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

Distributed Network Architectures
D1.7

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Table of Contents

List of Figures

List of Tables

References

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Acronyms and Abbreviations

Acronym	Means
ACE	Area control error
ACL	Agent Communication Langage
AGC	Automatic generation control
API	Application programming Interfaces
APX	Amsterdam Power eXchange
ATC	Available transfer capability
BA	Balancing authority
BO	Business Operations
BUSMOD	Business Modelling in a world of distributed generation
B2B	Business to Business
CBM	Capability benefit margin
CDI	Constrained Data Items
CHP	Combined Heat Power
CIM	Common Information Model
COP	Coefficient Of Performance
CPS	Control performance standard
CPU	Central Processing Unit
CRISP	Distributed Intelligence in CRitical Infrastructures for Sustainable Power
DCLM	Direct control load management
DCS	Disturbance control standard
DEGS	Directions EDF GDF Service, main French DNO
DG	Distributed Generation
DG	Dispersed Generation
DG-RES	Distributed generation based on renewable energy systems
DMS	Distribution Management System
DSM	Demand-side management
DNO	Distribution Network Operator
DNS	Domain Name Server
DoS	Denial of Service (security study)
DR	Distributed Resources
DSM	Demand Side Management
EMS	Energy Management System
EPS	Electric Power System
FCI	Faulted Circuit Indicator
FDD	Fault Detection and Diagnostics
FPI	Fault Passage Indicator
GIG	Global Information Grid
GPS	Global Positioning System
GW	Gateway
HF	High Frequency
HV	High Voltage
HVAC	Heating Ventilation and Air Conditioning
HVDC	High Voltage Direct Current
ICT	Information and Communication Technology
IED	Intelligent Electronic Devices
IEEE	Institute of Electrotechnical and Electronics Engineers
IEC	International engineering consortium
IP	Internet Protocol
IPP	Independant power producer
IROL	Interconnection reliability operating limit
IVP	Integrity Validation Procedures

LAN	Local Area Networks
LN	Logical node
LPS	Lightweight Privilege Separation
LV	Low Voltage
LSVPP	Large scale virtual power plant
MAS	Multi Agent Systems
MOM	Means, Opportunity and Motif
MV	Medium Voltage
NBW	Network-Based Warfare
NRU	No Read Up
NWD	No Write Down
OASIS	Open access same time information service
OATT	Open access transmission tariff
OLTC	On Load Tap Changer
OSGi	Open Software Gateway initiative
PAM	Pulse Amplitude Modulation
PCC	Point of Common Coupling
PLC	Power Line Carrier
PMU	Phasor Measurement Unit
PNO	Power Net Operations
POD	Point of delivery
POR	Point of receipt
PPP	Point-to-Point Protocol
PQ	Power Quality
PS	Power System
PSTN	Public Switched Telephone Network
PTP	Point to point transmission service
PV	Photovoltaic
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RCIS	Reliability coordinator information system
RAS	Remedial action scheme
RES	Renewable Energy Systems
RTE	Reseau de Transport de l'Electricite, French TSO
SCADA	Supervisory Control and Data Acquisition
SCL	Substation Configuration Langage
SDM	Supply and Demand Matching
SGAD	Smart Grid Automation Device
SO	Services Operations
SVC	Static Var Compensator
SVG	Static Var Generator
TBS	Time Based Security
TCBR	Thyristor Controlled Braking Resistor
TCP	Transport Control Protocol
TRM	Transmission reliability margin
TSO	Transmission System Operator
TTC	Total transfer capability
UDI	Unconstrained Data Items
UML	Unified Model Langage
UVLS	Under Voltage Load Shedding
VPP	Virtual power plant
WAN	Wide Area Networks

Summary

This document summarises a possible evolution of the merge of ICT network and EPS in the scope of a future electrical architecture. A general overview on several aspects of the transmission and the distribution networks (technical operation, trading, securing, defence plan) and on several aspects of ICT improvement and risks has been given in previous work packages of the part I of the CRISP project. This document brings a common point of view between the partners on this future merge of the various domains involved.

The approach is based on the study of given application based on chosen cases, trying then to show a more general view on the whole system. The MV network, including of course the main HV/MV substation, has a specific position in our purpose: historical, technical and trading boundary between the transmission and the distribution system, involving new functions in the context of a future massive and dispersed generation. The whole electrical system is not yet ready to work properly (supply performances maintained at the same level) with a lot of DG and DG-RES and at the same time with a new and complete electrical deregulated market.

The multiplication of actors (production, transmission, distribution, customers, local networks) led by the rules of deregulation is an additional issue for planning and operating correctly the network in the long term.

The interactions expected between the low level of the network (distribution EPS, VPP, customers, small aggregators) and the high level of the network (transmission EPS, large plants, LSVPP, large aggregators) require to structure the system in different integrated levels, allowing the operators at each stage to manage efficiently the power flux for steady-state, transients and temporary electrical variations. Compared with the present SCADA situation, the ICT will allow the needed information to be shared by various tools and actors at various locations, and will allow the local intelligence to be developed in depth. Hardware, software and communication protocols are converging nowadays for some EPS applications through numerous IEC and IEEE standards development.

Recent re-regulation of the power industry sector and the expected massive increase of the proportion of renewable energy generators will lead to an increased level of automation of lower nodes in the power network with increased market exposure.

During the last decade, numerous international projects target to standardize communication protocols and information exchanges between electrical products. The problem is not only to identify the right parameters, associated values and names, but also to meet the time frame requirements of the various applications needed. When dealing with real time operation (time response depending also of the given operating application), depending on the information nodes number and a lot of communication factors, the coherent development of a solution involves a “think-together” approach. Distributing and paralleling the analyses and data conversion allows the information system to meet the best time performance for a given application, enabling or not finally the real application in the EPS.

A future possible application is to make contribute the DG to specific power system support (parts of ancillary services traditionally defined for large plants connected to the transmission system).

1. Introduction

The electrical power system needs a great improvement in automation systems and information systems. Several additional effects lead to such a need: a general decrease of the technical margins caused by economical and ecological constraints, caused by a less increase of the production means faced to a regular increase of the consumption. The investment for projects of massive central production is difficult to launch in a context of general deregulation caused by the requirement of a higher competition in the electrical market. The last decade shows a great effort of the international community and industrial companies to develop more intensively DG and DG-RES. Their integration in the existing system asks for a lot of questions when they begin to contribute to a large amount of the energy consumed. The issue is at the same time local (at the scale of the distribution network) and global (at the scale of the transmission network). The traditional function of the distribution network, the size of these networks and the energy density locally supplied lead to develop the cheapest system as possible: the supervision and control of its components is very low compared with the transmission systems. The new position of these networks (massive and distributed production area) and the complexity rise due to the multiplication of actors (trading, producing, distributing and transmitting) lead to the rise of automation and information systems. Additionally more money will be spent in investments into power distribution than into additional transmission capacity. In this way, the information and communication technologies may bring a part of response to the questions.

A part of our approach deals with the ability of the distributed generation to increase the robustness of the electrical system when faced to a major disturbance or blackout. This objective is not only to reduce the risk of total black out (limiting the disturbance area or saving some specific area by intentional islanding) but also to allow a simpler and fast restoration, for instance by a better control of islanding for a variable scale of area.
In another way the purpose is to check by simulation and by experiment a proper operation of the system faced to possible events, taking into account the multiple aspects including the trading and distribution of the energy.

Another part of the CRISP-approach has to do with improving the market position of small-scale distributed generators and loads in pre-balancing their supply and demand in a bottom-up manner. In this document new types of coordination mechanisms are described that allow concerted operation of a large number of installations with minimal demands on inter-node communication facilities.

2. Glossary and definitions for EPS, ICT, market and CS

The following list gives common vocabulary used in the fields of electrical power system, of information and communication technologies and of computing science. Some similar terms are used by these fields but for different meanings: it is important to realize these differences to get as best as possible the information given by the experts and to avoid misunderstanding.
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.
(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
(c) concept of an algorithm ICT component able to achieve given functions and data transmissions, could be also consider as a node

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). The ancillary service may be associated to the system support service which is necessary in power system in order to face dynamical variations on production and demand.

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).

Application layer, CS. Part of the three-tiered architecture of today's ICT-applications. The application layer rests on the Middleware and the Physical layer and is the implementation of the requirement specifications. Examples of applications are a word processor or a load balancing application.

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

Architecture, EPS, ICT: in the context of the CRISP project, it is a combination of the electrical grid description and the ICT components associated to its planning and real time operation, market mechanism and ICT components associated to its organisation, and institutional entities.

Artifact, CS: Something artificial; 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 complete shutdown condition to an normal 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.

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.

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

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.

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

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.

Delay, EPS: For protection purpose, the time generally added in a relay system in order to meet coordination requirements or to avoid nuisance tripping.

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

Distribution Network Operator (DNO), EPS: Owner and/or operator of a, predominantly, local MV and LV network with or without DG

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.

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 transmission 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

Energy Management System (EMS): The ICT application managing energy balance in a network area. Operates by means of real-time control and programmed scheduling of controllable production and transmission facilities. The objective is to maintain real and reactive power balance with an optimal power price (regulated environment=cost).

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.

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

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, 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: part of and see "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 pose problem with protection detection (problem of safety and security).

Large scale virtual power plant, EPS: aggregation of VPP or of DER units dispersed widely among the network, controlled as a whole generating system.

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

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

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.

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.

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.

MiddleWare CS: A collection of software components supporting realisation of applications. The middleware rests upon the physical layer. An example of Middleware is the Microsoft .NET-framework.

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

Network, EPS: An electrical structure composed of conductors, transformers, and various electrical components allowing the generators and the loads to be interconnected.

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

Node, CS:
(a) concept or object representing an entity connected to other entities (see agent)
(b) a major point in a network where lies form 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 extrapolate in a N-2 criterion which means a right dynamical behaviour facing two important componens 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 interconnect (OSI) , CS: A seven layer data communications protocol model that specifies standard interfaces which all vendors can adapt to their own designs

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.

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

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

Physical layer, CS. The physical layer is the hardware and data-communication infrastructure needed for realising middleware components. Example of physical layers are the lower 3 levels of the OSI-model for data-communication.

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 discipline while they are connected to the network

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

Q, CS: Reactive load in the EPS. See also reactive power.

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

SCADA, SC: Supervisory Control and Data Acquisition. A collection of applications and middleware supporting online control and supervision of a power distribution system.

SDH. Synchronous Digital Hierarchy. An physical implementation of communication used in telecommunications.

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, ICT: entity of the electrical world that plays a role in a given EPS architecture. The definition of the future EPS architecture in the context of the market deregulation and of the massive insertion of DER needs to identify the expected stakeholders.

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.

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

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

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

Transmission System Operator (TSO), EPS: An entity operating a proportion of the transmission grid mostly consisting of EHV and UHV equipment and power lines.

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

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 form 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

Virtual Power Plant, EPS: aggregation of DER units dispersed among the network, but controlled as a whole generating system.

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 couls 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, peripехericals 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. A directory of billions of formatted text, graphics (stores in HTML) and multimedia-info that is at display to user a via a graphical user interface to the Internet.

3. Overview about EPS operation, market, security and ICT

3.1 EPS power and control view

3.1.1 Existing structure and future development expected

Existing EPS operation involves complex systems of automatically or manually controlled loops where these numerous systems have different time responses and are interlinked. The existing structure is highly centralized: the whole data are sent to a central point for decision. The communication involved is used for different kinds of applications and associated time responses: power demand studies, energy and power trading studies, marketing, planning and designing large plants or heavy installations, scheduling the daily or weekly or monthly production expectations, responding to real time technical constraints, and so on.
The exchange of information required in the EPS is generally bi-directional: need for remote supervision and control in the time required for the application.

The future link expected between the energy trading (real time tariffs) and the EPS operation is a new deal for the utilities, involving new constraints on the existing EPS information system: multiplication of information nodes, need of fast and easy adaptation for new inputs (new actors, new services, new systems), with the implicit constraint of maintaining at least the same level for the safety and security aspects, for the power quality and for the proprietary aspects. The technical time responses constraint being quite the same, the combination of real time wide area supervision and control, and the development of a very large information system lead to problems. Moreover security and dependability aspects lead to new kinds of dispersed intelligence in the future. The need of new kinds of architecture during the CRISP project leads us to have a more integrated view of the three main domains analysed: EPS power and control, EPS market and EPS information system.

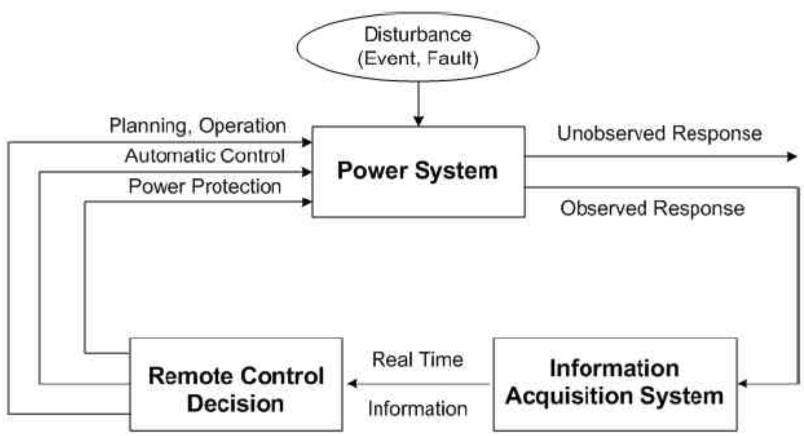


Figure 1: Existing simplified loop for EPS operation facing a disturbance

The EPS system cannot be a simple assembly of multiple local balances, the future EPS operation needs to reach a double target to maintain a correct technical operation and an interesting energy price level for the majority of the customers: global production and demand matching (view from the transmission system) and local defined control (checking power flow, ability to proper protection, ability to energy reconfiguration, ability to intentional islanding for instance).

The transmission system is already provided with a wide and complex information system, which has been developed gradually along the last decades. Up to now the monitoring and fast control of the distribution

network (MV and LV) is weak, except for the cases where the energy involved and the need of power quality supply are high (as in main cities as New York, Paris for instance).
For the transmission system the main question is how to manage the new potential constraints involved by a large insertion of distributed generation: connecting analyses and protections, planning adequately generation and spinning reserves, analysing correctly the real state of the network (to prevent the whole system from instability or cascading disturbances). In addition to the usual trend to improve the existing information system (planned for a long term), the recent evolution in transmission information system is mainly oriented towards admitting new actors in the day-to-day electricity market.

The existing real time monitored information system for the distribution EPS, is designed for protection and fast reaction to permanent faults. The monitored electrical parameters are, generally, currents and voltages in the substations (HV/MV level), the states of the circuit breakers, the states of feeder disconnectors and the states of some fault locators. The constraints of DG and local market actors will lead to a need for deeper monitoring of the network, ranging the public MV and LV.
An ongoing change is the remote tariff metering system, the frequency for reading of residential meters is low (typical manual energy measurement in a residential customer is nearly 6 months in France). Depending on the aim of the utility or the possible constraints due to the regulation, the frequency reading could be monthly, daily or even more frequent. One hurdle is the investment required equipping millions of customers, and the need of IS structures and programs to deal with the amount of information collected.

During an EPS emergency, possibly leading to a blackout, the distribution network associated to actions on HV on-load tap-changers transformers, may contribute substantially, to the system to recovery. The already available technical solution may be to regulate the secondary voltages (tap-changers of VHV/HV transformers or HV/MV transformers) in order to maintain or decrease current on the VHV lines. This limited solution may be extended by specific agent informed of the VHV frequency and magnitude, in real time. So the agent of the distribution network´s local cells may be informed of the emergency, and on an additional specific signal this agent may launch a second help state (because voltage is becoming too low locally) on its cell in order to limit the load (peak shaving, temporary load reduction, load shedding, feeder shedding).
When the EPS is returning from the emergency, the local agent can take action to return the local cell to its normal running state: a coordination (and so adequate communication) is necessary to avoid a new heavy inrush current caused by simultaneous reload in all the distribution cells.

When a blackout has occurred, a future restoration plan may include the deep-build-together technique: not only the transmission SCADA is restoring the system, but smaller or larger parts of transmission and distribution grid operation self-supplied. For this purpose many EMS applications must have been distributed in order to enable intentional islanding. The restoration process in the distribution cell is initiated by generators having black-start capability. A specific strategy needs to be implemented to connect cell by cell to neighbouring consumption and production sites. When a transmission-interconnected area is reconnected to the islanded cell, a synchronization sequence must be launched inside the cell in order to meet adequately the frequency, phase and magnitude of the adjacent voltage. The connection is then checked. This kind of fast reconnection is interesting for the system, enabling to exploit DG-RES also for EMS optimization strategies.

The future development expected for the distribution network technology could enable new DNO strategies. In Europe as in the US a main part of the distribution network is old and working at its electrical limits. The question today is how to invest taking into account the insertion of substantial DG capacity. A DNO might consider ICT investments as alternative or complement to more traditional equipment up-grade. A DNO operating local cells can attract DG investment by a combination of ICT capability and electrical capacity.

The local measurement and communication inside the distribution network is not a technical issue, different products are already available for various useful technical applications: for instance optimization of local EPS configuration adapted to load flow. The problem is more financial or market nature: the profit from the technical solution has to be high enough compared to the related investment. In some cases the profit takes into account avoided externalities, which are difficult to price, since it depends on the competitive climate or current energy regulation.

3.1.2 Need for specific fast control

The fast power control is a key point in the setting of the future network. A great question remaining is the required role of the DG and the DG-RES in contributing for this control. As explained in D1.1 and D1.3 of CRISP project, the EMS controlling centralized production connected to the transmission system plays has four major applications:

- allowing the EPS to reach a steady-state balance between active power produced and active power consumed (high influence on the ubiquitous voltage frequency),
- allowing the EPS to react to a dynamical variation of active power maintaining the frequency in a specific normal range by using primary reserve (then secondary and tertiary reserves),
- allowing the EPS to have a voltage level in any point within a specific normal range by using reactive power capability (absorbing or injecting this reactive power) during steady-state,
- allowing the EPS to react to a dynamical variation of voltage in nodes, maintaining these voltages within a specific normal range by using reactive power reserves.

An important point is to understand how the distributed generation may contribute on this fast power control. In the whole electrical Europe (network structured and observed by UCTE), all the generators equipped with primary frequency control contribute in a same relative effort to a frequency variation, without communication other than the frequency deviation. The synchronous working mode of the massive production is a kind of general message (frequency) sent to the whole network allowing a kind of local intelligence (unit control system) to change the associated production of a defined relative amount. The relative effort of each generator is given by the droop characteristic: this value gives the relative variation of active power produced to response a relative variation of observed local frequency. This deviation of frequency corresponds to a steady-state value when the frequency becomes stable. The control succeeds to find a new point of balance production/consumption following a first dynamical and oscillatory period. Then another sequence takes place with the secondary control, making the frequency moving slowly to the previous nominal value: this stage requires, in general, some kind of communication in order to coordinate the additional contribution (in plus or minus) of dedicated power plants.

As the frequency is the same in the whole interconnected network, in the transmission or in the distribution, the DG and DG-RES may contribute in the first role and the second role (dynamical capacity to recover an active power balance within the minute range). Nevertheless the second role is already an issue for the EMS: how sharing properly the needed fast contribution of all the producers, the machines being quite different in terms of internal parameters and inertia. The distinction between the first and second role (which is important feature for keeping a secure global control) is achieved by a large difference in the time response to a fast variation of frequency. Many questions remain:

- ➢ If a primary reserve is defined for DG and DG-RES, how much should be the amount of the reserve be, relative to the power of the generator (around 5% as for centralized generators?)? How should the control be defined, in terms of time response to a fast variation of frequency?
- ➢ If a secondary reserve is defined for DG and DG-RES, how should the the involved effort between the numerous generators distributed? How should the system collect information about the available secondary reserve? How should an additional equivalent tertiary reserve be coordinated in order to recover a sufficient local secondary reserve?

The voltage magnitude is linked to local exchanges of power: there is not a clear message (as in the case of the voltage frequency) commonly shared by all the generators giving the current global state. Furthermore there is a decoupling of the voltage levels through the transformers of the network: the voltage control needs a certain high level of coordination. The state-of-the-art solution is a part of the EMS called a state-estimator, which calculates the voltage profile throughout the interconnected area. The estimation is based on measurement of voltage in critical nodes and calculation of the estimated voltages in all other nodes. The main part of the voltage magnitude is regulated by centralized generators, which are connected to the interconnected transmission network. High currents in the transmission lines induce high reactive consumption, entailing at a point high reactive constraint in the large plants and a certain decrease of voltage in the transmission. The contribution of the DR to the voltage magnitude is double: contributing to a normal voltage amplitude at the point of connection in the distribution network by adequate active and reactive injection, contributing to a normal voltage amplitude among the associated HV/MV substations by relieving a part of the transmitted current (this second role as an effect by the accumulation of all the contributions of all the dispersed generators).

