LOSSES ASSESSMENT ON DISTRIBUTION NETWORKS IN PRESENCE OF DISPERSED GENERATION

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ABSTRACT

The present paper faces with the issues related to the energy losses occurring in distribution grids with large amounts of dispersed generation. In detail, the study aims to evaluate the performances achieved by assessing losses through approximated (deterministic) approaches. The losses estimations are compared to the results given by more complex (stochastic) techniques. With this purpose, a Monte Carlo algorithm, able to properly represent the randomness of dispersed generation spreading in distribution systems and its impact on network losses, has been developed.

INTRODUCTION

The increasing amount of Dispersed Generation (DG) in distribution systems has several benefits (such as a reduction of the greenhouse gas emissions, an improved exploitation of renewable energy sources, etc.), nevertheless it introduces also some drawbacks for the operation of electric networks, which must be properly addressed in order to avoid deteriorating power quality, reliability and supply efficiency [1].
The rising of network losses is one of the main consequences of strong DG penetrations. The relationship between DG power injections and losses is difficult to assess because of the wide set of parameters affecting the energy flows on the grid, such as DG location, generators injection profiles and load consumption profiles [2].
In the present paper, a Monte Carlo (MC) approach is used to properly represent the DG spreading in distribution systems. Each of the variables characterising the DG is defined by appropriate probabilistic distributions and assessed consistently with the Italian technical and regulatory framework.
The losses evaluated through the MC algorithm are compared to the estimations made through deterministic approaches.
In detail, two different indexes are investigated. The first assumes all the DG power concentrated in the same bus of the network (nodal approach) and requires to repeat the losses calculation for a given number of network busses. The second index provides to share equally the DG power among the busses of the grid and the losses assessment is accomplished by only one computation.
The study is motivated by the relative simplicity of deterministic techniques if compared to more complex stochastic methods; so that these approximated approaches could be the preferred choice for a DSO needing to assess the grid losses for operational/planning purposes.
All the analysis reported in the paper are carried out on the model of a real MV distribution grid; the time frame consists of a whole year, simulated on an hourly basis.

THE LOSSES EVALUATION TECHNIQUES

In the present section, the different methods proposed to assess the energy lost in distribution networks are depicted. As already mentioned, different approaches have been evaluated:

- a stochastic method based on the MC theory;
- two deterministic approaches providing to aggregate or to share the DG among the grid busses.

The stochastic approach

In order to assess the electrical losses affecting a MV distribution grid in the presence of DG, the proposed MC algorithm defines a large number of DG scenarios (typically about 2000) where the losses are assessed.
DG configurations, correspondent to real life scenarios, are defined on the basis of the actual DG spreading observed in Italian distribution systems. The MC procedure assigns to each power plant a size, typology and location on the grid. Appropriate generation and absorption profiles are applied to the DG units and to the final users. Finally, classical load flow procedures are implemented in order to calculate the electrical losses occurring in a year (the analyses are detailed as often as every hour).
The MC algorithm follows the steps described in the following.
Through a stochastic roulette-wheel, one-by-one, each power plant is initially defined and characterised using its typology. Referring to the Italian national generation sharing among the various production technologies [3] [4], and removing the technologies not suitable for the specific network under study (mainly because of geographical location), the following DG spreading (in terms of number of power plants) is achieved:

- Combined Heat and Power (CHP) 1.09%;
- Photovoltaic 96.48%;
- Run-of-the-river Hydroelectric 2.42%.

Depending on the production technology selected by the first roulette-wheel, a second extraction process defines the DG power category of the plant. Each type of DG has a specific probability distribution. After the selection of the class in which the DG unit power falls, the effective size of the plant is randomly determined within the limits of the power category previously selected.

