INVESTIGATION OF NEW DISTRIBUTION GRID ARCHITECTURE FOR ACCOMODATING HIGHER DG PENETRATION RATE

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ABSTRACT

Environment considerations combined to regulatory incentives and the opening of the energy markets has fostered the development of distributed generator (DG) in particular renewable ones. However, given the present operating modes and grid structures, a massive introduction of DG could deeply modify the behaviour of distribution networks. The two strategies used in France by the Distribution System Operator to anticipate the problems caused by DG are either reinforcement of the network or a dedicated feeder. The first strategy is acceptable as far as a marginal rate of DG is considered but could become too expensive in presence of a large amount of DG. The dedicated feeders strategy (direct connection of DGs to the HV/MV substation) could face a problem of local constraints. Inspired by the meshed operation of transmission network, a better way to integrate those generating units could be achieved through adding loops in the distribution network at appropriate locations.

In order to compare the current architecture and operation mode with a meshed structure for better enabling more DG penetration, a stochastic algorithm based on Monte Carlo method was developed. This method was tested successfully on several networks which are parts of real urban and rural ones.

INTRODUCTION

Distributed Generations (called DGs) are small production units (under 12 MW in France) connected to the distribution network. They can be renewable resources (such as wind or solar energy) or coming from fossil fuels energy (such as diesel group).

The global concern regarding the $C0_2$ emissions and the will of demand control lead to the 3x20 law [1]. The objective is to increase the penetration of DG by 20%, to reduce the CO_2 emissions and the consumption by 20% until 2020. Then, the distributed generations which are still marginal will increase in the next years. Nevertheless, the connection of DG can raise many impacts on the distribution network [1]. Those impacts are summarized in Table 1.

To face those problems, the French distribution system operator has two possible solutions: reinforcement or dedicated feeders. The reinforcement consists in replacing the over-constrained conductors by conductors with higher gauges. The dedicated feeder consists in connecting the DG directly after the transformer of the HV/MV substation. If the power of the DG is higher than 6 MW, the dedicated feeder is automatically chosen.

Table 1 : Possible impacts of connecting DG into the distribution network

Impacts on electrical values	- increase on the voltage profile, - bidirectional power flows, - voltage quality (flicker, harmonics…).
Impacts on planning	- modification of the planning procedure (investments, maintenance…).
Impacts on operation	- blindness of protective relays, - inappropriate trip of protective relays,

If the amount of DGs becomes too high, it may be possible that a big part of the distribution network has to be reinforced. This is economically inconceivable. Other solutions have to be found to help the distribution network to accept more and more DGs. This paper explores one possible solution: changing the operation rule of the network by introducing loops. First, a Monte Carlo approach is proposed to evaluate the ability of a network to accommodate DGs. Then, it will be applied on three different urban networks and the method of reinforcement and meshing will be compared.

EVALUATION OF THE MAXIMAL DG PENETRATION RATE

Definition

The ability of a given network to facilitate the penetration of DG can be described by the maximal DG insertion rate. This rate is the maximal power of DG that can be connected to the distribution network without violating the technical constraints. The remaining power to supply is provided by the transmission network. This rate is the ratio of the maximal power of DG ($P_{max\ DG}$) by the global power consumed (P_c) in a given network. The maximal DG insertion rate (in %) is given by formula (1).

$$\tau_{max} = \frac{P_{max DG}}{P_C} \times 100 \qquad (1)$$

Hypothesis

Assuming hypothesis on the power and the location of DG would be too daring because of the high uncertainties.

Then, in order to exhaustively evaluate this rate, all the possible types of DG and location would have to be tested. Distribution network have often thousands of nodes (MV/LV substations) per HV/MV substation. It would be time consuming to compute the maximal DG insertion rate with the previous method. A statistical approach such as Monte Carlo seems to suit well to solve this combinatorial problem. This method has already been used to compute security indexes in electrical network. Even if the computation time remains high, it enables to better model complex systems compared with analytic methods [2].

Monte Carlo algorithm to evaluate the maximal DG insertion rate

The Monte Carlo method

The Monte Carlo method is a numerical method that consists in repeating a given number of random samplings in order to compute a deterministic value. The example of the computation of a curve area can illustrate the Monte Carlo method [3]. Considering f defined by formula (2), the integral of f corresponds to the surface under the curve of the function f.