A new ICT system has to be defined for the development of this kind of system support (contribution to ancillary services normally assumed by the large plants of the system). Due to the multiplication of units and active possible actors, due to the required time response of the expected services, a more distributed ICT network is needed. The MV cell level 1 defined in D1.4 and D2.3 of the CRISP project has been viewed as an elementary electrical area (virtual utility) useful for coordination of fast local control and market responses. This can be viewed as an atomic EMS which acts as an agent by means of interconnection to neighbouring MV cells. This gives a coherent electrical area in term of stable and existing topology, which is useful to develop appropriate robust control and energy market transaction algorithms. The new ICT system must enable the virtual utility to act on the energy market and as a part of a DNO. The applications running on the new ICT system will be atomic EMS and SCADA applications, scaled down to the cell size and exploiting ICT advances to drive down costs to a level where the investment is profitable.

3.1.3 Concept of MV and LV cells

A concept of cells has been defined during the CRISP project. The historical and financial weight of the existing networks leads to assume that the physical topology of the distribution network is relatively stable. The deregulation and introduction of massive DG and DG-RES will change the operation of the distribution system in a more flexible way: reconfiguration caused by real time power flow needs, new kind of load shedding or load reconnection system or load shaving, contribution to frequency control and reactive local compensation.
The MV cell concept exists since a long time, already used at the beginning of electrification era. The difference today is the existing interconnected EPS which is the main supplier for the distribution networks. Nevertheless a level of distributed intelligence exists today in each HV/MV substation: for instance the protection system takes some local quick decision to open the circuit-breaker of the faulty feeder.

During the CRISP project, the concept of MV level 1 cell and MV level 2 cell has been discussed. The MV level 1 cell is composed of all the sections of feeder with a boundary in the substations at the sending-end CB location. The MV level 2 cell takes all the associated MV level 1 cells linked by the substations, the boundary being the HV/MV transformer of the substations (included). The following figure illustrates this MV level 1 cell. The level 2 cell includes several level 1 cells not represented in the draw: the boundaries of this level 2 are HV nodes interconnected by transmission lines.
The traditional emergency point, which is a EPS disconnector/sectionalizer, may change during the daily or weekly operation: the stable topology description in the MV level 1 cell enables fast response in order to face local disturbances. The remote control of EPS sectionalizers gives the structure of the local fast and remote controlled flexibility.

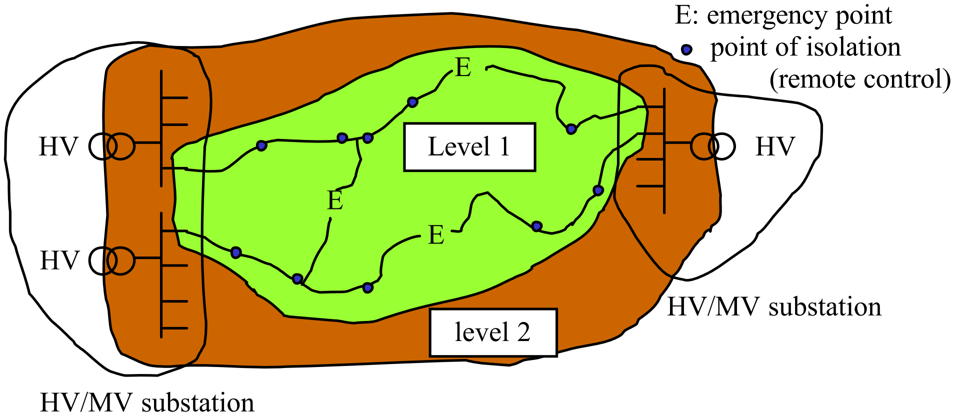


Figure 2: Simple illustration of the MV level 1 cell and level 2 cell

The main contribution to the short-circuit current comes from the interconnected network, even if the local distribution network includes enough capacity (DG and DG-RES) to supply the local demand. This situation comes from the existing impedance ratio between the various components of the network. So the concept of radial topology relative to the unique and clear path between the HV network and the loads remains a main electrical characteristic to keep in mind. The open loop operation in these radial networks means that there is no connection between sending-end feeders and no loop in the same feeder.

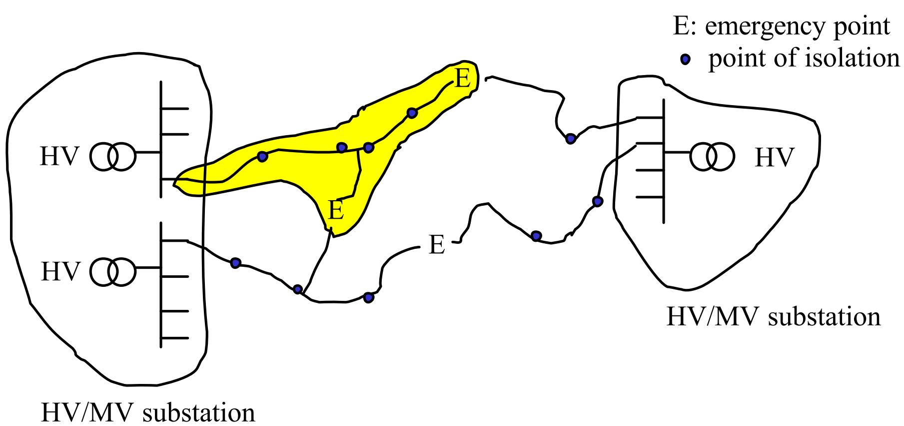


Figure 3: Radial operation of a part of the level 1 cell

The MV lines or cables have multiple distributed MV/LV transformers supplying public LV EPS as indicated in the following figure. The model could also meet this distribution of the loads.

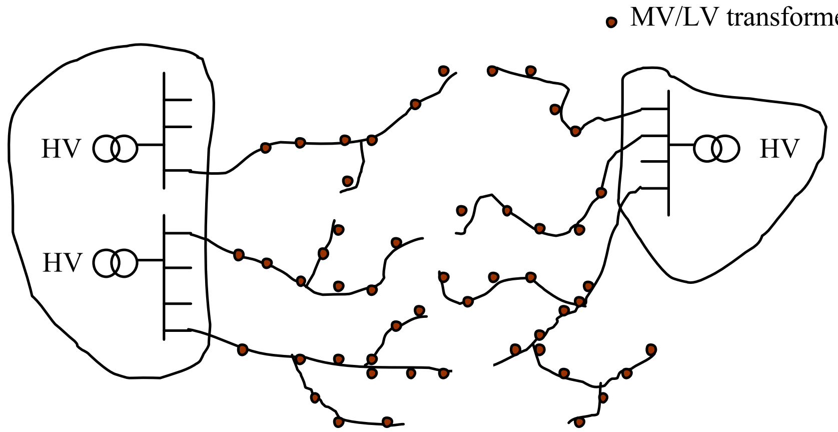


Figure 4: MV cell with multiple MV/LV points of delivery

This approach may be the same for interlinked LV EPS, a possible situation in a large city where heavy density of consumption leads the DNO to install also LV emergency loops. The same presentation may be used for a radial operated LV EPS as shown below.
In case of a rural LV network, the simple approach of a radial topology without possible reconfiguration is sufficient.

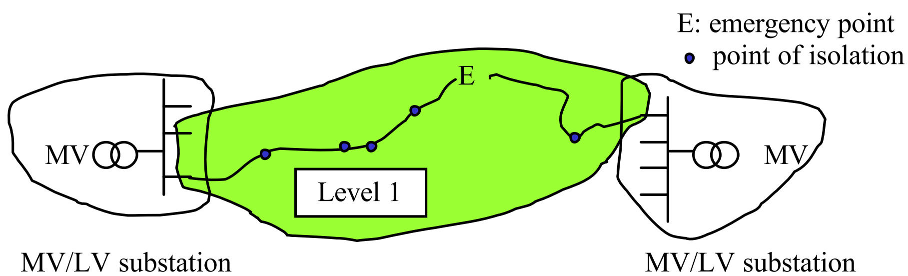


Figure 5: Similar approach for low voltage cells (urban type)

This concept enables us to identify new ways of configuration of the system in case of intentional islanding (for emergency or restoration purposes). The whole level 1 cell may be operated interconnected in a similar way as a radial network, as shown in the following Figure 6, when enough adapted DG (equipped with specific regulation needed during the islanding period) is available within the cell.

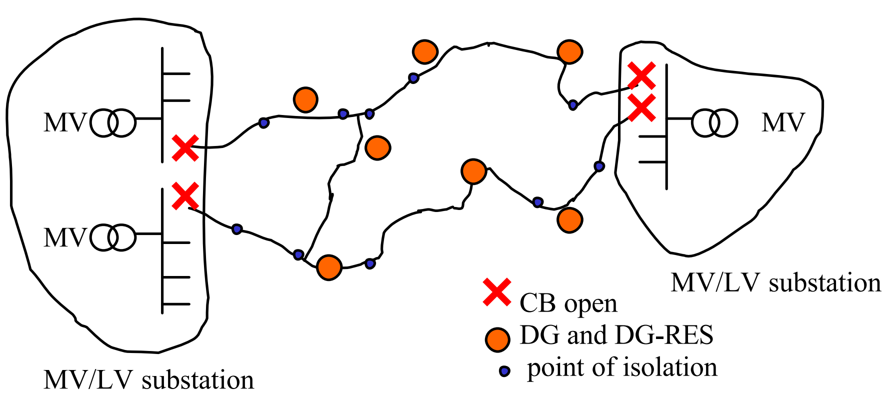


Figure 6: Level 1 cell during intentional islanding

The traditional communication system is not prepared today to comply with the wide and flexible monitoring and control requirements in the intentional islanding mode: variable scale of network, variable setting of the main protections and electrical control, real time check of local technical constraints caused by real time response of the trading system. The need of a level (not clearly identified) of local intelligence and the need of a high capacity of communications between numerous actors lead us to study the ICT abilities. Taking into account the described concept of distribution cells gives a physical scale of natural interlinking between electrical nodes, allowing the expert in EPS control and CS engineering to associate the local needed intelligence to the existing EPS.

In some cases the MV level 1 cell may have very large proportion, entailing to make internal virtual isolation for some of the fast application needed for power control and operation.

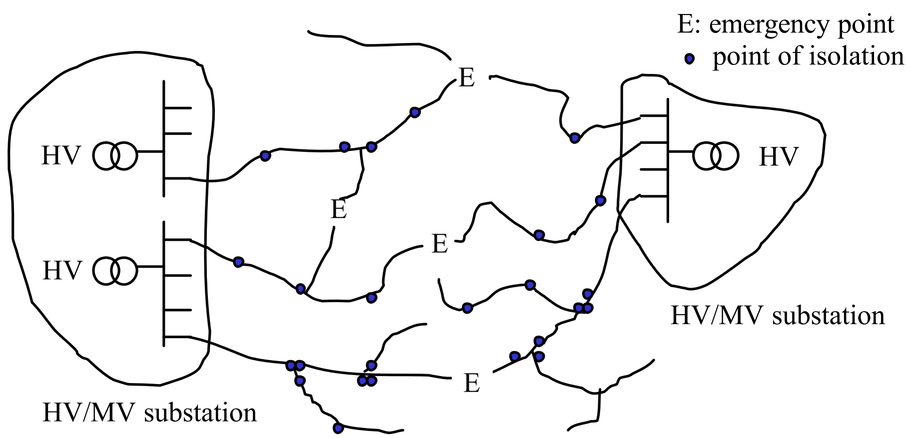


Figure 7: Level 1 cell composed of 6 main feeders

The figure 7 illustrates an existing case where the DNO is owner of a large territorial control and followed a high interconnection policy for enabling a high level of supply availability. If the number of feeders and communication nodes increase a lot, the information system, based on cell level 1, operating in real time mode may face some problems of required performance for some of the applications: sub-cell may be defined and designed (with specific interrupters and switching rules) in order to deal with the applications that require the fastest communication performances.
The virtual utility defined through the MV level 1 cell or the MV level 2 cell is operated by a local agent. This agent is a concentrated node of information collecting data from all the internal devices of the cell. A part of the information is locally analysed and results in local decisions and actions (real time applications dedicated for EPS operation).

3.2 Market view

Various kinds of market mechanisms may be defined for the future EPS. The first section (3.2.1) presents briefly three different markets targeted (application and time frame) during the CRISP project and three different techniques of payment. Then the following section (3.2.2) gives a combined view of the evolution expected for the markets, techniques of payment and associated changes in the information and communication systems.

3.2.1 Market applications and payment techniques

Various types of applications with a demand or production partially controlled by the electric real-time local price were studied during the CRISP project. Two main applications are categorized: the market for matching the local energy exchanges for reaching as a local balance, the market constrained by technical global conditions or local conditions.

For instance for the technical global condition, two main points was pointed out:

- the normal variation (not critical in this meaning) of power different from the daily scheduled energy, that is corrected with the balancing service,
- the critical situation in the large network caused by an important unbalance between production and consumption, that may be corrected with the intelligent load shedding

For instance for the technical local condition, a main point was analysed: the critical flow of power in some local lines in Öland during seasonal conditions, which may be partially corrected by structured price incentive policy.

The market deployment depends a lot on the payment techniques: at least the reliability and time response is involved by the price and bidding exchanges.

3.2.1.1 Day-ahead market

The production is scheduled one day before the real power exchange with the EPS: a reference daily curve is sent with a point for each 15min. The schedule is checked for collected energy every 15min and the producer is able to know its real position compared with the reference daily curve. Its response depends on the expected tariffs for penalties compared with energy costs involved to reach the reference curve (balancing tariff)

The cost of the deviation needs time to be evaluated: it takes nearly 48h to achieve this goal. Nevertheless the producer may be informed of its real time position to the need of the operator regularly: for instance with a simple signal every minute indicating the direction of the real time constraints for the system (in the global balance of production and demand). So the producer could develop a strategy depending on the estimated tariffs and its real time position compared with the system state: this possible strategy entails the creation of a market as '15min ahead market'.

The ICT network for this market resembles the trading strategies and reconciliation data generation in existing EMS systems, albeit at a much smaller scale. Reconciliation of contracts is principally identical to electricity trading systems. The main application associated with the day-ahead market is called 'Planned generation for steady-state': all the generation units (DG and large power plants) are scheduled to provide a given amount of energy for each 15min slot.

Supply and demand matching using agent algorithms requires additional data-transfers in an ICT-infrastructure. In order to operate, in essence, bid curves from component installations are to be supplied upwards in the grid and prices and granted allocations of power have to be distributed together with price-information. In some scenarios the settlement of transactions has to be done in a secure way. In this sense operation resembles modern mobile telephone communication.

3.2.1.2 15min ahead market

This market follows a daily market and is structured in order to provide enough real time reserve to the system. The typical application analysed with this market is called the 'balancing market': each energy slot that is not fulfilled correctly by the day-ahead market may be compensated by this market.

From the global EPS operator point of view, a deviation of a producer from its daily reference curve is:

- positive if the difference with the reference is in the same sign than the real time difference between the global demand and the global production
- negative for the reverse sign

The most important feature for the global EPS operator is to manage the real time balance between global production and global demand. Five main cases may occur for each 15min period of time and for each producer:

1. the amount of energy supplied is as expected, the producer is paid as contracted with the market,
2. the unexpected overproduction during a global deficit in production may be paid by the EPS operator as a system support contribution,
3. the unexpected overproduction during a global overproduction may be paid by the producer to the EPS operator as a penalty,
4. the unexpected deficit of production during a global deficit in production may be paid by the producer to the EPS operator as a penalty,
5. the unexpected deficit of production during a global overproduction may be paid by the EPS operator as a system support contribution,

The ICT network for this market resembles the trading strategies and reconciliation data generation in existing EMS systems, albeit at a much smaller scale. Reconciliation of contracts is principally identical to electricity trading systems.

This market may be seen as a ‘real time energy control market’.

3.2.1.3 Power control market

This market is dedicated for fast reaction from the generation or from the load to solve some technical temporary issues. The intelligent load shedding is one of the possible components of this market.
This market may be seen as a ‘real time power control market’.

Every x-min (x being settable between 15min and 120min) a local evaluation for fast possible reaction (load shedding for instance) is done, and depending on the updated technical requirement for the network, the price is increased or decreased to change the volume of the associated reserved power.

Others kinds of services could be developed as indicated in [D1.5]: smooth load relief, power oscillation mitigation for instance.

3.2.1.4 Current payment technique

Today most of the customers pay after reception and acceptance of the bill. Depending on the power involved the delay between the metering and the final payment may be last several days or months. A fixed price strategy is available for numerous customers in Europe, and especially in France, where time slots of the day have no the same price.

Typically for residential consumers in France (<36kW) a system with a night price and a day price allows the TSO to maintain a minimal consumption during the night (for instance water heating tank systems). Others type of contracts include different prices during the day, allowing the operator to have an influence on the daily peaks of consumption. Another pricing system takes into account 22 variable days in the year at a very high energy cost for the consumer, and a reduced energy price for all the other days of the year, enabling the TSO to reduce the annual critical period (annual peak around January in France).

But these systems are relatively fixed and don’t need fast reaction from the consumers. Even in the case of the variable 22 days in the year, the consumer is informed of the tariffs changes a few days before (typically in France the consumer is informed of the selected day one day before by power line carrier (PLC) technique, and the metering system is remotely changed of setting by the same PLC technique the D_day).

3.2.1.5 Price reactive consumers and DG

The previous technique with 22 variable days of the year (selected by the TSO when required) may be derived in a more reactive (in term of time response) system: this is the concept of price reactive consumers and DG. When the tariff is no more definitely scheduled slot by slot, and may vary at a scale of 15minutes, an automatic system with adapted ICT is required. The strategy may be decided by each consumer in order to reduce the global bill by a better daily energy consumption distribution. At a large scale this may contribute to flatten the global daily curve allowing price reduction and so on. In a ideal view the market itself may entail a global better efficiency of the system.

3.2.1.6 Electronic Markets

E-commerce and electronic trading have caught a lot of interest in recent years both commercially and in the research community. On consumer level anyone with a connection to the Internet may have visited electronic bookshops such as Amazon.com, auction sites such as e-bay, and search services claiming to search e.g. the electronic bookshops to present the best price given on a book that you are interested in buying. The extreme commercial interest in these aspects of e-commerce has disappeared in the turbulence of the last years.

The first attempts to use electronic markets for resource allocation problems occurred within the domains of computer usage themselves. As processor time was a limited and expensive resource, (pseudo) market models where developed for allocation of the resource [14]. Today the focus is on communications, with market based approaches to handling of network resources, e.g. routing problems and to problems related to the different needs of communication quality (fast, reliable, etc) [13][12].

The main field that attracts commercial interest today is electronic markets focused on b2b (business to business) solutions. Freight scheduling, airport scheduling, supply chain formation, and advanced combinatorial auction concepts are examples on problems that have attracted commercial interest and interest from the research community, [18][19][21][20].

Many concepts are based on agent technology, i.e. systems of independent electronic agents negotiating on behalf of market participants. Research is focused on both agent behaviour and on system properties, and further on construction of both.

3.2.2 Combination of markets and payments

The previous market and payment discussed in the previous section are crossed application by application. Some examples for the Nordic system are referenced.

3.2.2.1 Electronic Power Markets

In WP 1.2 the aim is to formulate and analyse market based, online approaches to supply – demand matching. In WP 1.5 the focus is on conditions for development of intelligent load shedding. Electronic markets are a novel and interesting approach to supply – demand matching. They present new ways to solve supply – demand matching problems by the introduction of active participation from load side and DG. This is a way to utilise flexibility within the system that is not utilised today since both load side and DG actors are exogenous to the dynamic power market(s). Furthermore, an electronic market setting has interesting properties from a load perspective. Such a property is that an electronic market may hold essential knowledge on system status, such as what load volumes are available to control and at what cost and benefit.

These dynamic markets do not exist today, and the challenges related to online markets that involve large numbers of actors are such that there is a need for mechanisms that differ from the mechanisms of power markets of today. There is an ongoing academic work on how to construct electronic market mechanisms for large power markets and markets that are similar [3][4].

This chapter gives an overview of electronic power markets with an ongoing comparison to a couple of alternatives, traditional techniques for peak load reduction and what we denote price reactive systems. The scene could simply be described in two dimensions, Figure 8.

\ Technique \ market For payment \ & time	Day-ahead market, Planned generation for steady-state	15-min market, Balancing service	Power control market, saving actions (seconds)
Techniques of today	Contracts/trading for financial hedging	centralized	Load shedding
Price reactive consumers and DG	Contracts/trading for financial hedging Physical hedging	Centralized with load response	Intelligent load shedding
Electronic markets	Demand-supply matching Hedging moves to primary energy sources	Demand-supply matching (energy reserve)	Demand-supply matching (power reserve)

Figure 8. combination of the markets and payment techniques

We define three technique (or market) levels, ranging from what we have today to a full electronic market. Furthermore, we define three time frames or perspectives, from the perspective of a planning market such as the day-ahead markets of today down to real time and load shedding.

