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Probabilistic siting and sizing of energy storage systems in distribution power systems based on the islanding feature

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ABSTRACT

Distributed storage systems embedded in distribution power systems could complement renewable generation and improve their operation, reducing peak power levels and providing supply support to island zones in the cases of outages. This paper proposes a multi-objective optimisation, which takes advantage of the possibility of operating in an island mode. The optimisation considers the siting and sizing of storage systems placed on power distribution systems with radial topology. The objectives to be minimised are: the amount of energy storage, power losses and expected energy not supplied (EENS). Loads and generators are uncertainty variables, and a probabilistic power flow based on the point estimate method helps with assessing the electrical parameters.

The optimisation uses the IEEE-34 and IEEE-123 test feeders. The Monte Carlo simulation benchmarks some results. The final results show that storage systems could reduce the peaks of power required from the central network and improve other electrical parameters. In addition, those systems with higher interruption probabilities or those working near their operation limits could benefit from storage systems.

This point of view is different from other authors'. Here, storage energy systems and the island mode of operation are defined by a probabilistic point of view. The siting and sizing of storage energy systems is decided from data obtained on the probabilistic power flow and the universal generating function.

1. Introduction

Distributed generation is growing more common with power distribution systems, especially those involving renewable sources, due to its benefits related to clean energy features and the possibility of energy independence for countries or customers who use it. Renewable generators allow distribution systems to reduce the power requirements placed on the central power system, thus decreasing power losses in transmission and distribution networks. Consequently, researchers developed methods for assessing the reliability of power distribution networks involving renewable energy sources [1,3].

Reliability could be improved through the operation of these generators when some failure in the network occurs. One method that several authors [2,4,7] have suggested is creating zones with generators, also called microgrids, that provide the necessary energy for the operation of some or all loads in them. These microgrids can be temporarily isolated from the network while continuing to feed the loads.

However, due to the uncertainty of power generated by renewable generators, the introduction of storage systems [5,6] in distribution networks is important for supporting renewable generators and island zones, making networks more reliable and reducing EENS. Storage systems could furthermore improve other electrical parameters placed on distribution networks; for example, they could help with peak shaving and voltage variability.

Some authors who manage the possibility of operating networks with an intentional isolated mode evaluate the reliability with different methods. The generation and load are modelled as a Markov process [2], and the authors calculate the reliability indices of the distribution network operated in an island mode. Other authors use Sequential Monte Carlo (SMC), in Ref. [3], to evaluate the reliability of a distribution generation system with the possibility of intentional isolation, or of a power distribution system with renewable distributed generation, energy storage and intentional islanding possibility [4–7]. Ref. [8] tested the adequacy of a distribution system with solar and wind generation, considering two operation modes, isolated and connected to the network, and two methodologies, SMC and analytical.

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Nomenclature

Acronym

BSU	Balance storage use
CDF	Cumulative distribution function
EENS	Expected energy not supplied
FOR	Forced Outage Rated
MPSI	Maximum power at the system input
MSS	Multi-state system
NSGA	Non-dominated sorting genetic algorithm
PDF	Probability density function
PEM	Point estimate method
PPF	Probabilistic power flow
PVSI	Power variation at system input
SMC	Sequential Monte Carlo
TLL	Thermal limits of the lines
UGF	Universal generating function
VLB	Voltage limit on buses
VUB	Voltage unbalanced on buses

Only a few authors treat the problem of the siting and sizing of the storage systems in the network with the island mode. The optimal mix and placement of storage systems for distribution networks focussing on optimising reliability cost, load priorities, and intentional isolation zones is described in Ref. [9], but authors use a deterministic power flow model, neglecting power losses, and consider an outage of a specific length.

Other authors optimise the siting and/or sizing of the storage systems in the classical distribution network to improve the reliability or the operation of the network, but they do not consider the isolated mode of operation. Some [10] apply the optimal allocation of batteries to store the surplus power that wind generators produce, using chronological series for wind velocities and load curve. Others [11] minimise the storage power and energy amount, the deviation of the voltage limit and the losses of rewards due to supplementary services and market exchange. In Ref. [12], the authors reused the optimisation model developed in Ref. [11] but added a voltage regulation parameter, power peak reduction and annual cost as objectives.