Figure 1 illustrates the given example.

$$f : [a,b] \rightarrow [0,h] \qquad x \mapsto f(x) \tag{2}$$

This surface is described as:

$$I_f : \{(x,y) : a \le x \le b, 0 \le y \le f(x)\} \tag{3}$$

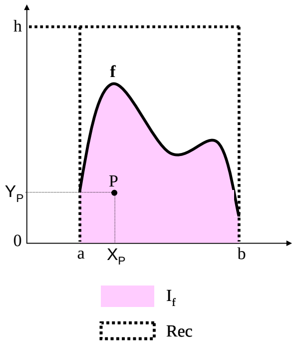
A rectangle is defined as :

$$Rec : \{(x,y) : a \le x \le b, 0 \le y \le h\} \tag{4}$$

The surface of the rectangle is:

$$A_{rec} = c \times (b - a) \tag{5}$$

Figure 1 : Computation of an integral using the Monte Carlo method



n points (X,Y) located in Rec are randomly generated following a uniform law in [a,b] for x and in [0;h] for y. For a given sample, a success is obtained if the generated point P is in I_f (ie $Y_P \le f(X_P)$). $n_{success}$ is the number of successes obtained for n samples. The probability that a generated point is in I_f is defined by:

$$p = \frac{n_{success}}{n} \tag{6}$$

When n goes to the infinity, this probability becomes:

$$p = \frac{I_f}{A_{rec}} \tag{7}$$

Then,

$$I_f = \frac{n_{success}}{n} \text{ x } A_{rec}. \tag{8}$$

If the number of generated points is high enough, the value of the integral I_f can be evaluated with a quite good precision.

Application for the maximal DG insertion rate

Considering a network of m nodes (HV/MV substations), the different parameters are defined by:

- $T = \{T_1, \ldots, T_m\}$ = nodes of the studied network
- P = global power consumed in the network (MW)
- P_{DG} = global power of DG connected to the network (MW)
- τ = DG insertion rate in the network (%)
- P_{min} et P_{max} = Minimal and maximal power of a DG unit.

There are many possible nominal powers for DG (from some watts for solar cells to several MW for wind farms for example). The algorithm is described in Figure 2. For each DG insertion rate τ, n iterations are computed. Each iteration consists in randomly generating the number of DGs, the power (in the interval [P_{min} ; P_{max}]) and the location of DG following a uniform law. A *loadflow* [4] is then computed. It takes into account the presence of tap-changer transformers located at the HV/MV substation. This *loadflow* enables to check:

- the voltage profile (the voltage at each node has to remain in the admissible limits (+/- 5% of the nominal voltage),
- The current in each elements of the network (the current in the lines and transformers has to be under the maximal allowed current),
- The power losses in the network.

If all the constraints are respected, then a success is obtained and is memorized in a binary form (1). In the other case, a failure is memorized as 0.

When the Monte Carlo simulation ends, for each DG insertion rate, the number of successes has been memorized.

The probability of success if given by:

$$p(\tau_i) = \frac{N_S(\tau_i)}{N_E(\tau_i)} \tag{9}$$

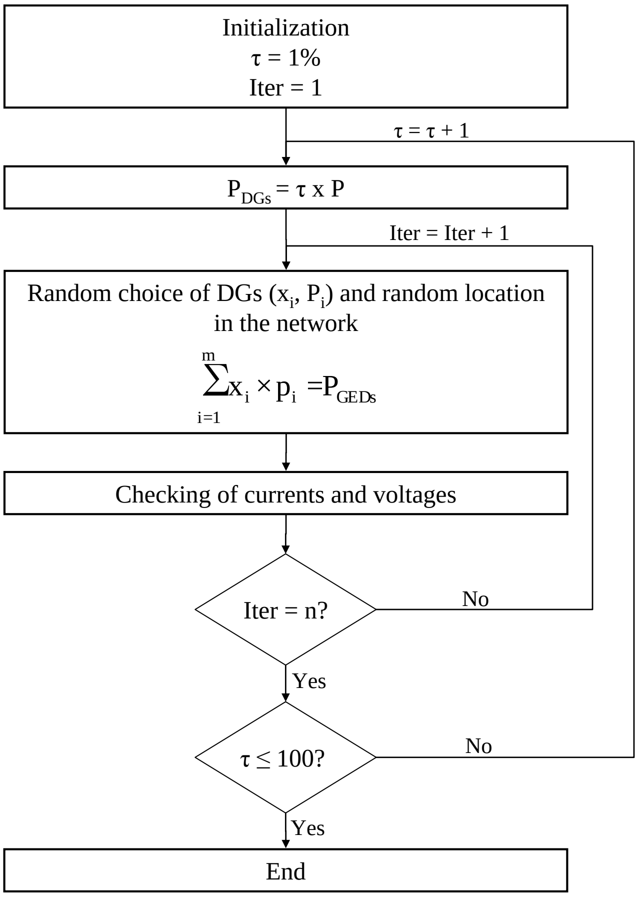
With :