The aim is to study the potentials to enhance market outcome with all combinations of techniques and time frames of Figure 8. This study, performed within WP 1.2 and WP 1.5, will be the base for decisions on simulations that are to be performed later in the project. The choice of time frames resembles what we have today, e.g. on the Swedish power market. Naturally the time frames of a future market set of markets could be different, but in principle this is a model that is sufficient for the study.

In the Nordic countries the **day-ahead (planning) market** of today is handled by Nordpool [8], Nord Pool Spot AS is owned by the five Nordic transmission system operators, Statnett (Norway), Svenska Kraftnät (Sweden), Fingrid (Finland), and Eltra and Elkraft System (Denmark).

In a future setting a planning market does not have to be bound to handle a 24-hour period at a time. In an electronic market setting, it might be more appropriate to handle smaller blocks of time periods at each occasion. The trade would be performed more often and hence the last hour traded would be closer to real time (today it is traded 36 hours ahead of real time).

Sweden and Finland have a common **adjustment market**, Elbas [7], to handle changes in consumption and sales situations. Elbas provides continuous power trading up to one hour prior to delivery. On this market hourly contracts are traded.

Today the Swedish **balancing service** as elsewhere, is handled entirely by a few large actors. The responsible party is Svenska Kraftnät, the Swedish TSO. The service is organised as a simple market, with bids on positive and negative regulation of power. The time frame from trade to effectuation is in the order of a few minutes.

As in the planning market perspective, there are potentials in engaging load side and DG actors in real-time balancing of supply and demand. That is, it might be handled utilising a lot more of the dynamics of the actors on the market, both large and small size actors, both production side and consumption side actors. In a distributed grid it might even be that a lot of the balancing is performed on a local basis.

Power control is a powerful tool in the hands of the grid owner (on all levels), a tool that he tries to avoid using due to severe side effects. With more sophisticated, or intelligent, load shedding techniques – e.g. based on dynamic pricing or dynamic market tools – load control might be a tool that could be used at a far earlier stage then when facing a threatening disaster. Even more, an intelligent load shedding system built upon sophisticated handling of the other time frames, the risk of entering a critical phase other than due to totally unexpected losses of power lines or production is reduced. This principle matches the increased complexity and heterogeneous nature of DG.

With the choice of comparing the three techniques we may achieve a better understanding of the advantages and disadvantages of both price reactive systems and electronic markets, as compared to what is possible to achieve with more traditional techniques.

The communicational and computational demand varies with the technological approach (today's technology, reactive price systems, and full electronic markets), and with demand on response times (i.e. how close to real time the market action takes place).

3.2.2.2 Communications

The communicational demand for the different concepts vary from the possibility to send and receive a simple signal, over one way communication of more complex data, to full bi-directional communications. The communicational needs are lowest for the implementation of some concepts that have already been in use for peak load reduction, such as broadcasting a set of tap water heaters to shut down for a predefined period of one or two hours. The highest demand on communications comes with the implementation of full electronic markets with end user (consumer and DG) bidding.

Moreover the demands on communication speed vary to the same extent. The variation is depending on how close to real time the operation takes place. Load shedding has the hardest demands on fast communications.

We denote the communication between a single consumer/producer and the system/market as *external communication*, whereas *internal communication* is the notation we use for communications e.g. within an actor's premises.

3.2.2.3 External Communications

Communications between system/market and end consumer/DG-unit can be built upon a number of technologies that are present or evolving, e.g. techniques based on radio, phone line, power line communications, communication structures mainly dedicated for Internet connection. Naturally, the requirements on the communications depend on a number of variables, mainly if broadcasting is sufficient or not, one-way or bi-directional communications, and demands on volume and speed.

3.2.2.3.1 Today's technique

A simple (in terms of volume), and cost efficient communication technique for peak load reduction that has shown to be appropriate in settings where it has been used in the past, is the usage of (broadcast) signals to trigger predefined action by groups of load. The signals have been transmitted both over the grid and over radio networks (RDS and similar systems). The new options given by current development of ICT are far more elaborate in terms of capacity than what is needed in this context, but if such an infrastructure is there it may of course be utilised as an alternative to the communication systems used in the past.

3.2.2.3.2 Price reactive systems

For price reactive systems it is still sufficient with one way (broadcast), but with bi-directional communication it is possible to think of enhancements such as leaf nodes (consumers and DG units) reporting how they respond to a price signal. This could help planning and fine-tuning of the system. On the other hand, it is hard to see any natural incitement for such reporting, particularly as it might increase costs for the participants. So, it is more likely fully sufficient with one-directional communications.

The volume of information transmitted in a price reactive system is higher than in the previous, but less than in an electronic market setting. For the planning perspective of a day-ahead market (or similar) a full price vector of all hours (time intervals) has to be transmitted. For the other markets, the information volume is less (in the order of a single price, maybe with additional information for timing, etc.). As the market moves closer to real time, communication speed becomes the crucial factor, not volume.

3.2.2.3.3 Electronic Markets

ICT is the foundation of an electronic market and it is not possible to achieve without distributed computational capacity and full bi-directional communications, such as the Internet.
Even here, as in the price reactive setting, the demand on communications differs from one market perspective and situation to another. The volumes are largest for the day-ahead market perspective, and less for the other. The demand on high speed is growing with closeness to real time, and hence it is highest for real-time demand-supply matching.

To minimise the information volumes and particularly the respond times of market actions close to real time (particularly demand-supply matching), the central node of a cell may utilise precompiled information on load available and cost. In this way, a critical situation can be handled efficiently with one-way communications, even broadcast, and with a low information volume to transmit.

3.2.2.4 Internal Communications

A leaf node of the system (representing a consumer or a producer) often has an internal structure and hence a need for internal communication. The communication is needed both for control of equipment and for collection of information.

The minimum internal communication needs are related to some systems that has already been in use for peak load reduction, i.e. systems based on sending signals to e.g. tap water boilers. The receiving unit and controlling unit can be the same and hence no internal communication need is there.

In the other end we have the internal structure of leaf nodes acting on an electronic market. Such a node might even organised internally as an electronic market in itself, for example we could think of a building comprising of a number of rooms, each one a climate zone of its own, and a number of other appliances with energy demands. An agent acting on an internal market could represent each unit in the system, negotiating with the other interests within the local system. An agent representing the building on an external market then uses the outcome of these negotiations (when constructing a bid).

In these settings the internal communication could be built upon different networking technologies and it is hard to estimate costs for this in any general sense, since there are too many variables involved. Both in e.g. industrial settings and office settings, networks that are installed for other purposes may be utilised, and even in residential settings different kinds of home networks for computers or media streams are becoming more and more common. When no such network is present, e.g. simple Bluetooth transceivers might be a cost efficient alternative (approximately €5 per unit today).

The internal communicational demands of a price reactive technology are closer to the demands of an electronic market than to the first alternative, due to the need for computations on an optimal price reactive behaviour.

3.2.2.5 Computations

The level of computational demands mainly corresponds to the level of communicational demands.
If the technique resembles peak load reduction *techniques of today* the set of actions is small and predefined, hence the computational capacity of the control unit may be rather low.

A *price reactive* system handling supply and/or demand price reaction, needs to be able to perform what is sometimes rather sophisticated multi-dimentional optimisation, planning their primary energy usage and electricity consumption. In general the optimisation problem varies a lot in complexity from simple threshold based decision strategies to complex calculations on e.g. indoor climate.
Price reactive systems dedicated to load shedding alone might resemble systems built on current techniques for peak load reduction to large extent. The main difference is that control is in the hands of the customer, and not in the hand of the grid owner or the energy supplier. A consequence is that the demand on control equipment and meters are different.

A system biased towards *electronic markets* has one more task, to construct bids representing the customer on the market. As in the price reactive case, the complexity of the task varies a lot.

3.2.2.6 Control Equipment

For the first category, today's technology, there is a need for control equipment that reacts on signals given by the party with control in their hands, i.e. the grid operator or the energy supplier. There is often no need for specific metering technology, since the action is based on long-term contracts stipulating that the customer hands over limited control of the equipment to the grid owner/supplier.

In both price reactive systems and electronic market settings, the demand on metering is higher. For supply – demand matching the resolution of meters has to be sufficiently high. For registration of load shedding actions there is a need for identification of the event.

3.2.2.7 Legal Aspects/Constraints

Depending on perspective, current regulation plays a more or less interesting part in the development and application of market based technologies for supply – demand matching and intelligent load shedding.
In the long run, regulation is adapted to the technology in use. In a shorter perspective, current regulations play a more active role, eg the ongoing debate about penalties for poor security of supply.
Studies on the issue are still to be done.

3.2.2.8 Stakeholders

It is sure that the different roles of the different stakeholders (DNO's, energy suppliers, consumers, ESCO's) will change as more advanced technology is implemented. These change of roles should be studied in the future.

3.2.2.9 Costs

It is hard to estimate costs of new complex systems. Still the ambition is to be able to give a rough estimate of some costs of implementation. At least we should give some ideas on the investments for an actor to be able to participate (and if there are possibilities to combine the investment in investment in other systems, e.g. in the residential sector we could think of combinations with other smart house equipment).

3.2.3 The Three Technological Perspectives

In this section the focus is on advantages and disadvantages of the three different technological approaches, today's technology, price reactive systems, and full electronic markets, applied to the three market time frames day-ahead (planning) markets, balancing services, and load control, c.f. Figure 8.

3.2.3.1 Today's Technology

With today's technology we refer to technologies that has been developed by utilities for load side action to reduce consumption during peak load hours. Sydkraft was highly involved in development of such schemes during the late '80s, see below. It is unavoidable that the potentials of such systems are changed due to deregulation of power markets. A major change is that the loss of vertical integration gives that whoever contracts a customer (supplier, distribution grid owner, or another party) will use the capacity mainly for his own benefit, and no party involved has the overall responsibility in a deregulated setting such as the Swedish power market. Another problem due to loss of vertical integration is that regarding customers that are not equipped with hourly[1] meters, it is harder to handle the benefits of an action when it comes to settlements between suppliers operating in the same distribution grid. (If at all, how should templates used to settle contract notes be adjusted with respect to a load reduction action that some supplier takes?)
Still it may be that the concept is not dead, a reason is that it has proved to be cost efficient and reliable.

3.2.3.1.1 Day-ahead

[1] Hourly meters when dealing with supply – demand matching on a day-ahead market, even more advanced meters are needed when it comes to (close to) real-time action.

As said in the introduction to this section, Svenska Kraftnät, the transmission grid owner handles the balancing service in Sweden as it is today. In their planning for critical winter days/hours, Svenska Kraftnät has contracts both on start-ups of production units that are not used during ordinary conditions, and on load reduction, the latter with large industrial consumers that are able to change production plans on (relatively) short notice

Utilities such as Sydkraft developed and used similar concepts in the late ‘80s i.e. peak load reduction based on contracts with industrial customers. The concepts might involve changes in production plans, switching from e.g. electrical boilers to alternative fuels, etc. The Sydkraft contracts with the industrial customers where on a five years basis.

One did furthermore developed concepts involving small-scale consumption in automated peak load reduction schemes. Residential consumers either with electrical tap water boilers or with both electrical tap water boilers and electrical heating systems where connected to systems for peak load reduction. A significant difference between these systems and the larger scale industrial consumer systems is that the residential consumer systems where automated. The principle was that a signal was sent to the control unit for load reduction, and the control unit automatically took action in a predefined way. Sydkraft contracts with the customers where on a ten years basis.

The development of this peak load reduction mainly was aimed at reduction of the power consumption during a few critical hours per year. The system was thought as an economically beneficial alternative to new production capacity. The use of the systems that Sydkraft developed ended with the deregulation of the power market. The reasons where twofold, *(i)* power prices on the Swedish market fell during the first years of deregulation and the interest from the suppliers was low, and *(ii)* the loss in vertical integration made it less interesting to develop systems and harder to get long time arrangements with customers. Detailed reports on the Sydkraft experiences can be found in **[11]**,**[16]**, and **[17]**.

3.2.3.1.2 Balancing Service

It is not far from the idea of utilising consumption side flexibility to handle fluctuations on a day-ahead perspective to utilisation of the same flexibility when it gets too close to real time balancing services.

3.2.3.1.3 Power control or load control

In the load control perspective we believe that realistic consumer side action has to be automated (i.e. the communication and effectuation has to be automated). Both the potentials of each available unit and the economic benefits are too small to use manual methods (this holds for both industrial settings and e.g. residential ones).

There are potential problems and uncertainty in the limited possibilities to estimate the effect of an action in advance. Hence it might be hard to pick the right amount of load to control. Furthermore, the simplicity of the basic idea is obscured by problems related to how to account for the actions taken by a party on the market. In order to clairify the potential benefit derived from “Load Control” it might be useful to distinguish between purpose and level of control action. A possible grouping is:

- Level 1: Load Control – Energy Production Scheduling and Network Switch State Management
    - Level 2: Smooth Load Control due to Energy Shortage – Supply/Demand Matching
        - Level 3: Rough Load Control due to Energy Shortage (Rolling Blackouts)
    - Level 2: Smooth Load Control due to Network Limitations – Demand/Supply Matching
        - Level 3: Rough Load Control due to Network Limitations (Load Shedding)

The need for fast action emphasises the demands on communication and control equipment.

3.2.3.1.4 Deregulated Environment

The great advantage of the existing technology is the relative simplicity and that it is an economically efficient instrument according to experiences of e.g. Sydkraft.

The major drawbacks come with application to deregulated environments. Supply – Demand matching techniques of today (developed for peak load reduction) suffer from some drawbacks stemming from the separation of responsibilities in a deregulated power market setting.

In the late '80s and early '90s, when Sydkraft developed their schemes for peak load reduction, they acted on a scene where the same party was responsible for both grid and energy supply. The scene of today looks different and the loss of vertical integration gives that some of the benefits of the technology are harder to establish. The grid owner and the energy supplier are separated. Both could be interested in load reduction, but their reasons might not coincide. Furthermore, interests in supply – demand matching action might not stem from the local situation, but originate on transmission or large-scale production level (regional, national…). Other problems due to loss of vertical integration that we pointed out above (on page 35) are related to metering technology.

3.2.3.1.5 Overall Pros and Cons

The greatest advantage of the concept is that it is already there, and hence that there are experiences to utilise. Probably it can be developed further utilising resent development within the ICT sector.
Main drawbacks are that current techniques for load reduction do not fit into a deregulated environment as they did when it came to a traditional monopolistic utility setting.

With this kind of schemes the control of action stays in the hands of supply side, and is not moved to consumption side even though action is taken on consumption side. Whether this is an advantage or a disadvantage could be disputed.

3.2.3.2 Price Reactive Systems

In short, a price reactive system is built upon dynamic prices, but the actors of interest are not taking part in the process of price establishment. That is, prices on the market continue to be an issue handled by the big actors, large companies on production and distribution side, as it is today.

The reason for this is obvious, even the volumes of relatively large consumers are really small in comparison to the actors that take part in price establishment. Markets with a large number of active participants have to be handled in different ways compared to the markets of today.

Price reactive consumers and DG are concepts that ought to be fully compliant with market structures of today at least as long as the volumes that are handled in a price reactive manner are small in relation to the total volumes traded on the market. On the other hand, to become interesting from a supply – demand matching perspective they should not stay marginal.

3.2.3.2.1 Day-ahead

It is common that large volume consumers (and even some residential consumers) in Sweden buy all or part of their energy at prices directly related to the day-ahead prices of the Nordpool spot market. It is unknown to what extent those consumers actually perform any cost optimisation related to the dynamic prices (i.e. dynamically move consumption due to price variations). They certainly have the opportunity to do, but probably the economic incitement to do so is to small for any manual action, except for e.g. large boilers that could be switched to alternative fuels.

In the last years some experimental work on the construction of automated consumer agents operating in a price reactive manner has been performed both in Sweden and in The Netherlands. This experimental work has contributed to knowledge that is applicable not only to price reactive systems, but to full electronic markets as well.
At Blekinge Technical Institute a student project in 1998 was directed towards electrical heating of (residential) buildings and optimisation with respect to prices. In this project the focus was on both optimisation and the internal structure of the comfort system and internal communication.

In the SMART project of ECN, ended in 2002, a test system on energy saving and cost effective building management with an advanced comfort management and optimisation system was developed [9].

A study on communicational aspects of both price reactive systems and full electronic markets, performed in 2000 – 2001, was part of the PALAS (Power line as an Alternative Local AccesS) project [10], [6].

The experience from the tests shows that price reactive behaviour is an option e.g. for the comfort system of an electrically heated building. When such a system would be economically motivated is hard to estimate, since too many variables are unknown (on one hand cost of optimisation system including internal and external communication, on the other hand the size of potential gains both for the end user and for the system).

From a system point of view, price reactive customers (both consumers and DG) would change the supply – demand relation in a positive direction. At the same time, if they do (more than marginally) the basis of price establishment is changed! How the participants in the price establishment process could take non-marginal exogenous price reactive behaviour into account when establishing prices is a non-trivial problem.

3.2.3.2.2 Balancing Service

When moving from the perspective of a day-ahead (planning) market to the perspective of a balancing service closer to real-time, a number of interesting questions arise.

If a larger number of actors are involved in the real-time balancing of supply and demand, the change relative what is today involves a number of technical and other areas. Many of these are out of the scope of this project, but some central issues are dealt with. The basic idea is that price signals could be utilised to change the behaviour of consumers and DG actors. These prices have to be established somewhere. By definition it is not established in a bidding process involving all participants that are affected by the prices. The simple solution is that the party that is responsible for the balance (in Sweden Svenska Kraftnät) simply acts on estimations of the effect of a price, in combination with bidding from the large production side actors. Obviously that is a high-risk scenario and if used, it has to be built on deep insight into the behavioural patterns of the participants.

Still another big issue related to prices is the basic price model. Today, with only a few producers involved in the balancing service market, *changes* in production is traded. If consumer side dynamics are utilised to balance supply and demand, this might not be possible. This is related to the basic dynamics of consumers, is a change in consumption due to a price change or is it due to other circumstances? How to solve this has to be studied if the concept is chosen for further studies.

Communications is another issue. The demand on communications stops at one-way communications, even broadcasting is sufficient. The information communicated is a simple price. If the time frames of action is not predefined, there is a need for some identifying (i.e. timestamp) information together with the price.
Metering is still another issue. How this is solved is intimately related to system construction. A solution is that consumer side action is based on fixed, short time frames. Then

With answers to the questions that arise in these fields, there is an interesting potential. It is well known that there is a potential to change behaviour on consumption side on short notice. To utilise this potential one needs to introduce incentives to change behaviour. The information volumes that have to be communicated are modest, a price and possibly some type of action identification tag to help identifying an actual change in consumption / production due to the signal.

3.2.3.2.3 Power control or Load Control

Load control benefiting from price information and utilizing some more information, e.g. phasor measurements comparing local and global network quantities, can achieve intelligence in the load control. Before such load control can become ubiquitous, investigations need to be made into the load character, particularly with DG supplying the controlled area and maybe even exporting power to neighbouring areas. Whereas traditional load shedding is independent of load and generation response, an intelligent load shedding function must factor in the expected load and generation response into the intelligence so as to avoid further aggravating an already disturbed energy supply and network operation.

3.2.3.2.4 Deregulated Environment

Price reactive behaviour might be viewed as a natural extension of deregulation. Particularly when focusing on markets such as day-ahead markets it is easy to see how the behaviour fits into the structure. Moving closer to real time we have to raise a number of questions. First we have bookkeeping and metering considerations (including synchronisation). Moreover there are problems that resemble those that arise with concepts built on today's technology. In a market situation with many participants sharing the responsibilities, prices are not only not only a potential instrument to achieve balance in the system, they have to be established in a natural way.

Still, the main objection that we express is regarding what happens when the volume on the market that is price reactive is not marginal. If a price is based upon an estimation of production, bottlenecks in transmission, and consumption, price reactive consumption and DG might wreck the stability of the price.
If price reactive actors should be an alternative, the price building process related to this concept is an area to look into further. How is it possible to make good estimates on the effects of different prices? Dealing with the interesting close to real time scenarios there are other unresolved questions. Prices are not mainly a control mechanism, they have to stem from somewhere, and a basic question is where is the price established, and by whom? Who has (or might have) the power/authority to act in relation to the end consumer or local producer – is it the same actor that has an incitement (e.g. for stability reasons) to act. How does the potential market look that one responds to, in the shorter time frames of balancing services and load control?

3.2.3.2.5 Overall Pros and Cons

The major strength and at the same time the main weakness of price reactive systems, we illustrate with two figures of a fictive market situation, Figure 9 and Figure 10. In the first figure we can see the prices, with one high price period (e.g. hour), followed by a low price period. In the second figure we can see an optimal behaviour of a price reactive consumer with capacity to adapt to the dynamic prices.

