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Functional Specifications of electric Networks with high degrees of distributed generation

Deliverable D 1.1

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References

[1] Cahier techniques Merlin Guerin n°155, http://sitelec.free.fr/datasheet/ct155.pdf

[2] RTE web site, French Transmission Operator : http://www.rte-france.com

[3] Jos Arrillaga. "High Voltage Direct Current Transmission",Ed. The Institution of Electrical Engineers, London, 1998. United Kingdom.

[4] Techniques de l'ingenieur, D 4070 "Réseaux de transport et d'interconnexion de l'énergie électrique. Développement et planification"

[5] Techniques de l'ingenieur, D 4080 "Concuite d'un system de production-transport"

[6] Techniques de l'ingenieur, D 4090 "Réseaux de transport et d'interconnexion de l'énergie électrique. Fonctionnement et reglage"

[7]Techniques de l'ingenieur, D 4210 "Réseaux de distribution : structure et planification"

[8] Techniques de l'ingenieur, D 4230 "Réseaux de distribution : exploitation"

[9] B.MWeedy and B.J.Cory."Electric Power Systems".Ed.Wiley.4^{tht} edition, New York, 1998. Unites States.

[10]Techniques de l'ingenieur, D4007 "Du monopole à la concurrence"

[11] 1996 European Directive. http://europa.eu.int/smartapi/cgi/sga_doc?smartapi!celexapi!prod!CELEXnumdoc&lg=EN&numdoc=31996L0092&model=guichett

[12] Peter TORKLER. " Sustainable development and the liberalisation of the energy. Preliminary Explanatory Memoandum". Strasbourg, 4 February 2002. Congrés de Pouvoirs Locaux et Régionaux de l'Europe. www.fedre.org/lang_en/Omsk/Discours_Torkler_en.pdf

[13] Powernext http://www.powernext.fr/

[14] Commission de régulation de l'énergie http://www.cre.fr/

[15] Eurostag documents

[16] J.F.Canard. « Impact de la génération d'Energie Dispersée dans les réseaux de distribution ».Thèse de l'INPGrenoble, Décembre 2000.

Acronyms and Abbreviations

DG	Distributed Generation
HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
ICT	Information and Communication Technology

Executive summary

The deliverable D 1.1 is the first step in the project. This D 1.1 deliverable treats the different components: networks, generation sources and also the actors presents in the energy market. The French system is usually commented but comments about the other countries uses are also mentioned. Special attention has been paid to the Dutch system, a comparison between the French and the Dutch system is done. The main goal of this work is to describe the electric system and its components.

Then, a benchmarking model is proposed in order to start the studies of the different work package. This benchmarking model implies: the transmission, sub-transmission and distribution electric sub-systems. From this model, different scenarios of perturbations are studied, these scenarios correspond to different frame work times (transient and steady states) and they could become fatal for the system operation.

Introduction

The principal objective of this Work Package is developing innovative ICT-enabled strategies and study scenarios and optimal solutions for:

- Improving system robustness with distributed generation and renewable energy when major events and system disturbances with important social and economical impacts happen.
- A more cost-efficient management of the distribution system by using ICT for better demand-supply matching under a deregulated environment.
- Fault detection, localisation/diagnosis for better performance of distributed generation when it is connected to the main grid.
- Optimal ways of utilising renewable energy systems in various types of power distribution networks using recent ICT developments, EU liberalised market trends and considering RES process and context-specific factors.

As it have summarised at the kick-off meeting in Amsterdam, the scheme of Work Package is the following one:

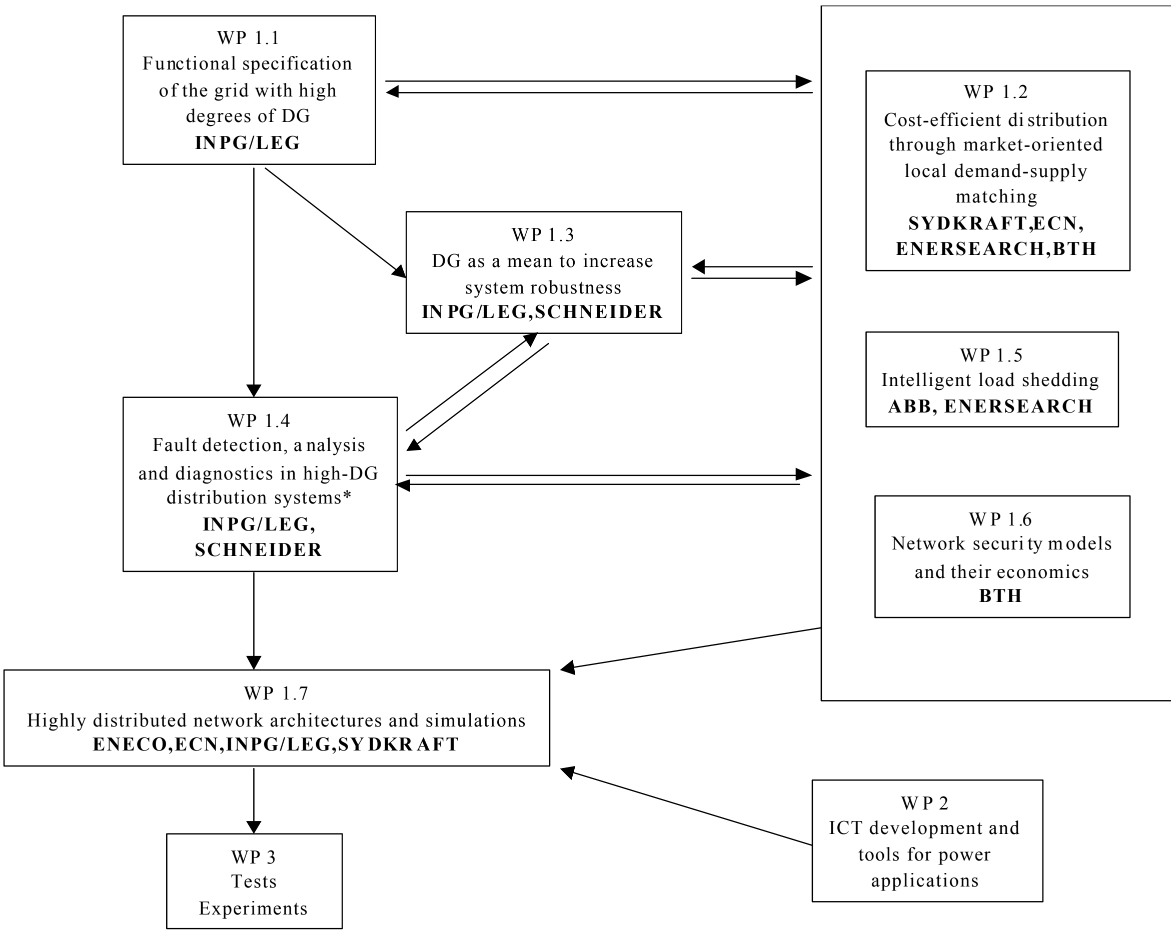


Figure.1.-Summary of Work Package I with main actors and leaders partners

In this scheme (see fig.1), we must emphasise the importance of the action WP 1.1, because the results of this action will be used in next tasks and actions. Therefore, we want to ask all partners for their needs and requirements of information in order to carry out the work and reach the goals and aims of everyone.
As it's known, this modelling task defines the common generic components, system relations and impacts of distributed generation on the grid. The various institutional operative roles for players in the transmission and distribution arena are modelled. This provides a baseline reference model shared by all consortium partners to be used in their more specific scenarios, simulation case studies and tools. The scheme of this task WP 1.1 can be summarised in the following scheme:

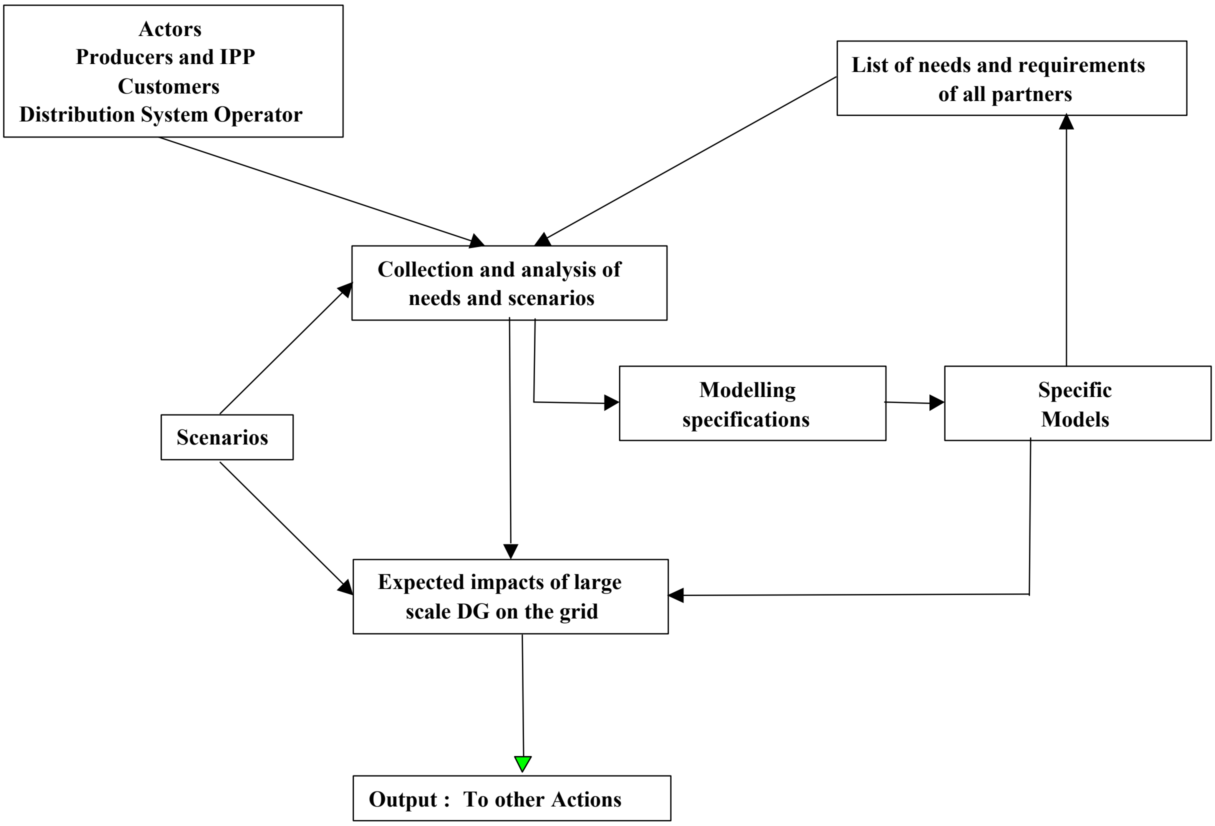


Figure.2.- Summary of WP 1.1 with main actions

Thus, several tasks which compose the main action WP 1.1 could be defined:

- Actors, producers, Customers, Distribution System Operator (DSO) requirements
- Scenarios to be defined and treated
- Modelling tools and specific Modelling needs of the partners.
- Expected impacts of Large DG on the grid.

The idea is to define the main actors and their needs with a kind of priority. For example:

- Customer: availability, power quality…
- Producers and IPP: energy sale…
- Distribution System Operator: correct network operation…
- …

The aim of the scenarios is to define the kind of scenarios to be treated. Some suggestions can be quoted:

- Catastrophic scenarios caused by weather conditions: storms, fires.
- Scenarios caused by technical limitations: loss of lines (line congestion, cable fire), load evolution,
- Scenarios caused by general blackouts and islanded operation by zones.
- Scenarios caused by wrong operation of the protection system.
- Operating scenarios for DG generators (global control? , local control ?, without control?)

This report of WP 1.1 treats the different component: kinds of lines, architectures, voltages levels, protection and methods of control of the electric system. Then the new organization of the market is commented: actors, producers, market regulator agents…

The dispersed generation and the liberalisation favour the apparition of new producers. This new producers due to the amount of the investments are based on decentralised generation sources. A complete list of the different forms of dispersed generation is detailed. Then, a benchmarking model is defined and the expected impacts of DG penetration are mentioned. Finally, the scenarios are studied for the benchmarking model and the perturbation on the electric system is shown.

In short, this report is the first step of the project and its aim is to clarify the agents, components, operations and needs of the electric system.

1. Description of LV, MV and HV networks

1.1 Introduction

This first chapter of WP 1.1 will introduce the electric system. Special attention must be paid to the different roles and characteristics of the various networks. Then the different protection systems and communications used to control the system are explained.

Traditionally, one can distinguish three types of electric networks:

- Transmission and interconnection networks: these networks relay the main generation centres with the consumption areas. The voltage level depends on the country, but normally the voltage level is established between 220 and 800 kV (e.g. 765 kV in South Africa).
- Sub-transmission networks: they receive the energy from the transmission networks and its role is to conduct the electricity to the small towns, cities or important industrial customers. The voltage level of these networks is between 45 and 160 kV.
- Distribution networks: they irrigate the domestic customers and the medium-size industrial customers. The voltages are between 4 to 45 kV for the middle voltage and some hundreds of volts for the low voltage (400/230 V)

In a country, the transmission and public distribution networks ensure the transfer of electrical energy from production points to consumer units. The production points are power stations that generate electrical energy from various primary energy sources (nuclear, hydro-electric, coal…)

The points of consumption in MV (medium voltage) are substations, from which the energy is delivered to customers. This takes place by the MV distribution system.

In the figure, it is shown these different networks with the common levels in the French case (400/225 kV for transmission, 90/63 for sub-transmission, and 20kV/ 230 V for distribution) [1]

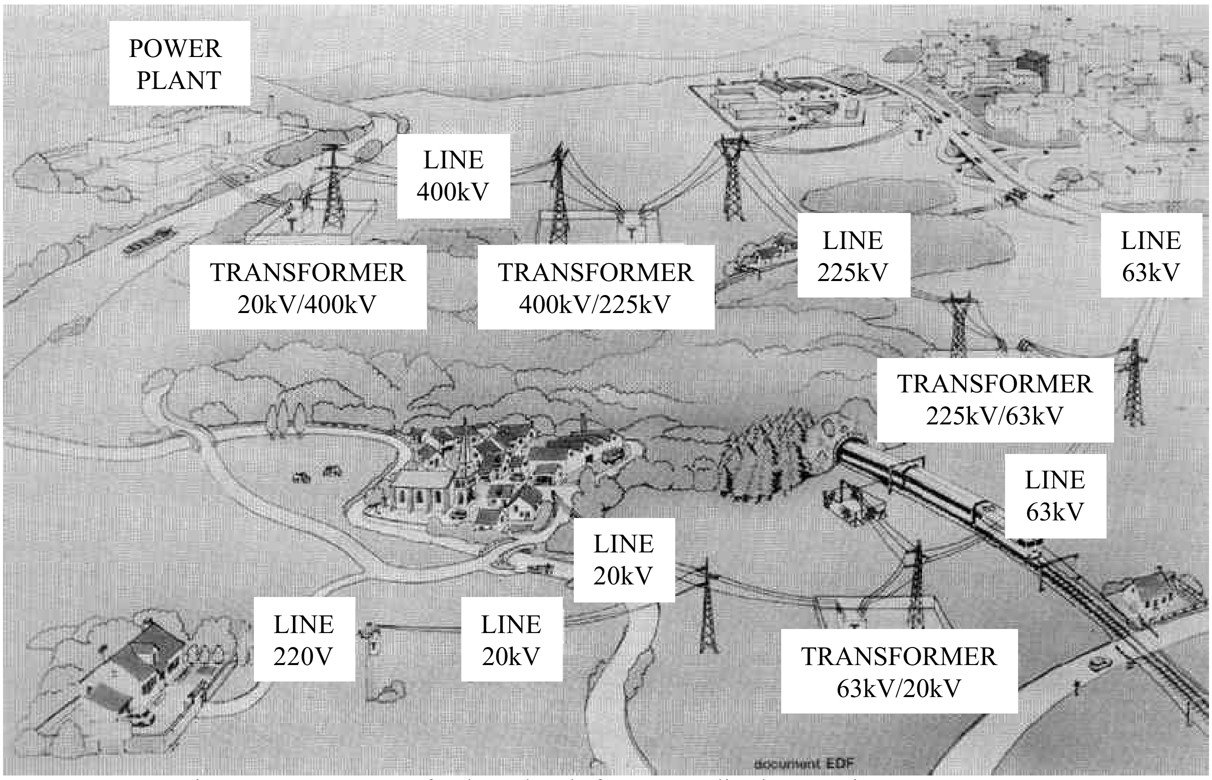


Figure.1.1.-Structure of voltage levels from centralised generation to customers: Transmission lines, sub-transmission lines and distribution lines.

1.2 Transmission and interconnection lines

The geographical distance between production sites and consumer centres, the irregularity of consumption and the impossibility of storing electrical energy create the need for an electrical network that is able to direct and transmit it across large distance.

These lines can stretch across thousands of kilometres, for example in the French network exists 100 000 km of lines (transmission interconnection and sub-transmission lines, owned by RTE, French transmission operator) [2]

The object of this network is threefold:

- A “transmission” function with the aim of carrying electricity from producing power stations to the main consumer zones.
- A “national interconnection” function that manages the product distribution by relating the production to the geographical and time-dependant nature of the demand.
- An “international interconnection” function that manages energy flow between countries dependant on programmed exchanges or as back-up.

In general only few customers with a high consumption are connected to these networks. These networks are essentially of overhead type structure. The voltages are normally between 225 and 400 kV and sometimes 800 kV (e.g. 765kV South Africa). The use of such high voltages is tied with cost saving objectives. Indeed, for a given power, the line losses by joule effect are inversely proportional to the square value of the voltage ($p= k/U^2$) with U= network voltage and k a constant dependant on the line.

In addition the transmitted power values are such that using low voltages would require totally unrealistic cable cross-sections. The use of high voltages is thus imposed in spite of the drawbacks involved in higher equipment insulation costs, the easiest solution being the use of overheads lines. In any case, the choice of transmission voltage is above all a techno-economic one, dependant on the power to be transmitted and the distances to be covered.

The safety aspect is fundamental for these networks. Indeed any fault at this level can lead to important supply failures for all consumer units. The networks' protection must be very high-performing. The electrical energy is permanently monitored and managed from a control centre.

The electric current on energy transmission is accomplished using direct or alternate current. AC transmission over long distances, especially via underground cab e, requires frequent shunt compensation and causes stability problems. AC interconnections increase the fault level of the overall system. DC transmission is free from these problems and has lower losses and design costs.
These advantages were realised early and the idea of generating AC power, converting it into DC for transmission and converting it back into AC, was taken seriously. However, the use of static AC-DC and DC-AC power conversion is expensive and in general the comparison of alternatives is not straightforward.

Direct current or HVDC (high voltage direct current) links are used for exchanges between countries exclusively on a transmission network level and for bulk-energy transfer.

With reference to system interconnection, the need to operate the whole system in perfect synchronism often prevents the transfer of power by alternating current [3]:

- The economic power ratings of such interconnections are often small in relation to the installed capacity of the systems to be interconnected; in such cases an AC tie line may not be able to cope with the power flow and stability control problems. A DC interconnection in the AC systems, and can provide stability improvement for the two interconnected systems.
- AC interconnections always result in a reduction of the overall system impedance and hence in increases of the short-circuit levels. These may exceed the capability of the existing circuit breakers or cause unacceptable electrical and mechanical stresses on the system equipment.
- If the systems to be interconnected have different frequencies, an AC is not possible
- Even with network systems of the same nominal frequency but controlled according to different principles, as AC interconnection is impractical.

The choice of this technique enables optimization of the use of transmission cables, particularly by cancelling “the skin effect”. Such intercontinental and even continental links exist, for example a link between France and England at (2000MW/270kV) or the link between Italy and Sardinia via Corsica (300MW/200 kV) [4].

In other cases links are through alternate current. Indeed, the use of direct current can not be profitable: losses reduced in short networks, equipment made more expensive (requirement of numerous direct/ alternating converters). In addition alternate current is well adapted to voltage changes (transformers) in the course of its transmission as electrical energy.

The current frequency on the whole system is 50 Hz with very few exceptions (Saudi Arabia) and outside of the American continent where 60 Hz is used throughout. One particular case is Japan where half of the country is on 60 Hz, and the other half on 50 Hz.

The transmission networks are meshed; so there is a redundancy in the supply of the energy. In the next figures, one can see the 400 kV and 225 kV French networks transmission lines. The lines are made with cables from 570 mm^2 to 1200mm^2 (EDF data 1985 for the transmission lines) [5], [6] and [7].

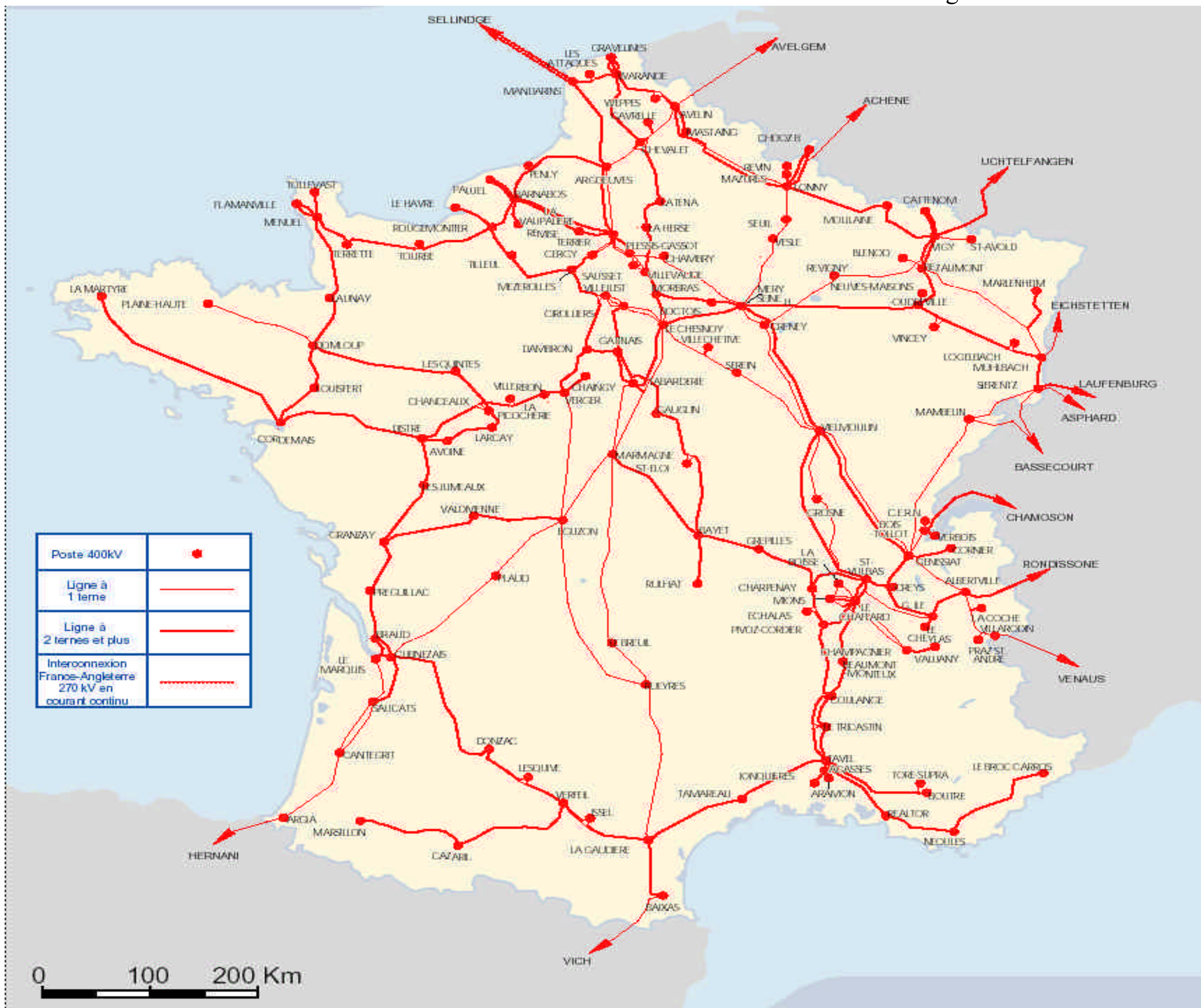


Figure 1.2.-French architecture of 400 kV transmission lines

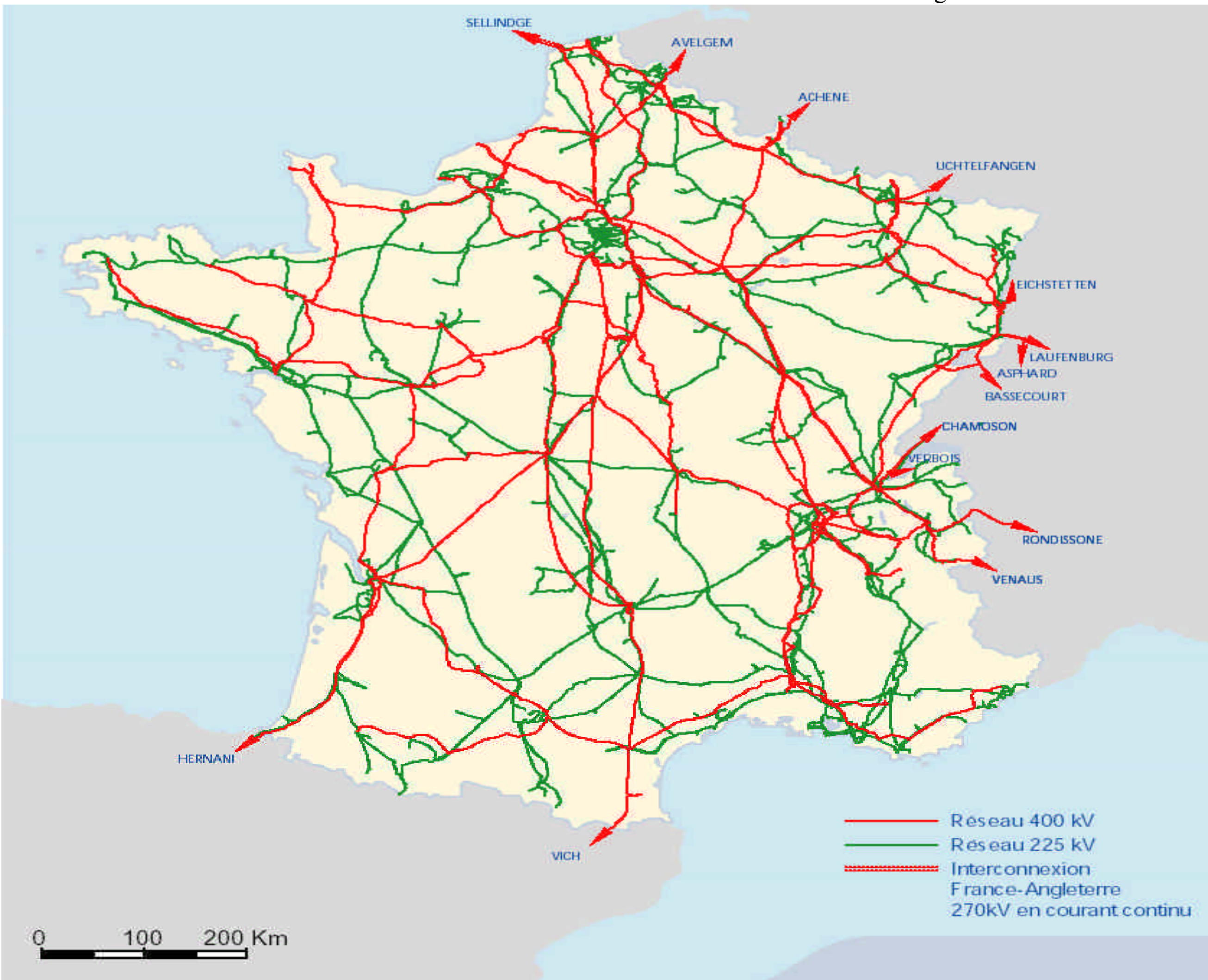


Figure 1.3.-French architecture of 400 and 225 kV transmission lines

1.3 Sub-transmission network

Normally, the sub-transmission networks are organised in a loop way. This loop is used to operate the network in a closed loop. Energy can flow from both directions and one can change this direction with a switch but this change doesn't mean an interruption of electrical supply: the loop assures the service in case of loss of supply from one of the transformer 400 or 225 kV to 90 or 63 kV. So this sub-transmission has a role of security. In France, the voltage levels for sub-transmission networks are: 90 or 63 kV.