The presence of DG with a size greater than 3 MW along MV feeders is not considered, according to Italian regulations. Power plants above this size are directly connected to the primary substation MV busbars [5].
Finally, a last MC roulette-wheel defines the DG connection point to the grid. According to the Italian standards [5], the power plants with a rated power equal to, or greater than, 100 kW can be connected only at the MV level. Plants with a power lower than 100 kW can be connected to both MV and LV buses.
The DG extraction process within a given scenario continues until the sum of the generators power reaches the desired value (all DG configurations share the same total DG rated power but not necessarily the same number of generators, varying from a few units, up to 200-300 units). The scenario creation ends when a specific convergence criterion [7] is satisfied.

The deterministic approaches

Two deterministic (approximated) methods are proposed for the losses estimation.
The first approach assesses the DG impact on losses in a number of scenarios equal to (or lower than) the number of busses of the network (or of the feeder) under analysis. In each scenario the overall DG power is assumed to be installed in only one bus of the grid (nodal approach). A flat injection profile is applied to the DG, with a number of equivalent yearly hours of production, h_{eq}, equal to 5000.
This algorithm gives typically conservative results (as confirmed by numerical analysis), overestimating the amount of losses occurring in the grid. Concentrating DG generation in only one bus, DG production does not reduce the energy flows (and thus the losses) in most of network. Moreover, power flows reversals can originate along the single impacted feeder, resulting in an increase of network losses.
An alternative method for the losses assessment provides to equally share the overall DG power among a given number of network (or feeder) busses (i.e. among all the load busses). Analogously to the previous approach, also in this case, the DG is assumed to produce energy during the year at constant power (h_{eq}=5000).
Contrary to the nodal approach, the results obtained applying this second method usually underestimate the DG impact on network losses, being the generation injections distributed over all the network.
An advantage of this technique is the very low computational effort required for its implementation: while with the MC method the losses calculation is necessary in a wide set of scenarios, reduced but not negligible in the nodal approach, in this case the number of DG configurations to take into account results very small (one for each value of DG power).

THE DISTRIBUTION NETWORK MODEL

To provide accurate evaluations, the losses analyses have been conducted on the model of a real distribution network. The grid under study has a radial structure, starting from a HV/MV primary substation equipped with two 10 MVA transformers, and covers an urban area.
Only the MV level is represented: the LV loads are introduced in the model as equivalent power exchanges at the MV/LV interfaces.
For the sake of simplicity, this paper will refer to only one feeder of the network (feeder 2 of Figure 1; peak value of yearly exchange profiles equal to 5.49 MW).

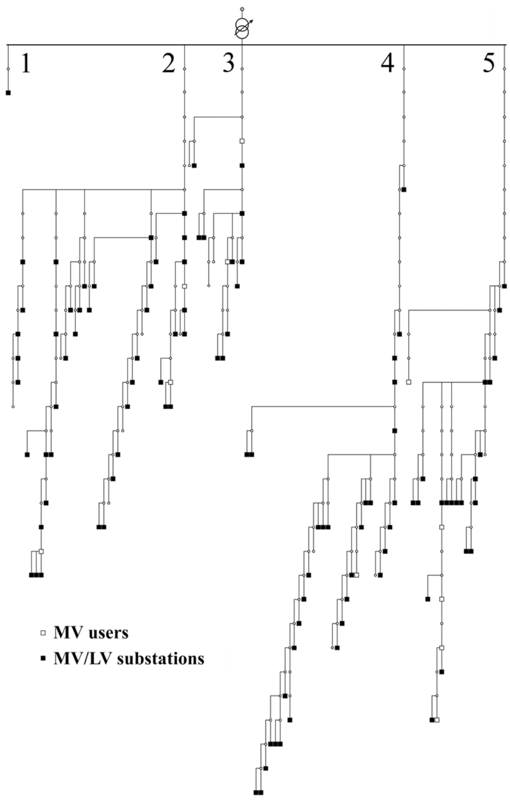

Figure 1. The MV network model adopted.

All the energy flows in the grid are represented on an hourly basis over a whole year (8760 hours).
The loads are classified in two different categories, MV users and MV/LV substations, and are supposed absorbing energy with a power factor equal to 0.9 lagging. All users belonging to the same category are assigned the same absorption profile obtained from the yearly characteristic of the overall Italian national load.
Similarly, each typology of DG is characterised by a specific injection profile with a unitary power factor.
In particular, the generation profile of the photovoltaic resources is obtained from data of solar irradiance registered by sensing satellites, on an hourly basis for five years (1995-1999) [6].

