# HV AND MV NETWORK PLANNING INVOLVING DISPERSED GENERATION

**F. Dispot - S. Motte**
**Electricité de France - Direction des études et recherches**
**1, Avenue du Général de Gaulle, 92141 CLAMART Cedex (France)**
**Tel: +33 1 47 65 36 44 - Fax: +33 1 47 65 42 06 - E-mail: francois.dispot@edf.fr**

***SUMMARY***

*The emergence of efficient dispersed generation units imply some changes in the current network planning decision making process. This article presents an extension to the existing methods, giving consistent results when applied to previously released studies, with both medium and high voltage particularities. An algorithm giving the suitable size of a generation plant is described, with its application carried out in the working group GS-23 led by the French Ministry of Industry.*

## INTRODUCTION

The development of dispersed generation in France leads to an important evolution in the field of network planning, which has relied on the existence of a strong, reduced set of generation plants.
Rather than developing a totally new method for network planning, the key feature of the principles explained hereafter is to extend the existing system, so that the previous set of methods become a subset of the new one. This process ensures that the results of previously made studies, which did not include dispersed generation, will remain unchanged when the new rules apply.

This article describes a way to determine whether a network element is constrained or not, then how quality is taken into consideration, then an algorithm used to determine the size of a dispersed generation unit. These methods were applied to a real case as a part of the study group GS 23, led by the Ministry of Industry.

Since the situation of medium and high voltage network differ, both in their consistency and in the kind of respectively available data, the methods dealing with each voltage level have been separated when necessary.

## RESTRICTION DETERMINATION

The aim of restriction determination is to provide the planner with a quick and efficient method to find the location in both space and time where a reinforcement is likely to be suitable. This step does not replace economic optimisation which occurs as a second step, but it saves a lot of time and effort to avoid making complex calculation in irrelevant situations.

### High voltage

A reinforcement is necessary when the correct operation of the system is not possible. HV network deficiencies are determined by four main technical criteria:
- the maximum permissible loads of the network elements must not be exceeded
- a maximum number of long and short cuts must not be exceeded
- a minimum level of short-circuit power at each bus bar must be met and the maximum short-circuit currents admissible by the equipment must be respected
- voltage level must be in the range of the voltage limits.

These requirements must be verified not only in the normal operating scheme ("N" rule), but also in the case of lines or generation units outages ("N-k" rule).

In a context involving centralised generation plants, the groups are mostly connected to the VHV network which allows, in a HV study, to take only the loss of HV lines into account. Moreover, due to their unavailability rates (around $5.10^{-4}$) it is not relevant to consider the loss of more than one line. So the "N-k" rule becomes a "N-1" rule. However, when considering dispersed generation connected to HV network and having high unavailability rates (around $5.10^{-2}$), the consequences of the joint loss of a network element and a generation unit or of several generators must be studied. In fact all situations reaching an occurrence probability of $10^{-4}$ have to be taken into consideration. As a result, it can be seen that the situations that have to be studied are: N-1 network element, N-1 generator, N-2 generators, N-1 network element + N-1 generator, N-3 generators.

HV network planning is carried out considering several consumption levels. These are a high consumption level (traditionally a winter point in France, but more and more summer peaks can be found due to air-conditioning), a low consumption point (which can lead to excessive voltage values for example) and one mid-season point (with substantial consumption, but low network capacities). Taking dispersed generation into consideration does not affect these hypotheses.

### Medium voltage

Traditional restriction determination on a medium voltage network consists in a single study in normal operation, using a low probability consumption level (likely to appear but 20 hours per year). In this situation, a check for excessive currents and voltage drops is carried out, leading to a possible set of constraints. In a context involving few, reliable generation plants, such an approach can be maintained.