On the other hand, the aim of this network is essentially to carry electricity from the transmission network to the main consumer centres. These consumer centres are: either from the public sector with access to the MV network or from the private sector with to the high-consumption customer (higher than 10 MVA) supplied directly with HV. In any country the number of HV consumers is very small (e.g. 600 in France). They are essentially industries such as iron and steel, cement, chemicals, rail transport,…

The structure of these networks is generally of overhead type (sometimes underground near urban areas). In this respect environmental constraints (care for the environment and protection of certain natural sites) are often raised in opposition to the construction of lines. As a result it is more and more difficult and expensive for sub-transmission networks to reach high population density areas. The protection systems are from the same kind as those used for transmission networks and the control is regional.

1.4 Distribution network

1.4.1 The MV network

The object of this network is to carry electricity form sub-transmission network to points of medium consumption (higher than 250 kVA in France). These consumer points are: either the public sector with access to MV/LV public distribution substations or the private sector, with access to delivery substations for medium consumption users. The number of customers (e.g. 160 000 in France) is only a small proportion of the total number of customers supplied directly with LV. They are essentially for tertiary sector such as hospitals, administrative buildings, small industries…[7] and [8]

The structure is of overhead or underground type. Voltage in these networks ranges from a few to 40 kV. The operation of these networks can be carried out manually or more frequently by remote control from fixed/mobile control centres. However, in order to account of specific needs for control of MV networks, these control centres are different to those used on transmission and sub-transmission grid.

1.4.2 The LV network

The object of this network is to carry electricity from the MV network to points of low consumption (less than 250 kVA in France). It represents the final level in an electrical structure.

This network enables supply to a very large number of consumers (26 million in France) corresponding to the domestic sector. Its structure, whether overhead or underground is often influenced by the environment. Voltages in these networks are between 100 and 400 V. Such networks are often operated manually.

The choice of the voltage level and frequency is the result of a technical-economic and historic consideration. Thus, every country owns different voltage levels and its frequency. Nowadays, in France the nomenclature for the different voltage levels is the next one:

- HTB: U > 50 kV
- HTA: 50kV>U>1kV
- BTB: 1kV> U> 500 V
- BTA: 500 V > U > 50 V
- BTB: U< 50 V

In order to reduce the material costs, an agreement in the voltage levels has been taken into account. Thus the voltage levels to consider are the next ones:

HTB	**63kV,** 90 kV**, 225 kV, 400 kV**
HTA	5.5 kV**,** 10 kV, 15 kV**, 20 kV,** 33 kV
BTA	**400 V**

Table.1.1.-Main French voltage levels

In France, the voltage levels of the public LV distribution network are 230 /400 Volts (with a range of variation of +6%/-10%) and the frequency is 50 Hz ((±1%).

	Frequency	Amplitude	Unbalance	Harmonics	Over voltages
HTA	**50 Hz** • **+/- 1 % for the interconnected system** • **+ 4 / - 6 % for the islanded networks**	Un = 20 kV +/- 5%.	τ_i < 2 % $\tau_i = V_i/V_d$ (%)	**95 % of time (average in 10 minutes)** • **H3<4%, H5<4%, H7<4%** • Distortion percentage <8%	Transitory (1.2/50µs) < 125 kVc with Vc Volt max pour le 20kV

	Frequency	Amplitude	Unbalance	Harmonics	Over voltages
BT	**50 Hz (average in 10 s) Variations to 95% of time :** • **+/-1% for the interconnected systems.** • **+/-2% for the non-interconnected system.**	**Vn = 230 V (average of 10 min)** • **slow variations 95% or time : + 6 /- 10 %.** • **Quick variations: +/- 5**%.	τ_i < 2% for 95% of time (average 10 min) $\tau_i = V_i/V_d$ (%)	**95% of time(average in 10 minutes)** • **H3<5%, H5<6%, H7<5%** • Distortion percentage **< 8%**	Transitory (1.2/50µs) < 6 kVc with Vc Volt max

Table.1.2.-Some example of standard for energy quality

1.4.3 Layout of different distribution networks

- Radial layout

This layout can also be called antenna-type. Its operating principle is based on using a single supply line. This means that all consumer units in such a structure only have one possible electrical feed path (arborescent type). This layout is particularly used for MV distribution in rural areas. Indeed, it enables easy and low-cost supply to low load density consumer units with a wide geographical dispersion. A radial layout is often used with an overhead type distribution system.

- Open loop layout

Its operation principle uses several lines of supply. This means that any consumer unit on this structure can be supplied by two possible electric paths, each path is activated at any time, back-up is provided by the possibility of using the other loop. This layout is often employed with an underground type distribution system and in highly populated urban areas.

The next table is a comparison between both base MV network layouts:

Technologies	**Strengths**	**Weaknesses**
Radial	Simplicity Operation Installation costs	Quality of service
Open loop	Simplicity Quality of service	Operation with more frequent switching Installation costs

Table.1.3.-Comparison of MV layouts

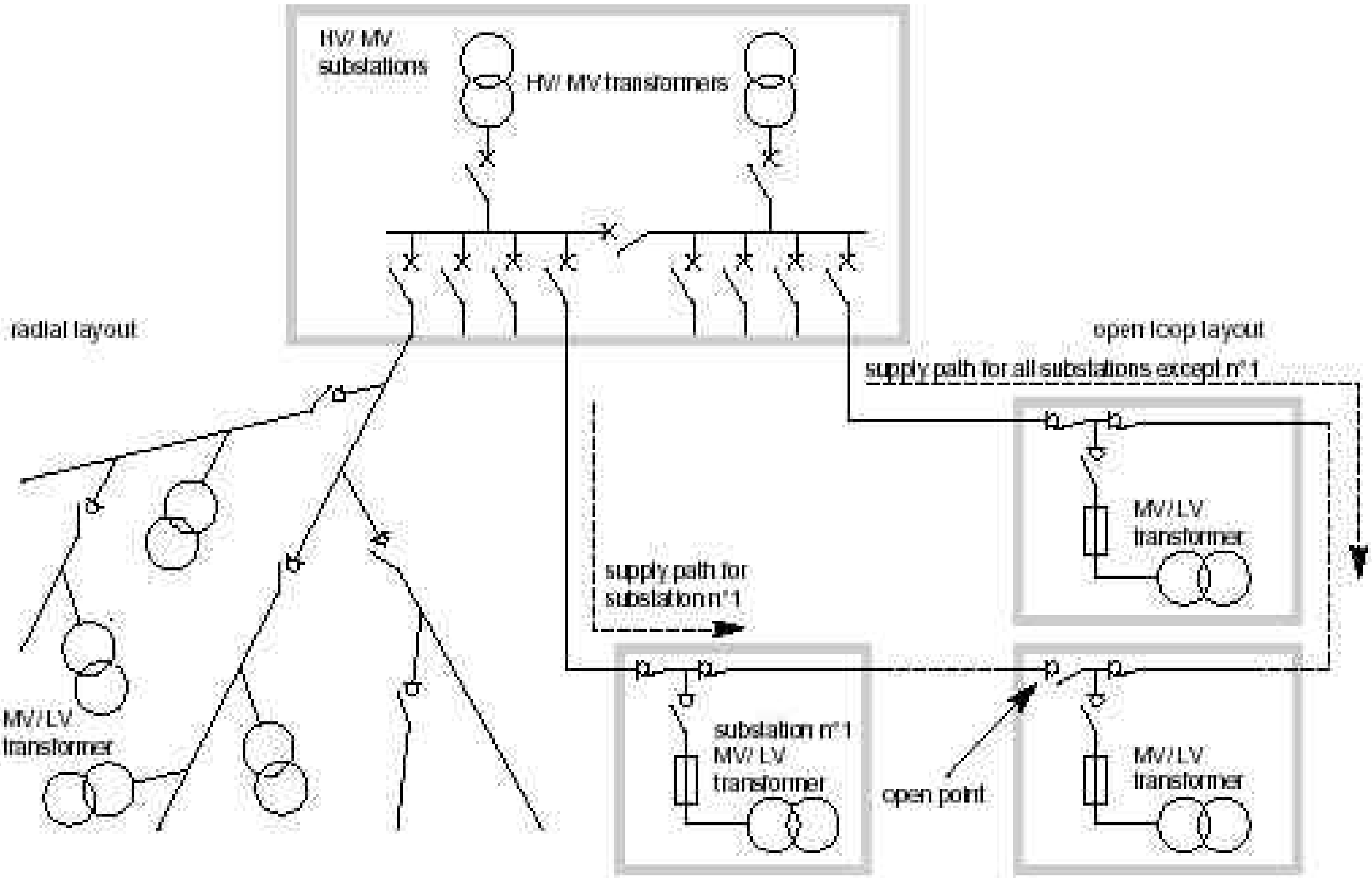


Figure.1.4.-The two basic layouts of a MV distribution network, radial (or antenna) and open loop (or artery break)

- Double shunt layout

This rather uncommon layout is mostly used by EDF in the Paris region. It is shown in the figure

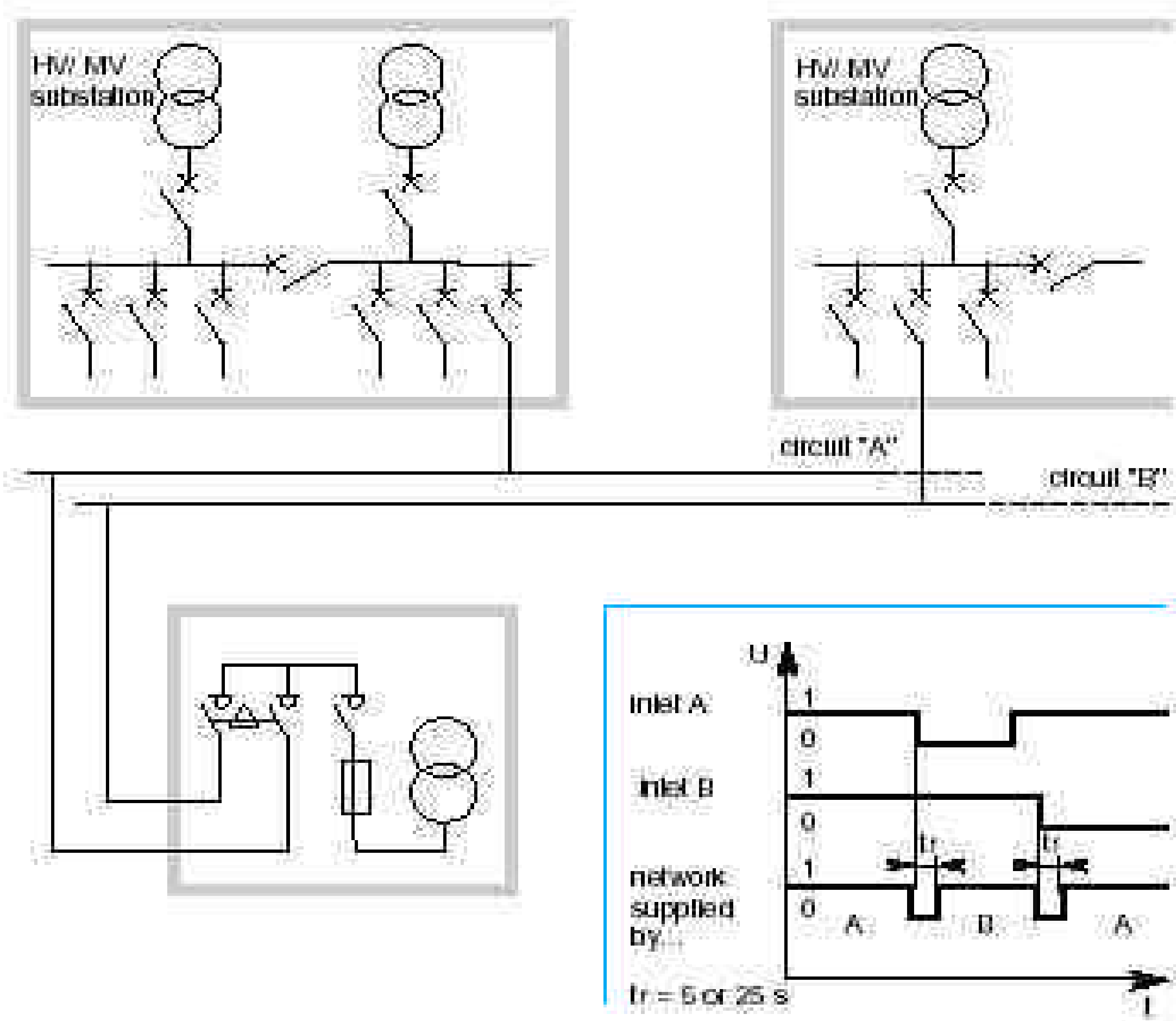


Figure.1.5.-Double shunt distribution layout, used by EDF-France. In the inset, automatic control sequence of a permutator.

The operating principle is the following: the MV network is doubled up containing two circuits A and B. Every MV/LV substation is connected to both MV cables (A and B) but it is actually live to one of the cables (MV switched closed on A). The MV/LV is also equipped with a simple control device. In case of failure of A, the automatic control detects the lack of voltage in the cable, checks the existence of voltage in cable B and commands closing of one MV switch and the opening of the other MV switch.

1.4.4 Description de different cables

In the distribution of electric energy is difficult to take a standard because each distributor uses different cables depending on the technical, historic and economic characteristics. In any case one can summarize some common practical choices, thus in France:

Medium voltage	
Overhead lines	**Underground Cables**
Main lines: Almélec section 75, 117 or 148 mm² (or 228 mm²) Secondary lines : Almélec de section 54 mm², Aluminium-steel de section 59,7 mm²	Main lines: Aluminium section 150 mm² (or 240 mm²) Secondary lines : Aluminium section > 95 mm².
Low voltage	
Overhead lines	**Underground Cables**
Main lines: Aluminium de section 70 mm², Copper de section 45 mm². Secondary lines : Aluminium section 50 mm², Neutral : Almélec section 54 mm²	Aluminium 3 * 150 mm² + neutral 70 mm² Aluminium 3 * 70 mm² + neutral 50 mm² Aluminium 3 * 240 mm² + neutral 95 mm² Aluminium 3 * 50 mm² + neutral 35 mm²

Table.1.4.-MV and LV cable data

The LV networks are usually made by an overhead or an underground configuration. Normally, the underground lines are employed in the case of urban high density population and the overhead lines supply the rural areas. Nowadays, the use of overhead lines is higher in order to improve the service quality and fulfil the environmental norms. Thus, in France in 1997, 84 % of the LV network was overhead type.

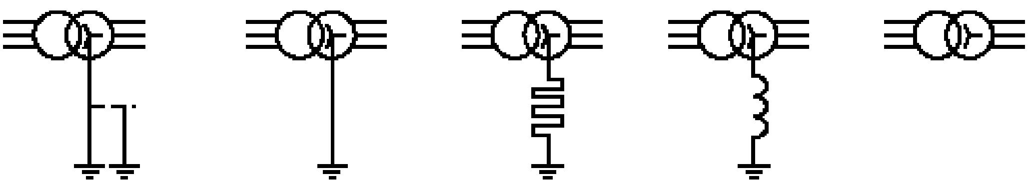
1.4.5 Neutral earthing layout

The choice of neutral layouts (or neutral MV systems) defines amongst other things the voltage surge ratings and earth fault currents that could be found on a network. It must be noted that these two parameters are contradictory, in view of the fact that obtaining a low fault current level leads to a high voltage surge and vice versa. These values create electrical constraints that the electrotechnical equipment must be able to withstand. At the bottom, the choice of a MV neutral earthing layout is always the result of a compromise between installation and operating costs. There is not a standard neutral earthing layout. However, it is possible to bring together all the various cases met around the world into five categories:

- Direct distributed neutral earthing
- Direct non-distributed neutral earthing
- Neutral earthing via an impedance
- Neutral earthing via a designated circuit
- Neutral insulated from earth

As it has already been said, none of the categories is dominant throughout the world: some solutions are specific to some countries, and several categories can be found within one single country, or even within the network of one single electricity distributor.

method



country	neutral distributed with numerous earthing points	neutral earthed directly and undistributed	neutral earthed via an impedance	neutral earthed via a designated circuit	neutral insulated from earth
Australia	■				
Canada	■				
Spain		■	■	■	■
France			■		
Japan					■
Germany				■	

Figure.1.6.- Various MV neutral earthing layouts and their application throughout the world

The choice of neutral earthing layout influences the performance of the network and the design of its protection system. Indeed, the main differences between the five categories lie in the behaviour of the network in an earth fault situation. These differences translate in real terms to the degree of: ease of detection of these faults, people security and impact on the requirements of electrotechnical equipment.

In the figure 1.7, it is shown a comparison of the different earthing layouts in terms of weakness and strengths.

neutral earthing method	strengths	weaknesses
direct earthing and distributed	authorises one-phase and three-phase distribution	■ requires numerous high quality earthing points (safety) ■ requires a complex protection system ■ leads to high values of earth fault currents
direct to earth and undistributed	eases detection of earthing faults	leads to high values of earth fault currents
insulated	limits earth fault currents	leads to surge overvoltage
designated	favours auto-extinction of earth fault currents	requires complex protection systems
impedant		
(compared with neutral direct to earth)	limits earth fault currents	requires more complex protection systems
(compared with neutral insulated from earth)	reduces surge overvoltage	leads to higher earth fault currents

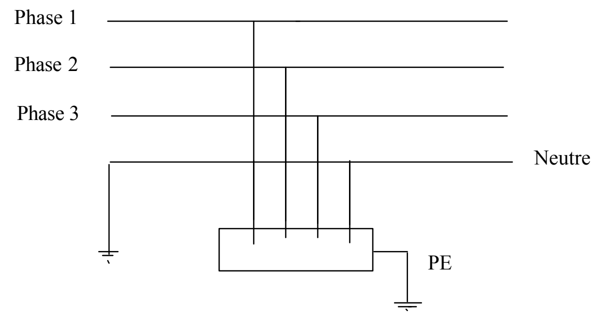
Figure.1.7.-A summary of strengths and weakness of the five MV neutral earthing methods

1.4.6 LV neutral earthing layout

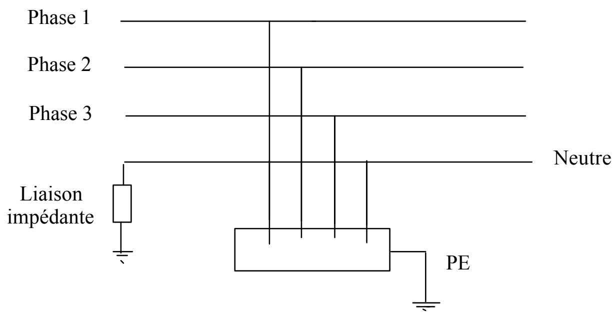
The LV earthing layout influences all the system The French LV. The LV earthing layout is defined by three symbols:
The first refers the connection of neutral to the earth (T direct connection, I no connection or impedant connection). The second one refers the ground connection of the installation (T local earth, N neutral connection). Finally, the third one is only for the TN scheme and revels the state of the protection cables and the neutral cable (C the same cable, S separated cables with the name of PE and N)

Thus, four different schemes are distinguished for the LV neutral layout:

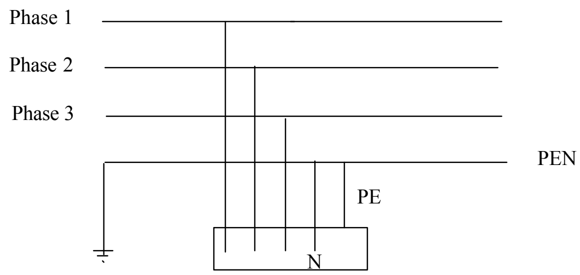
Scheme TT



Scheme IT



Scheme TN-C



Scheme TN-S

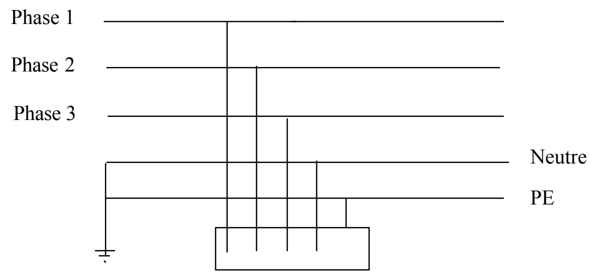


Table.1.5.-Different LV earthing layout

There are not any statistic data that helps us to say that one scheme is better than other one for a distribution network. One can only say that EDF has taken the TT scheme in order to avoid the risk of ground voltage in case of a neutral layout break.

1.4.7 Substations on networks

A substation is a physical entity defined by its position and its function within electrical networks. The role of a substation is essentially to perform the transition between two voltage levels and/ or to supply the end user.

The HV/MV substation is positioned between the sub-transmission network and the MV network. Its function is to ensure the transition between HV (63 kV) and LV (20kV). Its typical layout involves two HV inputs, two transformers HV/MV and 20 kV feeders

The MV/MV substation performs two functions:

- to ensure the demultiplication of MV feeders downstream of HV/MV substations. In this case, the substation does not include a transformer.
- to transfer between two MV voltage levels. Such substations do contain transformers. They are necessary in countries that use two successive voltage levels in their MV networks, for instance in Great Britain where the MV network is broken down into two levels 11 kV and 33 kV.

The MV/LV substation is positioned between the MV network and the LV network, this installation performs the transfer from MV (20kV) to LV (400 V). The typical layout of this substation is of course simpler than the previous installations

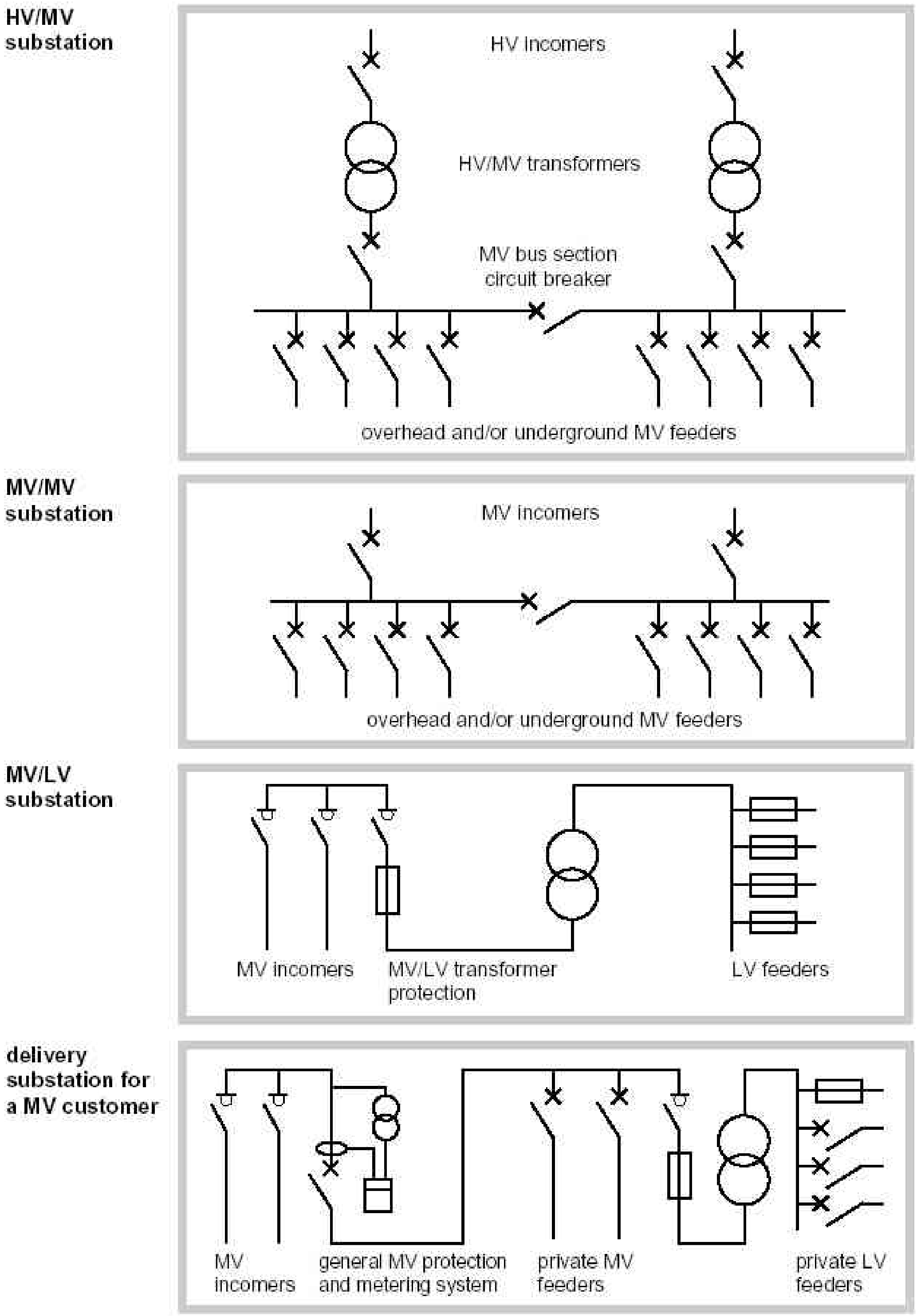


Figure.1.8.-Various layout types for substations used on public networks

The delivery substation for a HV or MV customer: these installations perform the transfer from public distribution to private distribution. They enable connection:

- to the HV sub-transmission network for a high-consumption customer (MVA) via a HV/MV substation.
- to the MV network of a medium-consumption customer (100 kVA) via a MV/LV substation.

1.4.8 Load connection

The connection to the grid of the different charges depends on the absorbed power, thus in France the load LV connection is done if the absorbed power is less than 36 kVA, in other case the connection is done in HTA (MV) level. The main characteristic of the LV lines is that the loads are usually one-phase loads. So, these loads would cause an unbalanced that gives new requirements to the LV lines.

The electric energy is today used in the entire activity sectors:

- The industrial sector: with around 70 % of the employed energy for motors, lighting and activities of heating.
- The residential sector with around 45 % of the energy for lighting…and also apparatus for cooling and heating
- The tertiary sector, where more than 33% of the demand is used for lighting, cooling, heating…

1.5 Protection plan

1.5.1 Faults and outages

For customers, the consequences of an incident or a failure depend above all on the type of fault. A fault can be:

- Momentary or permanent in duration;
- One-phase or three-phase depending on the type of its cause.

A momentary fault often means a brief interruption of the order of several 100 ms, essentially related to the operating time of a recloser.

A permanent fault implies an interruption that lasts between several minutes to several hours and it requires the human intervention.
Overhead networks are naturally more exposed than underground networks and they require specific solutions to problems encountered such as:

- Tree branches failing on overhead lines
- Birds landing on the line or its supports
- Faults due to lightning, wind, frost, snow;
- Vandalism

As a consequence, the type of failures differ between overhead and underground networks: on overhead networks, the faults are mostly momentary (80 to 90 %) and one-phased (75%) since they are often due for example to storms, to a line fallen to the ground or to shorting across an insulator; on underground networks, the faults are mostly permanent (100%) and multi-phased (90%) since they are very often the result of severing a cable.

The short-circuit current created by the faults perturb the correct operation of the system. One can enumerate some impacts of this short-circuit current:

- Voltage sags
- Heating effect and electrodynamics forces in the materials which can break down the materials
- Dynamic effects as increasing the speed of the generators.

1.5.1.1Faults on transmission networks

One can distinguish two types of causes for faults in transmission lines:

- Climatologic perturbations: storms, ice, snow…usually on overhead lines.
- Accidental perturbations: tree branches, pollution…

The next table presents the number of faults per year in the whole French transmission and sub-transmission system:

Voltage level	400 kV	225 kV	90 kV	63 kV
Nombre/100 km/ an	**3.8**	**12.1**	**14.3**	**29.3**
Momentary	**3.1**	**10.5**	**12.7**	**24.8**
One-phase	**2.8**	**8.8**	**10.1**	**14.3**
Poly-phase	**0.3**	**1.7**	**2.6**	**4.5**
Permanent	**0.7**	**1.6**	**1.6**	**4.5**
One-phase	**0.5**	**1.1**	**0.9**	**3**
Poly-phase	**0.2**	**0.5**	**0.7**	**1.5**

Table.1.6.-Faults statistics in transmission and sub-transmission lines

In 400 kV, it is necessary to eliminate the fault in a low time in order to keep the generator stability. The fault elimination time is of the next range:

- Line faults: 70 to 120 ms
- Bars faults: 70 ms
- Switch failure fault: 190 to 240 ms

In 225, 90 and 63 kV the elimination time (switch time included is 50 to 80 ms) is around 80 to 130 ms for the static equipment and 210 ms for the electro-mechanical equipment.

