaces which all vendors can adapt to their own designs

Overhead, CS: Any noninformation bits such as headers, error-checking bits, start and stop bits, etc, used for controlling a network

Operating security limits, EPS: they define the acceptable operating boundaries (thermal, voltage and stability limits). Violation of operating security limits for prolonged time could cause damage and/or an outage of another element that can cause further deterioration of system operating conditions.

Packet, CS: A unit of data information and error-detection and trailer records

Primary frequency control, EPS: it maintains the balance between generation and demand in the network using turbine speed governors. Primary control is an automatic decentralised function of the turbine governor to adjust the generator output of a unit as a consequence of a frequency deviation. The link between the frequency deviation and the contribution of local variation of power is driven by the droop (see droop of a generator). The primary control is effective during the first minute following a power balance deviation in the system (see secondary control).

Primary voltage control, EPS: it maintains the voltage at the PCC of the generator close to a voltage reference given by the TSO. The regulation acts on the excitation current in order to control the exchange of the reactive power with the network, so acting on the voltage local magnitude.

Protection, EPS: the means used in the system to face the various situations endangering men and equipment. It is a very large field of applications, a part dealing with clearing the faults in the system conveniently.

Protocol, CS: The conventions used in a network for establishing communications compatibility between terminals and for a maintaining the line disciple while they are connected to the network

Protocol converter, CS: A device that converts one communications protocol to another

Radio frequency, CS: Electromagnetic spectrum that lies frequency range 10 kHz and 3000 GHz

Reactive power, EPS: In mathematical words it is the imaginary component of the apparent power. An inductance consumes reactive power and a capacitor produces reactive power: the resulting current is phase at 90° with the voltage across these components. It is usually expressed in kilovars (kVAr) or megavars (MVAr). Reactive power is provided by generators, synchronous condensers or electrostatic equipment such as capacitors and directly influenced the electric system voltage (see active power, apparent power). In general this power is unwanted (inducing losses in the network) but controlling this flux is useful in the transmission network to control the voltage in different points.

Redundancy, CS: The provision of more than one circuit element to assume call processing when the primary element fails

Reliability, EPS: a general term encompassing all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilisation within acceptable standards and in the amounts desired. Power system reliability (comprising generation and transmission facilities) can be described by two basic and functional attributes: adequacy and security.

-Adequacy: a measure of the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings and voltage limits, taking into account of planned and unplanned outages of system components. Adequacy measures the capability of the power system to supply the load in the steady states in which the power system exists.

-Security: a measure of power system ability to with stand sudden disturbances such as electric short-circuits or unanticipated losses of the system components together with operating constraints. Another aspect of security is system integrity, which is the ability to maintain interconnected operations. Integrity relates to the preservation of interconnected system operation, or the avoidance of uncontrolled separation, in the presence of specified severe disturbances.

Repeater, CS: A bidirectional signal regenerator (digital) or amplifier (analog). Repeaters are available to work on analog or digital signal form audio to radio frequency.

Routing, CS: The path selection made for a telecommunications signal through the network to its destination

Secondary control: it is a centralised automatic function to regulate the generation in a control area based on secondary control reserves in order to maintain its interchange power flow and to restore the frequency in case of a frequency deviation originated in the control area to its set value in order to free the capacity engaged by the primary control (and to restore the primary control reserve). Secondary control is applied to selected generator set in the power plants. Secondary control operates in the range of tens of minutes and so is dissociated from the primary control, its function being also to recover as fast as possible a primary control storage.

Security, CS: Immunity of networks resources to accidental or intentional unauthorized access. Three levels are defined:

-High, where access is limited to predefined and validated clients
-Medium, where access is granted to nay client meeting simple criteria
-Low, where access (usually read only) is granted to any client

Server, CS: In a telecommunications network servers are the trunks on the service process, such as call center agents, that fulfil the users` service requests. In a LAN servers are devices that provide specialized services such as file, print ,and modem or fax pool services

SHF, CS: Super High Frequency

Simple Mail Transfer Protocol (SMTP) , CS: A protocol for delivering messages across a TCP/IP network

Simple Mail Management Protocol (SNMP) , CS: A management protocol for monitoring and controlling network devices

Spread Spectrum, CS: A radio modulation method that transmits its signal over a broad range of frequencies or rapidly jumps from one frequency to another. Spread spectrum provides excellent security and resists interference

SQL, CS: Structure Query Language, simple, commonly used standard, database programming language that is only used to create queries to retrieve data form the database

Stability, EPS: the ability of an electric power system to maintain a state of equilibrium during normal and abnormal system conditions or disturbances.

-Small-signal stability: the ability of the electric system to withstand small changes or disturbances without the loss of synchronism among the synchronous machines in the system. This study deals with the regulations of the production units in order to meet a convenient damping of possible system oscillations.

-Transient stability: the ability of an electric system to maintain synchronism in the whole network when facing a severe disturbance (as short-circuit in a transmission line). The risk is a loss of synchronization between different parts of the system (by some synchronous generators), leading to a risk of general collapse.

Stakeholder, MS, EPS: entity that play a role in a given architecture

Synchronous, CS: A method of transmitting data over a network wherein the sending and receiving terminals are kept in synchronism with each other by a clock signal embedded in the data

Supervisory control and Data Acquisition (SCADA), EPS: a system of remote control and telemetry used to monitor and control the electric system. This kind of system is largely used in the transmission EPS, and less developed for the distribution EPS.

Supply and demand matching, EPS: name of an application studied in CRISP project, whose the goal is iterative and cost-effective: predict the demand and supply one day before, schedule the energy price (using the concept of money), update then the previous prediction and so on. The expected result is a self-control of energy balance by a better spread of load in time scale and space.

System reconfiguration, CS: (a) Procedure to manage changes in power system connectivity, (b) Procedure to overcome failures in redundant secondary systems

Tertiary control, EPS: it is any automatic or manual change in the working points of generators (mainly by re-scheduling), in order to restore an adequate secondary control reserve in the range of a few hours.

Throughput, CS: Information bits correctly transported over a data network per unit of time

Token ring, CS: A type of computer network in which all the computers are arranged (schematically) in a circle. A token, which is a special bit pattern, travels around the circle. To send a message, a computer catches the token, attaches a message to it, and then lets it continue to travel around the network.

Transmission Control Protocol (TCP) , CS: A protocol for providing end-to-end delivery data across an internetwork, usually with IP

THF, CS: Tremendously High Frequencies, radio frequency between 300 GHz and 3000 GHz

Trunk, CS: A communications channel between two switching systems equipped with terminating and signalling equipment. It usually refers to large-bandwidth telephone channels between switching centers that handle many simultaneous voice and data signals.

UHF, CS: Ultra high Frequencies, range of frequencies normally used to transmit television signals

Unified Modelling Language (UML), CS: The modelling language is the mainly graphical notation that methods use to express designs. UML defines the semantics of the object metamodel and provides a notation for capturing and communication object structure and behaviour

Uplink, CS: The radio path from an earth station to a satellite

User Data Protocol (UDP) , CS: A connectionless, unreliable, transport layer network protocol for the exchange of requests and replies between connected stations

VHF, CS: Very High Frequency, range of radio frequencies between 30- 300 MHz

Virus, CS: Self-replicating, malicious program segment that attaches itself to an application program or other executable system component

VLF, CS: Very Low Frequency, range of frequencies between 3-30 kHz

Vulnerability, CS: Weakness in an information system or cryptographic system, or components that could be exploited

X.25, CS: standard that defines the connection between a terminal and a packet-switching network

X.400, CS: standard that defines an electronic mail transfer method

WAN, CS: Wide Area Network in which the computers, peripehericals and terminals are far apart and linked by radio, telephone or microwave connections

Wireless, CS: A radio or infrared-based service that enables telephone or LAN users to connect to the communications network without wire

www, CS: World Wide Web thousands of formatted text and graphics (stores in HTML) that allow a user to have a graphical user interface to the Internet.

1. Introduction

This task lists the potential of distributed generation to increase the robustness of electrical system when faced to major weather disturbances and large blackouts. The objective of such strategy is to reduce the dependency of supply on transmission lines and avoid catastrophic social and economical impacts of resulting blackouts. Furthermore, it may avoid high investment costs for network upgrade, increase system autonomy, etc.

The recent projects for DG integration are going to change the EPS. This EPS is in a metamorfosis from the energy market deregulation and the new international agreements to reduce the Greenhouse gazes emissions. So, the actual tendency is the change of traditional and very polluting power plants for new technologies. In this context, there is a huge opportunity for DG and new actors.

However, the DG insertion in the system could cause some problems and impacts (positives and negatives); DG is not always a benefit for the EPS and operators should solve some questions before problems will appear. The DG technology is continuosly evolving and possible changes are expected for the next years; so different scenarios of DG dynamic reponse must be taken into account such as: different setting points of DG disconnection protections, influence of the intermittence or the participation of DG in EPS controls.

On other side, the DG could change the present radial architecture of distribution networks and new operations in closed loops and in islands could appear. These new operating points would require an increase of the intelligence distribution, observability, DG dispatchability and coordination between components.

In short, the main points treated in this report are the next ones:

- Appropriate penetration of distributed generation with respect to different risk levels and catastrophic scenarios
- Ability of distributed generation to provide islanded supply with respect to operational constraints and safety standards. Protection system should be appropriately investigated and sited.
- Communication and control aspects with respect to dispatchability, observability and co-ordination
- What intelligence should be developed in order to increase the autonomy of such systems with associated operations?
- Performance evaluation/criteria for the required robustness.

2. General knowledge on transmission and distribution

This chapter constitutes a description of different concepts and general knowledge about the EPS. Different points are treated briefly such as: security theats in EPS, regulation and control aspects, current indices to evaluate the EPS performance, the possible mechanism of the major events, the national defence plans against these major disturbances, the protection at the distribution networks and the DG disconnection protection and some specific events that DG can cause.

Finally, the robustness is defined and a new robustness indice is proposed in order to evaluate the behaviour of the system against major events and normal contingencies.

2.1 Security Challenges in Electric Power System Operation

The dependence of the actual society on the electricity supply does that the electric power supply is one of the critical points in the normal life and defence of a country. The absence of electricity provokes problems for normal life such as miss of heating, cooking, hot water, communications and industry operation between other aspects.

It is obvious that after the last terrorist attacks, 11-S and 11-M, everything is possible and a terrorist attack into the electric power system could cause enormous consequences to civil and/or military terrorist targets. As example of the importance of the electric power system, one of the Spanish government measures after the 11-M was the increase of the security in the nuclear, thermal and hydro reservoir (for water consumption and/or power production) stations.

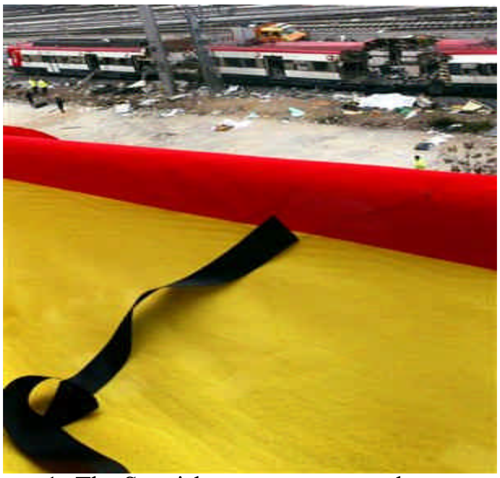


Figure.1.-The Spanish army surveys and protects the power plants (Narcea thermal power plant in the region of Asturias) after the 11-M

Photos from La Nueva Espana, 7thApril 2004 and El Mundo (report of 11-M), 8th April 2004

The attacks into the EPS could be thought by different means **[AMI-02], [JAM-96], [JON-99].**

- Attacks upon the system: the electricity network could be a primary target (the attack of power plants, critical lines in the system, substations…). Other possible attacks could happen to the electricity markets and/or to EPS communication system. The worst problems would be an attack on a nuclear power plant or a resulting black-out in which terrorists could profit the originated chaos to hit the population.

- Attacks by the power system: terrorists could use power plant cooling towers to disperse biological or chemical agents. This attack could have catastrophic consequences in the population (such it was seen in Irak by the use of chemical and biological agents).

- Attacks to the EPS communication system: the communication systems are necessary to control the system, estimating the state and taking the measures necessaries in abnormal operation states. Furthermore, the deregulation of the EPS leads to the need of coordination between different actors. In this new situation, the information must be shared between the different actors for an operation in equal terms. The system security depends on the cyber and communication security and the integrity of the associated information systems. The use of wrong data or the intrusion of unauthorized agents could lead the system to abnormal and/or uncontrolled operations which could damage the system and generate catastrophic social consequences.

The vulnerability of the electric power system is described by the possibility of different attacks to the system, but its study is not the main goal (as a whole) of the CRISP project. However, the aspects related to the security and integrity of the communication system and the transmission of the data are described in other deliverables (D.1.6 and D.2.4) of this CRISP project and they do not be repeated here. This report treats only the security or robustness concept from an electric point of view providing new solutions to enhance the system robustness by the use of high DG integration.

2.2 Communication systems

The new developments of information and communication technologies (ICTs) imply the improvement of the efficiency of the electric power operation by means of an increase of the system observability and controllability. The communications must be operated with high reliability and security to guarantee a high quality power supplies. The actual communications system of a power system will be commented in this report. Normally it is composed of several types of communication systems such as **[FIN-00], [LUQ1-94], [LUQ2-94], [MAR-01], [SHA-03]**:

- Fixed networks including public switched telephone and data networks
- Wireless networks including cellular telephones and wireless ATM (Asynchronous Transfer Mode), radio systems, microwave (radio signals operating in the 150 MHz to 20 GHz frequency range)
- Power line carrier is the most commonly used communication media for protection function. However, this medium does not offer a reliable solution for wide area data transmission. Communication with remote sites can not be maintained during a disturbance.
- Computer networks including various dedicated LANs, WANs, and the Internet.
- The satellite network is another segment of the communications system that can provide important services which are difficult to carry out with normal communication techniques. These services include detailed earth imaging, remote monitoring of dispersed locations and time synchronization using signal from GPS (global positioning system).

Communication delays for different communication links normally used for wide area measurement networks **[NAD-02]**:

Communication link	Associated delay-one way (milliseconds)
Fiber-optic cables	100-150
Digital microwave links	100-150
Power line (PLC)	150-350
Telephone lines	200-300
Satellite link	500-700

Table.1.-Communication delays of some communication in wide area measurement networks

A detailed description of these and others communication media is included in Annexe A. The different data rate of the currently media used in the power system are compared in Table 2 **[QIU1-02]**:

Transmission media	Data Rate
T1	1Mbps. Effective bandwidth considering network traffic, data collision etc is 125 kbps
Frame Relay	280 kbps
ISDN	140 kbps
T1 fractional	62.5 kbps
56k leased line	565 kbps (effective bandwidth lower than this)
Internet	Effective rate 40 kbps depends on network traffic
Radio frequency	9.6 kbps
Power line carrier	1.2 kbps

Table.2.-Data rate of currently media used in the power system

Although, some operations of the power system such as the islanding operation of a portion of the system can take some hours or even some days, the high-speed of the communications is desirable for the real time operation of power systems. The need of the real time information can be understood by the typical applications of communications in the power system:

- Data acquisition from generation, transmission, distribution and customer facilities

- Communication among different sites, substations, control centers and various utilities.
- Real-time information provided by power markets and weather service
- Database information exchange among control centers
- Relay settings adjustments
- Load frequency control and generation control
- Load shedding based on contingency analysis
- Control of devices such as FACTS

These are normal examples of applications of the system communications in the operation of the power system. But, one can think that the use of the communications will be spread not only to the control, protection and acquisition tasks but also to the maintenance or the metering. Therefore, the system requires a high bandwidth and low latency data transmission which is susceptible to be increased in the future with innovative uses. In any case, the use of the communications is relayed to the transmission of information about the system to a center which will elaborate remedial actions in case of disturbances (protection, control) or will use the information to utilise them in other task of the power system (planning, control).

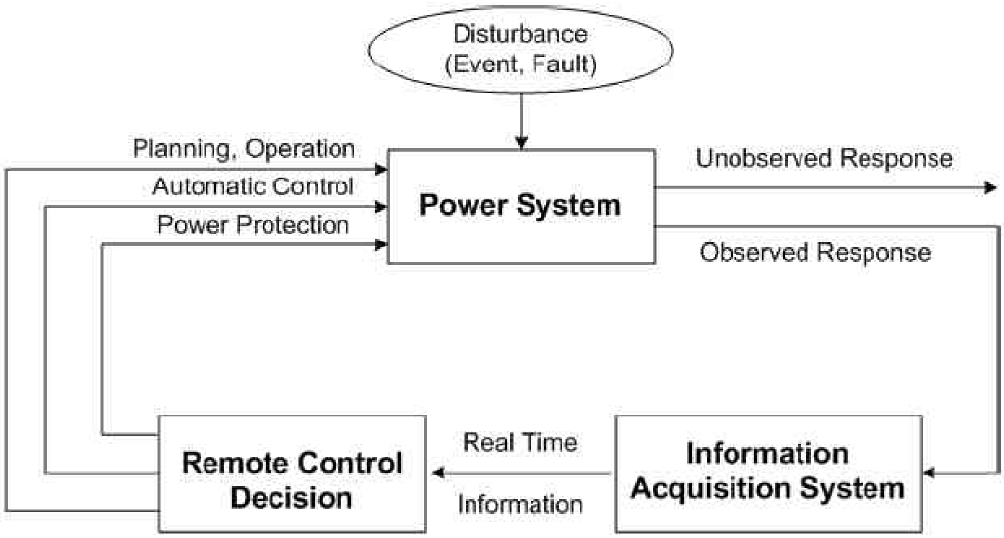


Figure.2.-The circle of measurement, information and decision making

The different tasks of the power system have different amount/ volume of information to be transmitted, that is the bandwidth needs for each task are different and with a current time response related to the nature of the task. The next table introduces the requirements of bandwidth and time response of some significant actions **[WEB01-04]** :

Power System Task	Bandwidth requirement	Current response time
Load shedding(local decision)	**Low**	**Seconds**
Adaptive Relaying (i.e. Blocking relaying)	**Low**	**Not available**
Hierarchical Data Acquisition and Transfer	**High**	**Seconds**
Line/ Bus reconfiguration	**Low**	**Minutes (by manual)**
Control devices (e.g. FACTS, Transformer)	**Medium**	**Seconds (by manual**
Fault Event Recorder Information	**Medium**	**Minutes**
Generator Control	**Low**	**Seconds**
National Strategic Power Defense Plan	**High**	**Not applicable**

Table.3.-Bandwidth requirements and response time for different power system tasks

As an example of the needs in speed and data volume of a power system task, the next table shows the different data-sampling rate and time latency requirement for the protection system **[QIU1-02]**:

Type of relay	Data volume Present (kbps/s)	Data volume Future (kbps/s)	Latency
Over current protection	**160**	**2500**	**4-8 ms**
Differential protection	**70**	**1100**	**4-8 ms**
Distance protection	**140**	**2200**	**4-8 ms**
Load shedding	**370**	**4400**	**0.06-0.1 s**

Table.4.-Data volume in protection system

In table 4, a comparison between the present data volume and future data volume is presented. The difference in the data volume does not correspond in an increase of the electric data to transmit, instead it corresponds with the forecasted changes of the communication media loaded with the electric information transmission (sampling rates (from 16 samples/cycle to 96 samples/cycle), word length (16 bits to 32 bits), communication overhead (from 1.5 to 2.0)) **[KHA1-02]**. The data of load shedding refers only the data measures of one critical point, in the normal practice of the load shedding, the critical points are N, the volume data for this system task must be multiplied by this factor to obtain the total load shedding data volume.

On other hand, power system substations become more complex due to the growth of new service requirements. The information must be transmitted under few milliseconds for the proper and adequate protection and control. The application of LAN and WAN communication technologies for substation's automation has become more and more common practice. Thus, the use of WAN communication between substations and between substations and control centres is now enabling the utilities to perform control and protection functions in a substation, using data from other sites and from different voltages levels **[CIG-03], [KEZ-03]**. That would represent a rise of the transmitted data in the SCADA.

The transmission of data and information must be carried out with a security protocol and procedure in order to prevent the intrusion of external agents which could put the system in danger. The security common tools to guarantee the normal operation (authentification, authorization, encryption, firewalls…) depend on the operating system (UNIX, Java, Microsoft.NET…) of the servers and the communication media (further information of network security models is included in D.1.6).

A new standard about power system control and its associated communications was published in May 2003, it is the IEC/TR 62210 **[WEB02-04]**. It treats the applications of computerised supervision, control, metering, and protection systems in electrical utilities. This standard deals with security aspects related to communication protocols used within and between such systems, the access, and use of the systems and it discusses realistic threats to the system and its operation, the vulnerability and the consequences of intrusion, actions and countermeasures to improve the current situation.

SCADA characteristics

As it was introduced in D1.1, the SCADA system is a part of the EMS (Energy Management System) which mission deals with the data measurement, collection and transmission to a decision central control.
SCADA usually process discrete and continuous information coming from measurements done in the field **[WEB03-04]**:

- Measurements: active and reactive power flows, bus voltages and network frequencies, for transmission networks at 2 or 4 seconds periodic update and for sub-transmission network at 20 seconds periodic update.

- Signals: breaker positions with max. 1s delay, tap changer and isolator positions with max. 4 s delay

- Chronological registration of events, consisting in changes of status of protection systems, as well as switching and regulating devices, coming from each transmission bus and incident branches. Binary information associated to the component operating configuration is locally refreshed in terms of milliseconds.

- Analog registration of significant quantities in instantaneous form (sampling time about 1 ms) or in RMS form (sampling time of about 100ms), including a subset of logical quantities to recognise protection system interventions.

In order to carry out all of these measurements and operations, the typical architecture of a SCADA system is the next one:

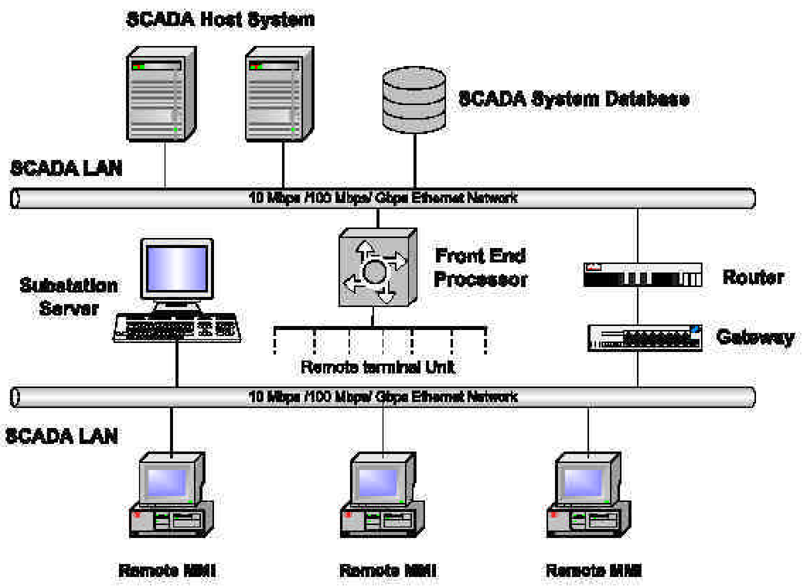


Figure.3.-Typical architecture of a SCADA system

The major components of the SCADA system are:

- Substation remote data acquisition, metering, control unit such as RTU (Remote Terminal Unit)
- Data processing unit such as a substation server or an Intelligent Electronic Device (IED)
- MMI (Man Machine Interface) and centre data processing unit installed in the control enter

The French system was one of the largest systems operated by a single company (EDF) **[CAR-86]**. The operation was obviously split in several hierarchical levels. So, real time control of the French transmission system was built around the real time data transmission subsystem; it contained four levels like most of SCADA systems:

- **Level 1:** it is the local points which pick up the information at the substations and generators by means of IEDs or PMUs. The substation of level 1 can be controlled from the bigger substations of level 2.
- **Level 2:** it is composed by big substations and this level represents a collection of data form different points in the distribution system (they are normally called RTU, remote terminal units)
- **Level 3:** It corresponds to the regional control centers (in France there are 7 control of this type). They have the mission of control the voltage at the distribution (20kV), sub-transmission (90 kV,63 kV) and transmission system (only 225kV). They do some functions of back-up if the level 4 as well.
- **Level 4:** This is the main national center which has information of everything in the system and controls it as a whole through the transmission network (400 kV). One of its most important functions is the interconnection with other countries and so the frequency control in the system and the voltage control of the 400 kV. The decisions in power control are sent to the generators connected in the sub-transmission level through the regional centers

The systems directly controlled in real time by the national control center typically contained:

- 70 substations at 400 kV (the whole 400 kV system)
- 100 substations at 225 kV.
- 40 substations representing the foreign network near the borders
- 230 generating units for which active and reactive power is transmitted to the national control center, they include all units connected to the 400 kV network and the main units connected to the 225 kV level.

The links between the different hierarchical levels were as follows:

- **Level 1-Level 2**: The speed of these links was low. Transmission always takes place by asynchronous mode. It uses telephone lines, power line carriers or radio links.
- **Level 1-Level 3**: A few direct links exist between level 1 and level 3, especially for remote controlled gas turbines or pumping hydro plants with the same characteristics as previous mentioned.
- **Level 2-Level 3**: The speed depends upon the size of the level 2 (data accumulators or collecting centers), with synchronous or asynchronous modes. It uses rented telephone lines or power line carriers.
- **Level 3-Level 4**: This part is a packet switch data transmission system. It uses telephone wire of superior quality with a very low probability of loss or error (10^{-9}). It links the computers of the regional centers with the national center computers.
- **Level 4-Foreign countries**: This is a link between the different national control centers of a country with its neighbour's countries. They have dedicated communication, and it is normally used the telephone connection.

Other important parameters in the communications between the different entities are the protocols. They are the language that allows the communication between the different devices presents in the system. These protocols are a little bit as the diplomatic tools of the system because they tell how to do the things, in which order…Different protocols can be sited: ICCP, TCP/IP, Modbus, Profibus, LON, UCA by EPRI…(further description of this protocols is available in Annexe A and B). There are a wide variety of protocols because every device manufacturer usually uses its own protocol. Anyway, the variety of protocols is not a great problem and it can be solved by means of the gateways, protocol converters or translators. The choice of the protocol depends on different parameters **[MCD-01]**:

- System area, RTU to IED, RTU to master SCADA, SCADA utility to SCADA TSO, SCADA national TSO to SCADA national TSO center…

- Time of the installation

In the case of the communication between a RTU and the IEDs the most used protocols are :DNP3, Modbus, Modbus Plus, EPRI UCA2…

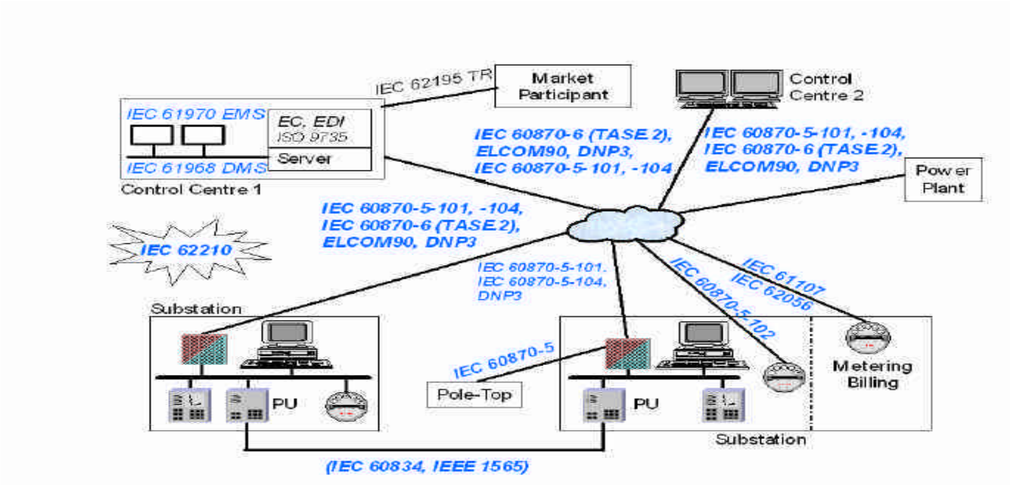


Figure.4.-Standards of Electric Power Communication

In figure 4, different standards of communication in electric power system are shown (for more information see Annexe B or CICRE.B5.11).

One commercial example: SIEMENS SCADA system

The REE (Red Electrica Española) National Grid (Spanish Transmission Operator) is driven by the SPECTRUM system from SIEMENS. This one supports next protocols for external communications: BCN, MBCN, ELCOM90 and ICCP, all running over TCP-IP.

Concerning ICCP, two ways of communication are available on the REE system:

- Exchanging real time data using ICCP frames through a dedicated redundant server

- Using the existing ICCPNT Gateway for retrieving information in flat files or in RDBMS.

Siemens Spectrum **[WEB04-04]** is a distributed network based SCADA/EMS/DMS software package. It is used as the major monitoring and control systems supports real time information acquisition and advanced EMS applications. Spectrum was developed in C/C++/Pascal and was designed to run on UNIX operating system. The main characteristic of this SIEMENS product are the following ones:

- **Archive**: the archive contains analog, digital and accumulated measurements.

- **Data processing:** the data processing includes analog, digital and accumulated measurements and it also offers averaging and maximal/minimal processing. In addition, the accumulator processing includes the calculation of load group-related consumption, hourly, daily, weekly and monthly reports. Historical Information System based on commercial relational dat-base management system (RDBMS)

- **Process interface**: the field data can easily be transmitted via various standard protocols, such as PROFIBUS, IEC 60 870 5-101,-102,-104 and SINAUT 8-FW

- **Interfaces**: interfaces on ODBC/OLE facilitate the integration of tools such as Microsoft Excel. An SQL interface is provided to get historical data. A simplified SQL interface was implemented to get access to facility data, real time data and calculated data

The future of the SCADA system could evolve to the wide used of Internet, Java or Microsoft .NET with new faster microprocessors. In the literature, several proposal solution are described, for further information the next references could be useful **[KHA2-00], [QIU2-02], [TOM-04].**

The REN (Portuguese TSO) present telecommunications network

It corresponds to an IDN (Integrated Digital Network) in large regions of the country whenever digital interfaces between switching and transmission equipments are possible. The network covers an area of 89,000 km² with 100 installations, served by approximately 90 PABX, 57 microwave links (including 31 of 8 Mbps and 16 of 2 Mbps), 7 optical fibre systems (of 34 Mbps), 220 analog single-channel PLC systems, 7 digital (2 Mbps) rented circuits and 9 symmetric pair line systems (2 Mbps). The main evolution of services concerns the National Dispatch, which will require circuits up to 9600 Mbps for the interconnection with RTU equipment **[CIG4-03]**.

2.3 Transmission networks

In this paragraph the different strategies of regulation that the system operator has to control the system are exposed. These strategies are mainly related to the frequency and voltage control. These two regulations have an obvious influence in the dynamic response of the power system.

2.3.1 Voltage control

The voltage control of the system is split into three main actions or levels of control:

- Primary control: it is the voltage regulator of the different generators that have a fast response to keep the voltage at the generator equal to the setting point. The system operator fixes the voltage setting points of the different generators in order to guarantee an adequate operating point regarding the (n-1) criterion, the maximal reactive power which is possible to generate by each generator, the voltage drop in the transmission lines and finally the voltage profile at the transmission buses. The dynamic reaction of the voltage primary control is about some seconds to one minute.

- Secondary control: it consists on the measurements of the voltage magnitude in some critical buses of the system, these buses are known by the operator as the result of its experience in the control of the system .So, if the voltage in these voltages are out of range, the operator is going to change the settings points of the voltage regulators (generators) in order to recover a voltage profile in the normalised interval. The time response of the voltage secondary control goes up to one minute and less than several minutes.

- Tertiary control: its aim is to satisfy a certain objective; the operator optimizes, with it, the system voltage profile and provides reference values of the secondary voltage control. Normally the tertiary control operates in a 15 minutes cycle.

2.3.2 Frequency control

The main goal of frequency control of the system is to maintain the value of the frequency into a normal interval of values. The frequency of the system (50Hz) is the result of the balance between production and consumption. In case of frequency deviation, the system can elaborate remedial actions in the field of the load or in the field of the generation. These two actions are of different nature and also the reaction time is different.

- Load shedding: the control of the load under abnormal operation (frequency drop) is one of the emergency actions that the operator can initiate to prevent the loss of the system. The load shedding correspond to the situation in which the load is higher that the generation and so the value of the frequency decreases down to the 50 Hz, so one remedial action is switch off loads to recover the balance production-consumption. As it was detailed in D1.5 the load shedding is done in several steps in order to give the possibility to supply the higher number of loads as possible and enable the system to recover the balance.

- Active power generation control:

    - Primary control: the primary control or speed droop is the automatic evolution of the active power with the frequency variation. After a variation of the consumption-production balance, the frequency can go out of the 50 Hz to find another operating point. The primary control uses the automatic primary reserve that the system operator disposes (at least 2.5 % of the nominal power of each generator unit up to 120 MW in France, at least 2% of nominal power of each generator unit up to 100MW in Germany) in the system in order to limit the frequency variation. The time in which the primary reserve must be injected goes from 15 s to 30 s. The participation to the primary reserve is normally reserved to centralised power plants.

    - Secondary control: it consists on the active power setting point change of selected generators. The participation on the secondary control is only reserved to some specific units and the frame time of action is about some minutes.

- Tertiary control: it consists on back-up units that will be started to recover primary and secondary reserves. The starting of units depends on the nature of the unit and the technology e.g. a hydro unit spends 20 minutes to start, a thermal unit can last 3 hours or more before the connection to the grid.

The frequency control of the system is carried out by the definition of an amount of energy reserves for each type of control (primary reserve, secondary reserve, tertiary reserve). The primary reserve of a country is normally recommended by the UCTE in the case of South Europe and it corresponds to the split of the 3000 MW of primary reserve (two largest units of the UCTE zone) between the different countries integrating the UCTE. This split is computed taking into account the net power production of a country compared with the total UCTE production. Thus, for example, in France the recommended value is 750 MW but in practice the TSO takes more primary reserve in order to have a surplus.

2.3.3 Ancillary services

The ancillary services designate the whole range of services necessary for power systems' successful performance and different from the basic functions of generation, transmission and distribution of energy. One example of definition is that given by the Federal Energy Regulatory Commission FERC; it defines ancillary services as those "necessaries to support the transmission of electric power from seller to purchaser given the obligations…to maintain reliable operations of the interconnected power system". It recognizes six types of ancillary services: Scheduling, System Control and Dispatch service, Reactive Supply and Voltage Control, Regulation and Frequency response, Energy Imbalance service, Operating Spinning reserves and Operating supplemental reserve. **[MIT-99]**

Between these ancillary reserves, one can include the reserves of active power presents in the system; it is interested to explain the economic aspects of these reserves:

- The primary reserve is not paid for example in the Spanish case and in most of countries, it is normally obligatory for generators up to a defined active power (France up to 100MW). This primary reserve allows the interconnected system to keep the frequency until a 200 mHz deviation from the 50 Hz.

- The secondary reserve is normally calculated in relation with the maximum forecast load for a day (Spanish law) or the anticipated variation of load in 15 minutes from a state to other one (UCTE empirical equation). In the Spanish law, it is fixed a procedure of secondary reserves share between the different generation units with a cost minimisation. **[BOE-98].** There is a market to solve the secondary reserve contracts.

- The tertiary reserve is also paid and it corresponds to pre-established units to be started. There is a market environment to award the contracts. For more specific questions, there are other parallel markets to decide between different technical solutions when face to the intraday control.

2.4 Distribution networks

The insertion of DR units in the electric power system (EPS) introduces some impacts on the system as it was mentioned in D.1.1. However, these new injections of energy can have some benefits in the operation on the whole system:

- **Losses reduction**:

The production of energy near the load reduces the losses in the whole system because the energy is generated there where it is consumed.

- **Participation to the voltage balance in the distribution level**:

The control of the voltage profile at the distribution level is carried out normally by means of tap changers that adequate the voltage from the HV to MV and/or from MV to LV. These tap changers can be operated manually or automatically, that is if the voltage decreases down or up to a certain threshold the relation between the primary and the secondary of the transformer is changed in order to maintain the voltage of the different buses of the feeder into the range values specified by the norms.

Other spread way to control the voltage profile in the distribution networks is the utilisation of capacitors bank at the beginning of the distribution feeder HV/MV (in France this bank capacitor can reach values of 4.8 Mvar for a 20 kV network).

So, the voltage magnitude at the end of the distribution feeder buses can be reduced in some operating points and cross the normal limits in spite of the normal actions control. In these cases, the existence of DR units in the distribution network could be a valuable way to vary up the voltage. The insertion of a DR unit in a bus rises the bus connection voltage. Only larger distributed generation are normally expected to participate to this control.

- **Participation to the frequency balance:**

In some special periods of droughts, the system operators can share the primary reserve between centralised power plants and distributed generation. In Norway the distribution generation units up to 40 MW participate to the normal operation primary reserve.

- **DG associations for Market competition**:

The DR units integrated on the distribution level can be associated together to propose an amount of energy (bids) into the pool of the day ahead trade or even, in the hour ahead trade. An example of this association of DG is the Virtual Power Plant concept.

2.5 List of indices in electrical networks

The present paragraph is a summary of different indices commonly used in electric networks in order to qualify the system regarding different criteria of evaluation. Thus, the behaviour of the electrical networks are characterized by different indices, these indices give us a good estimation of the system operation:

- Congestion indices
- Reliability indices
- Generation adequacy criteria
- Security criteria
- Quality indices
- Voltage stability indices

2.5.1 Congestion indices

The congestion phenomenon appears when the system exceeds the limits of the components e.g. limits of the lines: power flow in the lines, current limits, stability limits. One of the indices to detect a bottleneck is the ATC (Available Transfer Capability)

- Available Transfer Capability (ATC): it is a measure of the transfer capability remaining in the physical transmission network (in terms of power).

2.5.2 Reliability indices

As it was defined in the glossary, the reliability of a system is the ability of the system to deliver energy within some standards. Reliability of power delivery varies widely from customer to customer and from utility to utility. Utilities use two main indices: SAIDI and SAIFI.

- SAIFI, System average interruption frequency index

$$SAIFI = \frac{Total\_number\_of\_customer\_\text{int}erruptions}{Total\_number\_of\_customer\_served}$$

- SAIDI, System average interruption frequency index

$$SAIDI = \frac{Sum\_of\_all\_customer\_\text{int}erruption\_durations}{Total\_number\_of\_customer\_served}$$

- CAIDI, Customer average interruption duration frequency index

$$CAIDI = \frac{Sum\_of\_all\_customer\_\text{int}erruption\_durations}{Total\_number\_of\_customer\_\text{int}errumptions}$$

Other specific indices about reliability can be found in the literature in other to define the degree of supply continuity to the customers. However, the most important aspects of the reliability are measured by the security criteria and generation adequacy indices. An interruption of supply of a customer or a group of customers for a short period of time does not represent a real danger for the EPS; the impact is normally the quality of service.

2.5.3 Generation adequacy criteria

Adequacy is a measure of the ability of the power system to supply the aggregate electric power and energy requirements of the customers within component ratings and voltage limits, taking into account of planned and unplanned outages of system components. Adequacy measures the capability of the power system to supply the load in the steady states in which the power system exists. The adequacy is a part of the reliability of the system and traditionally is quantified by two criteria; probabilistic criteria that try to measure the capacity of the system in terms of probability to supply a certain level of energy; and deterministic criteria that consist on different rules to be respect in the normal operation of the system.

Some Probabilistic criteria/index are**[MIT-99]**:

- LOLE (loss of load expectation) (unit: hours/year)
- LOLF (loss of load frequency) (unit: failures/year)
- LOLP (loss of load probability): a loss of load will occur when the system load exceeds the generating capacity in service. The overall probability that the load demand will not be met is called the loss of load probability or LOLP (unit: dimensionless)
- LOEP (loss of energy probability) or LOEE (loss of energy expectation): the loss of energy method is a variation of the loss of load method. Here the measure of interest is the expected non-served energy split by the total energy demand over a period of time.
- EUE (Expected Unserved Energy) **[MAK-03]**:

$$EUE = 8760 \sum_j p_j * \Delta L_j \, (MWh : Yr)$$

EUE integrates the probability of contingencies p_j and their consequences (load loss ΔL_j)

Some Deterministic criteria **[MIT-99]**:

A common practice to evaluate the system adequacy is to consider some working rules, which are called deterministic criteria (to differentiate them from the probabilistic techniques). Some of these working rules are the next ones:

- Percentage reserve: it consists on defining a reserve for each system, representative ranges are 10-30% of peak demand in installed capacity and 2-10%in operation. This criterion compares the adequacy of reserve requirements in totally different systems on the sole basis of their peak load.
- Another widely used criterion calls for a reserve equivalent to the capacity of the largest unit on the system plus a fixed percentage of the dispatched capacity.

The next figure gives a comparison of different generation adequacy criteria used in the countries of the UCTE.

Country	Deterministic or probabilistic	Mandatory standards on generation adequacy
B-Belgium	Probabilistic. (LOLE, 16 hours/year)	No mandatory standards
D-Germany	Deterministic for primary control power; Probabilistic approach used by the TSOs	"Transmission Code" requirements
E-Spain	Deterministic	"Operation procedures" requirements
F-France	Probabilistic, (10% of probability of loss of load within one year, fairly consistent with a LOLE of 4/year)	No mandatory standard but agreement with the Ministry in charge of Energy
GR-Greece	Deterministic for the short term, probabilistic for the medium and long term	Operation code, Power Exchange Code and the "Authorisations Regulation for Generation and Supply" requirements
I-Italy	Both	-
SLO-Slovenia	Deterministic	"System Operating Instructions for The Electricity Transmission Network" requirements
HR-Croatia	Probabilistic, LOLE	"Annual Energy Balancing Plan"
JIEL	-	-
L-Luxembourg	-	-
NL-The Netherlands	None	"National system code" requirements
A-Austria	-	No mandatory standards
P-Portugal	Probabilistic: ⇨ LOLE - less than 2.5% of the months ⇨ Loss of energy probability (in dry hydro conditions) - below 0.4% of total consumption	No mandatory standards
CH-Switzerland	Deterministic	No mandatory standards – shared responsibility between the Federal Ministry of Energy, the cantonal ministries and the Power Utilities
CZ-Czech Republic	None	No mandatory standards
H-Hungary	-	-
PL-Poland	Deterministic	"Polish Grid Code" requirements
SK-Slovak Republic	-	-
BG-Bulgaria	-	-
RO-Romania	Deterministic for short term ("largest unit"), probabilistic for medium and long term (LOLE and LOLP)	"Grid Technical Code" requirements
UA-Burshtyn Island	-	-
BIH-Bosnia	-	"ZEKC Book of Rules and obligations" requirements

Figure.5.-UCTE countries generation adequacy criteria

2.5.4 Security criteria

Security of the system is the ability of the system to withstand disturbances and abnormal events. The main security criterion is the (n-1) criterion. Thus, any probable single event (loss of a line, generator, transformer, compensator, communication link...) leading to loss of system elements should not endanger the security of the system operation. The other network elements that are still in operation must be able to adapt and withstand the system to new load situation, voltage deviation or transient stability caused by the initial failure.

2.5.5 Quality indices

These indices refer the different national and international norms dealing the voltage range, voltage magnitude, frequency, harmonics… for HV, MV and LV. They are not on the scope of the research for this report but they are important indices in the system operation, it is why are mentioned here.

2.5.6 Voltage stability indices

The voltage stability is one of the studies of the power system stability and one of its aim is to prevent the phenomenon of voltage collapse. Voltage collapse is the process by which the sequence of events accompanying voltage stability leads to a low unacceptable voltage profile in a significant part of the system. The voltage stability have been analyzed by the application of different methods present in the literature **[KUN-94]**, e.g. one of these methods is related with the definition of indices to define the voltage stability: indices of Glavitsch-Kessel

2.6 Major events in network operation

The major incidents in the electric power system are usually the result of the combination of several single events such as mentioned in D1.1: a load variation, loss of lines, loss of generators, low voltages in certain buses of the system. These losses of elements can be provoked by the protection disconnection of some component of the system after a short-circuit or other disturbance in the EPS. A brief description of the most important major incidents is presented by the following points **[TI-01]**:

- Cascading lines tripping: it consists on the tripping of lines, it starts for an initial disturbance (e.g. load variation, loss of a generator, low voltages in some bus or a short-circuit) that provokes an overload and the disconnection of the overloaded line. This disconnection can change the split of load between the different lines and so it can lead to other overloads and then the successive line tripping. The main consequences of the cascading lines tripping are: the loss of synchronism of the system, voltage collapse (it is not possible to supply correctly a zone in active and/or reactive power) and/or the creation of sub-networks in the tripping sequence.

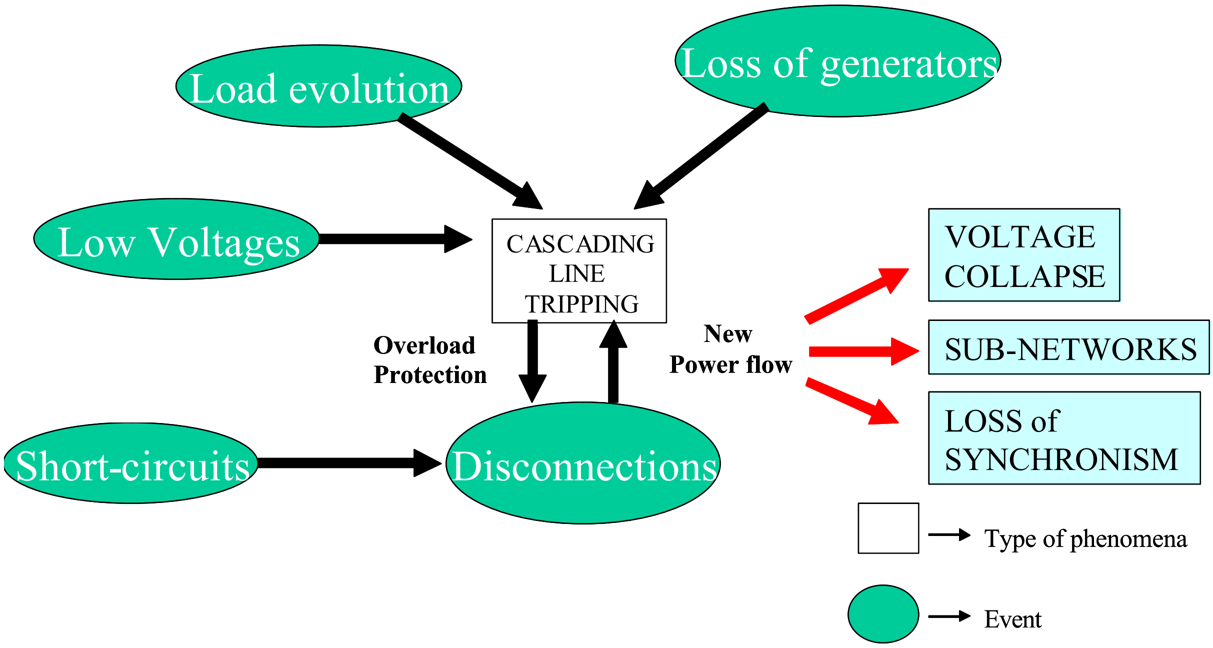


Figure.6.-Cascading line tripping initial events and consequences

- Voltage collapse: the main initial cause of the voltage collapse is the insufficient reactive power production. Some incidents like the loss of a generator or the loss of some line in the system can provoke a drop in the voltage of the transmission system and therefore a drop in the distribution and sub-transmission voltages. In order to avoid the drop in the voltage supplied to the loads at the distribution and sub-transmission system, the distribution and/or sub-transmission tap changer are going to change the tap automatically and in this way they are able to maintain the load voltage (63 or 20kV). However there is a negative impact on the transmission system, because at each change of tap, the reactive power needed by the sub-transmission and distribution system is increased and so the voltages at the transmission system are decreased. The main consequences of the voltage collapse can be: line tripping (lower voltage, higher currents in the lines), disconnection of generators (low voltage protection) and/or the loss of synchronism of the generators (not able to produce more reactive power). The dynamic of the voltage collapse is in the range of the minute, the variations of the tap are every 10 s as max.

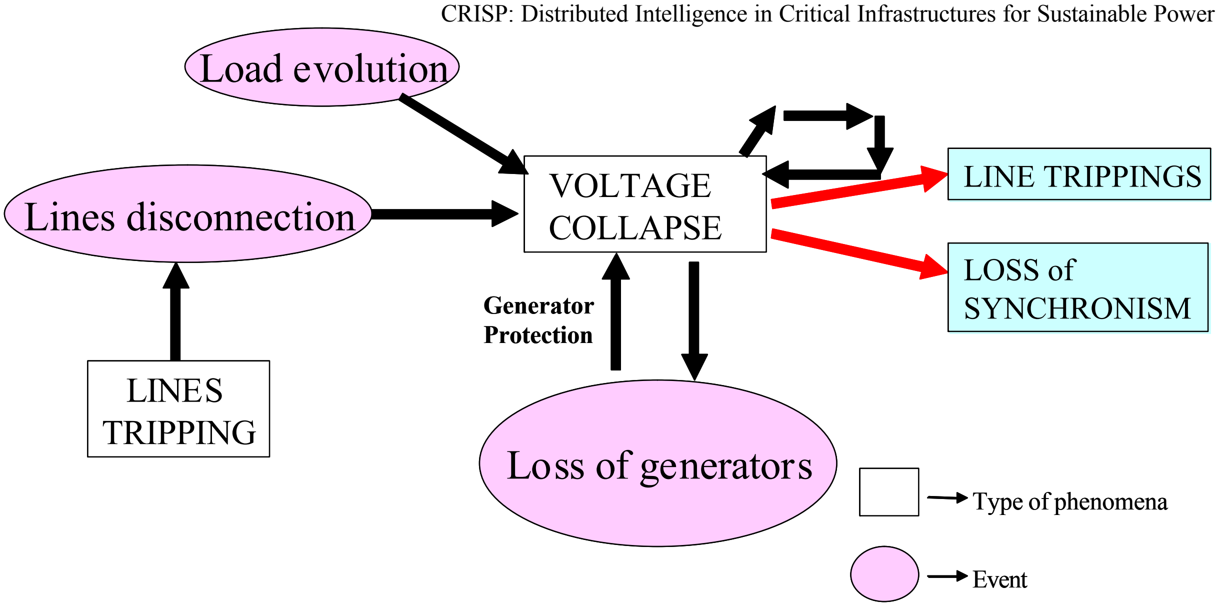


Figure.7.-Voltage collapse initial causes and consequences

- Frequency decrease: the frequency in the system is the result of the balance between the power generated and consumed so a balance between production and consumption. The frequency can change as consequence of a load or generation variation. In order to limit the variation of the frequency, the operators use the primary reserve to keep the frequency in an adequate interval of values. However, if the primary reserve is not sufficient the frequency drop can reach the system to abnormal values. The solutions to a frequency decrease are: the load shedding and the increase of the produced energy: storage and back-up units. The dynamic of the frequency drop is in the range of the second.