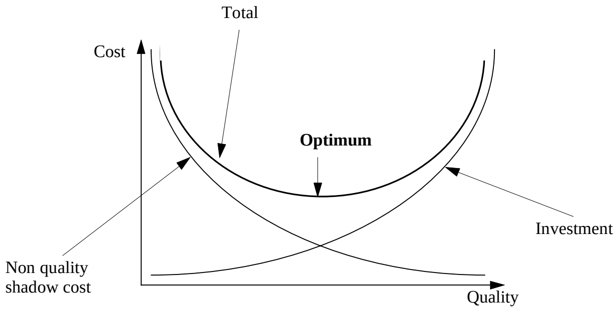
However, multiple generators, or unreliable ones can create ambiguous situations with partially solved restrictions, or constraints appearing in particular situations. In such cases, a probabilistic approach can be developed. In any network situation, a simulation provides the highest voltage drop and overload values. From these figures, it is possible to estimate the average yearly duration while constraints are met for each generation situation. Multiplying the worst duration for a given generation availability situation by its probability of occurrence leads to a probable hazard duration. Adding these duration obtained for every availability situation gives the global constraint duration for the network. Among he various availability situations, only the most relevant ones are taken into consideration, assuming their occurrence probability reaches $10^{-4}$.

As previously explained, restrictions are determined in a low probability context. This reference context can be considered as a probability threshold (e.g. 20 hours), which can itself be compared with the probable constraint duration. This process allows to extend the conventional approach to a complex situation, giving identical results in identical generation-free situations, but answering the "is a 10% overload solved when it is solved 90% of the time" question.

Another evolution comes from the fact that network planning without dispersed generation used to be carried out using a single reference value for consumption, i.e. peak power. In a situation featuring dispersed generation, several points arise, that imply the use of several different consumption levels. The first point is the potential emergence of evacuation restrictions when a low consumption level cannot compensate the overload or excessive voltage value created by an oversized generation plant. This point creates the need for a low consumption level study. Another problem comes from the fact that the generated power is likely to vary with the date, according to contractual and tariff-related issues. This leads the planner to introduce a mid-season situation study to check the state of the network when dispersed generation can reach low levels while consumption remains substantial.

## FAULTS PRICING

One of the aims of network planning is to provide a good compromise between quality and development costs. A way to achieve this goal relies on a global optimisation of investment, losses, operating costs and quality. This global calculation can be perform through the assertion of a shadow cost for non quality. The figure below shows how a global optimum is met.

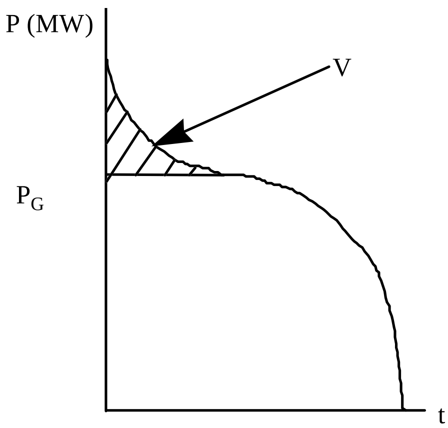



This is the system used at EDF, featuring normative costs for short and long outages, combined with occurrence probabilities and duration for each potential outage. This method calls for quite intuitive extensions, as described hereafter.

### High voltage

Having detected all the constraints generated during significant situations of N-k HV network elements, planners evaluate the cost of non-quality induced by each constraint. For each case, the cost of unsupplied energy or cut power has to be multiplied by the probability of occurrence of the situation. As a result, a yearly probable value of non quality is obtained by adding all these costs.

To calculate the volume of unsupplied energy on HV networks, planners do not use load curves, but load monotones. They obtain the mathematical probability of the time during which the demanded consumption will be greater than the nominal capacity of the network. This nominal capacity, called guaranteed power $P_G$, represents the load that can be supplied without having constraints on the network. Assuming the guaranteed capacity of the network to be constant over the year, the mathematical probability for non-delivered energy is calculated as shown below.



where V is the volume of non-delivered energy considering that the deficiency situation has occurred.
Let p be the probability rating awarded to the deficiency situation considered, then the yearly probable amount of unsupplied energy is proportional to $p \times V$.

