# CONNECTION OF EMBEDDED GENERATION TO LV NETWORKS

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## *1. INTRODUCTION*

*EDF has been facing in the last five years a significant growth of the number of generating facilities connected to MV networks. This move is mainly due to the expanding of peak diesels and more recently of industrial and residential combined heat and power (CHP) units. Breakthrough in the embedded generation market are expected in the next few years among which the emergence of units dedicated to LV networks.*

*As MV networks, LV networks have not been designed to host dispersed generation. Several technical problems appear with the connection of units to these networks : constraints for public and equipment safety, correct network control and operation as well as power reliability and power quality.*

*Up to now, units connected to LV networks have rather been marginal in terms of quantity and average capacity. This has enabled the use of simple technical solutions as well as the definition of requirements similar to the ones in application for MV networks. A significant expanding associated with the arrival of new types of generating units requires nonetheless a deeper analysis of the constraints. For French networks, the problems which appear to be the most critical are : impact on voltage control on LV feeders, impact on LV systems protection plan, special arrangements for networks operation and for production units monitoring and control. If a significant amount of dispersed generation is connected to several LV networks located in the same area, investigations should also be carried out to determine the consequences for voltage control along MV feeders, MV systems protection plan and MV equipment behaviour against an increase of the short-circuit level.*

## 2. TYPES OF INTERCONNECTED UNITS

### 2.1 Current situation and prospects for the next few years

Designed for power supply to customers, LV networks presently host a small number of electricity production units. Up to the nineties, most of the generating plants interconnected with LV systems are hydraulic units driven by river current flow or small water fall. To minimise the costs and optimise the units reliability, producers give preference to asynchronous machines.

The mid-nineties is the beginning of a significant development of peak diesels and cogeneration units, essentially on MV and HV networks. On the opposite, interconnection of new production units on LV networks remains marginal. This situation can be explained by the limitation down to 215 kW of the cogeneration purchase contract and by poorer electrical efficiency of small capacity units. New generating plants connected to LV systems are then mainly equipped with synchronous machines. It has to be pointed out that a few small capacity solar cells connected through an electronic interface also appear on LV networks.

The next few years might be characterised by significant technology progresses in the field of decentralised generation. Several versions of microturbines are already available for mere electricity generation or cogeneration facilities. In a few years, additional types of units will probably be mature enough to take some parts of the market : fuel cells, piston engines, Stirling engines, wind turbines, solar cells…Predictions on the rate of development of these new types of units are harsh to perform now.

### 2.2 Characteristics of the new types of production units

It is interesting to mention several common characteristics among all the types of units that are likely to arise on the dispersed generation market. First of all, their capacity ranges usually from a few tens to a few hundreds kW. Products benefit from advanced technologies developed by other industries (electronic, cars, defence…).

On an electrical point of view, use of power electronics is very common for the interfacing with the grid. The converter provides a DC to AC transformation that is required for electrochemical storage or generating units. It also allows a more simple use and the optimisation of the efficiency of the prime mover driving the electrical generator (microturbine, wind turbine). Figure 1 shows examples of electronic structures that can be used for interfacing microturbines and fuel cells with the grid.

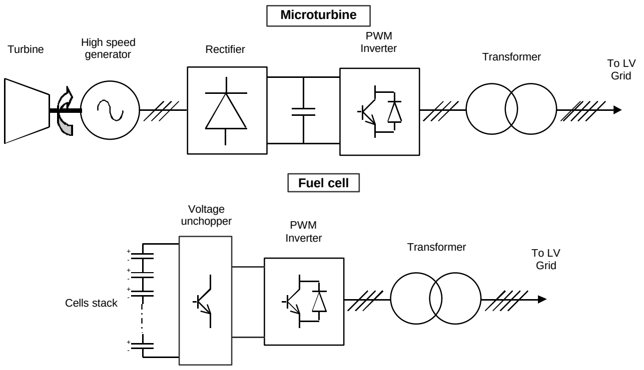


Figure 1. General electrical structure of microturbines and fuel cells

In comparison with conventional rotating machines, power electronics converters have specific characteristics that need to be taken into account for the study and the realisation of the interconnections :

- frequent use of an output transformer,
- electronic soft coupling to the grid,
- possibility to inject or absorb reactive power,
- injection of low or high frequency harmonic currents,
- difficulty to anticipate and model the behaviour in the case of a grid perturbation (short-circuit, frequency or voltage drift).

