Investigation of the Use of Batteries for Voltage Regulation in Distribution Systems with Deep Penetration of Photovoltaic Generation

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Abstract
Several benefits are associated with the use of energy storage systems in electric power distribution networks, such as batteries, which one can use to solve voltage regulation problems in power distribution systems with deep penetration of photovoltaic solar generators. In general, these problems are associated with the intermittence of solar energy and can limit the hosting capacity of distribution networks to photovoltaic generators, which have clear advantages from an environmental point of view. In this context, this research proposes to investigate the use of batteries to solve the main problems resulting from the increase in penetration levels of photovoltaic generators in electric power distribution systems: (a) long-term (steady-state) voltage regulation; and (b) short-term voltage regulation. These studies rely on time-series load flow simulations to evaluate the performance of solutions based on batteries' active power support. Furthermore, a battery degradation analysis is provided to show the behavior of the total capacity loss during the time providing these services.

Key words:

Introduction
Often the peak power generated by photovoltaic generators (PVs) does not coincide with the peak consumption. Thus, in systems with deep penetration of PVs, there may be a violation of the limit of voltage imposed by regulatory agencies. Besides, problems caused by cloud transients in photovoltaic solar generation can occur. Therefore, battery systems can be an interesting solution, because it can supply enough energy to reduce or even eliminate voltage variations (ΔVs) and control the voltage on steady state. Additionally, batteries have multiple important applications in distribution systems, as peak shaving and energy backup. Although high cost and technological challenges have been obstacles for spreading the use of batteries, currently these barriers are expected to be overcome. In 2015, for example, the City Group elected energy storage systems as one of the ten key-technology investments. This group also estimates that the batteries global market will correspond to $400 billion in 2030. In this context, this work presents an analysis of a deep penetration of PVs with batteries in a real distribution network. The software OpenDSS is used for the proposed analyses. Furthermore, a battery degradation analysis is provided.

Results and Discussion
The real distribution network used in the simulations has 47 distribution transformers, 1675 buses, and 1818 loads. On the substation, the short-circuit level is 500 MVA and this network does not have any distributed generator. Firstly, batteries are used to keep the voltage within its limits and to shave the load peak (Image 1) and, secondly, to mitigate the fast variation of the voltage (Image 2). All these analyses are made on a bus located at the end of the feeder. Ramp-control is made to reduce the problem with cloud transients. Thus, when a variation greater than 5% of the PV output power is detected, the battery acts reducing this variation. In this case, Image 2 shows, for a day with intermittence, a comparison between the number of ΔV greater than 0.5% on voltage magnitude in intervals of 15 minutes when a battery is or is not used to control the output of the PV. Moreover, a battery degradation analysis is performed and the results show that the battery lasts 3 years if used to perform both services: long-term and short-term voltage regulation.

Conclusions
This work presents the use of batteries as a solution to increase PVs penetration and improve the quality of the energy delivered to the customers. Due to the high cost associated with it, a battery degradation analysis is performed in order to verify the viability of the technology.

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