The power injections of run-of-the-river hydroelectric power plants have been defined as the monthly average production of the hydroelectric units already connected to the network under analysis (historical data).
Finally, the CHP production is supposed to be driven by the heating demand: high in peak hours (production at the rated power) and low in middle/off peak bands (80% of the rated power in the middle peak band and null in the remaining hours).

NUMERICAL ANALYSIS

The performances of the proposed indexes are assessed on the model of the real distribution network depicted at the previous paragraph. As already mentioned, in order to simplify the discussion, only the energy lost in one distribution feeder will be considered; anyway the approach, and the results, can be extended to more feeders or also to the whole grid.

The stochastic approach

As first step of the analysis, the electrical losses occurring in the considered MV feeder in all the MC scenarios have been assessed. Because of the hourly basis of the energy profiles, the evaluation for each MC scenario required 8760 load flow calculations (one for each hour of the year).
The analysis involves scenarios with different DG amounts and, in particular, with an overall DG rated power equal to 0.5, 1, 2, 3, 4, 5, 6 and 7 MW. Each set of configurations includes a different number of cases (up to 3000) depending on the convergence criterion.
In the literature [8], the relationship between losses and DG injections is commonly cited as being a U-shape, because a limited amount of DG usually causes a reduction in the network losses, but increasing DG causes reverse power flows on the feeder, from the final users up to the primary substation, and network losses progressively increase as a consequence.
The MC approach allows for a correct evaluation on the impact of different DG penetration levels on network losses. In particular, in Figure 2, the variation of the energy yearly lost in the network w.r.t. the losses occurring without DG (passive scenario) is reported.
It's possible to observe that, for low DG penetrations, a loss reduction is nearly always achieved. When DG is equal to or lower than 1 MW, there is a loss reduction in 100% of the cases. With 5 MW (i.e., approximately the 91.1% of the peak value of the feeder exchange profile at the MV busbars), the percentage drops to 94.8%. The percentage remains quite high even in the presence of a strong DG penetration. With an overall DG amount equal to 7 MW, there is a loss reduction in 87.2% of the cases.

Moreover, the graph of Figure 2 highlights that increasing DG causes a greater variability in the resulting annual losses. With a power equal to 0.5 MW, the loss variation is always comprised between -5% and -15%. With a power equal to 5 MW the losses change between -75% and +167% (only 0.3% of cases report energy losses greater than +100% of variation), while, with 7 MW, the losses variation is included between -70.2% and 269.9% (1.9% of cases depict losses more than double of the base case).
The results generally confirm (and quantify) that small amounts of DG typically cause a reduction in losses. If DG penetration increases, losses also increase; losses can be even higher than without DG. However, for this general behaviour many exceptions could be identified due to DG size, technology, connection point, and so forth.

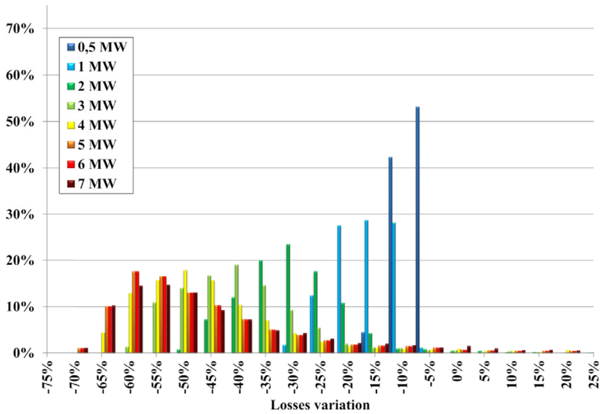

Figure 2. Losses variation probability in the MC scenarios (losses in percentage w.r.t. the feeder losses without DG).