## 3. CURRENT REGULATIONS

The regulations pertaining to the technical requirements for interconnection with LV networks and currently in application has been defined in a working group. The latter is composed of representatives of the main players on the French electricity market and is under the supervision of the French Ministry in charge of the Industry. Its conclusions have led to the publication of a Ministerial Order dealing with the technical conditions for connection of units rated at under 1 MW [1].

This text indicates that the maximum rate of a generating unit that is allowed to be connected to a LV network is 250 kVA with reserve though that the network interconnection capacity is not exceeded.

This capacity has to be determined in accordance with a list of technical conditions related to the following items :

- equipment thermal capacity,
- voltage control,
- 175 Hz remote control signalling and filtering,
- decoupling protections,
- neutral and live metal parts earthing,
- coupling to the grid,
- metering.

The analysis having led to the currently applied regulations must now be carried on. Several points dealing with the control and operation of LV networks have been partly investigated or not tackled : protection plan, machine neutral coupling, connection architecture, operation procedures, units monitoring.

Moreover, the study carried out by the working group was based on the hypothesis of the connection of a limited number of rotating machines whose capacity was marginal in comparison with the LV network equipment. It is now necessary to consider a significant penetration of generating units on LV systems and the arrival of new types of units whose behaviour is not entirely known. The connection of single phase units must also be investigated. Finally, it is essential not to underestimate the interaction between units connected to LV networks and the operation of MV networks.

## 4. CONSTRAINTS FOR NETWORK OPERATION

### 4.1 LV and MV voltage control

The problem of voltage control in the presence of producers connected to LV networks is crucial. The distributor is legally obliged to guarantee a voltage at 230 V +6%/-10% (mean value calculated during a 10 min window) to any LV customer. Voltage variations on MV networks also have to be limited as much as possible to be able to maintain the voltage at any MV client delivery point within ± 5% of a reference contractual voltage.

Generating units connected to LV networks can permanently or temporarily inject power on the grid. Inversely, a client who is also a producer can absorb power at any time. The choice that he makes between these two operating modes depend on the economical approach he decides for his electricity generating plant as well as for his heat or/and steam producing unit. His analysis takes usually into account the gas sales, electricity purchases and sales prices and his proper needs.

The voltage profile along a LV feeder depends on the balance between the power absorbed from or injected on the system by “clients-producers” and the other clients power demand. If no client produces power, the setting and the characteristics of the network are defined to comply with the voltage tolerable limits. To do so, maximum and minimum load conditions are considered. If a producer is connected to the LV system, the problem of the determination of the new maximum and minimum load conditions is raised. These new extreme load conditions are the superimposition of the yearly production and demand profiles. If the new value of the minimum network load is lower than the former value, the voltage control conditions will be more complicated in the presence of the producer than they used to be when he was not connected to the grid.

The assessment of the voltage levels in the presence of generation is all the more difficult that, even without any production, load imbalance on a LV feeder can create voltage profiles in medium or peak load conditions higher than they would be in minimum load conditions. As an example, Figure 2 gives the value of the three phases voltages at the remote end of a LV feeder as a function of the total load demand of this feeder. This plot is made under the assumption that the distribution of the loads between the three phases is constant, whatever the feeder demand is : 60% on phase a, 20% on phase b and 20% on phase c. At peak load, the voltage on phase b is equal to 243 V instead of 220 V if the loads were balanced. On can also notice that despite the voltage drop along the feeder, the voltage on one of the three phases can be higher than the voltage at the terminals of the MV/LV transformer.

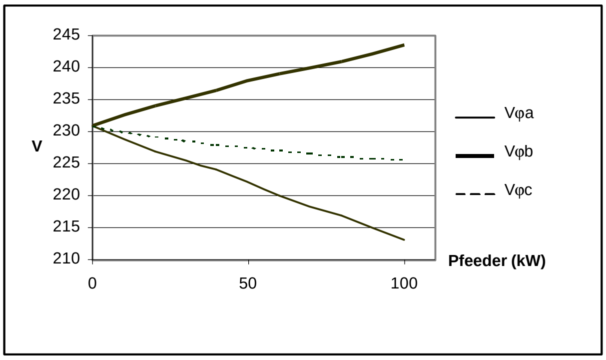


Figure 2. Three phases voltage at the remote end of a LV feeder as a function of the feeder total demand

Another difficulty comes from the lack of information on the sharing-out of the loads between the three phases at various times of the day and the year. Finally, the number of clients supplied by a LV feeder can be so small that the use of a statistical approach to model the loads can lead to significant errors in the determination of the voltage profiles on the LV network.