**Medium voltage**

The method previously defined for networks studies without dispersed generation involved a single yearly calculation taking into account every possible N-1 lines situation. The consumption level is calculated for an average peak day, much more probable than the low probability used in the constraints detection phase. The presence of dispersed generation can bring the need to make the calculation over three periods -peak time, mid-season and summer- as described in the previous section. Moreover, it creates new network situations varying with the availability or unavailability of each generation plant. For each of these situations, N-1 lines, N-k generators, the corresponding probability is calculated and is taken into account if it exceeds $10^{-4}$.

Since the raw estimation of the results for every time/availability situation can increase the calculation time by several orders of magnitude, some heuristics have been developed to keep computation reasonable. Moreover, a first pair of calculations, using the two extreme generation situations, in which the generators can be either all available or all unavailable, gives an estimation of the influence of dispersed generation on the possible emergency cases. This step enables the planner to chose between simply keeping an estimated result, and going on exploring all the possible situations.

## GENERATION COSTS

For safety and operation reasons, insulated generation, i.e. supply of a part of the network which is disconnected from the general network, has been forbidden. Moreover, HV and MV planning methods do not allow any temporary overload of lines and cables. In this context, it is therefore not possible to start a generation plant to decrease a constraint after a fault occurred, since an overload means instantaneous disconnection of the concerned network element.

Two ways to use generation in emergency situation remain. The curative mode consists in starting generators after a fault has occurred, to improve the re-supply capacity of the system. On the opposite, the preventive mode relies on a continuous operation of generators to increase the guaranteed power as long as the mere network is unable to keep it at a sufficient level. It is clear that the curative mode does not bring any improvement in the number of power cuts. Yet, it allows to reduce the unsupplied energy after the start-up time of the generator. The preventive solution, which leads to the same quality of supply than a network reinforcement, is likely not to be economically interesting since the additional generation costs are high and not balanced by the local profits on non-delivered energy, except in the case of short yearly duration of operation.

In curative mode, the average yearly duration of generation for a plant is extremely limited, up to a few hours. It is thus possible to neglect the difference between locally generated energy and energy supplied from a higher voltage level.

In preventive mode, including the use of dispersed generation to solve "N" constraints, the duration of operation can reach much higher values, up to several hundreds hours. The difference between the cost of locally and centrally generated energy must be integrated in this case.

## GENERATION SCALING

Dispersed generation can appear in some situations as a solution to network limitations. As a matter of fact, strategies based on generators that can be started up as a function of local network requirements (for example in case of a line unavailability) can be proposed by the network manager as an alternative to network reinforcement. In that case, both curative and preventive modes must be studied.

The main point of a solution based on dispersed generation is to set the power of the unit that is economically justified. In a given year, a generator is profitable if the benefit it provides is greater than its investment annuity. In practice, for a generator used in the curative mode, the benefit is equal to the cost of the avoided non distributed energy from which the annual fixed operating charges are subtracted. To determine the optimal number of generators to build in a given year, the units are progressively added, until the first generator that is no longer justified is found. At this point the process stops (and thus the last unit is not added).

There is a major difference between network reinforcements and dispersed generation setting. As a matter of fact, in the first case, it is not possible to "divide" the investment in order to make it fit exactly the consumption. Thus the construction of a new line often solves the constraint for a long time.
Considering dispersed generation, it is possible to follow exactly the consumption evolution since the units can have small sizes. As a consequence, the constraint comes back rapidly and makes it necessary to do more investments. This is shown on the following diagrams (the dotted lines represent the dates where the equipment, either a new line or new generation units, is put into operation) .

