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Risk aversion model of distribution network planning rules considering distributed generation curtailment☆

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ABSTRACT

In the coming years, the massive deployment of distributed generation connected to the distribution network may increase the required investments in the network components to prevent voltage and current violations. Generation curtailment may make it possible to defer such investments and to increase the capacity of the distribution network to accommodate new generators. Currently, investment decisions only consider classical upgrade solutions such as the reinforcement of existing assets or the creation of new ones. The valorization of generation curtailment and its integration with the planning method are a major challenge, mainly because of the high level of uncertainties. This paper focuses on the problem of reverse power flows at an HV/MV substation, which may occasionally be larger than its nominal power. We propose a stochastic algorithm, based on real generation and load profiles, to create a decision investment abacus for the Distribution System Operator (DSO). This abacus enables the DSO to simply make a trade-off between an upgrade of the HV/MV substation by adding a transformer and generation curtailment with the associated risk. We also discuss the main terms of the curtailment contract between the stakeholders and their expected efficiency in minimizing the global cost.

1. Introduction

1.1. Context

THE distribution network (DN) has traditionally been designed to guarantee an adequate quality of supply through efficient investments. Infrastructure costs are largely driven by two effects: the need for the grid to be able to operate during the most critical, but plausible, situations (i.e. the level of security of supply must be high) and the long lifetime of the grid equipment, which implies long-term strategic planning. As grid investments come at a significant cost, short-sighted investment decisions are likely to cause redundant expenses such as upgrading a part of the DN twice in a short period (typically a few years) [1]. Both of these effects cause the capacity of the equipment to be significantly larger than its mean usage.

As more and more distributed generators (DGs) are connected to the DN, the nature and the frequency of occurrence of these critical situations are changing: in some parts of the distribution grid, peak power flows and significant voltage variations may be caused by high generation rather than high load. The risk of breaching an electrical constraint is strongly related to the nature, number, and capacity of connected generators and loads and whether their production is likely to be synchronized [2]. Several studies have demonstrated that reactive and active power management of DG outputs could allow these constraints to be efficiently removed, thereby avoiding the need for investments [3,4]. This raises the question of the value of the flexibility associated with generation. One challenge is that the amount of curtailment required in the future is highly uncertain due to unpredictable weather conditions (short-term unpredictability) and the arrival of future producers (medium-term uncertainty). Thus, agreements should be flexible enough to cope with future needs without putting the stakeholders at risk financially.

1.2. Related work

In recent years, many papers in the literature have studied the option of curtailing generation in order to increase the penetration of DGs connected to the DN.

Some papers study different regulation models of distributed generation curtailment. For example, [5] performs a thorough literature review and deep comparisons between different principles of access. In [6], the authors also study the impact of various access rules on the

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penetration of DGs. In [7], a method is proposed to find the operating margins of an active power flow management, that is, the last secure operating point over which a constraint would appear in the DN. Three types of generation contracts are studied (firm, non-firm, and regulated non-firm). Other papers focus on the actual functioning of the distributed generation curtailment, which is associated, in some cases, with other advanced in management functions. For instance, [8] proposes a regional active management system to maintain the network within its technical limits and to provide a restoration procedure in case of faults. The procedure and performance are explained using a case study and time series measurements, but the long term value is not assessed. Finally, other studies focus on the integration of distributed generation curtailment in the DN planning. First, in [9], the authors integrate both curtailment and reactive control into an optimal power flow (OPF) and compare the cost with the reinforcement cost. Ref. [10] uses Benders' decomposition method to minimize the global cost (investment and energy curtailed). It focuses on the economic model (energy price, cost of curtailment deployment) for the case of wind power.

In all these studies, the uncertainties of distributed generation and consumption are generally not modelled. Authors who do discuss them generally do not provide any metric; however, to quantify the variability of the costs, only mean values are computed. Finally, in [11], which is the closest work to ours, the authors compare two regulations on the DN investments. The uncertainties of load and generation are dealt with using random trials of a modelled probability distribution function (pdf) for generation and load, based on real measurements. An OPF is used on a particular test case of the connection of two wind farms. Although this procedure is handled well, it does not simulate the dynamic of the producers' connection, which could impact the DSO's final decision. In this case too, no risk metric is used. Consequently, in the literature, many works underline the economic potential of integrating distributed generation curtailment into grid operation, but the decision-making process of a producer dealing with curtailment uncertainty is usually not developed.