- $N_S(\tau_i)$: Number of successes for τ_i% of DG insertion rate in the network,
- $N_E(\tau_i)$: Number of samples for τ_i% of DG insertion

rate in the network.
For example, for 40% of DG insertion rate, the Monte Carlo simulation gives 437 successes and 63 failures for 500 samples. Then the probability of success for a DG insertion rate of 40% is:

$$p(40\%) = \frac{437}{500} = 0.874 \qquad (10)$$

Figure 2 : Monte Carlo algorithm

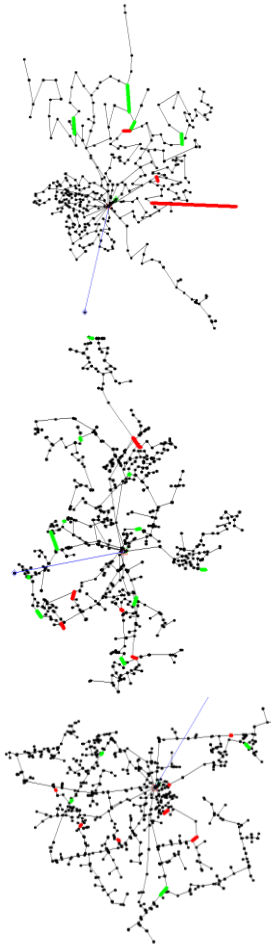


APPLICATION ON REAL NETWORKS

Studied Network

The Monte Carlo Method has been applied on three urban networks which are part from real networks. Figure 3 gives an illustration of each network and their electrical characteristics.
For each rate of DG, the number of simulations done is equal to the number of nodes of the network considered [5]. The maximal DG insertion rates for each network are summarized in Table 2. Network #1 has a better rate than the two other networks which rate are similar. Indeed, the global load of the network #1 is higher but the number of loads is lower. The conductors are more over-sized in network #1 than in the two other.

Figure 3 : Studied networks



Network #1
- 1 substation
- 3 HV/MV transformers
- 419 loads
- P_C = 62 MW
- Power losses = 444 kW
- Density of power per nodes = 0,15 MW/node

Network #2
- 1 substation
- 3 HV/MV transformers
- 696 loads
- P_C = 44.96 MW
- Power losses = 877 MW
- Density of power per nodes = 0,05 MW/node

Network #3
- 1 substation
- 3 HV/MV transformers
- 794 loads
- P_C = 34.9 MW
- Power losses = 668 MW
- Density of power per nodes = 0,05 MW/node

Table 2 : Maximal DG insertion rates

Network #1	Network #2	Network #3
25%	13%	19%

Then, the constraints are more rapidly reached in the two other networks. Indeed, the studied networks are urban networks. The constraint that is the first reached is on the current in the conductors.
The method currently used by the network operators is the reinforcement.

Reinforcement

During the Monte Carlo simulation, if the issue of a given simulation is a failure, then the over-constrained lines are memorized. At the end of the simulations, the lines are ordered following the number of times they were over-constrained. In the example of the Network #1, the over-constrained lines are depicted in Figure 4.
Once the over-constrained lines are identified, some of them are reinforced regarding the possible investment. The conductor chosen to reinforce the network is in aluminium and has a gauge of 240 mm². The total length of conductors added is 6.2 km.

Figure 4 : Over-constrained lines of Network #1

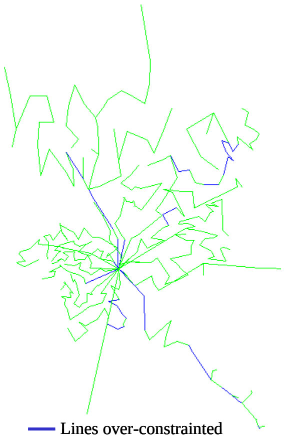


Table 3 : Maximal DG insertion rates

Network #1	Network #2	Network #3
34%	14%	20%

This method enables to increase the maximal DG insertion rate in the network. The amount of DG in the distribution network is still marginal. But if it increases, the reinforcement could be too expensive so other techniques have to be found to reduce costs.
The transmission network is meshed so the power flow can be well balanced. This operation way could be transposed to the distribution system.

Meshing

In order to compare the meshing technique with the reinforcement, the same length of conductor as the length of conductor reinforced in the previous case will be added. The automatic technique used to chose the location of the line is the following:
Step 1: Identification of nodes which degree value is 1 (nodes which have only one neighbour).
Step 2: The nodes which are the closest of over-constrained line are linked too by too. Figure 5 illustrated the lines added in the case of the network #1.

Table 4 : Maximal DG insertion rates

Network #1	Network #2	Network #3
39%	14%	21%

For the network #1, with the same investment the benefit of meshing is 5%. For the network #2 and 3, the benefit is null or very little. Those three different cases can lead too several conclusions:

- The meshing solution is very interesting for high density of power per node (3 times higher).
- For low density of power per node, the benefit is null but the advantages of the meshing is the presence of redundant paths which may improve reliability.

Figure 5 : Lines added for the network #1

CONCLUSION

A Monte Carlo approach has been used to evaluate the maximal amount of DG that can be connected to the distribution network without violating the technical constraints. By the way, the efficiency of meshing the network has been underlined thanks to the Monte Carlo algorithm. In some case, it can prove to be better for the DG penetration for a same cost than the classical rule (reinforcement).
Nevertheless, the protection aspect has not been studied here. It is necessary to check that the current protection scheme would not be disturbed by the meshing operation (increase of short-circuit current). Some solutions exist such as current limiters which cost has to be evaluated in order to properly compare the reinforcement and the meshing solution.

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