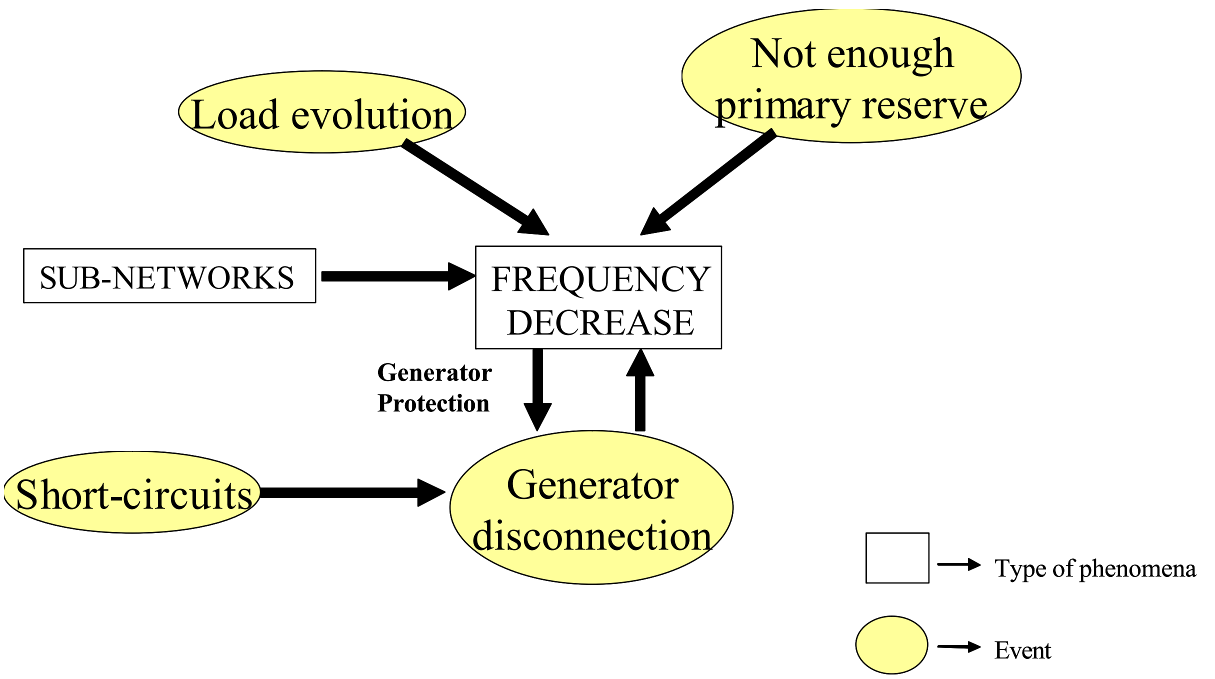


Figure.8.-Frequency decrease initial events

- Loss of synchronism: In normal state of the system, each group works in synchronism with other generators of the system; but after an incident in the network, it is possible that a generator or a group of generators could change its frequency, working at other frequency different to the synchronism frequency.

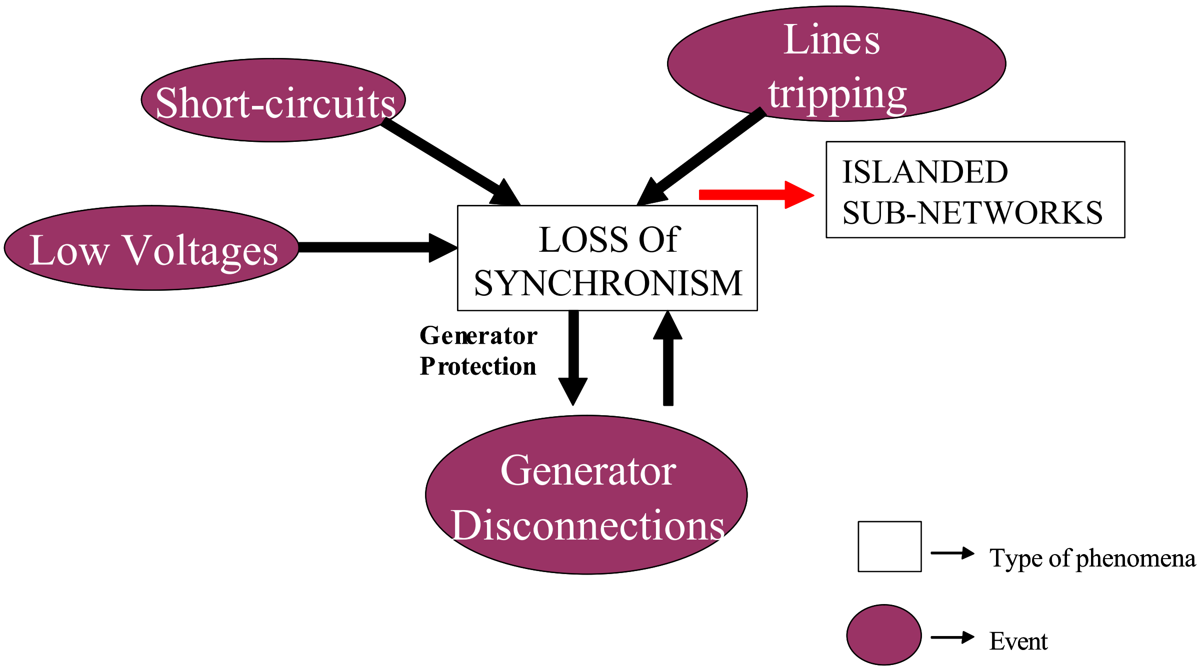


Figure.9.-Loss of synchronism

In the last years, several major events have happened in the world, some of them are the next ones:

- 28 th September 2003 Italy
- 23 th September 2003 Sweden & Denmark
- 28 th August 2003 South London
- 14 th August 2003 USA
- 3 rd February 2003 Algeria

- January 2002, Brazil
- October 2001, Australia
- 9th May 2000, Portugal
- December 1999, France
- Summer 1996, USA
- 24th August 1994, Italy
- 18th April 1988, Quebec
- 12nd January 1987, France
- 19th December 1978, France,
- …

The most important lessons and conclusions from the last black-outs can be summarized as follow:

- **14 th August 2003 USA** : The USA transmission system is operated by different operators, the deregulation has facilitated a split of the transmission operators. These new actors in the USA system are not always technically prepared (the doubt exists) to develop their supposed functions. In fact, the USA case give us two main lessons in one hand the sequence of events appeared after the absence of alarms, the system was overloaded in some of its elements (concretely some lines) and the responsible TSO did not know these overloads, and so the cascading line tripping was a logical response of the system. No external agent or cyber attack caused the shutdown of the system. However, the black-out could be interpreted by a mis-operation of the software that it did not check and renewal the necessaries data to define the state of the system (Normal, Alert, Emergency and Restoration).

The second main lesson is related with the communication between TSOs, the different TSOs involved firstly in the disturbance did not inform the neighbours TSOs to take measures to avoid the propagation of the disturbance (the islanding operation of some TSOs could have limited the final black-out area).

- **28 th September 2003 Italy** : The Italian black-out can be seen as a problem of economic optimization and system security. The blackout happened at night (3.00 am) when the consumption is very low. Italy was importing more energy that forecasted in the TSOs plan from others. The reason is clear; there is an economic optimization between importing cheaper energy than producing itself. Anyway, the Italian TSO did its job and it had taken all the securities rules to ensure the normal operation of the system. That deals with the (n-1) criteria and establishes a margin of reserves according to the risk of different contingencies. The problem appeared after the loss of several lines in Switzerland that reduced the interconnection capability, in other words, the interconnection lines between Switzerland and Italy were overloaded. So, the Swiss TSO telephoned the Italian TSO and advised/ordered it to decrease the energy importation to avoid the overload. The energy importation reduction did not result enough to avoid the tripping of the lines between Italy and Switzerland, and the tripping reached all the border countries with Italy. Thus, Italy was in a few seconds isolated from the UCTE network. In that moment, the frequency decreased (not enough generation for the existent load) and the amounts of load shedding decrease of pumped station consumption, reserves…and so on started to operate at the designated frequency levels (what it is defined by the TSO in advance). But, one fatal event appeared at 49 Hz, and it may also be caused by low voltage levels in some points of the system, a critical amount of generators were disconnected at this frequency. And then, the Italian system shut down completely from the north to the south.
  The problems were not stopped there with the massive importation of energy and the resulting black-out. In the restoration procedure, the Sicilia region saw a lot of problems of synchronization of areas for the re-connection with the main grid. The restoration plan in Sicilia failed as well and the re-synchronization lasted for several hours.

  It is obvious that this generation was mainly DG because the disconnection protection of the DG operates at 49.5, 49, 48.5, 48 Hz…and 0.85Un with different delays (instantaneous, 500ms…).It depends on the country and on the kind of DG (the disconnection protection is defined by the TSO in the DG connection to the grid contract). The centralised power stations (thermal. Hydro, nuclear…) are normally disconnected instantaneously at 47.5 Hz and 0.7 Un

- **23 th September 2003 Sweden & Denmark** : this blackout was described in detail in the ABB report about the measures taken in Oland for the WP 3 experiments (confidential and not public document). In short, after different events the system stood some first disturbances and the frequency was stable at 49.8 Hz (as it can be seen in the field data in Oland), but suddenly it appeared a voltage collapse and the system shut down.

2.7 The Defence Plan

The Defence Plan is a summary of actions that will be taken automatically or manually after a severe contingency. This plan contains the decision to take in order to minimize the consequences of severe disturbances.
Several studies are included in the defence plan: safety, emergency and restoration plans. The first is related to post-contingency manual corrective actions made by the operator to re-establish the normal conditions and it is based on preventive analyses of expected contingencies. The emergency plan tries to reduce contingencies effects based on automatic remote generation shedding and/or load shedding acting by frequency relays. Finally the restoration plan fixes a procedure to recover the electricity after the system shut down for severe contingencies.

French Defense Plan

The first French Defense Plan was developed by EDF, and then it was modified and adopted by the new transmission operator (RTE), it includes a collection of remedial actions to counteract voltage and frequency collapses, cascade line tripping and losses of synchronism **[EXA-04], [TI-01]**.

Corrective interventions may be either performed by control centre operators or carried out by dedicated automatic control loops, to tackle short-term critical evolutions. Main accounted remedial actions are generator start, under-frequency load-shedding, branch switching, blocking and/or reduction of voltage reference by on-load tap-changers, out-of-step relaying, “SYCLOPES” *(SYsteme Coordonne de LOcalisation PErtes de Synchronisme)* co-ordinated scheme.

DRS (*Debouclage sur rupture de synchronisme*) plan against losses of synchronism is an integration of conventional out-of-step relays placed by synchronous generators with similar devices located at both ends of strategic transmission branches, acting as interconnections between subsystems each showing coherent dynamic behavior. Whenever transient instability conditions are detectable (local voltage significant oscillations), such additional relays trip to isolate subsystems before loss of control within the whole electric network. The protection scheme operates in effective way only if out-of step blocking devices properly operate by branch distance relays.

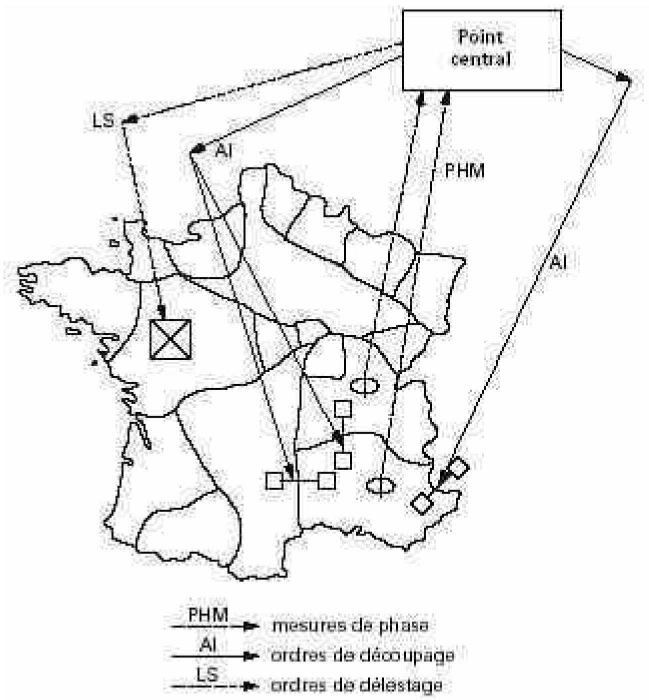


Figure.10.- SYCLOPES system, phase measures (PHM), load shedding orders (LS), Disconnection orders to create islands (AI)

“Syclopes” solution is the most recent evolution of the out-of-step protection scheme, this time profiting of angle and frequency deviations monitoring and evaluation on multiple strategic points, instead of local voltage measurement of doubtful complete efficiency.

Syclopes accounts for phasor measurement units (PMU’s), which send information to a central collecting point using mixed satellite/ground wire communication systems to simultaneously detect loss of synchronism, and promptly elaborate appropriate connection tripping as well as load shedding.

Generation rejection is instead adopted to avoid cascade line tripping in grid section where severely overloaded connections have been opened due to over-current protection that is with unsuccessful preventive intervention of the control centre operator.

On-load tap-changers blocking and voltage reference setting reduction is manually performed by control centre operators, in order to avoid fast voltage collapses within the significantly meshed French system.

Finally, under-frequency load-shedding acts when a predefined frequency or frequency derivative threshold is exceeded; its effectiveness has been proved several times, specially in peripheral regions showing reduced degree of interconnection.

2.8 National Previsions for the DG insertion in Europe

The generation of the energy is normally carried out in the transmission system by means of the huge power plant (1000-1300 MW) based on thermal, nuclear or hydro energy. But, this is not the unique power injection in the electric networks. There are other generation injections, called DG, e.g. CHP (Combined Heat and Power) generators and small local independent producers at the sub-transmission system, or the small dispersed generators at the distribution system.

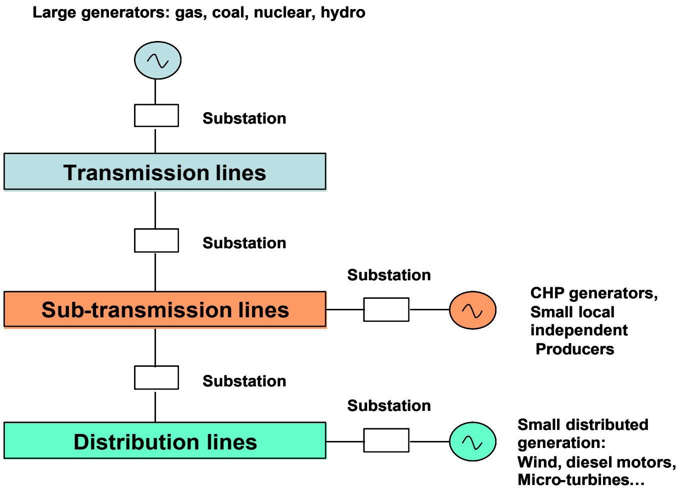


Figure.11.-DG insertion in Electric Power Systems

The voltage level for the DG connection (sub-transmission or distribution) depends essentially on the amount of injected power and the local network characteristics. The liberalisation of the energy market has favoured the apparition of these new DG producers. In figure 12, the share between the different generation types is detailed for some of the EU (European Union) countries.

Country	Nuclear energy	Coal, oil, gas, wood	Hydro-electric	Renewable energy
Belgium	55.2	44.3	0.5	-
Denmark		86.8	-	13.2
Germany	29.7	64.6	4.1	1.6
Finland	31.2	33.3	22.0	13.5
France	75.7	10.8	13.5	-
Greece	-	90.9	8.9	0.2
Great Britain	26.8	70.0	2.0	1.2
Ireland	-	94.7	4.8	0.5
Italy	-	78.6	19.0	2.4
Luxembourg	-	13.4	83.3	3.3
Netherlands	4.1	92.6	0.1	3.2
Austria	-	31.2	68.8	-
Portugal	-	64.9	34.8	0.3
Sweden	45.8	4.5	47.8	1.9
Spain	30.1	47.7	20.8	1.4
15 EU countries	34.3	50.2	13.8	1.7
Norway	-	0.7	99.3	-
Switzerland	40.3	3.1	56.6	-

Figure.12.-Generation type in some EU countries (%)

DG units are based on conventional and non-conventional energies. The conventional DG corresponds to micro-turbine, CHP, fuel cells or Diesels. The non-conventional energies refer to the renewable sources such as wind energy, hydro or PV. Renewable sources are widely seen as a relevant tool to comply the obligations coming from the Kyoto protocol. The estimation of new DG based on RES (Renewable Energy Source) is shown in figure 13 by ETSO (European Transmission System Operators) data **[ETS-03]** for the percentage of the total capacity which is based on renewable energies. In this figure, it is also shown the tendency to new DG installations. Hydro power is the renewable energy source that contributes the biggest share to the renewable generation in Europe.

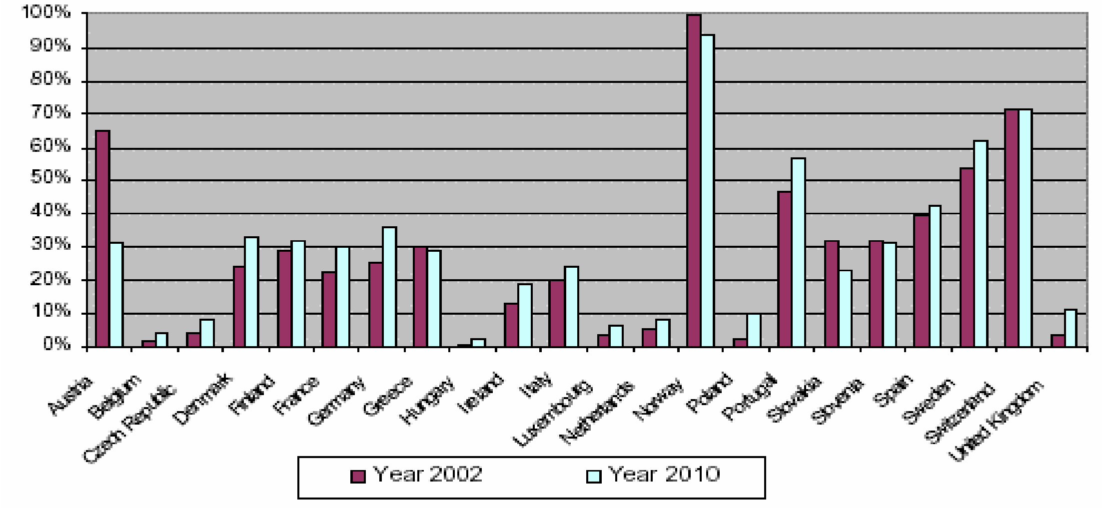


Figure.13.-ETSO data about the DG-RES capacity

However, the present plans to install DG-RES are concentrated in the off-shore and on-shore wind power potential. The exploitation of the wind energy is now expected to be the main driver for reaching the targeted RES development in the future.

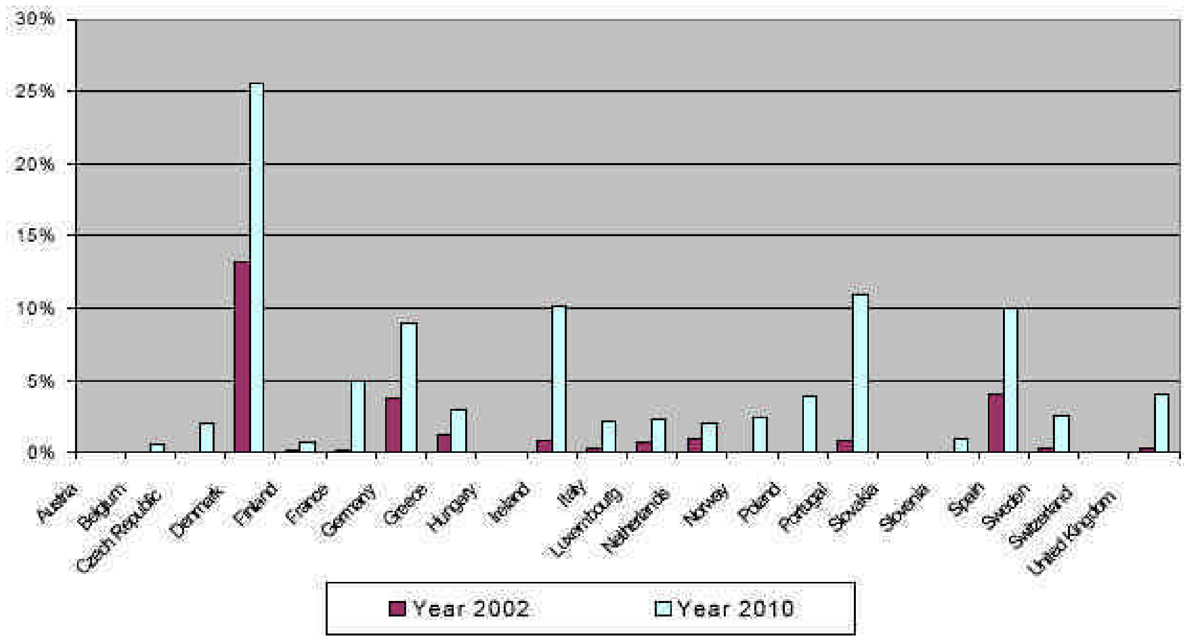


Figure.14.-Wind Energy Generation insertion ETSO prevision

Thus, countries such as Denmark or Germany are promoting the wind energy installation. Germany is planning to increase its wind capacity from around 13 GW wind capacity installed mid of 2003 to an expectation near to 30 GW in 2010. The Danish Government is also promoting the wind energy with plans to install 4GW off-shore and 1.5GW on-shore before the year 2030. In figures 14 and 15, there are shown the ETSO previsions for the Wind Energy insertion in the future network (up to 2010).

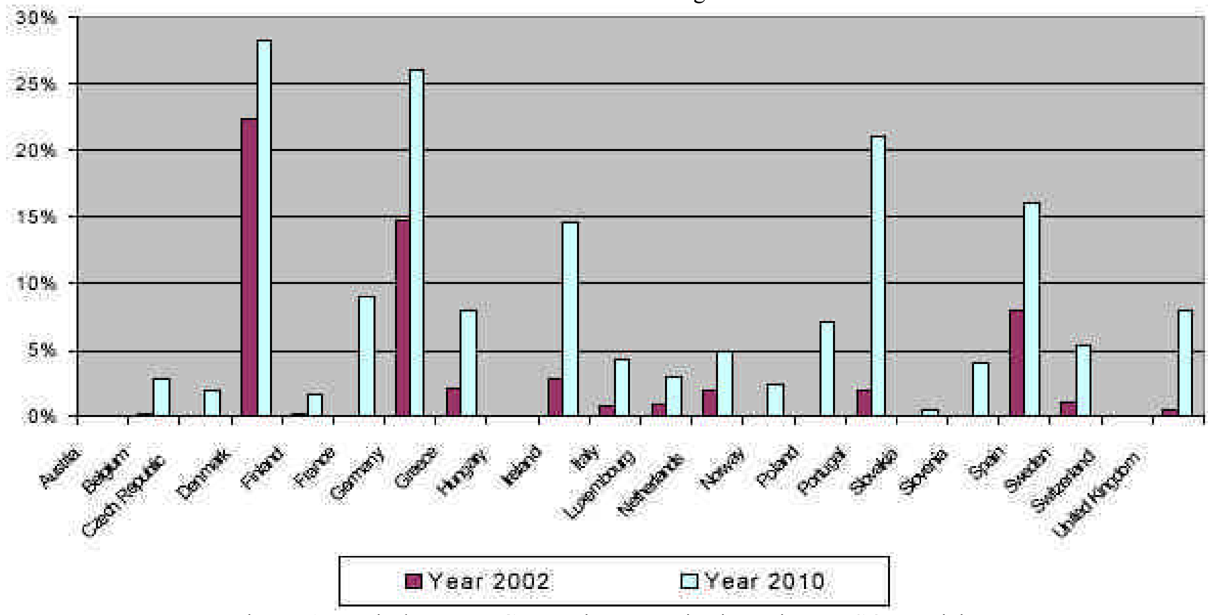


Figure.15.-Wind Energy Generation capacity insertion ETSO prevision

2.9 Distribution protections: DG disconnection protection

The French distribution networks have different types of protection depending on the goal of the protection. Three main types of protection can be enumerated: network protection, DG disconnection protection and protection for producers and industrial network.

- Network protection: this protection function consists on the elimination and isolation of a fault which appears in the network. It is carried out mainly by current measures (also with the zero-sequence voltage).

- Protection between the network and the DG (DG disconnection protection): the protection device is placed in the DG connection point with the network. These protections can be set in different ways in terms of delays, frequency and voltage threshold. The DG disconnection protection is put in the network in order to protect the DG from abnormal network conditions.

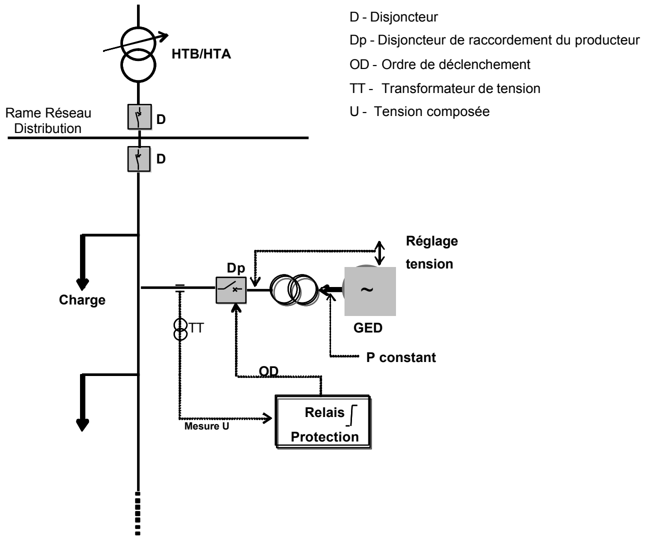


Figure.16.-Disconnection protection of the DG connected to the 20 kV

These abnormal conditions can come from faults in the network, non-intentional islanding operations and others which change the voltage and frequency magnitudes. In figure 16, an example of disconnection protection is shown, in this example the protection takes the voltage measure and from it, the frequency is defined in order to verfify the V&f thresholds. Some of cases of threshold setting points are shown in table 5 according to the French utilities recommendations **[EDF-01]**.

Parameter	Type 1.1	Type 1.2	Type 1.3	Type 1.4	Type 1.4 modif.	Type 1.5
Remote disconnection	No	No	No	Yes	Yes	No
Vo max (%Vnom)	10% 100 ms	10% to +500 ms	10% to +500 ms	10% to +500 ms	10% to +500 ms	10% to +500 ms
V max (%V nom)	115% 100 ms	115% 100 ms	115% 100 ms	115% 200 ms	115% 200 ms	115% 200 ms
V min1 (%V nom)	85% 100 ms	85% 100 ms	85% t1+500 ms	85% t1+500 ms	85% t1+500 ms	85% t1+500 ms
V min2 (% V nom)			25% 100 ms	25% 100 ms	25% 100 ms	25% 100 ms
fmax(Hz)	51	51	50.5	51 t1+500 ms	50.5 100 ms	51 t1+500 ms
fmin(Hz)	47.5 100 ms	47.5 100 ms	49.5 100 ms	47.5 t1+500 ms	49.5 100 ms	47.5 t1+500 ms

Table.5.-Thresold setting points depending on the type of DG protection

where t_1 is the delay time of the phase protection of the MV feeder and t_o is : a) the highest delay time of the zero-sequence threshold for the MV feeders with two case of neutral layout (compensated and impedant); b) twice the highest delay of the zero-sequence protection + 0.65 seconds with compensated neutral layout.

- Producers and industrial networks protection
  - Industrial network protections: switch in the network connection point, it is carried out by the current measure.
  - Producer protections: all the different protection in order to safe the machine (overspeed, excitation…)

The protection of DG is sometimes proposed by means of digital relays. In figure 17, it is shown the place where the relays take measures for the industrial networks and also a practical application of digital relays to ensure the different protection requirements (overvoltage, abnormal frequency, loss of field, unbalanced currents…) **[MOZ1-04], [MOZ2-04]**.

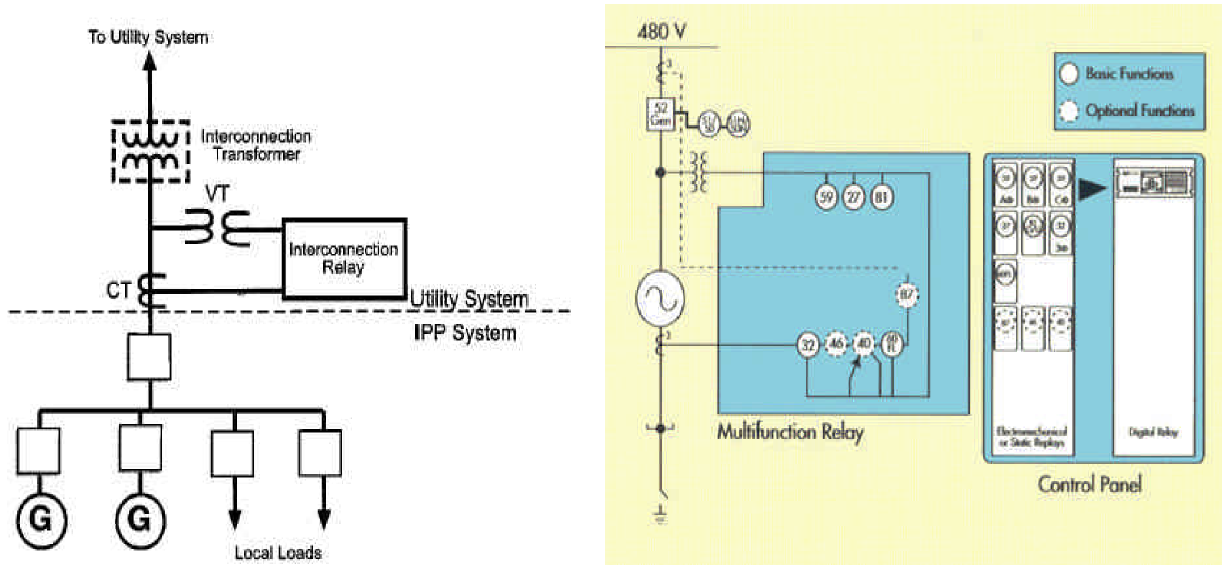


Figure.17.-Protection exemples of producers and machines

(on the left, relay situation for industrial networks, on the right, DG digital relays)

2.10 Specific events caused by DG and climatic aspects

As it was shown in D1.1, some of the different sources of distributed generation depend on the climatic conditions e.g. wind energy, PV or hydro. In the next paragraph, different specific events originated by the climatic conditions are treated; special interest must be paid to real events that change the state of the system into unusual operation points.

- **Wind:**

In the case of the wind energy, the dangerous events deal with the fast variation of the produced energy by a wind farm, e.g. a very fast wind can make that the wind turbines regulation disconnect the farm in order to prevent damage on the equipment. In this case, the injected power into the grid will be decreased drastically and so the grid must compensate the absence of a missing forecast production. The control actions of the grid are:

  - on one hand, the primary reserve should operate to compensate the active production.
  - on other hand, the voltage variation of the buses due to active power variations is compensated by fast reactive power control.

- **Sun:**

The sun variations should induce changes on the PV produced energy, PV installed power does not constitute a great percentage of the total installed power so, these sun irradiance variations should not cause a real disturbance on the whole system operation.

However, one can think about some particular applications of PV technology such as a LV cell where the participation of the PV combined or associated with other sources of energy could ensure the cell consumption. In these cases, the control associates with the LV cell should regulate the power balance in the cell (changing the setting point of the generators, adapting the load, controlling the voltage by means of the PV units…)

The most dangerous events regarding the sun are the very hot periods in the summer. Thus, the river water could reach temperatures high enough to forbid or limit the cooling operation of thermal and nuclear power plants and so these plants should limit its produced power or even stop. The operation of power plants raises the temperature of the water and an excessive water temperature can destroy the river fauna and cause an ecological catastrophe.

Furthermore, periods of drought reduce the hydro reserve, the lack of water flux prevent the use of hydro power. In this drought and heat peaks, the air conditioning use by the population increases the consumption of energy and the system is faced to a difficult situation (reduction on available capacity and peak of demand).

These two last points, problems of cooling of thermal and nuclear power plants and reduction of the availability of hydro power could lead the electric power system to critical situations in which the available power units are seriously reduced and the system operator must reclaim the participation of distributed resources (CHP, diesel…) in the system regulating tasks (participation of the DR to the voltage control, primary reserve…)

These intermittent power sources could cause problems in the interconnected system, notably in terms of the exploitation of the system: operative active and reactive power reserves. Furthermore, the intermittent and non intermittent DG has normally a protection that disconnects the system from the grid at a level frequency and voltage different than those one for central power plants (for DG between 49.5 to 47.5 Hz and 0.85 Un, for central power plants 47 Hz and 0.7Un). In the case of 28th September 2003 Italian blackout meant a problem, at 49 Hz a lot of DG were disconnected and the system could not recover itself and finally all the system were down.

This problem, it was also found in Spanish studies (ICAI, REE, Iberdrola…) about the Wind Energy integration **[ROD-02]**. These studies show how a short-circuit in the transmission grid could cause a voltage dip, this voltage dip could be propagated through the grid and reach the wind farms. When the voltage dip is in the wind generator, this is going to accelerate due to its small inertia. Then when the fault is cleared the active power tends to be higher than before the fault and so the required current is higher, lower voltage. Two events can happen during and after the disturbance: in one hand, the acceleration could active the over-speed protection (1.15 pu thresold), in other hand the undervoltage generator protection could disconnect the generator from the grid. This delay time of this protection is a critical parameter because an instantaneous operation could lead the system to the disconnection of the 3650 MW wind generation in the north-east part of Spain (from Galicia to Navarra and Aragon).

2.11 Definition of a robustness criteria

2.11.1 Robustness

A view of the robustness needs to be defined with the clear targeted EPS area and the given desired situation. In a global point of view, the robustness of the whole interconnected network should give the characteristics of the system to keep the normal working conditions (keeping the interconnection) during the occurrence of the high possible disturbances what ever the rate of distributed generation.
In a local point of view, when taking into account both interconnected situation and islanded situation, the robustness involves an approach of availability: even if the whole interconnected network is going down, the local area may be maintained under normal voltage condition thanks to local distributed generation (local ability to keep an intentional islanding).
But also in a local point of view taking into account only the islanded situation, the robustness of the island could be expressed in a similar way as the whole interconnected one.

Today without a high penetration of the DG, the main objective is to maintain the whole interconnection if possible. It allows the TSO to take a benefit of sharing the spinning reserves. In the UCTE this spinning reserve is defined by the loss of two main generators of the whole system (nearly 3GW). This kind of security margin allows the operator to keep the (n-1) rule: no major trouble caused by the loss of any component in the system (in a static or dynamical point of view). A few major events may shut down the whole system (a few losses of lines and generators). Today a main defence against this occurrence is the distributed load shedding tripped on thresholds of voltage and frequency magnitude.

The situation is changed if various local generations give the ability to an intentional islanding. A mean to avoid the total shut down is to try to commute from the interconnected situation to a normal disconnected situation.
The problem results from the trouble involved by this separation to the remaining system (reduction of available spinning reserve capacity for the not islanded parts).

Another possible strategy is to face the major events in a interconnected mode up to the blackout. The intentional islanding can then be used in order to improve and boost the restoration of the whole network.

In all the case, a temporary or long duration islanding needs to be operated: a dedicated robustness has to be defined during this phase. This definition is expected to be far different from the classical (n-1) rule in term of security design.

A general and common view on this aspect of robustness is behind the evaluation of the margin between a given steady state and a determined event causing instability. This kind of definition is scalable and difficult to express, because resulting of various quite different studies.

2.11.2 Simplify and clarify the RES integration

This paragraph summarizes the main conclusions of the DG insertion into the grid. The process of DG insertion starts when a producer requests for the connection to the grid, then there is an evaluation by the TSO if this connection is technically possible. In the South of France, there are a lot of projects of Wind Energy Insertion to the sub-transmission system, that creates a congestion problem in this sub-transmission level, because the lines and transformers are limited by its nominal capacity.

After the evaluation and network strengthening (if necessary) by RTE, a list of characteristics about the behaviour of new DG unit is given to the producer. The producer is so, responsible of its unit response with the required technical criteria, they consist usually in the DG behaviour (stability, disconnection protection, threshold of frequency and voltage that the DG unit should stand…) when face to short-circuit or other disturbances.

The level of the producer connection depends mainly on its nominal power, in the table 6, the different levels of voltage with produced power are shown.

Voltage level	P (MW)
LV (0.4 kV)	250 kVA
MV (20 kV)	<12 MW
HV (90 kV, 63 kV)	<40 MW
HV (225 kV)	< 250 MW

Table.6- Different levels for different DG nominal power

Then the DG producer can be connected to the grid and sell its energy. In conclusion, the connection of a new producer is located where it is possible by technical constraints and/or weather condition.

- **Impacts of the DG on the transport system**

The main problems that a large amount of DG insertion could cause to the transmission system deal with prevision of reserves and operation in real-time. The DG units are not going to stand the system in case of a disturbance. In one hand, as it was mentioned, the disconnection protection settings are a source of problems in case of major events. On the other hand, the intermittence of the DG implies a flexible control in the system (active and reactive power reserves, transmission lines capability to change the load flow) to avoid alert or emergency states.

As consequence, it is not a problem of a only country or TSO, the European network is interconnected in several synchronised zones (UCTE, NORDEL…), the map of the zones can be found in Annexe C. The loss of a generator in a country is going to affect all the countries connected to the same synchronised zone. In figure 18, it is shown the loss of a generator in Spain and how this event caused different oscillations in the frequency of the UCTE countries. Important variations in the power transfer between countries are also noted, by the power flow between France and Germany.

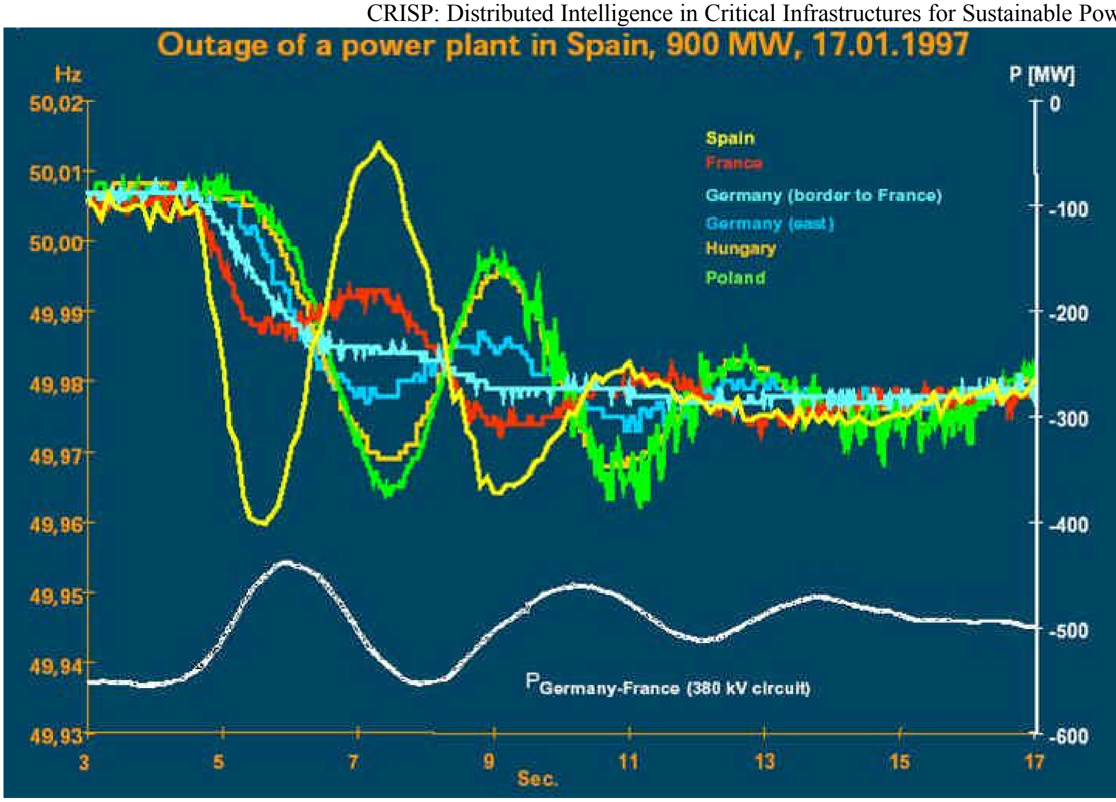


Figure.18.-Consequence of an outage of a power plant in the interconnected system

The main impacts on the transmission system of a high DG amount can be summarized as follow:

- Change of the reserve margins in order to avoid the intermittence problems: the dispatching of the system should be flexible in order to accommodate the system to lack or surplus of intermittent productions.
  - Change of real-time exploitation margins: the companies usually compute the secondary reserve by the next 15 minute load variation. The errors in the forecast of the intermittent energy are somewhere a variation of the expected power in the system. RTE announces a 2300 MW mobilising park in a delay of 2-hours (the UCTE recommended primary reserves are around 750 MW for France).
- Change of the real-time exploitation strategies: the DG energy is usually used by a based energy producing at the maximal output point (wind and solar), this cause the use of other types of energy to follow the load during the day. The special cases of CHP and micro-turbines have the inverse conclusion; they can profit to produce in the peak hours, more expensive energy.
  - The operator should use CHP in the hours where there is a higher need of heat, and solar energy during the day and wind energy when there is a profitable wind.
- Apparition of unexpected reactive power flows in the transmission. This is a fact that it was observed during the simulations in EUROSTAG. The DG production close to the load reduces the losses and the flow of energy in the transmission lines. If the power in a line decreased down to the natural power of the line, the capacitors of the pi-model inject reactive power in the system. That makes that the generators compensate reactive power and they absorbed it. The reactive power absorbed by the generators is limited by the generator stability and rotor current criteria.

- The DG disconnection protection is a critical component. This protection blocks the help of DG in case of major disturbances. In fact, the critical point could not be any more the 47 Hz (normal disconnection frequency of centralised power plants) and 49 Hz should be considered instead (a lesson from the 28th September 2003). This affirmation would imply a change in the load shedding strategy. The amount of load shedding traditionally at 49, 48.5, 48 and 47.5 Hz is partially inappropriate. These steps are normally considered to give the possibility to recover the system before a complete shutdown (for more information about intelligent load shedding, see D.1.5 by ABB) but if the system shut down irreversibly from 49 Hz, the load shedding below 49 Hz is not very useful. The new questions would be addressed to the optimal load shedding levels and amounts with a possible critical point in 49 Hz for the system.

- The interconnection of the national systems makes that the countries are involved in the events on other country. Special attention will be given to the German and Danish wind energy projects (a lot of off-shore wind energy insertion).

- The apparition of a high amount of DG and so a high percentage of the total produced power, could provoke the cloture of centralised power plants. This fact is based on several economic parameters:

    - The first one is the Kyoto protocol, the reduction of Greenhouse gas emissions and other environmental measures: the old thermal power plants and fuel-oil plants are very polluting. So, the new clean energies are a solution to substitute the most polluting plants to other cleaner sources and avoid international sanctions.

    - In some countries, the governments help the RES producers paying the difference between the normal price and the surplus cost of the RES energies. In some countries the clean energy is always bought by law because it is seen as an ecologic-friendly energy.

    - The centralised power stations do not operate below a defined percentage of the nominal power. The nuclear power plants do not operate below the 20% of nominal power, these nuclear power plants have problems of regulation and they usually produce around the 90% of Sn, they propose bids of energy at a very low price in order to not change the output. The minimal output power of the thermal units varies from 20% to 40% of Sn. The change of the production parks will be gradual because of the high investments done to build thermal or nuclear plants. So, the renewal process will take some time coinciding with the expected life duration of power plants.

- **The Danish case**

Eltra is the transmission system operator in the western part of Denmark (Jutland and Funen) and is responsible for the overall security of supply as well as efficient utilisation of the power system. Eltra's power system has about 1,900 MW onshore wind power (at the end of year 2000) with an annual power production of approx. 3.5 TWh (in year 2000). The hourly power demand in off-peak hours during winter and summer is as low as about 1,900 MWh and 1,700 MWh, respectively. Thus, Eltra has the largest amount of installed wind power in the world compared to the size of the power system.
In addition to this, the Danish government is planning a total Danish offshore wind power expansion of up to 4,000 MW before year 2030 and much of this capacity must be incorporated into Eltra's power system.

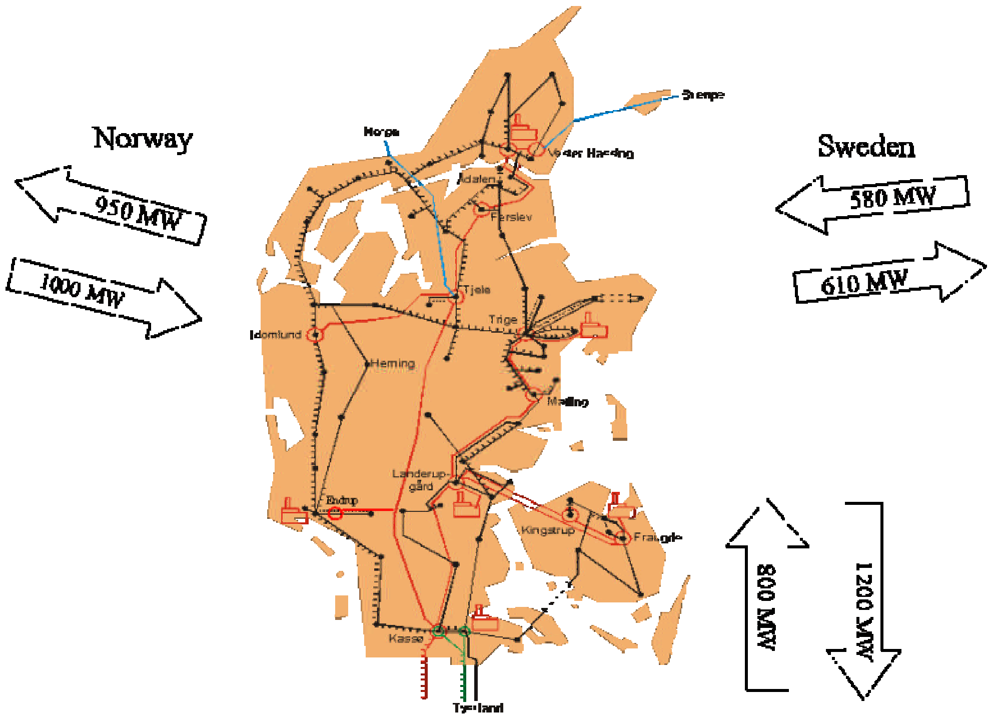


Figure.19.-Eltra system and normal exchanges capacities with neighbours countries

The Danish experience of large amount DG integration shows some characteristics of the DG in the normal system operation **[SUS1-03], [SUS2-03]**:

- Wind and CHP energies are considered as friendly energies and so they are prioritised; they produced at their maximum output point and the utilities are obliged to buy its energy.

- Unreliable wind forecast, the wind power imbalance is the difference between the day-ahead market and the measured wind power production. For the western part of Denmark, an average error in the magnitude of 35% of installed wind power capacity has been experienced. The maximum error is about 60% of installed wind power capacity. Furthermore, the errors in the forecast are not instantaneous instead they last a long time.

- Insufficient resources for system regulation: due to wind energy the system needs more regulating capacity than without it. Generally, resources for regulating down are missing during periods with high wind power; while, resources for regulating up are missing during periods with miss of wind power.

- **Appropiate amount of DG insertion**

The appropriate amount of DG insertion in a country should be established by different points of view. First at all, the possibilities of the country, some countries such as Denmark, Norway and Sweden have a high hydro and wind potential. So the expected DG integration in the system is more important than other types of countries. The same could be said by the CHP technology, the heat distribution needs are different from a country to other. So, this first parameter is the natural (cheap carbon, weather conditions, hydro reserves…) and social (acceptance degree of nuclear power, availability to pay a cleaner energy at a higher price…) characteristics of the country **[AMP-00], [CRA1-03], [CRA2-03],**

The second parameter that limits the DG integration is the strengthening network cost that blocks the insertion of DG. This is remarkable in MV and HV, notably by the congestion of the sub-transmission system. The construction of new lines is expensive and it could block the connection for some time.

The third parameter to define an appropriate amount is taken into account technical criteria. Some ways are being investigated during the works of WP1.3:

- Static security: technical limits of the system (max line currents, voltage, powers in lines, transformers and generators), (n-1) criteria…

- Dynamic security:

  - Small-signal stability: modal analysis of eigenvalues, the eigenvalues are obtained from the state matrix of the system. The difficult point consists that this matrix depends on the type of generators (synchronous, asynchronous; models) and in the dispatching powers.

  - Transient stability: the aim of the study is the analysis of a group of contingencies in order to look for the critical clearing time in which the system stands the contingencies. The DG units limit the critical clearing time due to its different characteristic parameters.

  - Voltage stability: this type of study depends mostly in the configuration of the system, dispatching between the generators (P and Q), and the primary voltage control to establish the initial voltage profile. It analyses each static situation.

  - Reserves margins in the system/ risk analysis: the systems can stand different contingencies depending on the new situation after the contingency. The idea of this point is fixed the limit of DG regarding a defined level of reserves in the system. In practice, UCTE recommends several rules to establish the reserves in each country, then it is known that the TSOs add an extra amount of reserves to dispose a larger security margin. In fact, the TSOs work with probability of the contingencies or disturbances and they allow a level of load shedding for the less probable ones. They do a risk analysis, it is the same that they do after the day-ahead economic dispatch, they do not accept the economic dispatch in case of technical limit violations or unacceptable risk situation. Then they propose solutions to reduce the risk level even if the day dispatching is more expensive.

    From this criterion point of view, the generators are classified in two types:

    - With reserves capacity: hydro, nuclear, thermal, diesel, micro-turbines…

    - Without reserves capacity: Wind energy and PV because they produce at the maximal output point.

    The appropriate DG insertion would be established in the dispatching of the day taking into account the maximal risk accepted by the operator for the real-time system control (the lack of all the Wind and PV sources is a relevant disturbance in terms of frequency and voltage stability) and the margins for real-time operation (as it was said 2300 MW in France for scheduled periods of 2-hours time).

The main conclusions proposed in this report for the increase of system robustness by the use of DG are:

- Problems of DG/RES insertion, these problems warn the operator to do changes in the system and the main point is knowing the problems turned them into advantages and changes.

- System robustness before disturbances: risk of lack of DG in one hand, but reduction of overloads in the transmission system and increase of variety of producers and installed capacity. Future possibilities of improve the control and dynamic characteristics of DG.

- System robustness after disturbances: the DG could enable the islanding operation by DSO or utilities control, the islanding could be ordered before a fault by measures or after a fault and black-out profiting the black-start capability and re-energizing the distribution system in a bottom-up way.

2.11.3 A deterministic method to limit DG insertion

The robustness criteria, which should guarantee the different technical requirements for a normal operation in whatever system, is the combination of different criteria. In one hand, it is necessary to remember the daily processus for the dispatching plan. Thus, the economic market proposes a solution to match the supply and the demand. However, this solution could not be adequate in terms of the system limits (static security and dynamic security). In this case, the TSOs must change the dispatching creating a new dispatching but increasing the energy prices. Thus, the new dispatching corresponds to a solution in which it is available from the technical point of view and with a reduced risk level.

