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Dispersed generation impact on distribution network losses

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ABSTRACT

Distribution systems are subject to increasing penetration of dispersed generation. The energy injections of the generators impact on many technical issues, including energy losses occurring in the grid. Given the technical and economic importance of losses, several statistical approaches are proposed in the literature to evaluate the effects of dispersed generation on the energy lost in distribution networks. In principle, these approaches require a great number of load flow calculations. This paper provides a novel index aiming to avoid complex and computationally expensive statistical analysis for loss assessment. Such an index does not require any detailed characterisation of the energy flows over the network (load flow calculations). The performance of the index is tested using a model of a real medium voltage network in a wide set of generation scenarios. Each scenario is defined by a Monte Carlo algorithm that was developed ad hoc for this study. Moreover, advanced convergence criteria are provided to optimise the number of scenarios to process.

1. Introduction

Climate issues, energy saving requirements and general energy needs are the impetus driving national governments to offer incentives to the large-scale deployment of Renewable Energy Sources (RES). This energy policy has significantly increased the amount of dispersed generation (DG) over the past decade and has resulted in several benefits, such as a reduction of the greenhouse gas emissions. However, DG diffusion has important consequences for the operation of electrical networks, which must be properly addressed in order to avoid deteriorating power quality, reliability and supply efficiency [1].

One of the previously mentioned consequences is the increase of network losses in the presence of a strong DG penetration. The relationship between DG power injections and network losses is difficult to assess because of the wide set of parameters that affect energy flows on the grid, such as the DG location, the generators injection profiles and load consumption profiles. Many statistical approaches are proposed in the literature to evaluate DG effects on network losses, and most of them aim to define the optimal DG location and sizing [2,3].

Because of the existing regulations on network connection (in Italy [4,5]), the Distribution System Operator (DSO) must accept all the requests for DG connections forwarded by the users. In this scenario, the DG siting, sizing and technology are not dependent on the DSO, and consequently, the approaches usually proposed in the literature (i.e., optimisations) [6,7] are not applicable.

However, the knowledge of DG impact on losses is cardinal in order to select the structural improvements to implement in distribution grids (planning purposes). Additionally, the losses evaluation on wide networks databases (very critical because of the number of load flow procedures to perform) is essential to estimate effectively the average losses behaviour on distribution systems at a national level (standard coefficients for economical losses repayment; general regulatory purposes) [8].

In the literature, one of the critical issues is the simulation of a multi-generator scenario (i.e., the DG siting on the network); accordingly, simplified hypothesis are typically adopted (e.g. DG location and network structure not investigated [9], only one generation technology taken into account [10], only one feeder considered [11]).

Because of the poor performance of the classical indices for the loss assessment (DG rated power, DG energy injections, reverse power flow time), in the present paper, a novel index is proposed that does not require a detailed characterisation of the energy flows over the network (i.e., it does not require the knowledge of the injection/load profile of each user for at least one year) or load flow calculations (i.e., the computational effort can be managed with a simple spread sheet). Consequently, this index is able to avoid complex and computationally expensive statistical approaches to DSOs when evaluating the impact of DG on network losses.

The performances of this indicator are tested with respect to the actual losses occurring on a real distribution grid (load flow calculations). The analysis involved over 24,000 network scenarios generated by a Monte Carlo (MC) approach. Each scenario was

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characterised by its unique DG distribution where the losses are assessed by load flow calculations over a whole year.

The MC algorithm is developed to represent properly the randomness of DG spreading in distribution systems. Each of the variables characterising the DG is defined by appropriate probabilistic distributions and assessed consistently with the Italian national framework. The generation scenarios defined through the MC algorithm are used to test the performance of some indices in the loss assessment.

The paper is organised as follows: first, the traditional and novel indices for the loss estimation are presented; then, the MC approach utilised to evaluate the indices performances through comparison is depicted; it is used to build the database of operating conditions for the network under study; with this database, the impact of DG on network losses is evaluated and the performances of the losses estimation indices are investigated; finally conclusions are provided.

2. The losses indicators

The assessment of DG impact on network losses is a particularly critical issue. In fact, the accurate evaluation of such an impact is typically difficult, because the analysis usually requires to take into account the grid topology and the time dependency of energy flows.

The complexity of the analysis limits its applicability to a small number of networks and DG configurations: this makes the losses evaluation for planning/regulatory purposes impossible (owing to the computational effort required for a generalised application). In this situation, because of the high number of scenarios to assess, the only way to estimate losses is to use simplified methods, based on the observation of losses indicators.