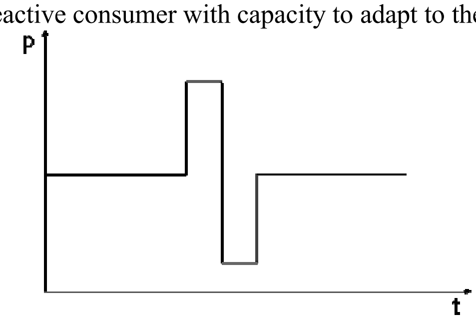


Figure 9: Double high price variation

The potentials of price reactive systems, and at the same time a main problem with them can be illustrated with the help of this rather extreme market outcome, a price peak followed by a price dip (we assume that it is related to a corresponding demand variation). The obvious response of a price reactive actor is expressed in the following figure.

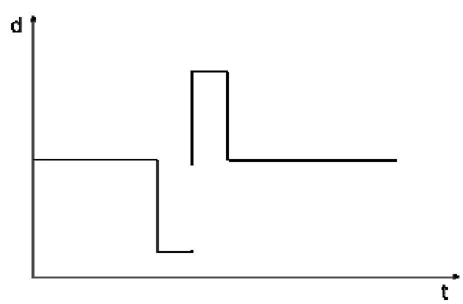


Figure 10: Response expected from the loads to the double price variation

With the prices of Figure 9, reactive agents with enough dynamic capacity change their consumption pattern drastically.

The behaviour of the consumer is precisely what we expect, as much as possible of his consumption is moved from the high demand period, with a corresponding high price, to the following low demand, low price period. From a system viewpoint this is positive, since it relieves some of the pressure on the high demand period. On the other hand, if the set of price reactive consumers is large, the impact on the market outcome becomes non-negligible. That is, the impact of price reactive consumers and DG producers on the actual demand has to be taken into account when settling prices, and this is nontrivial.

3.2.3.3 Electronic Markets

The concept of electronic power markets is a way to involve the full dynamics of consumption and DG on dynamic power markets and even in the price establishment processes. That is, today the actors on power markets (day-ahead markets, balancing services organised as market or in a similar fashion, ancillary services markets…) are few and large, consumption and DG that is not controlled by these actors are viewed as exogenous to the market. With the mechanisms of current markets this is the only alternative, they cannot handle large numbers of participants efficiently. Electronic markets change the scene and participation of small-scale actors is made possible.

The foundation of electronic markets is the ICT development that is currently penetrating Europe, the rest of the industrialised world, and at lower speed developing countries.

Key features of the electronic markets that we have in mind are automation, distributed market computations, and agent-based technology:

Automation. The power markets in focus are markets that are handled over and over again, with short periodicity. From system viewpoint we have that when introducing a large number of participants on the markets we need mechanisms that handle participants in an efficient manner, so that transaction cost are kept low. From the viewpoint of the new participants we have that since the volumes they are interested in are small, it is crucial for them too that transaction costs are kept low. Furthermore, automation gives the opportunity to build support for market behaviour into devices such as comfort systems and other thermal loads, as well as into small DG units.

Distributed market computations. A motivation for distributed computations is communications. If a central market node is to communicate with every single actor on the market to collect bids and give information on market outcome, bottlenecks in the communication system are probably unavoidable. This concern is of growing importance as the market perspective comes closer to real time and/or information volumes increase. Other reasons for distributed computations are that this gives the opportunity to extend the possibilities of the market instrument. Power grids can be viewed as hierarchical structures, and sometimes we model a level within the hierarchy as a *cell*, consisting of lower level cells or end users (consumers and producers), and connected to a higher level cell. Such a cell has a number of constraints that limits it, the most obvious one is a capacity limit – there are limits on the flow over a substation, and often the flow direction is given by protection equipment. If the structure of a distributed power market corresponds to the structure of the grid, and if the proper knowledge and behaviour is built in, the distributed market might be used to handle such limitations.

Agent-based technology. This is more of an implementation issue. If automation is a goal, and distributed computation with distributed knowledge and responsibility is another, then the computer science concept of *agent systems* is a way to obtain this. In short, what is of interest here is that agents in this context are software entities representing (e.g. negotiating on behalf of) real world entities (consumer and producer premises). They act on the market given a set of goals, including individual price sensitivity. In a conceptual way we can describe the market negotiations in ways that the agents of a cell gather and give their (selling and buying) bids. These bids are input to a process where the agent responsible for the cell calculates a bid summarising all these bids and taking constraints, losses, etc of the cell into account. If not only power, but transmission/distribution too has a dynamic price, this goes into the calculations. The cell responsible agent then moves to the next level of the hierarchy to take part in the negotiations there.

Research on agent technology and electronic markets focuses on both system construction (i.e. market mechanism design) [4][3][23] and on construction of individual agents [22], [23].

The basics of mechanisms for different market perspectives can be the same, but there are aspects on the different time frames that influence the mechanism design.

A property of electronic markets that we do not obtain with e.g. price reactive consumers and DG producers is that the knowledge within the system increases at the same time as the dynamics of small size actors are utilised. A major critique of price reactive systems is that they introduce new uncertainty into the market (regarding how the price reactive agents will act on a given price signal). In an electronic market the agents reveal central information on their behaviour, i.e. what they will buy or sell given a price, when they put their bids. In effect, the situation depicted in Figure 9 and Figure 10 will not occur in an electronic market – it is a problem strictly related to price reactive agents.

3.2.3.3.1 Day-ahead

In day ahead markets (and similar planning markets) of today each time slot (hour or half-hour) is traded as a separate good. On the Nordic day-ahead market there are some variations with possibilities to enter (buying and selling) bids on predefined blocks of consecutive time slots (the same volume for all time slots), and flexible selling bids relevant for potential peak-load periods [2], but basically each hour is traded independently. The mechanisms for handling of these bids could be developed further, but if the market is to handle a large number of participants this is a challenge that introduces a need for new market mechanisms.

Electronic day-ahead markets (or similar) may be constructed in the same way, but since small-scale actors have a relatively larger need for to be able to express combinatorial or XOR type bids, these market opportunities are of greater interest in an electronic market setting. In a resent paper by Per Carlsson, Arne Andersson, and Fredrik Ygge a proposal on a mechanism for e.g. day-ahead power markets, with some carefully selected combinatorial and XOR-type bid types is presented [3]. Further work on such mechanisms is part of activities in parallel with the project.

3.2.3.3.2 Balancing Service

Electronic markets are an option for balancing service markets too. As in the price reactive setting special there are some interesting problems to solve related to what the actors are trading. On a day-ahead market the good that is traded is energy on an hourly basis (MWh/h or kWh/h). Moving from the planning perspective of a day-ahead market (as it is thought of today) to a close to real time balancing service market, we move from an energy-centric market to a power-centric market. This is no problem when the involved actors are large producers with no incentives for drastic changes in generation, but with consumer side participation the situation is different.

Given that this problem is solved, it is possible to handle short time one good markets such as a balancing service market, even with participants expressing non-continuous demand [5].
A property of electronic markets that we discussed shortly above and that is of interest when it comes to this market perspective and load control, is that the knowledge in the system increases together with the possibility to utilise the flexibility of consumer side and DG. See also load control below.

3.2.3.3.3 Power control or Load Control

An Electronic Market can use the same mechanism, demand – supply matching, for both balancing and load control. A difference to the day-ahead market is that the short time to action (minutes down to fractions of seconds) emphasises that there is a need for precompiled information. That is, participants have to give their bids some time in advance, so that any level of the structure (the market structure is assumed to match the grid structure) that could be involved in a DG scheduling or load shedding action could compile the knowledge to be able to execute a stopt/go command instantly.

In an electronic market setting we have bi-directional communications and hence it is possible to update the market whenever an actor changes his behaviour. This in turn, gives that the outcome of an action should be well defined due to the aggregated knowledge (bids) that is present.

3.2.3.3.4 Deregulated Environment

The development of electronic markets is actually to go a step further, compared to deregulated markets, as we know them today. With electronic markets the dynamic market can move from wholesale towards the involvement of the end consumer.

3.2.3.3.5 Overall Pros and Cons

The major advantage is that electronic markets are a true way to involve consumption and DG in the dynamic markets. This gives a market outcome based on more knowledge compared to the outcome of current markets.

The major drawback is that the concept involves major changes to the market structure, and hence it is a rather drastic step.

How to handle different goods (voltage levels) in a dynamic electronic market involving both small-scale and large-scale actors is an open question. Furthermore we do not discuss whether the small-scale actors are to act on a single (distributed) market place corresponding to e.g. the Nordpool spot market or if a number of suppliers form their internal electronic markets. There are advantages with suppliers handling there own electronic markets internally and there are disadvantages with this, compared to the formation of one large electronic market where the role of a supplier is changed drastically.

The demands on communications and computational capacity is larger than for any of the other concepts, and it might be hard to motivate the investments in some interesting segments, such as residential settings. A motivation to do it even though the volumes in the segment are small is that the consumption pattern is clearly different from the industrial segment, and hence there is a large potential compared to the total consumption.

3.3 Security and dependability view

The security has to be analysed from the EPS power and control, market and information system point of view. The failure analysis is achieved in a comparative way when absolute real failure characteristics of various components are difficult to deal with. In this case two solutions may be simulated with similar assumptions for the doubtful failure data: the result analysed is not the absolute failure value output, but is the difference between the two absolute outputs.

The dependability approach is clearly identified for EPS power and control and associated information system when a clear structure with independent cells is defined. An example is the existing protection system for each feeder tripping for the current inrush caused by local fault. The communication between the devices of a given cell and the agent managing the cell should not been dependent of external other communications. In the same way, the computer unit used by the local agent may host different agents of various cells engaged in various functions, but the algorithms and the processes involved have to be compute in a way to avoid large failure distribution.

3.3.1 Specific aspects about the HTFD tool

The HTFD tool defined in D1.4 and D2.3 of the CRISP project is about a permanent fault occurring in a MV cell of level 1. The principle of the technical solution has been detailed in the previous deliverables. When looking at refinement solution from the computer and communication point of view, the main way is to avoid misinformation due to a bad communication connection or an internal failure in a device. The following part 1/ is a normal and simple description for the tool, the following part 2/ and 3/ give an additional security improvement.

1. the devices that have information to send try to send it, or as soon as possible. The HTFD tool makes its calculations and sends back orders eventually.
2. if the distributed device senses an internal failure (in the device observed or in the device converting and sending the information itself), it sends the corresponding error message to the HTFD tool.
3. the collecting node (HTFD tool in the central unit of the local cell) check regularly that connections with sending-nodes are available (in order to avoid bad interpretation of no sent messages). A possible checks every hour and after every important event is proposed. The devices not responding as declared 'temporary out-of-service'. Several checks are then done leading to a declaration as 'out-of-service' if there is no success to have communication link. The HTFD tool takes into account the corresponding information.

Inside the HTFD code, the analysis of the different information (current value collected from the protection relay and messages from the various FPI) may face non coherent situations. The robustness of the program lays in part on: how (move on) running with inconsistent information and how give an acceptable information and response to this situation.

3.3.2 Dependences between HV and MV EPS

The disturbances occurring in a given distribution area are not too much constraining for the HV level, so the impedance of a transformer in HV/MV substation behaves as a disconnecting component.

Nevertheless a synchronised event occurring in a lot of distribution networks may have a strong effect on the high voltage. A typical example is for inrush current following a large failure in the system: a lot of loads are following a similar process (for instance freezer and fridge, heating system).

A disturbance occurring in HV system with deep voltage variation (for instance a near HV fault) has a high impact on the adjacent distributions networks.

Consequently a wide impact on the distribution network may have a return impact in the HV system. A typical example is a fault occurring in HV systems, involving short voltage sag on various distribution networks. The disconnecting protection of all the dispersed generation has to trip because of the voltage decrease, what entails fast HV power flow changes in an apparent increased of local power consumed.

3.3.3 Dependences in the electrical market

The one-day-ahead market is based on forecast system and bids strategy (energy cost real time approach). The scheduled program is compared to the factual achievement 15min by 15min: each deviation may lead to penalties or royalties, depending on the real time global need of the system. So the system gives information (each 1 min) of the current situation (direction of the global imbalance) and the producer may adapt its energy cost strategy to the occurring situation. One difficulty is that the cost for 24h contract is relatively clear, instead the penalty or royalty is evaluated a posteriori (48h later) taking into account global cost of the imbalance during a given period of time.

3.3.4 Combination of the infrastructures

So there is a complex balance which is reached in this manner combining EPS and market constraints. In this kind of exchange, if a problem occurs on one part of the system (information communication, large EPS trouble, or market imbalance), the effect on the EPS operation may be very strong.

In order to avoid dependence between the structures some limitations should be given defining normal conditions for each infrastructure (market, ICT, EPS), these normal conditions being already given for EPS power and control. Each infrastructure has its own criterion for normal, critical and emergency situation.

3.4 ICT view

The ICT terms is widely use in the literature as a black box and its definition is not really clear. Different ICT are usable in electric power system. A lot of international standard and international work groups deal with the requirements to use them in the EPS conveniently. Detailed information has been reported in the deliverable of CRISP [D1.3], including a state of the art of ICT components and its uses in the Electric Power Systems.

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), (see in **[28], [29])**.

Communication is the fact of transmitting information between two or more points/agents of the system. The information and communication processes are close together. The information system is responsible of obtaining or measuring the parameters/variables that the systems need for an operation during normal or abnormal electrical conditions. The information exists and can be transmitted from this point of measurement to other points of the system for further utilization.

Different communication medias are used to transfer the information and different communication codes exist even if the same kind of protocol is used (for instance TCP/IP protocol). The information collected by the basic ICT component may be analog or digital, depending on the device observed or controlled. The information is then transformed into digital signal to be transmitted into the information system. In the reverse direction, the basic ICT component may have to convert digital to analog signal depending on the EPS device connected.

A main point in CRISP project is to focus on what is important to communicate to an upper layer (various layers of agents communicating between them), trying to define the necessary and sufficient information amount. In the case where numerous information nodes and fast application is expected, a reduced and appropriate information exchange gives the best expected performance for a part of the ICT design.

The communication information is converted adequately and sent to different information nodes where these signals are converted into other formats (data formats exploitable by the control 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 for control purposes.

The computerization consists in the use of the information or data in order to analyze the system or to establish a help for giving state estimation and for proposing correct decisions to the network operator. The computerization can be carried out locally (using a programmable logic controller for instance) in order to same space and time in the whole information system.

3.4.1 Existing ICT components in the EPS

As it was mentioned in deliverable [D1.3], the EPS telecommunication is based on the SCADA system, DMS (Distribution Management Systems) and EMS (Energy Management Systems) applications, which enables the system control, collection and supervision of data through different communications media (satellite, PLC, optical fibre…). These communication links have different latencies to send a message between two points. The latencies are critical for the EPS operation and thus, the next table shows the general requirements for 3 tasks of the system:

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.1.- General telecommunication requirements of different EPS applications

- Different communication links performance

Different studies of the CIGRE Study Committee 35 **[30], [31], [32]** have evaluated the use of new telecommunication technologies in the electric system. The next tables (table 2 and table 3) 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.2.-Operational services implementation

A comparison of different telecommunications is presented in table 3. Special attention should be paid to the absence on guarantee in the propagation time of messages in a IP network. That is a general characteristic of the IP systems. However, the existing IP protocol, IPv4, and the new standard, 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.3.-Telecommunication system characteristics

- Different communication protocols and standards exist in EPS as shown in the following figure.

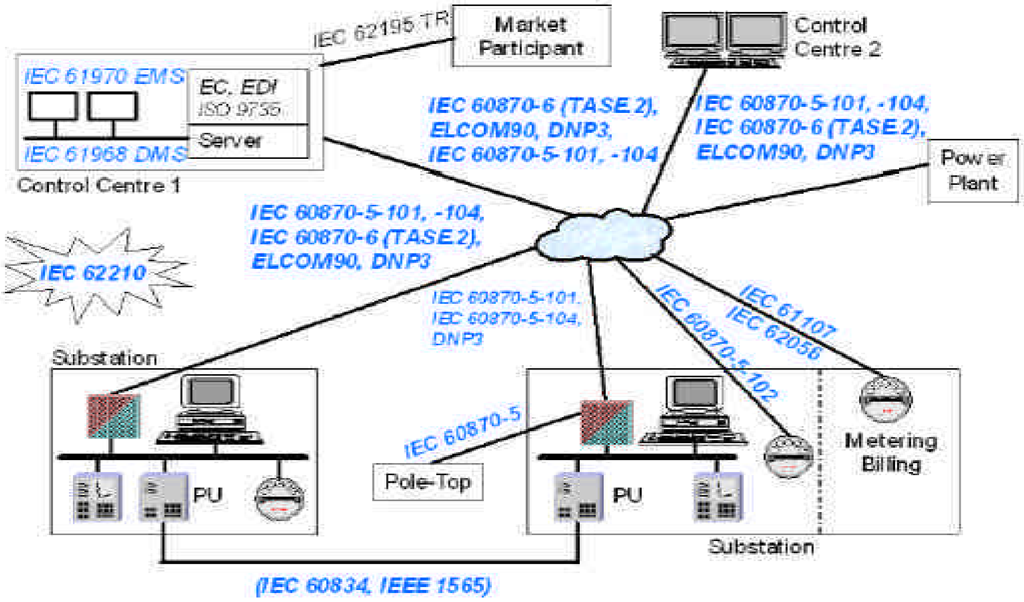


Figure 11: Standards developed in EPS

There are also different protocols to communicate between the entities of the SCADA system (IED, RTU and control centers); the protocols cover the physical and the middleware layer.

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.4.- Some protocol examples in Electric Power System Communication

The choice of the protocol depends on different parameters: a) System area, RTU to IED, RTU to master SCADA, SCADA utility to SCADA TSO, SCADA national TSO to SCADA national TSO center…; b)time to develop the installation

3.4.2 Expectation for future development

New ICT possibilities: the detected improvements and innovations in the ICT fields can be summarized as follows.

- Communication protocols: in communication systems there are different possibilities to choose a communication protocol (PPP (point to point protocol), ISO protocol, UDP, TCP, IP) unification of all the utilities' protocols in a universal one, the TCP/IP protocol.

- Programming languages: new programming language such as C#/.NET, which could enable the interfaces between applications. Due to the fact of security problems in applications based on the .NET-architecture, the use of the .NET-framework is not very clear at this moment by expected problems in security. It is necessary to remember that security depends widely on the operating system and Windows is not a one from the security point of view.

- Wide use of Internet: Public Internet is available everywhere but the main problem is related with security. It could be thought as the Virtual Private Networks or a Private Internet use with an intranet facility. This option seems easy to be developed in the future years.

- New equipment: faster processors and cards, Internet2, terabits and gigabits computing networks…

In conclusion, the main innovations in the ICT field are related to the way in which the applications are coded (language programming and protocols) and the available equipment. On the side of the communication media, there is no main improvement or innovation, the only conclusion that can be done is the extended use of the IP technology for EPS Utilities services.

The main goal of the CRISP experiments is the test of different ICT for further uses in different tasks inside the Electric Power System (EPS) at the Utilities level. These applications in the EPS are an application of fast fault localization and isolation (see CRISP D2.3 and D3.2), an experimentation of field test measurements using phase synchronisation system, and the achievement of a virtual power utility integrating DR units and controlled loads.

ICT components performance is a main aspect. The various functions are: acquisition, conversion, calculation, communication, process (distributed intelligence). The CRISP experiments have focused in the communication inside an IP network. Traditionally the communication is based on point-to-point links. The IP network is less traceable: addresses of clients and servers must be clearly defined to structure the communication exchanges. The channel of communication is synchronized at request between a server and a client to transmit a message. The intelligence distribution proposed with the insertion of an IP network should improve the computerization time of applications, thus it would be simpler to run a program to evaluate the state of a network part and then with all the results of the different computerization points determine the whole state of the network. The problem is the coordination and control of the different distributed intelligence in order to improve the operation of the system.

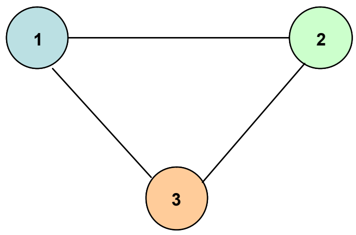


Figure 12: Point-to-point nodes connections

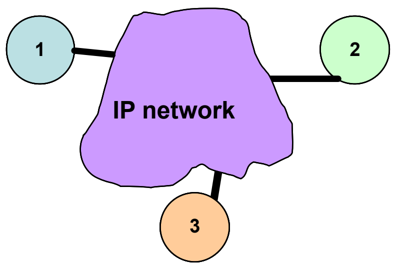


Figure 13: IP network nodes connection

The connection of the utilities entities, control centres and devices to a unique IP private network represents a change in the traditional philosophy of the SCADA system. Some ideas in this sense can be found in the present studies of the IEEE 1615 working group or the CIGRE SC 35. In the next figure, it is shown the communication between substations and feeders through a common communication network.