This paper develops a probabilistic model to optimise the siting and sizing of storage systems in distribution networks with renewable generators and islanding operation. The probabilistic model uses the point estimate method to evaluate the power flow, as well as the universal generating function to evaluate the EENS.

The rest of the paper is organised as follows. Section 2 describes the formulation of the problem. Section 3 introduces methodologies and tools for the estimation of objectives and indicators, the evaluation of the reliability index considering islanding, and the optimisation process. Section 4 presents the study cases and results. Finally, Section 5 presents the conclusions.

2. Problem formulation

2.1. Description

This model is based on two hypotheses: the elements of the network can be represented by their probabilistic distribution functions, or PDFs, and the network can operate in the island mode. In the following, the consequences of these hypotheses are explained.

Loads and generators are modelled with their respective PDFs, and therefore, a probabilistic power flow (PPF) is necessary. Due to the radial operation of the distribution networks, a Backward–Forward Sweep method is used. In it, we have in each node k that the injected power to node k, $P_{in,k}$, is equal to the generated power, $P_{gen,k}$, the demanded power, $P_{load,k}$, and the summation of the power that leaves node k to others m, $P_{k,m}$.

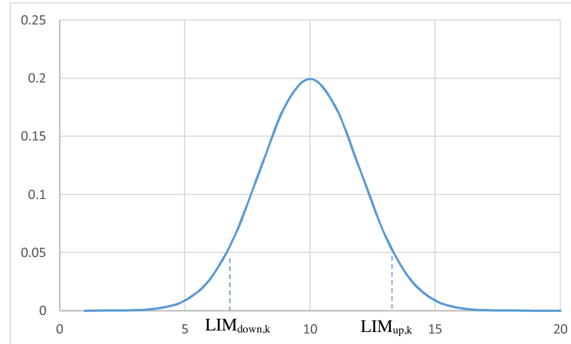

Fig. 1. Operational strategy of storage system in ‘peak saving’ mode.

$$P_{in,k} = -P_{gen,k} + P_{load,k} + \sum_{m=1}^{nk} P_{k,m}, \quad (1)$$

where $P_{gen,k}$, $P_{load,k}$, $P_{k,m}$ and $P_{in,k}$ are PDFs, and where nk are the nodes connected to node k.

If we introduce a storage system, $P_{sto,k}$ is the PDF of the power injected or consumed by the storage system, and Eq. (1) is converted to Eq. (2):

$$P_{in,k} = -P_{gen,k} + P_{load,k} + \sum_{m=1}^{nk} P_{k,m} + P_{sto,k}. \quad (2)$$

The strategy of the operation of a storage system determines its influence on the uncertainty of the node. If we want to reduce this uncertainty, then the storage connects in the node have to charge when the power is less than power $\mathrm{LIM_{down,k}}$, and they have to discharge when the power is greater than power $\mathrm{LIM_{up,k}}$ as shown in Fig. 1. This working mode is called ‘peak saving’:

$$\mathrm{LIM_{down,k}} = \mathrm{P_{in,k}(p_{down})} \text{ and } \mathrm{LIM_{up,k}} = \mathrm{P_{in,k}(p_{up})}, \quad (3)$$

where $\mathrm{p_{down}}$ and $\mathrm{p_{up}}$ are the percentiles defined by the operator of the network.

As a consequence of hypothesis 2 (the network can operate in the island mode), the distribution grid has several switches that divide the grid into zones. Depending on the positions of these switches (connect or disconnect), some zones are islanded or tighter with others, and this provides a number of possible island combinations created inside the distribution network that have different probabilities of being isolated from the main grid. The four switches integrated in the network of Fig. 2 permit 16 different states of the network that have their own probabilities.

2.2. Optimisation model

This work involves developing a multi-objective probabilistic optimisation for the siting and sizing of storage energy systems in distribution electrical networks with distributed renewable generators, considering support for the island operation mode.

We prefer to conduct a multiobjective analysis and to compare technical variables, as a comparison of costs could hide the technical conclusions. The cost of the storage devices depends on the chosen technology, but the objective of the installation cost is proportional to the capacity of the storage devices. The cost of the EENS is not the same for all of the consumptions. If we introduce the cost of the storage, we also need to introduce the cost of the losses and the EENS to compare different solutions.