The deterministc method which should be taken into account in the EPS planning of the day ahead is based on the behaviour of the system when faced to the next major events:

- Lack of the intermittence sources (Wind Energy and PV) after errors on the climatic forecast
- Loss of the DG protected by disconnection protection with instantaneous setting points with the voltage and the frequency. This could lead us to critical situations caused by (n-1)-(a part of the present DG).
- The emergency strategy should take into account the DG with frequency setting values at 49.5 Hz with or without temporization.
- The emergency strategy should take into account the intentional islanding areas which could be created after a major event. These intentional islanding is expected to be set at a frequency low enough to prevent a mis-operation of the system and high enough to be an efficient measure to avoid the complete black-out.
- Other influence on the emergency strategy after an initiating disturbance is the load shedding at higher levels. Thus, the contracts between customers and utilities will include special clauses in order to be disconnected at frequency levels between 49.8 and 49.5 Hz. In this way, the customers will pay the energy at a lower price but the supply continuity is not guaranteed and they can be disconnected in case of troubles. This idea is applied in several EU countries like in Spain in the generation side: the reversible hydro plants (pumped plants) are disconnected at 49.8 Hz if they are absorbing energy.

So, the lack of all DG insertion after a short-circuit represents a major event that the TSO should solve in real-time. If some DG could stand short-circuits the critical event for the system planning would be the lack of all the Wind and PV sources by extreme weather conditions. This could constitute a deterministic method to be taken into account to ensure a right operation.

2.11.4 Robustness indices

The robustness as it was defined represents the correct operation of the EPS in any condition. So, the robustness index must contain different terms in order to quantify the system response to different events. The scope of this report is mainly the participation of the DG in order to avoid major events and so, the index contains different terms to know in advance the risk of the system when face to major problems. Thus, the major disturbances correspond mainly to four events (see paragraph 2.6). The proposed index takes into account these major events: cascading outages, loss of synchronism, frequency deviations and voltage collapse.

The new robustness index (RI) is composed of four terms:

$$(\mathbf{RI}) = \max\{(\mathbf{SSS}); (\mathbf{SPIR}); (\mathbf{VCI}); (\mathbf{FD}); (\mathbf{LS})\}$$

where SSS (small-signal stability) is a view of the small-signal stability of the system, SPIR (static performance indices robustness) is a static view of the system overloads produced by loss of elements in the system, it takes into account the flows in lines and ensures that the voltage levels are in the normalized limits. Both, SSS and SPIR terms gives a static view of the system, they should be evaluated before and after a selection of contingencies that the operators consider relevant or probable for the system operation.

The VCI (voltage collapse indicator) gives an idea to the proximity to the voltage collapse if the voltages in the system exceed a defined threshold. The voltage collapse is a complex phenomena and the critical voltage point from the voltage collapse is initiated depends on the load and in the type of the system; traditionally the different studies about the voltage takes into account static situations of the system and evaluates different mathematical methods from the EPS equations.

The FD (frequency deviation) term gives an evaluation of the system response in terms of frequency. This is why the FD term includes the primary reserve, load shedding over 48.5 Hz and amount of DG disconnection protection with instantaneous disconnection or delay disconnection. Finally, LS (Loss of synchronism) contain the behaviour of the system after a contingency in terms of stability.

The application of this robustness index requires the evaluation of a contingencies selection, not only the (n-1) but also sequence of events (major events). The robustness indices enable us to compare different dispatching situations with and without DG and so it can be used to verify the increase of robustness that could be found with the DG when faced to some major events.

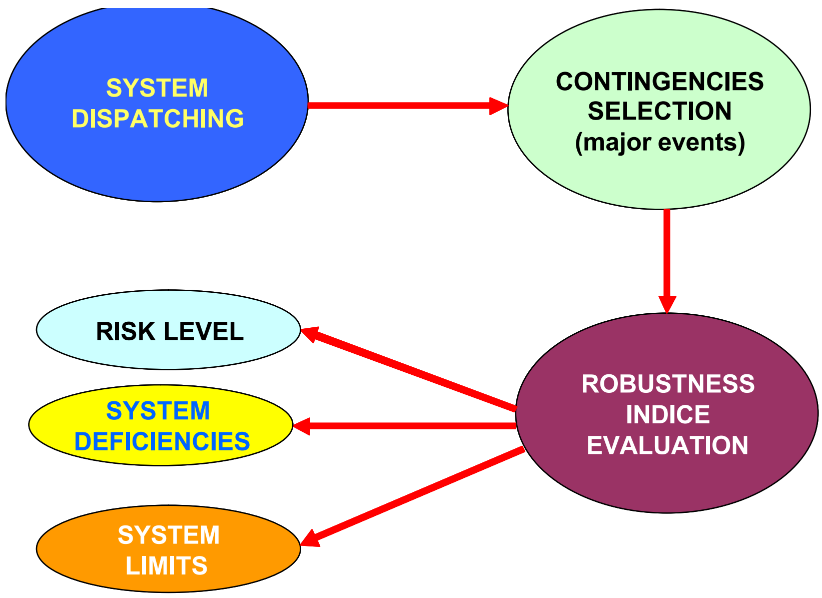


Figure.20.-Robustness criteria evaluation methodology

The evaluation of the robustness indices will give to the system operator different valuable informations about the chosen operation point such as: the expected limits of the system, the system deficiencies or the risk level of the analyzed case and the expected available time that the operator would dispose if the contingency appears.

$$(\mathbf{RI}) = \begin{cases} \mathbf{3 => Serious\_danger} \\ \mathbf{2 => 0perator\_control\_actions\_required} \\ \mathbf{1 => Alert\_operator\_sup\,ervision} \\ \mathbf{0 => Normal\_operation} \end{cases}$$

- If RI is equal to 3, the risk level is the higher one and the time in which the system shut down is reduced, in the range of some seconds.

- If RI is equal to 2, the risk level can not be neglected and cascading failure could occur if the line overloads are not solved by the operator; the expected available time for operator action is around one minute to 10 minutes.

- If RI is equal to 1, the system is in alert because some lines could be lightly overloaded and the maximal time to solve the overloads is around 15 to 20 minutes. On other hand, the voltage profil should be optimized in order to not exceed the TH_1 fixed value (390kV). The possibility of voltage collapse should be evaluated immediately because the voltage collapse can appear from some minutes to 10 minutes; the operator should compute and visualize the critical voltage at the buses and particularly at the low voltage buses.

- If RI is equal to 0, the system is in normal operation, all the parameters are in the expected intervals and no special critical state is probable under these conditions.

The different terms which form the RI indice are cescribed in detail in the next items:

- The term SSS must be evaluated from the state-space matrix of the system, the small-signal stability is guaranteed if all the eigenvalues have a negative real component; if this real component is equal to zero, neither the stability nor the instability can be confirmed and so this state constitutes an alert state by the incertitude of the system behaviour. Finally, if some real component of the eigenvalues is positive the system is instable to small-signals and so it is unstable to major events. The formulation of this indice is expressed as follows:

$$(\mathbf{SSS}) = \begin{cases} \mathbf{3} & \mathbf{if} \quad \mathbf{Re(Eigenvalues) > 0} \\ \mathbf{0} & \mathbf{if} \quad \mathbf{Re(Eigenvalues) = 0} \\ \mathbf{0} & \mathbf{if} \quad \mathbf{Re(Eigenvalues) < 0} \end{cases}$$

- The SPIR term must be evaluated to evaluate the capacity of the system when faced to overloads caused by the loss of elements in the system (mainly loss of lines). The SPIR term is composed of the evaluation of the technical limits of the system: power in lines, current in the lines and voltage in the normal interval.

$$(\mathbf{SPIR}) = \mathbf{max}\{(\mathbf{PII}); (\mathbf{PIV}); \mathbf{PIP}\}$$

  - The PII term evaluates the distance to the lines overload in terms of current on the lines, the severity of the overload defined different levels on danger depending the available time for operator's action to solve the overload.

$$\mathbf{PII_1} = \left[\frac{(|\mathbf{I}|)}{\mathbf{Im\,ax}} * \mathbf{100} \right]$$

Thus, the values of the PII term depend on the value of PII_1 identificating the severity of the situation or risk level for the system with the available time to solve the overload

$$\mathbf{PII} = \begin{cases} 3 & \text{if} \quad PII_1 > 170 \\ 2 & \text{if} \quad 130 < PII_1 < 170 \\ 1 & \text{if} \quad 110 < PII_1 < 130 \\ 0 & \text{if} \quad PII_1 < 110 \end{cases}$$

- The PIP illustrates the distance to a defined maximal active power on the lines (thermal limit)

$$PIP_1 = \left[\frac{(|P|)}{P\max} * 100 \right]$$

$$PIP = \begin{cases} 3 & \text{if} \quad PIP_1 > 170 \\ 2 & \text{if} \quad 130 < PIP_1 < 170 \\ 1 & \text{if} \quad 110 < PIP_1 < 130 \\ 0 & \text{if} \quad PIP_1 < 110 \end{cases}$$

- The PIV evaluates the distance of the voltage profil to the the normal voltage limits

$$PIV_1 = \frac{(|V-1|)}{\Delta V}$$

with ΔV= 0.05 (380kV-420kV)

$$PIV = \begin{cases} 3 & \text{if} \quad PIV_1 > 1 \\ 0 & \text{if} \quad PIV_1 < 1 \end{cases}$$

- The VCI compares the voltage levels at the different buses in the system with a threshold different from the normal limits disposed in the norms. This threshold (TH_1) would represent an alert to the system operator in order to predict the voltage collapse. The problem about the efficiency of the threshold is that the critical voltage depends on the type of load and so the efficiency of the proposed VCI is limited. The thresholds (critical voltage point) should be evaluated at each operation point; this requires a lot of computation for each situation. However, the authors introduce this VCI to give to the operator an alert in order to supervise the system and try to avoid the voltage collapse phenomena.

$$(VCI) = \begin{cases} 3 & \text{if} \quad Vbuses < TH_2 \\ 1 & \text{if} \quad Vbuses < TH_1 \\ 0 & \text{in} \quad other\_case \end{cases}$$

The threshold (TH_1) is established in the 2.5% of distance to the normal minimal limit in normal operation (390 kV); the threshold TH_2 is established at 360 kV as a serious indicator of voltage collapse.

- The FD term evaluates the dynamic responses of the system in terms of active power balance. Its value depends on the evaluation of the FD_1 equation:

$$(\mathbf{FD_1}) = \frac{[(\mathbf{PR}) + (\mathbf{IL})]}{[\mathbf{ALEA} + (\mathbf{DG_1}) + (\mathbf{DG_2})]}$$

where PR is the primary reserve (MW), IL is the amount of interruptible loads or load shedding (MW) planned up to 48.5 Hz, DG_1 (MW) is the DG with instantaneous or very quick (100ms) disconnection protection, DG_2 (MW) is the DG with temporized disconnection protection at 49.5 Hz and ALEA is the maximal load variation or generation loss forecast by the operator. The $alea_1$ is the load variation, short-circuit or event that provokes that the system arrives to the setting points of the disconnection protection before 49 Hz and 0.85 Un instantaneously.

$$(\mathbf{FD}) = \begin{cases} \mathbf{0} \quad \mathbf{if} \quad \mathbf{alea < alea_1\,)} \\ \mathbf{3} \quad \mathbf{if} \quad \mathbf{(alea > alea_1\,)and(FD_1 < 1)} \\ \mathbf{0} \quad \mathbf{if} \quad \mathbf{(alea > alea_1\,)and(FD_1 > 1)} \end{cases}$$

- The LS is an indicator to show if the system losses the synchronism after the selected contingency. The loss of synchronism is a very fast phenomenon. So, the resulting system after the disturbance shows as if the state of system relating this phenomenon.

$$(\mathbf{LS}) = \begin{cases} \mathbf{3} \quad \mathbf{if} \quad \mathbf{lost\_of\_synchornism} \\ \mathbf{0} \quad \mathbf{if} \quad \mathbf{system\_is\_not\_lost} \end{cases}$$

3. Study case description

This chapter is dedicated to the analysis of the robustness criteria shown in the chapter 2. Thus, a study case has been built adapting all the variable parameters and data to European data. Some preliminary simulations are explained before the deep study of future possible scenarios for the DG operation in EPS. The proposed scenarios go from the consideration of different kinds of DG protection settings points and the influence of DG in the regulation of the system. Then, the main conclusions are summarized and the ways in which the DG could enhance the system robustness are emphasized. In this sense, the ability of islanding operation supported by DG is specially studied.

3.1 Description of the network

The study case proposed for the work consists in the IDEA_CRISP_39buses network. It is a network of 10 generators, 37 lines and 40 buses. The network topology is shown in figure 21.

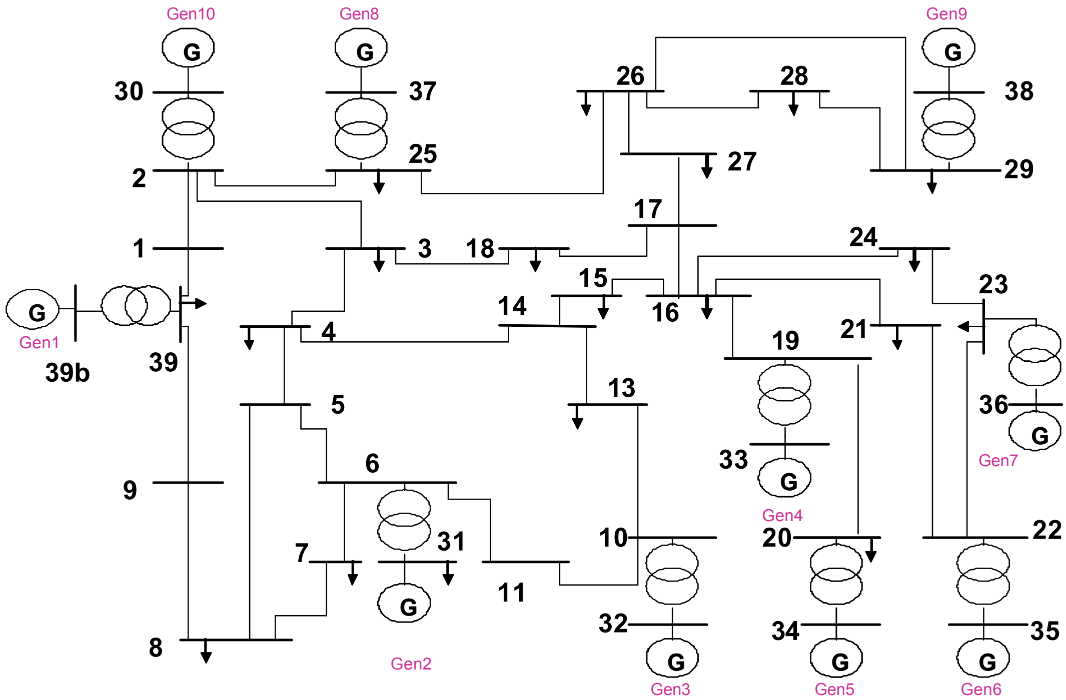


Figure.21.-Study case network topology

This IDEA_CRISP_39buses network is an adaptation of the IEEE New England 39 buses system. The architecture of this IEEE network is mostly kept. However, the parameters of its different elements have been adapted to normal European data. So, the transmission system is considered at 400 kV and the generators (Gen 1 to Gen10) produce the energy at 20 kV. The installed power is 9085 MVA and it is shared in three different types of generators:

- 4 thermal units: 1000 MVA each one,
- 3 nuclear units: 1080 MVA each one,
- 3 hydro units: 615 MVA each one ,

Load: The total consumption is 6230 MW split in 18 loads. The load profile and the generators dispatching is shown in figure 22. The load model associated with the consumption is the impedance model that is a square variation of active and reactive power with the voltage magnitude.

$$P(V) = P_0\left(\frac{V}{V_0}\right)^2$$

$$Q(V) = Q_0\left(\frac{V}{V_0}\right)^2$$

the subscript $_0$ refers to a state in which at a voltage level V_0, the active power consumed by the load is P_0 and the reactive power consumption is Q_0.

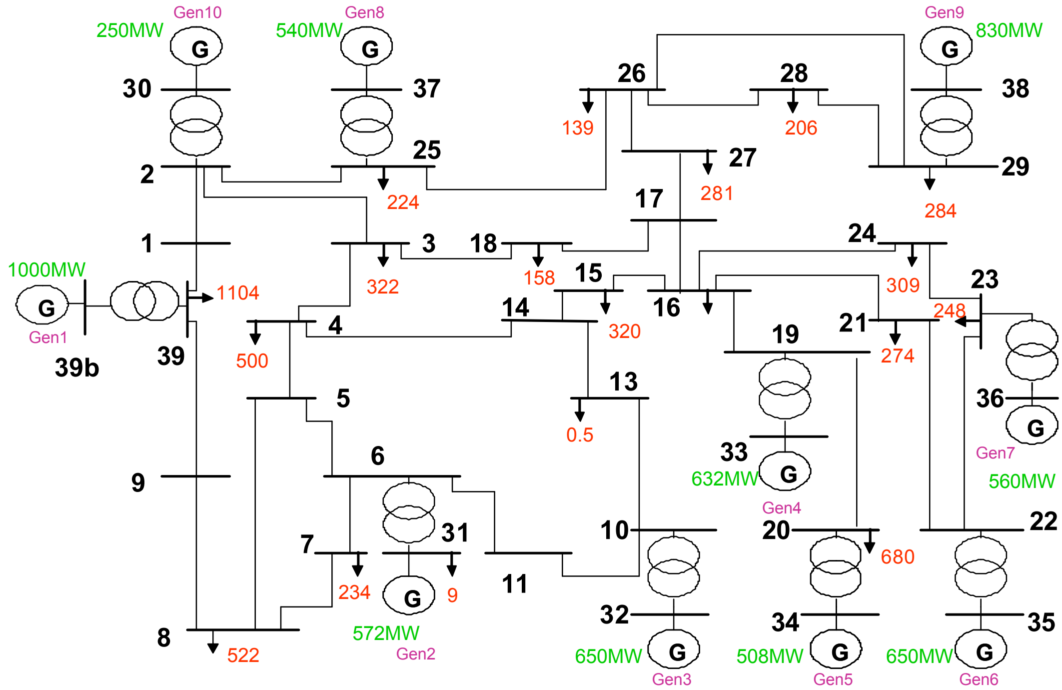


Figure.22.- Load profile and Generators dispatching

(green: generators active power in MW; red: load consumed active power in MW)

Generators: The parameters data of the generators are the next ones

- Thermal units: GEN4, GEN6, GEN8 and GEN9
- Nuclear units: GEN1, GEN2 and GEN3
- Hydro units: GEN5, GEN7 and GEN10

Parameter	GEN 1	GEN 2	GEN 3	GEN 4	GEN 5	GEN 6	GEN 7	GEN 8	GEN 9	GEN 10
X_d	2.43	2.43	2.43	2.57	0.8979	2.57	0.8979	2.57	2.57	0.8979
X_q	1.7	1.7	1.7	2.57	0.646	2.57	0.646	2.57	2.57	0.646
X'_d	0.393	0.393	0.393	0.422	0.2995	0.422	0.2995	0.422	0.422	0.2995
X'_q	0.815	0.815	0.815	0.662	-	0.662	-	0.662	0.662	-
X''_d	0.286	0.286	0.286	0.3	-	0.3	-	0.3	0.3	-
X''_q	0.307	0.307	0.307	0.301	-	0.301	-	0.301	0.301	-
T'_{d0}	10.1	10.1	10.1	7.695	7.45	7.695	7.45	7.695	7.695	7.45
T'_{q0}	0.736	0.736	0.736	0.643	-	0.643	-	0.643	0.643	-
T''_{d0}	0.044	0.044	0.044	0.061	-	0.061	-	0.061	0.061	-
T''_{q0}	0.27	0.27	0.27	0.095	-	0.095	-	0.095	0.095	-
X_l	0.22	0.22	0.22	0.219	0.2396	0.219	0.2396	0.219	0.219	0.2396
R_a	0.004	0.004	0.004	0.003	0.0001	0.003	0.0001	0.003	0.003	0.0001
H(MW*s/ MVA)	41.666 7	6	6	6.3	5.15	6.3	5.15	6.3	6.3	5.15
Un(kV)	20	20	20	20	20	20	20	20	20	20
Sn(MVA)	1080	1080	1080	1000	615	1000	615	1000	1000	615

Table.7.-Parameter data of the different generators

Generators regulators: The generators regulations are of two types: a voltage regulation and a frequency regulation

- **Voltage regulator**: it consists on an IEEE voltage regulation type A **[AND-77].** The regulator measures the voltage at the output of the generator and compares it with the setting point of the primary voltage control. The resulting error is compared with a excitation stabilizer feedback. Then, the difference is introduced in the regulator in order to create the new excitation voltage for the generator (necessary to recover balance between the real voltage and its setting point)

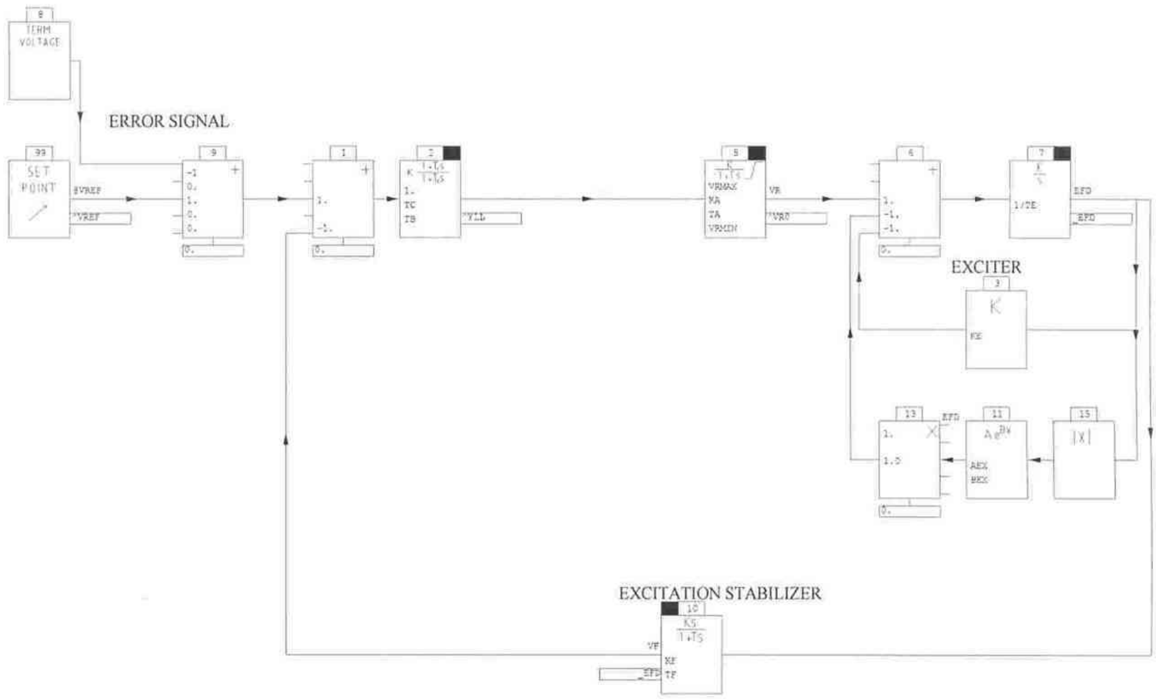


Figure.23.-Voltage regulator

- **Frequency regulator**: it is a torque regulation. It consists in the computation of the new setting point of the generators active power by means of the measure of the generator active power production and the speed droop influence. The new active power is limited to 10% variation of the nominal power in hydro units and 5% variation of the nominal power for thermal and nuclear units. These limitations are used to limit the primary reserve in the units and also to guarantee a realistic variation of the output power of the machine (MW/s).

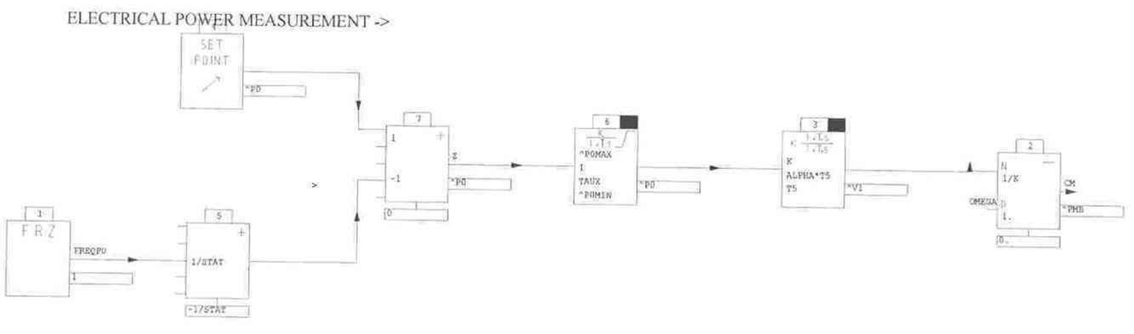


Figure.24.-Frequency regulator

Lines: 400kV : Aster 570mm^2
>> R = 0.02 Ω/km and X = 0.27 Ω/km
The maximal current in the system is taken equal to 900 A in summer (1200 A in winter) by conductor of 570 mm² and phase. The capacitor of the line is considered of 13.6nF/km. Taking into account these data the length and line parameters in pu (base: 400 kV and 100MVA) are shown in the next table:

LENGTH	LINE	R	X	(wC)/2	X/R	C
km		pu	pu	pu		nF/km
243.56	BUS1-BUS2	0.0030	0.0411	0.8325	13.50	13.6
148.15	BUS1-BUS39	0.0019	0.025	0.5064	13.50	13.6
89.48	BUS2-BUS3	0.0011	0.0151	0.3059	13.50	13.6
50.96	BUS2-BUS25	0.0006	0.0086	0.1742	13.50	13.6
126.22	BUS3-BUS4	0.0016	0.0213	0.4314	13.50	13.6
78.81	BUS3-BUS18	0.0010	0.0133	0.2694	13.50	13.6
75.85	BUS4-BUS5	0.0009	0.0128	0.2593	13.50	13.6
76.44	BUS4-BUS14	0.0010	0.0129	0.2613	13.50	13.6
15.41	BUS5-BUS6/1	0.0002	0.0026	0.0527	13.50	13.6
15.41	BUS5-BUS6/2	0.0002	0.0026	0.0527	13.50	13.6
66.37	BUS5-BUS8	0.0008	0.0112	0.2269	13.50	13.6
54.52	BUS6-BUS7	0.0007	0.0092	0.1863	13.50	13.6
48.59	BUS6-BUS11	0.0006	0.0082	0.1661	13.50	13.6
27.26	BUS7-BUS8	0.0003	0.0046	0.0932	13.50	13.6
215.11	BUS8-BUS9	0.0027	0.0363	0.7353	13.50	13.6
25.48	BUS10-BUS11	0.0003	0.0043	0.0871	13.50	13.6
25.48	BUS10-BUS13	0.0003	0.0043	0.0871	13.50	13.6
59.85	BUS13-BUS14	0.0007	0.0101	0.2046	13.50	13.6
128.59	BUS14-BUS15	0.0016	0.0217	0.4395	13.50	13.6
55.70	BUS15-BUS16	0.0007	0.0094	0.1904	13.50	13.6
52.74	BUS16-BUS17	0.0007	0.0089	0.1803	13.50	13.6
115.56	BUS16-BUS19	0.0014	0.0195	0.3950	13.50	13.6
80.00	BUS16-BUS21	0.0010	0.0135	0.2734	13.50	13.6
34.96	BUS16-BUS24	0.0004	0.0059	0.1195	13.50	13.6
48.59	BUS17-BUS18	0.0006	0.0082	0.1661	13.50	13.6
102.52	BUS17-BUS27	0.0013	0.0173	0.3504	13.50	13.6
102.52	BUS19-BUS20	0.0013	0.0173	0.3504	13.50	13.6
82.96	BUS21-BUS22/1	0.0010	0.014	0.2836	13.50	13.6
82.96	BUS21-BUS22/2	0.0010	0.014	0.2836	13.50	13.6
56.89	BUS22-BUS23	0.0007	0.0096	0.1944	13.50	13.6
207.41	BUS23-BUS24	0.0026	0.035	0.7089	13.50	13.6
191.41	BUS25-BUS26	0.0024	0.0323	0.6542	13.50	13.6
87.11	BUS26-BUS27	0.0011	0.0147	0.2978	13.50	13.6
280.89	BUS26-BUS28	0.0035	0.0474	0.9601	13.50	13.6
370.37	BUS26-BUS29	0.0046	0.0625	1.2659	13.50	13.6
89.48	BUS28-BUS29	0.0011	0.0151	0.3059	13.50	13.6
148.15	BUS39-BUS9	0.0019	0.025	0.5064	13.50	13.6

Table.8.-Transmission lines data for the case of IDEA_CRISP_39buses

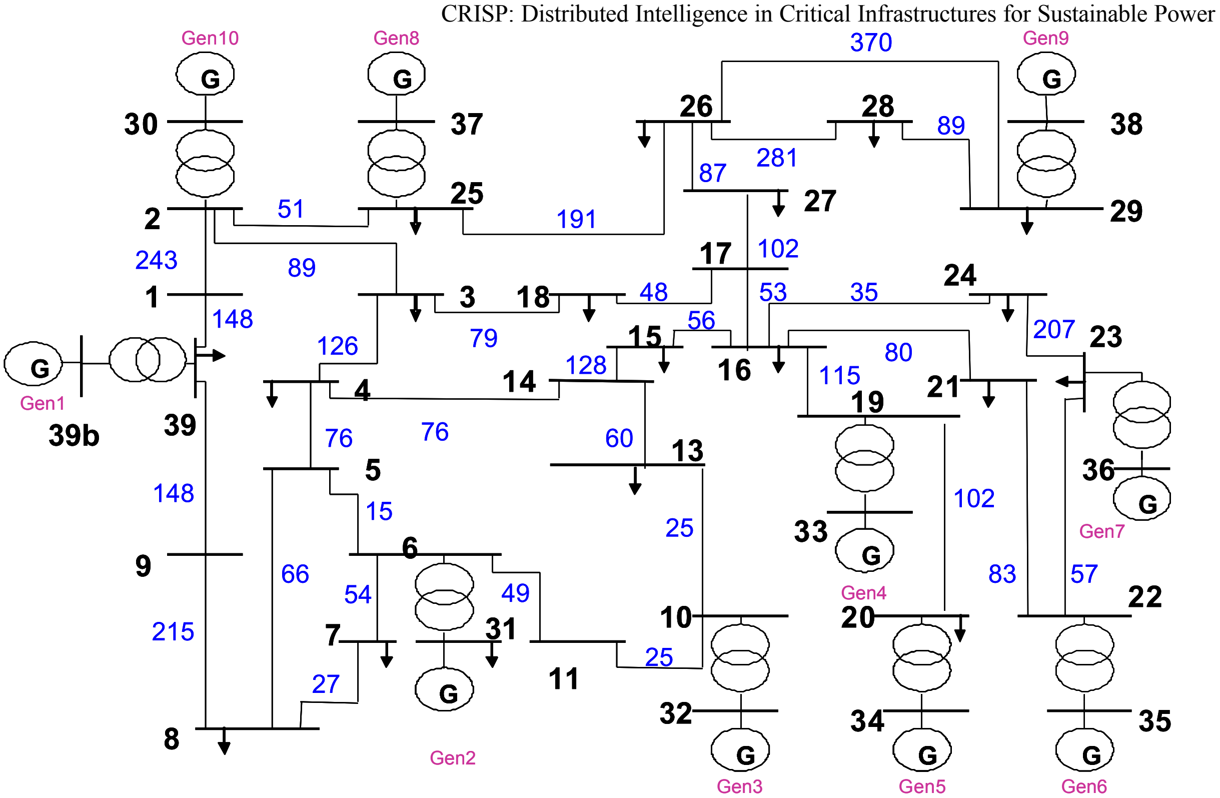


Figure.25.- Length of the transmission lines

Transformers:

20 kV/400 KV, Sn = 1300 MVA ; Ucc (%) = 10% ; Pcu = 0.24 %

The pu values of the transformer are: R= 0.000185 pu ; X = 0.00789 pu (base 100MVA)

3.2 Study of scenarios

The works developed in the WP 1.3 have as main goals to demonstrate the possibility that DG gives to the system in order to enhance the robustness of the system in normal operation and as well in emergency states (major incidents). To carry out these objectives, some main scenarios are listed:

- The simulated scenarios goes from the normal operation of the system to the major events provoked by the combination of several disturbances as mentioned in D.1.1 (short-circuit, load variation, loss of lines, loss of generators…)
- Insertion of different amount of DG penetration: comparison with the no-DG insertion case
- Insertion of RES and intermittence
- Influence of the DG disconnection protection in the dynamic system behaviour
- Participation of DG on the frequency control
- Participation of DG on the voltage control

The methodology which is used to carry out the study consists on the evaluation of the system in the power flows in the system, voltages magnitudes, and current in the lines in order to ensure that the security limits of the system are not violated. In parallel, other studies of the system such as the small-signal stability are also developed, because if the system is not stable at small-signal it can not be stable to major events.

So, in a first step of the project, the study case presented in the paragraph 3.1 has been modified by the insertion of DG units and a real French sub-transmission network (STN) system composed by a sub-transmission loop with 3 feeders to the distribution system. In two of these three feeders, real French distribution networks have been installed. The insertion of the STN introduced a case of 1% of decentralised generated power.

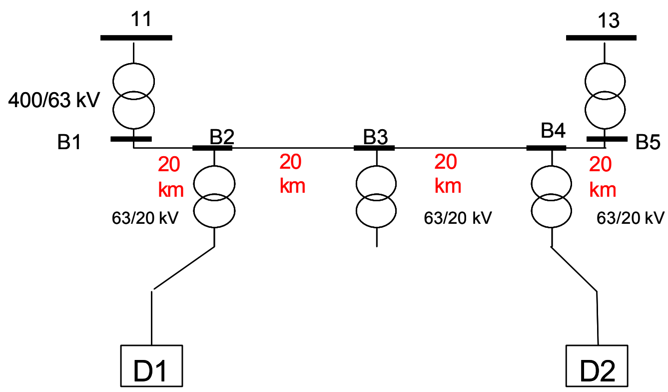


Figure.26.- Sub-transmission and distribution system

Then, DG units consisting on a 20kV, 100 MW synchronous machines that represent the aggregation of distribution and sub-transmission areas in terms of injected power into the transmission system, are located in the system in order to establish several main scenarios of DG penetration: 10%,20%,30%, 40% and 50% of the total produced active power in the system. Thus, a redispatching of the centralised generation has been carried out as it is shown in figure 27.

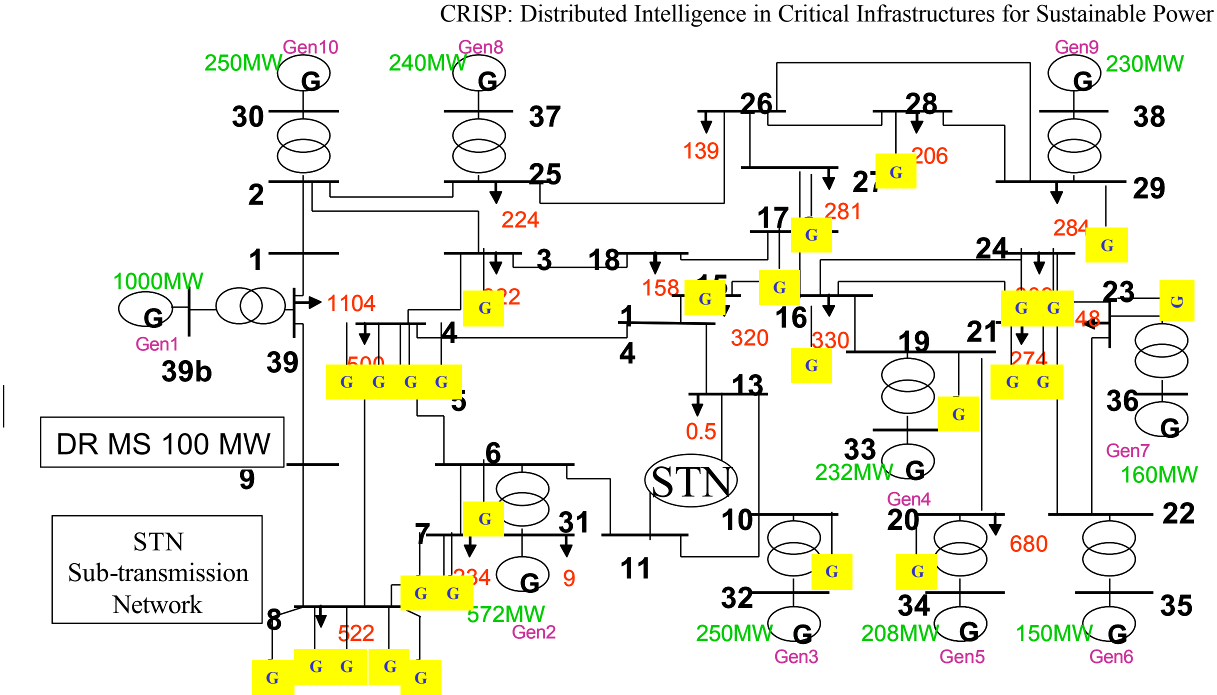


Figure.27.- DG insertion in the study case system

Thus, the comparison of losses between the different cases of DG insertion shows that an important reduction of electric losses can be obtained with the decentralised production. That is obvious if the DG connection is made near the load because in that case, the power does not have to be transmitted, it is produced there where it is consumed. However, one can see (figure 28, 1%GED and 40 %DG insertion) that a non optimal location of DG can reach the system to a rise of the losses in the whole system. One can add that the location is not always controllable, because it is always the network that must adapt itself to the new operating situations.

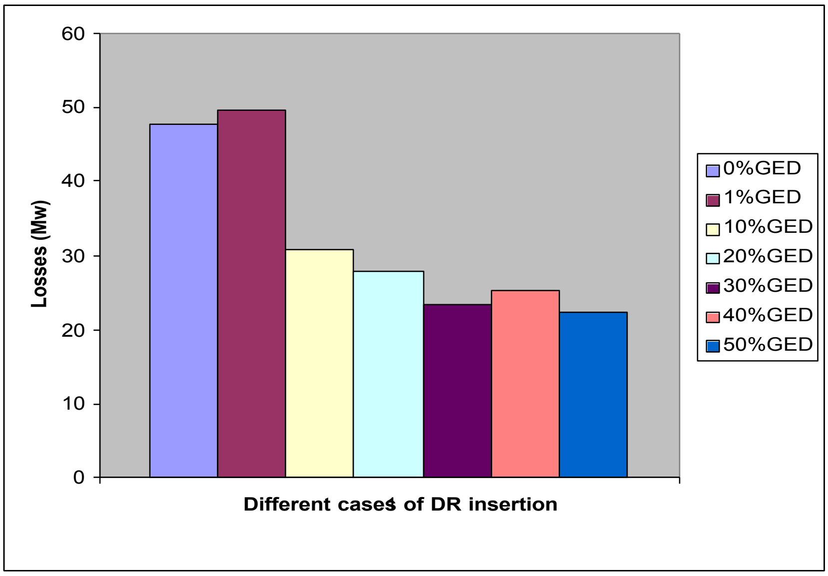


Figure.28.- DR insertion in the study case system

The rescheduling of the generation power between the centralised generation and the decentralised generators leads the system to a new power flow in the transmission lines, in the different simulations (0% DR, 10%DR...50%DR). One main conclusion can be commented, that is the unloading of the transmission lines, the most loaded lines changes its power flow to lower values. It is obvious because the transmission of energy is not required at the same degree. That gives us a system that can withstand better the losses of elements as it will be shown later.

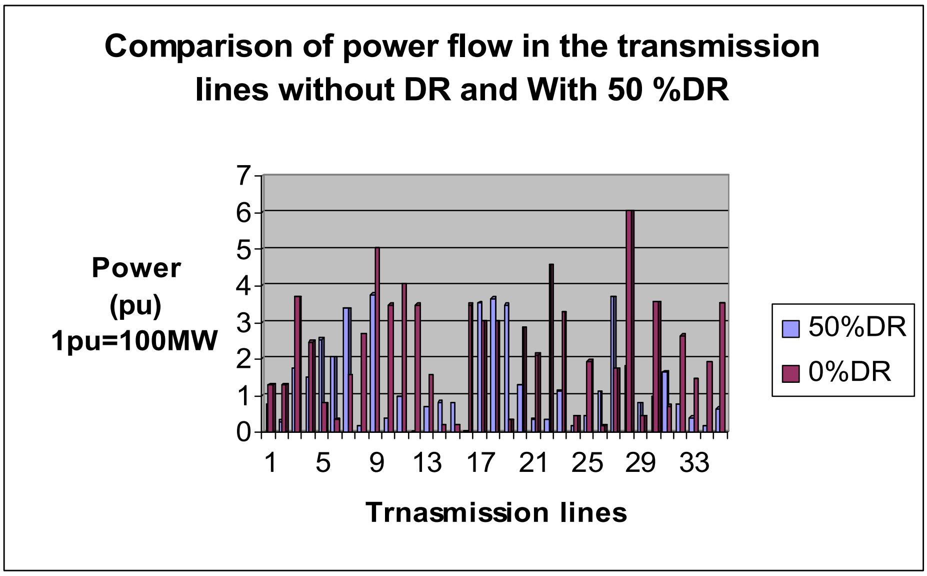


Figure.29.- Comparison of power flows in the transmission lines with 50% DR and without DR

The insertion of DR in the system raises the voltage profile in the transmission system; this is not a negative impact because the system operator is interested to operate at the maximal voltage power as possible (less current in the lines and so lower electric losses). However, the rise is limited by the technical voltage interval (420 kV to 380 kV). As it was mentioned in paragraph 2.3 a wrong voltage profile obliged the operator to modify the voltage by a secondary voltage control.

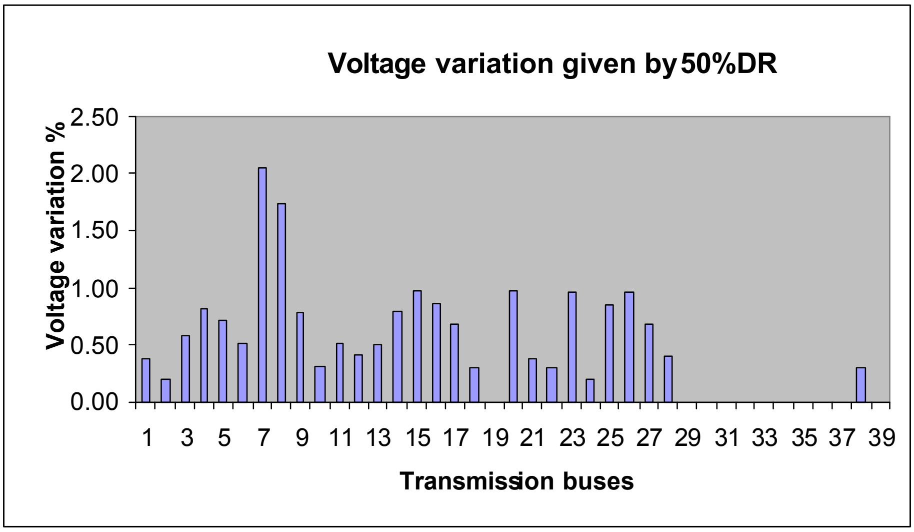


Figure.30.- Voltage variation caused by the insertion of 50% DR

These results constitute some first conclusions of the static analysis of the system. To spread the study, sequences of events are simulated in order to compare the dynamic response of the system with DR and without DR.

- **Loss of lines:**

The next simulation case contains the loss of two lines of the system 8-5 and 5-4. This loss provokes a cascading line tripping in the case of no-DG whereas the system with 50%DR stands the disturbance and it can continue the normal operation. Let's see the sequence of events in the 0%DR case:

- Lines tripping 6-7 in 20 minutes (line with 120% of the nominal power)
- Line tripping 13-10 and 14-10 in 2 seconds (lines with 190% of the nominal power)
- Sub-networks creation
- Loss of synchronism of generators
- Generator protection ➔ Blackout

After the loss of lines 8-5 and 5-4 the voltage profile in the system shows a violation of voltage levels in bus 7 and 8.

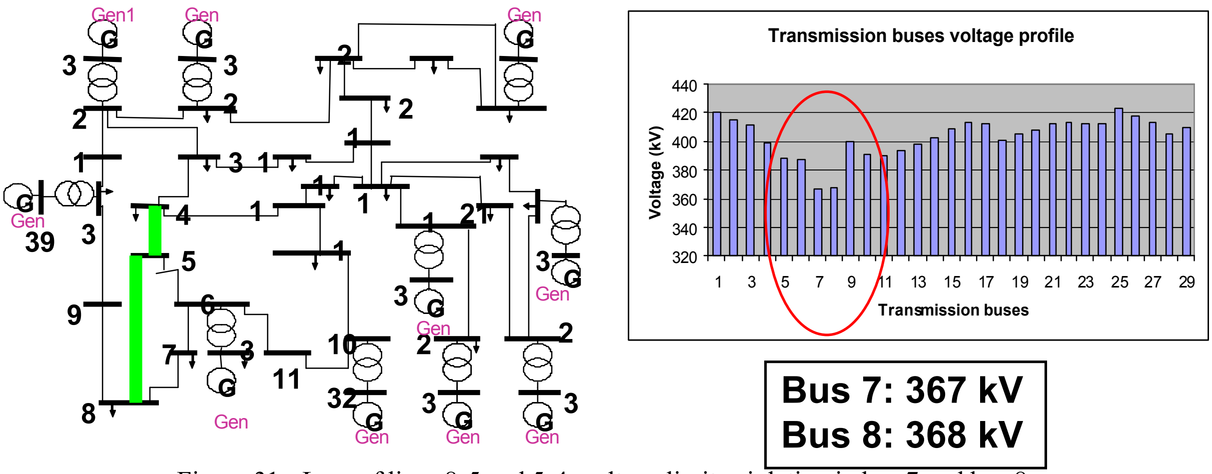


Figure.31.- Loss of lines 8-5 and 5-4, voltage limits violation in bus 7 and bus 8

The loss of these two lines provokes also the existence of an overload in line 6-7. This overload is of 20% and so if the system operator does not take some remedial action the line trip in 20 minutes.

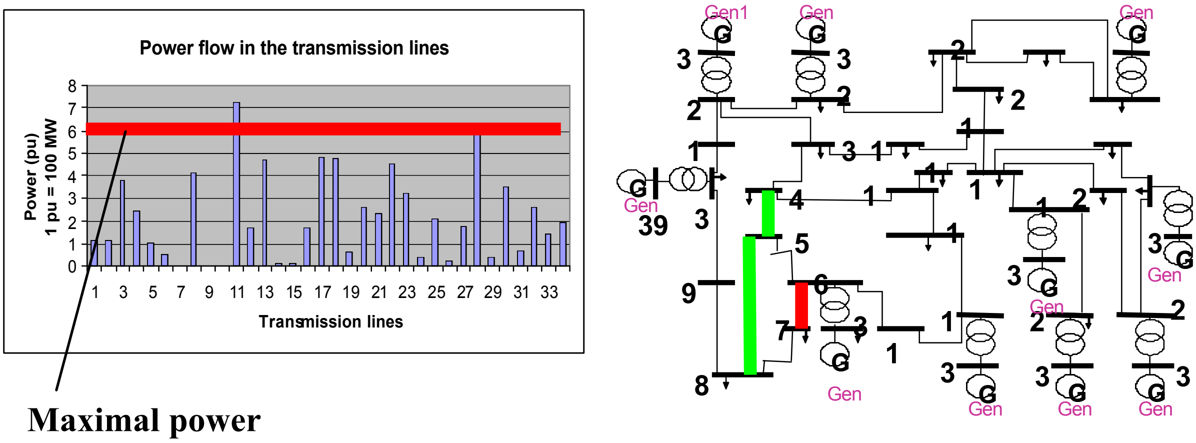


Figure.32.- Loss of lines 8-5 and 5-4, power limits violation in line 6-7, line 6-7 tripping in 20 minutes

After 20 minutes, the line 6-7 is tripped and in the new operation point the system is seriously in danger because lines 14-10 and 13-10 have an overload of 90% so its tripping last some seconds.

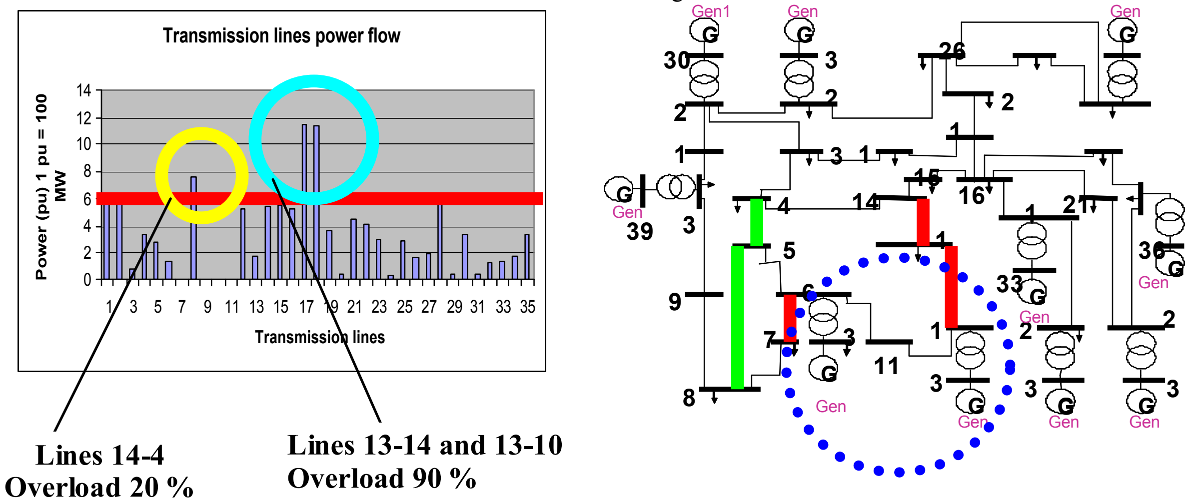


Figure.33.- Loss of lines 8-5 and 5-4, power limits violation in line 6-7, line 6-7 tripping in 20 minutes

The line tripping 14-10 and 13-10 creates two sub-networks in the system, these sub-networks are not prepared for the islanding operation and so, the generators of both sub-networks lose the synchronism and a resulting blackout is verified. On the other side (50%DR insertion), the loss of lines 8-5 and 5-4 do not cause the loss of the system in the case of 50%DR insertion

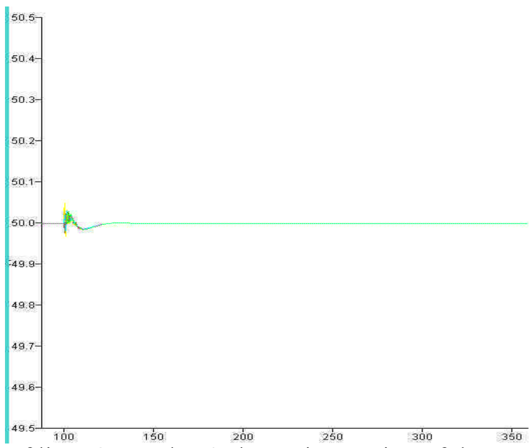


Figure.34.- Loss of lines 8-5 and 5-4, dynamic reaction of the system with 50%DR

- **Loss of a generator and a line:**

This simulation case consists as well in a (n-2) disturbance in the system by the generator GEN10 a line 4 -14 loss. The comparison of the subsequent events after the disturbances in the 0%DR case and 50%DR case shows how the system without DR loss the synchronism and on the other hand the system with DR can withstand the disturbances.