1.5.1.2Faults on distribution networks

Normally, in distribution networks some of the following faults can happen:

- 3-phase faults: they are short-circuit of the three phases (to ground or not).
- 2-phase faults: they are short-circuit of the two phases or one phase to neutral (to ground or not).
- 1-phase faults: they are short-circuits of the one phase to the ground. The value of the current depends on the ground resistance.
- Loss of the neutral cable: this type of fault has some consequences if the network is not balanced. Thus for the less loaded phase, the voltage is higher than for the other phases.
- Furthermore, double or triple faults can occur depending on the fault placement.

One can distinguish the following different types of disruptions:

- Short disruption: between 1 s to 3 min.
- Long disruption: more than 3 min.
- Voltage variation: diminution of the voltage from 10 to 100% of the voltage amplitude during a time range of 0.01 s to 1 s

1.5.2 Transmission and sub-transmission lines protection

In the transmission lines, the protection system responds to the exigencies of: operation security, selectivity and fast operation. This implies a redundancy in the material and equipment of every network. It is also necessary to consider an information exchange system between protections. There are two mains types of protections:

- Protections using local criteria made from current or voltage measures in every network: these protections correspond with the distance protections that help us to locate the fault by measuring the impedance to the fault. With the calculation of the fault, the protections order to open by remote control.
- Protection using as criteria the comparison of electric variables at the extreme of the lines. This correspond to the differential protection (current and current phase comparisons)

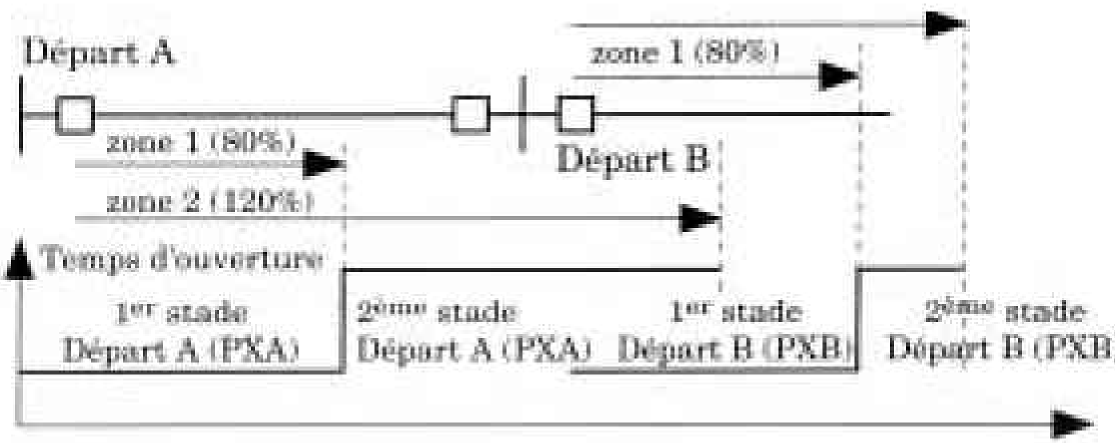


Figure.1.9.-Example of distance protection operation

1.5.3 Distribution lines protections

In every country the protection plan fulfils three mains goals: preserve the security of persons, avoids materials destruction ensures supply continuity.

1.5.3.1MV protection plan

- **Protections at the beginning and the end of the line :**

The disposition of a distribution network scheme protection is based on current protection at constant time; the earthing layout via an impedance at the substations allows us to limit the current (300 A for overhead networks and 1000 A for underground networks, so one can limit the effects on the materials. Since 1986 the evolution of distribution networks has made that new current protection at time dependant have been set up. These protections have been placed in every MV network: 2 phase relays+ zero-sequence relay + timing relay

The design of these relays is based on the following specifications:

- Phase relay : $A_{dmissible} \leq I_{réglage} \leq 0,8\ I_{cc\ bi}$

Where: $I_{cc\ bi}$: 2-phase short-circuit current for the further possible fault,
$I_{admissible}$: admissible current value in the line.

- Zero-sequence relay: $I_{réglage} \geq 1,2\ (3.\ C.\ V\ ")$

Where: C : capacity of all the considered line,
V : simple voltage at the concerned line.

- Timing relay: EDF use an unique time-programmed relay for the phase relevant for the zero-sequence relay. This timing is generally around 500 ms.

1.5.3.2LV protection plan

The protection plan is essentially composed by switch and fuse. These protection means are placed in different parts of the electrical installation:

- At customers' home: switch(d) et fuse (AD),
- At the entry of buildings: Fuse (FC)
- At the beginning of the LV lines: switch or fuse (FD)
- At the primary of the HTA/BT transformer: Fuse (FMT).

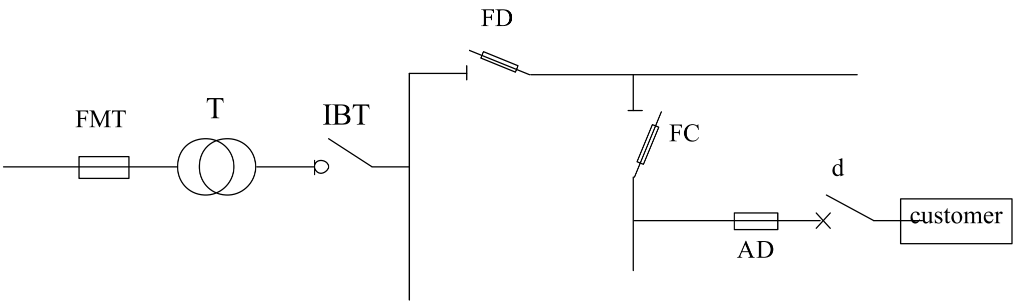


Figure.1.10.- Plan protection in LV networks

1.6 Control and communication systems

1.6.1 System monitoring and control

For a power system to be able to supply all its customers within normal voltage and frequency limits, it must be able to ride through unavoidable disturbances, some of which could be quite abnormal: shunt faults, equipment failure with subsequent isolation, e.g., transformers, generators…, switching surges and lighting strikes, mechanical damages.

Some of these disturbances can be dealt with by protective devices and the system restored to normal within a few cycles. In these cases no further control action is needed. Others may cause transient oscillations which could last for several seconds, producing large oscillations in power flow, abnormal voltages and frequency and subsequent tripping of plants items, then an Energy Management system (EMS) is needed.

An EMS enables engineers to operate and control the network in real time and includes facilities to capture the current state of the system and to instruct generating plants and other controllable system components. Considerable back-up facilities are necessary, including special software programs, displays, and support staff. The hierarchy of a power system with EMS is formed by 4 levels:

- Level 0: network and substations. At level 0 is the power system with its isolators, switch gear, interconnections, transmission lines, cables, transformer…
- Level 1: local controls or substations. These may include protection relays, tap-change controllers and compensator controls, with operating channels to ht level 0 units. Level 1 controls often comprise digital/electronic devices for voltage and current measurement, interlocking and facilities for receiving and sending data up to the next level.
- Level 2: area controls; at level2, man-machine interfacing and data concentrators enable control and maintenance to be exercised so that the whole system can be kept in reliable and efficient condition.

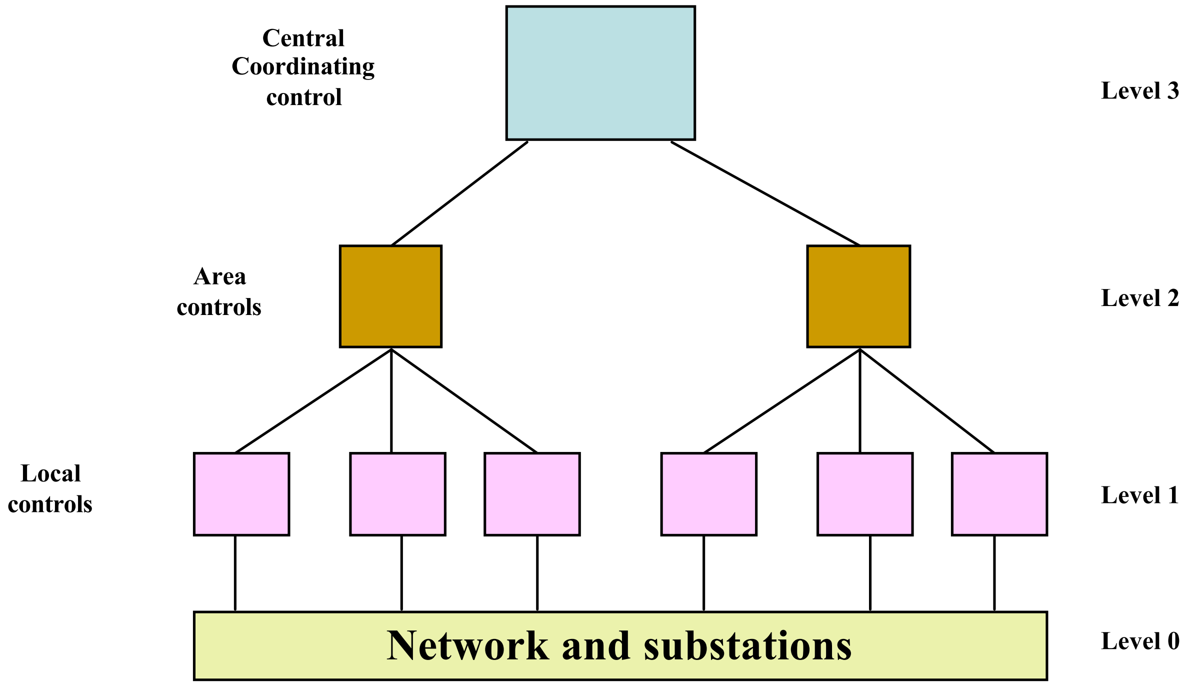


Figure.1.11.- Hierarchy of controls required for an Energy Management System (EMS)

- Level 3: Supervisory Control and Data Acquisition (SCADA). It is a single control centre that accepts data from the various level 1 collectors and displays it in a meaningful way to the control operators. With powerful computer processing, the SCADA feeds into an Alarm Management subsystem to supplement automatic relay operation and to give warning about any system abnormality that is not able to be detected at levels 1 or 2

The EMS processes SCADA data in various ways, including topology identification by using the dynamic data from switch gear, isolators and other connectors. This switch data can also be combined with current and voltage measurements to determine the system state. Such a procedure, using mathematical methods, is called “state estimation”. The data measurements and devices positions change minute by minute and the way to recording and receiving it in the control centre is by on-line digital processors.

The incoming data must be checked for further utilisation: contingency checking, economic scheduling, automatic frequency control…), this process is called data validation.

State estimation is used in modern control theory to enable processes to be controlled, mainly by an on-lie digital computer. It consists in a process whereby data, telemetered from network measuring points to a central computer. A static estimator is obtained from measurements taken within short time intervals (5-10s)

1.6.1.1 Frequency control

The Automatic control based on the frequency is doing in order to keep the frequency around 50 Hz. This frequency is normally enclosed in the concept of Ancillary services.

If the Generation > Consumption ➔ f increase ➔ Power plants disconnection
If the Generation < Consumption ➔ f decrease ➔ Load shedding

This control is a considered control for the new DG sources that can be interconnected into the grid and also for special operations: islanding.

1.6.1.2 Voltage control

The voltage control in the new DG interconnection may be in different positions of the system. Thus, one local control can be considered with a Automatic Voltage Regulator (AVR), other actions can be made: tap changer of MV/LV networks or a block of capacities at the MV/LV substations.

1.6.2 System security and emergency control

It has already been stated that the reason for deigning and operating a system in a meshed form is to provide a path from every generator to very load, despite the possibility that one or two circuits could be outaged .A network configuration and loading state which enables any one circuit to be outaged without loss of supply to any load is called (n-1) secure. To determinate the secure network configuration and state required for each hour of the day is a daunting task. Normally, secure network states are calculated for a few representative loading conditions up to 6 per day including the daily peak, night minimum, and intermediate subpeak conditions.

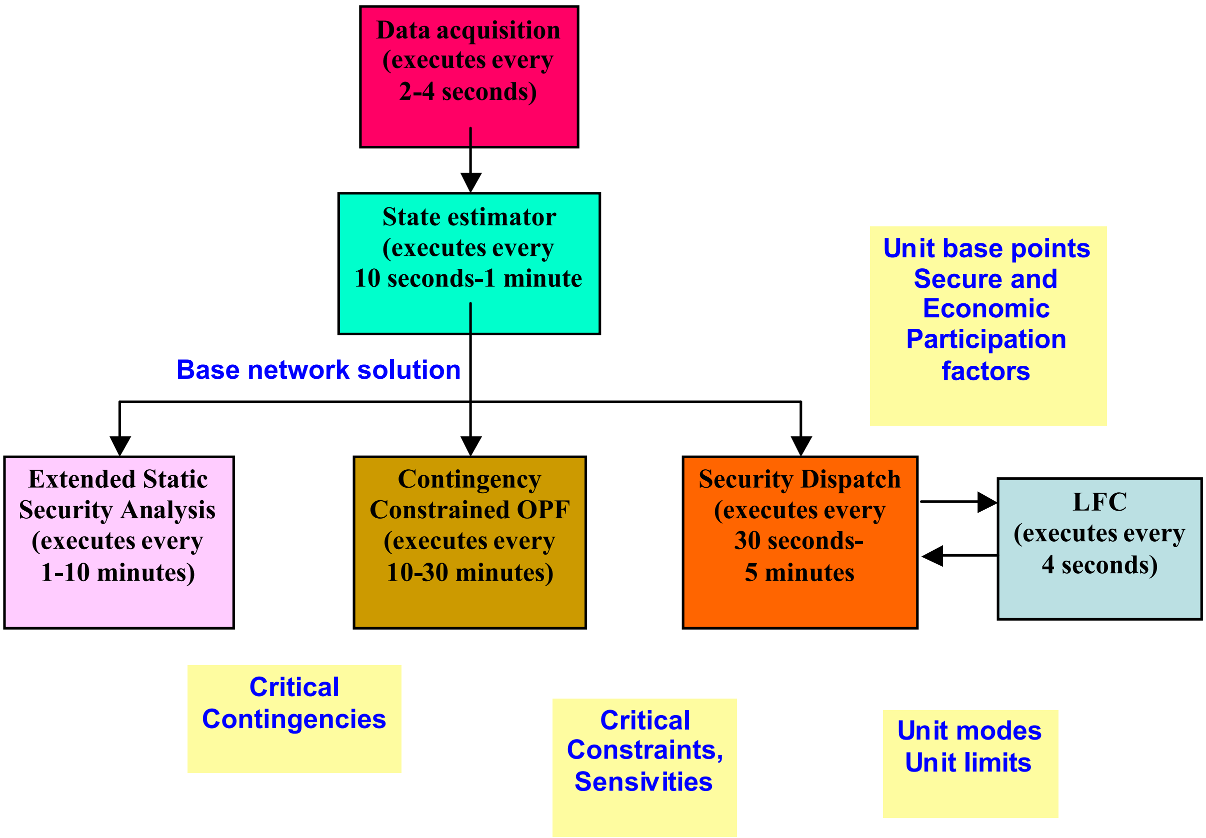


Figure.1.12.- Optimal power flow (OPF) in secure optimal automatic generation control. LFC, load frequency control (Siemens Power System Controls, USA)

Nowadays, optimal power flows with many constraints are employed to determine the secure network configuration and economic loading. Security calculations are made at least 24 j ahead by many ac and dc load flows calculations

1.6.3 Emergency control

The following system-operating states and transition between states may be identified.

1.-Normal to alert-reductions of security level. This could be caused by unexpected load increases, loss of generating units, derating of plant due to environmental constraints and rescheduled maintenance.
2.-Alert to emergency- inability of parts of system to meet requirements, e.g. lines (emergency ratings), voltage levels, frequency, machine and bus voltage angles. Cause by malfunction of protection, lighting.
3.-Emergency to extreme condition (collapse)-loss of integrity. Caused by loss of ties resulting in isolated generation islands which are unable to carry their internal loads.

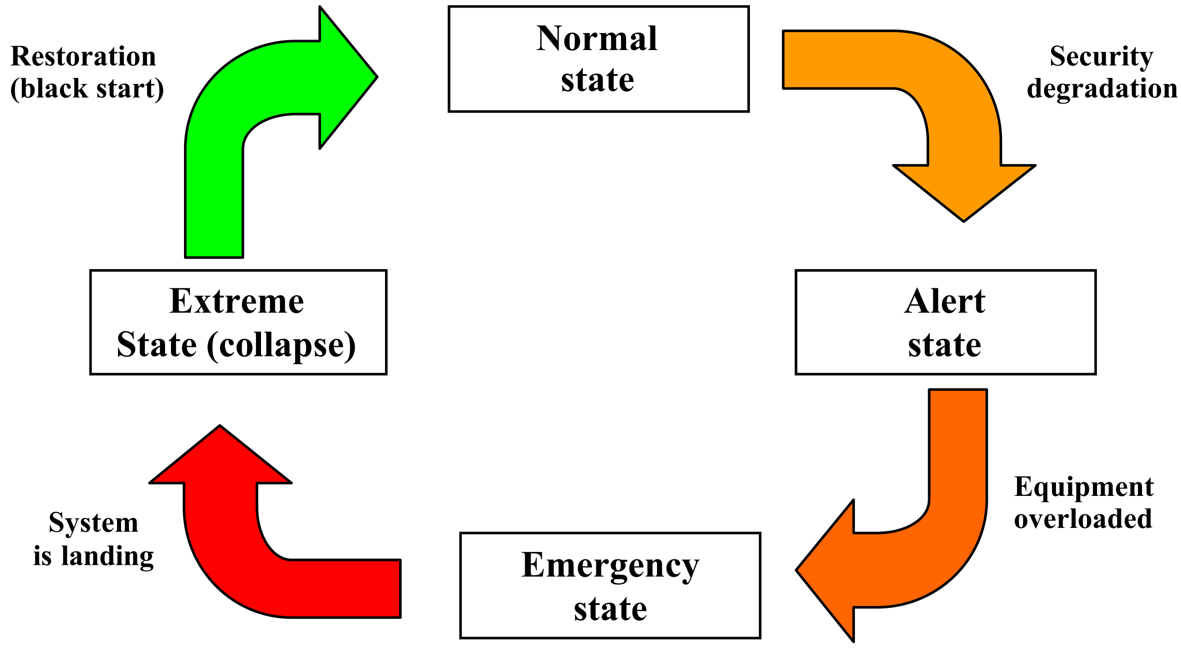


Figure.1.13.- System collapse and restoration process

Corresponding control measures to meet the above situations are as follows.

1.-Alert-This involves restoration of reserve margins, increased generation reserves, rescheduling of tie-lines and voltage reduction
2.-Emergency-This involves fast valving on steam turbine, dynamic braking of generators, load control, capacitor switching and immediate action to clear equipments overload.
3.-Extreme-This involves all of the above plus load shedding and controlled operation of isolated groups.

Following these emergencies action is taken to re-establish a viable system. This involves restarting and synchronization of generation units, load restoration and resynchronization of all areas.

1.6.4 MV remote control

In MV distribution this is a cost saving factor in terms of operation of the network. Indeed, without having to travel, the operator can continually monitor and control the operation of his network. As an example: following a fault it is possible to rapidly change the network operating layout in order to minimise the proportion of the network that is opened, this is carried out by a remote consultation of fault position indicators that are installed at different points on the MV network, followed by remote control of MV switches. The results are a network architecture optimisation with possibilities of optimum management of the load distribution. The network loading can be also analysed. In particular, by logging the load curve verification and optimisation of energy consumption can be performed. Finally, to increase efficiency, the operator can have rapid access to the most relevant information via an automatic pre-processing method such as a sorting operation, graphical representation operation, computing operation,…

The advent of digital technologies has had a considerable impact on the solutions employed in MV remote control. In particular, the ability to use compact and reasonably priced digital protection and control units enables, with centralised operation control, the use today of local intelligent systems. This development offers the following advantages:

- It reduces the disadvantages of intelligent systems concentrated in one single point.
- It offers the advantage of a better maintainability and an increased operational flexibility.

The elements of control of a MV network are organized in several levels:

- Level 0 : MV devices and sensors
- Level 1: protection and control of MV devices
- Level 2: local control of a substation or installation
- Level 3: remote control of a MV network

The assembly constitutes a MV control architecture, whose operation relies on numerous exchanges of information between the various priority levels. This information is essentially; remote data transmission, telemetering, remote control.

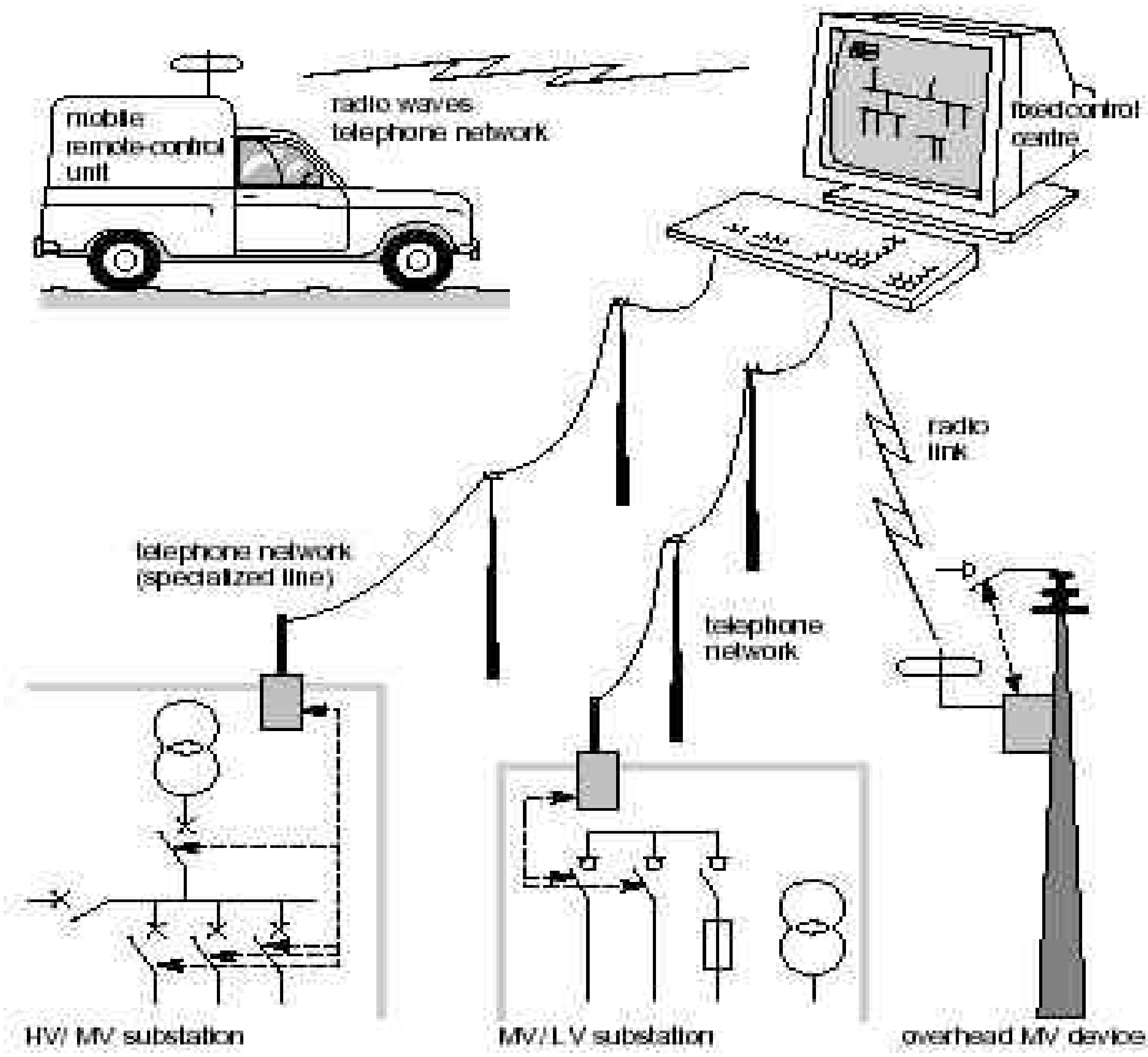


Figure.1.14.-Example of remote control of a MV network, with the various links required for information exchange

The exchange of such information can be continuous or as events occur (network incident, switching commands,…) and it requires high-performance communications networks. All of these exchanges are grouped together within the remote data transmission function, as defined by the following parameters: the organisation, the transmission equipment involved and the communication protocol

The simplest solution to the remote data organisation is to communicate between two transmitters-receivers. However, with links between only two points, the limit of this system's application is very quickly reached. When several units are involved in remote control, a single point-to-point link becomes insufficient, and this is where the idea of multi-point comes in. In this case, two organization types are possible:

- Master-master: all the units within this organization can take the initiative to communicate.
- Master-slave: the control unit with the highest priority level in the architecture is generally the master. It is responsible of the management of all transmissions. The slave units respond to the master interrogation and execute orders given by the master unit. In terms of control for electrical networks, the most frequently used and the safest organization is that of master-slave type. As for data transmission, it is of series type; this means that pieces of binary (0/1) coded information are sent one after the other using the same equipment. Above all the advantages of this type of transmission are simple cabling and good immunity to external disturbances.

1.6.5 Data transmission methods and protocols

Information transmission requires the use of one or several pieces of equipment. In the case of control of electrical networks, the common method used is:

- Paired wires, coaxial cable (specialised telephone links or national telephone networks)
- Radio waves (radio links)
- Power cable (power line carrier)
- Optic fibre
- Power line carrier systems

At the moment, no one type of method is predominantly used, the choice depends on various criteria:

- Amount of information to be transmitted
- Frequency of exchange (number and periodicity)
- Speed requirement for exchanges
- Type of information
- Transmission distance
- Geographical constraints
- Cost of exchanged information

In practice, an electrical energy distributor will always use various methods:

- Specialised lines for control of important installations HV/MV substation
- Radio-electrical or telephone links for control of secondary installations (remote controlled MV/LV substation.

Protocol is the language used for information exchange between the various protection and control units within architecture. It defines the structure of the exchanged messages, both in terms of requests for information and for response messages. These protocols can be unique to one equipment manufacturer (or to several manufacturers) or standardized, conforming to various standards. As far as public distribution is concerned, within the concept of architecture that has been presented above, which is becoming generalised, distributors are trying to standardize protocols between levels 2 and 3. However, internal switchgear transmission protocols remain the choice of the manufacturer.

2. Traditional network operation: from monopoly to liberalisation

2.1 Introduction

This chapter will analyse the traditional operation of the electric system. Traditionally, the electric market constituted a form of monopoly or quasi-monopoly. National companies had the control of the generation, transmission and distribution of the electricity, this structure can be explained by the government's priority to supply customer and ensure the quality of service.

But with the publication of a European directive by the European commission in 1996, this fact facilitated the liberalisation of the sector and the apparition of new actors in the market (new producers, separation of electrical functions: generation, transmission and distribution, trading pools, eligible customers which can choose its producers…)
So, the operation of the market has changed radically in the last years and the procedure of liberalisation is continuing and in some years all customers will be able to choose the producer and to carried out agreements in the price of electricity. The architecture and different actors and its functions of French electricity market are explained.

2.2 Traditional electric market operation

The traditional operation of the electric market was founded in the existence of huge operators of generation and transmission. This situation went with a monopoly or quasi-monopoly of the market. The monopoly can be explained by the evolution of the electricity; normally the electrical companies had licenses given by the governments in order to assure the supply to the customers.

One example of national monopoly is EDF (Electricité de France). EDF has been for 50 years an industrial monopoly for the generation, transmission and distribution of the electricity in the French territory.

2.3 The 1996 European Directive and perspectives

This situation of monopoly was questioned and changed by the 1996 European directive [11]. The European Commission had two strong convictions:

- The monopoly in the electrical sector like in another sector can create losses in the economic efficiency, discriminations and abuse caused by a dominant position.
- The collection of geographic monopolies, which was common in the traditional market operation, constitute an obstacle to develop the international commerce of electricity and the European integration of this sector

The opening of the national markets with competition means was essential to insure the sector economic efficiency and the creation of a European space. The main disposition of the 96 Directive can be summarised as follow:
- Separation of different activities: generation, transmission and distribution.

- Progressive opening of the market to facilitate the entry of eligible customers
- Creation of transmission operator, which is charged of ensuring the correct operation of the electrical system and conduction of the electric energy under non discriminatory condition.

The Directive defines as well the role of the distribution operator and it distinguishes officially:

- Producers
- Transmission operator
- Distribution operator

From 2005, European consumers should be completely free to choose their electricity supplier. That is the goal of the European Energy Commission.