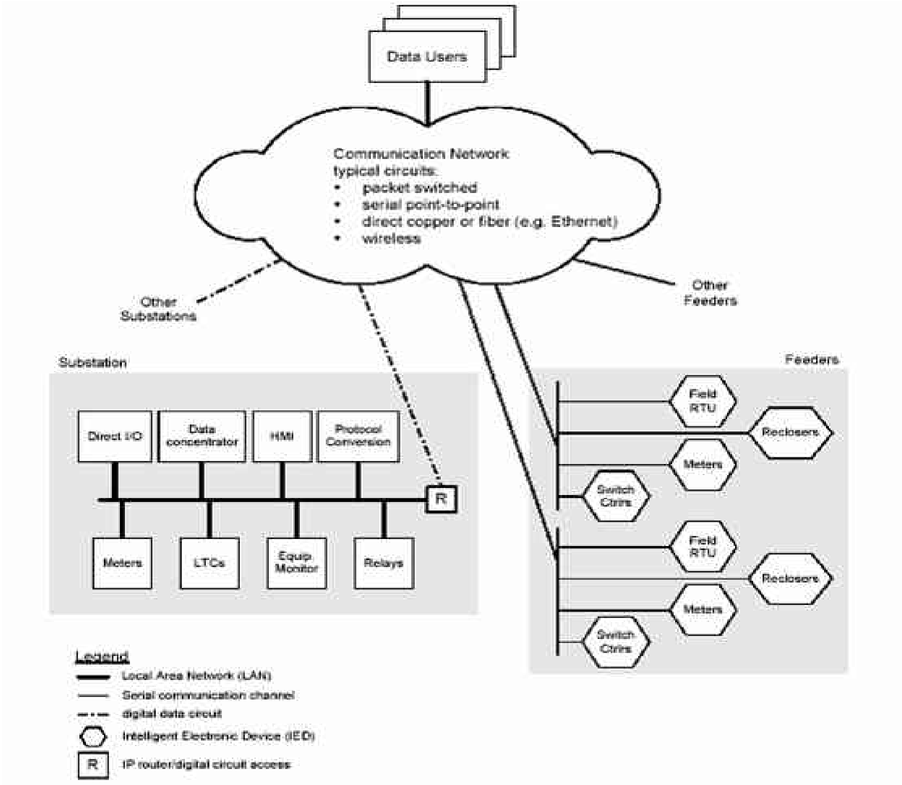


Figure 14: IEEE 1615 studies

The architecture is composed of 3 parts for different possible applications:

- Computer Network Architecture and Layout
- Data file Input from different applications (protocols with message-format and behavior specification)
- Node Application (fault finding help tool, MV cells control, Restoration coordination procedure…)

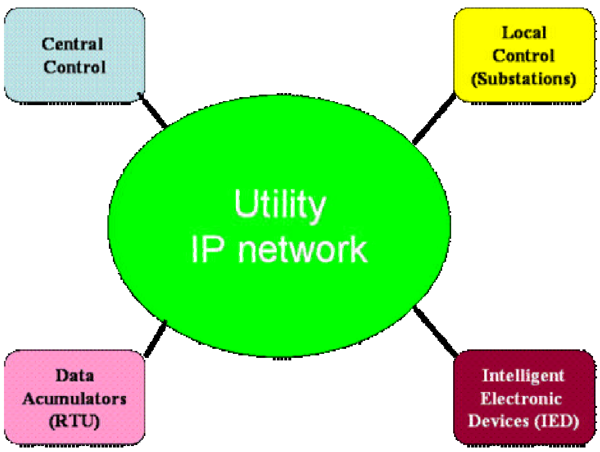


Figure 15: New architecture of Utility SCADA for communication, control and coordination

Points that have been studied: Protocols IP version 4 for the transport layer TCP.
Performance issues: Performance-Protocols-Throughout (bytes/second)-Latency (second)-Losses-Congestions.

- Message priorities: insertion of special number in the headers which will be able recognised by the routers and the routing of the message will be carried out faster. It exists the possibility to use some kind of software to develop the prioritisation (its implementation would take some time).

- Congestions simulations: overload of IP networks. The congestions in the Ip networks could have a negative effects in terms of the latency (seconds) and also in terms of throughput (bytes/second). If the throughout is reduced, the latency is also reduced and vice versa. The reduction of the speed rate or throughout could imply the loss of messages, these losses of messages make that the message are sent again until the reception and so the latency is seriously decreased. These aspects (loss, latency and throughout) are critical if the communication requirements are very restricted (like it is the case in protections with telecommunication).

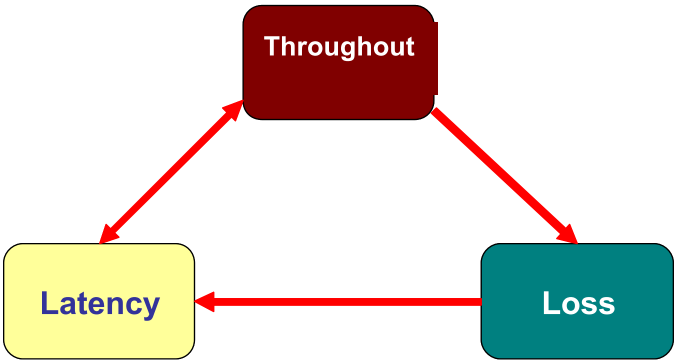


Figure 16: Performance requirements

4. Architectures and scenarios

4.1 Definition in the CRISP project

In the context of the CRISP project, “architecture” means a combination of EPS power and control description (including ICT component associated to its planning and real time operation), market mechanisms description, ICT network description (components associated to its operation and exploitation organisation) and institutional entities and rules description (laws and standards in application).
The approach is very large and needs as an integrated wide project. In the windows of CRISP, the partners have focus on power and control operation, possible market mechanism in order to integrate DG and DG-RES production and expectations in communication and processing technologies.

Various modes of operation of the grid should be considered in the presentation of a given EPS architecture: normal condition, critical situation for the control system or for the grid it-self, emergency situation for the control system or for the grid it-self. These three modes of conditions are possible for the three fields of interest (power and control for the EPS, market mechanism for the EPS and information system for the EPS). The nine basic running conditions lead to 27 possible states (3x3x3), the main expected one being when it is normal for the fields of interest.

When another running condition occurs, the structures and the mechanisms of the architecture should avoid more degradation and help the EPS to come back to a full normal condition.

The system must be less dependable in the sense of a common degradation of the running conditions, but also it must support a partial failure by mutual surrounding support.

A clear view of the time scale involved by the different proposed applications is needed: real time 1s, 15min, a day, a week and so on.

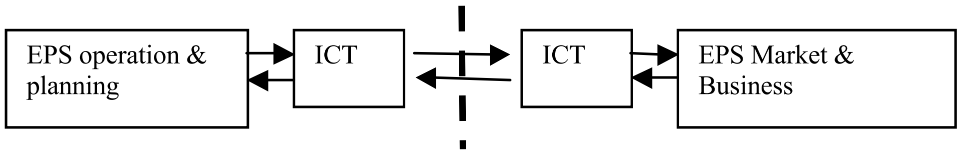


Figure 17: possible ICT architecture between Market and EPS systems

The architecture depends on the situation of the EPS, and should be analysed at least for the three different following cases: normal, critical and emergency situations.

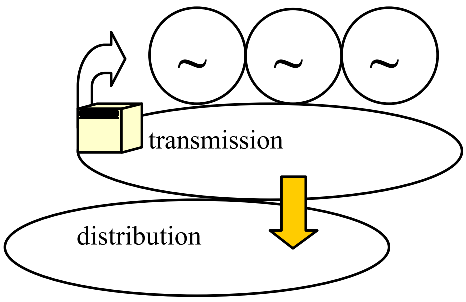


Figure 18: Traditional operation

The traditional structure based on transmission control and relative passive response of the distribution may be re-enforced by a more complex information system, enabling a large introduction of DG-RES (issue on power and energy prediction several hours ahead real time) and enabling a better sharing of constraints between the transmission and the distribution networks. New kind of services as DSM application may help the stake holders to reduce the power variation in different time scales (15min to 1 day), increasing at the same time the cost-efficiency for electricity supply and distribution.

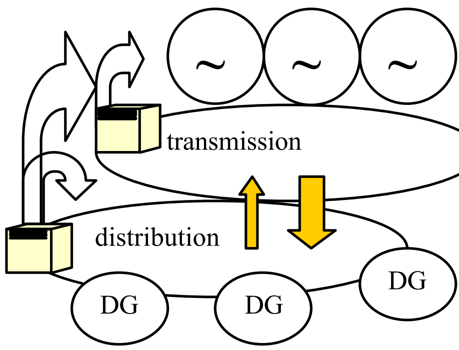


Figure 19: Operation in the future

The following figure shows the simplified view for nine operating states. Since the complete normal operation is not too much relevant for a very large system composed of millions of components, the critical operation is associated to a high level of troubles making the whole system endanger temporary. The concept of n-1 robustness (described in [D1.3] and used for EPS devices in large power plants and transmission operation) is no more interesting in the field of the distribution network with our scope of integrated EPS devices, local markets and ICT devices. The network is operated in a real time context, leading the system to be adapted progressively to any situation occurring: concept of flexible network, 'updated state n' robustness.

The failure modes for each main field may be connected to the failure in another field: problems in ICT field leading to a market disturbance (due to apparent unbalance between demand and production), problems in market field leading to an EPS critical operation.

The 27 possible states associated to categories 'normal', 'critical' and 'emergency' are shown in the following figure (the normal state for the three fields is expected to be the main state and the line is marked in red on the figure).

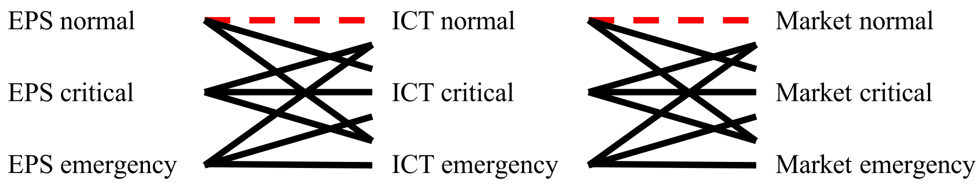


Figure 20: combinations of the failure modes

The fields ICT is dealing with the two main aspects described below, technical operation of the EPS and economical interface between the different actors of the market. The system is naturally designed to be stable field by field:

- protections in the EPS allow the network operator to limit the failure extension in its lines (general aspect of selectivity),
- market rules are set to meet technical requirements if needed (case of critical situation in the EPS), the scenario assumes there is enough average production to meet the demand (possible problem during the annual or seasonal peaks),
- ICT are designed and configured (hardware and software) to meet reliable criteria for 24h/24h work process, failure extension on networks is specifically designed for the purpose of technical (and local) applications,

In the existing operation of the network, a general blackout on EPS has a direct impact on the local EPS, on the local and on the global market. Generally the main ICT dedicated for EPS operation are maintained several hours (batteries and back up means).

In the future operation of the network, the cells of network are designed for partial autonomy and automatic local management of the energy: the cell includes some aspects of ICT local network area dealing with local market management and with local technical management (local EPS operation and maintenance).

In term of failure analysis, the electrical system is generally detailed into many parameters allowing the designers to evaluate different topologies of EPS combining different types of equipment. The parameters generally detailed are the failure modes (identification of the main events making the equipment no more available), the failure rate, the mean time to failure, the mean time between failures, the repairing time. These parameters enable to evaluate the availability in a given location of the network, and to take measures to make the system coherent with the expected level of service continuity. How to deal with the same kinds of parameters for the ICT field and the market field? As for the case of EPS study, the possible way is to describe in detail a study case and maintain the system in real time operation to identify the parameters for the given application and the real used equipments.

As indicated in the figure 20, there are different levels of consequences from the continuous variations occurring in the network, leading into various steady-state conditions. At the scale of a cell and for specific application including market mechanism the complete study may be achieved, but each failure needs to be listed and analysed during such experimentation. Depending on the real development of the application, some disconnection may be introduced to avoid coupling and extension of the disturbances. The main point remains around the ICT development and dedicated programs for the application (EPS devices and market rules tend to be rather stable when defined and successfully operated).

4.2 The Intelligrid architecture in the USA

This approach is mainly oriented on the ICT architecture description dedicated to an exhaustive list of EPS applications. In some industrial sectors a common framework for business operations has been developed. For instance, in the oil industry a comprehensive information architecture has been established and favors application integration and interoperability. In order for an architecture to be valid, essentially object models, application logic and events and responses for systems have to be described.

In the US, in 1991 the UCA (Utility Communications Architecture) was established, as a generic descriptive framework for utility operations. The architecture, then, was the incentive for the development of a number of standards in the utility field. As a successor to this architecture, recently a follow-up was developed as the results of the CEIDS-project, the IntelliGrid Architecture [26]. The architecture was the result of an inventory of 400 utility applications in a number of electricity infrastructure application domains and from existing standards. From these, an extensive, abstract framework is derived to get a common view on how to structure these applications and to get ready-to-use design frameworks for applications and a common reference for the development of standards. The view is derived using methods, well known in information analysis and system architecture as used for developing application software. The applications are mapped to object models using use cases via UML (Unified Modeling Language). The distributed operation of the applications is modeled with RM-ODP [27]. Using a combination of these two techniques, for each work area in the electricity sector, an architecture environment is generated including all necessary object models, links between these models and inter-process communication behavior. This enables a generic approach for applications and the possibility of reuse on the model level. The approach is suited to be implemented using WEB-based technology like XML and inter-process communication/context switching techniques like WSDL/UDDI and SOAP. A number of growth areas have been considered especially, mimicking the current CRISP-project:

- Wide area measurement and control. Special emphasis has been on a pro-active, self-optimizing grid and that has built-in reliability functions.

- Advanced Distribution Automation. Especially with regard to incorporating DG-RES resources w.r.t. fault detection and localization and pro-active response of distributed systems with a larger fraction of DG-RES.
- Customer portal. The portal facilitates real-time pricing, demand response, metering and mechanisms to implement market rules as well.

4.3 A few scenarios of architecture evolution

4.3.1 Architecture in France viewed by IDEA

4.3.1.1 Current structure

The last years are marked by thorough changes in the regulation for the electricity and in the market structure taking into account new stakeholders. The separation into separated activities for the production, the transmission system and the distribution activity is achieved. The electric market will be completely liberalized in 2007. The public TSO (transmission system company) is now independent and move on playing a major role of power balance in the national system for the long term.

HV and VHV system and customers

The control operation is shared by a main control room (national overview) and 7 regional control rooms (local VHV and HV networks). The EPS control is structured into four main layers: the main control room, the seven regional control room, a local aggregating system (called PCG and PEXI by RTE) and local installations (VHV and HV substations). The EPS technical description is detailed in [D1.3].

The main control room for the 400kV and 225kV is equipped with the SNC (‘Systeme National de Conduite’, meaning national operating control system) that allows very fast processes for analysis or monitoring purpose: 10000 remote measurements and 26000 states signals per 10 seconds may be updated and taken into account. The communication with the distributed devices among the national grid is achieved with a system called Artere (secured redundant networks using x25 commutators and TCP/IP protocols). This communication network is designed for a very high data flow to the control rooms: 20000 remote measurements and 80000 states signals per 10 seconds for the main control room, and nearly 5000 remote measurements and 130000 states signals per 10 seconds for the regional control rooms. This secured network has an availability of 99.96%.

A part of the electric market is now based in an open adjustment market since 2003: the real time difference between the expected daily consumption curve and the real one is compensated with this market. The balance responsible is a main actor making production and consumption balance in a daily sequence (productions planned a day ahead with a based time-slot of half an hour and 6 tariffs time-slots). Today there are nearly 70 balance responsible actors. They are dealing large amount of energy (this market does not concern directly MV or LV producers). Each large producer or large consumer connected to the VHV network may contribute to the market by scheduled offers (power (offer must be >10MW)/ time-slot/price) to the TSO with possible corrective requirements every two hours, the real time need of the TSO being to the increase or to the decrease of power. The most interesting offers are used by the TSO sending orders back to the generating units or production aggregators. The balance responsible is contracting large amount of energy for duration of a few weeks, a few months or a year and is allowed to trade, and make exchanges with other balance responsible: this kind of market 'de gre a gre' leads to nearly 250TWh energy exchanges during 2003 (compared with the nearly 450TWh consumed in France during the same period). An additional market is the electric stock exchange called Powernext (as Nordpool in Scandinavia or EEX in Germany). During 2003 the amount of energy provided with Powernext was nearly 12TWh. So the price for large producers and large consumers is now varying and is defined by the market.

MV system and customers
For the customers on MV various types of contracts are available and discussed directly with the distribution network operator. The tariffs for renewable energy for installed power below 12MVA are now fixed by the regulation. In the main part of the distribution network the information and the communication means are concentrated in the HV/MV substations for DNO applications, mainly for automatic protection systems. A few EPS switches are remotely monitored or controlled, they allow to boost the manual fault location, isolation and reconfiguration. A system has been implemented by EDF, called ACR ('Agence de Conduite Régionale' meaning regional operating control room) to improve and simplify the interface between the operation of the VHV or HV network (400kV, 225kV, 90kV, 63kV) and the operation of the MV network (20kV). This structure leads to nearly 30 Medium Voltage control room in France. The main part of the electric market is now liberalized (except for residential consumers until 2007), but the eligible customer that want to keep the previous fixed tariffs system is allowed to.

LV system and customers
The main part of the current consumer electrical market (residential loads) is based today on simple and long term contracts, the tariffs being reviewed every year by the utility. The metering and billing system is based on a manual record done periodically twice a year, with intermediate average interpolation. With the automated monthly payment the real metering is done once a year and it defines both the annual payment balance (difference between the advanced payment and the real consumption) and the monthly payment for the following year.

The market mechanism for most of the DG and DG-RES is based today on fixed prices given by a national regulation.

The traditional metering installation involves two main choices for the residential customer:

- the level of power installed (the instantaneous power is limited under 36kW by the setting of the operator circuit-breaker, the standard values being 3kW, 6kW, 9kW, 12kW, 15kW, 18kW for the flat or the houses),
- the type of metering system with one tariff or two tariffs (day / night),

For decades a lot of people are using electrical heating water systems (50 l, 100 l or 150 l water tank in general) that could be an important part of the residential electrical consumption. These customers have financial interest to choose a double tariff metering and to use the low night tariff to heat the water. This incentive was strongly used in the past and allowed the operator to maintain a global important demand during the night.

4.3.1.2 Near Future

During 2007 all the French customers may belong to the liberalized market. The law of the 3th day of January 2003 made some amendments to the important law of the 10th day of February 2000 about the electric structure in France. Some points deals with the access to the regulated networks by anyone, with the principle of agreement and offers from the production units. The distribution customers that belonged to the regulated markets have the choice to stay in the same state contracted with the DNO or to enter into the liberalized market with the trader preferred. Since decided for the liberalized market the customer cannot go back into the previous existing contracted situation. The various cases have been investigated: even if the trader can no more provide energy to the customer, the system borrows the energy for the duration of finding a new trader with adapted tariffs.

The customers in the near future begin to buy more and more reactive or controlled loads in order to manage more carefully their internal energy consumption.

New kind of market between large producers and relatively large industrial consumers appears: in order to have low fixed price for relative long term, direct contracts are signed between them. The induced stability for the price and so for the needed investments allows normal improvement and environmental effort in the production units. Contracts around 20TWh were discussed during round table in July 2005 with the public minister. A main existing principle continues in the near future: the 'stamp tariff' meaning that the price of the electric energy at VHV is lower than at MV and LV, taking into account the cost of transmission and distribution saved.

The aggregation of the existing operating control rooms into 30 main operating control rooms with associated teams of network exploitation is maintained for a long time, maintaining a strong link between operation activity and exploitation activity. The fields crew is highly equipped with dedicated ICT enabling secured and fast repairing duration: for instance the operating system may send exact location to the repairing team with GPS associated data and may validate the secured state (certain isolation from any power source) of the section isolated for technical work.

4.3.1.3 Far Future

The network is highly automated and controlled from the LV to the VHV, for technical operation purpose as for trading and billing operations. The main change appears in the distribution network. From a DNO point of view and for technical performances, it may be structured as included and adjacent cells that manage internal electrical constraints (exploitation and real time operation) and many internal energy optimizations. The amount of controlled or reactive distributed loads and DG is relatively high (nearly 50%) with a nearly 20% DG penetration rate. The reactivity of the distributed loads and DG may be based on DNO signals, aggregators signals, direct price signals or electrical signals (frequency or voltage). The electric market takes into account the prices of transmission and distribution, leading to the creation of regional markets for distribution consumers and producers. This regional market exchanges power with the national and the European markets. It is managed by a responsible of exchange that is associated with a national balance responsible, a part of the energy contributing to the adjustment market: the power produced or consumed hour by hour is scheduled from day to day, with expected accuracy due to internal consumers, producers and weather conditions (wind, temperature, sun…). The base energy exchange for this regional market is negotiated through long term contracts at relative stable price. For the very large producers and consumers connected to the VHV the structure is quite similar to the current structure, but with larger amount of energy exchanged between the actors. The aggregation of producers (VPP or LSVPP) begins at the LV scale. The optimization of the capacities of distribution and production entails some local difficulties facing quick load demand increase: temporary high local energy prices, reduced after local investment in structure and local production. The price indication becomes a general parameter for the strategy of the consumers (real time, daily and seasonal consumption, better combination of power installed and energy consumed) and of the DNO (dealing with local investments in short term and medium term). The optimization of energy consumption is generalized in the whole system and industrial energy optimization is generally contracted for remote monitoring, partial control and maintenance. This role of energy optimizing service is extended to a large part of building and residential customers.