Let's analyze the sequence of events in the 0%DR insertion, after the disturbances the line 6-5 has a 18 %overload above the nominal rate and so this line trips in 20 minutes.

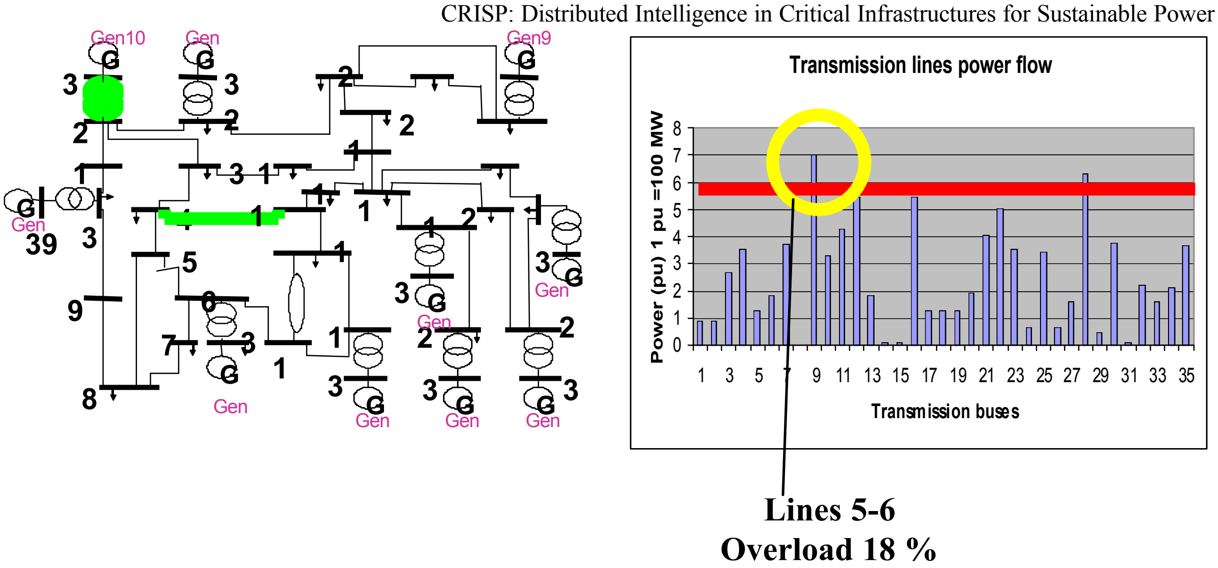


Figure.35.- Loss of line 4-14 and generator GEN10, overload of line 5-6

After 20 minutes, the line 5-6 trips and in the new operating point the line 7-6 is overloaded and its disconnection is expected after 10 minutes.

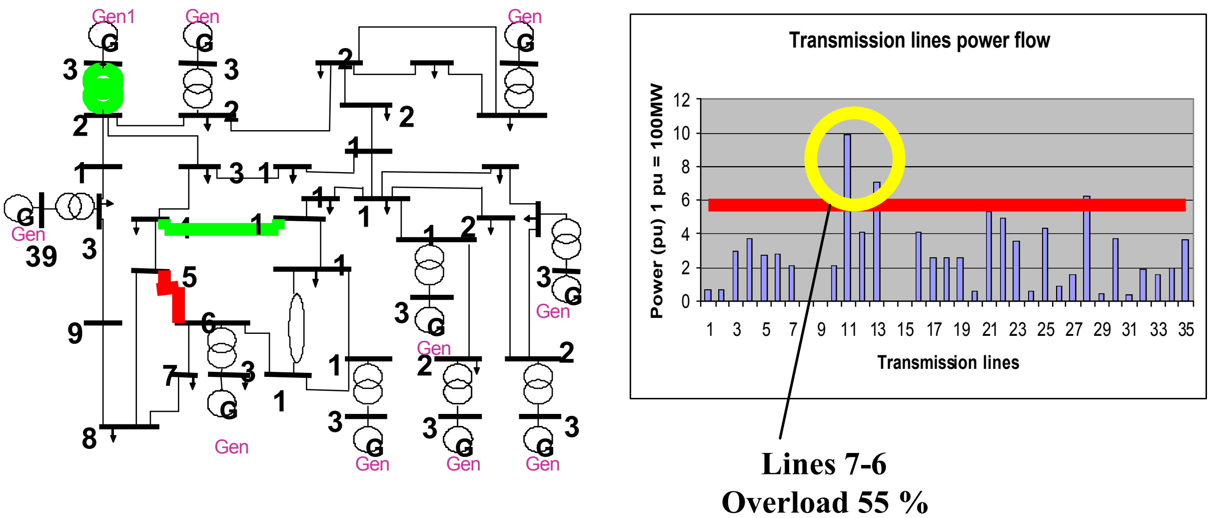


Figure.36.- Loss of line 4-14 and generator GEN10, tripping lines 5-6, overload line 7-6

Finally, with the trip of the line 7-6 the system loses the synchronism and so the blackout appears.

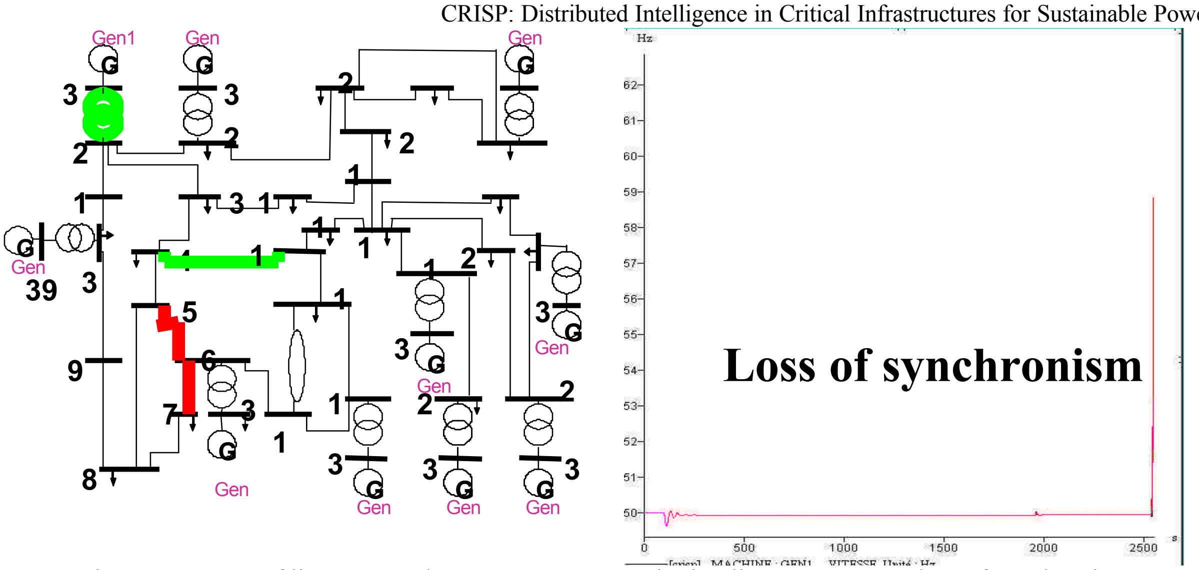


Figure.37.- Loss of line 4-14 and generator GEN10, tripping lines 7-6, system loss of synchronism

In the case of 50%DR, the system withstands the disturbances and it takes another operating point according with the primary control.

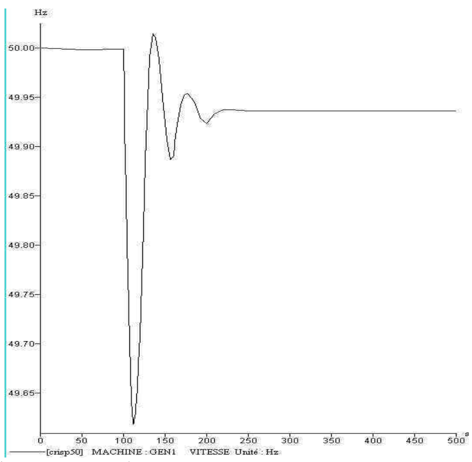


Figure.38.- Loss of line 4-14 and generator GEN10, 50%DR system dynamic reaction

- **Load variation under the primary reserve:**

In this simulation case, the load of bus 39 changes its load in 400 MW (near a 6.5% of the initial system's consumption) at t=100 s, This load variation is lower than the primary reserve of the system (535MW) and so the system can withstand the disturbance resulting a steady state (a new frequency according to the system speed droop).

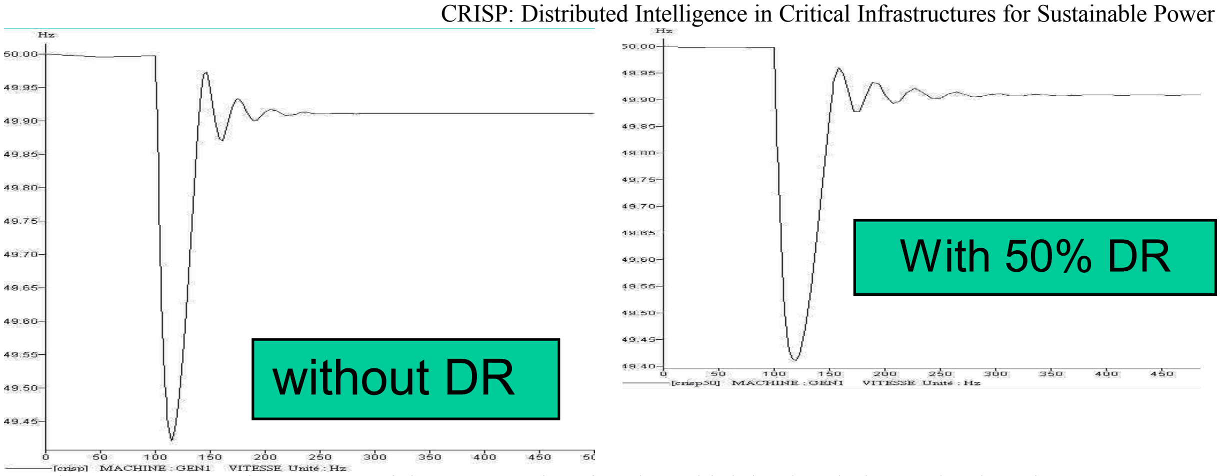


Figure.39.- Dynamic response of the system when faced to a high load variation under the primary reserve

- **Load variation above the primary reserve**:

In this simulation case, the load of bus 21 changes its load in 600 MW (near a 10% of the initial system's consumption) at t=100 s, This load variation is higher than the primary reserve of the system (535MW) and so the system is not able to withstand the disturbance resulting a state of loss of synchronism. This loss of synchronism is verified in both cases (with and without DR)

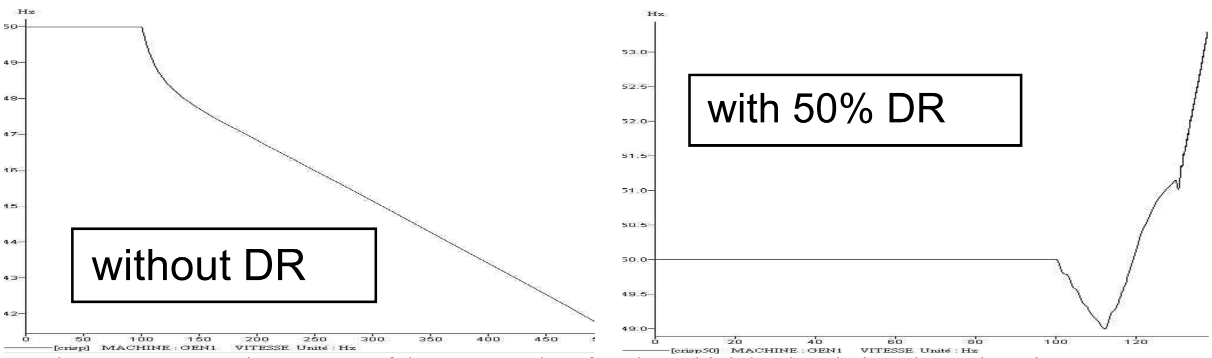
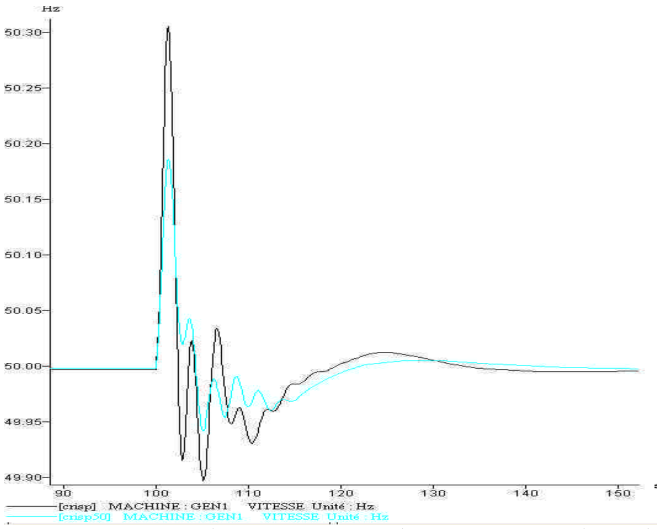


Figure.40.- Dynamic response of the system when faced to a high load variation above the primary reserve

- **Short-circuit:**

After a 150 ms short-circuit in line 21-22 (t=100 s), the dynamic response of the systems without DR and with 50%DR recover the steady state at the same time and no one of them leaves a stable situation. However, if one compares the fault current, this is increased by the DR units from 8860 A to 11004 A. this is mainly explained because the DR units are represented by synchronous machine. One can expect that with other types of DR the fault current decreases, the systems with power electronics interface are normally immediately disconnect from the grid and so they do not participate to the fault current.



Case	Icc (A)
0%DR	8860
50%DR	11004

Figure.41.- Dynamic response to a short-circuit without DR and with 50%DR

3.3 Robustness criteria performance evaluation

After the first preliminary results which there were shown in the paragraph 3.2, this paragraph will analyse the application of the proposed robustness criteria in different scenarios. These scenarioas are the next ones:

- Scenario 1: DG with instantaneous disconnection protections
- Scenario 2: DG disconnection protection combination
- Scenario 3: DG without problems in the disconnection protections
- Scenario 4: Insertion of the intermittence
- Scenario 5: Participation of the DG on the frequency control
- Scenario 6: Participation of the DG on the voltage control

3.3.1 Evaluation of the robustness indices

3.3.1.1Scenario 1: Instantaneous DG disconnection protections

This first scenario consists on the study of the influence of the DG disconnection protection on the dynamic behaviour of the system when faced to disturbances. The evaluation of the robustness criteria is shown in different tables. These robustness indices have been evaluated after a selection of contingencies composed by loss of lines, load variations, loss of generators, short-circuits and combination of disturbances until (n-6). This contingency selection represents different small and severe disturbances that the system could face during the operation.

a) Cas 30% of DG insertion with instantaneous disconnection protection

The first studied case was the case of a 30% DG insertion. The 30% of DG insertion was disposed with instantaneous disconnection protections at 49.5 Hz and 0.85 Un. The results of different contingencies are shown in the next tables.

- Loss of lines:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOSS OF LINES	(n-1)											
1-2	0	0	1	0	0	1	0	0	0	0	0	0
1-39	0	0	1	0	0	1	0	0	1	0	0	1
2-3	0	0	0	0	0	0	0	0	0	0	0	0
25-2	0	0	0	0	0	0	0	0	0	0	0	0
4-3	0	0	0	0	0	0	0	0	0	0	0	0
3-18	0	0	0	0	0	0	0	0	0	0	0	0
4-5	0	0	0	0	0	0	0	0	0	0	0	0
4-14	0	0	0	0	0	0	0	0	0	0	0	0
5-6/1	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1	0	0	0	0	0	0	0	0	0	0	0	0
8-5	0	1	1	0	0	1	0	0	0	0	0	0
7-6	0	1	0	0	0	1	0	0	0	0	0	0
6-11	0	0	0	0	0	0	0	0	0	0	0	0
7-8	0	0	0	0	0	0	0	0	0	0	0	0

8-9	0	0	0	0	0	0	0	0	0	0	0	0
9-39	0	0	1	0	0	1	0	0	1	0	0	1
11-10	0	0	0	0	0	0	0	0	0	0	0	0
13-10	0	0	0	0	0	0	0	0	0	0	0	0
14-13	0	0	0	0	0	0	0	0	0	0	0	0
15-14	0	0	0	0	0	0	0	0	0	0	0	0
16-15	0	0	0	0	0	0	0	0	0	0	0	0
17-16	0	0	0	0	0	0	0	0	0	0	0	0
21-16	0	0	0	0	0	0	0	0	0	0	0	0
24-16	0	0	0	0	0	0	0	0	0	0	0	0
17-18	0	0	0	0	0	0	0	0	0	0	0	0
27-17	0	0	0	0	0	0	0	0	0	0	0	0
21-22/1	0	0	0	0	0	0	0	0	0	0	0	0
22-23	0	0	0	0	0	0	0	0	0	0	0	0
24-23	0	1	0	0	0	1	0	0	0	0	0	0
26-25	0	0	0	0	0	0	0	0	0	0	0	0
26-27	0	0	0	0	0	0	0	0	0	0	0	0
23-24	0	1	0	0	0	1	0	0	0	0	0	0

The dynamic behaviour of the when face to single line losses is acceptable in the case of 30% DG insertion with instantaneous disconnection protection. However, the index FD_1 warns the operator that the present state of the system has an unacceptable risk level because the $FD_1 < 1$, too much DG which could be disconnected after an ALEA touching the disconnection setting points and provokes a blackout. As the loss of single lines does not cause an ALEA, the FD index is equal to 0.

- Loss of generators:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOSS OF GENERATORS	(n-1)											
GEN1	0	3	1	0	0	3	0	0	0	3	0	3

The system stands dynamically the loss of the most important generator of those presents in the system. This is the main criterion of the generation adequacy. However, some problems in the voltage levels should be solved by the operator with secondary actions. We see the risk level detected by FD.

- Load variation:

If the load variation is very important, the frequency is seriously perturbed and so the 49.5 Hz is reached provoking the disconnection of DG units.

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOAD VARIATION												
BUS-3; 1200MW	0	0	0	0	0	0				3	3	3
BUS-4; 1200MW	0	0	0	0	0	0				3	3	3
BUS-7; 1200MW	0	2	1	0	0	2				3	3	3
BUS-8; 1200MW	0	1	0	0	0	1				3	3	3
BUS-15; 1200MW	0	2	0	0	0	2				3	3	3
BUS-16; 1200MW	0	0	0	0	0	0				3	3	3

BUS-18; 1200MW	**0**	**1**	**0**	**0**	**0**	**1**				**3**	**3**	**3**
BUS-20; 1200MW	**0**	**3**	**0**	**0**	**0**	**3**				**3**	**3**	**3**
BUS-21; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-23; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-24; 1200MW	**0**	**2**	**0**	**0**	**0**	**2**				**3**	**3**	**3**
BUS-25; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-26; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-27; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-28; 1200MW	**0**	**1**	**0**	**0**	**0**	**1**				**3**	**3**	**3**
BUS-29; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-31; 1200MW	**0**	**1**	**0**	**0**	**0**	**1**				**3**	**3**	**3**
BUS-39; 1200MW	**0**	**0**	**0**	**0**	**0**	**0**				**3**	**3**	**3**
BUS-3; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-4; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-7; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-8;500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-15; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-16; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-18; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-20; 500MW	**0**	**0**	**0**	**0**	**0**	**0**				**0**	**3**	**3**
BUS-21; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-23; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-24; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-25; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-26; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-27; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-28; 500MW	**0**	**0**	**0**	**0**	**0**	**0**				**0**	**3**	**3**
BUS-29; 500MW	**0**	**0**	**0**	**0**	**0**	**0**				**0**	**3**	**3**
BUS-31; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
BUS-39; 500MW	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

- Short-circuits in the transmission lines:

CONTINGENCY	**0%DG**						**30%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	**Transmission System**											

1-2	0	0	0	0	0	0					3	3
39-1	0	0	0	0	0	0	0	0	0	3	0	3
3-2	0	0	0	0	0	0					3	3
25-2	0	0	0	0	0	0					3	3
4-3	0	0	0	0	0	0					3	3
18-3	0	0	0	0	0	0					3	3
5-4	0	0	0	0	0	0					3	3
14-4	0	0	0	0	0	0					3	3
6-5	0	0	0	0	0	0					3	3
8-5	0	0	0	0	0	0					3	3
7-6	0	0	0	0	0	0					3	3
11-6	0	0	0	0	0	0					3	3
8-7	0	0	0	0	0	0					3	3
9-8	0	0	0	0	0	0	0	0	0	3	0	3
39-9	0	0	0	0	0	0	0	0	0	3	0	3
11-10	0	0	0	0	0	0					3	3
13-10	0	0	0	0	0	0					3	3
14-13	0	0	0	0	0	0					3	3
15-14	0	0	0	0	0	0					3	3
16-15	0	0	0	0	0	0					3	3
17-16	0	0	0	0	0	0					3	3
19-16	0	0	0	0	0	0					3	3
21-16	0	0	0	0	0	0					3	3
24-16	0	0	0	0	0	0					3	3
18-17	0	0	0	0	0	0					3	3
27-17	0	0	0	0	0	0					3	3
22-21	0	0	0	0	0	0					3	3
23-22	0	0	0	0	0	0					3	3
24-23	0	0	0	0	0	0					3	3
26-25					3	3					3	3
27-26					3	3					3	3
28-26					3	3	0	0	0	0	0	0
29-26					3	3	0	0	0	0	0	0
29-28					3	3	0	0	0	0	0	0
19-20	0	0	0	0	0	0	0	0	0	3	0	3

The initial system had a critical clearing time (CCT) lower than 200 ms for the short-circuist on lines 26-25, 27-26, 28-26, 29-26 and 29-28. In the case of DG insertion, after the short-circuit there is a dip on the voltage profil and so the DG is disconnected by the 0.85 Un threshold. However, after the disconnection of some first DG units the frequency is perturbed and so the 49.5 Hz threshold could also disconnect the DG.

- Evaluation of (n-2) events:

CONTINGENCY	**0%DG**						**30%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
Events	**(n-2)**											
1-2; 2-3	0	0	0	0	0	0	0	0	0	0	0	0
1-2; 3-4	0	0	0	0	0	0	0	0	0	0	0	0
1-2; 2-25	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 6-7	0	2	0	0	0	2	0	0	0	0	0	0
6-5/1; 4-5	0	0	0	0	0	0	0	0	0	0	0	0
13-14; 27-17	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 6-5/2	0	1	1	0	0	1	0	0	0	0	0	0

4-5; 5-8	0	1	1	0	0	1	0	0	0	0	0	0

- Evaluation of (n-3) events:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-3)											
6-5/1; 5-4; 7-6	0	1	0	0	0	1	0	0	0	0	0	0
5-4; 39-9; 7-6	0	3	1	0	0	3	0	3	1	0	0	3
5-4; 3-4; 7-6	0	1	1	0	0	1	0	0	0	0	0	0
4-5; 5-8; 6-7	0	3	3	0	0	3	0	2	3	0	0	3
GEN4; 15-16; 16-21	0	1	1	0	0	1	0	0	0	0	0	0
15-16; 16-21; 10-11	0	0	1	0	0	1	0	0	0	0	0	0

- Evaluation of (n-4) events:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-4)											
6-5/1; 6-5/2; 4-5; 6-7	0	3	3	0	0	3	0	2	3	0	0	3
5-4; 3-4; 7-6; 18-3	0	1	1	0	0	1	0	0	0	0	0	0
GEN10; GEN10B; 4-14; 6-5/1	0	1	0	0	0	1	0	0	0	0	0	0
GEN4; 15-16; 16-21; 16-24					3	3	0	3	0	0	0	3
25-26; 3-18; 4-14; 6-11					3	3	0	0	0	0	0	0

- Evaluation of (n-5) events:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-5)											
5-4; 3-4; 7-6; 18-3;14-4	0	2	0	0	0	2	0	0	0	0	0	0
4-5; 5-8; 6-7; 13-14; 10-13					3	3				0	3	3
6-5/1; 6-5/2; 6-7; 5-8; 8-9					3	3	0	2	0	0	0	2
6-5/1; 6-5/2; 6-7; 5-8; 4-5	0	3	1	0	0	3	0	2	0	0	0	2
6-5/1; 6-5/2; 6-7; 3-4; 4-5					3	3	0	2	0	0	0	2

- Evaluation of some (n-6) events:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-6)											
11-10; 11-6; 6-7; 8-5; 9-8; 18-3					3	3	0	0	0	0	0	0
6-5/1; 6-5/2; 6-7; 3-4; 9-8	0	3	0	0	0	3	0	2	0	0	0	2
5-4; 3-4; 7-6; 18-3;14-4; GEN10	0	2	0	0	0	2	0	0	0	0	0	0

The main conclusions regarding the results of the simulations is that the system can not stand short-circuits in the transmission system. Thus, all or almost all the DG, depending on the short-circuit position, is disconnected from the grid and then the system lost the synchronism because it can not stand the severe contingencies of (short-circuit + loss of DG). The system becomes in a critical state with that DG insertion and so it should be limited.
Regarding overloads and cascading, the system with DG has a better or equal behaviour (in general the distances to overloads are incremented by the Dg insertion).

b)Case 10% of DG insertion with instantaneous disconnection protection

The main problem shown in the previous case was the dynamic behaviour against short-circuit and that is what it is studied in the case of 10% of DG insertion with instantaneous protection setting points. The reduction on the DG insertion makes that FD > 1 and so the state is not classified as a risky one regarding the reserves and amount of load shedding (up to 48.5 Hz).

CONTINGENCY	0%DG						10%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	Transmission System											
1-2	0	0	0	0	0	0	0	0	0	0	0	0
39-1	0	0	0	0	0	0	0	0	0	0	0	0
3-2	0	0	0	0	0	0					3	3
25-2	0	0	0	0	0	0					3	3
4-3	0	0	0	0	0	0	0	0	0	0	0	0
18-3	0	0	0	0	0	0					3	3
5-4	0	0	0	0	0	0	0	0	0	0	0	0
14-4	0	0	0	0	0	0	0	0	0	0	0	0
6-5	0	0	0	0	0	0	0	0	0	0	0	0
8-5	0	0	0	0	0	0	0	0	0	0	0	0
7-6	0	0	0	0	0	0	0	0	0	0	0	0
11-6	0	0	0	0	0	0	0	0	0	0	0	0
8-7	0	0	0	0	0	0	0	0	0	0	0	0
9-8	0	0	0	0	0	0	0	0	0	0	0	0
39-9	0	0	0	0	0	0	0	0	0	0	0	0
11-10	0	0	0	0	0	0	0	0	0	0	0	0
13-10	0	0	0	0	0	0	0	0	0	0	0	0

14-13	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
15-14	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
16-15	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
17-16	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
19-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
21-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
24-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18-17	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
27-17	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
22-21	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
23-22	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
24-23	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
26-25					**3**	**3**					**3**	**3**
27-26					**3**	**3**					**3**	**3**
28-26					**3**	**3**					**3**	**3**
29-26					**3**	**3**					**3**	**3**
29-28					**3**	**3**					**3**	**3**
19-20	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

The 10% of DG is not satisfactory for the normal behaviour of the system because the apparition of load shedding to save the system. In fact, if we consider the 49 Hz in the FD indice, this is going to give us a value 0 and the problems of the system are noted by the loss of synchronism (LS) equal to 3. In some cases, the system can have a RI equal to 0 thanks to the load shedding at 49 Hz that saves the system. However, one can think that a simple failure in the transmission system should not provoke a load shedding and so, tha appropriate DG insertion should be limited by a not load shedding after a fault and a not loss of synchronism of the whole system. If the load shedding is not taken into account in the indice FD, the level of DG with instantaneous is limited to the primary reserve, and it will have a value equal to 3.

c) Case 9% of DG insertion with instantaneous disconnection protection

CONTINGENCY	**0%DG**						**9%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	**Transmission System**											
1-2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
39-1	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
3-2	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
25-2	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
4-3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18-3	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
5-4	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
14-4	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6-5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
8-5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
7-6	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
11-6	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
8-7	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
9-8	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
39-9	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
11-10	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

13-10	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
14-13	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
15-14	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
16-15	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
17-16	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
19-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
21-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
24-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18-17	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
27-17	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
22-21	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
23-22	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
24-23	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
19-20	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

In this case, we continue to see problems in the stability of the system and load shedding that save the system. In the next cases, only the worst cases will be analysed.

d) Case 7.5% of DG insertion with instantaneous disconnection protection

CONTINGENCY	**0%DG**						**7.5%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	**Transmission System Comments:**											
3-2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
25-2	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
17-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18-17	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**

The global behaviour becomes satisfactory but there is two short-circuits that cause the loss of the system. So, the appropriate DG insertion should decrease.

e) Case 6% of DG insertion with instantaneous disconnection protection

CONTINGENCY	**0%DG**						**6%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	**Transmission System Comments:**											
3-2	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
25-2	**0**	**0**	**0**	**0**	**0**	**0**					**3**	**3**
17-16	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
18-17	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

The 200 ms short-circuit constitutes a very severe short-circuit and the maximal time in which it should be eliminated goes from 70 ms to 150 ms depedending on the location. So, a computation of transient stability has been carried out to see the critical clearing time in line 25-2 for different DG insertions.

DG INSERTION	CCT (s)
0%	0.233-0.24
2.6%	0.213-0.220
4.25%	0.192-0.199
6%	0.179-0.185
7.5%	0.165-0.172
9%	0.144-0.151
10%	0.130-0.137

Table.9.-Computation of the critical clearing time (CCT) for the short-circuit at line 25-2

The critical clearing time decreases with the insertion of DG as it is illustrated in the last table (that depends on the position of the DG and the configuration of the system). Thus, some assumptions can be taken into account to define an appropriate amount of DG insertion

DG INSERTION	Assumption
2.6 %	CCT= 200 ms
7.5%	CCT= 150 ms
9%	CCT= 120 ms
9.5%	No problem of CCT The limit is fixed by: No Load Shedding after a short-circuit

Table.10.-Results of appropriate DG insertion for different asumptions

As a final conclusion, the case of 7.5 % seems to be the most appropriate DG insertion because it stands the short-circuits without load shedding. If the operator does not have problems with the CCT, the limited is fixed by the fact of not having load shedding after a fault and so the appropriate DG insertion is around 9-9.5% which corresponds to a slightly lower level than the primary reserve.

3.3.1.2 Scenario 2: DG disconnection protection combination

In this case, the limit of DG insertion in the system it is analyzed regarding to two cases: with instantaneous disconnection protection (9% of the total 30% DG insertion and 30% of the total 30% of DG insertion) and without problems in the disconnection protection. The appropriate amount of DG insertion without disconnection problems is studied in the scenario 3 and the rules to limit this kind of insertion it is given in the study of that scenario 3. On the other hand, the limit of DG insertion with disconnection protection is given by the fact of not provoke load shedding after the disconnection of DG in the system. The dynamic behaviour of the system (transient stability and critical clearing time) is improved with the integration of the DG areas equivalents and so the system does not have any problems in CCT as it was possible to see in the study of the scenario 1.

CONTINGENCY	9/30%DG instantaneous						30/30%DG instantaneous					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	Transmission System Comments:											
1-2	0	0	0	0	0	0					3	3
39-1	0	0	0	0	0	0	0	0	0	3	0	3
3-2	0	0	0	0	0	0					3	3
25-2	0	0	0	0	0	0					3	3
4-3	0	0	0	0	0	0					3	3
18-3	0	0	0	0	0	0					3	3
5-4	0	0	0	0	0	0					3	3
14-4	0	0	0	0	0	0					3	3
6-5	0	0	0	0	0	0					3	3
8-5	0	0	0	0	0	0					3	3
7-6	0	0	0	0	0	0					3	3
11-6	0	0	0	0	0	0					3	3
8-7	0	0	0	0	0	0					3	3
9-8	0	0	0	0	0	0	0	0	0	3	0	3
39-9	0	0	0	0	0	0	0	0	0	3	0	3
11-10	0	0	0	0	0	0					3	3
13-10	0	0	0	0	0	0					3	3
14-13	0	0	0	0	0	0					3	3
15-14	0	0	0	0	0	0					3	3
16-15	0	0	0	0	0	0					3	3
17-16	0	0	0	0	0	0					3	3
19-16	0	0	0	0	0	0					3	3
21-16	0	0	0	0	0	0					3	3
24-16	0	0	0	0	0	0					3	3
18-17	0	0	0	0	0	0					3	3
27-17	0	0	0	0	0	0					3	3
22-21	0	0	0	0	0	0					3	3
23-22	0	0	0	0	0	0					3	3
24-23	0	0	0	0	0	0					3	3
26-25	0	0	0	0	0	0					3	3
27-26	0	0	0	0	0	0					3	3
28-26	0	0	0	0	0	0	0	0	0	0	0	0
29-26	0	0	0	0	0	0	0	0	0	0	0	0
19-20	0	0	0	0	0	0	0	0	0	3	0	3

The changes of the transient stability depend on the configuration of the system (generators, dispatching, loads and available lines), all these different parameters are mentioned to establish a general methodology for the evaluation of the appropriate amount of DG insertion in a general case.

As it was said, when explaining the (n-1) criterion, utilities considered the different events which can occur with an associated probability. Thus, the less probable events do not cause major consequences in the system that is obvious because the weight of the different (n-1) elements is not the same. Some elements as huge generators or interconnection lines are more dangerous for the system than others, utilities allow an amount of load shedding to be appeared when these important elements are lost.
The appearance of a short-circuit at the transmission level is an event which can appear easily and so it seems not very serious to allow a load shedding to save the system. DG should be limited in order to not create abnormal load shedding. One should take into account that load shedding it is an emergency tool and if the load shedding is used (at 49 Hz) by a first short-circuit; the system could remain in a bad operating point to face second events.

So, this case shows the dependence on the transient stability (critical clearing time)of the system configuration. In conclusion, a slightly lower level than the primary reserve is the appropriate amount of DG insertion (instantaneous protections) in order of not having load shedding after a short-circuit.

3.3.1.3 Scenario 3: DG without the problems derived from the disconnection protection setting points

In this case, the DG is supposed to have disconnection protections that are not causing problems for the whole system. So, these DG protections are supposed to behave with the same performance than the big power plants protections. Several cases of DG insertion have been considered: 30, 40, 50, 60 %... The different systems have been compared with a constant primary reserve (that is no DG participation to the primary frequency control) and without intermittence problems.The main results and conclusions and results are shown in the next items.

a)Cas 30% of DG insertion

- Loss of lines:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOSS OF LINES	(n-1)											
1-2	0	0	0	0	0	0	0	0	0	0	0	0
1-39	0	0	0	0	0	0	0	0	0	0	0	0
3-2	0	0	0	0	0	0	0	0	0	0	0	0
25-2	0	0	0	0	0	0	0	0	0	0	0	0
4-3	0	0	0	0	0	0	0	0	0	0	0	0
18-3	0	0	0	0	0	0	0	0	0	0	0	0
5-4	0	0	0	0	0	0	0	0	0	0	0	0
14-4	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1	0	0	0	0	0	0	0	0	0	0	0	0
8-5	0	1	0	0	0	1	0	0	0	0	0	0
6-7	0	1	0	0	0	1	0	0	0	0	0	0
11-6	0	0	0	0	0	0	0	0	0	0	0	0
8-7	0	0	0	0	0	0	0	0	0	0	0	0
9-8	0	0	0	0	0	0	0	0	0	0	0	0
39-9	0	0	0	0	0	0	0	0	0	0	0	0
10-11	0	0	0	0	0	0	0	0	0	0	0	0
13-10	0	0	0	0	0	0	0	0	0	0	0	0
13-14	0	0	0	0	0	0	0	0	0	0	0	0
15-14	0	0	0	0	0	0	0	0	0	0	0	0
16-15	0	0	1	0	0	1	0	1	0	0	0	1
17-16	0	0	0	0	0	0	0	0	0	0	0	0
21-16	0	0	0	0	0	0	0	0	0	0	0	0
24-16	0	0	0	0	0	0	0	3	0	0	0	3
18-17	0	0	0	0	0	0	0	0	0	0	0	0
27-17	0	0	0	0	0	0	0	0	0	0	0	0
22-21/1	0	0	0	0	0	0	0	0	0	0	0	0
23-22	0	0	0	0	0	0	0	0	0	0	0	0
24-23	0	1	0	0	0	1	0	0	0	0	0	0
26-25	0	0	0	0	0	0	0	0	0	0	0	0
27-26	0	0	0	0	0	0	0	0	0	0	0	0

- Loss of generators

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOSS OF GENERATORS	(n-1)											
GEN1	0	3	1	0	0	3	0	0	0	0	0	0

- Load variation:

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOAD VARIATION												
BUS-3; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-4; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-7; 1200MW	0	2	1	0	0	2	0	0	0	0	0	0
BUS-8; 1200MW	0	1	0	0	0	1	0	0	0	0	0	0
BUS-15; 1200MW	0	2	0	0	0	2	0	0	0	0	0	0
BUS-16; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-18; 1200MW	0	1	0	0	0	1	0	0	0	0	0	0
BUS-20; 1200MW	0	3	0	0	0	3	0	3	0	0	0	3
BUS-21; 1200MW	0	0	0	0	0	0	0	1	0	0	0	1
BUS-23; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-24; 1200MW	0	2	0	0	0	2	0	2	0	0	0	2
BUS-25; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-26; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-27; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-28; 1200MW	0	1	0	0	0	1	0	0	0	0	0	0
BUS-29; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-31; 1200MW	0	1	0	0	0	1	0	0	0	0	0	0
BUS-39; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-3; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-4; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-7; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-8;500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-15; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-16; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-18; 500MW	0	0	0	0	0	0	0	0	0	0	0	0

BUS-20; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-21; 500MW	0	0	0	0	0	0	0	1	0	0	0	1
BUS-23; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-24; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-25; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-26; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-27; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-28; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-29; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-31; 500MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-39; 500MW	0	0	0	0	0	0	0	0	0	0	0	0

- Short-circuits:

CONTINGENCY	**0%DG**						**30%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	**Transmission System Comments:**											
1-2	0	0	0	0	0	0	0	0	0	0	0	0
39-1	0	0	0	0	0	0	0	0	0	0	0	0
3-2	0	0	0	0	0	0	0	0	0	0	0	0
25-2	0	0	0	0	0	0	0	0	0	0	0	0
4-3	0	0	0	0	0	0	0	0	0	0	0	0
18-3	0	0	0	0	0	0	0	0	0	0	0	0
5-4	0	0	0	0	0	0	0	0	0	0	0	0
14-4	0	0	0	0	0	0	0	0	0	0	0	0
6-5	0	0	0	0	0	0	0	0	0	0	0	0
8-5	0	0	0	0	0	0	0	0	0	0	0	0
7-6	0	0	0	0	0	0	0	0	0	0	0	0
11-6	0	0	0	0	0	0	0	0	0	0	0	0
8-7	0	0	0	0	0	0	0	0	0	0	0	0
9-8	0	0	0	0	0	0	0	0	0	0	0	0
39-9	0	0	0	0	0	0	0	0	0	0	0	0
11-10	0	0	0	0	0	0	0	0	0	0	0	0
13-10	0	0	0	0	0	0	0	0	0	0	0	0
14-13	0	0	0	0	0	0	0	0	0	0	0	0
15-14	0	0	0	0	0	0	0	0	0	0	0	0
16-15	0	0	0	0	0	0	0	0	0	0	0	0
17-16	0	0	0	0	0	0	0	0	0	0	0	0
19-16	0	0	0	0	0	0	0	0	0	0	0	0
21-16	0	0	0	0	0	0	0	0	0	0	0	0
24-16	0	0	0	0	0	0	0	0	0	0	0	0
18-17	0	0	0	0	0	0	0	0	0	0	0	0
27-17	0	0	0	0	0	0	0	0	0	0	0	0
22-21	0	0	0	0	0	0	0	0	0	0	0	0
23-22	0	0	0	0	0	0	0	0	0	0	0	0
24-23	0	0	0	0	0	0	0	0	0	0	0	0
26-25					3	3	0	0	0	0	0	0
27-26					3	3	0	0	0	0	0	0

28-26					**3**	**3**	**0**	**0**	**0**	**0**	**0**	**0**
29-26					**3**	**3**	**0**	**0**	**0**	**0**	**0**	**0**
29-28					**3**	**3**	**0**	**0**	**0**	**0**	**0**	**0**
19-20	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

In this case, the DG insertion enhance the transient stability and the system can stand the severe 200 ms short-circuit at lines 26-25, 27-26, 28-26, 29-26 and 29-28.

- Events (n-2)

CONTINGENCY	**0%DG**						**30%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
Events	**(n-2)**											
1-2; 2-3	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
1-2; 3-4	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
1-2; 2-25	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6-5/1; 6-7	**0**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
6-5/1; 4-5	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
13-14; 27-17	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
6-5/1; 6-5/2	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
4-5; 5-8	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

- Events (n-3)

CONTINGENCY	**0%DG**						**30%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
Events	**(n-3)**											
6-5/1; 5-4; 7-6	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
5-4; 39-9; 7-6	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**1**
5-4; 3-4; 7-6	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**
4-5; 5-8; 6-7	**0**	**3**	**3**	**0**	**0**	**3**					**3**	**3**
GEN4; 15-16; 16-21	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**
15-16; 16-21; 10-11	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**

- Events (n-4)

CONTINGENCY	**0%DG**						**30%DG**					
	SSS	**SPIR**	**VCI**	**FD**	**LS**	**RI**	**SSS**	**SPIR**	**VCI**	**FD**	**LS**	**RI**
Events	**(n-4)**											
6-5/1; 6-5/2; 5-4; 6-7	**0**	**3**	**3**	**0**	**0**	**3**					**3**	**3**
5-4; 3-4; 7-6; 14-4	**0**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**
5-4; 3-4; 7-6; 18-3	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
GEN10; GEN10B; 4-14; 6-5/1	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
25-26; 3-18; 4-14; 6-11	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
GEN4; 15-16; 16-21; 16-24	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**1**

- Events (n-5)

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-5)											
5-4; 3-4; 7-6; 18-3;14-4	0	2	0	0	0	2	0	0	0	0	0	0
4-5; 5-8; 6-7; 13-14; 10-13					3	3					3	3
6-5/1; 6-5/2; 6-7; 5-8; 8-9	0	3	0	0	0	3	0	2	0	0	0	2
6-5/1; 6-5/2; 6-7; 5-8; 4-5	0	3	3	0	0	3					3	3
6-5/1; 6-5/2; 6-7; 3-4; 4-5					3	3					3	3

- Events (n-6)

CONTINGENCY	0%DG						30%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-6)											
11-10; 11-6; 6-7; 8-5; 9-8; 18-3	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 6-5/2; 6-7; 5-4; 9-8; 8-5	0	3	0	0	0	3	0	2	0	0	0	2
5-4; 3-4; 7-6; 18-3;14-4; GEN10	0	2	0	0	0	2	0	0	0	0	0	0

b) Cases 60% of DG insertion

The cases of 60% demonstrated transient stability problems: reduction of critical clearing time and loss of synchronism. Other main problem of a very high DG insertion is the control of the system that is it can be problematic to ensure good voltage stability and of course, if big power plants are closed there is a reduction of the primary reserve. Primary reserve is a delicate parameter in study of the system and so, a reduction of primary reserve implies a reduction of the robustness. So, the DG insertion should be increased until the operator could not guarantee any more the voltage and the adequated reserves.

c) Cases 40-50% of DG insertion

- Short-circuits:

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
SHORT-CIRCUIT (200ms, 3-phases, in the middle of the lines)	Transmission System											
1-2	0	0	0	0	0	0	0	0	0	0	0	0
39-1	0	0	0	0	0	0	0	0	0	0	0	0
3-2	0	0	0	0	0	0	0	0	0	0	0	0
25-2	0	0	0	0	0	0	0	0	0	0	0	0
4-3	0	0	0	0	0	0	0	0	0	0	0	0
18-3	0	0	0	0	0	0	0	0	0	0	0	0
5-4	0	0	0	0	0	0	0	0	0	0	0	0
14-4	0	0	0	0	0	0	0	0	0	0	0	0
6-5	0	0	0	0	0	0	0	0	0	0	0	0
8-5	0	0	0	0	0	0	0	0	0	0	0	0
7-6	0	0	0	0	0	0	0	0	0	0	0	0
11-6	0	0	0	0	0	0	0	0	0	0	0	0
8-7	0	0	0	0	0	0	0	0	0	0	0	0
9-8	0	0	0	0	0	0	0	0	0	0	0	0
39-9	0	0	0	0	0	0	0	0	0	0	0	0
11-10	0	0	0	0	0	0	0	0	0	0	0	0
13-10	0	0	0	0	0	0	0	0	0	0	0	0
14-13	0	0	0	0	0	0	0	0	0	0	0	0
15-14	0	0	0	0	0	0	0	0	0	0	0	0
16-15	0	0	0	0	0	0	0	0	0	0	0	0
17-16	0	0	0	0	0	0	0	0	0	0	0	0
19-16	0	0	0	0	0	0	0	0	0	0	0	0
21-16	0	0	0	0	0	0	0	0	0	0	0	0
24-16	0	0	0	0	0	0	0	0	0	0	0	0
18-17	0	0	0	0	0	0	0	0	0	0	0	0
27-17	0	0	0	0	0	0	0	0	0	0	0	0
22-21	0	0	0	0	0	0	0	0	0	0	0	0
23-22	0	0	0	0	0	0	0	0	0	0	0	0
24-23	0	0	0	0	0	0	0	0	0	0	0	0
26-25	0	0	0	0	0	0	0	0	0	0	0	0
27-26	0	0	0	0	0	0	0	0	0	0	0	0
28-26	0	0	0	0	0	0	0	0	0	0	0	0
29-26	0	0	0	0	0	0	0	0	0	0	0	0
29-28	0	0	0	0	0	0	0	0	0	0	0	0
19-20	0	0	0	0	0	0	0	0	0	0	0	0

In this case, the DG insertion enhance the transient stability and the system can stand the severe 200 ms short-circuit at lines 26-25, 27-26, 28-26, 29-26 and 29-28.

- Loss of generators:

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOSS OF GENERATORS	(n-1)											
GEN1	0	0	1	0	0	1	0	0	0	0	0	0

- Load variation:

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
LOAD VARIATION												
BUS-3; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-4; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-7; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-8; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-15; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-16; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-18; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-20; 1200MW	0	3	0	0	0	3	0	3	0	0	0	3
BUS-21; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-23; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-24; 1200MW	0	2	0	0	0	2	0	2	0	0	0	2
BUS-25; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-26; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-27; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-28; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-29; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-31; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0
BUS-39; 1200MW	0	0	0	0	0	0	0	0	0	0	0	0

- Events (n-2)

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-2)											
1-2; 2-3	0	0	0	0	0	0	0	0	0	0	0	0
1-2; 3-4	0	0	0	0	0	0	0	0	0	0	0	0
1-2; 2-25	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 6-7	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 4-5	0	0	0	0	0	0	0	0	0	0	0	0
13-14; 27-17	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 6-5/2	0	0	0	0	0	0	0	0	0	0	0	0
4-5; 5-8	0	0	0	0	0	0	0	0	0	0	0	0

- Events (n-3)

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-3)											
6-5/1; 5-4; 7-6	0	0	0	0	0	0	0	0	0	0	0	0
5-4; 39-9; 7-6	0	1	0	0	0	1	0	1	0	0	0	1
5-4; 3-4; 7-6	0	1	0	0	0	1	0	1	0	0	0	1
4-5; 5-8; 6-7					3	3					3	3
GEN4; 15-16; 16-21	0	0	1	0	0	1	0	0	0	0	0	0
15-16; 16-21; 10-11	0	0	1	0	0	1	0	0	1	0	0	1

- Events (n-4)

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-4)											
6-5/1; 6-5/2; 5-4; 6-7					3	3					3	3
5-4; 3-4; 7-6; 14-4	0	0	0	0	0	0	0	0	0	0	0	0
5-4; 3-4; 7-6; 18-3	0	0	1	0	0	1	0	0	1	0	0	1
GEN10; GEN10B; 4-14; 6-5/1	0	0	0	0	0	0	0	0	0	0	0	0
25-26; 3-18; 4-14; 6-11	0	0	0	0	0		0	0	0	0	0	0
GEN4; 15-16; 16-21; 16-24	0	3	1	0	0	3	0	3	1	0	0	3

- Events (n-5)

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-5)											
5-4; 3-4; 7-6; 18-3;14-4	0	0	0	0	0	0	0	0	0	0	0	0
4-5; 5-8; 6-7; 13-14; 10-13					3	3					3	3
6-5/1; 6-5/2; 6-7; 5-8; 8-9	0	2	0	0	0	2	0	2	0	0	0	2
6-5/1; 6-5/2; 6-7; 5-8; 4-5					3	3					3	3
6-5/1; 6-5/2; 6-7; 3-4; 4-5					3	3					3	3

- Events (n-6)

CONTINGENCY	40%DG						50%DG					
	SSS	SPIR	VCI	FD	LS	RI	SSS	SPIR	VCI	FD	LS	RI
Events	(n-6)											
11-10; 11-6; 6-7; 8-5; 9-8; 18-3	0	0	0	0	0	0	0	0	0	0	0	0
6-5/1; 6-5/2; 6-7; 5-4; 9-8; 8-5	0	2	0	0	0	2	0	2	0	0	0	2
5-4; 3-4; 7-6; 18-3;14-4; GEN10	0	0	0	0	0	0	0	0	0	0	0	0

The behaviour of both systems against short-circuit is equivalent. The appropriate DG insertion is fixed by the resources of the system (active and reactive power) and the dynamic behaviour of the system when faced to the chosen contingencies (transient stability and not loss of synchronism). The high degree DG insertion makes that some centralised generators could be closed. So, the operators should be able to guarantee reserves and a good voltage plan with the existants generators. That was one of the problems in Denmark. By the moment, the maximal amount of DG insertion is placed here between 40% to 50% because with 60% stability problems were found.

About the margins in real time control, one can have the next conclusions in the case of 50% DG (3.1 MW) and we remember that the system has a load of 6.2 MW and 9.085 MW of installed power. If we fix a constant margin for the real control of 2 MW (to face problems in generators…) and we suppose the maximal variation of the load variation (to historical maximum) is around 15%-1.1MW. We should guarantee 3.1 MW of tertiary and secondary reserves. In addition, if we look at the deterministic criteria the system should stand the lack of all DG (3.1MW) so the appropriate amount of DG insertion is around 50% or less (12.2MW (total installed power with DG)-3.1MW (permanent reserves for real time operation)-3.1MW (DG lack) = 6.2MW (maximal load to supply with the real time margins)).

A new index can be included to verify if the generators are close to its reactive power limits.