The state of liberalisation in 2001 was the next one [12]:
Germany, Finland, Sweden and Great Britain have already completely liberalised their electricity markets (100%). In Belgium (33%), consumers of more than 10 GWh (the equivalent of a large hospital) will be free to choose their electricity suppliers by 2003. Italy (30%) aims to reduce the consumption threshold to 9 GWh in 2002. Austria (27%) wants the electricity market to be completely free from 2001 and Denmark from 2003 - the Danish figure is currently about 90%. In contrast France, Greece, Ireland and Portugal are the only countries to settle for the minimum target in the EU directive. In these countries, the share of the market opened to competition ranges from just 26 to 30%. Finally the degree of market opening in: Netherlands 33%, Spain 42%, Luxembourg 45%.

2.4 Market Energy Architecture

The European directive gives the opportunity to every country to decide the type of structure to introduce the competition in the market. In this way, for example, France and Italy have taken structures to minimize the eligible customers. On the other hand, Great Britain and Germany decided to an immediate and complete opening to all customers. The domestic little customers are also eligible.

Different ways was used to organize the competence in the market: Great Britain preferred the pool system, Spain also. The majority of the countries allowed the entry of other companies taking into account certain rules. All countries created the transmission operators and a specialized regulator (sometimes in the form of a regulation commission).

In the case of the French market, one can find the next architecture of actors:

- Producers: EDF, Dalkia…
- Eligible customers
- Distribution lines Operator: EDF and some local distribution companies
- Transmission lines Operator: RTE
- A trading pool: POWERNEXT
- Market regulators: CMF, CRE

The deregulation of the market has facilitated the apparition of new producers connected to the grid. So, one can find a large list of different generation entities apart from EDF. On the hand of the customers, those ones that have consumption bigger than 7 Gwh per year can choose their producers; and in this way bilateral transactions can be effectuated. The consequence is the customer choice of the energy price between the different producers' proposals. Finally it is confirmed the energy reduction because the generation companies are forced to increase their efficiency to produce electricity at a lower cost.
The market is organised by a trading pool where the different actors can change the offers and demand and so they can effectuate commercial transactions. The whole system is supervised by two market regulators which try to ensure the normal and legal system operation.
In the next paragraph, the roles and mission of the market regulators and the Powernext trading pool are detailed

2.5 Powernext

The 1996 European Directive was transposed into French law by the February 2000 law. Powernext [13] is a new trading tool available to all European electricity traders and its aims are:

- To create an indisputable reference price in France through new means of trading an increase in the diversity of players, and by benefiting from the privileged position of the French electricity hub.
- To be a player in the "rationalisation" of European electricity markets by providing a spot market of European scope (block products, compensation of bilateral contracts, indices, opening up to other hubs).
- To be a major player in the construction of a unified financial power market in Europe and to launch a range of hedging products for all power-related risk (gas, electricity futures contracts, CO2, weather derivatives

This share price is used to exchange agreements between the different components of Powernext in order to buy and sell electricity.

2.6 Market regulators

In France, two different organizations are present to regulate the electric marke [14]t:

- **"Conseil des Marchés financiers (CMF)"** The Conseil des Marchés Financiers (CMF) is a unique professional body in charge of the regulations and the monitoring of both regulated and OTC markets. It establishes the general organisation and operating principles of markets through its "Règlement général". This collegial institution is composed of various professional categories involved in the securities market such as exchange intermediaries, industrial and commercial firms, institutional investors and employees' representatives. The sixteen members of CMF are appointed for a four-year period by decree of the ministry in charge of Economy and Finance. The CMF takes all decisions required to ensure the proper working of markets:
    - It supervises compliance with exchange rules and regulations by investment companies operating in France, and market's adherence to the rules of proper working that it defines.
    - It oversees the compliance of the transactions performed on a regulated exchange.

  - It establishes the rules for financial operations such as public tender offers, which are subject to the CMF's prior approval.
  - It is empowered to sanction.

- **"Commission de Régulation de l'Energie (CRE)"**. In accordance with the law, the CRE's missions are about access to the transport and distribution networks, and about the power and gas markets regulation. Competition can indeed be fair only if producers and eligible consumers can access the transport and distribution networks according to fair, transparent and non-discriminatory rules. In the same spirit, the smooth transition to competition into the French power market needs to be regulated by an independent authority; the CRE shall intervene on points such as entrance of new producers and protection of non-eligible consumers. As examples, the CRE will assume the following tasks:
  - It grants competition on the distribution network. It ensures the implementation of the RTE's accounting autonomy towards EDF.
  - It thus guarantees neutral and transparent tariffs to access the network.
  - It ensures the implementation of the RTE's accounting autonomy towards EDF.
  - It thus guarantees neutral and transparent tariffs to access the network.
  - It is in charge of approving the RTE annual investment program and gives its opinion on the comprehensive pluri-annual investment scheme.
  - It gives its opinion on new comers' subscription demands.
  - It manages requests for production proposals submitted to new producers.
  - It balances between the objective of enhancing competition and the necessity to maintain some public utility missions.

3. Description of different decentralised energy sources

3.1 Decentralised production or distributed Generation (DG)

The connection to the network of new energy producers leads to new concepts. Thus, these last years, terms such as Decentralised production, Distributed production, Integrated production, Distributed Generation or Dispersed Generation have invaded the electric networks literature.

There is not a unique criterion about the signification of each term. Each association, work group or author establish its own definition and from this definition it defines its work.
The majority of documents coincide that the DG concept does not correspond to all the electricity producers connected to the grid, in fact DG correspond to those generators that satisfy some conditions. Generally the critical parameters used in the DG definitions are:

- The location of the producer and the production system that is positioned in the customers' installations or just outside. This is the case of the definition given by *Energy Department of the United States* and by *California Alliance for Distributed Energy* - *CADE*.
- The second important parameter to be considered is the connection point to the network. Thus, only the energy sources connected to the distribution network and not to the transmission network constitute DG. This is the criterions employed by *Cigre Work Group* WG *37-23* and by *Trade and Industry Department of Great Britain* – DTI.

In this report, Decentralised Production or Dispersed Generation (DG) is considered as every generator connected to electric networks in the sub-transmission system or in the distribution system and without any limit in the power that is generated by the energy sources.

Finally, one can remark that the DG concept refers the electricity generation systems and also those elements of energy storage. The technologies of energy storage are extended from batteries, super capacitors, super magnetic storage systems, flywheels and superconductivity systems. But it must not be forgotten the main storage mean: dams for hydraulic energy.

3.2 Decentralised production vs. Centralised production

Historically, growth in electric load has been served by adding new central station generating units, building high voltage and extra high voltage transmission lines and extending traditional distribution systems. But, nowadays the liberalisation of the market facilitates the integration of little independent producers in the form of decentralised generation. If a comparison between decentralised production and centralised production is developed, some differences, advantages of DG can be in evidence:

- New independent producers base usually the production in renewable energies. So, they constitute less polluting emissions and in general the waste generated has a low influence on the environment. If we think about nuclear and thermal power plants, the polluting emissions are higher and the risks faced to incidents are not always solved.
- The installation time for central station generation and transmission lines including environmental impact studies, archaeological studies, permits, rights-of-way acquisitions, and design and construction time can exceed seven to ten years. The distribution time can last from 6 months to 2 years. Self generation and all underground micro grids are typically installed in less than six months.
- The high power plants require some special infrastructure such as: roads to supply fuel, maintenance elements,…Expensive transmission lines have to be dispose to lead the generated electricity.
- The risk of investment done is more critical in the case of centralised production because they are normally computed as a function of the load evolution and this evolution can be different from the forecast evolution. This was confirmed during

the oil crises of 1979. The DG will be placed close to the points with energy needs and this implies a loss reduction in the electric lines and less risk of the investments.

- The decentralised production and the deregulation favour the population to confront the investments of a DG installation. This constitutes a employment source and an incentive to new little companies, an activation of the country economy. The eventual agreements between little producers could form a whole offer in the energy pool. It is evident that could activate the competence.
- More strength in the market competence and as consequence the price reduction for the final customers. The high cost of central power plant and the complexity of the studies to be done and the consequences in case of accidents make difficult that the governments allow building them.
- The reaction time to start the energy generation (dispatchable energy) is lower with DG because the centralised power plant has a time to entry in service that varies from some hours to a day.
- However, the decentralised production is not the panacea and they have some disadvantages such as the intermittence of the production for example solar and wind energy.

The next table shows the share of different energy sources in the European Union:

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

Table.3.1.-Electricity sources in the EU : Share of different energy sources in total energy generated (percentage)

3.3 Description of different decentralised energy sources

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

In France the voltage level for the dispersed Generation depends essentially on the injected power in the network. Thus, the 12 MW is the border value between the susb-transmission and the distribution network connection. For generators from 12 MW to 250 kVA the connection is done into the MV distribution network. Finally the generators of less than 250 kVA are branched into the LV system, but this is not rigorous and one can find generators of less than 250 kVA that are connected at the MV network because they are placed near the MV network. From an economical point of view it is cheaper to connect to the MV level.

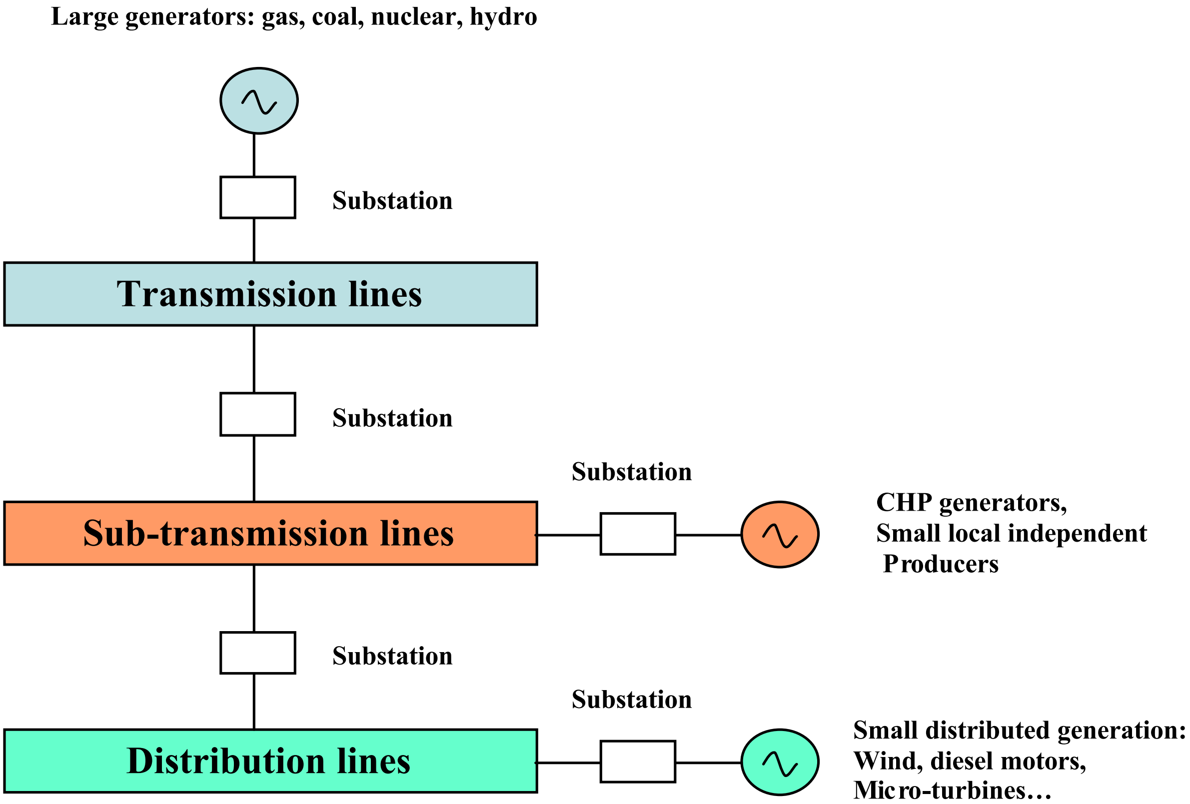


Figure.3.1.- Different connection network of generators

3.3.1 Conventional energy sources

- Combustion turbines: They have an interval of power between 25 kW and 200 MW.

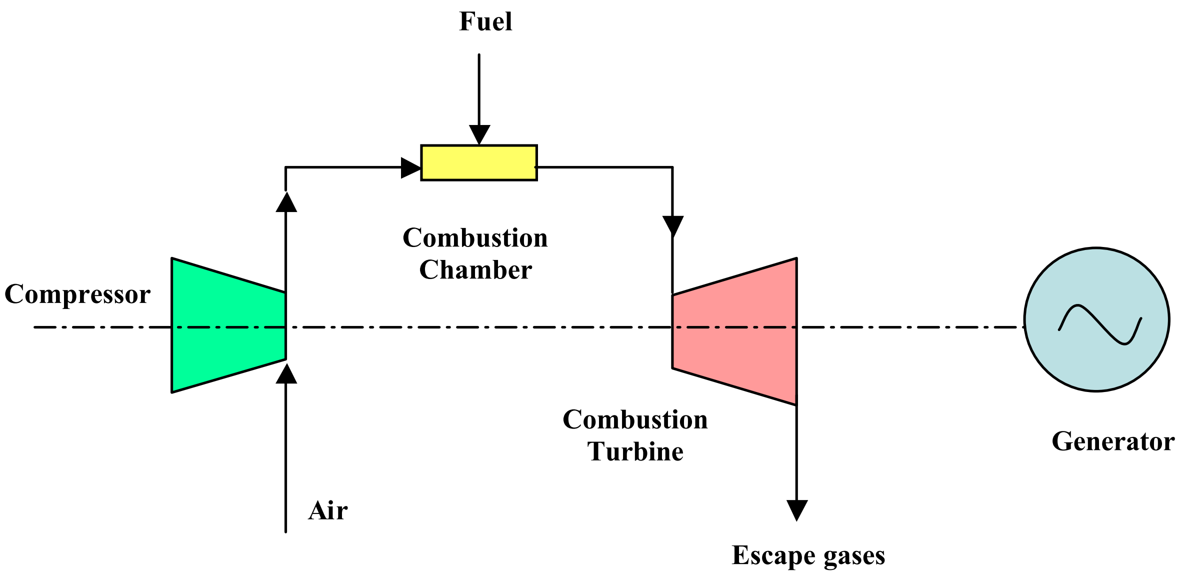


Figure.3.2.- Combustion turbine scheme

There are two main types of gas turbines: with two different trees or with a unique tree (see figure 3.2). Actually the integration of this kind of generators is made in HTA or HTB. They are interesting to the CHP (Combined Heat and Power) units.


Figure.3.3.-CHP unit example

- Combustion micro-turbines: they are little combustion turbines with a power of 30 kW to 250 kW. They can work with different fuels. These generators are designed to little commercial uses of CHP. The interface to the network is normally made by an equipment of power electronics (AC/DC converter and DC/AC converter). These converters adapt the fast speed of the turbine to the grid frequency. The integration voltage level is 400 Volts.

- Gas motors: They are used to CHP uses and the power interval is from 5kWe to 5 MWe. The first utilisation of these motors was the safety and back-up groups but today the tendency is to use them in production and CHP. The voltage level of integration in the network is 400 Volts with a electric efficiency around 25-30% and a CHP efficiency of 90%.

- Diesel motors: The power range is around 100 kW to 25 MW. They are used in CHP and as back-up or emergency groups. The mechanical efficiency is about 35 to 50 %. The integration on the grid is made at MV or LV. The diesel motor is relay to a generator (asynchronous, direct current motor, synchronous).

- Steam turbines: they can use every kind of fuel for example sources of renewable such as biomass or geothermal energy. The disadvantage is the installation costs, the complexity and the weight. The grid integration is normally done at HV or MV.

- Stirling motors: the pre-commercial interval of power is about 5 to 50 kWe. It can be possible to generate energy from biomass sources, fossil fuels. They are also employed to the CHP uses. The motor is relay with a permanent magnet and it works at a constant speed and the integration on the grid is direct.

- Fuel cells: there are different offers in the market from 1kW to around 1 MW (it depends on the type of fuel cell). They are in a research step of development and the integration voltage level is LV (230 V). The fuel cells convert the chemical energy to a direct electric energy. So, the power electronics interface is necessary to insert the fuel cell on the grid.

Figure.3.4.- Fuel cell example of 250 kW

The fuel cell voltage level is low some volts, so a DC/DC converter is necessary to rise the voltage to the voltage of the DC/AC converter. A storage element is usually placed in the DC bus in order to ensure a power level (the variation of power caused by variations of fuel supply are avoided). In this way, the behaviour of the fuel cell will be that one of a PQ bus.

3.3.2 Renewable energy source

Between now and 2010, renewable energy's share of electricity generated should rise to 22%, thereby doubling. This is provided for in the EU Directive on Electricity from Renewable Energy Sources, which was approved by the European Parliament on 3rd July 2001. Most of the renewable energy sources are expensive or they are in a research evolution, but in anyway important efforts are being done by the EU states to increase their utilisation and so reduce the polluting emissions. Some of the renewable energy sources are detailed in the next paragraphs:

- Micro-hydraulic power plants: from some kW to 500kW. There are different types of turbines: Pelton, cross flow (action turbines, $P_{entry} = P_{exitt}$ high height), Francis, Kaplan (reaction turbines, $P_{entry} > P_{exit,}$ lower height). The generator machine can be: asynchronous, synchronous machine or a direct current motor. Generally for <50 kW it is used an asynchronous machine, for > 50 kW a synchronous one.
- Wind turbines: there are two main types of generators used in wind energy: asynchronous and synchronous. The connection of the generators to the grid can effectuated:

Figure.3.5.-Small wind turbine (1kW)

- Directly, the frequency is conserved by the adjustment of the pales angle. They have a STATCOM or a SVC in order to improve the power factor and the voltage level and behaviour faced to a perturbation.

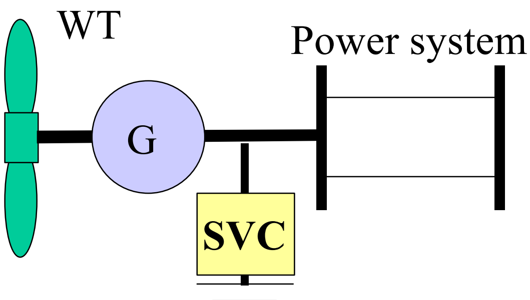


Figure.3.6.- Direct wind turbine connection

- With a power electronics interface: AC/DC converter and DC/AC converter

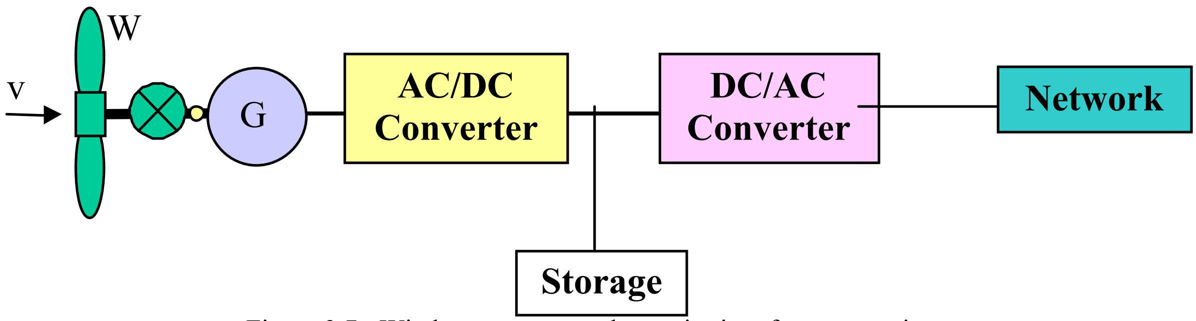


Figure.3.7.- Wind energy power electronics interface connection

- Double exit asynchronous generator (Spanish system): the speed variation is larger; the power is around some hundreds of kW. This system reduces the noise and helps us to improve the energy quality.

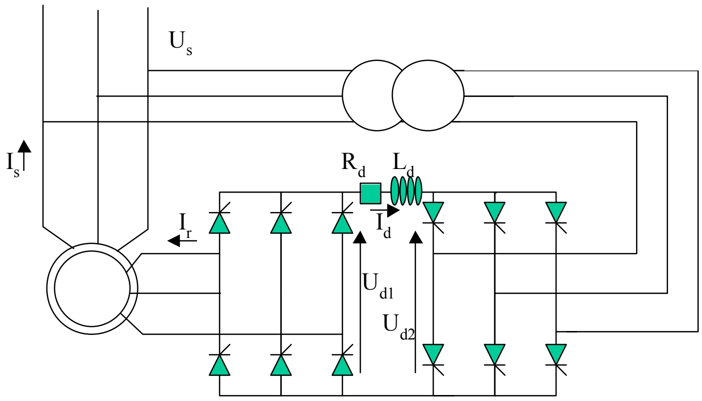


Figure.3.8.-Double exit asynchronous generator

Sometimes, the wind turbines are associated with other sources of energy, e.g. a diesel motor or a storage element in order to avoid the intermittence of the generated power caused by the variations on the primary fuel.

The next major development in wind energy is the offshore installation. There are already small offshore wind farms located rather shallow waters off Denmark and Holland. However the new wind farms now being considered will be large, typically 50-100 MW and may be located many kilometres offshore. The advantages of offshore installations include: reduced visual impact, higher mean wind speed, reduced wind turbulence but they have some disadvantages: higher capital costs, access restrictions in poor weather, submarine cables required.

Figure.3.9.- Middelgrunden wind farm (2 MW, 20 wind turbines), Copenhagen, Denmark.

The integration of offshore wind farms with distribution networks poses a challenge due to the size and its remote location. A serious consideration is being given to using voltage source HVDC transmission to bring the power ashore and so avoid the problems and expense associated with long AC high-voltage submarine cables.

- Solar Photovoltaic generation:

Photovoltaic generation or the direct conversion of sunlight to electricity is a well established technology for power supplies to remote sites from the distribution network. However, it is now also being seriously considered as a potentially cost-effective means of generating electricity. The current produced by a solar cell is proportional to its surface area and the incident irradiance. So, here one can find the incertitude of the generated power, because it depends on the incident irradiance. The Photovoltaic units will have outputs of 1-2kW and the connection with the grid is done with the architecture shown in figure 3.8.

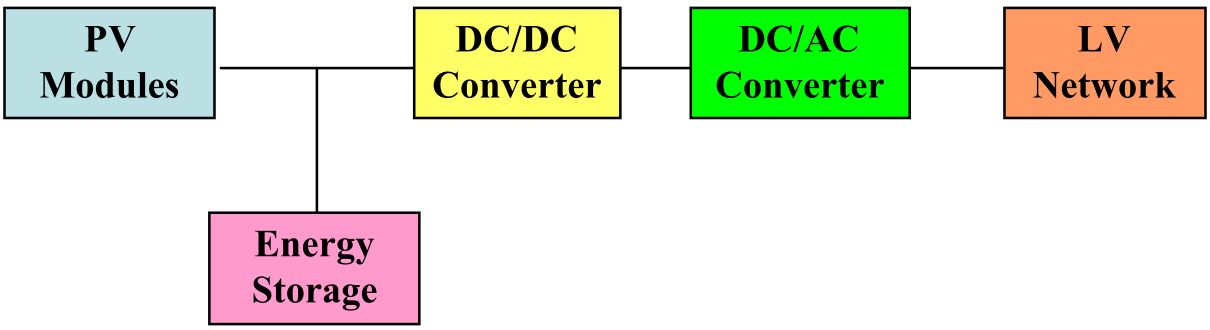


Figure.3.10.-Photovoltaic units connection to the grid

The normal interface of PV is made with DC/AC converter. In order to ensure a constant power injected to the network, storage elements (batteries) are disposed.

A special characteristic of the renewable sources is that in the case of a failure happens in the system, the unit is immediately disconnected from the grid due to the electronic power interface.

3.3.3 Storage energy sources

The tremendous difficulty in storing electricity in any large quantity has shaped the technology of power systems. Various options exist for the large-scale storage of energy which may be converted into electricity but all of them are expensive and care must be taken in the economic evaluation. There are different kinds of energy storage: pumped storage, batteries, super capacitors, flywheels, chemical and gases storage…one particular case id the batteries power plants that can generate 120 MW.

- Pumped storage: it consists on an upper and a lower reservoir and turbine-generators which can be used as motor-pumps. The upper reservoir has sufficient storage usually for 4-6 h of full-load generation with a reserve of 1-2 h. The sequence of operation is as follows. During times of peak load on the network the turbines are driven by water from the upper reservoir in the normal way. The generators then change to synchronous motor action and, being supplied from the general power network, drive the turbine which is now acting as a pump. During the night the energy is cheaper, and it is the moment to reload the water from the lower to the upper reservoir.

- Compressed-air: air is pumped into large receptacles during night and used to drive gas turbines for peak; day loads. The compressed air allows fuel to be burnt in the gas turbines at twice the normal efficiency. One of disadvantage is the much of the input energy to the compressed air manifests itself as heat and is wasted.

- Heat storage: No large scale storage involving heat has yet evolved. Water has many advantages as heat storage.
- Superconducting magnetic energy stores (SMES): continuing development of the called high- temperature superconductor, where the transition temperature can be around 60-80 K has led to the possibility to store energy in the magnetic field produced by circulating a large current (over 100 kA) in an inductance. For a coil of inductance L in air, the stored energy is given 0.5 L I2 which can provide 100 MW for several seconds with a coil diameter of around 20m. Initially it is expected that commercial units will be used to provide energy for sensitive loads to guard against voltage sags or to provide continuity whilst emergency generators started. Another use in transmission networks would be to provide fast response for enhanced transient stability and improved power quality

- Flywheels: A flywheel, in essence is a mechanical battery - simply a mass rotating about an axis. Flywheels store energy mechanically in the form of kinetic energy. They take an electrical input to accelerate the rotor up to speed by using the built-in motor, and return the electrical energy by using this same motor as a generator

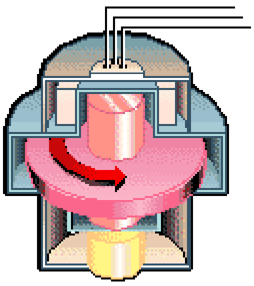


Figure.3.11.- Flywheel system

- Supercapacitors: the interface between an anode and cathode in an electrolyte has a very high permeability; this property can be exploited in a capacitor to produce a 25 V with a capacitance of 0.1 F. Many units in series and parallel would have the capability of storing many MWh of energy, which can be quickly released for transient control.

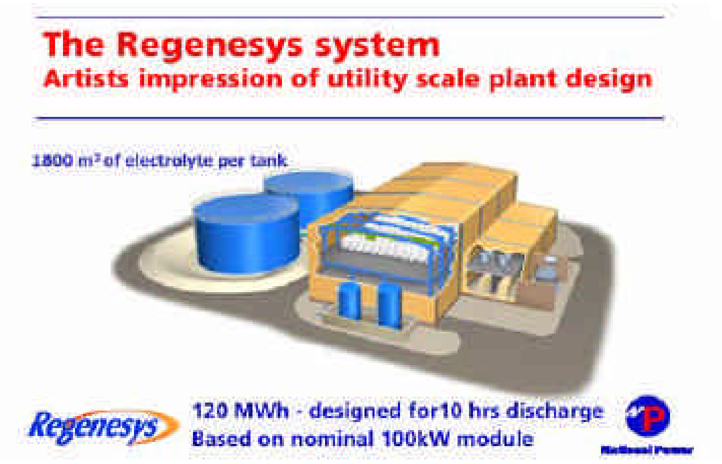


Figure.3.12.- Regenesys batteries power plant

- Batteries plants: One example is the Regenesys system that has been developed in the United States and in Great Britain . The operation principle is the reload of the batteries between the night (cheaper energy) and the generation of energy during the peak hours (higher demand of energy, more expensive energy price). The interest of this installation is essentially economic but it can help to control and supply the peaks of energy. So this power plant could be as a back-up plant that it is ready to produce when it would be necessary.