4.3.2 Architecture in the Netherlands as viewed by ECN from a commercial SDM-perspective.

4.3.2.1 Current structure:

The current electricity infrastructure has been described in the first deliverable, [D1.1] Annex A, of this project. The Dutch grid has a circular topology with a relatively large proportion of underground transmission and distribution capacity. Import from Germany and Belgium/France accounts for 10-15 percent of supply. Looking at the national generation side there is a large proportion of gas fired co-generation and waste incineration plants.

Production is, for a substantial part (30 %), at places below the transmission level in the network. This occurs near production facilities of large industries, in horticultural areas, in combination with heat and carbon dioxide production, and in residential areas in combination with heat distribution networks through large scale CHP. Wind energy is also connected to the MV level and lower. In the nineties of the previous century, the onset to these developments was government subsidized because of the primary energy efficiency gain due to simultaneous production of heat and power using natural gas, abundant in the Netherlands. In the current market situation, the rapid increase of gas price as compared to the electricity price has switched the usage of this mechanism from production, induced by requirements of the primary process, to optimized production within the external market context especially during price spikes on the Amsterdam Power eXchange, the day-ahead market. With respect to wind energy, nearly all locations suitable for production on land already are occupied. Plans are currently in development for realizing large-scale offshore wind energy parks. The Netherlands were the first to plan but the last to realize offshore wind parks. Connection capacity currently is under construction for a bi-directional DC transport line to Norway.

The grid is operated by 9 distribution companies and 1 national grid operator (TenneT). Because of the large amount of co-generation, a strong link exists between heat production and storage and electricity production. Primary energy efficiency leads to joint generation of these primary energy carriers. In general, the electricity demand in the Netherlands is increasing steadily as is the power factor. In view of the total capacity, the network is operated more and more to its limits. In 2003, in summer during cooling capacity problems of thermal plants, and in 2005 in winter during strongly varying wind supply conditions in Germany near critical capacity problems occurred and prices were found to soar. This is illustrated in Figure 21, where prices are plotted three dimensionally over a time-span of a year. It can be seen, that the spiky character in 2003 is lower during 2004; in late winter, in March 2005, however, the spikes appear again due a sudden cold and snow period. Portfolio owners using smart operation strategies of installations increase the value of flexible generation and demand capacity. An example of distributed balancing services is given in [24].

In the Netherlands, ICT Network technology and computerized applications are used for operating the network using SCADA-based EMS and DMS. To this end glass-fiber based communication network stretches from the HV-network to the transformer stations on the distribution level. Another type of ICT-applications is more market oriented. Especially large consumers and producers are active on the power market. Clusters of demand and supply are managed in portfolios of program responsible parties. These parties are operating on a number of markets, depending on there flexibility in demand or supply. Having real-time information is increasingly necessary for portfolio optimization. Metering and settlement of contracts and predicted programs is done on the basis of measured data on intervals ranging from 5 minutes (for large consumers) up to 1 year (for small customers). Meter read-out intervals vary from real-time to meter readings to be estimated by end-users with yearly intervals. The metering business has been liberalized as well in the Netherlands. Dedicated metering companies may be operating in the market, but at this moment, essentially, network companies fulfill this role. Metering is necessary to settle market cost and to settle distributions costs, which are charged separately to the customers. The market price development in the Netherlands, as shown in Figure 21, markedly differs from the development of prices in other countries. In Figure 22 market price developments are given for Norway, a hydraulic EPS, and Western Denmark, a hybrid EPS with large interconnection transport capacity. The plots show, that flex-capacity on the hour scale has a much larger value in the Netherlands as compared to hydro EPS-systems, where price peaks extend during several days.
Apart from the APX-market, the control power and the imbalance market reveal opportunities for exposure of flexible demand. The optimization target then is to:

- reduce the deviation between the day-ahead programme and the realisation
- counteract the nationwide sign of the imbalance
- include expected/predicted imbalance cost in determining how far to counteract the imbalance
- offer imbalance compensating power to the system operator

4.3.2.2 Near future:

At this moment, it is still favourable to invest in wind energy. The technology is in a mature stage now, but the subsidies are decreasing while the market spikes are decreasing and production peaks do not coincide with APX-peak prices. A number of offshore wind parks will be added to the generation infrastructure. Transport capacity to neighbouring countries will be increased and new transmission lines will be constructed. The proportion of combined heat power in the horticultural sector will not become larger due to current high fuel prices; for utility buildings and heat distribution networks near residential areas, however, the contribution to the EPS will increase. The largest EPS-architectural shift will be the increased amount of small generation units at small customer premises. First commercial versions of Stirling engine powered micro-CHPs have a heat generation covering the heat and hot tap water demand of a typical Dutch household while simultaneously generating 60-70 percent of the real-time electricity demand. For fuel cells the amount of electricity as compared to heat is even considerably larger. In combination with Photo-Voltaic cells, introduction of these new technologies will create 'hotspots' of electricity generation. Together with increasing possibilities for local storage of heat or electricity the challenge exists for ICT-applications operating either 'behind the meter' or belonging to a commercial cluster (Virtual Power Plant) with market exposure to reach a common objective. Demand side responsiveness at all levels of the grid then will have increased substantially.

ICT facilitates exposure of demand and supply to (real-time) market incentives. One way to implement these mechanisms is via residential gateways operating a WebServer. With a WebServer based architecture, applications may transparently be integrated into a SOA (Service Oriented Architecture)-framework operating from a centrally managed and maintained place. SOA will also facilitate interoperability with back-office ICT-applications and utility data warehouses and information systems of actors in the electricity market. Webservers and SOA-based applications will form the basis for the middleware of next generation power related applications.

4.3.2.3 Far future:

In the Dutch vision on generation and grids for 2050, 25-30 % of electricity is generated using renewable resources. The main generation form will be based on windparks (8000 MW in 2020 extending to possibly 10 GW in 2030). Intelligent ICT-components will be necessary in the grid for security of delivery and autonomous control. In energy transition scenario's up to 2050, in the Netherlands, a very significant role is attributed to distributed generation and to local generation. I.e.: close the point of consumption. Furthermore a diversification of electricity producers is foreseen in order to spread risk. Green energy will be based mainly on wind and solar energy. These systems will be fed-in on the distribution level or 'behind-the-meter'. Further liberalization will make long-term investments in large generation capacity not attractive, because the payback-period is uncertain. Energy efficiency measures are conducted to avoid transport losses and to deliver simultaneously the right amount of heat and electricity to the customer at the right place. In the built environment, for newly built dwellings, the direct conversion of natural gas and electricity to heat or cold will vanish. The reduction rate in the renovation sector will amount to 50 %. Local generation will amount to 60 % renewables for newly built houses and to 10% for the whole building sector. Integrated energy related systems will have to be used targeting synergy between demand and supply. The current interest in electricity-based mobility in the US is one of the first signs, which indicate, that these developments actually may occur sooner than expected and will lead to cost-efficiency and energy efficiency [25].

In terms of ICT-architecture, the traditional hierarchical control system will be replaced by a bottom-up system with semi-autonomous parts operating at a number of grid levels. This architectural autonomy and distributed character nicely fits with the agent-architecture as used in the algorithms tested during WP 2.2.

Main problems then, are the accommodation of a large amount of intermittent power (35 % is considered to come from the combination of off-shore wind parks, residential co-generation and PV-solar) and the large increase in the number of feed-in points in the grid. Supply and demand of electricity will not be simultaneous. Power quality in the grid deserves more emphasis locally because there will be fewer possibilities to solve these on the central level. Distributed coordination with millions of small energy sources will require bottom-up coordination and plug-and-play components in the grid which get their context and operation mode using discovery protocols, as currently becoming the standard in Internet based ICT-environments.

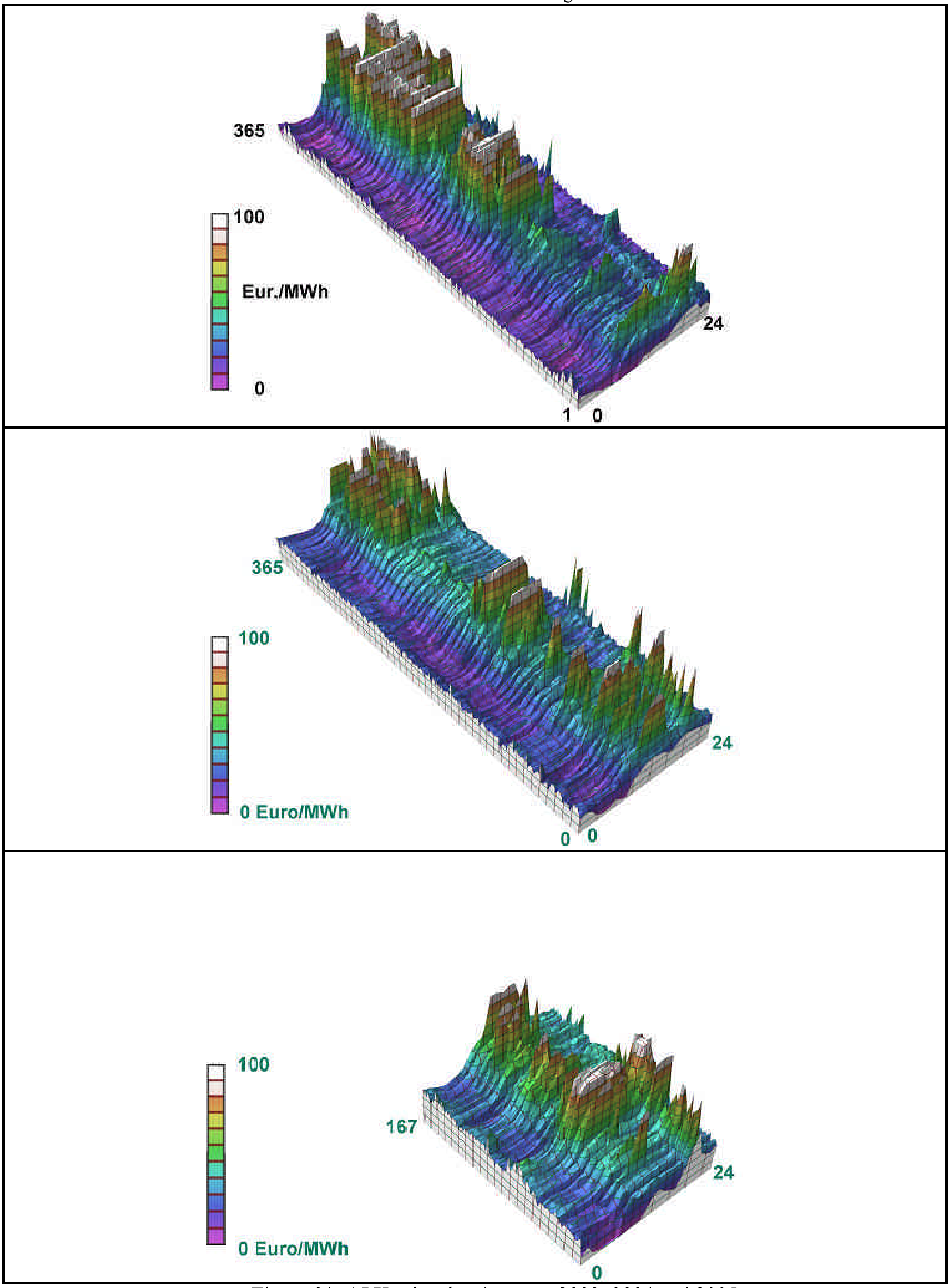


Figure 21: APX price development 2003, 2004 and 2005.

0-24 corresponds to the time-of-day; the other axis indicates the day-number.

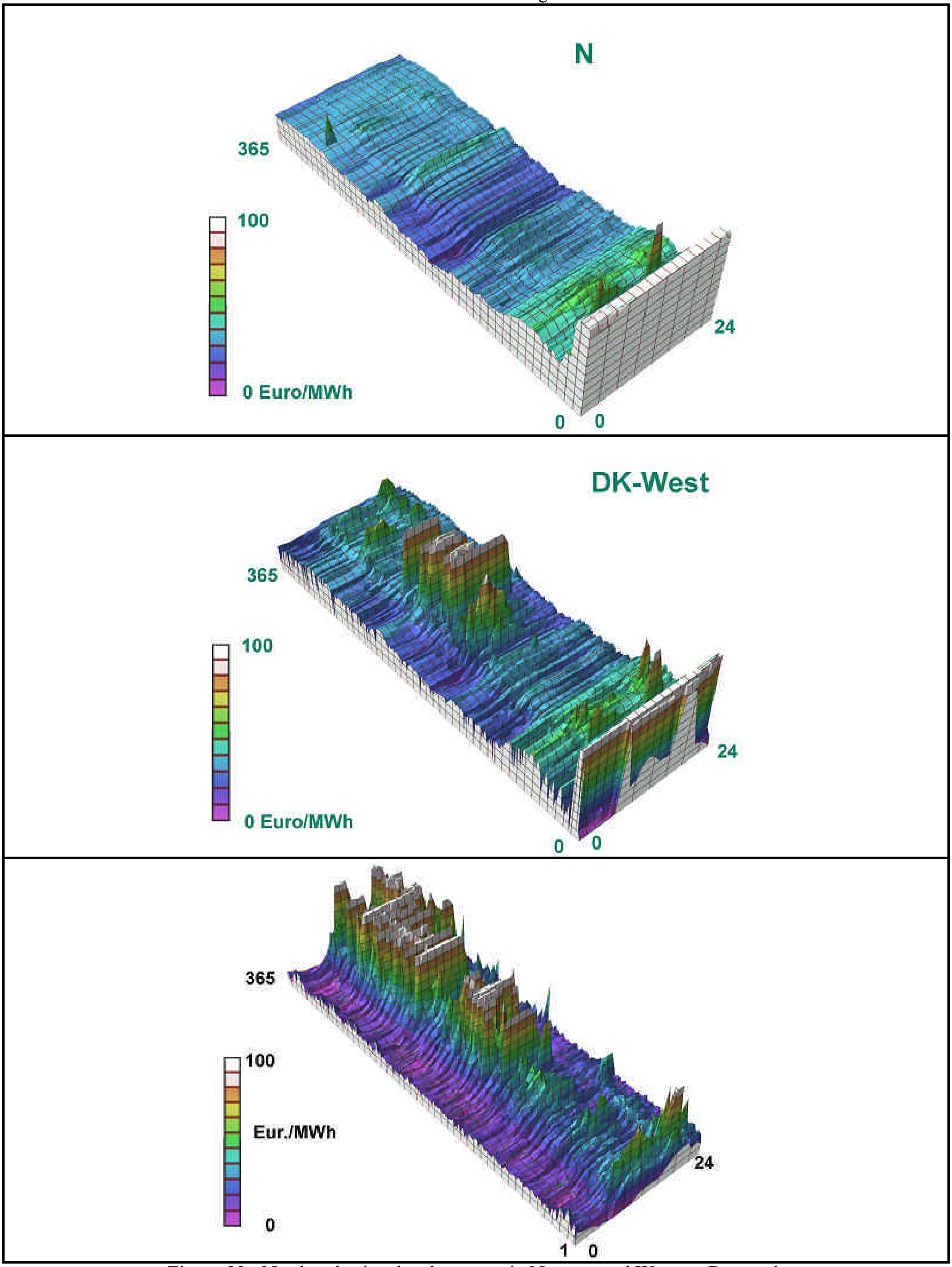


Figure 22: Nordpool price developments in Norway and Western Denmark

The figure 22 shows Nordpool price developments in the Norwegian hydraulic system and the West Denmark mixed thermo/wind system compared to the APX-price developments.

4.3.3 Architecture in Sweden viewed by Sydkraft

Sydkraft's view on the future design/structure of the Swedish power grid

4.3.3.1 Current structure (timeframe one: present - 2007)

Consumption

The total installed DG capacity is 250 MW in the Sydkraft's grid and in Sweden totally 400 MW producing approximately 0,7 TWh/year out of a total consumption of 150 TWh. The DG consists of almost solely of wind turbines. Hence the transmission/distribution is traditional in the way that the electricity comes from larger generations units (hydro: ~45 %, Nuclear: ~45 % and CHP ~9 %), are transformed up to transmission voltage and distributed via 130-50-20/10-0.4 kV transformations and wires to the end-user.

Production

The European Union has stated a goal stating that 4,5 TWh/year of the electricity in Sweden should come from DG by the year 2010. The Swedish government has stated a similar goal stating that DG should produce 10 TWh/year by the year 2015. These goals, if achieved, will increase the amount of DG considerably, especially in the southern parts of Sweden creating a situation like the one in west Denmark, where DG and prioritised production occasionally creates a surplus of electricity forcing an often uneconomical export to Norway or Germany.

Today Sydkraft have little or no control over the DG in our power grid. The available means of control are that we have some control over the protection settings of the wind turbines regarding over and under frequency/voltage/current protection. We can also disconnect the DG by opening the circuit breaker at larger DG units.

The solutions we see to solve these problems are a combination of load and production control in order to be able to handle a high penetration of DG in our power grid and at the same time reduce peak loads and to lower the strain of the power grid. An important part of this control is the use of hourly updated prices both for consumption and production.

The next 2-3 years we foresee that more than 95 percent of the new installed DG in Sweden will be wind turbines. Due to political uncertainty regarding to subsidies to wind turbines we expect an installation of 150-250 MW new DG in this period in Sweden. As the production cost of wind turbines are very low (0,3-0,4 € cent per kWh) it lies in the nature of wind turbines to produce as much as the wind allows. A consequence of this is that regulation through pricing probably will have no effect. To maintain stability and reserve power in case of unpredicted production from the wind turbines we foresee a main focus on prediction of the production from the wind turbines through careful meteorological studies and the need for reserve production in large plants to functions as spinning reserves. This spinning reserve could come from the hydro plants in the north of Sweden.

4.3.3.2 Near future (timeframe two: 2008 - 2014)

Consumption

By reporting the Nordpool price by relatively uncomplicated and cheap one-way communication to participating households every hour the daily peak loads could start to be minimised with the use of household agents controlling the loads in these households. The controlled loads could be room and tap water heating, refrigerators and freezers witch consume the larger parts of the electricity in a typical Swedish household.

By comprising the electricity price, outside temperature, the day of month (weekend or weekday), typical electricity price patterns, the settings of the user et cetera the agent would try to optimise the load pattern in order to minimise the energy expenditure. This could be done by lowering the temperature in freezers and refrigerators a couple of degrees when the electricity is cheap during the hours before the morning peak (industry start-up) and at the same time heating up the house (or certain rooms) and the tap water a bit extra. This would create an energy buffer so that when the electricity price goes up during e.g. a weekday morning, the house could lower its electricity use, sawing money for household, lowering the load peak, the stress on the power grid and transmission losses. Corollary the need for reserve power plants during peak loads would be reduced.

In order to get this system in place a reward through lowered yearly fees could apply to participating households, and as an indirect consequence non-participating households would get a slightly rise in their yearly fee. Alternately the electricity cost reduction could be motivation enough fore the households to invest in the apparatus needed. To get an acceptance for this passive indirect load control, it is important that the consumer's level of comfort are maintained.

The system could also comprise the voluntary option for the household to be completely disconnected, or to "emergency lower" their consumption, should the need arise due to a fault in the power grid. Every time this function is used the household would receive some kind of economical compensation.

Production
In this timeframe the level of subsidies to DG will be stable and the public awareness of the environmental will create a greater demand for non-polluting energy. 800 – 1 500 MW of new DG will be installed in Sweden. Wind turbines will still be the predominant form of DG, but some households will start installing micro CHP's. The total DG production will still be so small that "traditional" production control will still be implemented.

4.3.3.3 Far future (timeframe three: 2015 - 2024)

Consumption
In 10 years stabile two-way communication will be standard in most households in Sweden due to the demand for hourly readings of electricity meters. Hence the one-way communication from timeframe two are now replaced by two-way communication (ICT), enabling households to act individually as bidders on the electric market, partially sizing their consumption and, if available, production from micro CHP's according to the price of electricity. The penetration of micro CHP's in households depend very much on the economics in installing a CHP (benefit for the end-user using CHP versus investment on the equipment). Concerning the interest in load management, the consumer has to have an (economic/environmental) incitement to contribute to its development, otherwise the different technologies will probably not get the wanted breakthrough.