- Reactive power generator limits: this indicator must be evaluated for all generators, and it evaluates the reactive power capacity of the generators, when the indicator is equal to 1, the generator can not supply more reactive power that it is supplying at that moment.

$$\mathbf{QLI_1} = \left| \frac{(\mathbf{Qg})}{\mathbf{Qg\,lim\,it}} \right|$$

Thus, the indicator of the reactive power capacity of generators is not necessary a serious danger for the system but it could evolve into problems for the TSO because a deficiency of reactive power could appear in local zones where the reactive power is not produced and so the voltage levels decreased. Other case it is when the generators are absorbing reactive power to guarantee a right voltage profil, if the generator reaches its limit, some problems could be seen in the voltage profil.

$$\mathbf{QLI} = \begin{cases} \mathbf{2} & \mathbf{if} \quad \mathbf{QLI_1 = 1} \\ \mathbf{0} & \mathbf{if} \quad \mathbf{QLI_1 < 1} \end{cases}$$

3.3.1.4 Scenario 4: Insertion of intermittence

The study of the intermittence effects on the EPS has been carried out with the insertion of asynchronous generators in the study case and with a 10% of DG by means of the power equivalents and the two real French networks. The asynchronous generators have a wind distribution which depends on the installation point of the windmill because the different wind speeds in each position. The parameters of the considered asynchronous generator are shown in the next table:

Nominal apparent power [MVA]	2
Inertia constant [MW s/MVA]	0.5
Stator leakage Reactance [pu]	0.0232
Stator Reactance [pu]	0.08
Rotor-Stator Reactance [pu]	3.0258
Primary leakage Resistance [pu]	0.0106
Primary leakage Reactance [pu]	0.062

Table.11.-Asynchronous machine parameters

The variation of wind provokes a variation in the output active power and a variation of reactive power and voltage. The variation of voltage in the connection point is known by Flicker effect. Several cases were analysed creating windmill farms.

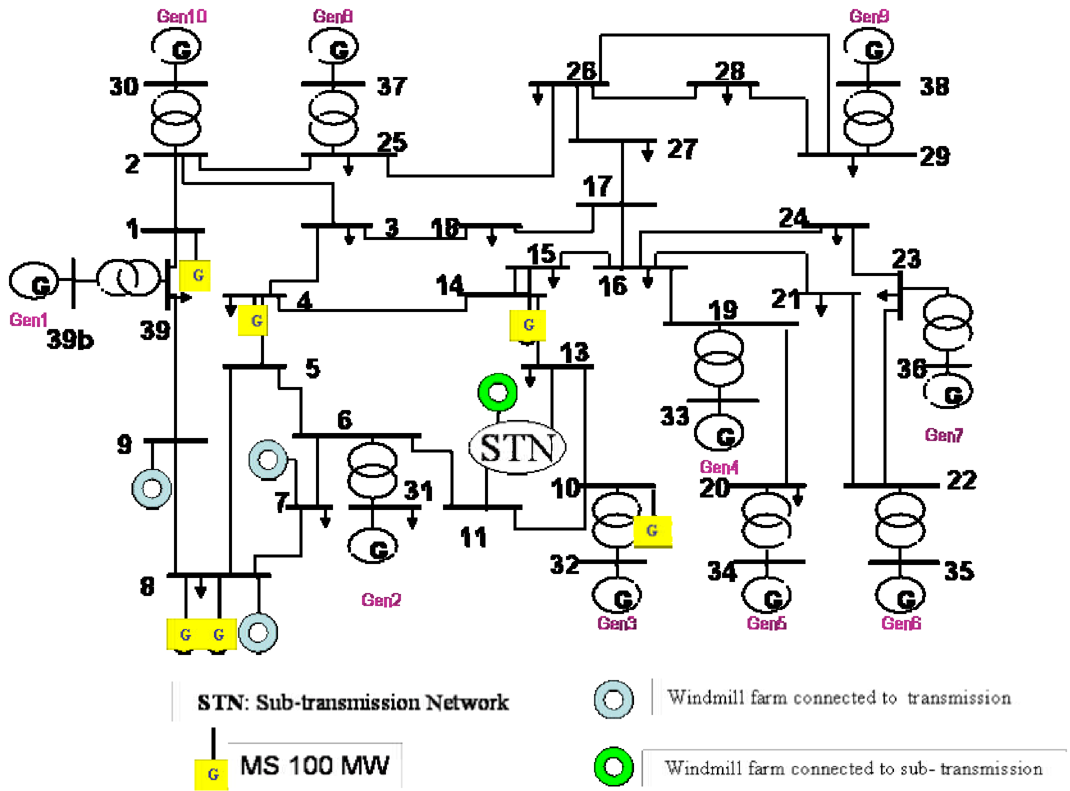


Figure.42.- Windmills farm insertion in the study case

The windmill farms have been placed into two different voltage levels: sub-transmission system (the green circle crown, composed by 9 asynchronous machines, 15.3 MVA) and the transmission system (the blue circle crown, composed by 10 asynchronous machines each one, 17 MVA).

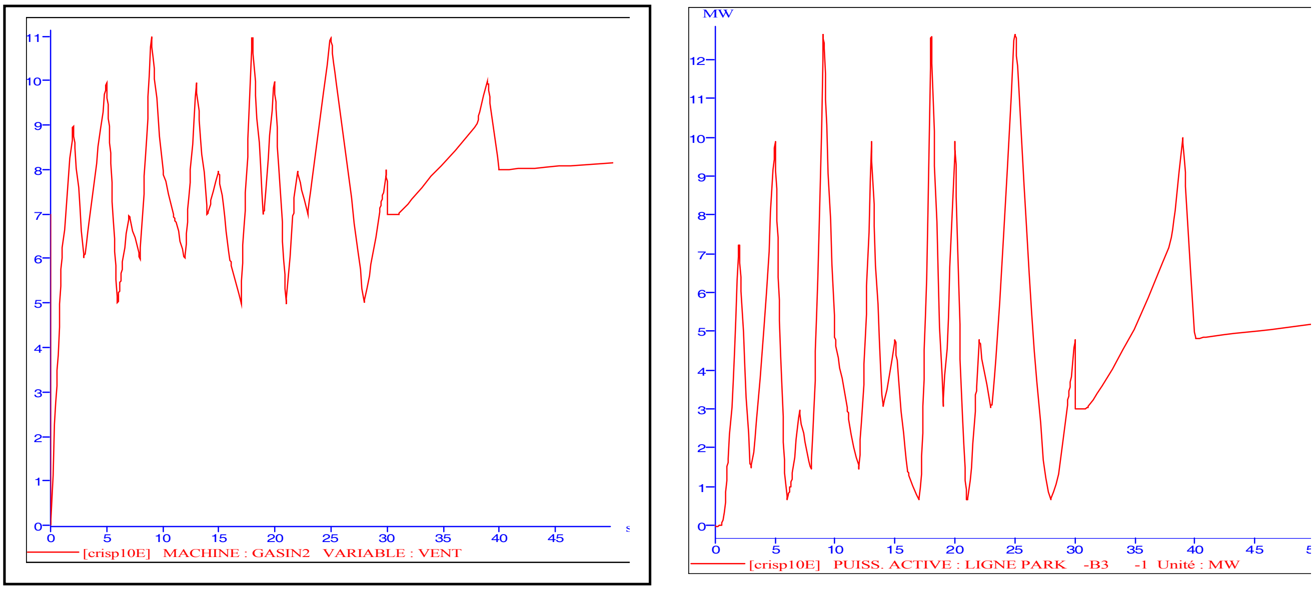


Figure.43.- Example of wind speed (m/s) and active output power (MW) in the sub-transmission windmill farm

The results of the simulations have enabled to conclude that the effects of the intermittence are a local voltage variation depending on the wind speed and so depending on the reactive and active power production. In general terms, the intermittence has mainly a local impact because the different wind speed distribution from one site to others. The voltage variation is propagated from the sub-transmission system (distribution system in case of DG intermittence insertion at this level) to the transmission system. This fact can be noted in the figure 44 with the voltage variation in the transmission buses.

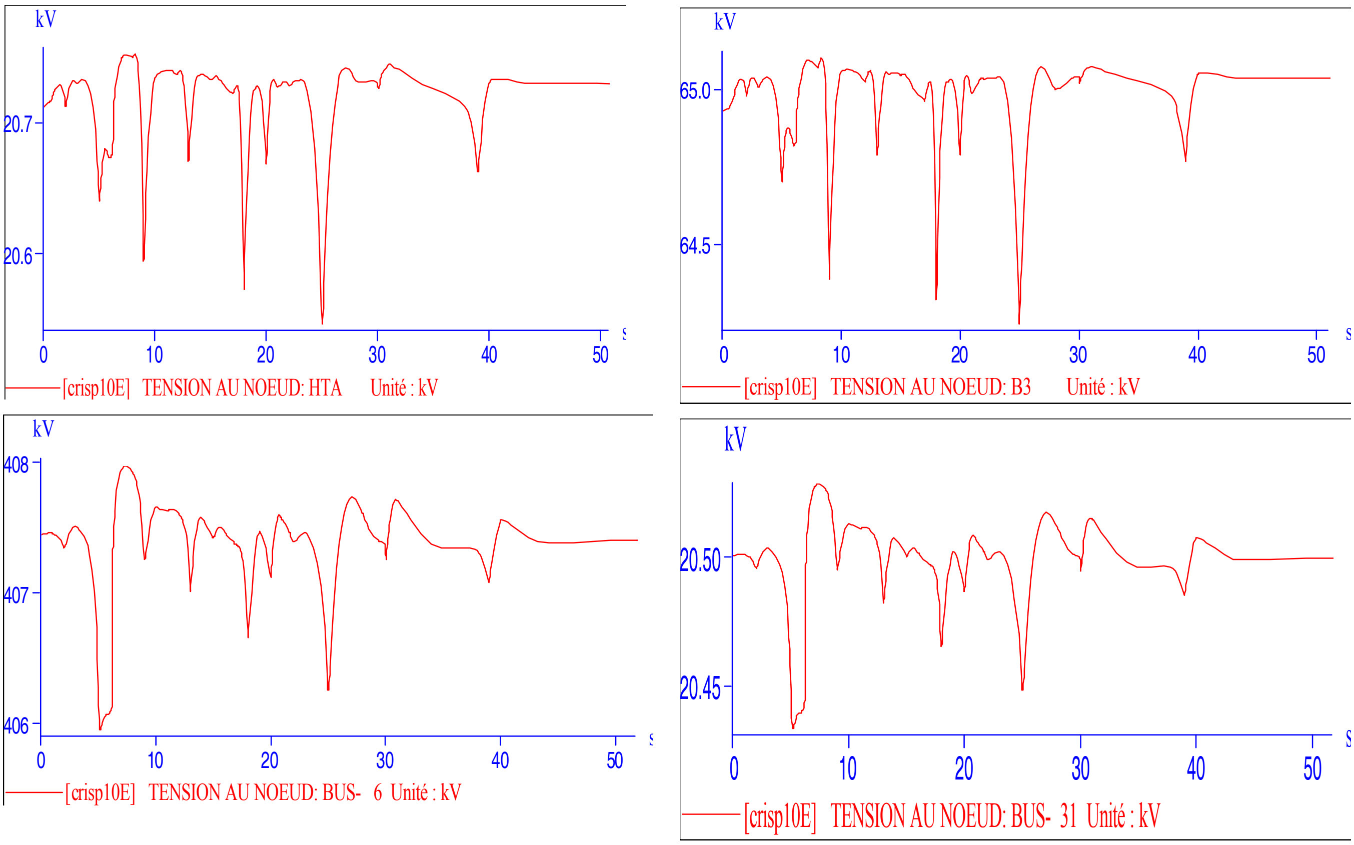


Figure.44.- Distribution, Sub-transmission, Transmission voltage and centralised generators voltage variations

The voltage variations at the different buses show how the local voltage variations are caused by the local wind speeds. On the other side, the voltage variations at the transmission systems are the result of the combination (superposition) of all the different local variations and the action of primary voltage and frequency regulations. In fact, the primary voltage regulations are going to change the reactive power output in order to ensure the voltage setting point. The primary frequency regulations are going to operate in order to compensate the active power variations due to the intermittence.

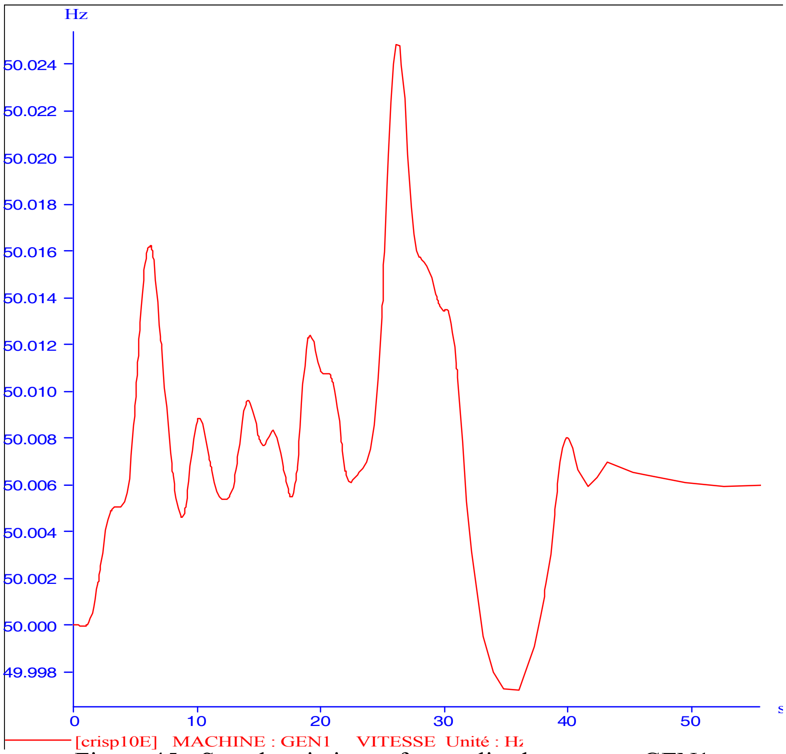


Figure.45.- Speed variations of centralised generator GEN1

The primary reserve could be used after high active power variations caused by the intermittence and so the system will be placed in a critical situation if something happens during the restoration of the reserves (secondary control). The problem is keeping the schedule plan of production; the imbalances cause new costs which are the result of the open market mechanisms. Besides, it must be noted the uncertainty in the position and time (miss of observability at the distribution networks) in which the intermittence resources are going to be integrated which means a major problem for the planning and operation of the system.

In this scenario, the appropriate DG insertion is fixed by the resources of the system (active and reactive power reserves). The TSO should be able to control the system in real time and adapt the system to the real-time events and so it should take into account some special reserves and exploitation margins. For example, RTE takes 2300 MW of reserves for each next 2 hours period. Two new indices could be considered in addition to those presented:

- Real-time TSO margins: the margins of real time are for two kinds of operations up and down the output power.

$$\mathbf{RTM_1 = \frac{(Real\_time\_Reserves)}{TSO\_expected\_variations}}$$

The term of TSO expected variations refers the security margin that the operator plans for the real-time operation

$$\mathbf{RTM} = \begin{cases} \mathbf{2} & \mathbf{if} \quad \mathbf{RTM_1 < 1} \\ \mathbf{0} & \mathbf{if} \quad \mathbf{RTM_1 > 1} \end{cases}$$

The index indicates a 2 if the system does not count with enough reserves, this warns the operator about a situation which can become critical in case of high rise of the demand. The operator could mobilize new generators (tertiary reserves) or proposed some loads to be disconnected (CAISO voluntary load reduction program, only in a short interval of time, 1-4 hours during the day). This latter technical option is in some point of view a new concept for load management; in this way the loads which are available to be reduced by the operator are paid for it because they supply a service (it could be seen as a new ancillary service for future networks) to the operators and so, to the grid healthy and operation **[CAI-04], [PGE-04], [SCE-04].**

As it was commented in the scenario 1 and 2, about the DG protection setting points, most of wind power is disconnected from the network in case of a system disturbance near their location or the propagation of a voltage dip through the transmission system. This could lead the system to a huge lack of generators in a domino effect and a final global blackout.

In conclusion, the problem of a high scale insertion of intermittence sources is mainly detected on the real-time operation and control of the system. The system must be able to compensate the intermittence and that can lead to changes on the control margins (active and reactive reserves) and, of course, changes on the control of intermittence in order to ensure a fixed output power (regulations up to nominal speed), but the problems of intermittence could appear in any case for low wind speeds and asynchronous machines directed coupled to the grid.

The lack of intermittence sources is a problem that can be compared to the scenario with the lack of generators by the disconnection protection. The system stands the lack of generators without load shedding at a level slightly lower than the primary reserve (see results and conclusions of scenario 1)

3.3.1.5 Scenario 5: DG participating to the frequency control of the system

One possible scenario which can appear in the next years is the participation of the DG to frequency control. In fact, it is something that it is carried out nowadays in terms of secondary and tertiary controls. Thus, some DG is controlled to ensure correct operation points (local voltage control, mobilisation of reserves). The new point, that this report wants to emphasize, is the participation of the DG to the primary reserve in a situation in which the system do not dispose enough resources.

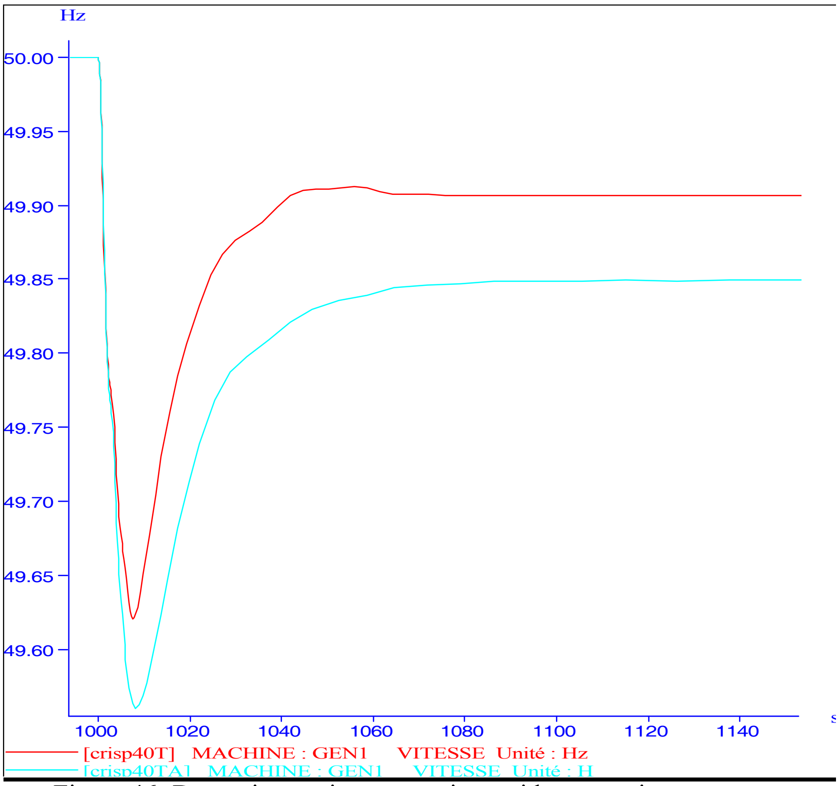


Figure.46.-Dynamic reaction comparison with more primary reserve

(red: case with increase of primary reserve; blue: normal primary reserve)

The increase of reserves in the system influences the transient response of the system. In the figure 46, it is shown the comparison between the case of 40% DG insertion with and without participation in the frequency control. The frequency deep after a load variation is lower and that would create a better dynamic behaviour from the frequency point of view. Special attention should be paid to the transient and dynamic stability of the system in order to guarantee that the insertion of speed regulators for the DG do not lead to stability problems. That was not the case in the developed simulations.

The conclusions of the simulations carried out are the next ones:

- The participation to the primary reserve implies improvements in the system robustness because the better behaviour of the system when face to some events such as loss of international interconnection, loss of generators and load variation. The increase of the primary reserve enhances the security of the system in terms of generation adequacy.

- Possibility of oscillations between the different generators caused by the different dynamic performances, specially when face to a short-circuit. The small generators have a faster reaction (lower inertia constant) than the big generators (bigger inertia constant).

3.3.1.6 Scenario 6: DG participating to the voltage control of the system

The French legislation contains the possibility of DG participation into the voltage control but with the open possibility of a time constant slower than those of big generators. Thus, the regulations can be called “slow dynamic” regulation. In short, some different voltage regulations that the DG could incorporate are:

- Constant excitation: no regulation, it is the general case and it is supposed to be the case for small units because the price that the regulators could have. The generator behaviour is equivalent to a PQ bus (see scenario 1 to 5).
- Slow dynamic regulation: primary voltage regulation with around 100 s of time constant. The generator would behave as a PV bus.
- Fast dynamic regulation: the same time constant regulation which are used in transmission.
- Constant tan (phi) regulation: It is a common used regulation in France which introduces a compensation of reactive power to improve the voltage profile and avoid the negative impacts that the generator insertion could cause to the feeder voltage levels. The behaviour of the generator is assimilated to a PQ bus with a fixed ratio between P and Q.

The main problem of the changes in the voltage regulators are the whole network stability. The wrong tuning of the DG voltage regulations could lead the system to an unstable situation in which the system can not stand the perturbations and the system loss or undesirable oscillations (around 1 to 2 Hz frequency) happened.

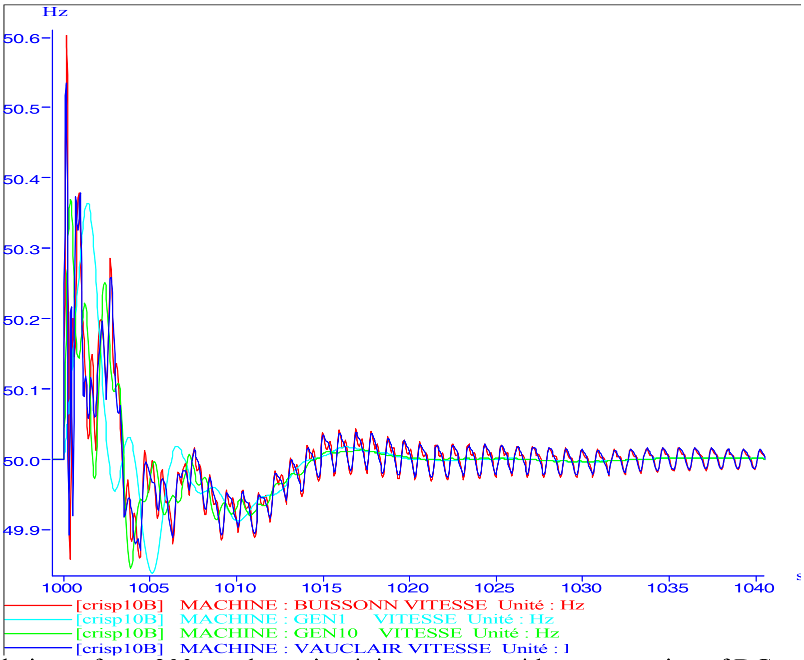


Figure.47.- Oscillations after a 200 ms short-circuit in a system with wrong tuning of DG voltage regulations

(small-signal stability verified and transient stability, computed CCT= 0.494 s for the simulated short-circuit)

However, if the tuning of the regulators is carried out correctly, the DG participation to the voltage control could imply some valuable advantages. They are summarized as follows:

- Local reactive power productions: possibility of improvement when facing to voltage collapse.
- Local voltage regulations to optimize electric losses at the distribution system.

Reduction of reactive power dependency of distribution networks from the transmission system

The insertion of voltage regulators has been studied in the case of 10 % of DG insertion and the main changes were analyzed.

Case 6.1: Constant excitation

The voltage regulations with a constant excitation voltage have been the model used in all the previous scenarios in other to study separately each parameter-scenario influenced in the behaviour of the system. The consideration of constant excitation represents the absence of voltage control in the DG connection point. That is the case of small units and in general terms ca be assumed as general for the DG.

Case 6.2: Fast dynamic regulation

The insertion of this type of regulation for the small generators show how the system behaves better when faced to disturbances but the improvements were only relqted to the voltage local compensation. However, a bad tuning of the regulator could cause the lack of small-signal stability and the apparition of new modes in the study of the system eigenvalues.

Case 6.3: Slow dynamic regulation

The tuning of the voltage regulators caused a problem when the time constants were too different. In the developed simulations if the regulations are not very slow, the behaviour was equivalent.

Case 6.4: Constant tan (phi) regulation

This case study supposed the local compensation of the impact provoke by the new active injection. Thus, the reactive power is compensated in order to not impact a lot of the voltage profile.

3.3.2 Main conclusions when faced to major events

The main conclusions of the robustness indices evaluation and simulations are sited in the next points:

- The appeareance of short-circuits is a critical parameter when the appropriate amount of DG is evaluated. The DG disconnection protection prevents their support to the whole system when faced to major events. This is a critical point that makes DG to deteriorate the system robustness if it is not considered an appropriate amount which respects the primary reserve and the transient stability problems.

- The cascading outage is prevented by the DG insertion. The transmission system is less loaded with DG and so the overloads caused in the system after a loss of lines is less important. This is an important conclusion because the incidents caused by overloads were detected in the last blackouts.

- The frequency deviations caused by the load variation and generation variations are critical if the system does not have enough resources to compensate the active power and ensure a good voltage profile

- The participation of DG to the local voltage control should decrease the injected reactive power from the transmission system to the distribution system and so, the influence during voltage collapse phenomena would be improved. However, this voltage collapse phenomena is a complicated event and nothing general could be said in this report.

- The loss of synchronism of different generators depends on the configuration of the system. Special attention should be paid in the connection step (location and tuning of regulators) of DG in order to not deteriorate the global system stability.

As main conclusions, the appropriate amount of DG insertion depends on the system characteristics and the performance that the DG could stand during disturbances. Thus, if the DG does not stand the system the appropriate amount of DG has a low value close to primary reserve in the study case. On other cases where the DG behaves as the centralised generators, the appropriate amount of DG is defined by the capacity of the system to compensate the frequency and the voltage; if the operator fixes some margins for the system real time, the DG insertion should be limited to these margins taking into account the possibility of lack DG and the possibilities of the system. In the simulations developed by the amount, the appropriate amount of DG insertion is placed around 40%-50% (the system could go on with the central power plants in case of DG lack keeping always a margin to have secondary and tertiary reserves, see scenario 3).

3.4 Ability of islanding operation

This chapter deals with the ability of the system to reconfigure itself in order to ensure the continuity of supply when some part of the electric system is seriously damaged (in a blackout situation). The islanding operation can be thought at two levels: the transmission level and the distribution level. In both cases, the islanding operation implies three main steps:

- Disconnection from the interconnected zone.
- Sustainable islanding operation.
- Restoration of the whole system (synchronisation of the different islanding zones according to collaborate in the restoration of the whole system).

After a resulting blackout, the restoration of the system can take from several hours to some days depending on the damage occurred in the EPS. So, the operator should prepare the islanding areas previously, this preparation could need an increase of system observability, an intelligence distribution (see chapter 4) and the installation of new devices such as PMU and others to make possible the save of the system and the final recover of the total EPS.

The paragraph treats the ability of the islanding operation at the transmission levels and its disadvantages in the case of the transmission system islanding. Then, special attention is paid to the distribution islanding: the phases for its creation, control strategy and protection scheme changes are detailed and sited.

3.4.1 Ability of islanding operation in the transmission system

The ability of the transmission islanding operation deals with the possibility of creating different islands in a national transmission network. Thus, these islands split will belong to the national defence plan.

The main idea is the detection of an abnormal operation in the transmission system through the measures of voltages or/and frequency of the system which causes the decision of isolate the country in islands in order to guarantee the service continuity of the customers and to save some parts of the electric system from a total blackout.

This is currently included in the French national Defence Plan. Thus, the measures of a loss of synchronism of the power plants may lead to the split of the national grid into islanded areas depending on the location of the faulted unit. However, this transmission system islanding operation is the last measure that the TSO takes in order to save a part of the system. The creation of islands in the transmission prevents the solidarity of the whole system in terms of frequency control and so, the new sub-systems could become less secure than the whole system. So, this is really the last action that the TSOs order before the total collapse of the EPS.

Some recent researches supported by EPRI have proposed an islanding creation criteria based on coherent generators groups and least load-generation imbalance. The islands are formed by the action of out-step relays. These relays only require local informations and elaborate the tripping decision regarding to the result of offline contingency analyses. In case of severe imbalance, a two layer load-shedding is proposed to control the imbalances. It is based on the rate of frequency decline (for large disturbances) and frequency decline (for small disturbances). The identification of the severity of the disturbance is obtained by the analysis of the frequency decline rate at the beginning of the disturbances. If the disturbance is classified as large, the load shedding based on frequency decline is inhibited by the one based on the frequency decline rate. This second layer could save the system shedding more loads and quickly than the first one **[HAI-03]**.

3.4.2 Ability of islanding operation in the distribution system

The study of the ability of islands in distribution system implies to take into account the next points:

- Strategies of regulation V/F in the islanding system, ways to regulate the system

- Load shedding on isolated systems, special load shedding behaviour for the island
- Protection system: the protection must allow the islanding operation in its three steps. At this point an adequate coordination between protections should be developed. The critical point is the right operation of the protection system in the islanding normal operation.
- System security: in the islanding operation the (n-1) criteria could not be guaranteed.
- Economic cost of load shedding vs. cost of new storage and back-up units

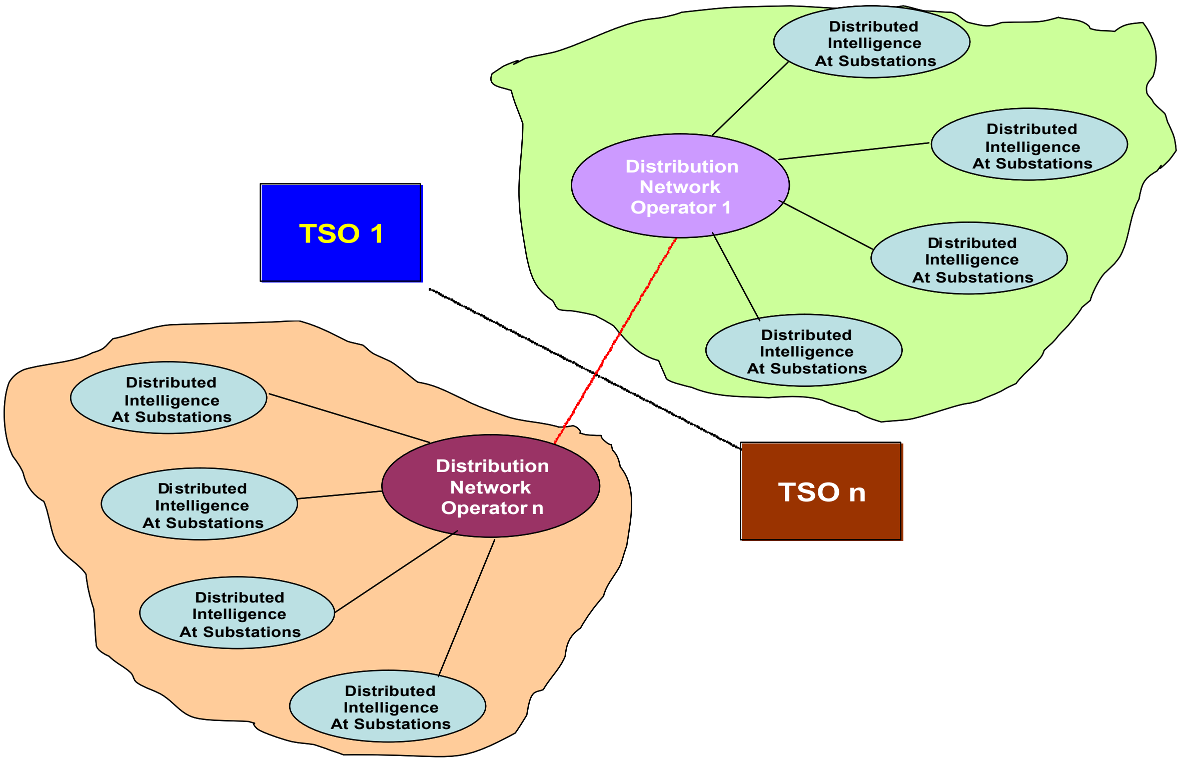


Figure.48.-Distribution of the intelligence: new ICT components at the substations

The islanding operation in distribution systems leads to the concept of a Distribution Network Operator or Utility that would control a wide distribution area. This DNO will need new ICTs components (distributed intelligence) in order to carry out this type of behaviour and a co-ordination between the different distributed intelligence at the substations is necessary to be complied by these DNOs. The ICT components or distributed intelligence necessaries to order this special operation are the next ones:

- ICT components to control the voltage and frequency in real-time (generators and load shedding orders).
- ICT components to evaluate the protection system and change the setting points of the protections.
- ICT components to reconfigurate the network, change the size of cells, resynchronized different areas
- ICT component to advise the DNO the islanding operation of an area (the decision could be also automatic if some thresholds are exceeded in a defined delay).

These ICT components described the main functions of a distributed intelligence placed at the substation levels in order to represent a help to the operator decision or to become an agent (taking decisions automatically). The agents will communicate with the operator through communication systems to a central control and/or through a man machine interface at the main substations.

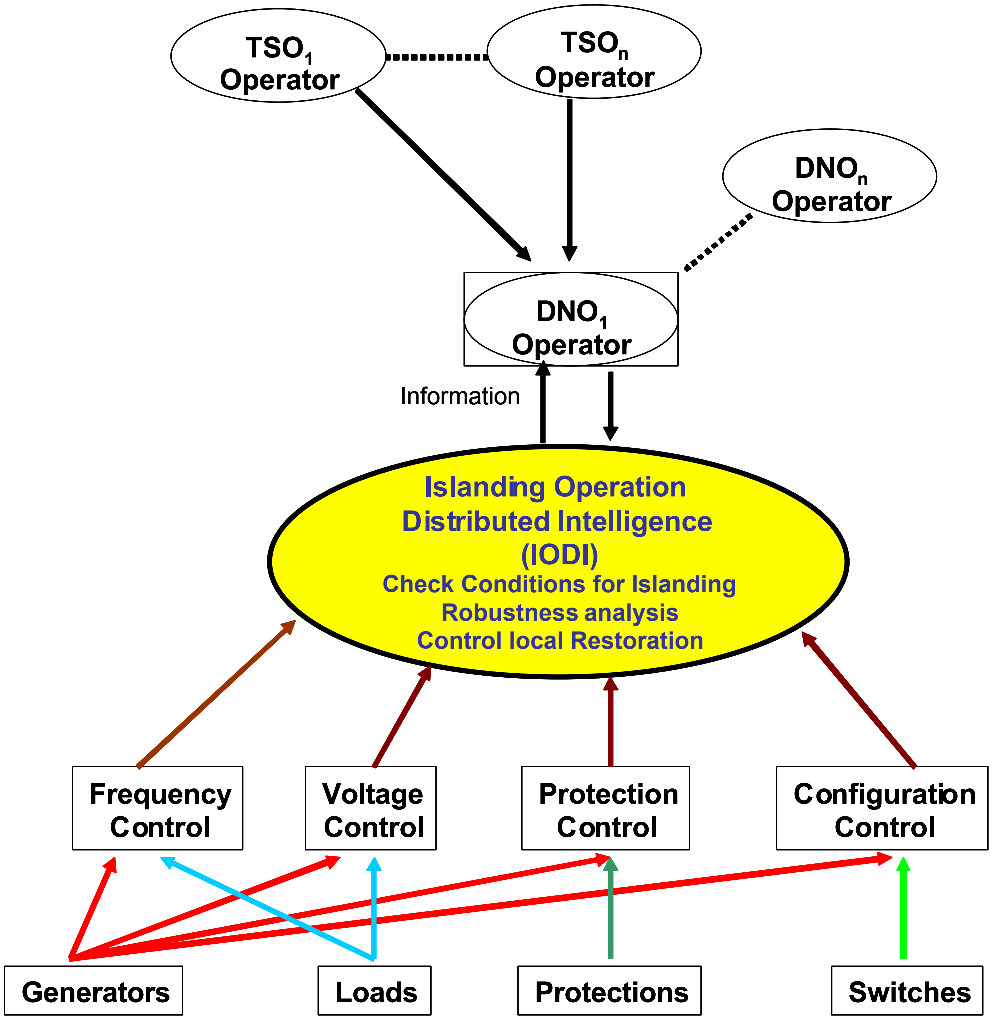


Figure.49.-Distribution of the intelligence: IODI, islanding operation distributed intelligence

3.4.2.1 Phases of the islanding operation

The phases involved in the islanding operation can be described from the formation of the islanding area to the reconnection with the main grid. Three main phases can be enumerated:

- Phase 1: Formation of the island. The formation of the island can be ordered at the substation if some technical conditions are respected (see paragraph 3.4.2.4). The order of island creation would based on:
    - A voltage measure in the sub-transmission/distribution transformer. A low voltage in the primary of the transformer will change the position of the tap changer and it will increase the distribution consumed reactive power. So, a low voltage at the transmission level could indicate two major problems: in one hand, the possibility of a voltage collapse and in other hand, a fault at the transmission.
    - A frequency measure below 48 Hz with a short time of validation (100-200 ms). If the frequency of the system is low enough, the islanding should be ordered automatically taking into account that the system is close to a total black-out and having as goal to continue the supply of a part of the distribution customers.

  - A high rate of the frequency variation.

- Phase 2: Islanding exploitation and control. The control and exploitation of an islanding area requires the installation of a tool at the main substations. These tools area a mean to decentralised the intelligence and their main functions are the next ones:
  - Preparation of zones to isolate (consumption and production balance)
  - Technical evaluation of the criteria to order the islanding operation (voltage and frequency measures)
  - Protection setting points changes to enable the islanding operation
  - Control of the islanding areas: DG telecontrol in order to ensure the frequeny and voltage requirements.

These functions, as it was said they can be shared between the different proposed ICT components.

- Phase 3: Resynchronization of different islands in order to reconstitute the whole system. The resynchronization of the different islands is a critical action in order to reconnect the whole system. This resynchronization requires the measures of voltage magnitude, voltage angle value and frequency value. The two zones to connect together should have a low difference in the mentioned parameters at the connection point between the areas.

3.4.2.2 Strategy for the islanding operation: exploitation and control

The strategy for the islanding operation consists on the existence of a tool at each substation. These tools are going to favour the creation of islanding areas and their size will be controlled also by the tool. The islanding areas represent a sub-system that it is necessary to regulate and control.

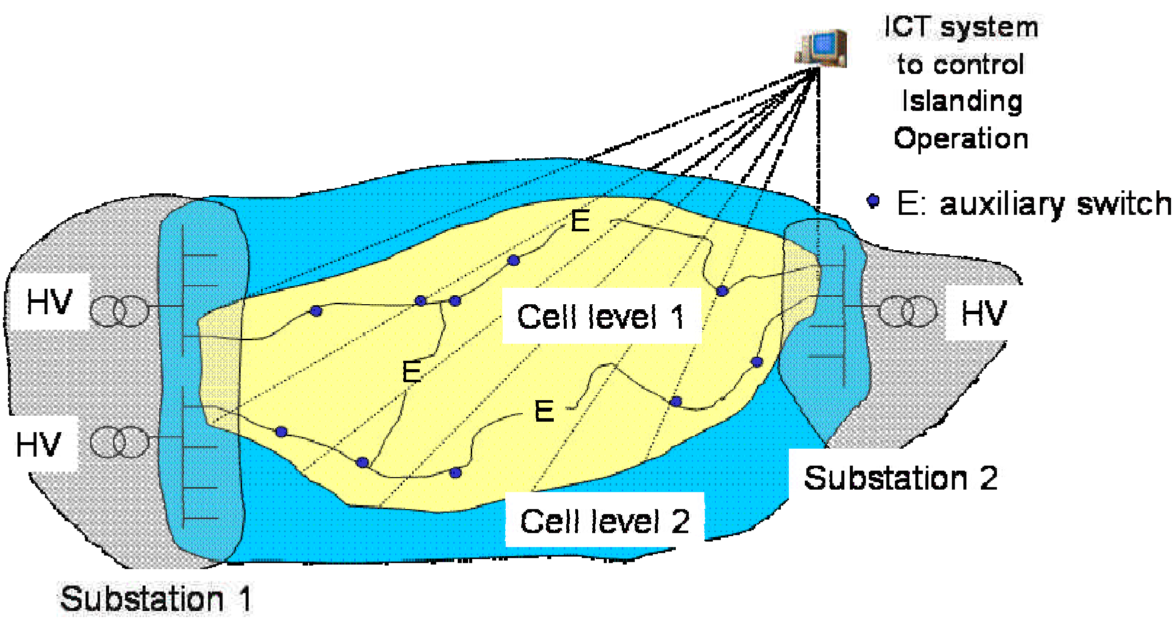


Figure.50.- Auxiliary switch to reconfigurate cells according with the ICT control system

Two kinds of MV cells can be differentiated in order to distinguish the size of the cell. A cell level 1 is composed by those sub-systems which can comply the technical conditions to operate in islanding. In the islanding operation there are different technical questions which must be evaluated:

- Voltage and frequency regulation:

Nowadays and according to present French laws, the DG sources are not supposed to participate to the frequency control but their participation to the voltage control is possible with slow time constants (slower that those commons in the transmission system). The absence of frequency regulation implies that DG can be considered as a PQ or a PV bus, these behaviours are not appropriate to the islanding operation because the system should follow the load variations and other events. So, the DG regulators will be changed into others which would enable the frequency and voltage regulation in the normal time constants. One main condition it is the existence of adequate reserves and regulation capacity.

- Demand & Supply balance: load shedding, generator mobilisation.

- Load flow computation in order to verify that the technical limits of voltage, currents and powers are respected.

- Small-signal stability computation: if the system is not stable at small-signal, it is not stable when face to major incidents.

- Transient Stability: simulation of different disturbances and verification that the synchronous generators do not loss the stability. If the disturbance is a fault, it is interesting also to define the critical clearing time (CCT) because this CCT defines an input for the protection system in which the machines stand a fault without the synchronism loss.

- Contigences Analysis: definition of the critical events that the system can stand.

- Protection verification: it consists on the analysis of the protection setting points in order to enable the islanding operation.

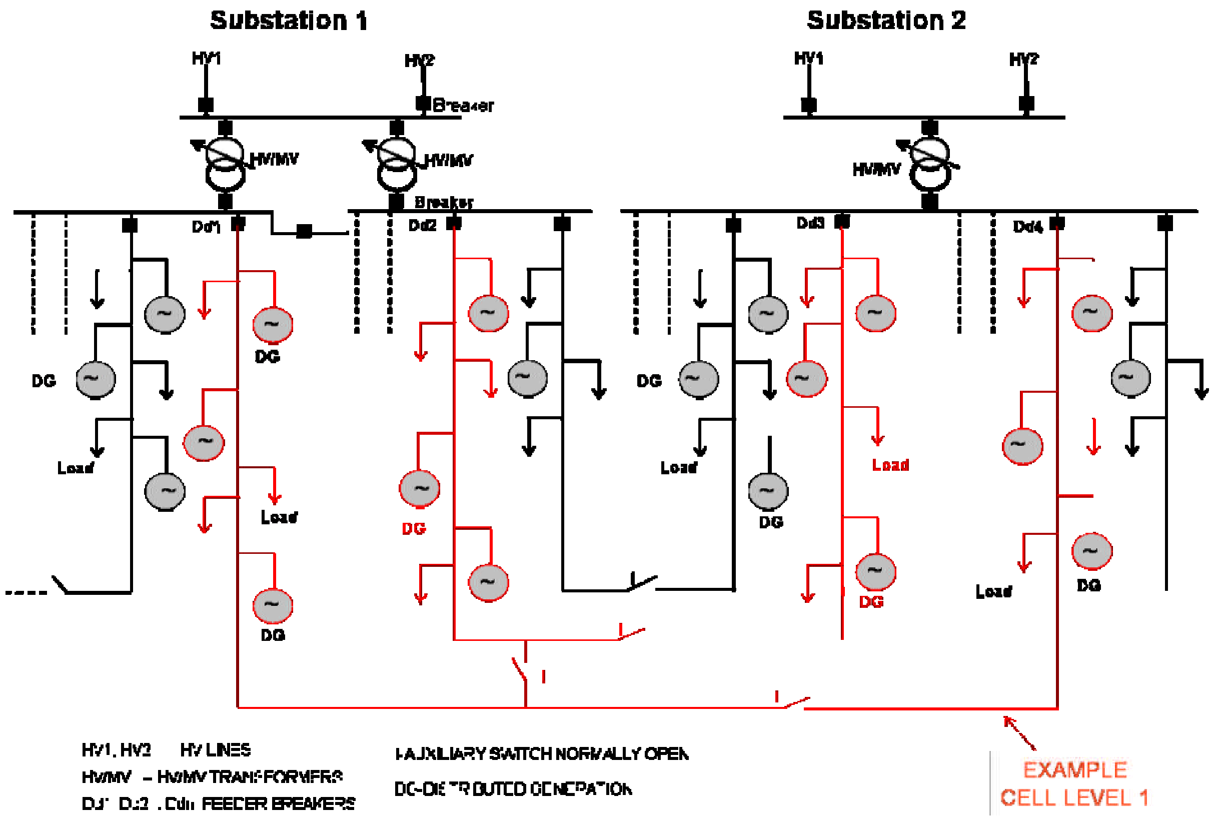
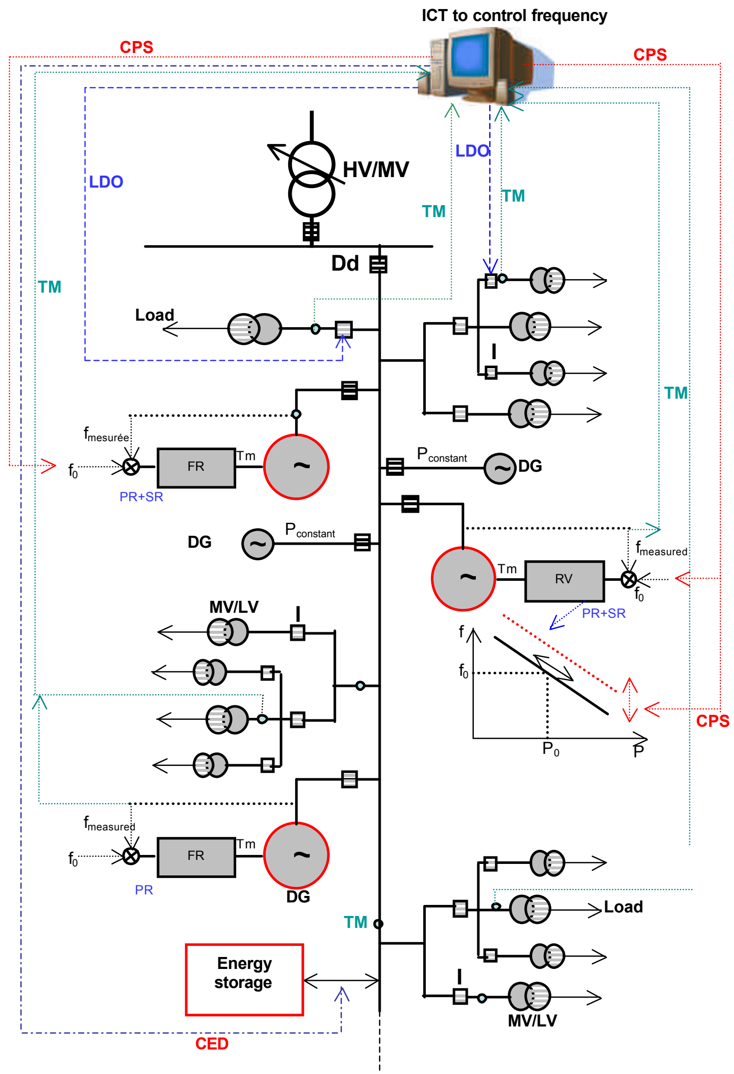


Figure.51.- Example of cell level 1



HTVMV – TRANSFORMER HV/LV

PR – PRIMARY FREQUENCY REGULATION

MV/LV –TRANSFORMER MV/LV

PR+SR – PRIMARY FREQUENCY REGULATION + SECONDARY FREQUENCY REGULATION

$P_{constant}$ –ACTIVE POWER SETTING POINT

Dd – FEEDER BREAKER

I – SWITCH

TM – TELEMEASUREMED

f_0 – FREQUENCY SETTING POINT

CPS – CHANGE POWER SETTING POINT

Tm – MECHANICAL TORQUE

CED – CHANGE ENERGY DIRECTION IN THE STORAGE UNITS

FR – FREQUENCY REGULATOR

LDO – LOAD SHEDDING ORDER

Figure.52.- Frequency regulation and ICT associated component

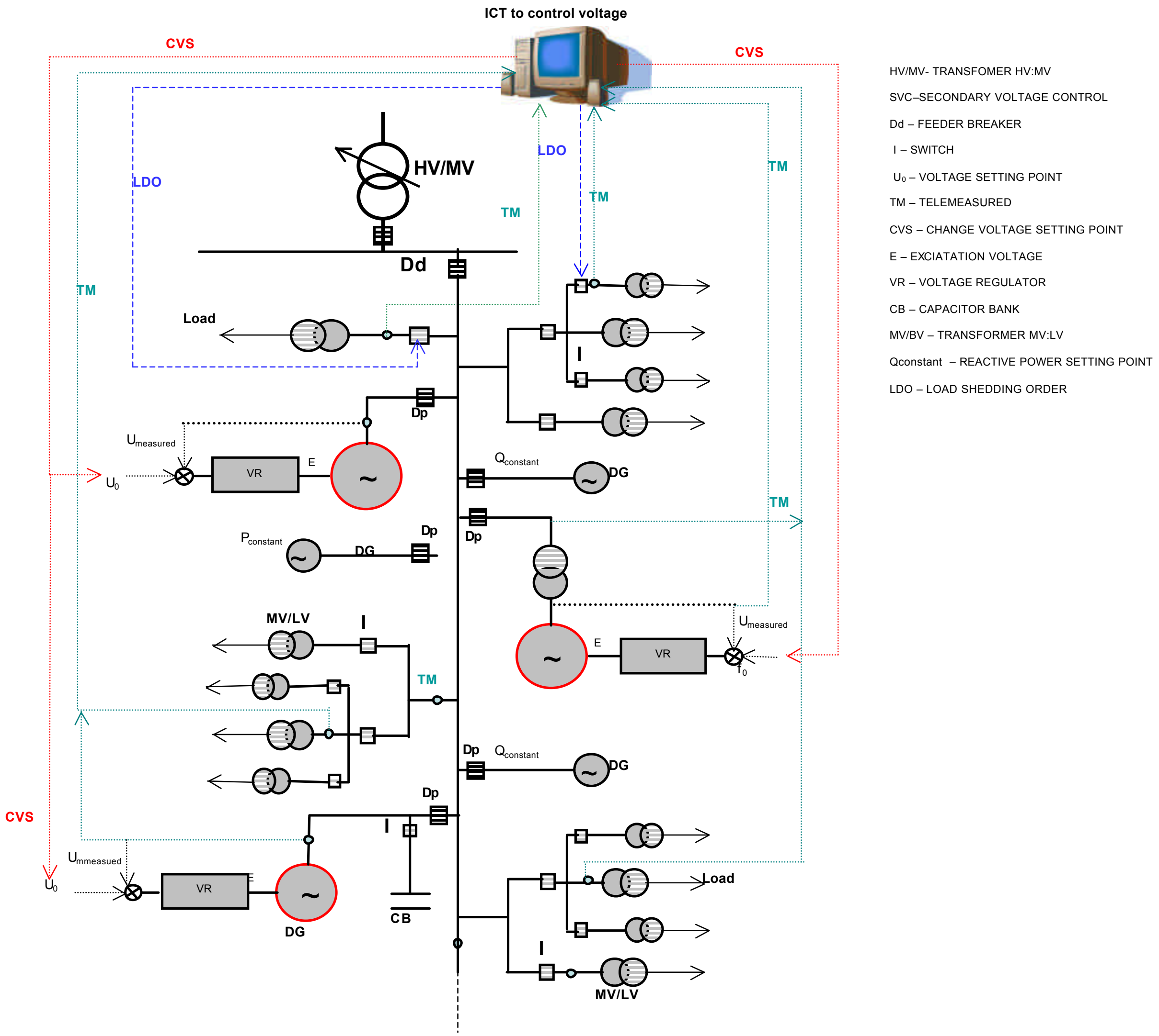


Figure.53.- Voltage control in the islanded area and associated ICT component

3.4.2.3 Protection system

The main protections of the distribution can be summarized as follows:

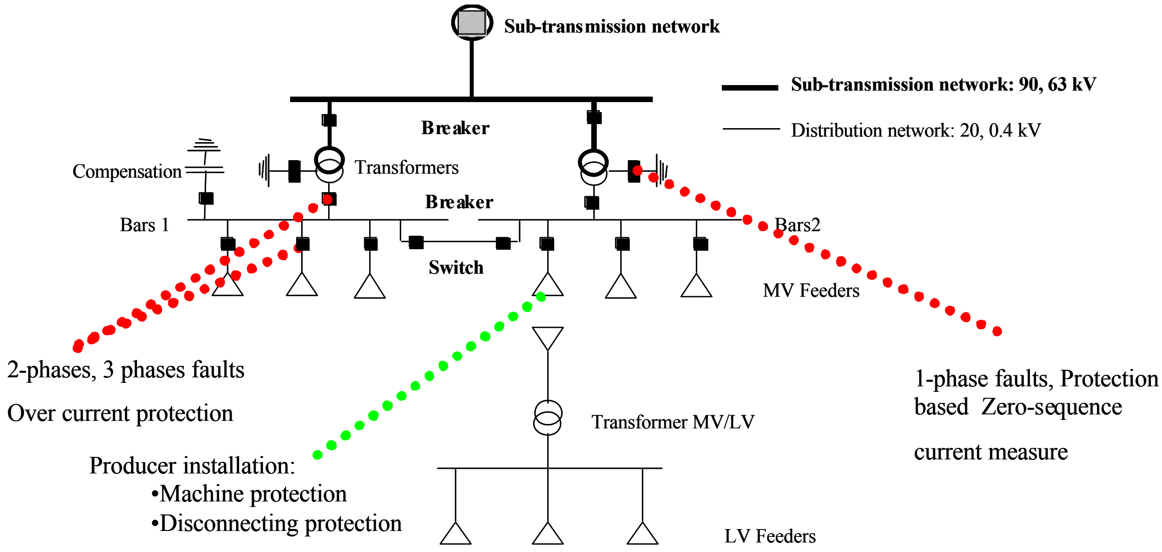


Figure.54 .-Simplified distribution protection scheme

- Network protections: the main protections are the feeder breakers; they are placed at the beginning of each feeder ant they are based on current measures.
- DG disconnection protections: these protections have as main goal to detect abnormal network conditions (threshold based on U and f) to avoid the participation of DG units in the supply of sort-circuits and non-intentional islanding.
- Producer protections: A producer can be composed by one generator, a group of generators and/or tertiary factories which inject a power in the grid. Thus, the main protections which can be found are:
  - the main breaker of the installation
  - the machine protections (over-excitation, over-speed…)

These protections are completed by switches and LV fuses. The switches can not open in case of failure and their use is indicated to reconfigurate the network and supply from different paths.