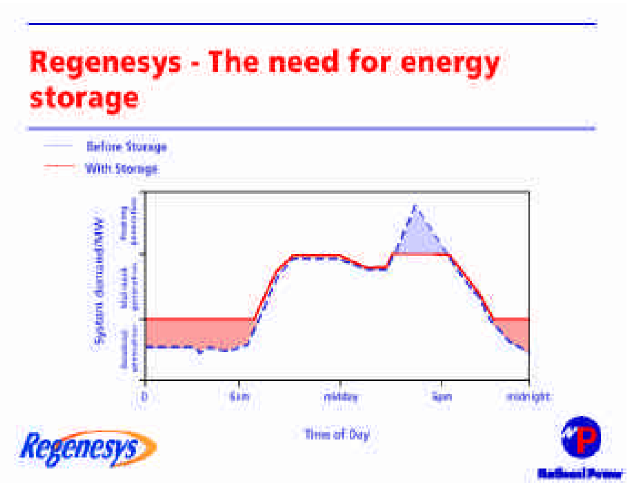


Figure.3.13.- Participation of the power plant to control the peaks of energy

In the next table, it is shown a comparison between different storage elements:

Energy	Storage system	Efficiency	Storage density (kWh/m^3)	Download time
Gravitational	Reservoir	0.73	2(pour 1000m of	Every day, week

			H)	or season
Thermal	Heat storage	0.65-0.85	20 to 150	Every day
Pressure	Air compression	0.7	2 to 5	Every day or week
Chemical	Batteries	0.7 to 0.9	5 to 150	Some days to some minutes
Kinetic	Flywheel	0.7 to 0.9	10 to 100	Some minutes
Electromagnetic	Superconductor coil	0.9 to 0.95	0.1 to 5	Some milliseconds
Electrostatic	Super capacitor	0.9 to 0.95	1 to 10	Some seconds

Table.3.2.-Comparison between different storage elements

3.4 Conclusion

The number of installations and different types of power plants connected to the networks is increasing. These new energy injections can offer social and economical benefits, e.g. reduction of gas emissions. On the other hand, they can not be placed everywhere, e.g. the voltage level where the new generator is going to be placed depends on the impact in the distribution network and also on the social and environmental impact. In anyway, all these energy sources constitute an available alternative to the centralised production but, nowadays, they have to be understood as a mean to generate only a part of the total energy demand.

4. A distributed grid with DG penetration: benchmarking model

4.1 Introduction

This chapter proposes a case to be used in the different work package of the project. It is composed by a transmission network 400 kV at two French distribution networks. The different components of the system will be defined.
This can constitute a first model from every one can start to develop their works; for example in WP 1.3, the baselines given in this model will be used in order to study different scenarios and finally define the optimal DG penetration value.

4.2 Benchmarking model: proposed case

The proposed case for the benchmarking model is composed by a transmission network (400 kV), a sub-transmission network (63 kV) and two French distribution networks (20 kV, 1and 2).

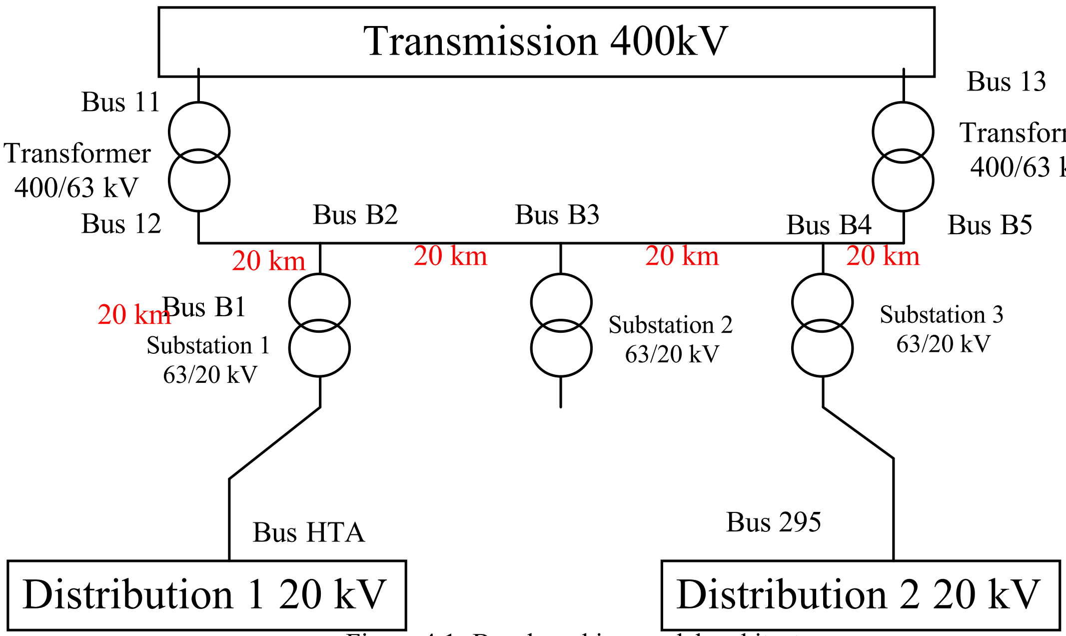


Figure.4.1.-Benchmarking model architecture

4.2.1 Transmission network

The transmission network architecture is based on the IEEE New England architecture. From this architecture, the impedances and resistances of lines have been adapted to a common French case, in this way the cables correspond to an Almelec 570 one (R = 0.06 Ω/km, X =.0.38 Ω/km and C = 10 nF/km). The current limit imposes a power limit of 780 MVA for a 0.6

Imap. The transmission is composed by 18 lines, 10 generators and 39 buses. The total generated power is 6280.78 MW and 874.42 Mvar and the transmission lines load is 6150.10 MW and 874.42 Mvar. The generated power and load in every bus are detailed in the paragraph 4.5 (file enclosed crisp.txt).

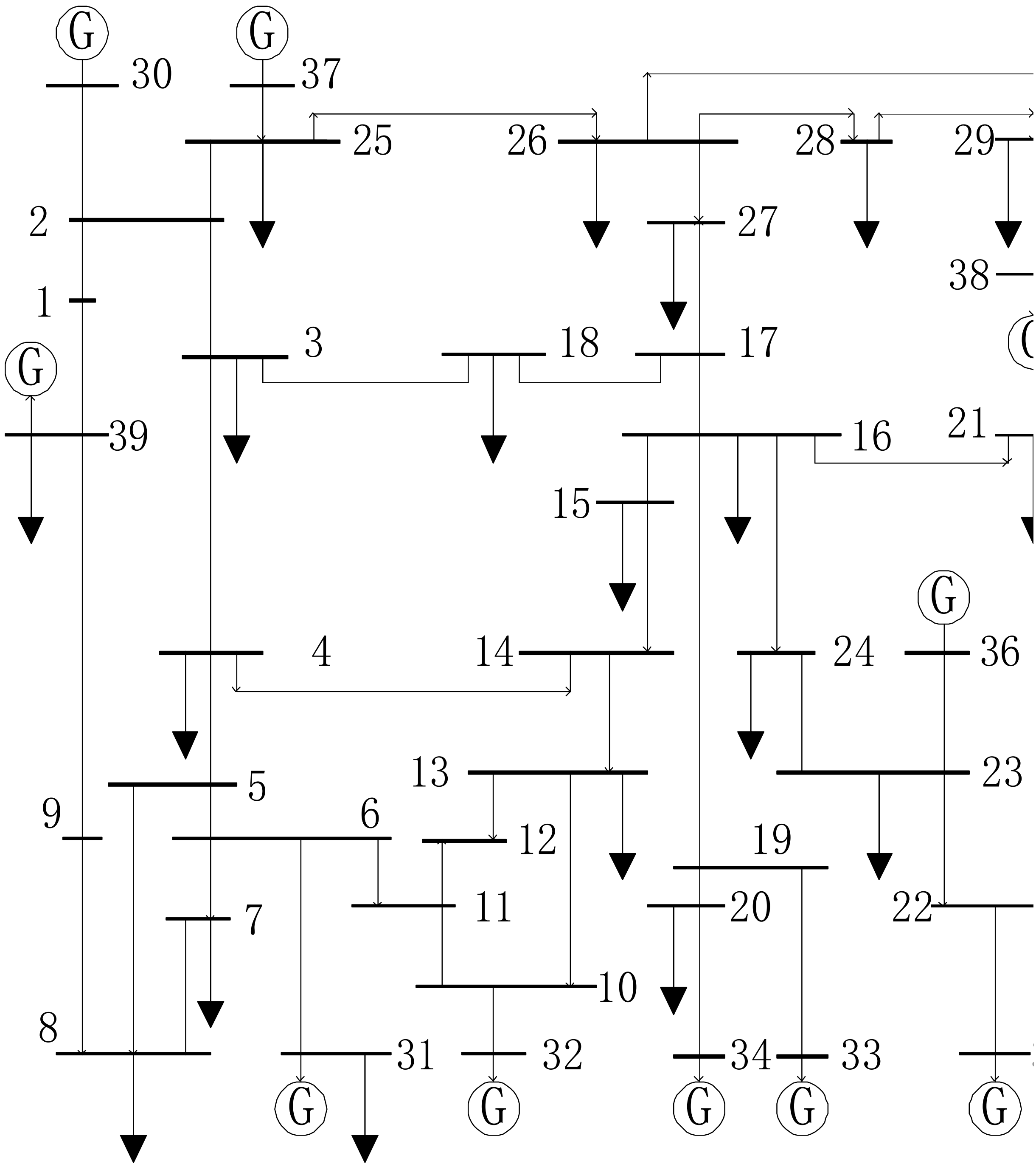


Figure.4.2.- Transmission network for the proposed case

4.2.2 Sub-transmission network

The sub-transmission network 63 kV is included to take into account the redundancy in the supply of the different distribution networks. The architecture of the sub-transmission network is in loop with two different bus connections into the transmission system. The transmission line points of connection are close one from the other and they are buses 12 and 13. The distance between the different substations to MV is 20 km and the chosen cable is also Almelec 570.

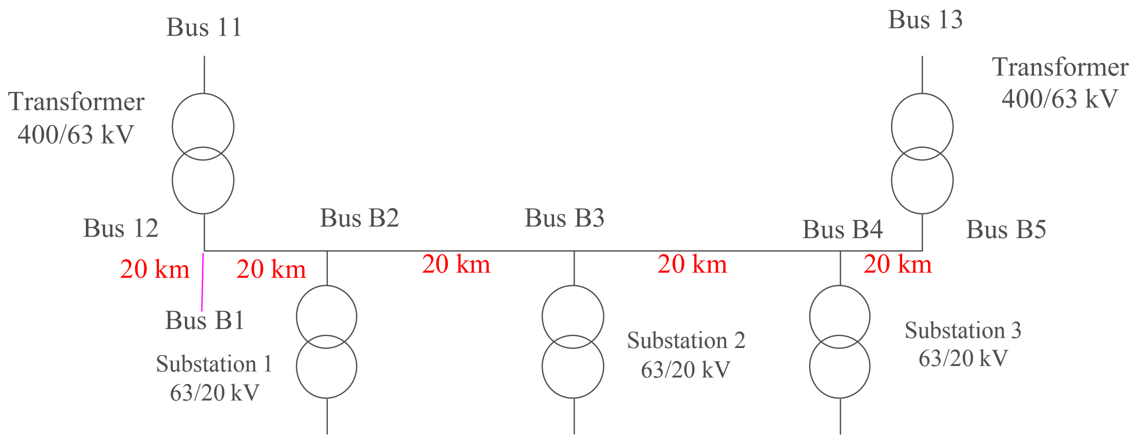


Figure.4.3.- Sub-transmission network architecture

4.2.3 Distribution networks

The benchmarking model contains two different French networks: 1 and 2. Both networks are voltage level of 20 kV as is common in France.

- Distribution 1 network: it is a radial distribution network with a total load of 27.53 MW and 11 MVar. This load in shared in 6 different areas with a total number of 54 buses. The compensation of the reactive power is carried out with a capacity of 15 MVar (4.80Mvar in bus RAME1 and 10 MVar in bus HTA). This capacity adjusts the value of the voltage profile in normal limits. The architecture of this network is shown in the next figure.

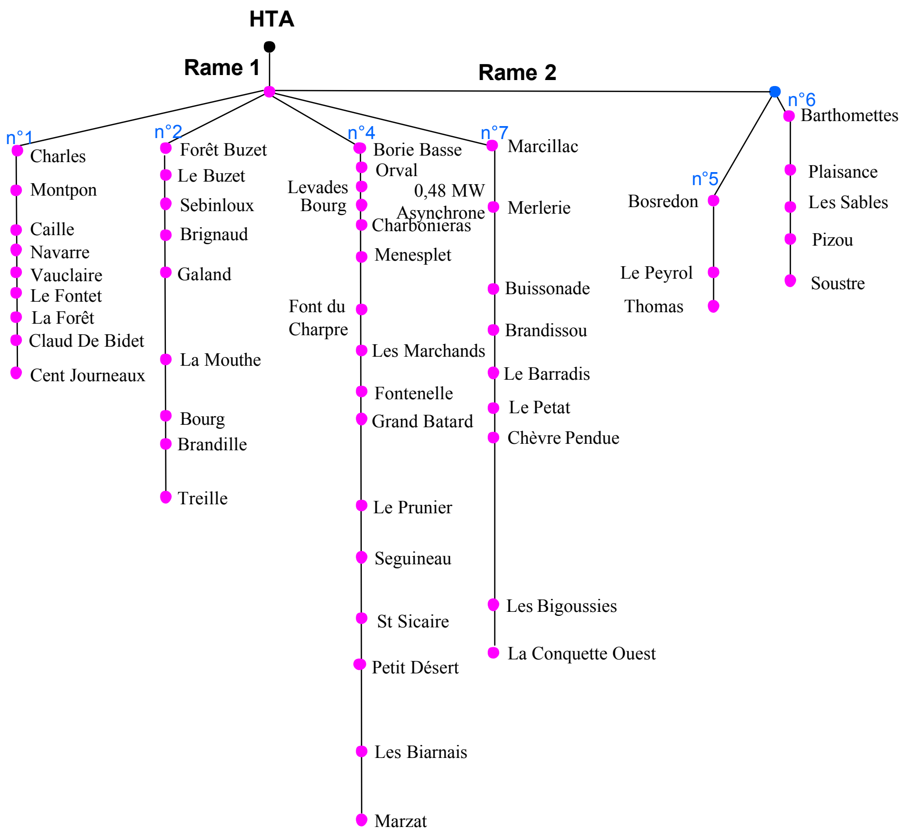


Figure.4.4.- distribution 1 network, 20 kV

- Distribution 2 network: it consists in a distribution network loaded with 25.11 MW and 12.14 Mvar. This network contains 294 buses and 297 lines. The voltage compensation is made by a capacity of 15 Mvar placed in bus 295 (the beginning of the network)

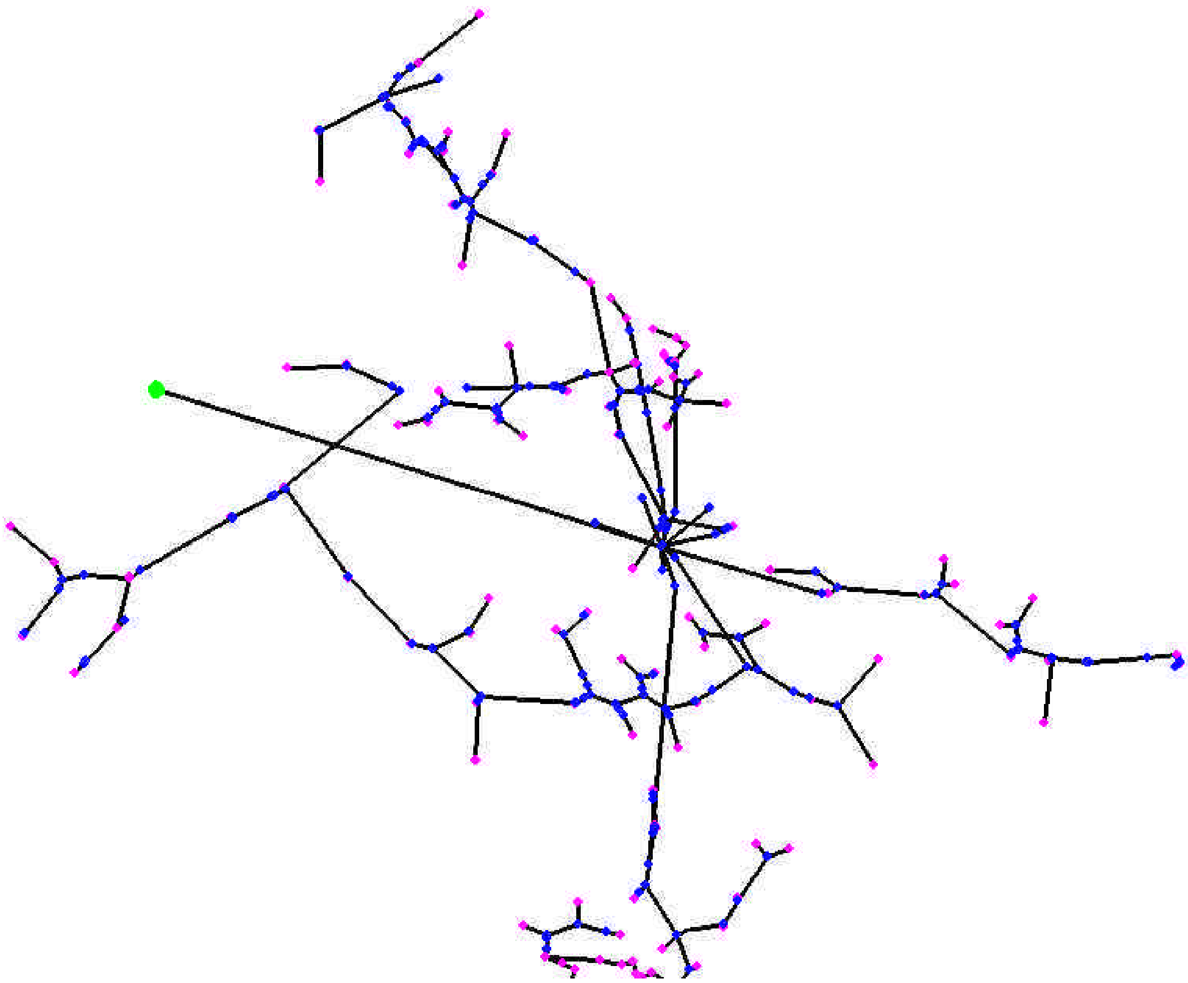


Figure.4.5.- 20 kV distribution 2 network architecture

4.3 EUROSTAG

These networks are implemented in EUROSTAG [15]. EUROSTAG is a software dedicated to the dynamic simulation of large electric power systems in the field of transient and long term stability. It has been developed by Tractebel Energy Engineering and Électricité de France

The following recent examples illustrate the uses of EUROSTAG :

- Defence plan: plans against widespread losses of synchronism; undervoltage load shedding plans in systems including many dynamic loads (air conditioning); frequency load shedding plans.
- Operation (in control centres) : Voltage Stability Assessment (VSA) for on-line detection of voltage collapse risks; simulation of blackouts and restoration procedures; transfer capability determination. Interconnection studies, such as the European East-West interconnection connecting synchronously the UCPTE and CENTREL systems to the UPS one (CIS countries). Equipment specification: detailed modelling of various GE LM 6000 gas turbines for co-generation. Industrial sites:

security of supply of process-critical industrial loads, including induction motor starting procedures.

- Dispersed generation: new setting of protections at distribution level.
- New technologies: UPFC, TCSC, and other FACTS and HVDC.
- And of course the basic calculations such as critical clearing times, PSS tuning, reactive power management, etc.

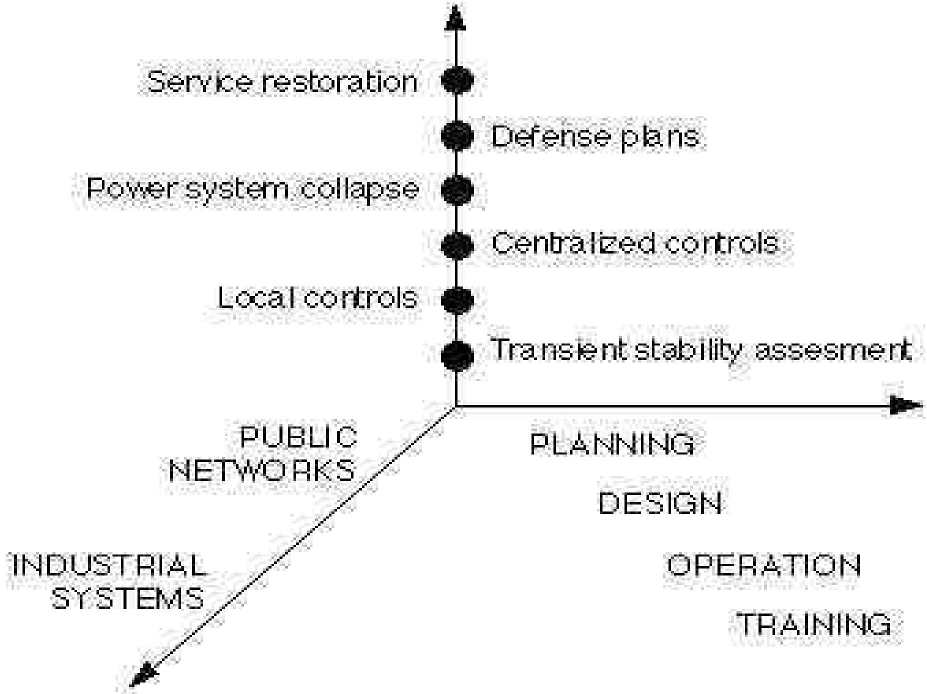


Figure.4.6.- EUROSTAG examples of use

EUROSTAG is now also running “on line” at the Belgian National Dispatching and is connected to the SCADA, through the results of the state estimator. The power system security can be monitored in real time.

The different components of the distribution networks are modelled in EUROSTAG. In this paragraph, the different kinds of models are detailed:

- Synchronous machine:

The model of synchronous machine is made by the classical theory of Clark. The park equations for the synchronous machine are the next ones in a reference (d,q) fix to rotor:

$$u_d = -r_a i_d + \omega\lambda_q - \dot{\lambda}_d$$
$$u_f = r_f i_f + \dot{\lambda}_f$$
$$0 = r_D i_D + \dot{\lambda}_D$$
$$u_q = -r_a i_q - \omega\lambda_d - \dot{\lambda}_q$$
$$0 = r_{Q1} i_{Q1} + \dot{\lambda}_{Q1}$$
$$0 = r_{Q2} i_{Q2} + \dot{\lambda}_{Q2}$$

where:

d: stator direct axe
q: stator quadrant axe
D: amortissement direct axe
f: excitation
Q1: 1st amortissement axe in quadrant
Q2: 2ndamortissement axe in quadrant
r_a: stator résistance
λ: flux

- Asynchronous machine:

This machine can be modelled in several ways but always with a Park modelisation. The models present in EUROSTAG are the complete model and a simplified model that neglect the rotor transients. With this simplified model the motor has behaviour as a passive load. The park equations for the asynchronous machine are the next ones:

$$
\begin{aligned}
u_{1d} &= r_1 i_{1d} + \dot{\psi}_{1d} - \omega_{ref}\psi_{1q} \\
u_{1q} &= r_1 i_{1q} + \dot{\psi}_{1q} + \omega_{ref}\psi_{1d} \\
0 &= r_2 i_{2d'} + \dot{\psi}_{2d'} \\
0 &= r_2 i_{2q'} + \dot{\psi}_{2q'} \\
0 &= r_3 i_{3d'} + \dot{\psi}_{3d'} \\
0 &= r_3 i_{3q'} + \dot{\psi}_{3q'}
\end{aligned}
$$

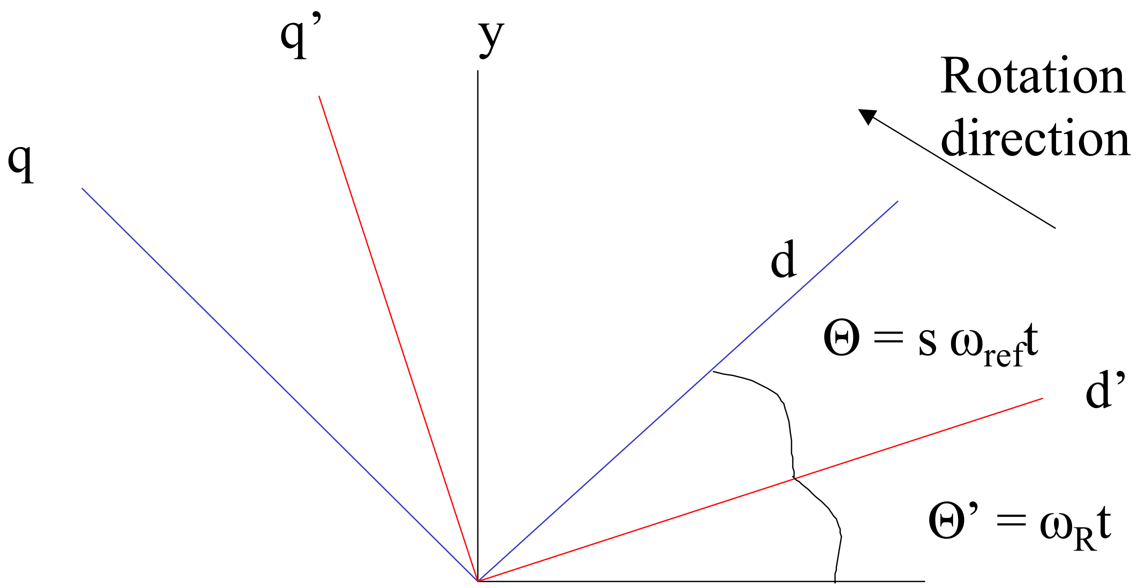


Figure.4.7.- Relation between the axes (d,q) and (d',q')

The rotor equations are expressed in reference (d',q') joint to rotor.

- Loads: the load flow calculation has a static model of load with the active and reactive power consumption and generation in every bus. These powers allow to start the calculation of the dynamic simulation. Then there is a dynamic behaviour of the load. This dynamic variation depends on the properties of the charge: impedance, sensibility to the frequency, or constant load…

$$P(V) = P_0\left(\frac{V}{V_0}\right)^{\alpha p}\left(\frac{f}{f_0}\right)^{\beta p}$$

$$Q(V) = Q_0\left(\frac{V}{V_0}\right)^{\alpha q}\left(\frac{f}{f_0}\right)^{\beta q}$$

Where the exponents: αp, βp ,αq, βq fix the variation of the power with the voltage and frequency.

- Lines: the lines are represented by a serie impedance (R, X) of the cable between the buses and a shunt admittance (B_s,G_s)

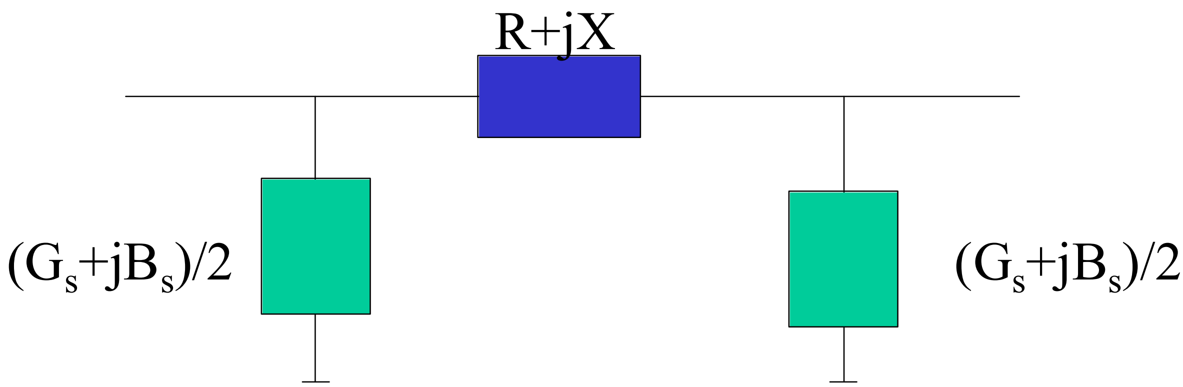


Figure.4.8.- EUROSTAG line model

- Other elements such as transformers, converters, injectors… are also modelled in EUROSTAG software.