Production
The new installation of DG in this period amounts to 2 000 – 3 500 MW. The composition between wind power, CHP's and other sources of DG is hard to predict, as the CHP's needs easy access to cheap fuel which requires an adapted distribution net.
This amount of DG raises the need for control of this production. Therefore we see the need to be able to at least monitor any DG over a certain size, perhaps 300 kW, in order to maintain stability and control in the grid.

4.3.3.4 General view point

From Sydkraft's point of view the economical use, and thus a main driving force, of load and production management, passive (timeframe one and two) and active (timeframe three), lies in lowering our transmission losses, postponing grid and production investments.
For the consumer the drive probably also have to be at least partially economical. Economical or environmental, the consumer needs a reason to be interested in the system, or else the system might not get the preferred penetration. An other important property for the consumer is that the system remains as simple as possible (easy to connect, easy to use, etc…).

4.3.4 Architecture viewed by ABB

The cell-based architecture, as pioneered in CRISP for DG using ICT, has been presented by BTH at a work-shop at ABB in Västerås, Sweden on May 10, 2005. From the reaction to the cell-based architecture, it is clear that existing solutions for distribution automation and energy management do not fit its distributed and autonomous character when DG is introduced in scale. However, technology, i.e. ICT, is also enabling adaptation to the new requirements and ABB is promoting technologies, which are leading in this direction. Examples:

- Products using open and vendor independent communication and application standards for protection and control, energy management and distribution automation.
- Network management solutions with a control span from high-voltage to low-voltage in one integrated system.
- Introduction of WAMS - Wide-Area Monitoring Systems, for real-time grid and load control.

- FACTS (Flexible AC Transmission Systems) and HVDC (High-Voltage DC Transmission Systems) applied in a more distributed manner.

ABB will continue to work with the electricity industry also beyond this. It can be assumed that aspects of future work will include:

- Interconnections
- Management systems for vertically integrated and disintegrated electricity industry participants
- Decentralization of grid, load and generation management
- Load control to match supply/demand

Interestingly, these aspects are interdependent so a convergence between technologies and equipment can be expected.

4.3.4.1 Interconnections

Interconnections are promoted in Europe by the EC and ABB supports this. In USA the latest legislation is trying to promote investment in infrastructure. ABB argues that interconnections can serve as alternatives to generation investments while at the same time keep or improve security of supply, [*Breaking the Gridlock,* Public Utilities Fortnightly, July 2005, Mr. Rana Mukerji ABB]. While the argument against interconnections centers on increased complexity and higher short-circuit power, ABB argues that existing and future technologies and solutions can manage the additional complexity (e.g. ICT for DG) while the higher power available is easier to manage with strong interconnections and, ideally, using HVDC interconnection technology. Pooling of RES capacity in an interconnected network has potential to further enhance environmental benefits from RES in general and DG-RES in particular.

4.3.4.2 Management Systems

Management of electricity assets is moving from enabling technology to becoming the spearhead of competition. When transmission system operation is becoming an alternative to generation investments and when power trading and balancing services, black-start, etc. can be provided in a central IPP plant or in a DG cluster, the management aspect becomes critical for commercial success. Just as for ISPs (Internet Service Providers), the only remaining natural monopoly will be the last-mile access, where regulation will tend to remain cost-based. Oversight (ISO) and related trading/reconciliation systems will need interconnection to the same management systems. LSEs (Load Serving Entities) will manage metering services and billing etc. The industry structure will remain complex for a transition period but industry participants must start to adapt to bulk transport of electricity and to DG.

4.3.4.3 Decentralization

While interconnections tend to make hierarchies deeper, the organization of the industry will work in the opposite direction. A solution for operation, trading, reconciliation and billing for two parties is easy to generalize to several parties. Integration of one DG plant in an EMS (Energy Management System) zone is difficult if the SCADA system is molded to a regulated vertically integrated utility, but as soon as one DG plant is in, the threshold to add another is substantially lower. The MV cell structure, as proposed in CRISP, will make system design more complex, but the increased information depth from ICT, used to enable DG insertion, will more than match the added complexity. If the MV cell can assume some of the historically centralized applications such as balancing, system protection and load control, then the decentralization could open paths to a box-in-a-box structure. Interconnections on any voltage level define the structure in real time between nodes representing LV-cell/MV-Cell/HV-Cell/Plant-Cell. The final evolution would be totally autonomous cells self-configuring their optimal nodal interconnection, much like a cellular mobile phone network.

4.3.4.4 Load control

Although electricity demand is lagging GDP growth in industrialized countries, third world GDP growth will draw more of the primary energy resources henceforth, and for them, electricity demand tends to lead GDP. Furthermore, more and more of the demand will strain the installed capacity in generation, transmission and distribution. The summer peak effect in southern Europe, Middle East and USA is becoming the bottle-neck for grid operation and managers dread each new season. Simply put, the installed load will outgrow production capacity globally and locally. If more of the supply comes from non-controllable DG sources (wind, solar) the demand – supply matching can become a key component. Today the available technology is limited to controlled and emergency load shedding (brown-out, rolling black-out). If the effects on load will grow when DG provides a larger proportion of the electricity, today´s load control will not suffice. Two steps are possible:

a) Use of price information to intelligently shed load which is uneconomical (price<utility)
b) Match demand to supply (demand – supply matching). Send price/quantity curve to market, receive call volume and drop loads which are uneconomical

4.3.4.5 Conclusion

ABB will study the possibility to do intelligent load shedding in CRISP. It will be a study on the pretext that the EPS will be characterized by more interconnections, availability of business management systems and more decentralization of control. The device used for experiments will be a product, which is suitable for management of a MV Cell in general, and suitable for load control in particular.

4.4 Possible future architecture: ICT structure for EPS cells

The architecture studied by the CRISP partners assumes a large incoming of dispersed generators and deep change in the market process. The very large increase of needed information exchanges involves adapting and developing the information system and network drastically. The expected changes in the electrical trading and services offers and also in the information network entail some deep possible changes in the EPS operation, exploitation and design. The following description assumes a far future with a high level of distribution automation. The ICT is highly distributed in the network: it is already the case in the transmission network, but not at all in the distribution network. The ICT developed and installed in the distribution network are based on low cost solutions, with performances adapted to the various function involved. A studied solution for communication and information system is using open source software and operating systems. The network structure must be designed in a combined approach for the EPS topology and technical operating functions, and also for the information and control system. This combined approach enables to reach simultaneously targets of global installed cost and also of reliability (for the EPS functions as for the ICT functions).

Two main steps may lead the present system to a new architecture including all studied aspects. The first step may based on the existing regulated economical power dispatch associated to a specific information system, based on cells concept, enabling to deal with a high number of actors. In order to coordinate operation of the grid, more ICT-components will be present in the LV and MV grid, communicating in a bottom-up fashion. The second step may take into account a more liberalized market mechanism, enabling various new kind of services and more flexibility in the choice of the actors in contributing on different services and support for the system.

In this part a final view combining full deregulated market mechanism and high automated MV network is presented.

4.4.1 Agent of an EPS cell: SGAD

The first level of the virtual utility includes many components that are controlled by an agent that may located in a dedicated substation (the agent may be called SGAD meaning Smart Grid Automation Device). This level deals with the public LV or MV level, depending on the local aggregation of the LV networks or not. SGAD is the central point of intelligence for the given EPS cell (concept described in D1.4 and D2.3).

The figure 23 shows an example of a LV_SGAD managing all the controlled or monitored devices under the MV/LV transformer. The box with LV_SGAD represents the information node that centralized the needed local information. The information paths are illustrated in the figure by the arrows: direct connection between each device and the LV_SGAD. But the communication may be structured from device to device, or structured with intermediate concentrators: the key point is that the LV_SGAD is a key point for the local information network (we could talk about an internal information structure) and also a key point for communication with external information nodes. The best location of the LV_SGAD depends on various parameters, a logical one being near the cell itself (the figure proposes a possible location near the MV/LV transformer).

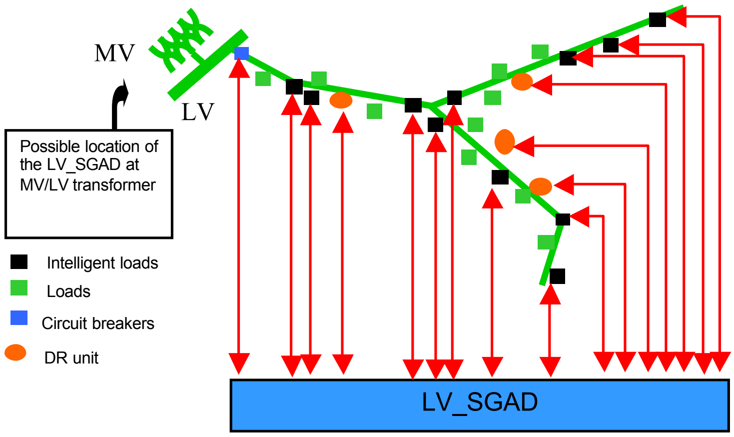


Figure 23: initial cell of the distribution at rural LV network

In general in rural structure the LV cell have a unique MV/LV transformer. For urban LV network, depending on the local electric policy, there are in general one or two MV/LV transformers. The figure 24 illustrates a case in MV network, but changing the HV into MV, and the MV into LV in the figure gives a possible case in LV typical urban network. In this case the LV_SGAD may manage the whole LV part of network, from a transformer to the other, even if the operating condition leads to two sub-networks connected together by the MV conductors.

Some MV/LV have several feeders to the residential squares: the LV_SGAD may control the whole LV network, or each feeder may split into several LV_SGAD. The cell associated to this last one is proposed to be called LV cell level 1 as an elementary cell. The summation into a single LV cell of all the adjacent cell of level 1 is proposed to be called LV cell level 2.

The figure 24 shows a case where distribution automation may play an important role: two or more input entails the possibility of flexible network operation. The reconfiguration becomes a tool used by the MV1C_SGAD to meet some functions: local optimum power flow (losses reduced, voltage constraints reduced, current constraints reduced, non distributed energy reduced (in case of network maintenance)) or fault effect minimization. As in LV cell case shon on figure 23, the MV cell agent MV1C_SGAD becomes a key point for the internal and external parts of the cell. The detailed knowledge is necessary for the internal operation, but for the external information system, more summerized or aggregated information should be exchanged. For instance the square called loads in the figure 24 that is linked to MV1C_SGAD may represent the whole figure 23: the LV_SGAD exchanges information with the MV1C_SGAD. The simplified information exchanged could be: updated power exchanged, expected power exchanged for the next period of time, updated level of controlled power (rising or decreasing) available with confidence level for the next period of time. In this case the MV1C_SGAD does not need to download the detailed topology of figure 23 neither to be in communication with each device of figure 23: the interface is simplified to LV_SGAD.

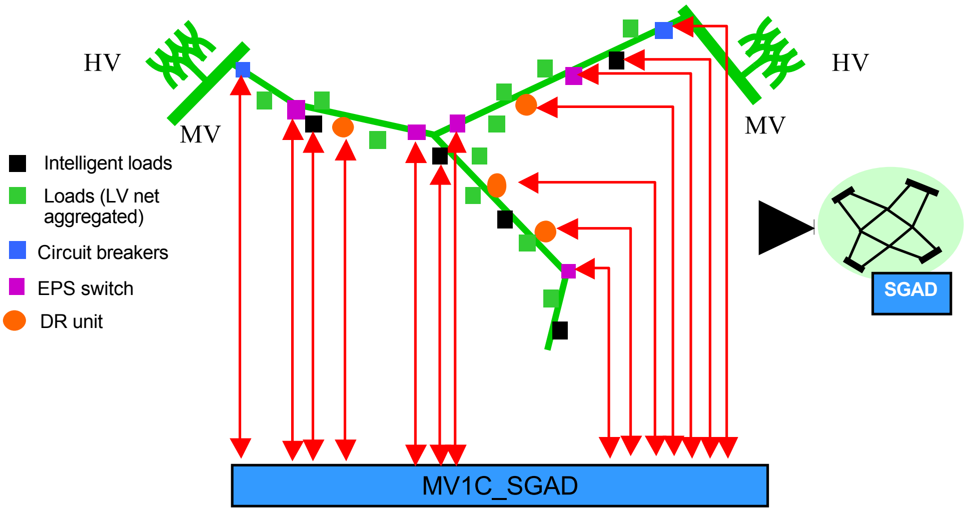


Figure 24: initial cell of the distribution at MV network

At the MV distribution level, various feeders supply separated cells. The same principle of cell level 1 and cell level 2 is used. The cell is defined by a part of EPS topology description and an associated part of information system description. We assume that the pilot of the cell is an agent that has a certain level of intelligence, including of course some responsibility for decision-making.
In the existing MV EPS, two main kinds of MV cell are taken into account:

- MV cell level 1 interconnecting feeders by internal ties, without taking into account the connection by the secondary busbars of the HV/MV substations.
- MV cell level 2 interconnecting the MV cells level 1 by the secondary busbars of the HV/MV substations, including also the transformer and its system of control on load (typically on-load tap-changers).

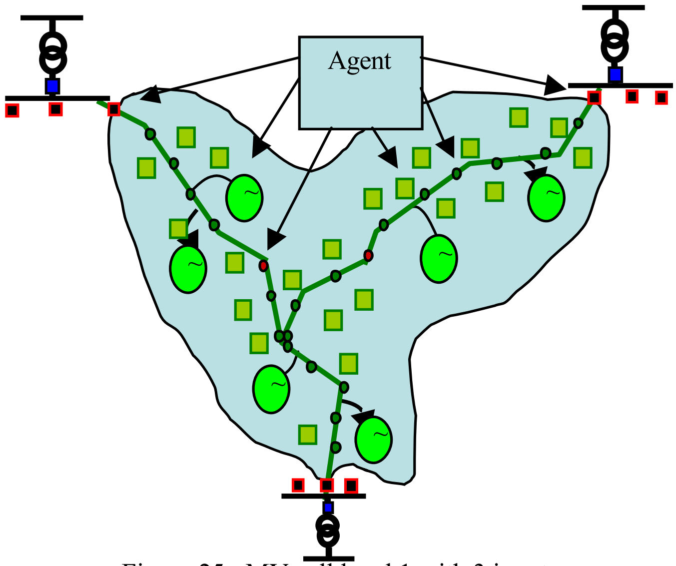


Figure 25: MV cell level 1 with 3 inputs

The growth of DER in the distribution network is entailing the DNO and the TSO operators to structure and develop the information system deeply. The first cells are included in an higher level cell and so on (imbrication of cells), allowing automated localized decision for action and allocation of resources, and reducing the data and components controlled by the higher level (successive aggregation of the data and needed control).

The DNO cell is designed in order to keep a simple use of the various possible applications. For instance, the change of configuration of the network in case of fault is included in the cell area (no real change in the topology, only the states of circuit-breakers and interrupters are changed).

4.4.2 Imbrications of agents

In general two adjacent agents do not need to exchange information, since the common point of coordination is done by the agent at the upper level. For specific purpose, as for instance stability analysis or single-phase fault contribution analysis, a cell SGAD may require information from the other adjacent cells. Aggregated models or values may be sufficient, but need to be defined and planned for the ICT network exchange.
Each SGAD belongs to another one SGAD at upper level. Each SGAD may manage several SGAD, which represents information nodes.

As indicated in the figure 26 for a given whole MV network composed of 3 MV cells of level 1, the 3 associated agents (SGAD1, SGAD2, SGAD3) may be located in the substation 1 (MVS1). SGAD1 manages the whole first cell in real time, meaning today that it manages three sub-networks at the same time (because of operation with normally open switches).

In this particular case with a common substation with all the adjacent cells of level 1, the level 2 agent that manages the group composed of the 3 agents may be located in the MVS1 also. The action of this agent of level has to deal with the settings of the tap-changers of the transformers in MVS1, MVS2, MVS3, MVS4.

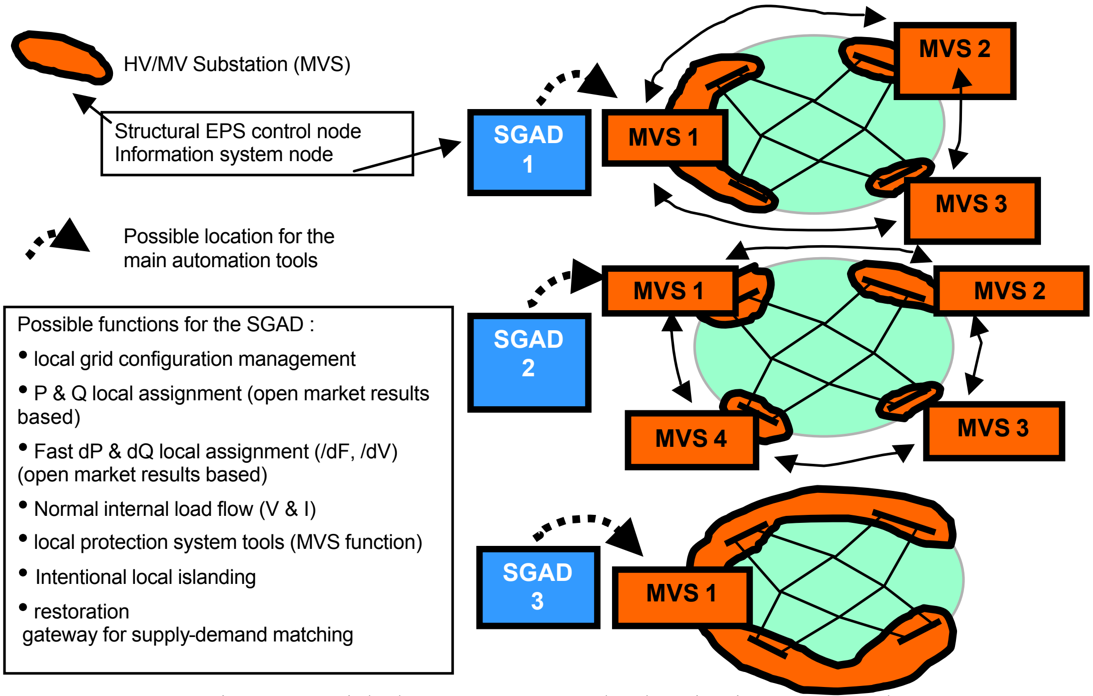


Figure 26: Links between SGAD and Substation in MV networks

As indicated in the figure 27 and 28, the integration of the network is done step by step, each level being modelled by aggregated parts of network and some parts of physical links (electrical components and lines). The simplified modelling resulting from this aggregation and the reduction of the needed information exchanged with all the surrounding agents allows very fast calculation for internal and local functions. This approach comply with the emergence of a possible regional market, taking into account step by step of the technical coherency of the energy offers (in injection or in absorption). The SGAD may play a role of responsible of exchange dealing with energy exchange expectation and local power reserve management.

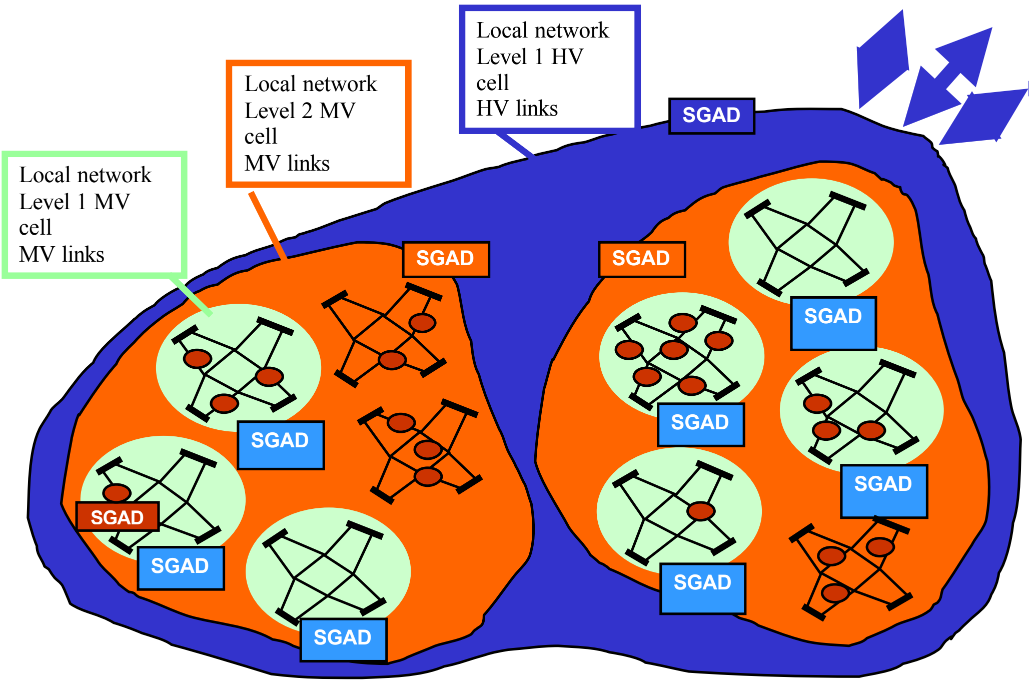


Figure 27: integration of EPS cells step by step

The DNO information structure allows the emergence of new kinds of operator of the open market: groups of consumers, groups of producers, groups of producers and consumers. The information exchanges at various stages allow the auction agents to manage the local markets and to propose the adequate bids up-side (selling or purchasing energy).