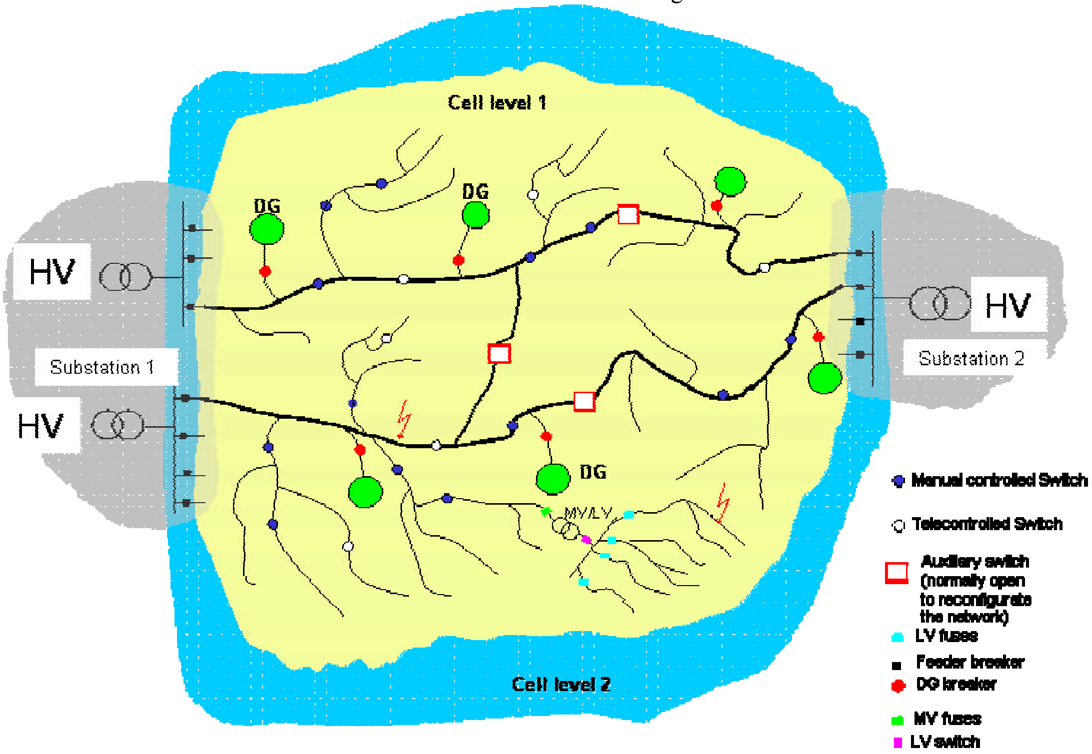


Figure.55.- Normal breakers and switches at the distribution system

The mentioned protection scheme is not adapted to the islanding operation. The protection scheme should be adapted to ensure the traditional goals of the protections. Two main technical solutions can be sited in order to detect a fault when it is produced:

- A first economic solution based on the present protection scheme; in this case, the DG disconnection protection is supposed to operate in case of failure and the system will be out of service with a simple fault. This could be accepted taking into account that the islanding operation is a critical state of the system near the total collapse.

- Creation of new protection schemes with the insertion of new breakers and FPI (fault path indicator) at the lines. The insertion of a new protection scheme is supposed to be activated only in case of islanding and the thresholds elaborated by the distributed intelligence. The main problems associated with the new protections are related to the neutral layout and the selectivity between protections.

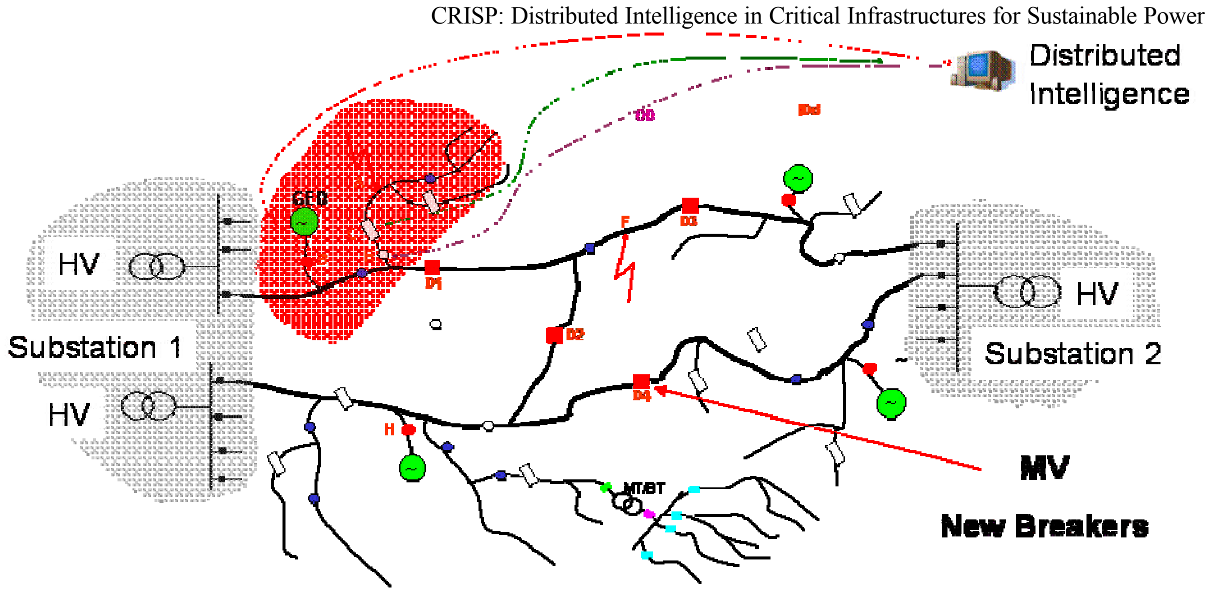


Figure.56.- New protections components for an islanding-adapted protection scheme

3.4.3 Demand and supply matching in emergency situations

The intentional islanding operation of a system could last from several hours to some days, in that period of intentional islanding time the generation inputs into the system should be extremely important to the availability and sustainability of the system, so in this emergency state of the system, the price of the energy could be exorbitant in a pure market demand & supply matching (one can think the case of California with the very high price of the energy in the peaks hours)

So the goal of this paragraph is to carry out a thought about the pricing of the energy, fix the actors capable to assume this extra cost (as everybody knows utilities have the main goal of maximising the economic profit, and they would be encouraged with some incentives). This paragraph constitutes an interaction, link with the CRISP partners from demand & supply matching.

The most logical solution to price the energy during islanding operation is the share of the extra-price between the utilities and the generators in order to not increase the energy costs to the customers. Thus, the utilities will pay more expensive the energy to the generators according to defined clauses in the generator contracts. One must not forget the social action of the enterprises and the wide need of electricity in the daily normal life.

Threrefore, the generator will be encouraged to produce by higher prices but they should renounce to speculate in a market dynamic to avoid exorbitant prices and as a test of the generator solidarity with the EPS operation. Neverthless, the possibility of a matching through a market is opened; from the technical point of view, one can think that the islanding operation is a critical state to try to save the system (see comments on protection scheme) and it can last some hours to one day or more, so it could be possible that after the first moments in which the operator save the system and order the remedial actions (pricing the energy below a defined limit), the open market strategy could appear again and the prices would be fixed by the market matching.

3.4.4 The Restoration procedure

The restoration procedure is the way of restoring the whole system after a blackout situation in the system. Normally all the utilities and operators should define a restoration strategy in case of failure of the system. The way to re-energize the system, the order of the zones re-synchronization, loads to be supplied first…

So, the proposal in this paragraph is the improvement on the restoration system time using the transmission islanding and/or distribution islanding zones. Thus, the central control should have measures of the frequency and voltages levels of each islanding area because one of the conditions to put together two zones is the synchronisation and coherency in frequency, voltage and phases magnitudes.

The restoration procedure can require some improvements in the equipment actually available in the EPS and also the installation of decentralised intelligence electronic devices (IED) to control the system.

In general, a restoration plan will include the following tasks:

- Definition and demarcation of each area involved in system operation (control centers, power plants, operators, customers…)
- Description of methods applied to the diagnosis of network conditions and the status of power plants, as a first stage in the reconstitution process. A number of situations may arise following a blackout, number of isolated power plants supplying its auxiliary's services.
- Description of procedures of voltage restoration
- Description of agreements on action to be undertaken by the various parties in respect of active, reactive power and voltage levels.
- Description of restoration f the loads in the different voltage levels.
- Description of emergency communications (resources, spokesmen, priorities..)

The different TSOs of the system are the responsible of establishing the restoration plan and the y take into account all the actors present in the system such as other TSOs, utilities and/or distribution operators and customers. A key point in the restoration plan is the possibility of start-up of some units without external voltage supply (black-start).
The start-up time is one of the parameters necessaries to control the system (tertiary control), the restoration procedure and the creation of an island. The next table gives an idea of the start-up time of different kind of power plants.

Type of power plant	Start-up time
Classic thermal	Some hours
Nuclear	From 20 to 30 hours
Gas Turbines	Some dozen of minutes
Hydro groups	Some minutes
Wind turbines	Very fast
Fuel Cells	Very fast
PV	Very fast
CHP	Related to the industrial heat processes

Table.12.-Start-up time for different power plants

The black-start capability of the main power systems can be summarized in the next table **[SUS1-03],**

Type of power plant	**Generation flexibility**	**Reserve**	**Frequency control**	**Voltage Control**	**Black-start capability**	**Fault current participation**
Traditional plants	Yes	Yes	Yes	Yes	Yes	Yes
CHP	Yes	Yes	Yes	Yes	Yes	Yes
Diesel	Yes	Yes	Yes	Yes	Yes	Yes
Wind Energy Induction generator directly coupled	No	No	No	No		No
Wind Energy-Doubly-fed Induction Generator	Yes	Yes	Yes	Yes		No
Wind Energy Synchronous generator coupled via a converter	Yes	Yes	Yes	Yes		No
PV	No	No	Yes	Yes		No
Micro-turbine	Yes	Yes	Yes	Yes		Yes
Fuel Cells	Yes	Yes	Yes	Yes		Yes
Stirling	Yes	Yes	Yes	Yes		Yes
Hydro Plant	Yes	Yes	Yes	Yes	Yes	Yes

Table.13.-Different generators characteristics

4. Communication and control aspects: dispatchability, observability

4.1 Introduction

The communication and control aspects of the EPS could vary with the insertion of a high amount of DG. The variation on the number of the generator coupled to the network makes necessary an increase on the observability of the system. This observability is traditionally done by measures that are collected by the SCADA system and with the next skeleton:

- A national coordination center.
- Several regional coordination centers.
- Local centers (substations) that collects data form the PMUs
- Local measures points, breakers, switch…

Traditionally, the systems were controlled by only one entity or national operator, the TSO. The deregulation of the market enables the split of the functions in several actors: markets, customers, utilities, TSOs…One example of the communication between the different actors are the Nordic case, EDIEL **[WEB07-04]**. Further information about the role of ICT in network management and market is included in **[SUS2-03].**

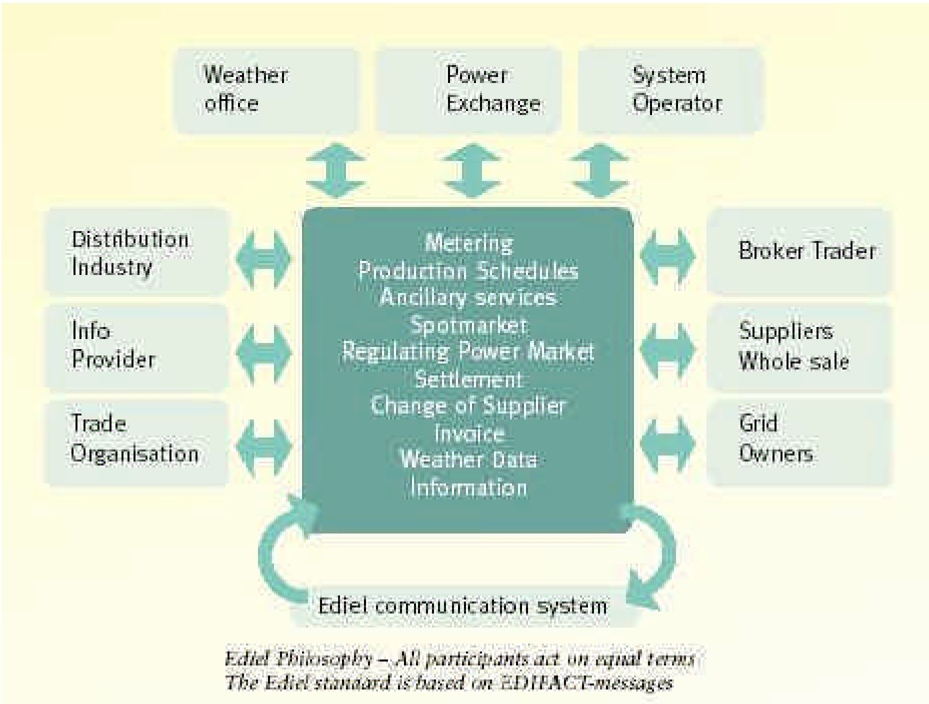


Figure.57.-EDIEL Nordic communication model

The uses of new ICTs could change this traditionally conceptions and the system control could evolve by the decentralisation of the intelligence in distribution areas that will be able to work as autonomous areas. Furthermore, the apparition of new DG units makes necessary the connection and acquisition of data to the remote controls of the system [**BON-01], [BRO1-02], [BRO2-02].** These DG connections need to be controlled by the system operator. This control could be done in a centralised way by the regional centers. These regional centers are currently loaded of the frequency control (back-up of the national center) and the voltage control in the 225 kV transmission lines and in the 90, 60 kV sub-transmission lines. So, they can change the setting points P and Q of the generators in each national region.

Other possibility of the system control leads to the decentralisation of the control. Thus, the regional control will interact with DNOs or utilities loaded of an optimisation of the voltage control by zones. They should solve the local problems of the distribution medium voltage and low voltage areas with a function close to the DSM (distribution system management) one. This is the sense of the LV cells that are being testing in ECN and ENECO works. These DNOs entities will allow and control the special islanding operations in co-ordination with the national control center. Some function of the DNOs can be summarized as follow:

- DG telecontrol, real-time reporting of critical data.
- DG metering
- Weather forecast
- Distribution voltage control (DG participation, capacitors, tap changers).
- Supply Continuity of distribution areas.
- Local optimization of resources.
- Participation to the Ancillary Services of the whole system.
- Distribution Defence Plan.
- Distribution Emergency Plan
- Distribution Restoration Plan
- Ability to interface network system, national market system, regional market system and market participants simultaneously

The intentional islanding operation brings also the installation of PMU for the synchronization between islanding areas in the restoration procedure. That will create new data to be processed in the SCADA.

The concept of DSOs may imply the apparition of new regional markets of the energy (for further information about general energy markets, see D1.2. All the changes in generation have a price, the pricing of the changes should be paid and the resulting price would be the result of the analysis of DG energy cost and technical viability of the solutions. A good example of the price calculation is found in the Spanish law about the secondary reserve computation. **[BOE-98]**.

The SCADA system would be adapted to transmit more and more data from the lower levels to the upper levels. The need of improvements in the SCADA system should be sited regarding with the new ICTs .The application of the new ICTs should give new possibilities to the system: faster data transmission communication, higher amount of information transmitted in the same period of time. However, all these improvements should not be independent from the system security. A global view of improvements of new ICTs and system security should be taken into account in order to evaluate the possibility and reliability of changes in the system.

In short, the conclusions of this chapter are the result of the interaction between different fields and point of views involved in system security, power system operations and new ICTs description.

4.2 New architecture for the communication and control

The present report proposes a new architecture for the communication and control system in EPS. This new architecture is based on a telecommunication IP network, what it could be seen as a Virtual Private Computer Network (VPCN) or Intranet. This IP network would connect all the entities inside the utility from the low levels to upper levels of control. It will contain the different LANs and WANs. Thus, the different IED and RTU will be connected to the Utility Network directly or through the LAN present in the substations, the both options would be taken into account. A directly connection of all the data accumulator could create a high data volume flowing in the IP network and that can derive in problems of congestion and collision inside the IP network.

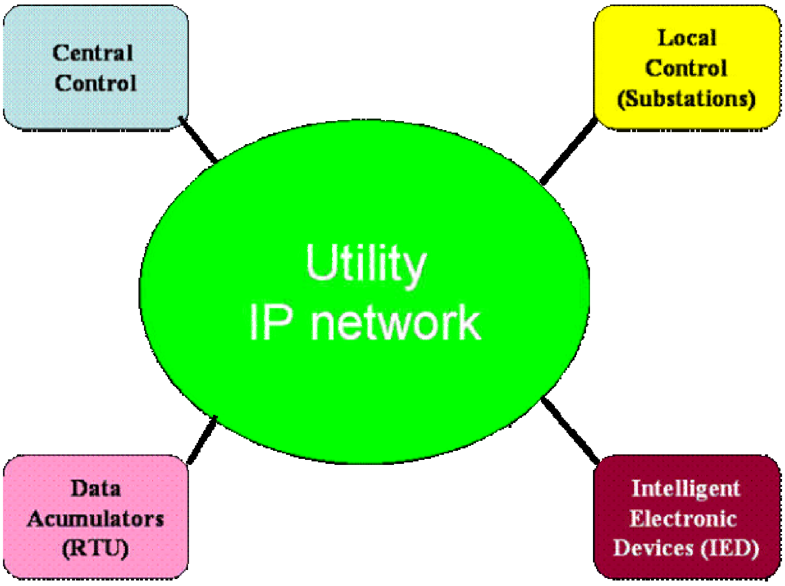


Figure.58.-New architecture of Utility SCADA for communication, control and coordination

The integration of services in a unique communication network is a way to minimize the cost of those functions and increase the flows of information between the different applications in the company system. The critical problem that the IP network could cause, is to maintain the QoS requirements during congestions inside the telecommunication network. The next table summarizes the main requirements of teleprotection, SCADA and operational telephony **[CIG2-03]**.

Operational Service	General Telecommunication requirements
Teleprotection	End-to-end delay < 5-10 ms Service reliability, 99,99%
Telecontrol/SCADA	End-to-end delay around 1s
Operational telephony	High degree of availability, 99,99% ITU-T Series H.323

Table.14.- General telecommunication requirements of different EPS applications

Different studies of the CIGRE Study Comitee 35 **[CIG2-03], [CIG3-03], [CIG4-03]** have evaluated the use of new telecommunication technologies in the electric system. The next tables (table 15 and table 16) show the main conclusions of those studies.

Operational Service	**Service Requirements**	**Network architecture**			
		Pure IP IP over SDH	**LAN emulation**	**Classical IP over ATM**	**Multiprotocol over ATM**
Telecontrol SCADA	Non-critical Real-time QoS	-Native application for Control Center interconnection -Service guaranteed required	-Native application for Control Center interconnection -Direct connection -Transparent transmission	-Native application with QoS provided	-Native application with QoS provided -No experience
Operational Telephony	Real-time QoS	-Native application using voice over IP (VoIP) -QoS required	- No flow QoS guarantee -Native application (VoIP)	-Native application (VoIP) -Per-flow QoS required	-Native application (VoIP) -Per-flow QoS required
Corporate Data	Best-effort	-Native application	-Native application	-Native application	-Native application
Teleprotection	Very critical real-time QoS	-Possible uncontrolled end-to-end delay -No experience reported	-Bandwidth inefficiency -Possible uncontrolled end-to-end delay -No experience reported	-The most likely approach -No practical experiences reported	-No practical experience or theoretical study reported
Video Surveillance	Real-time QoS	-Native application when using IP protocol -QoS required	-Bandwidth inefficiency -Typical application	-Native application -Per-flow QoS required	-Native application

Table.15.-Operational services implementation

A comparison of different telecommunications is presented in table 16. Special attention should be given to the abscense on guarantee in the propagation time of messages in a IP network. That is a general characteristic of the IP systems. However, new versions on IP protocol as IPv4 and IPv6 contain some header in which one can include a priority of the messages. In that way, the routing of the messages with high priority can be made and so the propagation time reduced.

	Propagation time	Propagation time variation	Propagation time symmetry (differential delay)	Add/ Drop time	Routing recovery time/ network restoration time	Channel crossover probability	Bit Error Rate (typical)	Bandwidth
Pilot wires	Signal propagation time 5-10 µs/km	<< 1ms	< 1 ms if the same route	Not applicable	Not applicable	Low (human error)	Not applicable	Few kHz << 64 kbps
Power Line Carrier links (High Voltage Lines)	Signal propagation time on HV line 3.3 µs/km (+1.5 ms for each PLC terminal equipment)	<< 1ms	< 1 ms	Not applicable	Not applicable	Low (human error)	$< 10^{-3}$	>64 kbps
Microwave links	Signal propagation time in air 3.3 µs/km (+1-2 ms for each terminal equipment)	<< 1ms	< 1 ms if the same route	Not applicable	Not applicable	Low (human error)	$< 10^{-3}$	> 64 kbps
Fibre Optic Cables	Signal propagation time in fibre optic 5 µs/km	<< 1ms	< 1 ms if the same route	Not applicable	Not applicable	Low (human error)	$< 10^{-6}$	> 64 kbps
GEO Satellites	Signal round trip 250-280 ms (up + down)	No data available	No data available	Not applicable	No data available	No data available	$< 10^{-3}$	> 64 kbps
MEO Satellites	Signal round trip 100 ms (up + down)	No data available	No data available	Not applicable	No data available	No data available	$< 10^{-3}$	> 64 kbps
LEO Satellites	Signal round trip 10-30 ms (up + down)	>> 1ms	>> 1ms	Not applicable	No data available	No data available	$< 10^{-3}$	> 64 kbps
SDH networks	Signal propagation in cabla 5 µs/km +35 µs for 2 Mbps port to STM1, +40 µs STM1 aggregate, +110 µs STM1 to 2 Mbps port	< 3ms typical	< 1 ms with directional protection	< 120 µs per ADM or repeater	1 ms for single failure	Exists (syns; failure)	$< 10^{-6}$	> 64 kbps
ATM networks	Signal propagation in cabla 5 µs/km +1ms processing time, +6 ms packetization delay, +0.5 ms for each ATM core switch	< 3ms cell delay variation for QoS class 1	No data available	Similar to SDH	Same as SDH if SDH is transport layer	Cell misinsertion ratio (CMR) < 1/day	$< 10^{-6}$	> 64 kbps
IP networks	Non deterministic; no guarantee	No guarantee	Critical, no guarantee	Not applicable	Not applicable	Exists (routing error)	$< 10^{-5}$	> 64 kbps on demand
Ethernet 10 MB LAN	5-15 ms shared hub/ 1-2 ms switched hub/ 6-12 ms WAN time	Few ms; no guarantee	No data available	Not applicable	Not applicable	Exists (addressing error)	$< 10^{-5}$	> 64 kbps
Ethernet 100 MB LAN	1-3 ms shared hub/ < 1 ms switched hub/ 6-12 ms WAN time	Few ms, no guarantee	No data available	Not applicable	Not applicable	Exists (addressing error)	$< 10^{-5}$	> 64 kbps

Table.16.-Telecommunication system characteristics

4.2.1 Improvements of the observability

The new insertion of the DG implies also the requirement of improvements in the control of the system. These changes in the control are mainly related with the telecontrol of the distributed resources. These controls require the acquisition of data in real time. Wind power is an intermittent power source which makes the performance of SCADA systems for the large wind plants very critical for operating reserves. Some technical challenges are implied:

- Real-time reporting of critical data (2-second).
- Effective versatile communications infrastructure
- Accurate wind forecasting.
- Ability to interface to network system, market system, and market participant system.
- Data statistic
- Alarming and annunciation of critical events. Normally the wind turbines stand wind speed until 25 m/s, after this speed they are disconnected from the grid in order to avoid mechanical problems. As it was mentioned in the lack in high-scale of wind turbines can become a critical event for the EPS.

The improvements in the observability of the system should not be limited to the distribution system. It is known the problem of alerts visualization during the last USA blackout which provoked the initiating events. Changes in the software should be planned to avoid this kind of failures in order to detect the lack of parameter visualization and the loss of messages. Futhermore, the existence of emergency telecommunications should be disposed to ensure the correct observability of the system at any instant.

4.2.2 Improvements of the dispatchability

The dispatchability of the system is not improved by the DG in general because the most important projects of DG insertion are based in CHP and Wind Energy and both depend on the weather conditions. So, their produced energy must be integrated in the daily production and sometimes it is not possible to dispatch the energy before by the changes in the weather local conditions. The forecast improvement of the weather conditions constitutes one of the most important points to enable the dispatchability of DG based on RES.

The dispatchability of DG could be also improved by the association of generators. For example, the wind-energy in association with Diesel generators or storage represents a valuable solution to improve the dispatchability. The secondary energy source (storage, diesel) will compensate the primary source (PV, Wind energy…) in some periods when the primary can not supply the dispatched power. The use of these secondary generators is generally expensive and so their uses are limited by their costs. One critical parameter for the storage designed is the time in which the secondary sources should supply the power to the grid. The storage is a very expensive tool and its use is limited to a few minutes or some seconds.

The association of generators concept could lead us to define a “virtual power plant”. A “virtual power plant” can be defined as a group of generators of the same geographical or not which are supposed to produce together a defined active and reactive power. In this way, an internal optimisation is done inside the group of generators to respect the technical constraints ordered by the operators (TSOs, DNOs) and share the output power among them. This share will be the result of the availability of generators and economic optimisation. The “virtual power plant” is supposed to reserve a part of its capacity in order to avoid the penalties of the energy non supplied. These reserves could be seen also as a tool and a capacity which could be exploited to sell secondary and tertiary energies.

4.2.3 Improvements of the control

The DG units are sometimes not controllable because they produce what they can at any moment. One example is the case of the intermittent. Thus, the wind turbines and the PV are producing at the maximal power output point, and they are not controllable. So, some DG creates problems on the system control by its variation of output power.

On other hand, the CHP depends also on the customer heat needs and normally the ratio between electric power and heat is fixed (as it is known by the authors, only some little CHP turbines have the possibility of variable P-Q ratio), but still they constitute a controllable DG. Other examples of controllable are the diesel and hydro µturbines.

Other important aspect in the controllability of the DG is the capacity of automatic reconnection after a disconnection. Thus, new studies in the field of wind turbines are being developed in order to guarantee a fast reconnection in case of disconnection. Some wind turbines are not telecontrolled and the reconnection step is carried out in a manual way what it is not always very quick because the trip of a technician to the field and his action take some time.

The new control aspects are also related to the intelligence decentralisation. This intelligence distribution implies a distribution in the possibilities of the system control. Thus, in case of intentional islanding , the distributed intelligence will be charged of the islanding area control. Therefore, the frequency and voltage will be controlled locally with the existent production means. The distributed intelligence would enable this type of operations and it could also collaborate in the restoration coodination as it was mentioned.

On the other hand, the distributed intelligence can also be used for other uses in real time such as: the control of “virtual power plants”, the running of local optimisations changing the DG setting points (voltage levels, losses minimisation), these optimisations represent recommendations for the DNO (Distribution Network Operator).

All the improvements in the control are new adaptations that the EPS should make for the exploitation of a system with high-DG penetration.

4.2.4 Improvements of the coordination

The coordination of the different actors presents in the EPS is a critical task. In the last blackouts, the coordination of the different operators was a question which didn’t work in an efficient way. So, the coordination of the upper levels of SCADA is an interesting topic to investigate the best solutions. In some cases, such as the Italian blackout, it seems that the (n-1) coordination between countries failed; an easy solution it would be the visualization of the state (power, voltages, disturbances happening) in the border lines of the neighbour’s countries. Nowadays, the ETSO established only some recommendations which do not oblige the TSOs. New ETSO working group are writing a new document in which the TSOs will be signed a real compromise to avoid cases like the 28th September in Italy.

Other case in which the coordination between TSOs failed was the last USA blackout, the blackout propagation could be stopped if the information would be exchanged efficiently. A good tool could be the sending of emergency messages to realize other TSOs major problems.

One conclusion it is cleared the new ICT developments are critical for the increased of the coordination efficiency. The different agents of the system must be coordinated in an optimal way to ensure the correct system operation.

The improvements of coordination are necessary to be spread to the distribution level. There, the DG telecontrol enables different tasks:

- Islanding operation
- Participation of DG to the “virtual power plants”
- Improvements of restoration procedure with the DG black-out capacity.
- Participation of the DG to the ancillary services (coordination of DG with DNOs and TSOs).

4.2.5 Improvements of the Distributed Intelligence

The distributed intelligence should be improved to enable the application of the new concepts introduced in this report. In this way, the intelligence must be improved locally at the substations levels in order to control the DG. Thus, new tools should run in PCs at the substations; these tools would represent a help to decision of the DNOs in order to optimise the voltage and minimise losses in normal operation, order intentional islanding, change the protection thresholds to enable the islanding, control the frequency and voltage in the islands, resynchronize different islands of a same substations.

The improvements of the distributed intelligence are also provoked by the development of new tools of fault localisation. The use of FPI (fault path indicators) is a source of data which must be computerized in a new tool to help the DNO to elaborate decisions. These new tools run as a distributed intelligence at the substations and their operations could become automatic actions instead of recommendations to the DNOs if the coordination between tools, ICTs and switches is efficient enough. This application is supposed to reduce the time necessary to locate a fault in a distribution system and isolate the fault in the smallest area as possible.

The distribution of the intelligence would enable a complete change on the exploitation of the system, thus the distributed tools at the main substations could be used to change the traditional energy flow and the radial topology of the distribution networks. This means that the distribution networks could be controlled in a pseudo-meshed or closed loop operation with the creation of non-energy depedent distribution areas from the transmission system. The distributed intelligence would reconfigurate the distributed networks in autonomous cells. So, some tomorrow's distribution networks could be based in bottom-up energy direction with MV and HV cells.

5. Conclusion

The document gives a glossary of usual technical words used in the field of EPS and Computer Science. This part has importance in order to avoid misunderstanding between the CRISP partners and create a common CRISP vocabulary.

The security challenges in Electric Power Systems are commented because after the last terrorist attacks of 11-S and 11-M, everything is possible. However, the goal of this WP1.3 is the security or robustness in a electric point of view and not the actions to prevent terrorist attacks in the EPS. Some of those security aspects are treated in D1.6 of CRISP project, but only those related to the security of communication and data integrity.

The old and current communication systems used during operation and exploitation of an EPS are described, including the data rate of the current media, the bandwidth for different tasks and data volume required for protection system. In that way, a SCADA description example has been given.

General information was provided in a previous document (D1.1). This document brings a more detailed description on how is working a transmission EPS for the fine control of the voltage magnitude and frequency. This kind of control becomes necessary at the distribution level when intentional islanding is under study. This is quite difficult to determine when the dispersed generation has to contribute to ancillary services including maybe this kind of control: for instance with a high rate of DG insertion, the contribution to a part of the power reserves (spinning) will be required.

Different robustness indices are proposed to evaluate the state of the sytem when faced to major events and to warn the operator to take remedial actions in order to avoid critical events. Different scenarios of DG performance are analysed and the DG appropriate amount insertion is defined regarding the robustness indices and other limiting factors.

The robustness needs to be defined clearly when talking about the future network. The ability to have intentional islanding and the increase of distributed generation (with ability to voltage and frequency control or without this ability) brings a more complex approach. In a relative point of view, an islanded area will be technically weak face to a disturbance and will create market problems: the islanding solution must be kept as an ultimate solution.

The load shedding is a solution used in the distribution system to make the whole system more robust for a long time. As the distributed generation will be inside this network, a more intelligent way will be to have a targeted action on dispersed loads. This scope is studied in WP1.5.

A detailed description of the study case has been given in the document. From the initial reference IEEE39buses model, a new model has been produced: IDEA_CRISP39buses. This modification allows us to make realistic dynamical studies and to identify the main technical limitation associated to a typical European network.
As already shown, the high DG introduction in this model may improve the whole characteristics for static and dynamical studies: it depends on the DG given location. In a general approach this DG location is not really controlled. Of course if the production at any location reaches the local consumption, the electric losses in the lines and the risk of over-current in there are reduced. More over the system is less loaded with this DG insertion and therefore, it could withstand better the disturbances and prevent resulting blackouts. The 50% DR penetration is only a simulated case; it does not represent the appropriate amount of insertion in the general case. This appropriate amount of DG insertion depends on the DG performance and the system characteristics.

In general, it is possible to conclude that DG could avoid overloads in the transmission system and so, it could avoid cascading outage of lines. On other hand, the DG could have negative influence on the dynamic behaviour of the system because its influence on transient stability and its disconnection protection setting points.

Some guidelines for the research about islanding are also given: ability of islanding operation, communication, intelligence and control improvements needed in the EPS.

Annexe A: Information and Communication Technologies (ICT)

A.1.-ICT definition

Information and Communication technology can be defined as:

The technology involved acquiring, storing, processing and distributing information by electronic means (including radio, television, telephone, and computers).

A.2.-Information vs Communication vs Computerization

Communication is the fact of transmitting information between two or more points/agents of the system. The information and communication processes are related very closely. The information system is responsible of obtaining or measuring the parameters/variables that the systems need for a normal operation. So, at this step the information exists and can be transmitted from this point of measure to other points of the system for further utilization.

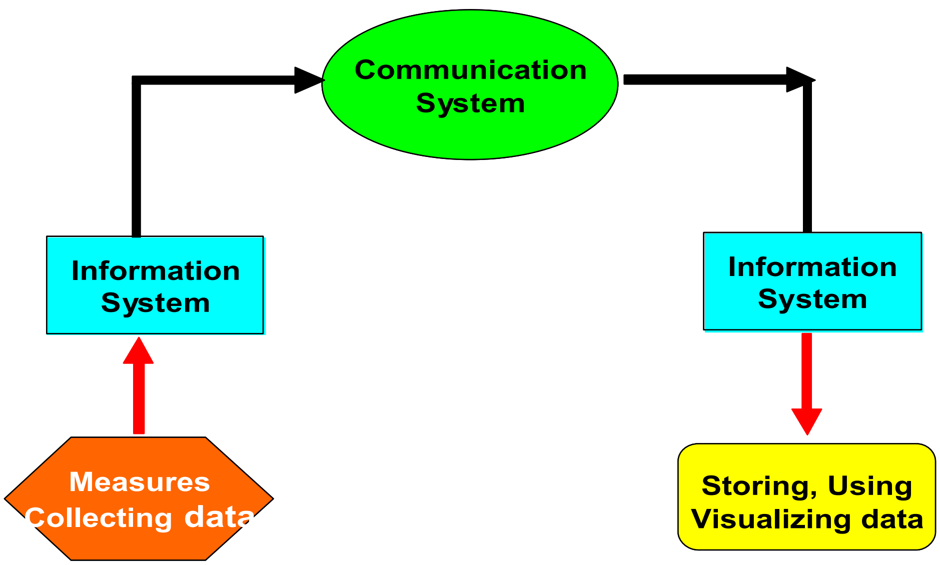


Figure.A.1.-Information vs Communication

The communication system is responsible of this transmission and it uses different communication medias to transfer the information and it can also choose between different ways of coding this information (analog or digital format) depending of the transmission devices. The information transformed into different signals (analog or digital) is transmitted by the communication system to different centers where these signals are converted into other formats (data formats exploitable by the centers) and finally the communication process finishes when these data (information) are stored, used or visualized by other system tasks or by the operator of the system.

The computerization consists in the use of the information or data in order to analyze the system or to establish a help for taking conclusions and so elaborating decisions. The computerization can be carried out there where there is the information (with or without communication between two entities because a same entity can obtain the information and computerized it). This computerization system corresponds mainly to the different computer tools that can be applied in a computer, PLC or Control unit.

A.3.-Information Systems

The information system means of a system can be defined in some applications as those which make possible the acquisition of the information on a primary way that is e.g. the measures of different parameters in the electric power system. In that way, all the intelligent electronic devices used to capture or obtain the information belong to the information system.

A.4.-Communication Systems

The communication system deals with every way of transmitting an information or data between two points. The communication system is composed currently by a large range of different transmission media, from the mobile communications to the fixed ones. All the different ways to communicate have its own language, structure and special characteristics of communication. **[ICAI-04], [HAR-00].**

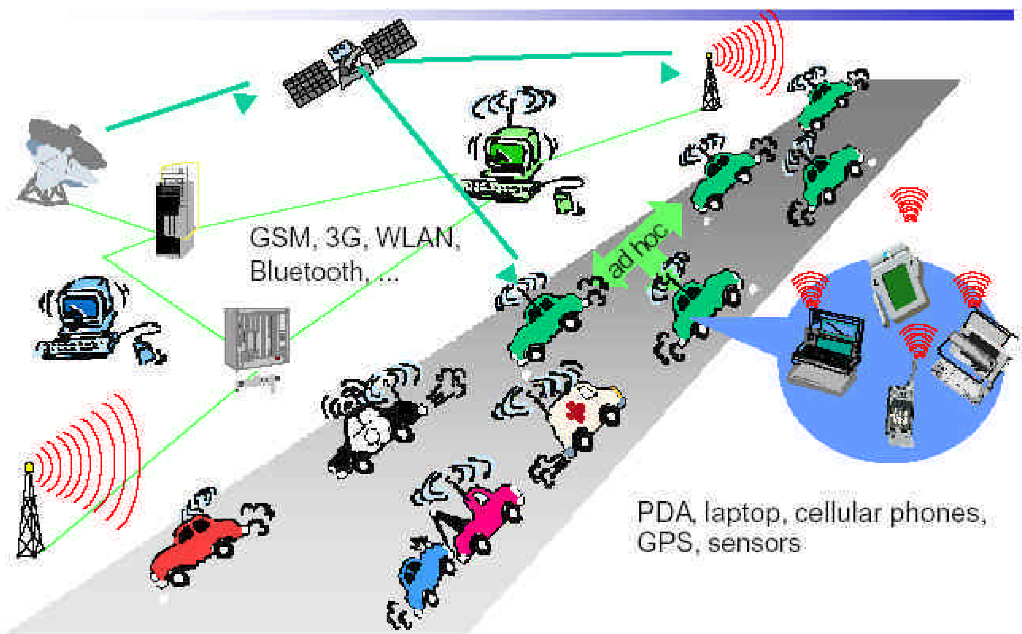


Figure.A.2.-Examples of communication medias: fixed and mobile medias

In figure A.2, several types of communication media are presented, the complexity and variety of different uses in the communication field is shown. Each manufacturer proposes a type of product with specific characteristics: protocol, language, interface possibilities.

The existing communication media share the electromagnetic in the sense that each technology uses a defined band of frequencies in order to avoid interferences between the media channels. In figure A.3, the electromagnetic spectrum is shown, from the Extremely low frequencies (ELF) to Extremely high frequencies and in this interval are included the different mobile and fixed transmission systems:

- Power and telephone, musical instruments, voice microphones: from very ELF to 10^4 Hz
- Twisted pair : from very ELF to 10^8 Hz
- Coaxial cable: from 10^3 Hz to 10^9 Hz
- Radios, televisions and integrated circuits: from 10^4 to 10^9 Hz
- Microwave, Radar, Microwave antennas: from $10^9$to 10^{12}
- Terrestrial and Satellite transmission: from 10^9 Hz to 10^{11} Hz

- Infrared, lasers, guided missiles: from 10^{12}o 10^{14} Hz
- Optical fiber from 10^{14} to 10^{15} Hz

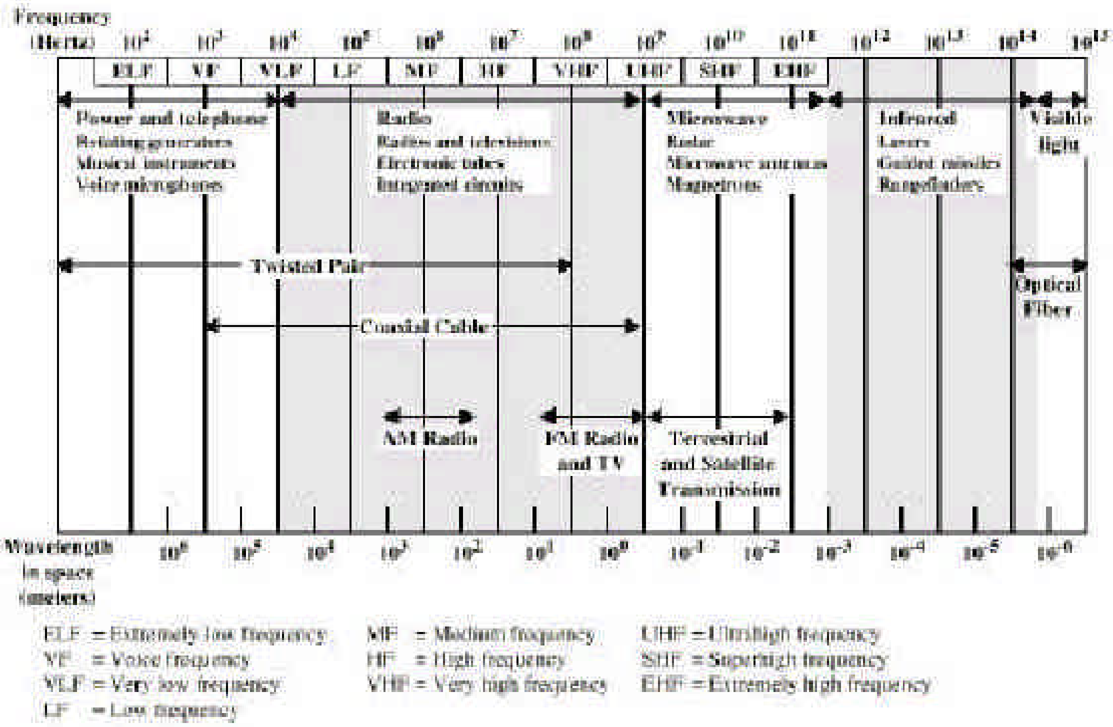


Figure.A.3.-Electromagnetic spectrum

A.4.1.-Mobile Communication Systems

The mobile communication systems are related with the need of the society of information inside a mobility concept, that is, that users can communicate anytime, anywhere and with anyone. Thus, the industry introduced in the market devices that could be connected anytime, anywhere to the main communication network. The wireless communications are a wide group inside the mobile communications, their main characteristics is the fact that they don't need physical wire attachment to transmit the information. In figure A.4, some examples of the differences between wireless and mobile communication are given. A clear example of the difference is the case of the Wireless Local Area Network inside a building that relies and allows the communications between several nodes and communication devices without any physical wire attachment, but it is not a mobile systems, its operation is fixed and limited inside the building and so it is not a system that is possible to carry it with you.

Wireless	vs. Mobile	Examples
✗	✗	stationary computer
✗	✓	notebook in a hotel
✓	✗	wireless LANs in legacy buildings
✓	✓	Personal Digital Assistant (PDA)

Figure.A.4.-Wireless vs Mobile

In figure A.5, some common devices are shown. These devices like the mobile phone or the PDA are mobiles communication systems, that anyone can carry and use them to communicate with anyone, anywhere (if the coverage is available) and at anytime. These mobile devices are connectable to main communication fixed networks through the application of new technologies i.e. Bluetooth or Home RF.

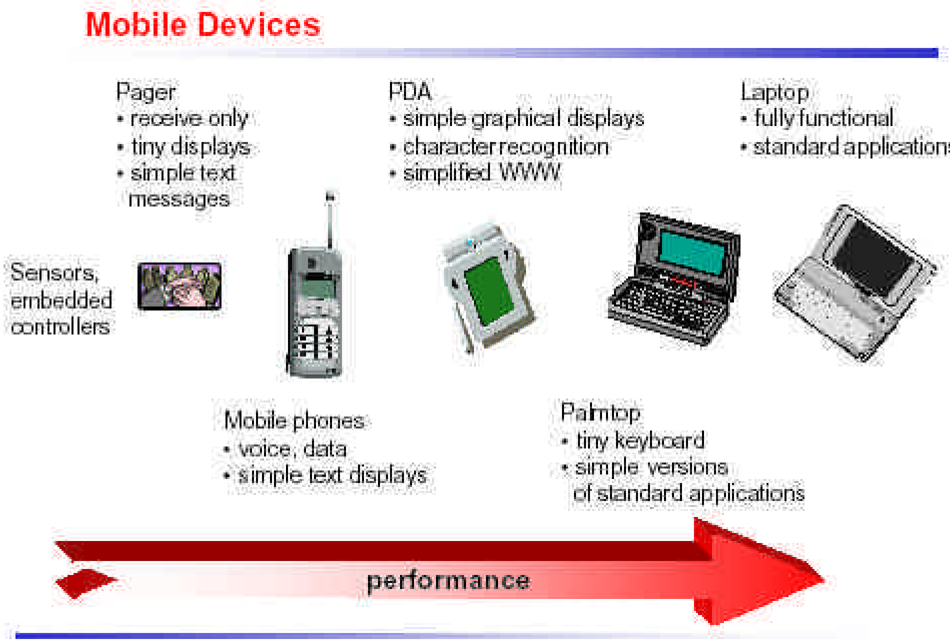


Figure.A.5.-Mobile devices

The communication in the case of mobile systems is very simple, the voice or data are transmitted from the sending point by the air (waves) or with a physical wire in some cases to the main network and centres that repeat and send the signal/wave to the receiving point.

Some examples of the mobile communication and characteristics are the next ones:

- Cellular or mobile phones: GSM, GPRS, UMTS (3G cellular)
    - GSM: Global System for Mobile Communications, one of the leading digital cellular systems. GSM uses narrowband TDMA, which allows eight simultaneous calls on the same radio frequency. GSM was first introduced in 1991. As of the end of 1997, GSM service was available in more than 100 countries and has become the de facto standard in Europe and Asia. The GSM system runs at 2.4, 4.8 or 9.6 kbps.
    - GPRS: General Packet Radio Service, a standard for wireless communications which runs at speeds up to 115 kbps, compared with current GSM (Global System for Mobile Communications) systems' 9.6 kbps. GPRS, which supports a wide range of bandwidths, is an efficient use of limited bandwidth and it is particularly suited for sending and receiving small bursts of data, such as e-mail and Web browsing, as well as large volumes of data.
    - UMTS: Universal Mobile Telecommunications System, a 3G mobile technology that will deliver broadband information at speeds up to 2Mbps. Besides voice and data, UMTS will deliver audio and video to wireless devices anywhere in the world through fixed, wireless and satellite systems.
- Wireless LANs: the LANs are usually based on the IEEE 802.11 standard. It works at 2.4GHz with a speed of 2-11 Mbps for local areas and 9.6-19.2 for wide areas. It is a type of local-area

network that uses high-frequency radio waves rather than wires to communicate between nodes. Wireless LANs use frequencies in UHF to SHF spectrum.

In figure A.6, the different frequencies of wireless system are collected; the spectrum of frequencies is normally supervised by national and/or government associations, so in each continent the range of values and kind of current used technology vary but, in general terms, the frequencies are in a narrow common interval.

	Europe	USA	Japan
Mobile phones	**NMT** 453-457MHz, 463-467 MHz; **GSM** 890-915 MHz, 935-960 MHz; 1710-1785 MHz, 1805-1880 MHz	**AMPS, TDMA, CDMA** 824-849 MHz, 869-894 MHz; **TDMA, CDMA, GSM** 1850-1910 MHz, 1930-1990 MHz;	**PDC** 810-826 MHz, 940-956 MHz; 1429-1465 MHz, 1477-1513 MHz
Cordless telephones	**CT1+** 885-887 MHz, 930-932 MHz; **CT2** 864-868 MHz **DECT** 1880-1900 MHz	**PACS** 1850-1910MHz, 1930-1990 MHz **PACS-UB** 1910-1930 MHz	**PHS** 1895-1918 MHz **JCT** 254-380 MHz
Wireless LANs	**IEEE 802.11** 2400-2483 MHz **HIPERLAN 1** 5176-5270 MHz	**IEEE 802.11** 2400-2483 MHz	**IEEE 802.11** 2471-2497 MHz

Figure.A.6.- Allocated frequencies

- Radio communications: Mobile radio communications operates in one of the three modes – single frequency simplex, two frequency simplex, and duplex. Both of the simplex modes use push-to-talk operation. When the transmitter button is in the talk position, the receiver cuts off. The radio frequencies for Mobile radio ranges between VHF and UHF.