4.4 Parameters of different components in the lines

The generators (20kV) presents in the transmission system are all of them modelled as synchronous generator with the simplified model and they have a nominal power of 1000 MVA. The machine GEN 2 connected to the BUS 31 is the infinite power bus, that is the bus which is going to balance the power. In the next paragraph the parameters of the generators at the transmission system are defined:

Bus-machine	P(MW)	Q(MVar)	H(MWs/ MVA)
BUS30-GEN10	250	91.26	3.5
BUS31-GEN 2	660.78	157.83	2.525
BUS32-GEN 3	650	140.58	2.9833
BUS33-GEN 4	632	42.38	2.3833
BUS34-GEN 5	508	218.23	2.166
BUS35-GEN 6	650	152.83	2.9
BUS36-GEN 7	560	31.70	2.2
BUS37-GEN 8	540	-19.13	2.025
BUS38-GEN 9	830	-67.71	2.875
BUS39-GEN 1	1000	116.36	41.66

Table.4.1.-Power generations of the transmission line

All the loads at every bus for the transmission and distribution networks can be seen in the enclosed file crisp.txt. The parameters are done referred to a power base: this power base changes with the level of voltage. Thus, three different bases can be found, 400 kV-100 MVA, 63 kV-100MVA and 20kV-100MVA. The lines parameters of transmission lines are in the 400 kV-100 MVA base. The sub-transmission line parameters are in the base 63kV-100MVA and the generators parameters and distribution line parameters are in the base 20kV-100 MVA.

Finally, the regulations of the generators are AVR and CMCONST for all the generators except GEN 10 that it has a regulation EFDCONST and PMCONST. These regulations have been taken from the IEEE New England architecture present in the software resources of the Power Engineering society.

The voltage regulation AVR and EFDCONST constitute a regulation at constant excitation. The speed regulation CMCONST and PMCONST correspond to a constant torque regulation.

5. Expected impacts of DG penetration on the grid

5.1 Introduction

This chapter is dedicated to the expected impacts of the Dispersed Generation on the grid. First of all, the changes on the energy flow will be analysed. This is the first consequence on the system provoked by the new energy injections. Then, different impacts on the sub-system where the DG is interconnected are treated .Thus, special attention has been paid to the impacts in the normal operation of the different components of the network: protections, loads (correct voltage profile in order to avoid wrong operation), synchronous machine stability, energy quality (harmonics, voltage variation).
Finally, different influences of new DG are commented such as: the economical impact or the impacts on the transmission system and the centralised production.

In short, the consequences and disadvantages of the DG penetration in the system are mentioned. On the other hand, each impact is detailed and a technical solution is proposed when that is possible.

5.2 Impacts on the transmission energy direction

Traditionally, the energy transmission direction changes with the penetration of new sources of distributed energy. The classic operation of electric networks consisted in a centralised power generation by means of nuclear, thermal or hydro energy. From these great units the energy is injected into transmission lines and then the energy is leaded through the distribution and sub-transmission networks to the customers.
The apparition of new distributed producers can cause the inversion of the energy flow direction. It’s the case, for example, of a MV/LV network where the generated power is higher than the absorbed power. So, these producers can supply energy to the adjacent loads and loops of energy may be established like it is shown in figure 5.1. If the generated power is really important, one can also imagine that an injection of power could be effectuated on the MV/LV substation (Inversion of P’o) [16]

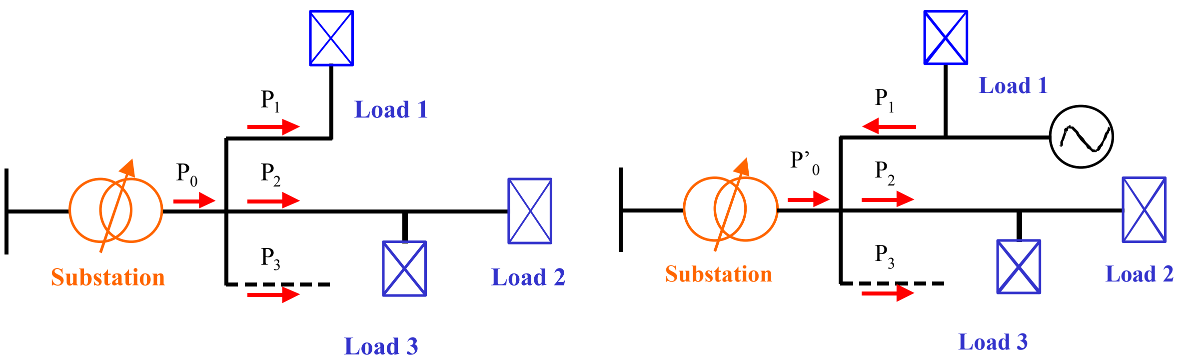


Figure.5.1.- Changes in the active energy flow direction

In conclusion, it is necessary to consider eventual modifications and changes on the materials presents in the network (measure equipment, protections…) because most of these materials are unidirectional.

5.3 Impacts on the protections

The impact mentioned in the previous paragraph about the variation of the energy flow causes the modification of the protection system operation. This operation change is essentially caused by a loss of selectivity between the different protections of the network. This loss of selectivity results as a consequence of the new values (with DG penetration) of the currents in normal operation and in perturbed operation (for example when faced to a short-circuit).

5.3.1 Short-circuit current variation

The connection of a new generator (asynchronous or synchronous) on the grid causes in case of fault the change of the short-circuit current values. In general, the collection of generators takes part in the fault currents. The participation of each generator depends on the distance to the fault. In any case, the fault current is the addition of the different currents in the network and the DG current participation. The variation of the current depends on the number of generators and it can be important if the generators have a high power. In short, the increase of the short-circuit current is influenced by:

- The power supply by the Distributed Generation
- The kind of generator: synchronous or asynchronous
- The type of regulation applied to the generator
- The position of the generator to the fault point

In conclusion, the new DG is going to change the impedance of the system and then the short-circuit current and power will be modified. The increase of the short-circuit current must be quantified for each new DG connection in order to verify the correct operation of the protection system. The protection system must be able to cut the short-circuit current in the time specified in the norms.
One possible solution is the introduction of impedance to limit the short-circuit current. The disadvantage of these impedances is the economic side, because they increase the electric losses and so, it is not economically interesting.

5.3.2 Protection plan modification

As it was mentioned previously, the variation of the short-circuit current provokes impacts on the protection operation. Thus, different cases of possible protection disoperation are treated:

5.3.2.1 Intempestive opening protection

The connection of DG may provoke a mis-operation of the protection system, for example the protection that is located at the head of a distribution line where the DG is placed. This mis-operation or non adequate operation appears when there is any perturbance or fault in a distribution line adjacent to the distribution line where the DG is positioned. The DG sources participate to the fault current and so the protection that detects the fault is the one of the DG's line. However, the fault happens in the adjacent line. This is more significant if the fault is closer to the MV/LV substation and the producer generation is higher.

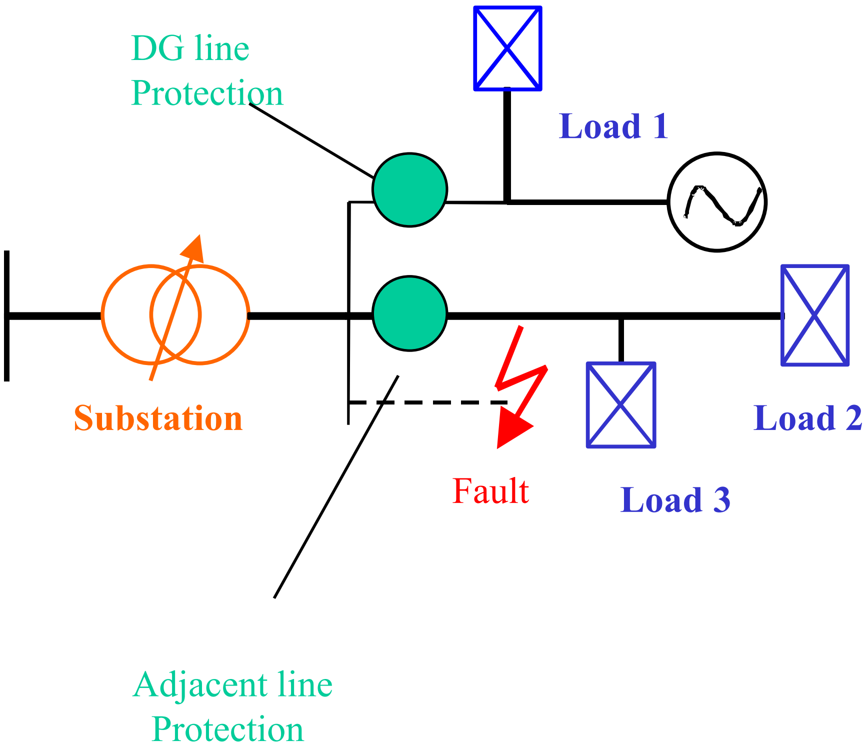


Figure.5.2-Intempestive opening protection

One can imagine some possible solutions for this problem:

- in order to avoid non adequate protection operation, directional protection must be taken into account. In this way, the line protection where the DG is branched, do not open in case of fault in other adjacent line
- Verify that the short-circuit current injected by the generator does not exceed the design value of the protection. The design value of the protection corresponds to a fault in the same line.

5.3.2.2Bad operation of a protection

The phenomenon of a bad operation of a protection consists in a mis-operation of a current protection of a line with a DG which can not any time detect a fault. Thus, if the DG is connected to a network where the short-circuit current is lower than the case where the DG is not connected. So, if the protection is designed for a fault current corresponding to the case without DG, the protection is going to detect the fault only if DG is connected. This phenomenon is normally called “bad operation of a protection”

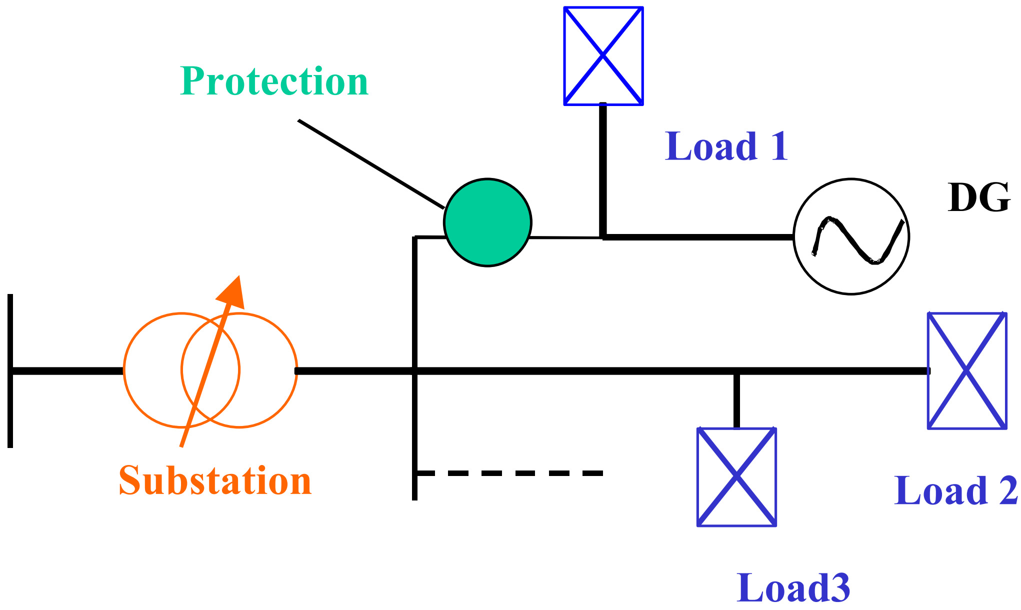


Figure.5.3.- Bad operation of a protection

One can imagine several solutions to this impact. Some of them are the next ones:

- To connect the generator to a line specially dedicated for it
- To obtain a good selectivity between the protections (protection of the generator and protection of the beginning of the line).

These solutions can be perhaps unfeasible or inefficient because:

- In some cases it could maybe impossible to connect the generator to other line (far away form other lines).
- A good selectivity can be useless if the fault current is lower that the designed current value of the protection.

In conclusion, the protection must be changed or modified (settlement designed value) and this settlement of protections in a distribution network with DG penetration needs an exhaustive study due to the complexity of the problem. The introduction of a DG in a distribution network can provoke a loss of protections selectivity. This protections selectivity must be checked in order to insure the people and materials security. Finally, this selectivity between generators must be right if DG units are connected or not. An unforgettable rule in a protection system is the fact that the protection must actuate if it exists a fault and it must not operate if it does not exist.

The adjustment of the settlement protection value or the change must take into account several things: the generator power, the kind of generator (synchronous or asynchronous), the fault current when the generator is branched into the grid and finally the transitory current when the generator is not connected.

5.3.2.3 Islanded operation

In the islanded operation the DG is the only source of energy. The islanded operation of a distribution network is the consequence of the opening of unless a line in the network. This line opening may be the result of a mis-operation or a fault in the operation (short-circuit, overload of a line…)
Traditionally, the islanded operation of a generator is seen as a non-desirable operation mode, because the change to islanded operation risks to be carried out with important frequency and voltage variations and these variations could cause material damages. Furthermore, it is not probably that the generator can supply the energy in a continuous way to the islanded zone, especially if the generator uses renewable energies (wind, sun). In order to disconnect these sources, the protections can be based on different kinds: frequency, current, voltage.

- The frequency protection let detect the frequency variation on the network. The frequency variation over the limits (f_{max}, f_{min}) causes the generator disconnection.
- The current protection is based on a current settlement value. It detects an unusual rise of current. The disadvantage of this protection is the risk of not detect a fault placed far away from it (lower current by a higher impedance)
- The voltage protection detects the voltage variation between the phases. This protection detects a higher number of faults than the current one because it is more sensible. But, this protection risks giving rise to non adequate protection operation for example in the case of a generator connection/disconnection in the same.

One solution to avoid the islanded operation is to dispose a remote controlled protection for the line protection where it is the generator. After the action of the protection of the line, the generator protection opens and disconnects the generator. This type of protection needs a communication between protections (generator and line one, or, generator and main substation one).

Schneider Electric proposes a digital protection that detects the loss in frequency of generators. Besides, this protection for DG includes several: over voltage and sags protection, frequency protection, neutral displacement protection, short-circuit protection…

However, the islanded operation could have a positive influence in the general restoration of the whole system after an incident and also an improvement of the system security and energy availability in distribution production areas and with pre-established loads (e.g. via load shedding). The security improvement and the service continuity is one important point on the whole system quality in terms of customer opinion and view about the whole system and companies in a deregulated environment.

So, studies must be done about the protection system which helps us to facilitate the islanded operation with DG penetration. The frequency and voltage control is also one critical point in order to do not affect the materials present in the area to isolate. Finally, storage's elements must be designed to avoid variations in the generated power, for example solar and wind energy generations depend on meteorological variations. The design of these storage's elements are the result of an economic compromise between the cost of load shedding and the cost of the storage that would be disposed for supply all the load existent in each distribution area to be isolated. In this case, special interest must be paid to the changes in the architecture of the distribution network; for example, close interrupter to mesh several distribution lines that will form together an islanded area.

5.4 Impacts on voltage profile

When a DG is connected, the voltage level in some buses goes up or down to the authorised limits and this fact in the steady-state. So if there is no change of any network element (load variation, generated power variation…) the voltage profile depends on the load state of the network and in the power generation injected to the network.
The impacts to the voltage profile of a distribution network when a DG is connected are mainly the next ones:

- Rise of voltage at the buses where DG sources are connected and the closer buses as well.
- Decrease risk on the voltage of adjacent lines without DG penetration.
- Increase of the voltage level after the disconnection of an asynchronous DG.

The over voltages can be eliminated by an adaptation of the DG reactive power generation. The change of the voltage profile activates changes in the voltage regulation system. Thus, several regulation methods can be applied:

- Tap changers
- Autotransformers
- Capacitors in order to regulate voltage and also correct the power factor and filter harmonics. They are inexpensive and easy to install, low maintenance and little losses.

5.5 Impacts on stability

The perturbation on the network such as a fault or a transmission line loss gives rise to perturbed states which are composed by two mains parts: a transitory state and a dynamic state. The transitory state appears from the start of the perturbation and it lasts for some milliseconds. This state corresponds to the apparition of phenomena in the time range of electrical time constants.
The dynamic state corresponds to slower phenomena like the regulations response and it appears after the transitory state. It can last for several seconds, e.g.: the response of generators when a DG source is disconnected.

The insertion of synchronous DG in a distribution network can cause power oscillation in case of a fault. These power oscillations between DG sources create power exchange between different distribution networks. If the DGs are asynchronous machine there is no energy exchange between generators. These oscillations must be controlled to keep the stability, so the regulation parameters must be adjusted optimally to reduce the oscillations. It can be remarked also that the disposition of current limit reduces as well the power oscillation between DG sources.

5.6 Impacts on the critical time of fault elimination

The critical time of fault elimination (TEC) corresponds to the maximal duration of a perturbation that the system can resist keeping the stability. The TEC is calculated, for a given perturbation from the variations of internal angles of the different synchronous generators. If a DG is connected on the distribution network, the TEC value decreases. Besides, the TEC value depends on the number of DG which are connected to the grid, the variation on the TEC depends on the electro-mechanic properties of the DG. As conclusion, one can keep as general tendency that more DG with little power, more important down variation of TEC.

5.7 Impacts on power quality

The electrical energy must be supplied by utilities with some technical proprieties. Concretely, the classical elements of quality of energy concern the voltage level, frequency and continuity of service. In the next table, it is shown the proprieties that the Standard EN 50160 establishes for the quality of energy in LV.

Norme EN 50160	Alimentation basse tension
Fréquence	50 Hz ±1 % pendant 95 % d'une semaine 50 Hz +4 %,-6 % pendant 100 % d'une semaine
Amplitude de la tension	Pour chaque période d'une semaine 95 % des valeurs efficaces moyennes sur 10 minutes doivent être dans la plage Un ±10 %
Variations rapides de la tension	De 5 % à 10 % de Un (4 à 6 % en moyenne tension)
Creux de tension	valeurs indicatives : ■ profondeur : entre 10 % et 99 % de Un, majorité des creux de tension < 60 % de Un ■ durée : entre 10 ms et 1 minute, majorité des creux de tension < 1 s ■ nombre : quelques dizaines à 1 millier par an
Coupures brèves	Valeurs indicatives : ■ profondeur : 100 % de Un ■ durée : jusqu'à 3 minutes, 70 % des coupures brèves sont inférieures à 1 s ■ nombre : quelques dizaines à plusieurs centaines par an
Coupures longues	Valeurs indicatives : ■ profondeur : 100 % de Un ■ durée : supérieure à 3 minutes ■ nombre : entre 10 et 50 par an

Figure.5.4.-Standard EN 50160 for power quality

There are different aspects about the quality of energy which are normally considered important: transitory voltage variation, harmonics, sags and outages, over voltages,… in the next paragraph these different important aspects will be analysed.

5.7.1 Voltage transient variation

The decentralised production can provoke problems and transitory voltage variations, for example in the case of connection or disconnection of a generator there are important over currents that change the voltage profile. Another example of voltage variation happens by the power oscillation between the different generators at low frequency.

The renewable energies in particularly the wind and solar energy are examples of apparition of the Flicker phenomena. The output voltage variation in solar systems can be correct by conventional voltage regulators (tap changers) because they have a slowly response.

On the other hand, the fast dynamic of voltage oscillations in the output voltage of wind generators need complex regulators such as SVC or D-FACTs. The gas generators can also give rise to flicker effect, e.g. in the case of a mechanical fault or a bad fuel quality. In order to avoid the Flicker effect the most common solution is the use of power electronic interfaces and a energy storage element. In this way, the grid would watch the DG as a bus with P and Q constants.

5.7.2 Harmonics

Some DG sources needs the power electronics interfaces to be connect to the network. This power electronic equipment injects harmonics in the grid and could provoke unacceptable voltage distortions.

In the case of rural networks, there are unbalanced caused by the loads and one-phase DG machines. In this type of network, the integration of wind turbines can create 5^{th} and 7^{th} harmonics out of authorised limits.

The main effect of the harmonics is the heating of the lines, rise of electrical losses and creation of additional voltage loss. The harmonics perturbed the regulation devices, mis-operation in the power switch commutation, errors in the energy meter,… others consequences are vibrations and noise in motors, transformers or electrical devices. These vibrations reduce the life of the device, especially by mechanical fatigue.

Finally, just to a say a word about the power electronics interface. They are not extended and last technologies create a low harmonics distortion rate. In any way it is always possible to filter the output of the DG.

5.7.3 Sags and deeps

A sag is an important decrease of the voltage in one point of the electric network with a value between 90% and 1% of the reference voltage (CEI 61000-2-1) and followed by a return to the normal voltage level after a short time instant (time range: half period of the network and one minute).

The deep is a particular case of sag with a variation of more than 90% and they are classified by the duration. The short dropout is that one lower than 3 minutes or 1 minute and they are caused by a slow restoration of the system in order to avoid long dropouts. One can enumerate some causes that provoke sags and deeps, for example: connection of motors or loads, faults in a line with DG (risk of synchronism loss) or an adjacent line…

The association of DG sources with energy storage means constitute a solution to avoid this problem. However, they exist special methods based on a co-ordinated control between generators and loads.

5.7.4 Surges

A surge is a rise of the value of the voltage out the nominal values in a time lower than 2.5 s. Surges can have different origins, thus surges are over voltage caused by a load variation, modification of the network architecture or by errors on the regulation systems.

5.8 Impacts on exploitation, planning and surveillance of the network

The distribution network haven't been designed to insert decentralised production in a high amount, it is probable that it will happen changes in the exploitation of these distribution networks. It is also possible that the structure of the distribution network will be remade (meshed architecture) in order to take advantage of this energy contribution closer to the consumption.

Several solutions and clues to follow are the next ones :

- Innovations to do and rules to respect with the amount of DG penetration.
- Problems with the dispatching and observability of this production in LV.
- Creation of a local centre to analyse all the data and measures of the different DG units.
- Control of the little power decentralised units

5.9 Economic impact of the distribution system

The decentralised production varies the direction of energy flow and so the electrical losses. If little producers are placed close to high loads, it is obvious that the electrical losses are reduced because there is no need of energy transport. On the other hand, if the producers are placed far away from the loads it would be a rise of losses. At the moment the little generators do not participate to the voltage control but it can be consider the employ of generators to export reactive power during the peak hours and absorb reactive during the valley hours.

Associations and agreements between different independent producers can generate a rise of the competence in the deregulated electric market and in this way improve the market efficiency in terms of price reduction to the final consumers.

5.10 Impacts on the transmission network

The energy power flow in the transmission system is going to be modified by the existence of DG. Thus, electrical losses are going to be reduced because energy is produced at the distribution level and the quantity of energy to transport from the centralised power plants will decrease. Furthermore, the congestion line costs would be avoided and this fact constitutes an economical reduction of the energy price and less loaded operation of the system. Finally, the decentralised generation will allow us to increase the transmission lines capacity.

5.11 Impacts on the centralised power

The tendency is the reduction of the centralised but on the other hand there is an increase of the variation of the generated power. The decentralised power generation introduce an additional uncertainty in the estimation and so, the need of back up generation. Important tasks have to be done to forecast the decentralised production

6. List of scenarios and study in the proposed case

6.1 Introduction

In order to study the behaviour of the whole electric system face to major disturbances and different time frame events, several natural and technical events must be studied. The scenarios and requirements of the different partners will be treated and studied.
Some of them are:

- Transmission line loss
- Loss of synchronisation of generators
- Short-circuit at different levels
- Connection and disconnection of generators
- Change of loads: overload
- Change of generators production

These perturbations can cause the system instability or it could change the normal operation of the system to another state where the system can operate a low time but not to long term. Furthermore, these perturbations are those ones which have caused the greatest incidents in the electrical networks. The different scenarios correspond to different framework time, thus the short circuit, connection and disconnection of DG, loss of synchronisation are scenarios from the transient reaction of the grid is the most important to observe. On the other hand, the cases of transmission lines loss, overloads and change of generators production correspond to a steady-state

Framework time	Parameter inputs	Solution
Steady state	Voltage, Current, protection operation…	Control devices, communication, DG reactions, best economical point of operation…
Dynamic Transient	Power oscillations, frequency, voltage, short circuit current..	System robustness, operation and reaction faced to very quick and transient perturbations

Table.6.1.-Different framework time of the scenarios

interest that is the most important aspect is the normal behaviour of the network faced to these last scenarios.

6.2 Scenario 1% DG penetration

From the base scheme of benchmarking model defined in the chapter 4, DG sources have been introduced in the distribution networks. The normal of DG power in France are around 30 MW by network. As first step, the networks have been modified to introduce the new DG with different two kinds of machines: synchronous generators and asynchronous generators. The complete data of the components are included in the file crisp03.txt. Concretely:

- Distribution 1 DG penetration: 28.35 MW
  - Synchronous generators:
    - VAUCLAIR: 1.23MW, 0.4 kV
    - BUISSONN: 2.85 MW, 0.4 kV
    - SOUSTRE: 6.27 MW, 5.5 kV
    - CENT: 6 MW, 5.5 kV
    - THOMAS: 6MW, 5.5 kV
    - TREILLE: 6MW, 5.5 kV
  - Asynchronous generators:
    - COLY: 0.582 MW, 20 kV
    - MOULIN: 2.33 MW, 20 kV
    - ST.CHARLES: 0.582 MW, 20 kV
    - CAILLE: 0.485 MW, 20 kV
    - MARCILLA: 0.485 MW, 20 kV
- Distribution 2 DG penetration: 37 MW
  - Synchronous generators:
    - GEN11: bus NGEN1, 1MW, 1kV
    - SYN01: bus 11, 6MW, 5.5 kV
    - SYN02: bus 111, 6MW, 5.5 kV
    - SYN03: bus 274, 6MW, 5.5 kV
    - SYN04: bus 135, 6 MW, 5.5 kV
    - SYN05: bus 57, 6MW, 5.5 kV
    - SYN06: bus 94, 6 MW, 5.5 kV

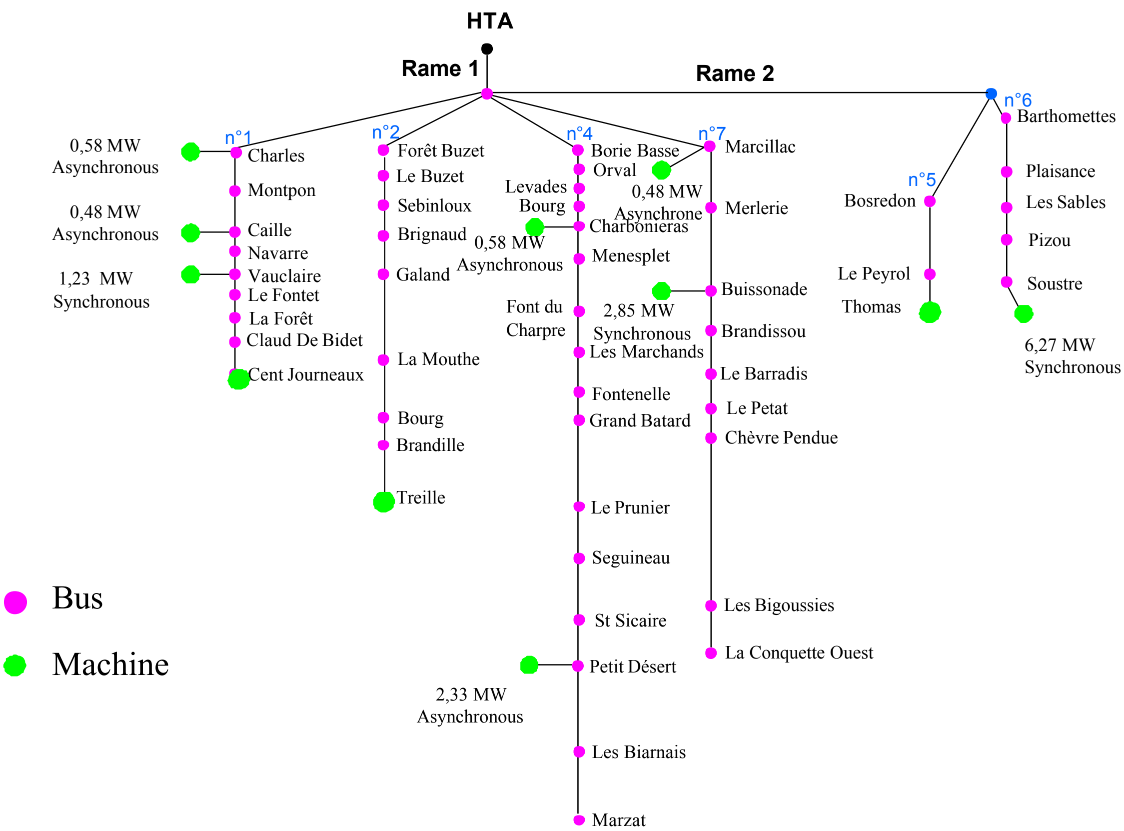


Figure.6.1.- Distribution 1 system with DG penetration

First at all, a static study has been done in order to define the more loaded lines in the transmission system and also a comparison of the voltage profile comparison (with and without DG). The DG penetration does not cause a change in the voltage profile of the transmission line, only little differences have been observed in the buses voltage angles. This fact is caused because the energy exchanges with the distribution system are not high enough.