The deterministic approaches

In Figure 3 we report the variation of network losses (w.r.t. the passive scenario) according to the overall DG power connected to the grid.
The black and blue bars indicate the losses assessed over the database of MC scenarios: the black bars are the maximum and minimum values observed on the set of scenarios, while the ticks on blue bars show the 5th and 95th percentiles and the losses mean values.
The red U-shape characteristics indicate the losses estimated by the nodal approach. According to the MC analysis, also in this case the energy losses are assessed for DG amounts equal to 0.5, 1, 2, 3, 4, 5, 6 and 7 MW. The losses trends are reported as continuous curves through interpolation.
The green curve shows the losses variation estimated sharing the overall DG power among all the load busses of the feeder under analysis.
The results obtained are consistent with the ones calculated with the MC approach, see Figure 2.

For low DG penetrations there is a losses reduction; increasing DG some scenarios report efficiency reductions, nevertheless in most cases the losses decrease (the losses mean value is always lower than the energy lost without DG). The spreading of the samples for great DG penetrations is caused by the presence of larger power plants. Considering the losses strictly dependent on the DG connection point to the grid, the cases with DG connected far from the primary substation show higher losses.

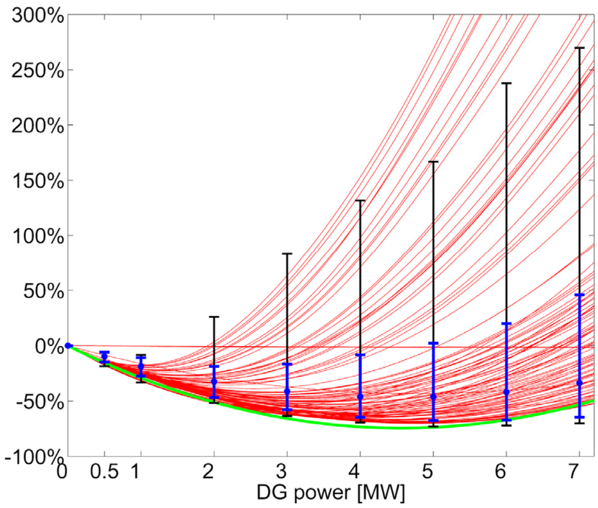

Figure 3. Comparison among the losses estimations of the various approaches under study (losses variation in percentage w.r.t. the feeder losses without DG).

The characteristics of the nodal approach show a wider variability w.r.t. the MC index, strictly dependant from the DG connection bus. This fact is less significant for low DG amounts and increases when the generation rated power rises.
One can observe that the losses in some network busses are quite constant when the DG increases (red horizontal lines approximately equal to zero). These busses are the ones nearest to the MV busbars. On the contrary, in other cases, the losses are strongly dependant on the DG power: the losses trend changes rapidly as DG increases (with a DG power equal to 7 MW, in the worst case, the losses reach the 1942% of the energy lost without DG).
Despite the nodal approach could seem, at a first glance, a bad indicator of the losses occurring on distribution grids, most of the losses values assessed by this method are consistent with the MC index. Considering the worst case, a DG power equal to 7 MW, the 68.0% of nodal results are included between the 5^{th} and 95^{th} percentiles of the MC set.
Finally, sharing DG among all the load busses of the network, losses estimations comparable to the best scenarios of both the MC method and the nodal approach have been obtained. Such a result is compliant with the assumption introduced.

CONCLUSION

In this paper, the performances of two deterministic indexes in the assessment of the energy losses occurring in distribution networks with DG have been evaluated. The interest in these indicators is motivated by their simplicity and by the limited computational effort required for their assessment. Through these indexes, a DSO could detect the DG configurations that decrease system efficiency.
The accuracy of the proposed methods has been tested through a stochastic model developed ad hoc; moreover, in order to correctly evaluate the approaches, a real life distribution network model has been introduced.
The analysis showed a good performance of the deterministic methods in the losses assessment. Despite the adoption of the nodal approach could, in some cases, introduce a losses overestimation, most of the results is compliant with the predictions of the MC algorithm.
Finally, sharing DG among all the network busses is a very simple and effective technique to identify the network losses obtainable in the best DG configuration.

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