The simplest losses indicator which can be used for this purpose is the total rated power of the DG plants connected to the distribution network (in absolute value and in percentage w.r.t. the peak value of the exchanged profiles at the HV/MV interface in the passive scenario).

An alternative index is the amount of energy produced by DG units over a whole year, which is easy to evaluate almost as the DG overall rated power. On the one hand, such index gives more information about the energy losses; on the other hand, it needs a proper characterisation of the various generation technologies with the relevant annual production.

In the past few years, the need for indices able to assess DG impact on the Quality of Service in distribution networks has risen. The goal is to identify the DG threshold beyond which the network control, protection and automation systems require updating (introducing the solutions proposed by the so-called smart grids paradigm [12]).

Recently, to this purpose, some Italian regulations assumed the yearly hours of RPF (reverse power flow time, RPFT) to be a suitable indicator. The national standard CEI 0-16 [13] states that, when the RPFT at the HV/MV interface is greater than 5% over the year, the protection and control devices equipping the primary substation have to be revised. In fact, it is necessary to adopt protection and control systems that are able to operate with an "active" grid.

Similarly, Resolution ARG/elt 39/10 [14], which provides incentives for the implementation of smart grid projects in the national distribution grid, establishes that smart grid developments are incentivised only if the network feeders present an RPFT at their point of connection to the primary substation, equal to, or greater than, 1%.

The relevance of the RPFT index in the Italian regulation for DG impact assessment motivates an interest in its performance also in losses estimation.

2.1. The novel indicator proposed

Although the indices reported in the literature and in the national resolutions typically provide important information about the trend of losses as a function of DG penetration, none of these indices is able to estimate effectively the losses occurring in a distribution system in the presence of DG (these indices present an excessive dispersion in cases with large DG amounts, see Section 6). This limitation is mainly attributable to the inability of the selected losses indicators to consider the DG localisation within the network, which is a parameter that affects the path followed by the energy produced by power plants and, consequently, the losses occurring in the various branches of the network.

To obviate this lack of information and to provide an improved assessment of the energy flows in the grid (taking into account the compensation between load and DG), the following novel loss indicator is proposed:

$$E_l = E_{0tr} + \sum_{i=1}^{n^\circ Br}\left[r_i \cdot \sum_{k=1}^{n^\circ Ty}(kc \cdot P_{hours,k,i})^2(h_k - h_{k-1})\right] \quad (1)$$

In Eq. (1):

- E_l represents the energy losses estimated by the proposed indicator [$p.u.$];
- E_{0tr} is the total yearly no-load losses of the HV/MV transformer [$p.u.$];
- r_i is the series resistance of each branch of the network ($n^\circ Br$ is the overall number of branches) [$p.u.$];
- kc is a simultaneity coefficient, between 0.8 and 1;
- h_k and h_{k-1} are the equivalent yearly hours of production at the maximum power, referring to the kth and $k-1$th technology of generation or load profile ($h_0 = 0$, technologies ordered according to increasing h_{eq}, $n^\circ Ty$ overall number of DG and load typologies).

The element $P_{hours,k}$ is the difference between the power injections and withdrawals of the active and passive users downstream of the ith branch of the network, for the kth equivalent time interval [$p.u.$]. It is equal to:

$$P_{hours,k,i} = \sum_{n=1}^{n^\circ DG} P_{DG,n} - \sum_{n=1}^{n^\circ Lo} P_{load,n} \quad (2)$$

where

- $P_{DG,n}$ is the rated power of each DG plant downstream of the ith branch of the network with h_{eq} equal to, or greater than h_k ($n^\circ DG$ is the total number of power plants downstream of the ith branch with a number of equivalent hours equal to, or greater than h_k) [$p.u.$];
- $P_{load,n}$ is the conventional power of each supply point downstream of the ith branch of the network with h_{eq} equal to, or greater than h_k ($n^\circ Lo$ is the total number of supply points downstream of the ith branch with h_{eq} equal to, or greater than h_k) [$p.u.$].

Eq. (1) is equivalent to applying a cumulative exchange profile to each power plant and load in the network. As additional simplifying assumption, the exchanges are supposed concentrated in the peak hours. These hypotheses are motivated by the following two aspects:

- the lack of knowledge usually concerning the actual DG/load injection/withdrawal profiles during the year;