However, in the sub-transmission system it is confirmed a change in the energy flow and also a change in the voltage profile and the effect of the DG is to increase the voltage level. Then different perturbations are studied: loss of transmission lines, short circuit, overload, loss of synchronisation…

The cases with and without DG are compared in other to compare the reaction of the system when faced to these perturbations. Some conclusions have been confirmed, for example,

- the loss of synchronisation of the little DG sources before the high transmission power plant (see figure 6.12)
- the change of operation point after a perturbation after a short circuit, change of generated power and frequency of machines (figures 6.7 to 6.11)
- the transient evolution of the system faced to a DG disconnection (figure 6.13) or an overload (figure 6.14) or the loss of transmission lines (figure 6.5 and 6.6)

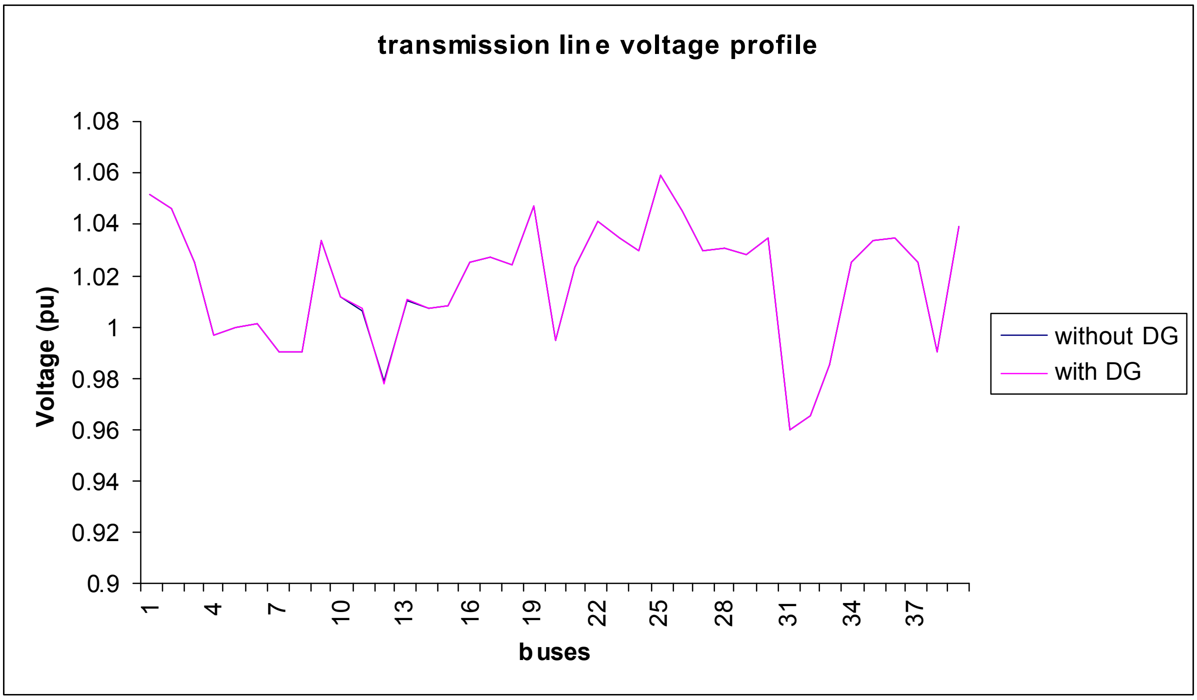


Figure.6.2.- Transmission line voltage profile comparison

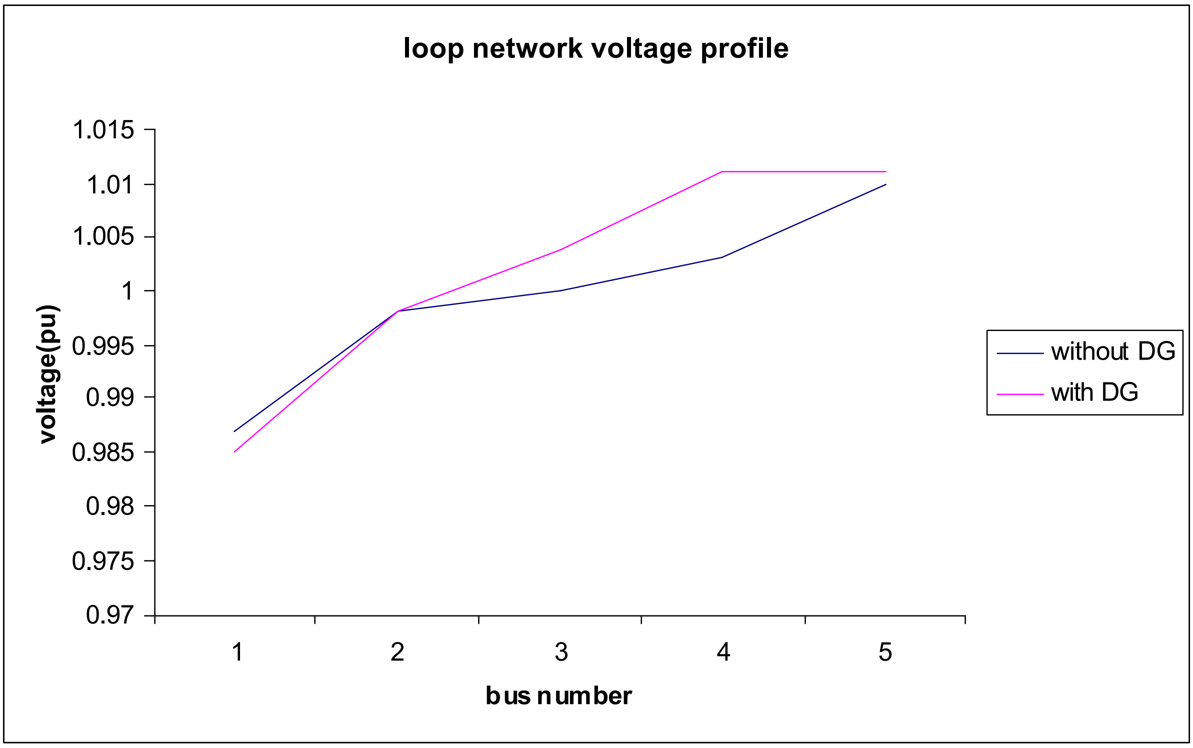


Figure.6.3.- Sub-transmission lines voltage profile comparison

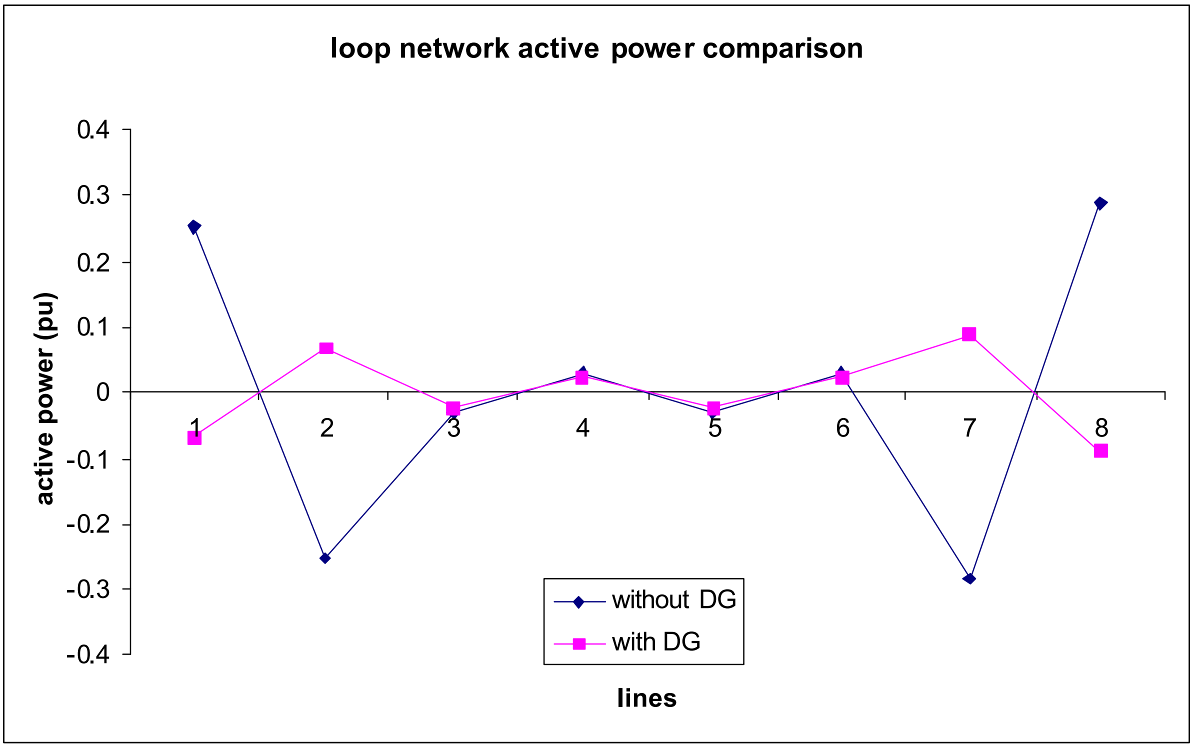


Figure.6.4.- Sub-transmission lines active power comparison

- Scenario: loss of transmission lines

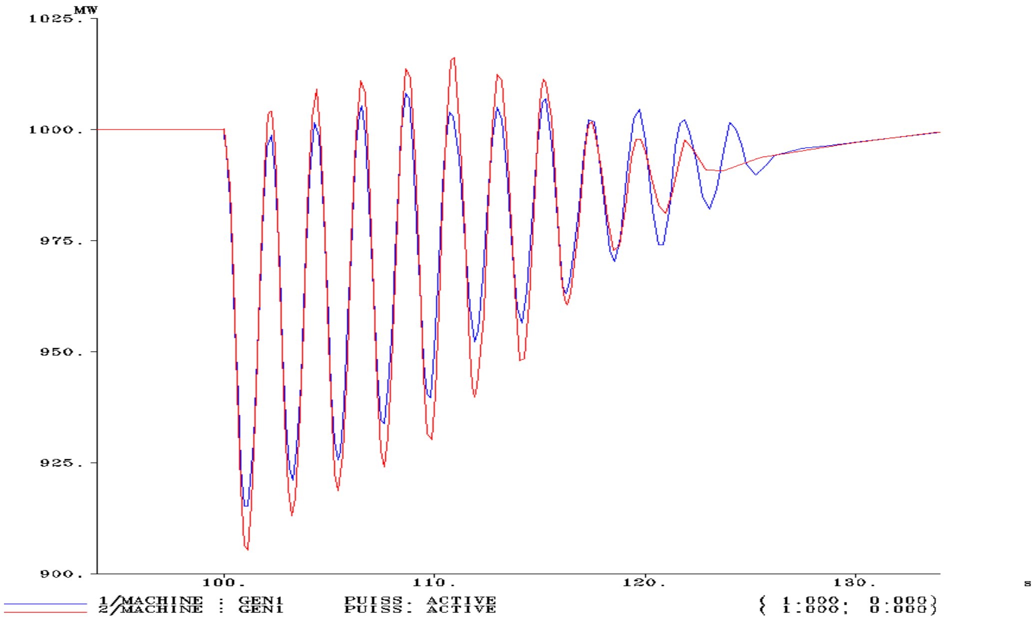


Figure.6.5.- Loss of BUS 8-BUS 9 in the transmission system: GEN 1 active power evolution (red; without DG; blue: with DG)

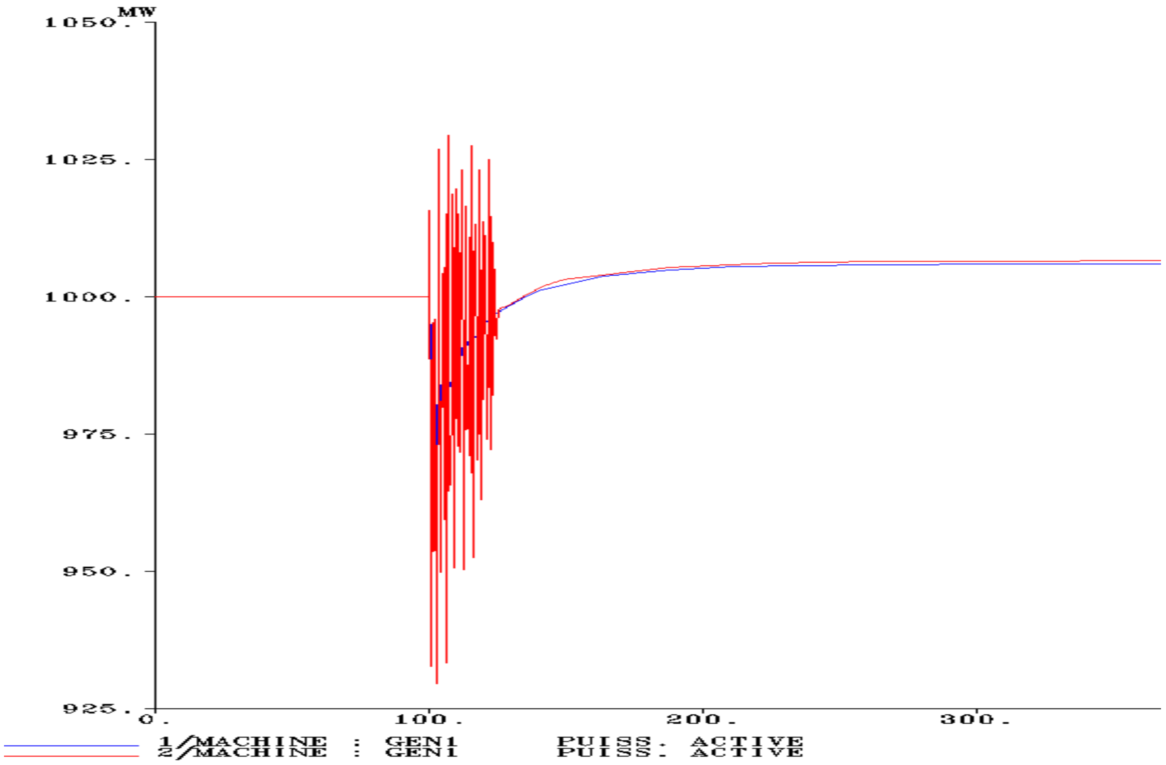


Figure.6.6.- Loss of BUS 5- BUS 6 in the transmission system: GEN1 active power (red; without DG; blue: with DG)

- Short circuit

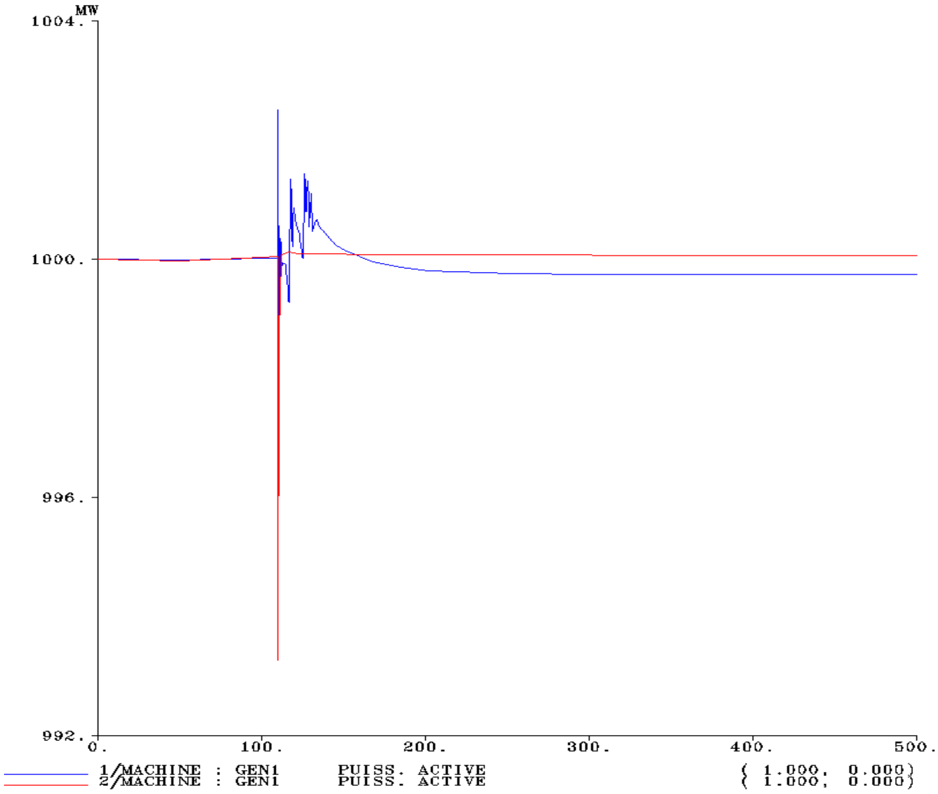


Figure.6.7.- Short circuit in the distribution 1 network (RAME2-05BOSRED): evolution of GEN1 active power (red; without DG; blue: with DG).

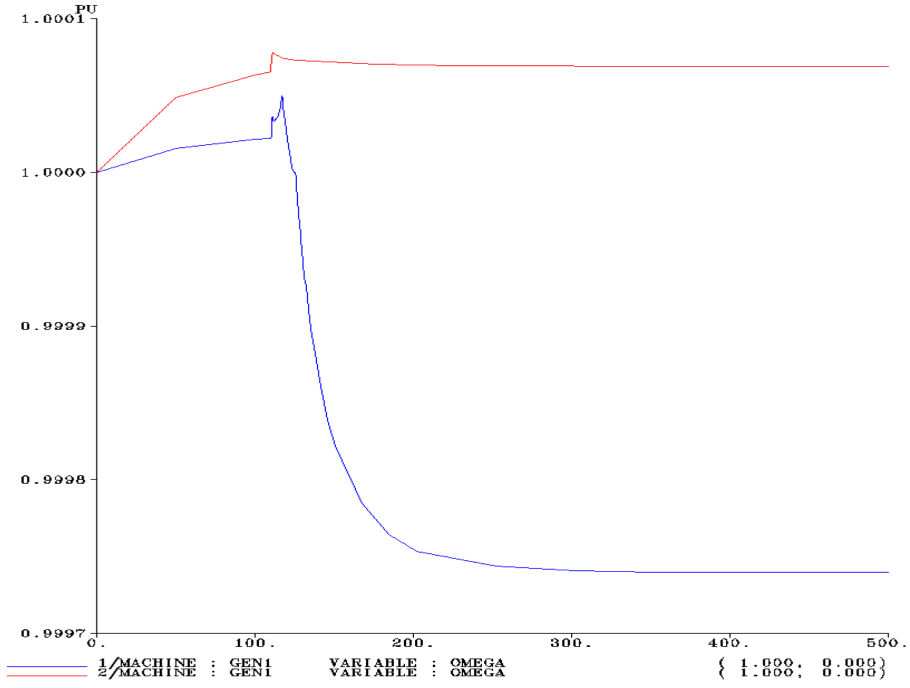


Figure.6.8.- Speed variation of GEN1 when faced to RAME2-05BOSRED short circuit(red; without DG; blue: with DG)

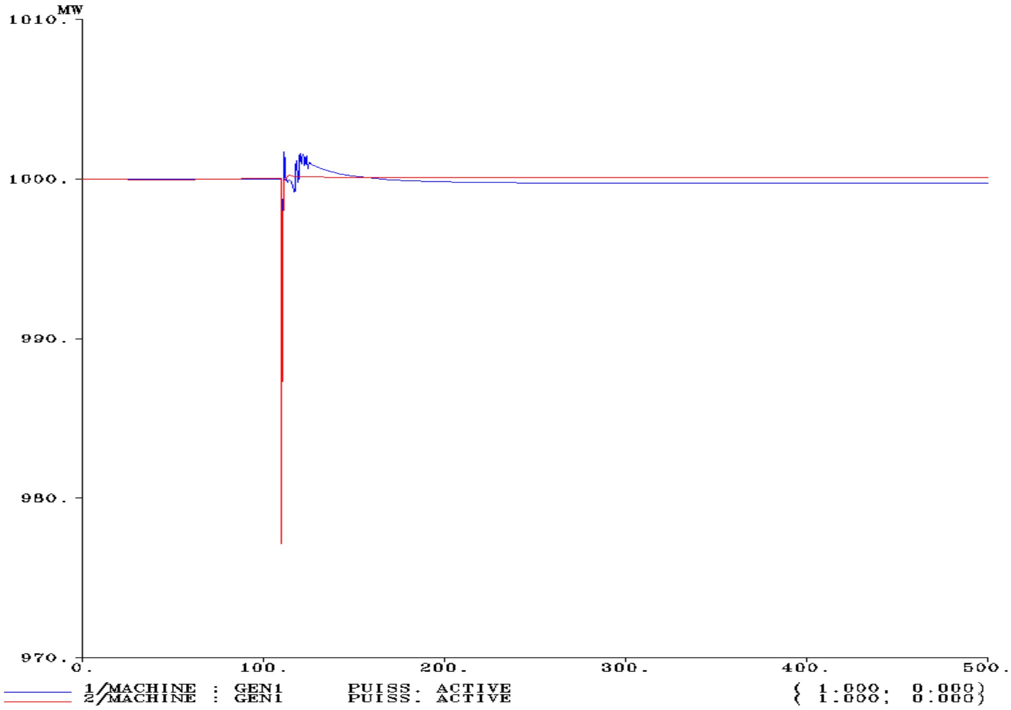


Figure.6.9.- Short circuit in distribution 2 network (295-294 line): active power evolution(red; without DG; blue: with DG)

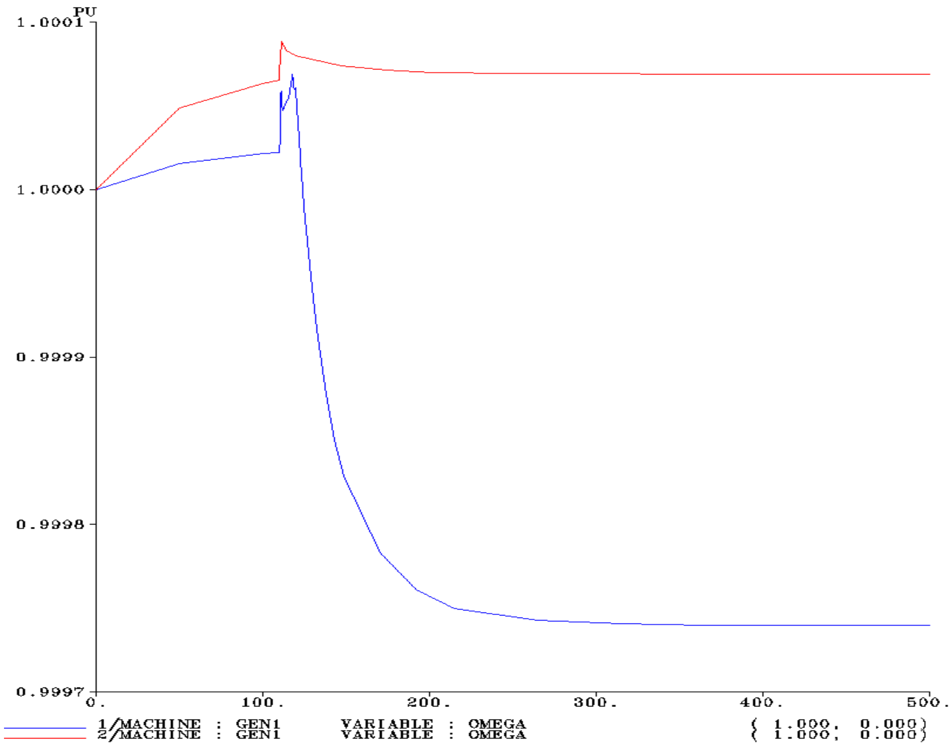


Figure.6.10.- Speed variation of GEN1 faced to 295-294 short circuit (red; without DG; blue: with DG)

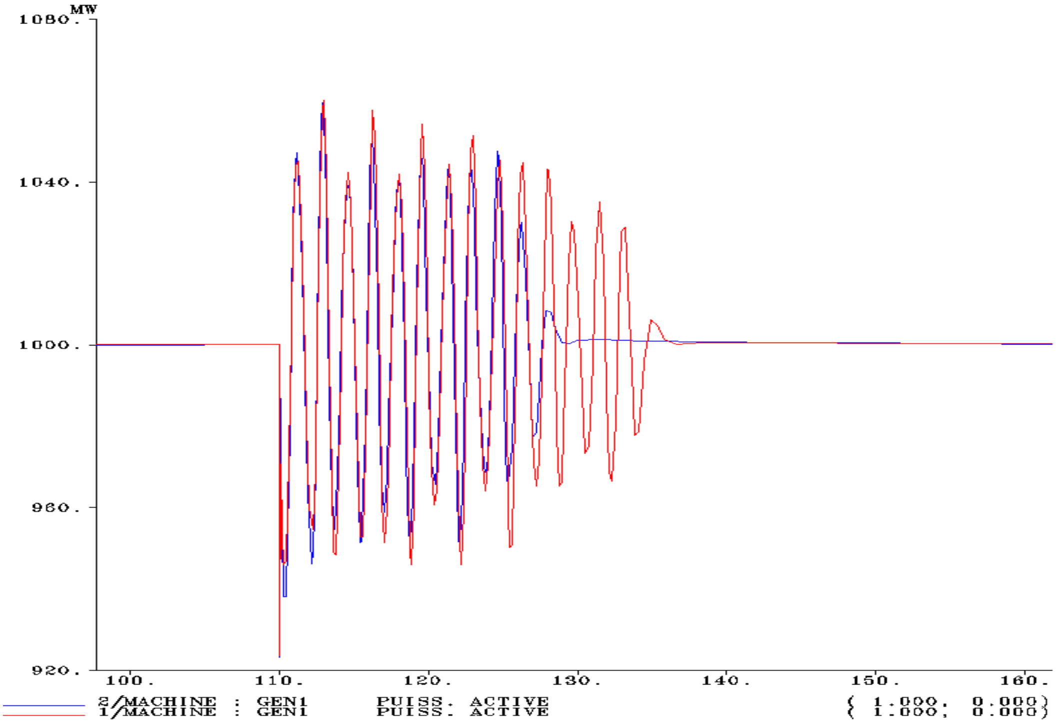


Figure.6.11.- Short circuit in the transmission system: line BUS 5-BUS 6: evolution of GEN1 active power.