- Bluetooth: It a universal wireless interface useful for the connection of peripherical devices to other communication fixed or mobile communication systems. The frequency baseband is 2.4 GHz and it can transmit simultaneous voice and high speed data at 1Mbps.

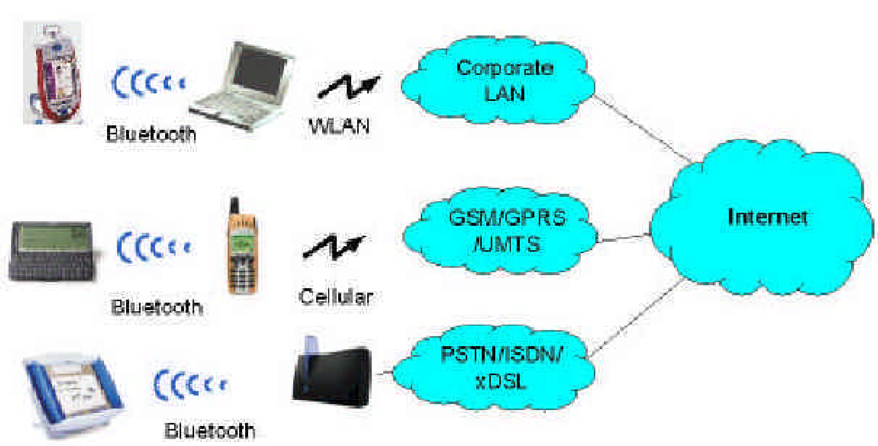


Figure.A.7.-Bluetooth functionality

- IrDA: Infrared data communications

Infrared Data Association, is a group of device manufacturers that developed a standard for transmitting data via infrared light waves. Increasingly, computers and other devices (such as printers) come with IrDA ports. This enables you to transfer data from one device to another without any cables.

IrDA ports support roughly the same transmission rates as traditional parallel ports. The only restrictions on their use are that the two devices must be within a few feet of each other and there must be a clear line of sight between them. IrDA devices communicate using infrared LED's. Wavelength used is 875 nm +- production tolerance (around 30 nm). IrDA devices conforming to standards IrDA 1.0 and 1.1 work over distances up to 1.0m with BER (**B**it **E**rror **R**atio - number of incorrectly transferred bits over number of correctly transferred bits) 10^{-9} and maximum level of surrounding illumination 10klux (daylight). Speeds for IrDA v. 1.1 range from 0.576 and 1.152 Mbps.

Figure.A.8.-IrDA communication between media

- HomeRF: networking voices and data to a PC anywhere in a home

It is designed specifically for wireless networks in homes - in contrast to 802.11, which was created for use in businesses -- HomeRF networks are designed to be more affordable to home users than other wireless technologies. It is based on frequency hopping and using radio frequency waves for the transmission of voice and data. HomeRF uses Shared Wireless Access Protocol (SWAP). SWAP is an open industry specification that allows PCs, peripherals, cordless telephones and other consumer devices to share and communicate voice and data in and around the home without the complication and expense of running new wires. The SWAP specification provides low cost voice and data communications in the 2.4GHz ISM band.

- DECT: Digital Enhanced Cordless Telecommunications

DECT is a digital wireless technology for cordless telephones, wireless offices and even wireless telephone lines to the home. The younger brother of GSM - Global System for Mobile - it is by contrast a radio access technology, rather than a comprehensive system architecture; DECT is designed and specified to interwork with many other types of network, such as the PSTN (conventional telephone networks), ISDN (new digital and data phone networks), GSM (mobile phone networks) and more.

Unlike the analog cordless phones you may have in your home, DECT (Digital Enhanced Cordless Telecommunications) is a digital wireless telephone technology that is expected to make cordless phones much more common in both businesses and homes in the future. Formerly called the Digital European Cordless Telecommunications standard because it was developed by European companies, DECT's present name reflects its global acceptance. Like another important wireless standard, Global System for Mobile communication (GSM). DECT uses time division multiple access (TDMA) to transmit radio signals to phones. Whereas GSM is optimized for mobile travel over large areas, DECT is designed especially for a smaller area (up to a few 100 m) with a large number of users, such as in cities and corporate complexes. A user can have a telephone equipped for both GSM and DECT (this is known as a *dual-mode* phone) and they can operate seamlessly. DECT operates in the frequency range between 1880 to 1900 MHz and the data rate is from 32kbps to 1152 kbps.

A comparison of the different wireless communication systems is given in figure A.9. The highest bandwidth correspond to the WLAN (Wide Local Area Network)

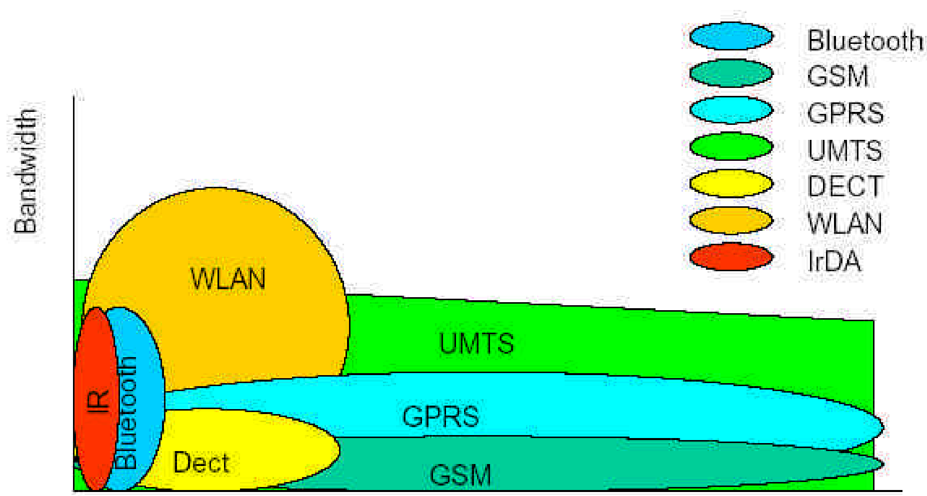


Figure.A.9.-Comparison of bandwidth (in y-axis)and coverage (in x-axis) of different wireless media

The mobile communication systems have some disadvantages if one compares them to the fixed communication systems that will be described in the next paragraph:

- Higher loss-rates due to interference
- Limited availability of useful spectrum, frequencies have to be coordinated and useful frequencies are almost all occupied
- Low transmission rates
- Higher delays
- Lower security, simple active attacking: radio frequency is available for everyone
- They are always a shared medium, so, secure access should be taken into account.

A.4.2.-Fixed Communication Systems

The fixed communication systems are based in a defined model of communication, whilst in the mobile systems the communication could be done by the waves here in the fixed case there are always wire links among the sources and the destinations.
A simplified model of fixed communication model (shown in figure A.10) is composed by:

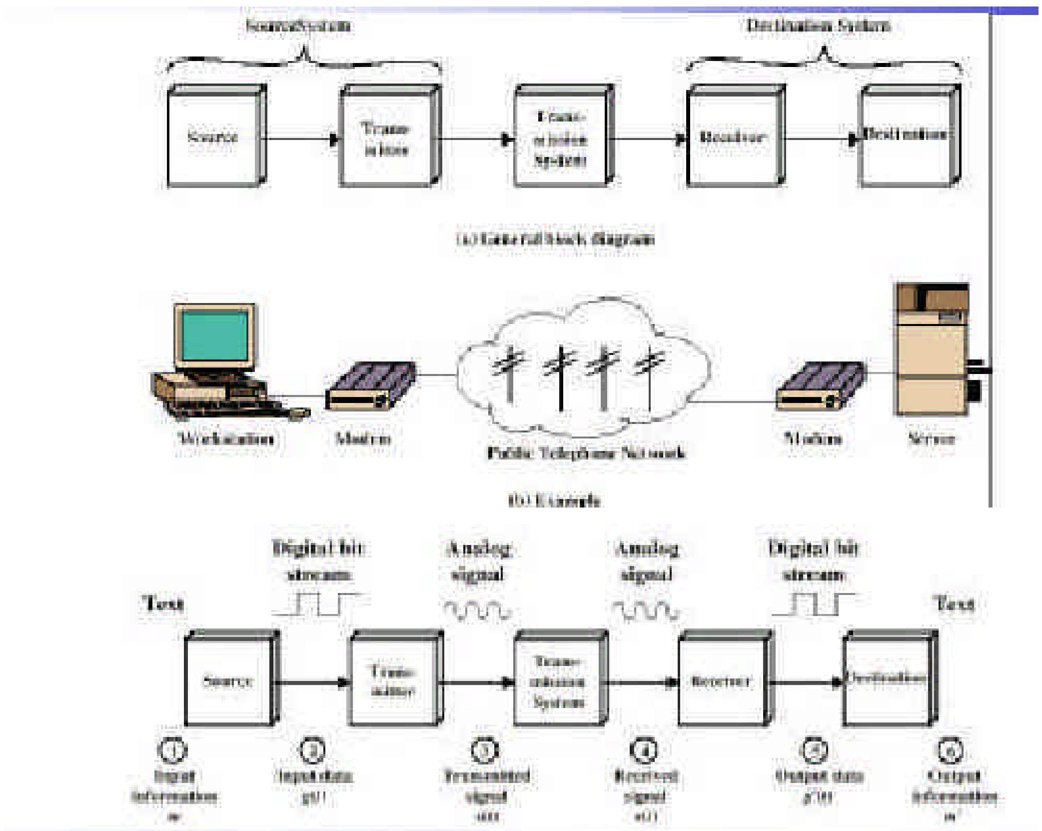


Figure.A.10.-Simplified communication model

- Sources that generate data which must be transmitted.
- Transmitter, if necessary, takes the data to be transmitted and convert it into transmittable signals (analog or digital and correct format depending on the transmission media). The most common transmitter is the modem that converts analog data into digital data and vice versa.
- Transmission system or medium: this system or network is charged to lead physically the signals (representing the data) to its destination address.
- Receiver: as the data was expressed into a special format/signal, this format or signal must be translated by the receiver (typically a modem) to a workable format
- Destination: the data in a workable expression are received and available for the receiving point use.

The transmission of the signals representing the data can be done in several ways:

- **Point-to-point circuit:** it is directly wired between the stations on the network but sometimes the destination and sending devices are far away one from the other and this point-to-point communication is not usually practical. The solution to this problem is the use of a communication network. .

- **Communication networks:** the communications networks links wide geographical areas and several technologies of communication can be mentioned:

    - **Circuit switching:** in a circuit-switched network, a central switch is connected to stations in a star configuration. Communication is between the stations and the switch, or the switch establishes circuits between two or more stations. The stations signal the switch to set up the connection, and when the stations have sent their traffic, they signal to disconnect the circuit. The switch can be a data PBX, a voice/data PBX, or a telephone central office.

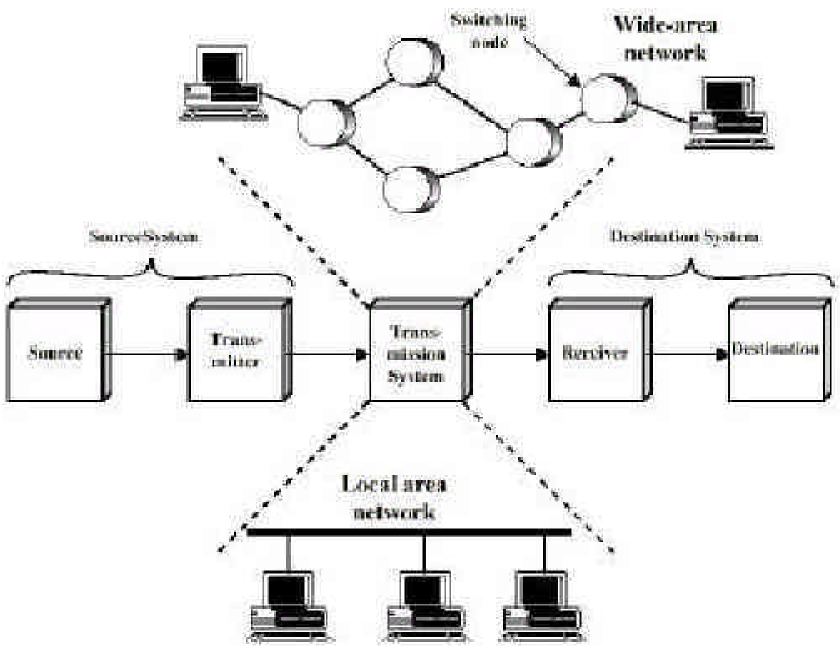


Figure.A.11.-Simplified network model

    - **Message switching networks:** are sometimes called store-and-forward. Stations home on a computer that accepts messages, stores them, and delivers them to their destination. Message switches route and queue messages, clearing them to their destinations at the scheduled delivery times according to the priority the sender establishes.

    - **Packet switching:** a packet-switched network has control nodes that host the stations. In a packet network, nodes are interconnected by sufficient trunks to support the traffic load. Data travels from the station to the node in packets, which are data frames with additional header records appended. The node moves the packet toward its destination by handing it off to the next node in chain. Nodes are controlled by software, with algorithms that control the congestions in the system and decide the way to the next station. The difference with the circuit-switched model is that there the circuits where physically switched and here in the packet switching model, virtual circuits are created between stations.

- **Frame relay:** the structure of a frame relay network is similar to a packet switching network, but there are some differences: packets network were designed in the 70s and so the network is mostly analog with high error rates, on the other side, frame relay appeared in the 80s and it could use digital networks operating with optical-fiber. Furthermore, the way in which errors are checked varied from packet-switched system (it checks errors at each node) to frame relay (the end devices check for and correct errors).

- **Cell relay:** the most significant example is the asynchronous transfer mode (ATM), it is a combination of multiplexing and switching protocol. The architecture of the network is similar to a packet network except the nodes are high-speed switching devices instead of packet store-and-forward devices. Data is sliced into short cells, 48 bytes in ATM, and forwarded across the network with a short header, which is 5 bytes in ATM. ATM is used for private and public networks

- **Local Area Networks:** Most LANs are confined to a single building or group of buildings. However, one LAN can be connected to other LANs over any distance via telephone lines and radio waves. A system of LANs connected in this way is called a wide-area network (WAN).
  Most LANs connect workstations and personal computers. Each node (individual computer) in a LAN has its own CPU with which it executes programs, but it also is able to access data and devices anywhere on the LAN. This means that many users can share expensive devices, such as laser printers, as well as data. Users can also use the LAN to communicate with each other, by sending e-mail or engaging in chat sessions.
  There are many different types of LANs Ethernets being the most common for PCs. Most Apple Macintosh networks are based on Apple's AppleTalk network system, which is built into Macintosh computers.

  The following characteristics differentiate one LAN from another:

  - topology : The geometric arrangement of devices on the network. For example, devices can be arranged in a ring or in a straight line.
  - protocols : The rules and encoding specifications for sending data. The protocols also determine whether the network uses a peer-to-peer or client/server architecture.
  - media : Devices can be connected by twisted-pair wire, coaxial cables, or fiber optic cables. Some networks do without connecting media altogether, communicating instead via radio waves.

  LANs are capable of transmitting data at very fast rates, much faster than data can be transmitted over a telephone line; but the distances are limited, and there is also a limit on the number of computers that can be attached to a single LAN.

- **ISDN (Integrated Services Digital Network):** it is an international communications standard for sending voice, video, and data over digital telephone lines or normal telephone wires. ISDN supports data transfer rates of 64 Kbps. There are two types of ISDN:

  - Basic Rate Interface (BRI) -- consists of two 64-Kbps B-channels (Bearer channel, main data channels) and one D-channel (Delta channel) for transmitting control information.
  - Primary Rate Interface (PRI) -- consists of 23 B-channels and one D-channel (U.S.) or 30 B-channels and one D-channel (Europe).

The original version of ISDN employs baseband transmission. Another version, called B-ISDN, uses broadband transmission and is able to support transmission rates of 1.5 Mbps. B-ISDN requires fiber optic cables and is not widely available.

- **Power line Carrier (PLC):** this is a special communication system that uses the electric power system to send the information. it is the reason for which it is included in the fixed communication system. The carrier system utilizes the electric line and cable conductors to carry voice and data. The carrier signal is injected in one of the conductors through a large capacitor known as coupler. The capacitor is sized to allow the passage of high frequency signals but also it gives a high resistance to 50 Hz electric current. The main use of the carrier system is for protective relaying but nowadays it can be applied for control areas and for communication and transmission of data.

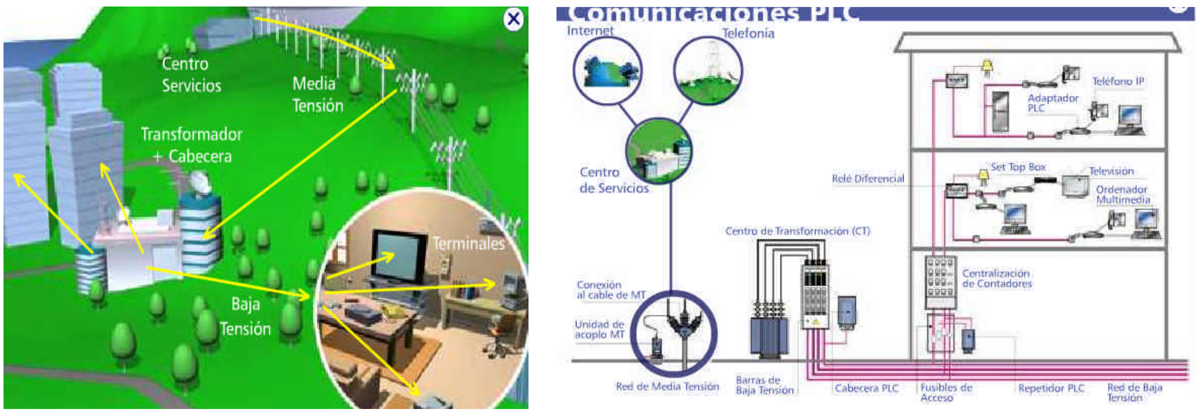


Figure.A.12.-Power Line Carrier Communication equipment

In Spain, utilities are investigating the use of PLC to provide telephone and high speed Internet. Some first tests have been carried out successfully and customers in some cities (Zaragoza and Barcelona) have the possibility of buying these services. In the figure A.13, it is shown one example of the necessary PLC equipment (Endesa-Auna). The proposed service is placed in the distribution medium and low voltage lines and has a speed rate of 2 Mbits/s and the radiofrequency is in the range of the short wave (1 to 30 MHz). The user has only to connect the PLC modem to the network and it disposes automatically the telephone and Internet services.

Figure.A.13.-Power line Carrier model of voice and high speed data transmission

A.4.3.-Protocols

The protocols are utilized to communicate between different entities presents in the communication system (user applications, e-mail, terminals…). These different entities must use a common language to speak between them, and the things they are going to do (e.g. send a mail or a file…) should be done according to defined protocols (similar to the protocols in the diplomatic area, how to sit, eat, and drink, etiquette, procedures…). In the telecommunications the protocols do a similar task.

But each entity may have a different protocol, it speaks a different language, so there are translators that solve the problem, these translators are called protocol converter in computer science and they correspond physically to gateways.

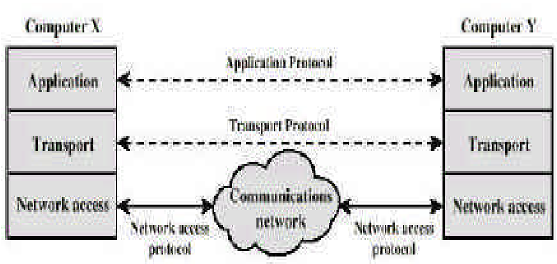
Protocol functions

The major function of the protocols is to create a session; it means the creation of communication between two entities. The data networks allow sessions in two different ways, connectionless protocol (it is like the postal service, you send the message and then this message is delivered to the receiving address) and connection-oriented protocol (the devices have a physical direct connection through the network, you put the information into the channel and it flows to the destination).

The protocols can be classified as peer-to-peer or master-slave according to how the communication is controlled. In the master-slaves protocol, the master controls the messages and the slaves have only the possibility of communicate information through the master which controls everything (connection with host, stations…). On the other hand, in the peer-to-peer protocols all the devices can communicate with each other.

After the session is set up, the protocol controls the flow of the data in the network. At the start of the session, the protocols checks the devices involved in the process in order to determine the highest speed with which the communication could be carried out, the resulting speed is the lowest of the maximal speed of all the devices. Every session needs addresses (sender and destination) to set up the communication but not all protocols contain addresses, many of them rely on higher or lower layers for addressing. The routing in the network is also a function of the protocols, it defines the path that the message will follow avoiding congestion and favouring variables such cost, distance and type of facility. The data are split in several frames, cells or packets if the message exceeds a defined length or volume, so the protocol put into the different packets, frames or cells a header or identifier bit in order to be able to identify each one and to reassembly all at destination and convert them into the full message. Protocols check for errors and repeat the send of some packets if necessary.

A simple architecture of protocol is the three layer architecture. It contains three layers as its name indicates. These layers are responsible of different functions that the protocol is charged:



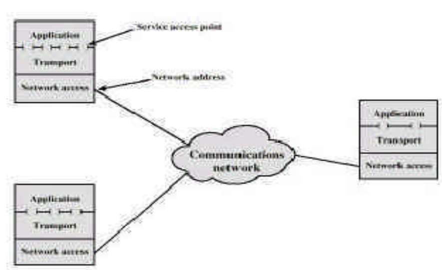


Figure.A.14.- A three layer protocol example

- Network access layer :
    - Exchange of data between the computer and the network
    - Sending computer provides address of destination
    - Dependent on type of network used (LAN, packet switched…)
- Transport layer:
    - Reliable data exchange, independent of network being used
    - Independent of application
    - Independent of network being used

- Application layer:
    - Support different user applications
    - E.g. mail, file transfer

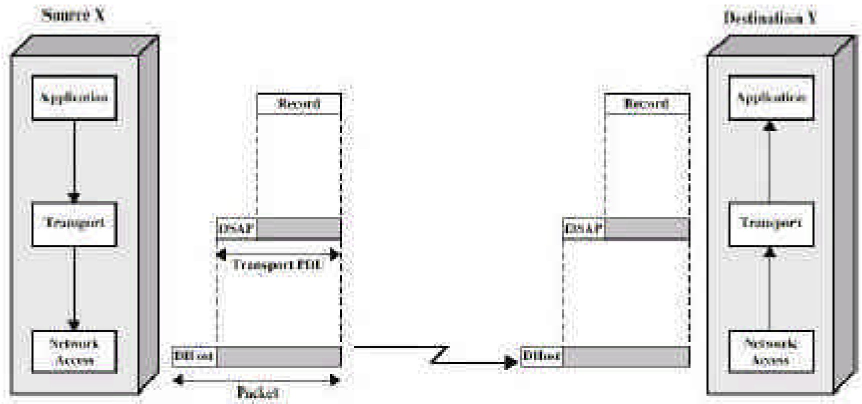


Figure.A.15.- Operation of a protocol architecture

Each layer has its own protocol to fulfil its designated functions, so there are application protocols, transport protocols and network access protocols (each layers` protocol ensures the communication two layers` entities). The operation of the system is the next one, in the process of an application (mail, file transfer…), it is necessary to create a session to communicate between to PCs or two general entities. So there is a message to communicate between the sending to the destination, the transport layer protocol is charged of split the information in packets. Then, the network access protocol looks for the path through the network that the data could follow to exchange the information and finally when all these steps are fixed the message is sent. At the destination point is received and the message is reassembled and input to the application store in the destination entity. This three layer architecture is a simple example of the structure of a given protocol. The most important protocol architectures for telecommunication are the ISO Open System Interconnection model and the TCP/IP protocol (Transport Control Protocol/ Internet Protocol)

ISO OSI (Open Systems Interconnection) Model

The standardization in protocols resulted in the creation of layered protocols. A layer is a discrete set of functions that the protocol is designated to accomplish, The International Standards Organization (ISO) has published a seven-layer protocol model, the Open Systems Interconnection (OSI) model. The architecture of the ISO Open Systems Interconnection model is shown in the figure A.16.

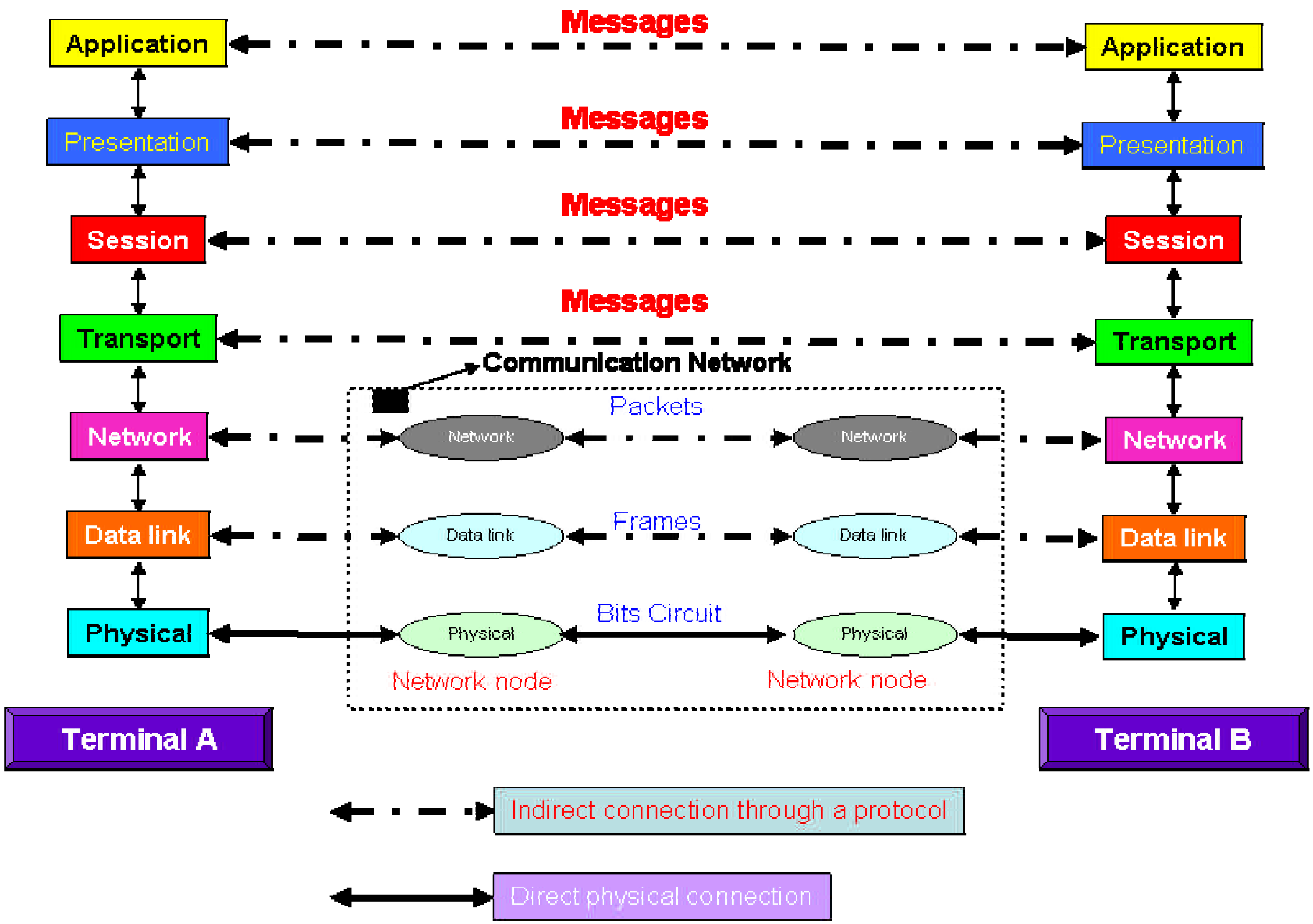


Figure.A.16.- OSI Open Systems Interconnection Model

TCP/IP protocol

TCP/IP is a collection of protocols developed by the United States Department of Defense (DoD) as a way to provide intercommunication and operability between devices. TCP/IP became an important protocol because it was available at a time when the world needed a standard, and nothing else was available, so TCP/IP is a standard de facto because its wide and spread use.

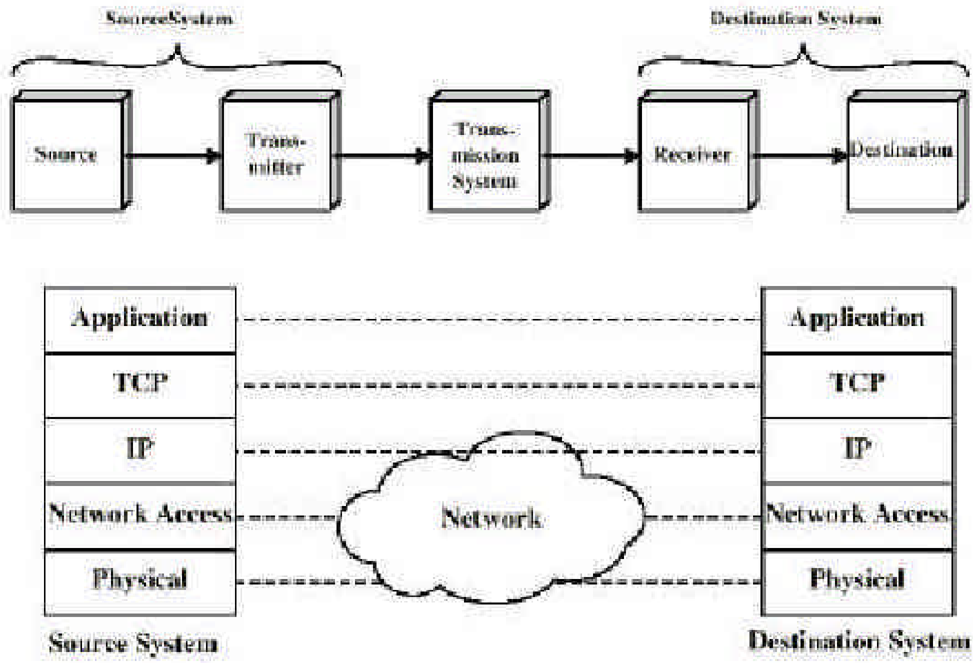


Figure.A.17.-TCP/IP Protocol Architecture Model

TCP/IP applications use 4 layers:

- An application protocol such as mail (SMTP), file transfer (FTP), connection to a remote terminal (TELNET)…
- A protocol such as TCP that provides services needed by many applications
- IP, which provides the basic service of getting packets to their destination
- The protocols needed to manage a specific physical medium, such as Ethernet or a point to point line.

TCP/IP is based on the Catenet model, this model assumes that there are a large number of independent networks connected together by gateways.

TCP is responsible of making sure that the commands get through to the other end. It keeps track of what is sent. If any message is too large for one packet, TCP split up into several packets, and make sure that they all arrive correctly resending packets if anything gets lost and put things back in the right order. IP is responsible for routing individual packets. Its job is to find the route in the network for the packet (packets of a message can follow different paths in the network) and get it to the other end. In order to allow gateways and other intermediate systems to forward the packet, it adds its own header. The main things in this header are the source and destination addresses, the protocol number and something else.

A.4.4.-Data transmission

The data transmission between the transmitter and the receiver can be carried out by guided (e.g. twisted pair, optical fiber) or unguided medium (e.g. air, vacuum). Then the mode how the transmission can give us different classes of transmission:

- Direct link: there are not any intermediate devices between the transmitter and the receiver and it is possible by a direct physical media
- Point to point: it is a type of direct link transmission in which only two devices share the link
- Multi-point: there are several devices that share the link

The data transmission system can be classified also according to the unidirectional or bidirectional transfer:

- Simplex systems: the transmission is only possible in one direction, e.g. television
- Half duplex systems: they transfer the data in either direction, but only one way at a time, e.g. police radio
- Full duplex systems: they transmit the data in both directions at the same time, e.g. telephone

The performance or capacity of the communication channels are normally measured with data rate (in bits per second). All the data communication channels require synchronization to keep the sending and receiving ends in step. The signal on a baseband data communications channel is a series of rapid voltage changes, and synchronization is necessary to know which pulse is the first bit in a character. Regarding the chosen synchronization method, the data transmission data systems can be divided in: asynchronous or synchronous.

- **Asynchronous:** A method of transmitting data over a network wherein each character contains a start and stop bit to keep the transmitting and receiving ending with synchronism with each other. The character begins with the start bit at the zero or space level followed by 8 data bits and a stop bit at the one level. So there are always to non-information bits that in other hand are necessaries.
- **Synchronous:** A method of transmitting data over a network wherein the sending and receiving terminals are kept in synchronism with each other by a clock signal embedded in the data. The synchronous method does not need the 2 overhead or non-information. Synchronous data are sent in a block mode with information characters between a header and a trailer records. The trailer and header contain the overhead bits, the information bits are transferred in multiples of 8 bits. The clock signal that the modem extracts from the incoming bit stream keeps the two devices in synchronization.

Analog and Digital Data transmission

The data transmission can be established by means of signals by which the data are propagated. These signals constitute an electric or electromagnetic representation of data. The signals may have different nature:

- Analog: the signals have continuous values within some interval, there are various media that allow this type of signals such as wire or fiber optic.
- Digital: the signals have discrete values, and they normally take two DC components (0 or 1)

An example of analog media is the telephone, when somebody speaks, the voice actuates as a transmitter and it is generated from it an analog signal that is proportional to the sound pressure or level.

Modems do the conversion of digital data format into analog signals and vice versa. That is normal at the exit of computers that produces digital data and most of times, the existing telephone wire is not a digital media and so the modem must change the nature of the signals.

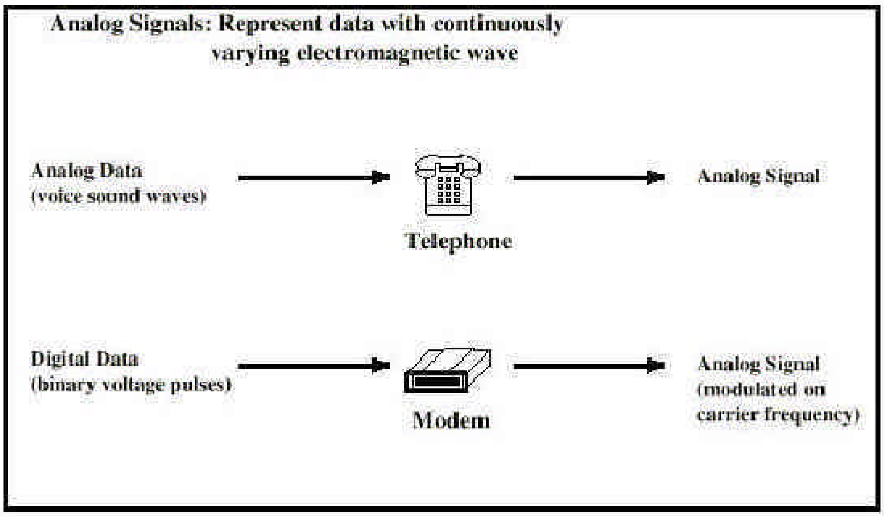


Figure.A.18.-Analog signals carrying Analog and Digital Data

The conversion of analog data into digital signals is carried out by the modem or a codec. The codec (contraction of coder- decoder) is equipment that converts the analog video signal into digital and compresses it for transmission.

A digital transmitter is a device that converts the digital data into digital signals in the correct format to be transmitted.

However, digital signals are usually used for digital data and analog signals for analog data, but it is possible to use analog signal to carry digital data (e.g. modem), and it is also possible to use digital signal to carry analog data (e.g. CD audio).
The characteristics of the analog transmission are the next ones:

- It is attenuated over distance
- It use amplifiers to boost signal
- And it also amplifies noise

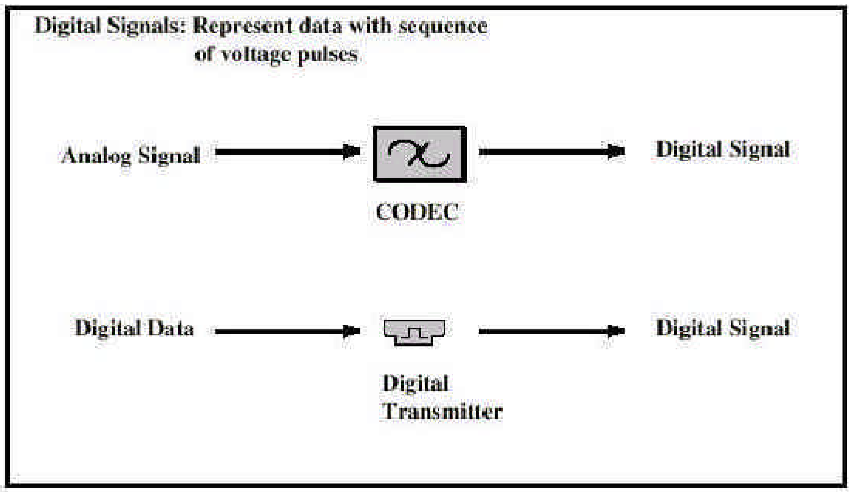


Figure.A.19.-Digital signals carrying Analog and Digital Data

On the other hand, the characteristics of the digital transmission:

- Its integrity is endangered by noise, attenuation
- Repeaters are also used
- Attenuation is overcome
- And noise is not amplified

The advantages of digital transmission over the analog transmission can be summarized as follow:

- It is a low cost technology, digital equipment is less expensive to manufacture than analog
- Digital transmission provides higher quality in most respects than analog.
- An increasing amount of communication takes place between digital terminal equipment such as computers.
- High bandwidth links economical
- Better security: possibility of encryption

Annexe B: Overview of Standards and International Working Groups about Communications in EPS

This annexe is a summary of the different standards and international working groups about communication in the Electric Power System. It is inspired in **[CIG-03]**:

- **IEEE 1525 Substation Automation Communication**
  http://grouper.ieee.org/groups/

  CIGRE SC35, Power system Communication and Telecontrol Working Group
  http://www.cigre-sc35.org/

- **IEEE P1615 (under preparation)**
  Power Engineering Society/Substations Committee/Subcommittee C3/Task Force 1
  Recommended Practice for Network Communication in Electric Power Substations

- **UCTE Operational Handbook, Communication Infrastructure and Data exchanges chapters are under preparation.**
  www.ucte.org

- **IEEE 802 LAN/MAN Standards Committee**
  http://grouper.ieee.org/groups/802/

- **IEEE Substation Committee**
  http://grouper.ieee.org/groups/sub/wgc3/

  - **IEEE Std 1613-2003** - IEEE Standard Environmental and Testing Requirements for Communications Networking Devices in Electric Power Substations.

  - **IEEE Std C37.1-1994** - IEEE Standard Definition, Specification, and Analysis of Systems Used for Supervisory Control, Data Acquisition, and Automatic Control.

  - **IEEE Std C37.2-1996** - IEEE Standard Electric Power System Device Function Numbers and Contact Designations *(C37.2-1996 was recently reaffirmed by the Standard Board at its December 2001 meeting and will be republished unchanged as C37.2-2002)*

  - **IEEE 1379-2000** - IEEE Recommended Practice for Data Communications Between Intelligent Electronic Devices and Remote Terminal Units in a Substation

From the document CIGRE B5.11, the following standards are related to the communications aspects in electric power systems.

- **Inside substations**

  - **IEC 60870-5 Series**: IEC Technical Committee 57 has defined a standard for relatively simple, bit serial communication: IEC 60870-5. The standard is optimized for efficient and reliable transfer of process data and commands to and from geographically widespread systems over low-speed (up to 64 kbps) fixed and dial-up connections. It harmonizes with the OSI reference model through its Enhanced Performance Architecture (EPA), which uses three layers from the full seven-layer OSI model. IEC 60870-5 communication standard consists of the IEC 60870-5 protocol standard series (with international standard status) and the IEC 60870-5 companion standard series. The Companion standard specifies the information services in a specific domain of activity, and specifies in detail the use of protocol standard parts for specific telecontrol tasks. The IEC 60870-5 protocol standard and companion standard series specify communication protocols optimized for telecontrol systems that require short response times in relatively low-speed networks.

  - IEC 60870-5-1 Transmission frame formats
  - IEC 60870-5-2 Link transmission procedures
  - IEC 60870-5-3 General structure of application data
  - IEC 60870-5-4 Definition and coding of application information elements
  - IEC 60870-5-5 Transmission protocols - Basic application functions
  - IEC 60870-5-101 Transmission protocols - Companion Standard for Basic Telecontrol Tasks
  - IEC 60870-5-102 Companion Standard for the Transmission of Integrated Totals in Electric Power Systems
  - IEC 60870-5-103 Companion Standard for the Informative Interface of Protection Equipment
  - IEC 60870-5-104 Network Access for IEC 60870-5-101 using Standard Transport Profiles

- **IEC 60870-5-103**: Companion standard for the informative interface of protection equipment. This standard used to upload protection data's is applicable for substation automation systems with star coupled protection devices using point-to-point links and a master slave transmission procedure. IEC 60870-5-103 describes two methods of information exchange. The first is based on explicitly specified ASDUs (Application Service Data Units) and application procedures for transmission of standardized messages, and the second uses generic services for transmission of nearly all possible information.

- **IEC 61850**: Communication networks and systems in substations. IEC 61850 defines a comprehensive communication standard for substations. This includes a consistent data and service model at all communication level. Operational information (indications, commands, and measured values) are coded and transmitted in the same way on a possible process bus and station bus. The use of the same application interfaces and protocol stacks at the station bus and process bus levels ensures that "gateway-free" communication links are established within the station. The objective of IEC 61850 is to design a communication system that provides interoperability between the functions to be performed in a substation, but residing in equipment (physical devices) from different suppliers, meeting the same functional and operational requirements. Functional requirements have to be met independent of substation size and operational conditions. The functions of a substation automation system are control and supervision, as well as protection and monitoring of the primary equipment and of the grid. Other functions are related to the system itself; e.g., supervision of the communication.

- **IEC 62010**: Communication Requirements of HV Switchgear Assemblies. Working Group 11 of TC 57 in IEC is working on a product standard that would specify the requirements of HV Switchgear and Assemblies such that they support the horizontal substation communication standard IEC 61850.

- **IEEE-SA TR 1550, UCA™ 2.0**: IEEE-SA Technical Report on Utility Communications (UCA™), Version 2.0. The Electric Power Research Institute (EPRI) developed a communication architecture networking all components of an electric utility. This architecture is named the Utility Communication Architecture (UCA™). IEEE-SA TR1550 documents the version of UCA™, known as UCA™ 2.0 as it was specified in 1999. The objective of EPRI's UCA™ project is to achieve a standardised networking of all control components such as control centres, power plants, substations, energy management systems, switchgears and customer's interfaces. Two critical components to understand are the data model and the common application service model. The model, which describes the data of the bays including protection and control, is outlined in the data model GOMSFE (Generic Object Models for Substation and Feeder Equipment). The model, which describes the necessary services needed to exchange messages, commands, data, etc. between the primary and secondary devices, is outlined in the service model CASM (Common Application Service Models). Both papers are included in IEEE-SA TR 1550.

- **IEEE 1379**: Recommended Practice for Data Communications between Remote Terminal Units and Intelligent Electronic Devices in a Substation. This recommended practice present a uniform set of guidelines for communications and interoperation of IEDs and Remote Terminal Units (RTUs) in an electric utility substation. It does not establish an underlying communication standard.

Instead, it provides a specific limited subset of two existing communication protocols, to encourage understanding and timely application. Both DNP and IEC 60870-5-101 have been specified inside. A mechanism for adding data elements and message structures to this recommended practice is described. The purpose of IEEE 1379 is to illustrate a recommended practice that will eliminate the need for time consuming and costly efforts by implementers to interface their equipment to other equipment on a project-by-project basis.

- **IEEE PC37.115**: Test Method for Use in the Evaluation of Message Communications between Intelligent Electronic Devices in an Integrated Substation Protection, Control and Data Acquisition System. IEEE PC37.115 defines standard communication modeling, terminology, evaluation criteria and performance measures for communication test scenarios, which specify messages to be exchanged between electrical power substation intelligent electronic devices (IEDs). These scenarios define message transactions between applications within the substation, and between substation IEDs and remotely located applications. The scenarios do not specify the communication protocol required to implement the transactions. There are currently no coherent communication modeling, terminology and communication test scenarios for the evaluation of one or more implementation concepts for communication between substation IEDs within a substation or between a substation and remote IEDs. Utilities and vendors will use this standard to evaluate, on a common basis, one or more implementation solutions.

- **Profibus**: General Purpose Field Communication System, Application Layer Service Definition PROFIBUS is a vendor-independent, open field bus standard for a wide range of applications in manufacturing and process automation. PROFIBUS can be used for both high-speed time critical applications and complex communication tasks.

- **Modbus**: de facto standard since 1979. MODBUS Protocol is a messaging structure developed by Modicon in 1979, used to establish master-slave/client-server communication between intelligent devices. It is a de facto standard, and used as network protocol in the industrial manufacturing environment. MODBUS is an application layer messaging protocol, positioned at level 7 of the OSI model that provides client/server communication between devices connected on different types of buses or networks. MODBUS is a request/reply protocol and offers services specified by function codes. MODBUS function codes are elements of MODBUS request/reply PDUs.

- **LON**: The term LON (Local Operating Network) was chosen to distinguish the network from a LAN (Local Area Network), developed for computer networks and office automation. LonWorks control networks are a standard for networking controls and machines in building, industrial, home, transportation, and utility automation applications. A LON network is intended for device control of intelligent network nodes and does not support the transmission of multimedia data.

- **IEC 61000-6-5:** Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for power station and substation environment. This technical specification sets immunity requirements for apparatus intended for use by Electricity Utilities in the generation, transmission and distribution of electricity and related telecommunication systems. The locations covered are the power stations and the substations where apparatus of Electricity Utilities are installed. Immunity requirements are given for the frequency range 0 Hz to 400 GHz, but only in respect of electromagnetic phenomena for which detailed test procedures, test instrumentation and test set-up are given in existing IEC basic standards.

- **Instrument transformer**:
  - **IEC 61850-9-1**: Specific Communication Service Mapping (SCSM) – Serial Unidirectional Multidrop**.**
  - **IEC 61850-9-2**: Specific Communication Service Mapping (SCSM) – Sampled values over ISO/IEC 8802-3.
  - **IEC 60044-7 and -8**: Instrument transformers - Part 7: Electronic voltage transformers, Part 8: Electrical current transducers

- **Metering**:

  - **IEC 60870-5-102**: Companion Standard for the Transmission of Integrated Totals in Electric Power Systems. IEC 60870-5-102 standardized the transmission of integrated totals representing the amount of electrical energy transferred between power utilities, or between a power utility and independent power producer on a HV or MV network as a part of energy management systems functionality. It is not concerned with LV networks or the interfaces to the energy consumption meters. In general the values of integrated totals are transmitted at periodic intervals to update the energy interchanges between utilities or between heavy industry and utilities. The periodically received information is used for supervisory and control purposes of energy distribution in wide area networks. The defined protocol is based on the three-layer reference model EPA. The standard utilizes IEC 60870-5.

  - **IEC 61107**: Data exchange for meter reading, tariff and load control -Direct local data exchange.

  - **IEC 62056**: Data exchange for meter reading, tariff and load control - Direct local data exchange.

  - **IEC 61334-4 DLMS, COSEM:** Distribution automation using distribution line carrier systems - Data communication protocols. IEC 61334 describes the structure of distribution networks for both medium and low-voltage levels and presents the architecture for a distribution automation system using distribution line carrier systems.
  - **American Meter Reading Association (AMRA) :** AMRA is an international, non-profit, membership organization founded in 1986 to address standardization, justification and deployment practices in the implementation of advanced metering technologies. Automatic Meter Reading (AMR) is the remote collection of consumption data from customers' utility meters using telephony, radio frequency, power-line and satellite communications technologies.

- **Communciation to substations, to Power Plants and to Control Centers**:

  - **IEC 60834:** Teleprotection equipment of power systems - Performance and testing, Part 1 – Command systems, Part 2 – Analog comparison systems. The information conveyed by the teleprotection equipment can be in analogue or digital form. The command type teleprotection equipment referred to in this standard can be power line carrier equipment or voice frequency equipment which is used in connection with various telecommunication systems, such as power line carrier (PLC), radio links, optical fiber, rented circuits, leased or privately owned cables. In addition, the command type teleprotection can be digital equipment, which is used with a digital telecommunication system, or media such as optical fibers, radio links, leased or privately owned digital links. The command type teleprotection equipment may be separate or provided as an integral part of the protection equipment. In addition to teleprotection equipment performance tests, tests have to be carried out on the power supply of the teleprotection equipment.

  - **IEC1565-2002:** Standard for N times 64 kilobit per second optical fiber interfaces between teleprotection and multiplexer equipment.

  - **IEC 60870-6:** Telecontrol equipment and systems - Telecontrol protocols compatible with ISO and ITU-T recommendations.

  - **ELCOM90:** Electricity Utilities Communication. ELCOM90 is a standard data communication protocol for the exchange of information between different control centers for the electric utility sector. Such communications may include links to external EMS systems, and to accounting, billing, and management information systems. ELCOM originates from a Scandinavian initiative to standardize information exchange between control centers. ELCOM is an international accepted de-facto standard running over TCP/IP and X.25 Wide Area Networks. The ELCOM standards consist of two parts. These are the ELCOM provider (OSI layer 6 and 7) and the User Elements (integration part between the provider and the SCADA system)

- **IEC 60870-5-101:** Companion standard for basic telecontrol tasks

- **IEC 60870-5-104:** Network Access for IEC 60870-5-101 using Standard Transport Profiles

- **DNP (Distributed Network Protocol) :** DNP is an open, public and non-proprietary protocol based on existing open standards to work within a variety of networks. DNP Version 3.0 was originally designed based on three layers of the OSI seven-layer model: application layer, data link layer and physical layer. The application layer is object-based with objects provided for most generic data formats. The data link layer provides for several methods of retrieving data such as polling for classes and object variations. The physical layer defines a simple RS-232 or RS-485 interface and an Ethernet interface. DNP was developed to achieve interoperability among systems in the electric utility, oil & gas, water/waste water and security industries. The IEEE Standard 1379 recommends the use of either DNP 3 or IEC 60870-5-101 for remote terminal unit to intelligent electronic device messaging. DNP can also be implemented in any SCADA system

- **IEC 61970:** Energy Management System Application Program Interface

- **IEC 61968:** System Interfaces for Distribution Management. IEC 61968 defines interfaces for the major elements of an interface-architecture for Distribution Management Systems (DMS). This standard identifies and establishes requirements for standard interfaces based on an Interface Reference Model (IRM). Subsequent parts of this standard are based on each interface identified in the IRM. IEC 61968 is limited to the definition of interfaces and is implementation independence. They provide for interoperability among different computer systems, platforms, and languages. Methods and technologies used to implement functionality conforming to these interfaces are considered outside of the scope of these standards; only the interface itself is specified in these standards. As used in IEC 61968, a DMS consists of various distributed application components for the utility to manage electrical distribution networks. These capabilities include monitoring and control of equipment for power delivery, management processes to ensure system reliability, voltage management, demand-side management, outage management, work management, automated mapping and facilities management.
- **IEC 62271-003 (IEC 62210) :** : Power system control and associated communications - Data and communication security. IEC 62210 applies to computerized supervision, control, metering, and protection systems in electrical utilities. The content deals with security aspects related to communication protocols used within and between such systems, the access to, and use of the systems. Safety, security and reliability have always been important issues in the design and operation of systems in Electrical Utilities.