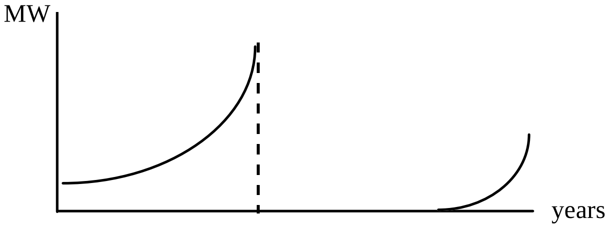



Fig.1. Evolution of non-distributed energy for a network reinforcement

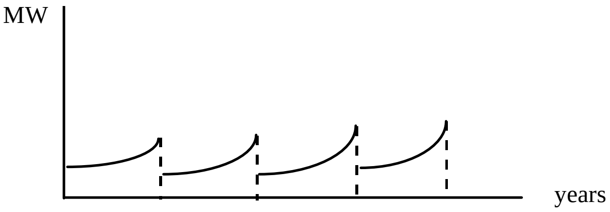



Fig.2. Evolution of non-distributed energy in a dispersed generation strategy

## SYNTHESIS AND DECISION MAKING PROCESS

Assuming that several feasible solutions have been found, that solve every detected constraint, a choice remains to determine which solution provides the best efficiency-cost ration, and when it has to be carried out.

To select the most optimal solution, the present value of each strtegy is calculated. It includes, for a reasonable time period (typically 20-30 years), the discounted value of each elementary investment, technical losses, faults shadow costs, and generation costs. On the last year, the usage value of each investment is deducted, to integrate the remaining lifetime of each equipment. Le least present value strategy is selected, provided its present value is lower than the one of the "do nothing" strategy.

Finally, the optimal investment date is determined through the calculation of the benefit-cost ratio of the most suitable strategy for each year until the value exceeds the discount rate. This precise year is the optimal date to carry out the decided investment.

## REAL CASE APPLICATION

This paragraph presents an actual implementation of the method described previously. This case has been treated by a working group co-ordinated by the French Ministry of Industry. The aim is to compare the cost of a solution based on network reinforcement and the cost of a strategy considering only dispersed generators to solve the constraints.

The network configuration is a dead-end HV/MV substation. When the HV line is unavailable, the whole consumption cannot be supplied until operations are made on the MV network. These operations allow to recover part of the load. Two main strategies can be determined to increase the amount of power that can be recovered: either building a second line or adding groups next to the substation. The "network" strategy does not depend a lot on the load growth rate, since once the line has been decided its capacity is sufficient until the end of the study. So no more investments are required. On the contrary, the "generation" strategy is strongly dependent on the load growth rate: the more the loads increase, the more groups are needed (and the more often too). Thus it is useful to consider two patterns in terms of growth rate, a high one and a low one.

Moreover environmental pressures may prevent the line from being build. In that case, the network strategy will be based on an underground cable, which leads to a more expensive cost.

In the table below, the results of the study are presented. Rather than giving the cost of each strategy (which would not be of any help for further studies), the table states which solution is the most interesting one regarding its balance.

| Load growth<br>Type of network | Low | High |
|---|---|---|
| Overhead line | ≈ | Network |
| Underground cable | Generation | ≈ |

The sign ≈ means that both network and generation strategies are economically interesting; their costs are almost the same and the difference between them is not significant (accuracy of the data).

## CONCLUSION

The growing development of dispersed generation means is pushed by a global deregulation context, the increasing concerns with environmental impact of network development, and the great adaptability of these equipment, both in terms of scalability and building delays. They are thus likely to play an important part in the development of electrical systems in the next decades.

Ensuring an optimal investment is a major issue for a power system operator. In this purpose, a global cost estimation must be carried out, taking dispersed generation into account, both in its positive and negative effects on the network. The present methods were aimed at extending the existing decision making process, thus ensuring a fair comparison with every existing study. Therefore, they can be adapted to different contexts where backwards compatibility is required.
These methods were designed to integrate big and average scale conventional generation plants. The foreseeable

development of small generation, below 100 kWe, as well as alternate power sources like wind generation, call for further development and extension of these principles to the low voltage networks.

The present methods were designed in a temporary context as far as the relationship between the distributor, generators and transmission network operator are concerned. The emergence of a new situation is likely to change a significant part of the above mentioned calculations, but the main principles of global, equitable optimisation will remain.

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