- Loss of synchronisation

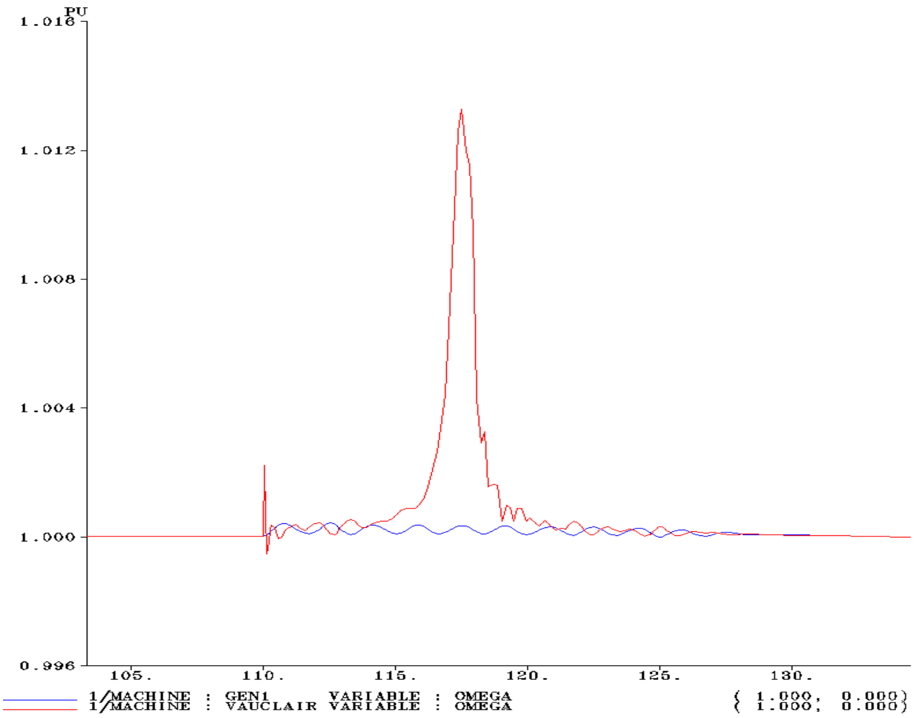


Figure.6.12.- Loss of synchronisation faced to BUS 5-BUS 6 short circuit, (Red: DG speed, Blue: GEN1 speed

- Generator DG disconnection

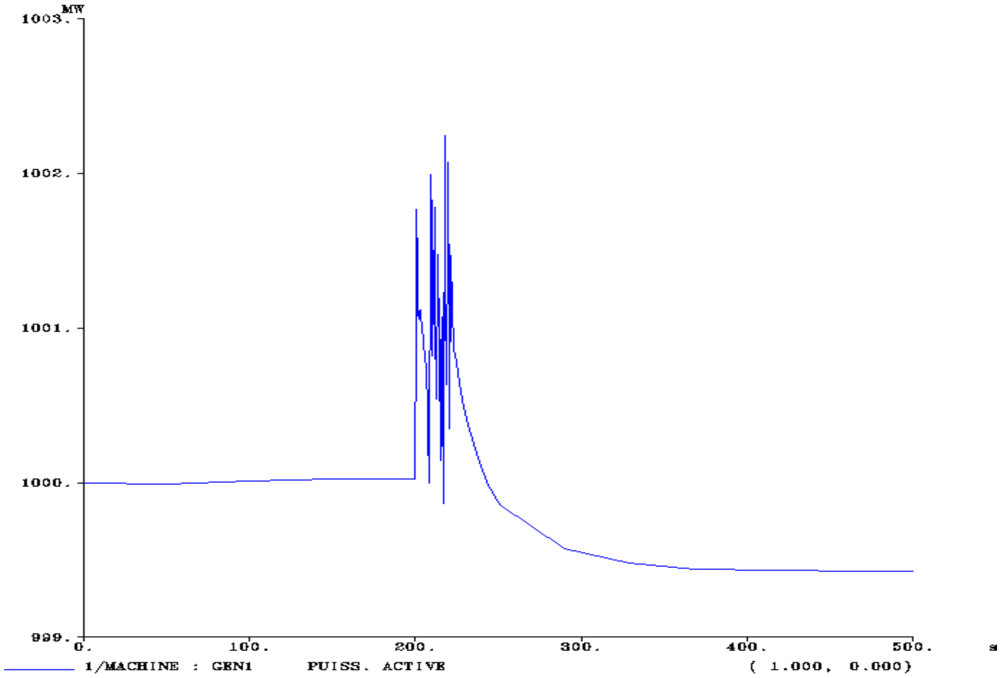


Figure.6.13.- GEN1 reaction faced to BUISSONN DG disconnection

- Overload

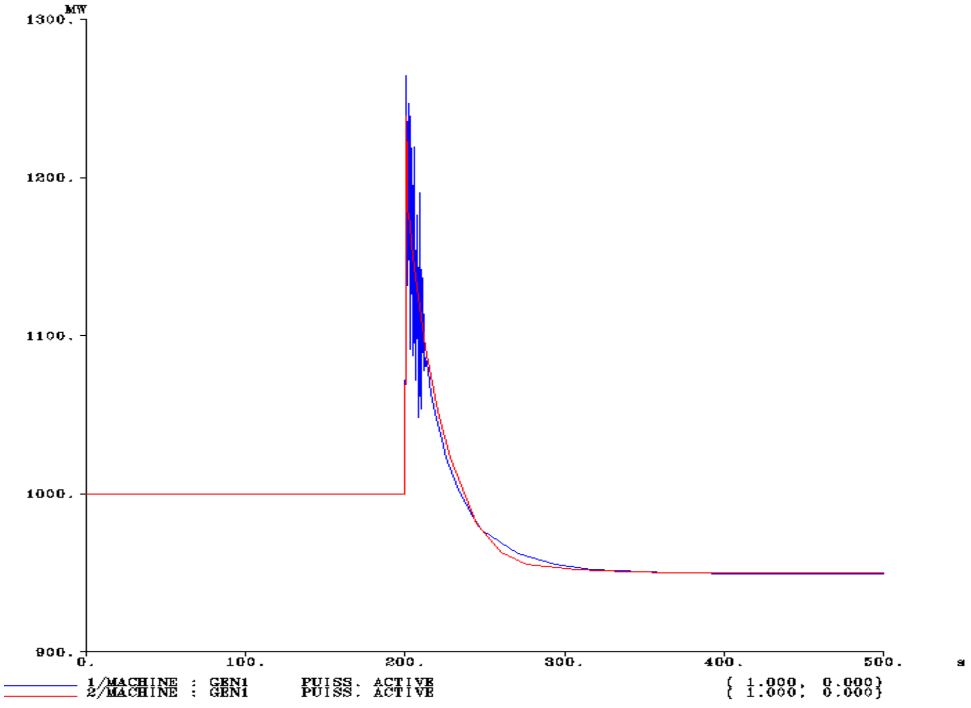


Figure.6.14.- Transmission line overload (BUS 4 overload of 100%)

6.3 Perspectives

The perspectives to follow for the WP 1.3 are the next ones:

- Establish different scenarios of DG penetration: 10%,20%,30%,40%,50%… In the first simulations done with 1% of the total power, the DG haven't got a real influence in the transmission line dependency and so the congestion problems created by the different perturbation was very similar with and without DG.
- Participation factors
- Aggregation of loads and generators in order to study the influence of the power injection at different points of the transmission system
- Optimal placement of the DG into the transmission system
- Introduction of renewable energies: Fuel cells (conventional energy), PV and Wind energy models into Eurostag simulator. Simulation of intermittent energy sources.

Conclusions

The present document has detailed the different component presents in the electrical system. First at all, the different electrical sub-systems (transmission, sub-transmission and distribution) are distinguished. These electrical sub-system are made in different ways: architecture, voltage level and exploitation. It is remarkable also the difference between one to another. One comparison between the French and Dutch system has been defined. Then, the control and protection system was explained.

Today, the market deregulation has changed the actors present in the market and an evolution from monopoly to liberalisation has been doing. News actors have appeared in the energy market: new producers, independent transmission lines operators, trade pools to exchange agreements to sell and buy, adviser companies and institutional market regulators that supervise the equitable and normal market operation.

The degree of liberalisation depends on the country but in all of them a real interest has been developed by the international environment: Kyoto protocol, European Union initiatives (renewable energy uses)…

This context facilitates the introduction of new energy resources. Nowadays, the public opinion is worried about the ecological subjects and so the conservation of the Planet. The traditional energies (thermal or nuclear) are very polluting and its consequences in case of accident are catastrophic. On the other hand, oil is a source of energy whose price is influenced by the international crises (1979, 1991 Iraq war or the actual war in course). So, new energy resources are explored to be applied.

But, the introduction of Dispersed Generation creates some impacts on the grid by the technical requirements of each DG or by the complexity of the system. So, it is not always possible to connect a DG. Nevertheless, the DG can give rise to favourable changes in the system. Thus, in order to check this affirmation different critical scenarios have been settled and defined. These main scenarios have been analysed in the benchmarking model.

In short, this first report has swept the different components and actors of the electrical system, the critical scenarios and a proposed benchmarking model to use in the different works of the CRISP project.

Annex A: the Dutch electricity grid

A.1.-General layout

The electrical infrastructure of the Netherlands is organised as a hierarchical network. Three main levels are distinguished: the transmission level, the sub-transmission level and the distribution level.
These levels have the following characteristics:

- *Transmission level* (380, 220 kV): the national extra high voltage grid. Typically a meshed network connected to large generation units and to transformers to the sub-transmission level. The main international connections are also at this level.
- *Sub-transmission level* (150, 110 kV). Regional radial or coupled network connected to large or medium sized generation units and very large customers (industrial complexes)
- *Distribution level*: ‘Medium-voltage’ network (50 to 10 kV) and ‘Low voltage’ network (400/230V). The 10 kV network is typically a meshed network connected to small generators, medium sized customers and LV (low voltage) stations. The LV grid is typically a tree network, throughout domestic areas for small customers and public lighting networks.

In figure 1 the layout of the network is shown (110 kV – 380 kV).

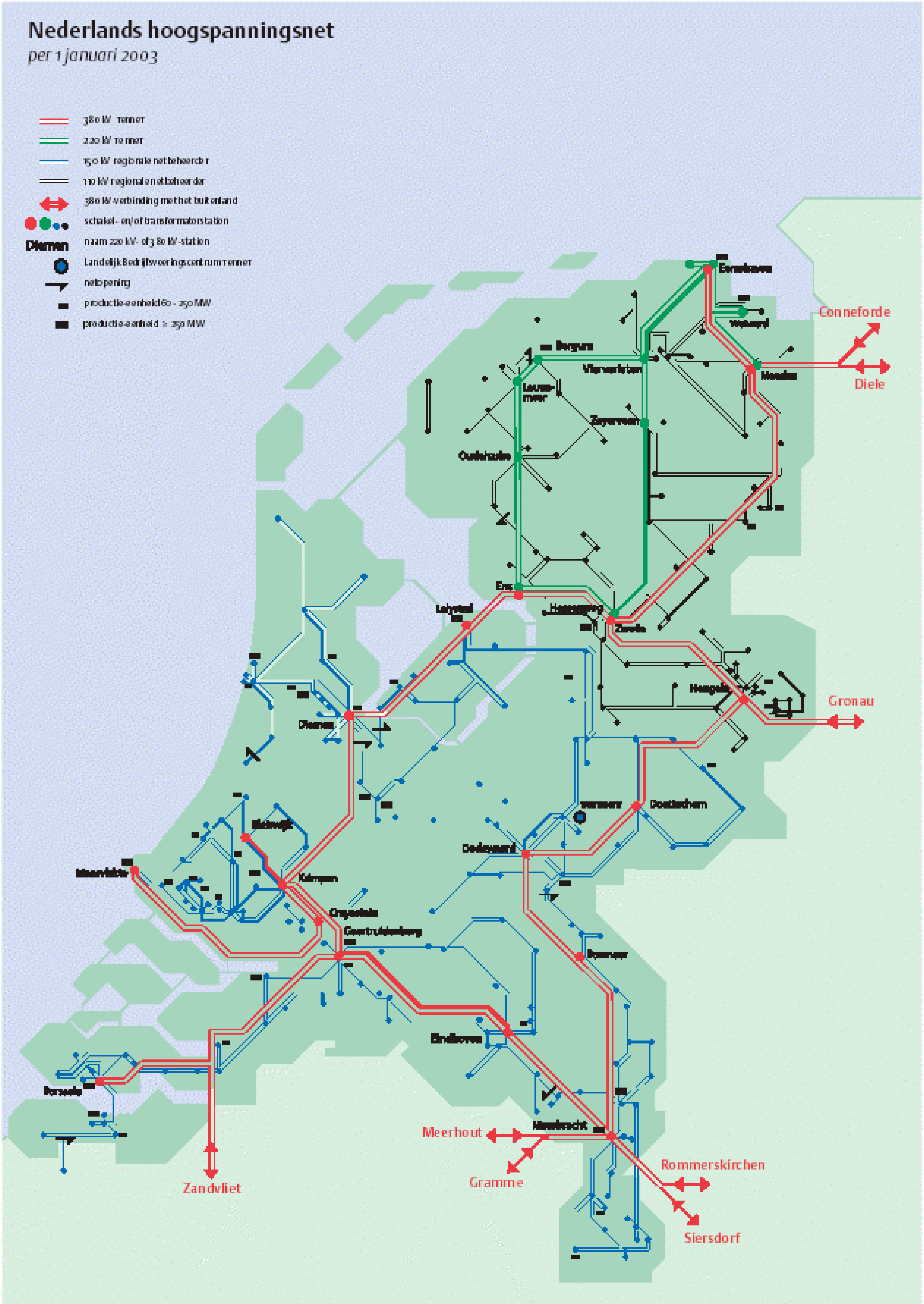


Figure.A.1.-National Grid in the Netherlands

A.2.-Energy production and consumption

At 5 locations on the transmission level there are power stations with a production capacity of 1000 MW or more (max: 2300 MW)

At several locations throughout the country there are production units with a production capacity of 200 MW to 1000 MW, coupled to the sub-transmission level.
Though, 30 % of the production capacity is found at the distribution level, throughout the country, in most cases near industry locations.
In figure 2 we see the main transports of electrical energy at each of the grid levels. The size of the arrow represents the average amount of energy flow per grid: generation (left) and consumption (right). The upper arrow represents imports from surrounding countries.

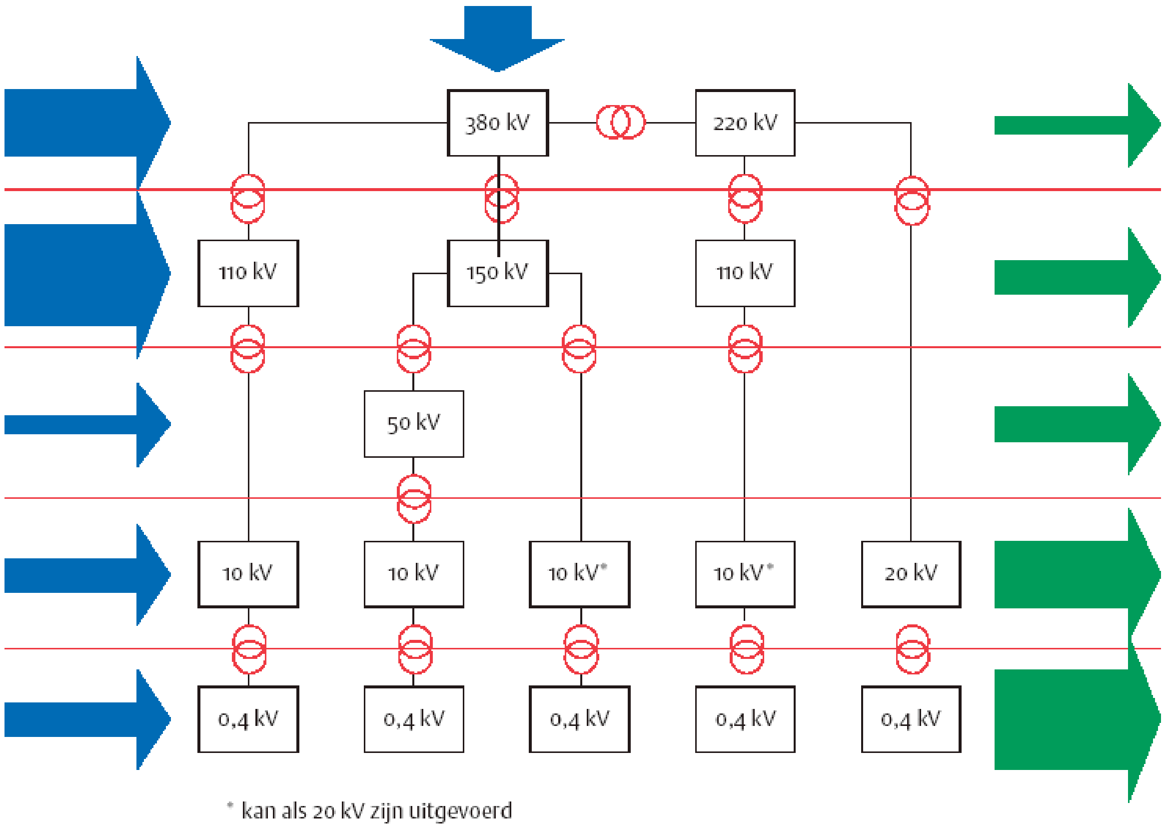


Figure.A.2.-Electrical energy flow per grid (source: TenneT [1])

A.3.-Actors

A.3.1.-National grid

Transmission System Operator (TSO) TenneT is manager of the 'highways' of the Netherlands high-voltage grid (380 and 220 kV). The national grid administrator TenneT is responsible for this high-voltage grid which connects all regional grids with each other and with the European grid. The TenneT grid has 22 points of delivery to the lower grid levels. TenneT is fully owned by the Dutch government.

A.3.2.-Regional grid

In these levels the administration is formed by 9 regional companies, who operate as Distribution Network Operators. The Distribution Network Operators are juridically separated units, owned by utility companies.

A.4.-Infrastructure

A.4.1-Transmission and distribution lines

The percentage of the network consisting of underground cabling is one of the highest compared to other European countries. Due to the dense population, space is a problem. Thanks to the sandy soil in the Netherlands it is possible to put most of its electrical energy infrastructure underground: The high and medium voltage network (380 to 10 kV) covers about 125,000 km; 93% of this amount is underground cable and only 7% are overhead lines. [2]

Grids at the transmission and sub- transmission level are formed by large overhead lines, which are clearly visible throughout the country (total 8500 km). In some cases 150 or 110 kV underground cable is used. (900 km)

In the 50, 25 and 10 kV grids all lines are underground cables. The low voltage network is always underground and covers a total of 170,000 km cable.

A.4.2.-Stations at the (sub) transmission level

At the transmission level (380-220 kV) every 25-50 km we find a transformer station to the sub- transmission level. At the sub-transmission level (150-110 kV) every 10-15 km has a transformer station to the distribution level. Details of these stations are not discussed, because they are not in the scope of this article.

A.4.3.-Stations at the distribution level

At the distribution level (50 -10 kV) an average distance of 500 m to 1 km lies between a substation or transformer station to the low-voltage customers. The size of the infrastructure at this level is the largest in the whole network. There are about 60,000 10kV stations (100,000 km underground lines) and 40,000 400/230 V stations (estimation).

A.4.4.-A typical 10 kV infrastructure

10 kV is the standard voltage in most cities and industrial complexes. Typically this grid is meshed, built in rings which are formed around household areas. These rings are mostly not closed and make it possible to switch the supply to a station from different directions. Stations are found every 500 to1500 m in most cities. A typical structure of a 10 kV grid is shown in figure A.3.

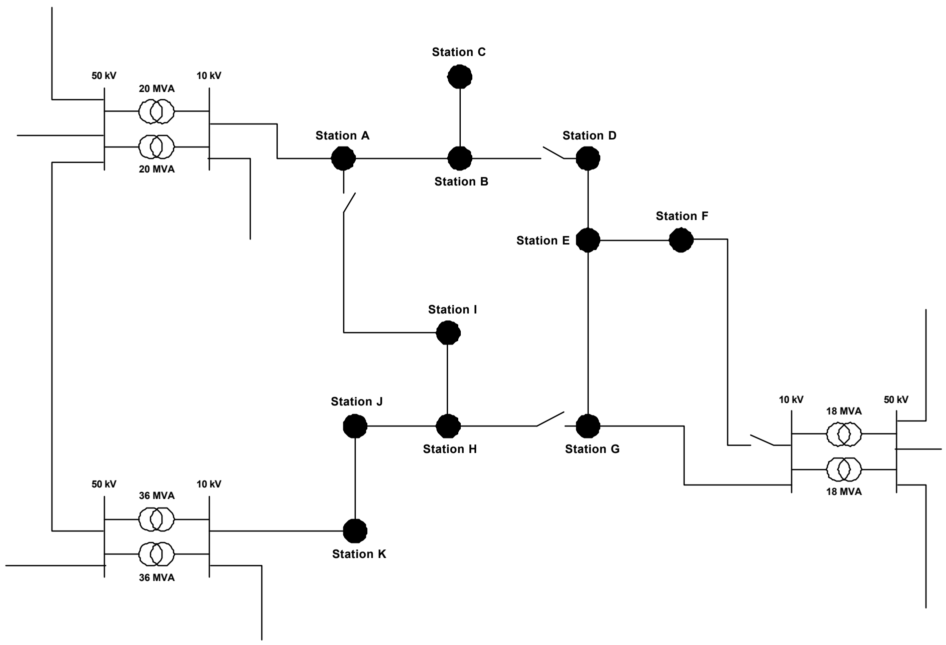


Figure.A.3.-Typical structure of a 10 kV grid as can be found in city areas (10 kV substations covering approx. 1 square km)

Most electricity companies use the basic design rule "n-1 criterion" for the structural setup at 10 kV level and higher. This means that every component should be replaceable during failure or maintenance by redundancy. The normal delivery of energy is not endangered during maintenance. Time between failure and restoring the supply can be very short.
Set up of stations in the 10 kV range is not general, but most of them will consist of switch gear on a double rail system and one or more low voltage transformers for local low voltage customers.
Grids with a voltage from 10 kV and more are generally not grounded. A typical cabling used is GPLK 8/10kV, varying from 3x35mm² up to 3x240mm² and triple single phase cables up to 500mm².

A.4.5.-Exceptions

The voltage most used is the 'standard' 10 kV. However there are some exceptions. In some few cases, a 3 kV or 6 kV voltage is used. Most of these grids are to be replaced by 10 kV systems in the near future. Within industrial complexes, voltages in this range are found, but these grids are not standard.
In some northern parts of the country 20 kV is used in former local transport / distribution grids. 20 or 25 kV systems can also be found in transport lines at windparks in relatively remote areas. This is done to feed directly into a 50 or 110 kV transport, instead of a local 10 kV system, to avoid power quality problems.

A.4.6.-Low voltage grids (400/230 V)

Low-voltage transformers in domestic areas will have a typical powerrating of 400 kVA, Dyn5. These low voltage grids are typically built in tree structure. Cabling is 3 phase plus Neutral; a typical main cable is 4x150mm² Al. Branches to households are made in underground joints and its branch will typically consist of 4x10mm² Cu cable.

A.5.-Operation of the grid

Delivery of electrical energy has proved to be very reliable in the Netherlands over the past years. Frequency and duration of outages are very low compared to other European countries. One of the reasons for this is that most grids are based on the n-1 criterion, which means that redundancy is present in most cases. Another reason is the small percentage of overhead lines. An overall figure is a failure rating of 25 minutes per year (99,995 % certainty of delivery).

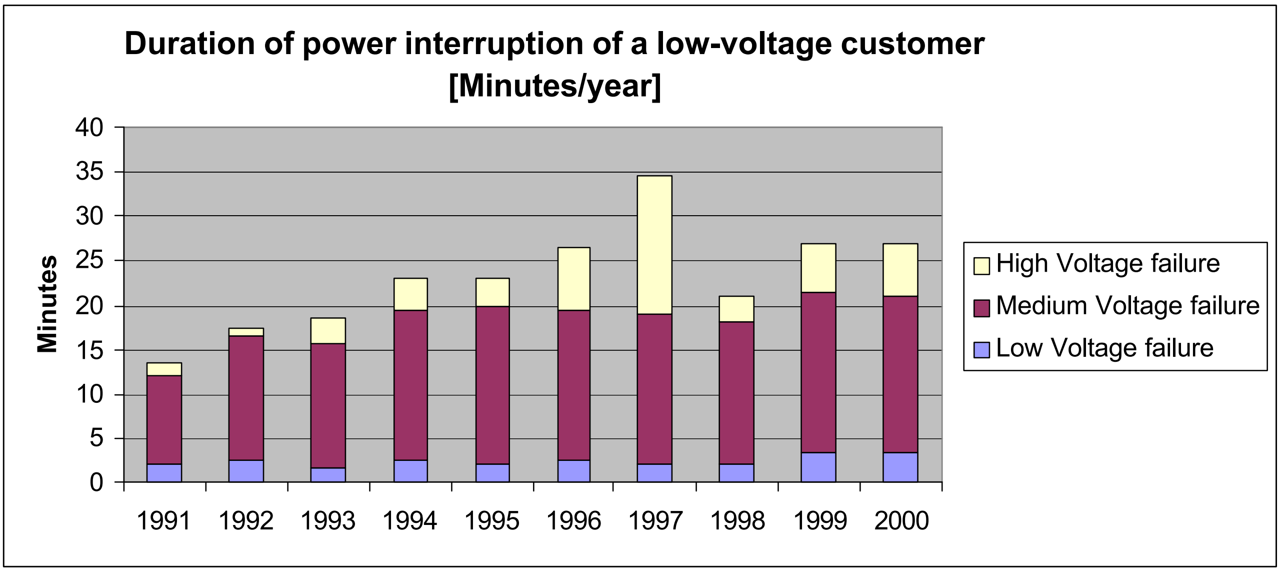


Figure.A.4.- Annual duration of outage (Source Energie Tehnik Maart 2002)

A.6.-Integration of Distributed generation

Large-scale generation units produce most electricity in the Netherlands; nevertheless there is a trend towards decentralized electricity generation. Already 30 % of the production capacity is situated near on the distribution level (50, 25, 20, 10 kV and LV). These units produce 32 % of the generated energy. [2] Much of this capacity is formed by cogeneration plants, mainly found in industrial complexes, in smaller numbers in horticultural complexes (greenhouse heating) and in some utility building complexes (like large hospitals, schools and office buildings).

However, the trend towards distributed generation in the Netherlands has been mainly based on gas-fired cogeneration plants. The profitability of these plants is dependent on fluctuations in the gas price and has dropped significantly over the past few years. Other forms of distributed generation from renewable energy sources are rising, but still comprise a small part of the Dutch electricity production (approximately 3%).

A.7.-Integration of renewable energy equipment

Most of the above mentioned distributed generation units are natural gas-driven engines or turbines in connection to rotating generator machinery. These generators are relatively easy to fit into existing grids, most of them can be controlled at a relatively constant point of operation, dependent on a certain production process, or what a thermal load requires.

Renewable sources however, like wind and solar energy, cannot be influenced by any control system. They are dependent on the meteorological circumstances of the moment. This makes the renewable generation units different in their behaviour compared to conventional systems and thus it is necessary to reconsider this in the grid designs.

Another aspect of (some) renewable generation units is its way of energy transfer. Unlike rotating machines, systems like photovoltaic generators, some wind turbines and fuel cells use electronic power converters. Their origin of electrical energy is direct current (DC). This current is to be transferred to alternating current (AC). Electronic converters (inverters) behave in a different way to the grid and cannot be considered as conventional generators. Therefore grid stability and power quality issues should be studied separately for Renewable Energy equipment as well as for conventional generators. In the Netherlands there is some experience with grid stability issues for renewable energy equipment both from practice and from simulations [5 - 8].

A.8.-Comparison with the French system

The first parameter that distinguishes the French and the Dutch system is the different voltage levels:

- France: 400 kV, 63 kV, 20 kV and 0.4 kV
- Netherlands: 380 kV, 110 kV, 50 kV –10 kV, 0.4kV

Then there is a layout difference because the network is meshed in the distribution system and it is not normal in France. The actors presents in the market are composed by a lot of different distribution operators and producers. On the other hand in France, there is a principal producer and distributor operator: EDF and then there are small distributors and different producers.

The transmission lines are in majority underground and in France is the opposite: majority of overhead. The MV/LV transformer is 400 kVA but in France is 630 kVA. Other difference is the high DG penetration in the Dutch system, in France the majority of the production is based on nuclear energy.

A.9.-References

[1] “Capaciteitsplan 2003 – 2009, TenneT” (Dutch), Arnhem November 2002.

[2] “Energy in the Netherlands; Facts and figures 1999”, EnergieNed ,1999.

[3] “Capaciteitsplan 2001 – 2007”, Noord West Net, December 2000.

[4] “Algemene richtlijnen voor het ontwerpen van hoogspanningsinstallaties”(Cursus OD-1), Quercus Technical Services BV.

[5] J.H.R. Enslin, W.T.J. Hulshorst, J.F. Groeman, A.M.S. Atmadji, P.J.M. Heskes, A. Kotsoppoulos, “Harmonic Interaction between large numbers of Photovoltaic Inverters and the distribution network” Report KEMA / ECN 4021004 TDC02-29719A

[6] P.J.M. Heskes, J.F. Groeman, M.J. Jansen, “Harmonic interaction between PV-inverters in parallel and their effects om the voltage distortion” Report ECN-CX—01-025

[7] A. Kotsopoulos, P.J.M. Heskes, M.J. Jansen, “Zero-Crossing Distortion in Grid-connected PV inverters”, TUE / ECN (IECON ’02)

[8] K. Burgers, “Pre-normative investigation (PV) inverters” Report Ecofys E21280

Annex B: Special scenarios

High PV penetration scenarios and high penetration of demand and supply matching in households and industries could be also interesting. High penetration (locally up to 100%) of microCHP-units for households. Additional information will be given in the next reports of the CRISP projet in order to specify the study case and also the models of CHP-units that ECN have been developed. Others interesting scenarios and critical situations could be:

- Micro CHP: Simulation of grid behaviour in a situation of high penetration of micro-CHP-units in houses, connected to the LV-grid: up to 100% on a street level.
- Demand and generation regulation: Simulation of grid behaviour in cases of high penetration of demand and (distributed) generation regulation units.
- Critical situations: maximum production steady state, simultaneous disconnection (5 microseconds) due to protection behaviour, simultaneous connection (within minutes) due to central production control.