Two regulation arrangements have been adopted to limit the risks of overvoltages :

- possibility to lower $\tan\varphi = Q/P$ down to 0 (increase the power factor up to 1). The effectiveness of this solution is limited due the high ratio R/X of LV conductors (between 1 and 3 for overhead conductors and between 1 and 6 for underground cables). As a consequence, voltage variations along LV feeders are mainly attributed to active power flow.
- obligation to use a dedicated feeder if the capacity of the generating unit exceeds 40 % of the MV/LV rate. This solution raises the problem of the interconnection costs.

Another arrangement that would strongly limit the impact on the voltage profiles would be the temporary reduction of the active power injected by the generating units onto the grid. Some adjustments of the current purchase contracts would then be necessary.

More effective solutions could be considered for plants connected through power electronics converters. Some of these devices can indeed inject or absorb high quantities of reactive power. One could for example add to the converter control a limiting loop to reduce the reactive power if the voltage at the point of coupling exceeds the tolerable limit. The use of a real voltage regulator can also be discussed. If this voltage regulator is sufficiently effective (wide reactive power range and individual control of the converter phases), one can also think of making the production unit contribute to the network voltage control and the voltage imbalance compensation.

Whereas the interconnection of a generating unit with a LV network causes local voltage control troubles (say on a LV feeder), the presence of several units connected to LV networks themselves supplied by the same MV feeder can have a wider effect. Recent investigations have shown that the study of voltage constraints caused by the connection of dispersed generation to MV systems requires network state estimations in both peak and low load conditions. Power injection on LV networks modifies loads along a MV feeder and consequently the voltage levels along this feeder as well as on the LV networks supplied by this MV feeder.

As a conclusion, the interconnection of generating units with LV networks can generate difficulties to control the LV and MV voltage profiles. The stakes for the distributor are critical due to his obligations towards the customers and the investments for networks reinforcement.

### 4.2 Load unbalance and neutral coupling

No regulation presently exists about the way to connect the neutral point of a generating unit on LV networks.

Nonetheless, it has to be pointed out that the coupling of the neutral point of a generating facility or its output transformer to the grid neutral wire would immediately reduce the voltage unbalance. Hence its impact on the voltage profiles would be limited. As an illustration, Figure 3 gives the variation of the three phases voltages at the point of common coupling of a generating unit versus the power it injects on the grid. In this case, the plant is located midway between both LV feeder ends. The first and second charts correspond to the situation where the neutral point of the producer output transformer is respectively decoupled and coupled to the network neutral wire. One notices that as the producer is coupled to the grid and operates his unit at zero power, the maximum difference between two phase to neutral voltages goes from 24 V when the two neutrals are disconnected down to 10 V when they are connected. The neutral points coupling provides therefore a 14 V gain.

Another advantage of the creation and coupling of a neutral point at the output of a generating unit is a better control of fault overvoltages as the producer is connected or disconnected from the MV/LV transformer.

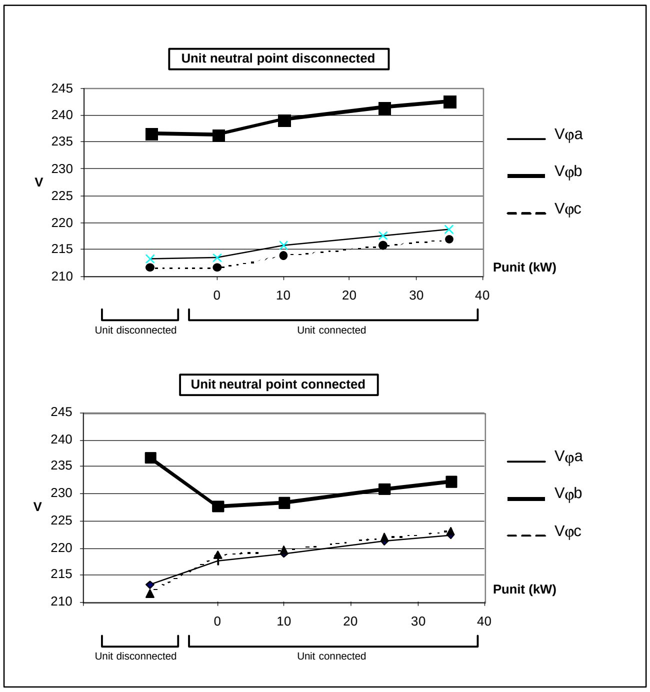


Figure 3. Impact of a generating unit neutral coupling on the voltage unbalance

The choice of a generating plant neutral point coupling mode is in reality a wider issue that needs to be treated by taking into account the protection plan performances, equipment and public safety, power quality and constraints upon the network and producer equipment (possible circulation of $3^{rd}$ rank harmonic current in the machines neutral for example). A study is currently in progress to define recommendations.