- **IEC 61400-25:** Wind turbines - Communication standard for remote control and monitoring of wind power plants.

- **IEC 62195 TR:** Power system control and associated communications - Deregulated energy market communications. IEC 62195 is a technical describing electronic communications in deregulated energy markets (communications between market participants). It identifies the requirements and functional needs for communications in deregulated energy markets. IEC 62195 makes a clear distinction between communications for control of energy systems and communications for the market. It addresses the interrelation and interworking between these separate fields.

Annexe C: European synchronised zones

The Union for the Co-ordination of Transmission of Electricity (UCTE) co-ordinates the interests of transmission system operators in 22 European countries. Their common objective is to maintain the security of operation of the interconnected power system. Through the networks of the UCTE, 450 million people are supplied with electric energy; annual electricity consumption totals approx. 2300 TWh. As of June 2003, the member companies of the UCTE come from the following countries : Belgium (B), Bosnia-Herzegovina (BIH), Germany (D), Luxembourg (L), Spain (E), The Netherlands (NL), France (F), Austria (A), Greece (GR), Portugal (P), Italy (I), Switzerland (CH), Slovenia (SLO), Czech Republic (CZ), Croatia (HR), Hungary (H), Serbia and Montenegro (SCG), Poland (PL), Former Yugoslav Republic of Macedonia (FYROM), Slovak Republic (SK), Bulgaria (BG) and Romania (RO).

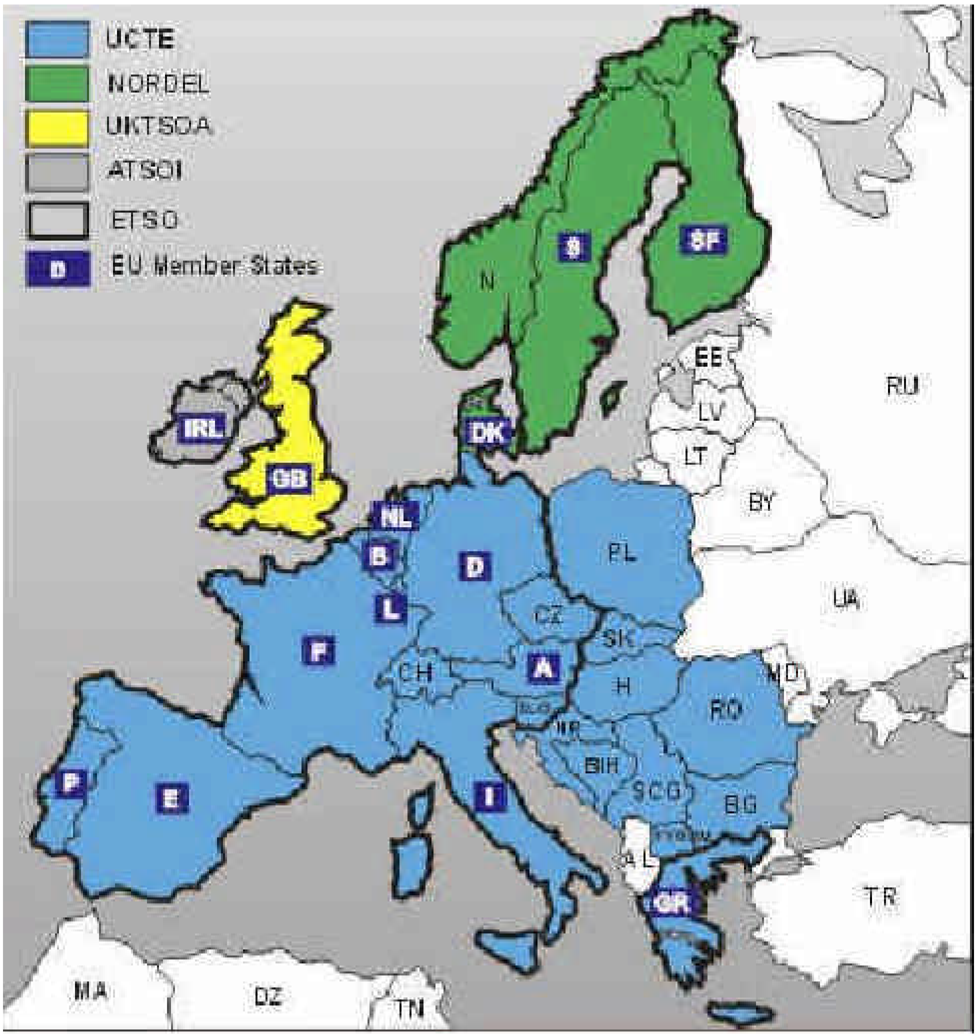


Figure.C.1.-Map of European synchronized zones

Annexe D: Article CRIS 2004 about the DG limits insertion

This article has been proposed for publication in the CRIS 2004 Conference with the next title: «Limits of DG Insertion in Electric power system ».

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Introduction

The dependence of the current society on the electricity supply does that the electric power system (EPS) is one of the critical points in the normal life and defence of a country. The absence of electricity provokes problems for daily life such as miss of heating, cooking, hot water, communications and industry operation between other aspects. The threats to the EPS go from terrorist attacks into, upon or through the EPS [1] to the data integrity and communication security [2], [3]. Other threats for the current operation may come from the system itself by means of distributed generation (DG) or new producers that the EPS is receiving.

The article gives an overview of the different impacts and the influence of DG in the EPS operation. Special attention is paid to the DG behavior during severe disturbances such as blackouts. The DG penetration is commented from different points of view: small-signal stability, voltage stability, transient stability, DG protection and security reserves margins. The amount of DG insertion in the EPS should be limited to prevent catastrophic consequences in real-time operation. The complexity of the studies, involved in the limit of DG insertion, is based on the variety of static and dynamic situations which could appear in the current operation of the EPS. However, some EUROSTAG simulations of an European-adapted 39buses network (based on IEEE New England 39 buses) are carried out to illustrate the conclusions.

Finally, the article proposes the use of DG as means to increase the EPS robustness. The DG insertion could facilitate the apparition of self-healing areas in the distribution and transmission sub-systems. So, operators (TSO and/or DSO) could ensure the supply continuity, with the help of DG, in two strategies: one to avoid the propagation of black-outs and another to profit the DG black-start capacity to restore the system. The works included in the article are integrated in the CRISP[1] project supported by the European Union.

[1] ***CRISP: Distributed Intelligence in Critical Infrastructures for Sustainable Power.*** Project funded by the European Community under the Fifth RTD Framework Programme (2002-2005). Project Co-ordinator: ECN. Partners: ABB, BTH, IDEA, ECN, ENECO, EnerSearch and Sydkraft. Contract No. ENK5-CT-2002-00673.

DG insertion in EPS

The generation of the energy is normally carried out in the transmission system by means of the huge power plant (1000-1300 MW) based on thermal, nuclear or hydro energy. But, this is not the unique power injection in the electric networks. There are other generation injections, called DG, e.g. CHP (Combined Heat and Power) generators and small local independent producers at the sub-transmission system, or the small dispersed generators at the distribution system.

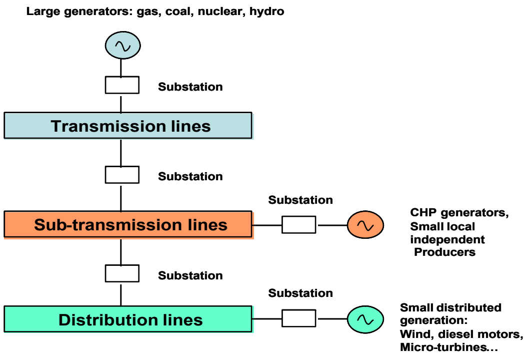

Figure D.1.- DG insertion in Electric Power Systems

The voltage level for the DG connection (sub-transmission or distribution) depends essentially on the amount of injected power and the local network characteristics. The liberalisation of the energy market has favoured the apparition of these new DG producers. In figure D.2, the share between the different generation types is detailed for some of the EU (European Union) countries.

Country	Nuclear energy	Coal, oil, gas, wood	Hydro-electric	Renewable energy
Belgium	55.2	44.3	0.5	-
Denmark		86.8	-	13.2
Germany	29.7	64.6	4.1	1.6
Finland	31.2	33.3	22.0	13.5
France	75.7	10.8	13.5	-
Greece	-	90.9	8.9	0.2
Great Britain	26.8	70.0	2.0	1.2
Ireland	-	94.7	4.8	0.5
Italy	-	78.6	19.0	2.4
Luxembourg	-	13.4	83.3	3.3
Netherlands	4.1	92.6	0.1	3.2
Austria	-	31.2	68.8	-
Portugal	-	64.9	34.8	0.3
Sweden	45.8	4.5	47.8	1.9
Spain	30.1	47.7	20.8	1.4
15 EU countries	34.3	50.2	13.8	1.7
Norway	-	0.7	99.3	-
Switzerland	40.3	3.1	56.6	-

Figure D.2.- Generation type in some EU countries (%)

DG units are based on conventional and non-conventional energies. The conventional DG corresponds to micro-turbine, CHP, fuel cells or Diesels. The non-conventional energies refer to the renewable sources such as wind energy, hydro or PV.

Renewable sources are widely seen as a relevant tool to comply the obligations coming from the Kyoto protocol. The estimation of new DG based on RES (Renewable Energy Source) is shown in figure D.3 by ETSO (European Transmission System Operators) data [4] for the percentage of the total capacity which is based on renewable energies. In this figure, it is also shown the tendency to new DG installations. Hydro power is the renewable energy source that contributes the biggest share to the renewable generation in Europe.

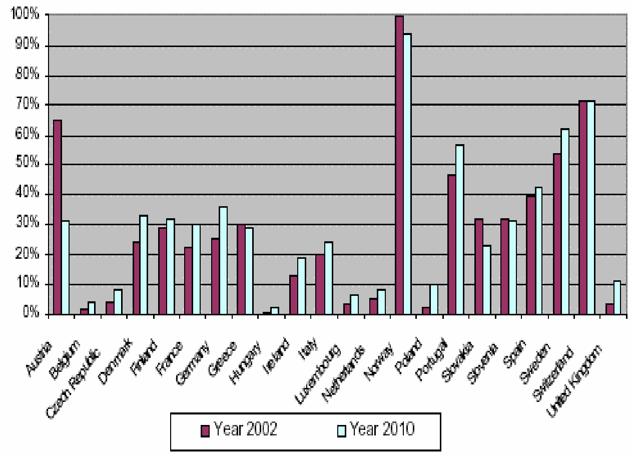

Figure D.3.- ETSO data about the DG-RES capacity

However, the present plans to install DG-RES are concentrated in the off-shore and on-shore wind power potential. The exploitation of the wind energy is now expected to be the main driver for reaching the targeted RES development in the future.

Thus, countries such as Denmark or Germany are promoting the wind energy installation. Germany is planning to increase its wind capacity from around 13 GW wind capacity installed mid of 2003 to an expectation near to 30 GW in 2010. The Danish Government is also promoting the wind energy with plans to install 4GW off-shore and 1.5GW on-shore before the year 2030.

Impacts of DG insertion

The DG impacts on the EPS may be classified in two different groups: impacts on the distribution system and impacts on the transmission system.

In one hand, the main impacts that DG could cause on the distribution system are the next ones [5], [6]:

- Impacts on the energy direction: traditionally the EPS was designed for an up-bottom energy flow but the DG implies a bottom-up energy flow. Thus, it is possible that the energy is injected into the sub-transmission and transmission systems

- Impacts on the protections (setting points, selectivity and bad operation of protection): the short-circuit current could be increased by the DG insertion (mainly by synchronous generators) and so the protection schemes should be reviewed to avoid bad operations.

- Impacts on voltage profile: DG increases the voltage in the connection bus and in the buses around the DG connection. Furthermore, fast changes in the voltage level are caused by the DGs flicker effect.

- Impacts on stability: the insertion of synchronous generators could cause power oscillations in case of fault; power exchange between different distribution networks could be created by these oscillations.

- Impacts on power quality (harmonics, sags, surges and deeps): some DG sources need power electronic interfaces to be connected; these inject harmonics in the grid and can provoke unacceptable voltage distortions.

- Impacts on the planning, exploitation and observability of distribution networks: the distribution networks were not designed to insert the DG in a high amount. So, it is probable that some changes will be taken place in its exploitation and observability [7], [8], [9]. The DG should be controlled by the utilities and DSO (Distribution System Operators) what it will mean an increase of SCADA data. It is also possible that the traditional radial architecture will be changed into a meshed one in order to take advantage of the energy generation close to the consumption.

- Economic impact on the energy markets: associations and agreements of DG producers to propose bids in energy markets (day before, 15 min before or ancillary services markets).

On the other hand, the main problems that a large amount of DG insertion could cause to the transmission system deal with prevision of reserves, operation in real-time and emergency strategies. The main impacts of a high amount on the transmission system can be summarized as follows:

- Change of the primary reserve margins in order to avoid the intermittence problems: the dispatching of the system should be flexible in order to accommodate the system to a production lack or an overproduction. The intermittence implies a flexible control in the system (active and reactive power reserves, transmission lines capability to change the load flow) to avoid alert or emergency states.

- Risk of congestion in specific areas where hydro plant leads to periodical overflow in HV loop lines, in general during the spring. The design of lines is optimized for this purpose and an added important wind power in the same area brings heavy technical power flow constraints.

- Change of real-time exploitation margins: the companies usually compute the secondary reserve by the next 15 minutes load variation. The errors in the forecast of the intermittent energy are somewhere a variation of the expected power in the system. So, the secondary and tertiary reserves should take into account the incertitude in weather forecast.

- Change of the real-time exploitation strategies: the DG energy is usually used as a based energy producing at the maximal output point (wind and solar). Other types of energy should be used to follow the load. Governments help the RES producers paying the difference between the normal price and the surplus cost of the RES energies. In some countries, the clean energy is always bought by law because it is seen as ecologic-friendly energy.

- Apparition of unexpected reactive power flows in the transmission system. The DG production close to the load reduces the losses and the flow of energy in the transmission lines. If the power in a line decreased down to the line natural power, the capacitors of the line pi model inject reactive power in the system. That makes that the generators compensate reactive power and they absorb it. The reactive power absorbed by the generators is limited according to the generator stability and rotor current criteria.

- The interconnection of the national systems makes that the countries are involved in the events on other countries. Special attention will be given to the wind energy projects.

- The apparition of a high amount of DG and so a high percentage of the total produced power, could provoke the closing of centralised power plants. The reduction of Greenhouse gas emissions and other environmental measures favoured the closing of old thermal power plants and fuel-oil plants. The new clean energies are a solution to substitute the most polluting plants to other cleaner sources and avoid international sanctions and fines.

  Centralised power stations do not operate below a defined percentage of the nominal power [10], [11]. The nuclear power plants do not operate below the 20% of nominal power, these nuclear power plants have problems of fast regulation and they usually produce around the 90% of Sn, they propose bids of energy at a very low price in order to not change the output. The minimal output power of the thermal units varies from 20% to 40% of Sn. The change of the production parks will be gradual because of the high investments done to build thermal or nuclear plants. So, the renewal process will take some time coinciding with the expected life duration of power plants.

Influence of DG insertion during major events

The DG insertion in a network could have some influences during disturbances:

- After a short-circuit: In some Spanish studies about the Wind Energy integration [12], it is shown how a short-circuit in the transmission grid could cause a voltage dip, this voltage dip could be propagated through the grid and reach the wind farms. Two events can happen during and after the short-circuit: in one hand, the acceleration could active the over-speed protection (1.15 pu threshold), in other hand the undervoltage generator protection (0.85 pu threshold) could disconnect the generator from the grid. The delay time of this protection is a critical parameter because an instantaneous operation could lead the system to the disconnection of the 3650 MW wind generation in the north-east part of Spain (from Galicia to Navarra and Aragon).

- In case of major disturbances: the DG disconnection protection is a critical component. It blocks the potential support of DG in case of major disturbances, and on the contrary, the system has to deal with added missing produced power. In consequence, the critical frequency point could not be any more the 47 Hz (normal disconnection frequency of centralised power plants). Instead, 49 Hz should be considered, this would imply a change in the strategy in emergency (amount of load shedding and reserves). The steps of reserves and load shedding are normally considered to give the possibility to recover the system before a complete blackout, but if the system shut down irreversibly from 49 Hz, the load shedding below 49 Hz is not very useful. The new questions would be addressed to the optimal reserves and load shedding levels and amounts with a possible critical point in 49 Hz for the system operation.

Appropriate amount and Limits of DG insertion

The appropriate amount of DG insertion in a country should be established by different points of view. First at all, the possibilities of the country: solar, hydro and wind potential. So, the expected DG integration depends on the characteristics of the country. The same could be said for the CHP technology, the heat distribution needs are different from a country to other. This first parameter befits the natural (cheap carbon, weather conditions, hydro reserves…) and social (acceptance degree of nuclear power, availability to pay a cleaner energy at a higher price…) characteristics of the country [13], [14].

The second parameter that limits the DG integration is the strengthening network costs. This is remarkable in MV and HV, notably by congestions on the sub-transmission and distribution systems. The construction of new lines to avoid local bottlenecks is expensive and it could block and delay the DG connection.

The third parameter to define an appropriate amount is taken into account technical criteria [15]:

- Static security: technical limits of the system (max line currents, voltage, powers in lines, transformers and generators).

- Dynamic security: that is a variety of studies such as small-signal stability, transient stability, voltage stability, (n-1) criterion and reserves margins for the operation of a given network.

The small-signal stability study consists on a modal analysis of system eigenvalues. The eigenvalues are obtained from the state-space system matrix. The difficult point consists that this matrix depends on the type of generators and in its dispatched powers.

The transient stability study consists on the analysis of a group of contingencies in order to look for the critical clearing time (CCT) in which the system stands the contingencies. The CCT should be higher than the operation protection time.

The voltage stability study depends mostly in the configuration of the system, dispatching between the generators (P and Q), and the primary voltage control to establish the initial voltage profile. It analyses each static situation.

The reserves margins with a risk analysis consist on the definition of a reserve amount which determines different probable contingencies stand by the system. The amount of reserves limit DG integration because one expected contingency is the loss of all DG. In practice, several rules to establish the reserves in each country are recommended by TSO associations, then it is known that each TSO adds an extra amount of reserves to dispose a larger security margin. In fact, the TSOs work with contingencies or disturbances probability. A level of load shedding is enabled for the less probable ones [16]. This defines a risk level of the system, it is the same that they do after the day-ahead economic dispatch, they do not accept the economic dispatch in case of technical limit violations or unacceptable risk situation. Then they propose solutions to reduce the risk level even if the day dispatching is more expensive.

From this criterion point of view, the generators are classified in two types:

- With reserves capacity: hydro, nuclear, thermal, diesel, micro-turbines…

- Without reserves capacity: Wind energy and PV because they produce at the maximal output point.

The appropriate DG insertion would be established in the dispatching of the day taking into account the maximal risk accepted by the operator for the real-time system control. The lack of all DG insertion after a short-circuit represent a major event that the TSO should solve in real-time. If some DG could stand short-circuits the critical event for the system planning would be the lack of all the Wind and PV sources by extreme weather conditions.

Study case

This IDEA_CRISP_39buses network is an adaptation of the IEEE New England 39 buses system. The architecture of this IEEE network is mostly kept. However, the parameters of its different elements have been adapted to normal European data. So, the transmission system is considered at 400 kV and the generators (Gen 1 to Gen10) produce the energy at 20 kV. The installed power is 9085 MVA and it is shared in three different types of generators: 4 thermal units of 1000 MVA each one (GEN4, GEN6, GEN8 and GEN9), 3 nuclear units of 1080 MVA each one (GEN1, GEN2 and GEN3) and 3 hydro units of 615 MVA each one (GEN5, GEN7 and GEN10). The total consumption is 6141.6 MW/ 1470.9 MVar split in 18 loads. The load model associated with the consumption is the impedance model that is a square variation with the voltage. The generators regulations are of two types: a voltage regulation and a frequency regulation. The voltage regulator is the IEEE voltage regulation type A [17]. The frequency regulator is a torque regulation with a speed droop of 4% [18].

In order to carry out the studies about the appropriate amount of DG insertion, the study case is adapted with the insertion of a 63 kV sub-transmission loop and 2 real French 20 kV distribution networks (STN) and several distributed resources (DR) by means of equivalent synchronous machines injecting 100 MW in the transmission system to build different DG insertion cases: 10%, 20%, 30%,40%..

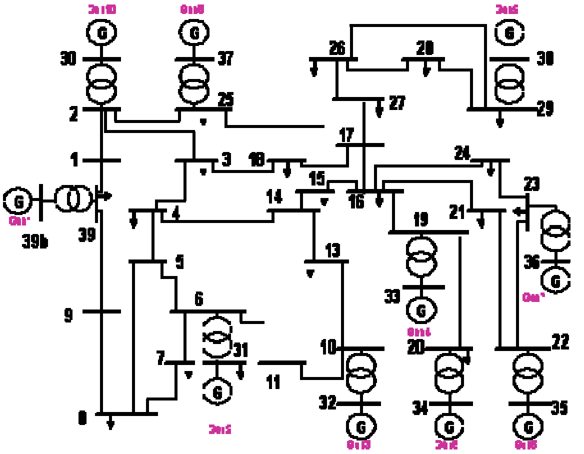

Figure D.4.- Study case architecture

In the two real French distribution networks (loads of 23 MW-13.2MVar and 25MW-12MVar), several asynchronous (5, in total 4.6MVA) and synchronous (13, in total 83.83 MVA) are placed and dispatched injecting 7.65 MW and 2.04 MW in the sub-transmission loop. A load shedding is disposed as well consisting in 4 steps and disconnecting the 15% of the load at 49, 48.5, 48 and 47.5 Hz.

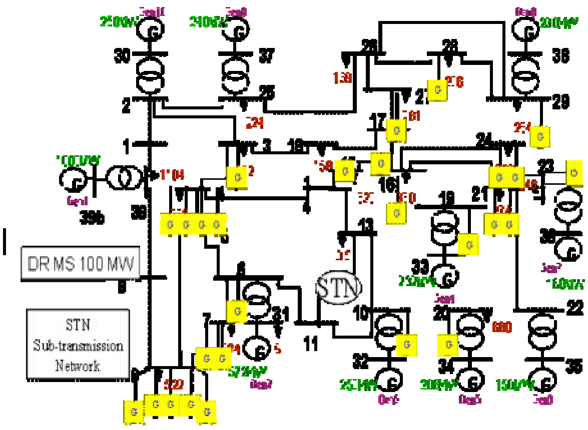

Figure D.5.- Study case architecture with DG penetration

a) Small-Signal Stability Study: the small-signal stability study is based on the analysis of the state-space system matrix. If some of its eigenvalues has a positive real part, the system is unstable. If all the real component of the eigenvalues are negative the system is stable at small-signal and so it can be stable when faced to major disturbances. The state-space matrix depends on the dispatching generation and on the type of generator. The state-space is composed by the differential equations of the generators; these equations vary with the nature of generator and its regulation. In the simulations that they were done, the insertion of 40 %DG implied the apparition of an unstable eigenvalue. The results changed with the dispatching of the generators. The case of 30% DG penetration will be used for the next simulation examples.

b) Voltage Stability Study: the DGs in the two real distribution networks were protected with protections (49.5 Hz and 0.85 Un). After a 100 ms fault in line 10-11, all the synchronous DG in the two networks are disconnected instantaneously by the undervoltage protection. In figure D.6, the system's frequency response is shown.

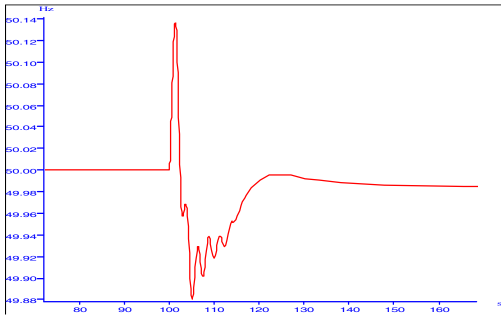

Figure D.6.- Frequency of the system after a 100 ms fault in line 11-10

c) Reserves Margins Study: the system should stand the lack of all the DG, thus the reserve margins (P and Q) should be changed in order to enable the normal operation of the system after this event.

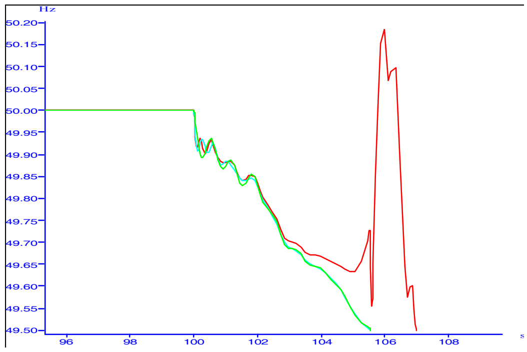

Figure D.7.- Several DG disconnections by the underfrequency criterion when faced to a loss of generation

If the system sees a generation loss of 600 MW, which could happen with a variation in the wind conditions, the synchronous-DG of the two real networks are disconnected by the 49.5 Hz protection (figure D.7). Nevertheless, the system is standing by the other generators. The settings of the under frequency protections vary for DGs from 49.5 Hz to 47.5 Hz and with different time delays (instantaneously, 500ms,…).

DG as a mean to increase system robustness

The use of DG could be spread to increase the EPS robustness. DG insertion could facilitate the apparition of self-healing areas in the distribution and transmission sub-systems. So, operators (TSO and/or DSO) could ensure the supply continuity, with the help of DG, in two strategies:

- Order intentional islanding to avoid the propagation of a disturbance.

- Utilize the DG black-start capacity to re-energize the system and then profit the islanding areas in the restoration process.

Conclusions

The article gives an overview of the different technical criteria which could limit the insertion of DG in a network. The appropriate amount of DG insertion depends on several parameters: DG dynamic behaviour, system reserve amounts and system characteristics. Some important conclusions should be noted such as the influence of the DG protection in the operation of the EPS.

The influence of the new DG leads TSOs to carry out some changes in order to take it into account. Otherwise, the DG could provoke catastrophic consequences such as blackouts. The main changes are related with the reserve margins that TSOs fix for real-time operation and the strategy in emergency operation. DG characteristics make that the system is not stand by it in case of disturbances. Nevertheless, DG could improve the robustness of the EPS with intentional islanding operation in distribution and transmission sub-systems. The intentional islanding could be ordered in two ways: before the propagation of the disturbances or after this propagation with the black-start capability of DG units.

References

[1] Amin.M "Security Challenges for the Electricity Infrastructure". Computer, Pages: 8-10, Volume: 35, Issue: 4, April 2002..

[2] David.A.Jones, Ronald.L,Skelton. "The next threat to grid reliability-Data Security". IEEE Spectrum, Pages: 46-48 , Volume: 36 , Issue: 6, June 1999.

[3] Rune Gustavsson et al. "Network security models and their economics", Deliverable D1.6 of ENK5-CT-2002-00673 CRISP-project.

[4] "Report on Renewable Energy Sources (RES)", ETSO report, Brussels, December 2003.

[5] J.F.Canard. "Impact de la génération d'Energie Dispersée dans les réseaux de distribution". INPG PhD Dissertation, December 2000.

[6] R.Caire. "Gestion et Strategies de conduite de la Production Decentralisee".INPG PhD Dissertation, April 2004.

[7] P.Bongrain, J.L.Fraise "Connection of Edf's remote control system to Dispersed Generation Units". CIRED. 16th International Conference and Exhibition on Electricity Distribution, 2001.

[8] Brent Brobak et al "Real Time Data Acquisition from Wind Farms in Power System". IEEE Power Engineering Society Summer Meeting, 2002. Volume: 1 , 21-25 July 2002 Pages:512 vol.1.

[9] Brent Brobak et al "SCADA Systems for Large Wind Farms: Grid integration and Market Requirements". IEEE Power Engineering Society Summer Meeting, 2001.Volume: 1 , 15-19 July 2001.Pages:20 – 21,vol.1.

[10] NORDEL Report 2002-00213-01-E, "Operational Performance Specifications for thermal Power Units larger than 100 MW", 1995

[11] NORDEL Report 2002-00214-01-E, "Operational Performance Specifications for small thermal Power Units", 1995

[12] Juan. M.Rodriguez et al, "Incidence on Power System Dynamics of High Penetration of Fixed Speed and doubly Fed Wind Energy Systems: Study of the Spanish Case". IEEE Transactions on Power Systems, Vol.17, No.4, November 2002.

[13] Rapport final de la Commission Ampere, October 2000. http://mineco.fgov.be/energy/ampere_commission/ampere_commission_fr.htm.

[14] Crappe, Michel et al, "Stabilite et sauvegarde des reseaux electriques".Ed.Lavoisier. Paris, 2003

[15] M.Fontela et al, "Distributed Generation as a means to increase system robustness", deliverable D1.3 of ENK5-CT-2002-00673 CRISP-Project.

[16] RTE "Memento de la Surete du Syteme Electrique", Ed.2002

[17] Paul.M.Anderson and A.A.Fouad, "Power System Control and Stability". The Iowa State University Press, 1977.

[18] Prabha Kundur, "Power System Stability and Control". Ed.McGraw-Hill, 1994.

Annexe E: Article CRIS 2004 about the ICTs overview

This article has been proposed for publication in the CRIS 2004 Conference with the next title: «Overview of ICT components and its application in Electric Power systems »

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Introduction

The recent deregulation of the electric power system has facilitated the apparition of new actors (producers, market agents…) and the split of the old national entities, which controlled the different parts of the system (generation, transmission and distribution), in new companies and operators that are responsible of the system operation.

Thus, the system is changing day by day in a metamorphosis process with the integration of the new elements. The network and market management represents a complicated task which needs the acquisition, communication, share of data for equal terms for market competitors and analysis of information. These information and communication requirements of the EPS (Electric Power System), under different states are described in detail in the paper.

The traditional EPS communication system was slightly adapted to accomplish the new required functions. This traditional EPS communication system is detailed as well in the article.

New developments in ICT components can improve the system but an adaptation of the EPS communication system is necessary to response to the traditional and innovative communication requirements. The recent terrorist plans and attacks (11-S and 11-M) have emphasized the concept of the EPS as a critical infrastructure for the normal life of a country. So, the new ICTs into EPS must be gone with a high security of the associated communication media and data integrity.

The paper analyses some practical uses of the new ICTs networks, which could appear in the tomorrow's system. The works included in the article are integrated in the CRISP[2] project and in the EURODOC program (PhD mobility) of the French Rhone-Alpes Region.

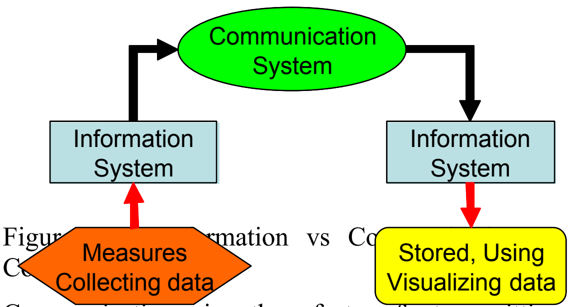
[2] ***CRISP: Distributed Intelligence in Critical Infrastructures for Sustainable Power.*** Project funded by the European Community under the Fifth RTD Framework Programme (2002-2005). Project Co-ordinator: ECN. Partners: ABB, BTH, IDEA, ECN, ENECO, EnerSearch and Sydkraft. Contract No. ENK5-CT-2002-00673.

ICT definition

Information and Communication Technology can be defined as:

The technology involved acquiring, storing, processing and distributing information by electronics means (including radio, television, telephone, and computers).

Three processes are involved inside the ICT definition: information acquisition, communication of the information between different entities and information computerization (it includes information analysis, storing and visualization).



Figur… mation vs C… C…

Communication is the fact of transmitting information between two or more points/agents of the system. The information and communication processes are related very closely. The information system is responsible of obtaining or measuring the parameters/variables that the systems need to control for a normal operation. So, at this step the information exists and can be transmitted from this point of measure to other points of the system for further utilization.

The communication system is responsible of this transmission and different communication media are used to transfer the information. The information transformed into different signals (analog or digital) is transmitted by the communication media to different centers where these signals are converted into other formats (data formats exploitable by the centers) and finally the communication process is finished when these data (information) are stored

The computerization consists in the use of the information or data in order to analyze the system or to establish a help for taking conclusions and so elaborating decisions. The computerization can be carried out there where there is the information (with or without communication between two entities because a same entity can obtain the information and computerized it). This computerization system refers mainly to the different computer tools and operating systems that can be applied in a computer, PLC or Control unit.

Current communication media in EPS

The use of communication media in SCADA (Supervisory Control and Data Acquisition) systems or EMS (Energy Management Systems) for EPS depends on different factors such as the nature of the media, possibility of interference or electromagnetic distortion, investment cost for installation or the requirement of special licenses. For example, the use of wireless media is not adequate for substations communications because the electromagnetic distortion that can appear especially during faults.

Figure E.2.- Some Standards of Electric Power System Communication

The International Standard Associations like IEC or IEEE have been working to establish standards and recommended practice for the communication between different agents and for different tasks in EPS (market, substation automation, communications inside SCADA…) [1]. In figure E.2, some standards of EPS communications are sited.

The main component of the EPS communication system is the SCADA system. Basically, it is the architecture to acquire, store and process the parameters needed to control the system. The SCADA of TSOs or utilities is normally composed of several types of communication systems such as [2]:

- Fixed networks including public switched telephone and data networks
- Wireless networks including cellular telephones and wireless ATM (Asynchronous Transfer Mode), radio systems, microwave (radio signals operating n the 150 MHz to 20 GHz frequency range)
- Power line carrier is the most commonly used communication media for protection function. However, this medium does not offer a reliable solution for wide area data transmission. Communication with remote sites can not be maintained during a disturbance.
- Computer networks including various dedicated LANs, WANs, and the Internet.
- The satellite network is another segment of the communications system that can provide important services which are difficult to carry out with normal communication techniques. These services include detailed earth imaging, remote monitoring of dispersed locations and time synchronization using signal from GPS (Global Positioning System).

The delays or latencies and data rate of such communication media differ from a system to another. In table E.1, a comparison is carried out in the case of wide area measurement networks [3]:

Communication link	**Associated delay-one way (milliseconds)**
Fiber-optic cables	100-150
Digital microwave links	100-150
Power line (PLC)	150-350
Telephone lines	200-300
Satellite link	500-700

Table.E.1.-Communication delays of some communication in wide area measurement networks

The different data rate of the currently media used in the power system are compared in Table E.2 [4]:

Transmission media	**Data Rate**
T1	1Mbps. Effective bandwidth considering network traffic, data collision etc is 125 kbps
Frame Relay	280 kbps
ISDN	140 kbps

T1 fractional	62.5 kbps
56k leased line	565 kbps (effective bandwidth lower than this)
Internet	Effective rate 40 kbps depends on network traffic
Radio frequency	9.6 kbps
Power line carrier	1.2 kbps

Table.E.2.-Data rate of currently media used in the power system

SCADA usually processes discrete and continuous information coming from measurements done in the field for the normal operation of the EPS [5]:

- Measurements: active and reactive power flows, bus voltages and network frequencies, for transmission networks at 2 or 4 seconds periodic update and for sub-transmission network at 20 seconds periodic update.
- Signals: breaker positions with max. 1s delay, tap changer and isolator positions with max. 4 s delay
- Chronological registration of events, consisting in changes of status of protection systems, as well as switching and regulating devices, coming from each transmission bus and incident branches. Binary information associated to the component operating configuration is locally refreshed in terms of milliseconds.
- Analog registration of significant quantities in instantaneous form (sampling time about 1 ms) or in RMS form (sampling time of about 100ms), including a subset of logical quantities to recognise protection system interventions.

The operation of SCADA is split in several hierarchical levels:

- Level 1 is composed by the local points which pick up the information at the substations and generators by means of IEDs (Intelligent Electronic Devices) or PMUs (Phase Measurement Units). The substation of level 1 can be controlled from the bigger substations of level 2.
- Level 2 is composed by big substations and this level represents a collection of data from different points in the distribution system (they are normally called RTU, remote terminal units)
- Level 3 corresponds to the regional control centers. They have the mission of control the voltage at the distribution (20kV), sub-transmission (90 kV, 63 kV) and transmission system (only 225kV). They do some functions of back-up of the level 4 as well.
- Level 4 is the main national center that has information of everything in the system and control the system as a whole through the transmission network (400 kV). One of its most important functions is the interconnection with other countries and so the frequency control in the system and the voltage control of the 400 kV.

The links between the different hierarchical levels in the French system are as follows [6]:

- Level 1-Level 2: The speed of these links is low. Transmission always takes place by asynchronous transfer mode (ATM). It uses telephone lines, power line carriers or radio links.
- Level 1-Level 3: A few direct links exist between level 1 and level 3, especially for remote controlled gas turbines or pumping hydro plants with the same characteristics as previous mentioned.
- Level 2-Level 3: The speed depends upon the size of the level 2 (data accumulators or collecting centers), with synchronous or asynchronous modes. It uses rented telephone lines or power line carriers.
- Level 3-Level 4: This part is a packet switch data transmission system. It uses telephone wire of superior quality with a very low probability of loss or error (10^{-9}). It links the computers of the regional centers with the national center computers.
- Level 4-Foreign countries: This is a link between the different national control centers of a country with its neighbour's countries. They have dedicated communication, and it is normally used the telephone connection.

Different studies are allowed by the SCADA data collection such as: state estimation, load frequency control (LFC), security dispatch, security and contingency analysis.

Figure E.3.- Computer analysis of SCADA data

Protocols are the language that allows the communication between the different devices presents in the system. Different protocols can be sited: ICCP, TCP/IP, Modbus, Profibus, LON, UCA by EPRI... There are a wide variety of protocols because every device manufacturer usually uses its own protocol. The variety of protocols can be solved by means of the gateways, protocol converters or translators.

Application area	Protocol
IED to RTU	DNP3, EPRI UCA2, Modbus,
RTU to Utility SCADA	DNP, DNP3,ELCOM90, IEC-870-5
Utility SCADAs to TSO SCADA	ICCP, ELCOM90
TSO SCADA to TSO SCADA	ICCP

Table E.3.- Some protocol examples in Electric Power System Communication

The choice of the protocol depends on different parameters [7]:

- System area, RTU to IED, RTU to master SCADA, SCADA utility to SCADA TSO, SCADA national TSO to SCADA national TSO center…
- Time to develop the installation

ICT components requirements of EPS

The communication requirements of EPS correspond to the different tasks that EPS realize to control the the system under normal, emergency or restoration operations.

In normal operation. The different tasks of the power system have different amount of data to be transmitted, that is the bandwidth needs for each task are different and with a current time response related to the nature of the task. Some tasks like the monitoring of the system are carried out in a real time operation. Others are not critical for the normal operation and real time operation is not necessary, such as metering or data statistics and store.

Power System Task	Bandwidth requirement	Current response time
Load shedding(local decision)	Low	Seconds
Adaptive Relaying (i.e. Blocking relaying)	Low	Not available
Hierarchical Data Acquisition and Transfer	High	Seconds
Line/ Bus reconfiguration	Low	Minutes (by manual)
Control devices (e.g. FACTS, Transformer)	Medium	Seconds (by manual
Fault Event Recorder Information	Medium	Minutes
Generator Control	Low	Seconds
National Strategic Power Defense Plan	High	Not applicable

Table.E.4.-Bandwidth requirements and response time for different power system tasks

Table E.4 introduces the requirements of bandwidth and time response of some significant actions [8].

In emergency operation. The emergency situations in the EPS correspond to violations of the current security criteria. These emergency situations can be classified from two points of view**:** the electric point of view in one hand and the communication point of view in other hand.

The electric point of view deals with pre-black-out events and extremely critical operation of the EPS. The result of such events depends on its duration, automatic consequences and the disturbance nature. Information must be shared and given to the different actors in order to optimize its operation and be prepared to major disturbances. Thus, the coordination of SCADA upper levels is one of the main actions to avoid the propagation of blackouts. If the entities could have enough time to react, the disturbance propagation can be completely or partially stopped. Otherwise, the system shut down and then the restoration procedure will be started.

The communications point of view refers to the loss of communications, wrong operations of software (data verification, unavailable alarms…) and intrusion of external agents. The loss of a communication in the EPS should not provoke a variation or high influence in the operation of the system as a result of the (n-1) criteria. It is why, it exists a redundancy in the communication links to ensure the information transmission in emergency situations and some dedicated links are reserved only for emergency operation. E.g. SCADA system contains back-up control centers (national and regional) which guarantee the operation in case of loss of the main control center.

In Restoration operation. The restoration of supply after a major disturbance is a heavy task due to the different parameters involving the event: determination of damaged network, existing communication links, generation capacity, available black-start capability, and coordination of control centers…The most important communications during this operation are the next ones:

- Communication for the detection of undamaged parts in the network.
- Detection, synchronization and interconnection of existing autonomous sub-areas
- Communication between re-energized areas to the utility or DSO, between utilities, customers and TSOs.
- Emergency communication facilities in case of loss of main and back-up links.

Basis for an ICT network

The ICT networks are a mean to establish the transmission of information communication between nodes on the electrical power grid. These nodes can be substations, relays, control devices or other equipment that collect information, or should be controllable from remote. The standard TCP/IP protocol is used on the Internet and essentially all private networks, Intranets. By using the TCP/IP protocols, a variety of different underlying link level protocols are enabled, such as Ethernet for the local communication within a substation, different type of fibre for fast long distance communications, and even dial up communications to remote locations.

These ICT networks based on TCP/IP could have a special interest in the utilities environment. The different tasks that the utilities are supposed to carry out could be done through the TCP/IP networks, e.g. protections using communications, telecontrol of generators and system coordination when faced to disturbances. The EPS requirements are addressed to the correct reception of messages and in the required latencies (the protection system communication requirements are the fastest because its typical response time and with the highest requirement in bit errors)

When building an ICT network, many lower-level communication problems are handled by the protocols. E.g. Bit errors that may occur during transmission are handled by the link level protocol, such as Ethernet, or by the IP protocol. The cost of this automatic error correction, and other features offered by the communication protocols, is that it is not possible to guarantee the maximum time it will take to deliver a piece of data from one node to another. Smaller transmission errors or small overloads of the communication channel are handled transparently by the communication protocols resulting in longer transmission times for the data transmitted.

The automatic error handling in the communication protocols is useful when connecting devices active on the electrical power grid to an ICT network, but the non-deterministic transmission times and occasional loss of transmitted data is an issue when transferring critical data over the information network. In addition, by default there is no prioritizing of traffic, so critical control messages have the same priority as arbitrary log messages and should traffic congestion occur either message has the same risk of being dropped by the network for later retransmission.

The messages in EPS do not have the same priority, thus the response time depends on the tasks as it was mentioned in the table E.4. From the ICT point of view, there are a number of techniques for prioritizing different network traffic, typically based on which node sent the message or the message destination. It is also possible to prioritize traffic of higher-level properties such as TCP and UDP port numbers. As these prioritization criterions are rather coarse, it is likely that a high level of cooperation from the different nodes and applications is required to make a good prioritization of network traffic.

ICT networks as a tool to enhance EPS coordination

The mentioned ICT infrastructure can enable coordinated control of the power grids. Coordination of System Protection Systems (SPS) is one application area that has been raised as an interesting research area. Coordination of the components in the ICT network can be handled by a coordination middleware, a layer within the application layer in the ISO-OSI model. This enables an analysis of the coordination criteria in the context of the full system instead of just for a single application [9], and as it is the case in the power grids, the coordination criteria of an application changes along with the state of the system.

Traditional coordination research is focused on techniques for coordination given a specific context. Some fundamental research in this area is models and middleware for coordination of control-oriented tasks [10] which supports low latency coordination with weak robustness, and blackboard-oriented tasks [11] which are more robust at the cost of higher latency. However, the power network isn't controlled by technology alone. Consequently, coordination models that account for human agents [12] are of interest.

As it is known, the power grid will evolve at a faster pace in the future; as distributed generators are added, command and control of facilities is changed when businesses are sold, and when Grid- and Business- Operations software is updated, just to name a few scenarios. Different operators may have different incentives and priorities to invest in different parts of their networks – for economical and political reasons. Consequently, the networks will become heterogeneous and it is necessary to plan the issue from the start so that the heterogeneity is an enabling and not a disabling factor. An operator should be able to upgrade its system without requiring that all operators in the system implement the same upgrade.

No single coordination technique can account for the diverse requirements of the power grid. Several factors, such as the real-time requirements, prevent the coordination layer from enforcing a common base model. Instead, the best suitable coordination technique for the task at hand should be used. To that end, meta-coordination could be a tool [13].

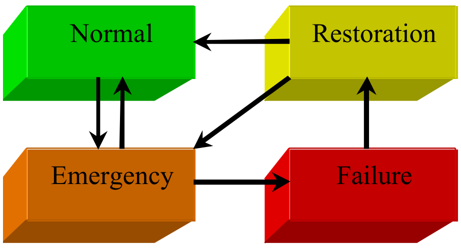


Figure E.4.- State based coordination

The state of the power grid affects which information is needed where and what actions should be coordinated. The main phases are normal operation, emergency (e.g. the loss of a line), failure (blackout), and restoration, as depicted in figure E.4. The coordination requirements differ between these states, in that normal operation is focused on coordinating wide-area measurement data, emergency operations need quick reactions (e.g. load shedding), in failure the network may be incommunicable, and in restoration wide area consensus and planning is needed so that the system can safely be brought back into normal operation.

Conclusions

The paper analyses the current ICT uses in EPS. The introduction of new ICT network could enhance the EPS operation, notably when faced to major disturbances. These new ICT networks could represent valuable tools in the system for utilities, TSOs and DSOs to acquire information, communicate it for further utilisation (computerization, analysis…) in order to improve the coordination in the EPS and avoid resulting blackouts.

In this article we propose the use of an ICT network based on the TCP/IP, which is a wide-spread protocol on the Internet, and Intranets, worldwide. The use of TCP/IP avoids the problems of the variety of protocols. However, the latencies depend on the ICT network and some tasks such as protection are very sensitive to the messages time propagation and bit errors and so, higher requirements are needed in the routing of its messages. So, special ICT methods should be considered for the different messages in the EPS in order to guarantee the QoS (Quality of Service) required by EPS tasks.

References

[1] CIGRE B5.11, "The automation of new and existing substations: why and how". Draft. August 2003.

[2] Donald.G. Fink and H.Wayne Beaty, "Standard Handbook for Electrical Engineers". Section 10, Supervisory Control and Data Acquisition, pp-10-147 to 10-168. Ed.Mc-Graw Hill, 2000.

[3] Biju Naduvathuparambil et al, "Communication Delays in Wide Area Measurement Systems", Proceedings of the Thirty-Fourth Southeastern Symposium on System Theory, 18-19 March 2002, Pages: 118 - 122

[4] Bin Qiu, "Next Generation Information Communication Infrastructure and Case Studies for Future Power Systems" Ph.D dissertation Virginia Tech, April 2002.

[5]: Project ExAMINE, http://www.examine.ree.es

[6]: Carpentier.J "The French National Control Center ". IEEE on Power Systems, Vol.PWRS-1,No.4, November 1986.

[7] John McDonald "Managing the Data and choosing the right protocol", IEEE/PES Transmission and Distribution Conference and

Exposition, 2001, Pages:970 - 973 vol.2, 28 Oct.-2 Nov. 2001.

[8]Amin.M.,http://www.citris.berkeley.edu/defense/slides/Amin-Feb-04.PDF

[9] Janssens, N., Steegmans, E., Holvoet, T., Verbaeten, P., "An agent design method promoting separation between computation and coordination", Proceedings of the 2004 ACM sym-posium on Applied computing, 2004.

[10] Hsieh, C. S., Unger, E. A., "Manifolds: A very high-level conceptual framework of inter-process synchronization and communication", Proceedings of the 15th annual conference on Computer Science, pp196-204, ACM Press, 1987.

[11] Gelernter, D., "Generative communication in Linda", ACM Transactions on Programming Languages and Systems (TOPLAS), Volume 7, Issue 1, ACM Press, 1985.

[12] Wagner, T., Guralnik, V., Phelps, J., "A key-based coordination algorithm for dynamic readiness and repair service coordination", Proceedings of the second international joint conference on Autonomous agents and multiagent systems, 2003.

[13] Tornqvist, B., Gustavsson, R., "On adaptive aspect-oriented coordination for critical infrastructures", accepted for publication in WCAT04, June 2004.

Annexe F: Abstract for CIRED 2005 (Robusteness)

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Title: Limiting the DG Insertion: a deterministic criterion

Abstract: 212 words

“The deregulation of the energy market and the international agreements (European directives or Kyoto Protocol) facilitates the apparition of new producers and actors. The last ETSO (European Transmission System Operator) studies and the national plans for the RES (Renewable Energy Sources) insertion show large scale DG integration in the Electric Power System (EPS) for the next years.

The article will give an overview of the different impacts and the influence of DG (Distributed Generation) in the EPS operation. The influence of the new DG leads TSO (Transmission System Operators) to carry out some changes in order to take it into account. Otherwise, the DG could provoke catastrophic consequences such as blackouts.
The DG penetration will be commented from different technical points of view: small-signal stability, voltage stability, transient stability, DG protection setting values and security reserves margins.

A main change in the system control is related to the reserve margins that TSO keep for real-time operation and the strategy involved during emergency operations. Finally, the article proposes a deterministic criterion to be taken into account to evaluate the consequences of the insertion of different DG in the tomorrow’s network. This criterion is tested with EUROSTAG simulations of a 39 buses network adapted from the IEEE New England test case to European data”

Annexe G: Abstract for CIRED 2005 (Islanding operation)

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Title: New control strategies to prevent blackouts: islanding operation in distribution networks

Abstract: 266 words

“The recent blackouts in the transmission networks such as in Sweden, Italy and the USA have emphasized the problems of the electric system exploitation in real-time and the negative impacts of the major events such as the social and economical catastrophic consequences. On other hand, the electric system is being modified by the insertion of new distributed resources (DR) at the sub-transmission and distribution levels. The new DR reduces the traditional dependency of the distribution networks from the transmission system.

The article introduces a new control strategy to face of major disturbances. This strategy is based on the creation of intentional islands cells, including adequate DR, in the HV and MV levels. New concepts must be introduced to enable such strategy changing the traditional structure and exploitation of the distribution networks deeply. This ability to supply some cells in the network makes possible to change the strategy of restoration the whole system, a trend being to boost the process.

The availability of the intentional islanding operation is studied with a proposed methodology. This methodology consists on the evaluation of different technical criteria such as: regulation and control aspects, small-signal stability, transient stability, contingencies analysis, load shedding, power balance strategies and protection system changes.

Finally, the mentioned methodology is applied to a real French distribution network. The main conclusions obtained from the study case are commented. The use of the proposed methodology by utilities or distribution network operators would require the introduction of new ICT (Information and Communication Technologies) components. The needed ICT components are described and placed in a utility communication architecture based on IP networks”.