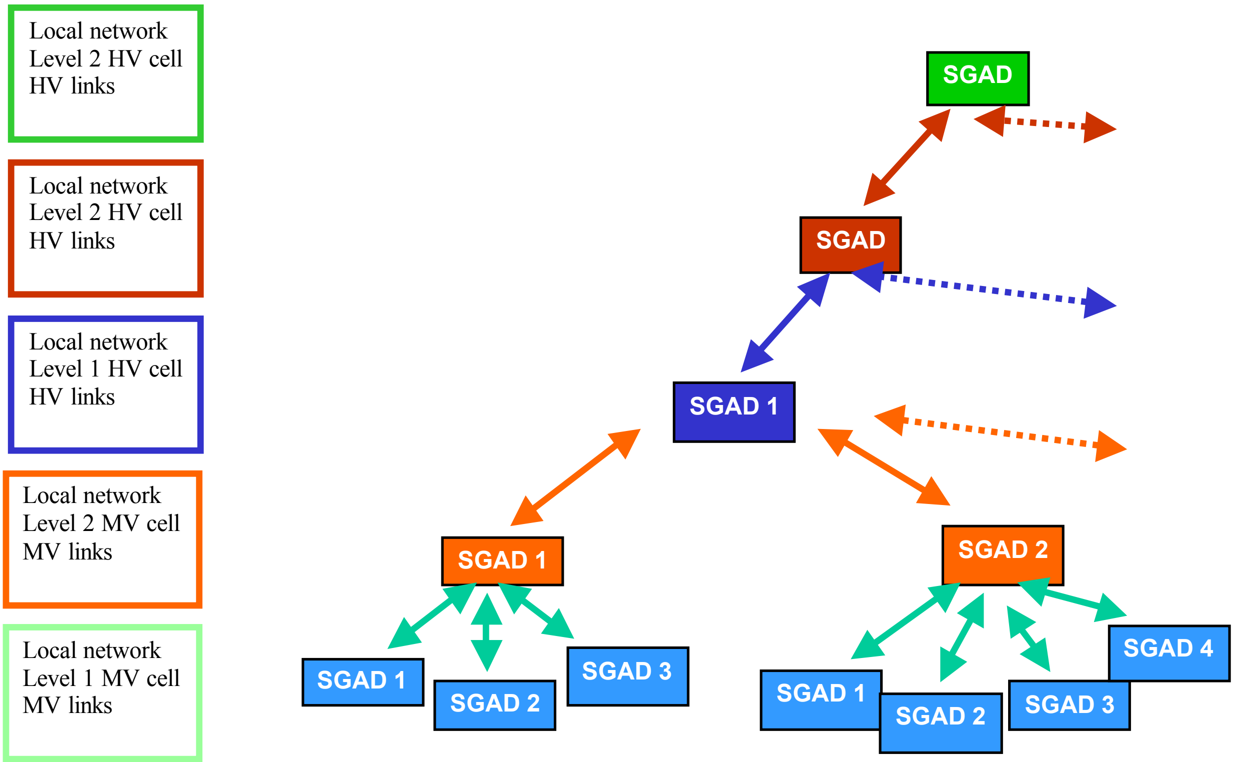
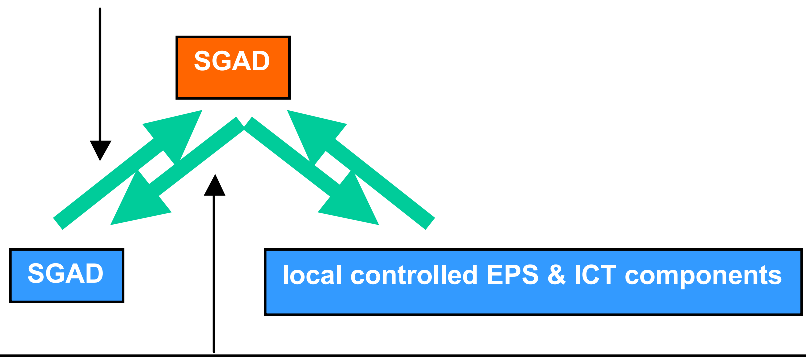


Figure 28: Structure of the information system

The information between SGAD is simplified in order to keep a fast capacity of exchange between the highest level of decision and the lowest one. In case of regulated system, the aggregation may be relatively simple and the final balance is based on economical approach of cost production. For a whole liberalized and decentralized market, the detailed offers should be allowed for all the customers, but the situation would be too much constrained due to the real time operation needed. So an integrated system is already in process and is certainly the best direction. The final balance responsible has nearly one hundred main actors to deal with, these one concentrating the whole demand and production and maintaining a balanced situation them-self (large portfolio of consumers and producers). At a regional scale the aggregation of numerous small power plants will create some VPPs (virtual power plant) that have a clear connection with the already defined cells. The regional market (from LV to HV scale) may play a role with a clear and coherent control of the technical impacts on the local cells. In the same way that the adjustment market done by the RTE, the cells may includes dynamical control (by price incitative for example) to avoid too much extension of internal disturbances outside of the cell. The technical and market stability may take into account the energy lost in the transmission and distribution system and the cost of the global pollution (typically CO2 in the present context), making clearly appear the interest of producing a part of ‘clean’ energy at the same location that the consumption.

The figure 29 gives an example of possible main messages exchanged in real time between the cells of two different levels (bottom up and down iterations), the upper SGAD having also its part of electrical components to deal with.

S available (external exchange proposed) [curves power & energy / time / prices]
dS available (ext. exch. Prop.) [curves power & energy / prices]
Area droop data (ext. exch.) [curve dP / dF due to production/demand]
General data (internal RES production, internal S consumed and produced)



S required (ext. exch.) [curve power / time scheduled]
dS required (ext. exch.) [curves power / time scheduled]

Figure 29: Information exchanges to define between levels

4.4.3 Technical approach and market approach

With the open market, new actors as LSVPP are introduced. Their bids may include scheduled (with high level of certainty) power exchange and system support capacity, this ability being a strong and positive position for a technical acceptance from the DNO and an associated correct valuation of the local energy produced.

A high issue is to keep a clear view of the system structure, the LSVPP being dispersed among the network and via various voltage levels as indicated on the figure 30.

A solution is to keep the collection of the bids level by level, keeping in mind that the bids are connected together at a higher level for a global offer. During the aggregation process of the bids from cells to cells the technical problems may be evaluated, introducing an information for the later distribution of the power scheduled orders in order to avoid too much iteration caused by technical constraints. The regional market could be an interesting intermediate actors that will deal with the national market.

The figure 31 gives an example of inclusion of LSVPP among the technical cells. The cell is more a concept for the DNO, adapted for network analysis, control, protection and aggregation. The LSVPP is more a market approach making appear virtual large power plant enabling small actors to deal with the different large markets (reducing the problem of the size threshold for their contribution to the system, and improving the overall reliability by their number.

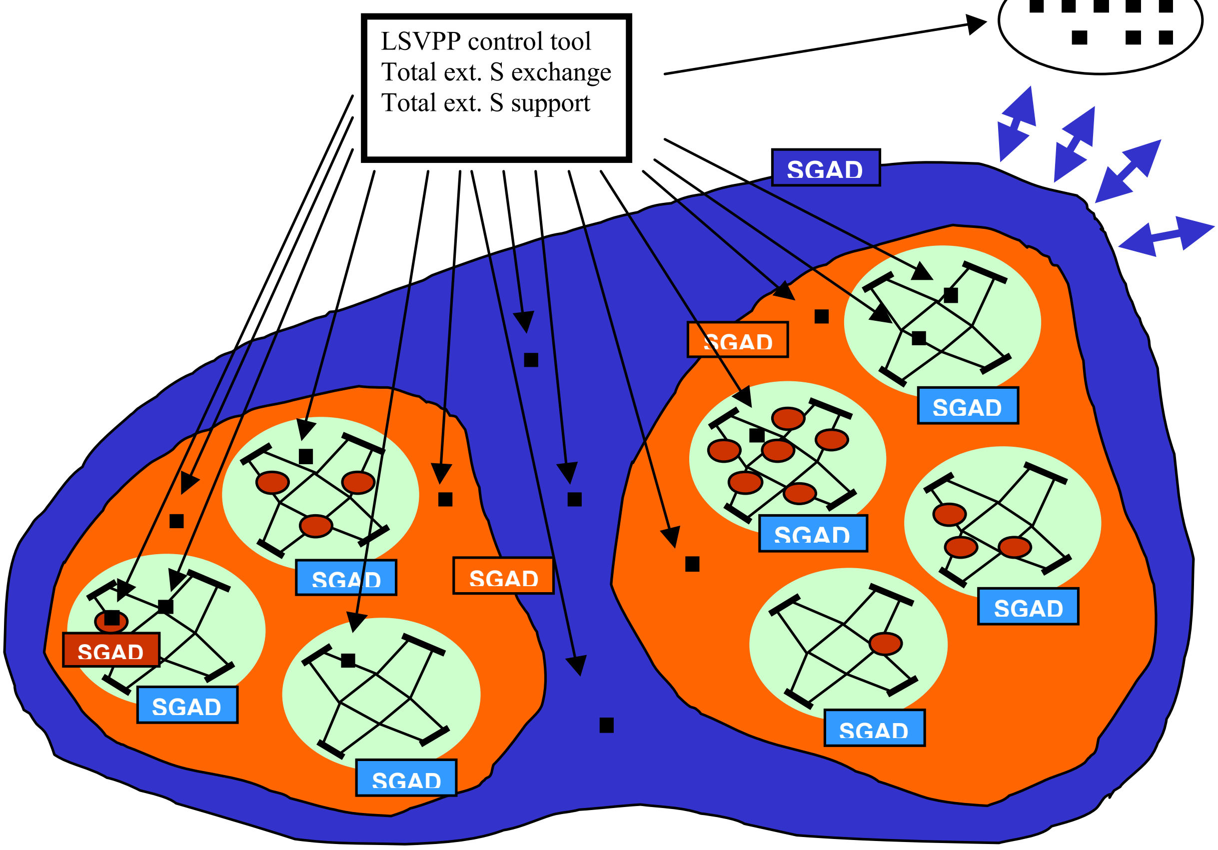


Figure 30: Specific actors dispersed in the network, the LSVPP

A solution on the DNO information exchanges illustrated previously is to add specific data relative to the LSVPP, allowing the auction agents to take into account the bids of the LSVPPs at the right aggregated level.

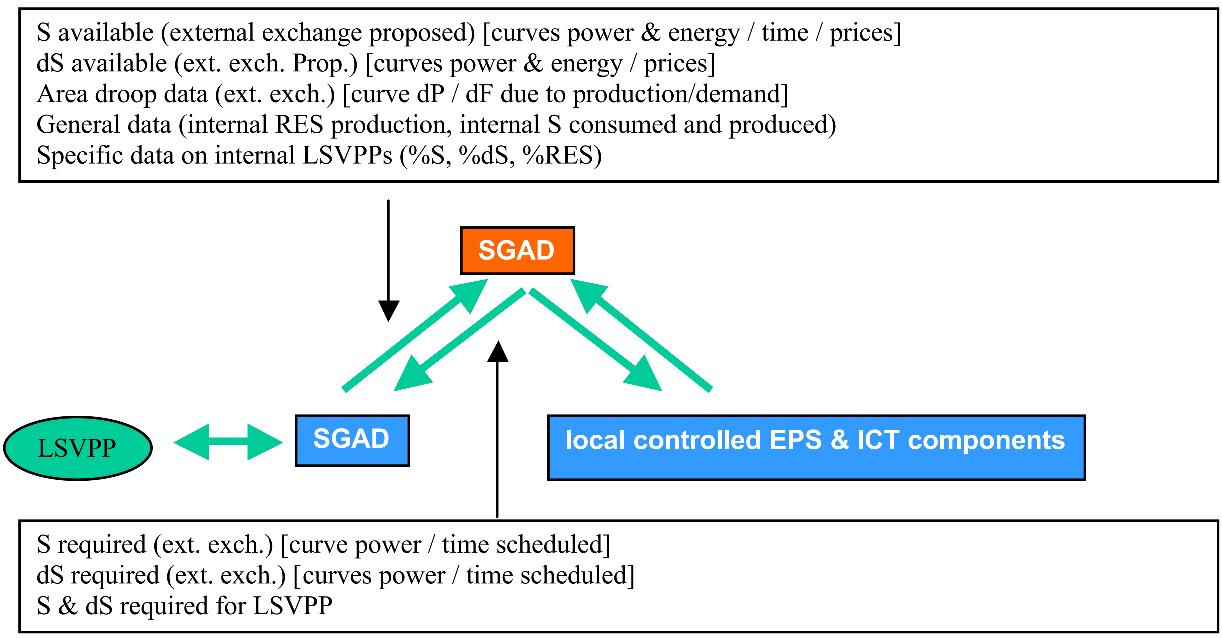


Figure 31: Exchanges of information including LSVPP and aggregators

For a producer or aggregator using variable prices based on the last hours market (24h, 6h, 0.25h), a bid defined by a curve of power versus price is sent (in fact the power is directly relative to an energy since the value of power must be maintained constant during the timeslot contracted (in general basic timeslot of 0.25h)).

The total bids are used to extract the first economical balance: the first final price is given by the crossing of demand and production accumulated prices. The associated first dispatch need to be check in the technical aspects (possible constraints on voltage and on power flow in lines): the main actors for these evaluations are the DNO and TSO. If no constraint is reached, the final price is available and the information is dispatched to the various actors (the price indicating to each actor their expected contribution timeslot by timeslot.

The ICT component for a producer should help him to chose the right price strategy depending on its resources. The strategy defined, it should inform properly (meeting data and time requirements)

5. Recommendation and expectations

Collaboration between different fields implies the need for mutual understanding
To integrate DG and DG-RES in an efficient way in EPS will need an intense integration of EPS with real time network operation and also real time market exchanges. Actors from different worlds (electric engineers, market experts and ICT specialists) have to closely collaborate to reach this. As these worlds are rather separated as of today, many terms are used with different meanings in different areas. A glossary and definition section has been carried out in our combined CRISP approach for these three fields and is necessary for future similar work in order to share clear and correct information about concepts and problems of each other.

Redundancy should be integrated as a bottom-up process with fallback options
A common assumption, when analysing architectures, is that the main challenge is for the integration of ICT and market with EPS structures, and that the two other fields are working rather correctly. In the purpose of the CRISP project, a strong difficulty is to make the right iterations quickly between the market solution proposed, the expected load flow and EPS analysis resulting from the updated price, and the information back for the expected local technical constraints (the technical constraint may lead to find a new market solution for a given time-slot). Making a bottum-up power and energy market, a solution could be to avoid incoherent (for technical solution) bids from bottom cell to the higher cells. Also a default operation procedure, in case the flexible automated market mechanism fails, must be defined to function as a back up. This kind of approach building the market with included technical updated limitations (in a real time information system and at local and at global scale) is important for the future optimized system with less over-capacity in the structures. This is very important for the expected reaction of the system in case of critical situation (ILS), avoiding cascading nuisance effects in the last minute.

Experience in real-life settings is essential for further knowledge development
The project Intelligrid led by EPRI in the USA is briefly reported in our document. This approach, quite similar but in a larger scale to the approach followed during CRISP, is focusing on the ICT structures and on the EPS functions description and computation. The real description and relevant information of a given application only emerges when a given application is implemented. The demonstrators (or experimental benchmarks) and practical applications will continue to be the best field of investigation in the future studies of combined infrastructures used in a real time. In the future, theoretical research and computation development should avoid partially this fastidious step, but the strong dependency between the analysed infrastructures exists today, and the crossed failure modes are difficult to be modelled and simulated.

Modularity and bottom-up communication might keep ICT reliability at desired level.
The question of reliability of ICT remains a key point. The availability of 99.97% reached for some ICT system involved in real time TSO application might be difficult to reach in distribution application, because of the price involved for such a performance in continuous working. Nevertheless the level of availability in a given EPS application will have to be measured. The idea proposed by CRISP to have modular communication boxes and analysis computation boxes in open source will allow, in the long run, to have statistical figures about a given module and detailed installation.

For distribution purpose, a main point is the cost of the solution, and the ability of the solution to be correctly checked and inserted in the existing network. Using an open source code and a free operating system is a possible way to fulfil these conditions.

Smart Grid Automation Devices (SGADs) should be developed further
To account for all the necessary and possible functions grid cells have to be able to perform and communicatie with other grid cells, the concept of SGAD was proposed. It is believed that without SGADs it will be quite difficult if not impossible to operate the grids of the future, including a large share of DG and DG-RES. As the concept is elaborated now to a certain extent, further research and development should be aimed at developing, designing, implementing and testing SGAD's in laboratory and real life settings.

Appropriate ICT standards are protocols are to be developed
There are many current ICT standards and protocols that apply or might apply to DG and DG-RES integration in EPS. However, there are still many different options for real-time communication and control operations.

Information security issues have not yet been taken fully into account. Our recommendation would be not to use the open Internet, although internet technology could help. Virtual Private Networks and Private Internet Networks could be used in the near future to get experience. Communication protocols and the alignment of programming languages such as .NET and C# will have to be developed as well.

6. Conclusion

A great change is expected in the future architecture of electrical power systems. The term 'architecture' itself is moving to a more complex definition including EPS, ICT and market aspects. The future distribution automation is obvious. Question however are still remaining, e.g. with regard to how to manage the coming investments, what are the right choices for the ICT infrastructure, what are the functions to develop first, what are the expected benefits, how will the market contribute to accelerate the installation of observation equipment in the distribution network.

The competition between the traders will certainly focus on energy optimisation, entailing many more measuring equipment, more controlled loads or reactive loads, and more controlled DG in the distribution network. At the same time, the future optimisation by the DNO on the installed EPS structures will involve more technical constraints. The control equipment and cell management will allow this global optimisation, the benefit for the actors being a better global usage of the energy produced, and also deferring some investment in lines and transformers, even if the demand is growing.

An overview about EPS, market and ICT architectures and expected performances is reported. The term 'security' has different meanings and approaches according to the three main fields of interest for the real time applications. ICT developed for real time EPS operation may be implemented into local secured network allowing physical data and remote control protection. This enables dedicated reliable, easy to install, easy to configure, and easy to maintain technical solutions (the control actor is the DNO and its main information source is in equipments installed within its cell). The ICT developed for market purpose need to interlink a large number of bidders and market actors within a national or international system, what entails mixed possible solutions for achieving the accepted level of data integrity and system availability. For instance with today's technologyh and for time response of a few tens of minutes, the possible technological option for communication are internet, public phone system or specific private phone system. For time response expected under the minute, the system can no more deal with a large number of bids and send back orders correctly. The solution expected is to have prepared the possible energy and power reaction by a global market approach within 15 minutes time-slot, and let the TSO and the DNO deal with the technical choice within the last minute time-slot by fast ‘ready to execute orders’ in the distributed terminal devices.

A view by CRISP partners of various architectures (Sweden, the Netherlands and France) has been given. The electric system is changing today and the rules are not completely defined. The competition and DG insertion is increasing in most of the countries, step by step. The traditional large power plants are expected to be the main source of power, giving large capacities of power and energy stable reaction. The optimization of the design, operation and exploitation in the distribution EPS will lead in some years in more local technical constraints that will be faced by more reactive and controllable distributed loads and DG. The protection as the network will be operated in a flexible way, to reach enough supply availability and robustness. Especially the DG protection (against faults and loss-of-mains) will be set in order to enable some contribution from the DG to the network.

A new concept of 'cell' has been proposed in the document. The proposed separation into sub-networks, the natural area from topology configuration point of view, is extended for all the functions that could be automated in real time in the future. One of the main ideas is that the local agent downloads and updates its part of electric map of the network (specific link with a data base located in a regional operation control room), using local communications and local analysis to make local decision (on changing the configuration or on controlling loads, DG or specific devices). The concept of cell proposed may help to coordinate the different levels of ICT access inside the network, enabling a global parallelisation of the complex and real time work. The detailed calculation and analysis achieved in the leaves of the tree, are then progressively simplified and aggregated through the tree trunk where global balance is checked and main decision are taken. If the leaves and following steps have correctly informed the trunk about future power and energy expectations (consuming or producing), and if the declared power reserve is prepared to work in real time indication (physical signal (frequency or magnitude of the voltage), dedicated messages or tariff variation), the stability and the robustness of the total EPS network is maintained as a distributed contribution. In this last way of running there is less blocking point to the massive insertion of DG in the network. A crucial key for the future is evaluating the real reliability of a given ICT distribution set.