1.3. Contribution of the paper

To our knowledge, there is no paper in the literature that focuses on proposing a planning process for the DSO to find a trade-off between curtailment and reinforcement while computing the risk associated with a decision. This paper proposes a stochastic algorithm that builds a decision investment abacus that enables the DSO to decide between reinforcement and curtailment of an HV/MV substation. The decision to concentrate the study on an HV/MV substation is explained in Section 2.2.

The major contributions of this paper are as follows:

- It provides a dynamic planning tool that is able to model the investment decision of the DSO in the presence of a scenario of increasing DG connections over several years,
- It takes into account uncertainties in distributed generation and load profiles, depending on their types, and using two alternative methods: random draws (the method usually used in the literature) and a realistic probabilistic model of load and generation that we devised using real-world data from 4200-MV generators and load curves with a step time of 10 min over two years (these data were provided by the major French DSO, ENEDIS),
- It proposes a risk-aversion model associated with an investment decision for both the DSO and the producers,
- It is easily understandable by the planning crews and easily implementable in the DSO software.

1.4. Plan of the paper

The paper is organized as follows: In Section 2, we explain the existing method of planning the connection of the DGs and discuss one possible way to integrate distributed generation curtailment. Then, Section 3 details the methodology used to integrate curtailment in the planning method in practice, highlighting the way in which uncertainties are modelled and taken into account. Several criteria to evaluate the cost decision between curtailment and reinforcement with risk aversion are also detailed. In Section 4, the proposed algorithm is applied to two realistic studied cases built by ENEDIS. Finally, Section 5 provides the main conclusions as well as some perspectives to improve the model.

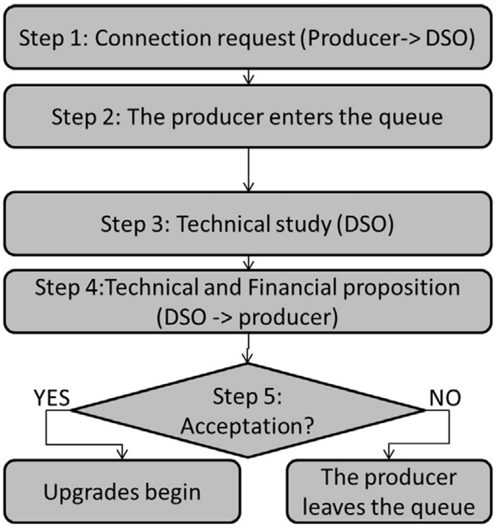

Fig. 1. Traditional planning rules for the DG's connection.

2. Integration of distributed generation curtailment into the traditional planning procedure

2.1. Traditional planning rules for the connection of DGs and their evolution

In France, the connection of a DG to the distribution network requires the five steps depicted in Fig. 1. In Step 1, the generator sends a request to the DSO, specifying its capacity. Then the generator enters a first-in-first-out queue (Step 2). In Step 3, the DSO carries out a technical study by considering producers one by one in the order in which they appear in the queue. If the connection of the generator creates technical constraints in the network, the DSO defines the upgrades that are required and their associated cost. These upgrades consist in the creation of new assets in the DN and their reinforcement. The technical constraints that are studied by the DSO are:

– The violation of the maximum acceptable current of each device and conductor of the grid,
– The voltage profile within the boundaries of ± 10% of the nominal value,
– The non-detectability of short circuit current in the grid.

In Step 4, the DSO sends the producer a technical and financial proposal that contains the details of the share paid by the DSO and the share paid by the producer. The producer has to pay for almost all the upgrades of the distribution network except for those of the HV/MV substations and transmission grid, whose costs are shared with the DSO. Finally, in Step 5, the producer may either accept the technical and financial proposal or withdraw from the process (and consequently leave the queue).

In this system of "fit-and-forget" connection of generators, as soon as the grid-hosting capacity is reached, the next producer has to pay high investment costs to be connected; this threshold effect limits the