### 4.3 Protection plan

Protection plans on LV systems against phase to phase and phase to neutral faults are provided by fuses. Their principle hinges on the clearance of the short-circuit by the blowing up of one or several fuses on the faulty phases. The co-ordination between several fuses in series is then ensured by an adequate choice of their (I,t) characteristics. The presence of generating units on LV networks modify the circulation of currents at the occurrence of a fault and put to the forth three types of problems related to the protection plan behaviour.

If one considers a fuse at the sending end of a LV feeder to which a producer is connected, the following phenomena will be encountered :

- if a fault occurs upstream the fuse, a current injected by the producer will flow through the fuse. If the latter is activated outside its normal fusing zone, the blowing up might be dangerous. For significant contributions of the unit to the fault current, the fuse will nuisance melt.
- if a fault occurs on the feeder, the fault current flowing through the fuse will be lower than when the producer is disconnected. This can result into an improper co-ordination of the fuses along the feeder or the non-detection of the fault.

Similar problems have already been experienced in the case of connection of embedded generation to MV networks [2].

Unlike MV breakers which operate three phase line tripping, fuses have the distinctive feature to only disconnect the faulted phases. Therefore, in the case of a single phase to neutral fault leading to the blowing up of a fuse, a producer connected downstream this fuse will remain connected to the MV/LV transformer through the two sound phases. This situation can be harmful for the equipment inside the generating plant.

The above mentioned problems can imply the specification of a connection architecture dedicated for mere generating plants or for existing clients who desire to install their own production units.

It is also advisable to check that the connection of several units to LV different networks supplied by the same MV feeder does not confuse the functioning of the overcurrent relay in charge of the protection of this feeder.

### 4.4 Decoupling protection

The decoupling protections used on LV systems are in charge of disconnecting the units when a fault occurs on the grid and when, following a breaker tripping, a part of a LV network is separated from the grid and supplied by generating units. The utilisation of these protections causes nevertheless a few problems due to the characteristics of LV networks and costs constraints which require the use of very simple technical solutions.

Since MV and LV neutral points are entirely decoupled, a zero sequence voltage criteria cannot be used to detect from the LV side a single phase to earth fault occurring on a MV network. When such a fault appears, the decoupling of units connected to LV networks will be performed if the frequency and voltage drifts are sufficiently large and fast. These conditions are fulfilled if the total capacity of LV generating plants connected to the same MV feeder does not exceed 50% of the feeder minimum load. This rule has been set up under the assumption that all facilities were equipped with rotating machines. Its validity must therefore be validated for units connected through power electronics converters.

It is also necessary to verify that the use of power electronics does not decrease the sensitivity of decoupling protections in the event of faults on MV and LV systems. Most of the electronic interfaces internal protections are nowadays implemented within their control system. The easiness to implement new relaying functions inside the control units raise the question of their acceptance by the utility as a proper decoupling protections.

### 4.5 Harmonic injections

One of the main features of power electronic converters is the harmonic currents that they inject into the grid. Due to the present low proportion of generating units connected through converters, only a few studies have been carried out on the impact these types of units can have on the voltage distortion and on the network and customers equipment.

In the absence of international standards explicitly related to maximum emission limits in the 0-2 kHz band for generating units, the French regulations have not been defined.

Nevertheless, it should be noted that advanced electronic technologies allow the design of high frequency chopping converters (PWM type) that shift the first harmonic currents in the 2-20 kHz band. The effect of these high frequency currents on the LV networks and the customers is presently under investigation. The studies results should enable the definition of maximum tolerable emissions in the 2-20 kHz band.

### 4.6 Single phase connection

The development of heavily decentralised storage and production units let us think of a significant growth of the number of single phase interconnection cases. This perspective draw some questions among which the impact of single phase units on the voltage unbalance, the protection plan, the connection architecture and the definition of operating procedures.

Part of these questions have already been discussed during the recent analysis of solar cells plants which up to now have made up most of the single phase interconnection cases. This analysis should shortly lead to the publication of regulations applicable to this type of installations. Two conclusions must be pointed out :

Actual regulations impose that an opening device shall be installed at the output of the facility and accessible from the public domain. This device must be able to perform a visible disconnection from the grid.

For units rated at under 3 kVA, the inverter is admitted as a decoupling protection, providing that it complies with the specifications mentioned in the current regulations. In such case, separation from the grid must be performed by a discrete contactor (not by semi-conductor components for example). The compliance of the equipment to the prescriptions must be verified by an registered laboratory. General regulations pertaining to the decoupling protections and devices apply for units rated at over 3 kVA.

## 5. CONSTRAINTS FOR NETWORK CONTROL AND MANAGEMENT

Growing difficulties encountered to control the MV networks in correct reliability and safety conditions have called for the setting up of rules dealing with systems administration and control.
These rules are applicable to units whose capacity is deemed non-marginal in comparison with the rate of the network equipment. They can be classified into two types :

- for network predictive management, providing the utility with a generation program,
- for real time control, being equipped with a device capable of sending information about the plant state and receiving remote control signals.

Presently, LV networks are characterised by the absence of monitoring and measuring equipment that could detect faults and give information on the network state. Current regulations do not impose any obligation to the LV producers towards the utility in the field of system control. Investigations are undertaken to determine the information to be exchanged as well as the monitoring and control means that would be required as soon as the number or the capacity of units connected to LV networks must be taken into account for a correct control of specific parts of the system. For remote monitoring, bringing back measured data and information from MV/LV substations to the central control room is conceivable. For remote control, centralised systems capable of sending orders (coupling authorisation, decoupling orders …) by line carried signals or vocal frequency signals could be considered.

The increasing number and the diversity of types of generating units will also render maintenance and works on the network more complex. Special procedures will have to be defined to ensure the security of operating crews : operating procedures, requirements for coupling, decoupling, recoupling following a contingency.

## 6. METHODS AND TOOLS

The above mentioned analysis of constraints caused by decentralised generation connected to LV systems puts to the forth the difficulty to establish simple rules allowing the determination of the maximum interconnection capacity of a part of a LV network. The interconnection feasibility depends indeed on various parameters among which :

- characteristics of the LV network and the MV feeder supplying the LV network : conductors, LV and MV load profiles, protection plan settings …
- possible presence of other generating units on the LV and MV networks,
- type of unit that has to be connected
- type of neutral coupling mode that can be adopted for the unit.

For several technical points, only a case by case study will give precise answers on the interconnection feasibility. A similar conclusion had already been drawn for interconnection to MV systems and EDF decided in 1996 to start the ESTERE project whose goal was to develop a decision making support software. This tool is now available and enables to study on a unique platform four crucial interconnection problems : thermal constraints, voltage profiles, short-circuit level and setting up of the protection plan.

The addition to ESTERE of new functions which could provide assistance in the study of interconnection to LV systems is considered. The main advantage of this approach would lie upon the use of existing MV and LV networks data bases and on the improvement of calculation algorithms already developed for MV systems. The study of the interaction between LV producers and MV networks would also be facilitated.

## 7. CONCLUSION

The first studies carried out by EDF show that the expected development of decentralised generation on LV systems causes constraints for the operation and control of LV and MV networks. To be in the position to create satisfying interconnection conditions for the producers and the clients, EDF has decided to start a study program for the next two years which aim at fulfilling the following objectives :

- analyse the constraints of interconnection with the grid, especially by taking into account the technology progresses in the generating equipment,
- define interconnection study methods and integrate them into a guide,
- develop and distribute among distribution centres software tools to ease the study of the impact of a producer onto the network and determine adequate technical solutions.


[1] "Arrêté du 21 mai 1997 relatif aux conditions techniques de raccordement au réseau public des installations de production autonome d'énergie électrique de moins de 1 MW", *Journal officiel de la République Française du 21 juillet 1997*

[2] J.L. Fraisse, P. Michalak, P. Juston, A. Grandet, "Technical conditions for the connection of generating facilities to the medium voltage network – Development of a 175 Hz active filter for independent power producers", *in Proceedings of CIRED'97,* Vol. 1, Paper No.5.14, Birmingham, UK, June 2-5, 1997

[3] Y. Pourcin, J. Fourgous, B. Battaglia, "Raccordement des petites unités de Production sur les réseaux publics de distribution MT et BT d'Electricité de France - Aspects techniques et économiques", *Actes du CIRED 1983,* Article No.a.02, Liège, Belgique, 1983