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Long-term sizing of lead–acid batteries in order to reduce technical losses on distribution networks: A distributed generation approach

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ABSTRACT

The increase in the consumption of electric energy and its reflexes have brought new problems and challenges to engineering. One of such problems is the understanding of the effects that occur on electric energy distribution networks with distributed generation (DG), mainly with photovoltaic (PV) cells. Due to the nature of this type of system and the consumer demand profile connected at the distribution network, increases in technical losses are usually detected. In this scenario, the use of energy storage systems (ESS) is highlighted, which sets as one of its objectives the reduction of such losses. In this sense, this article proposes the sizing of the capacity of ESS, using the lead–acid type battery, for the reduction in technical losses in distribution networks with high PV penetration. In order to verify the proposed method, simulations and analyses are performed taking into account the State of Charge (SoC), the Depth of Discharge (DoD), the State of Health (SoH), and the energy consumed over the total life span of the ESS. One short-term and two long-term (for 5 and 10 years) sizing were made. In comparison with the short-term sizing, it is projected a loss reduction of 33% more for the 5 years long-term sizing, with an investment reduction of 14% at the end of the third short-time sized batteries change. For the 10 years long-term size, a 50% greater loss reduction is projected, in comparison to that over the short-term sizing, along the battery life span, with an investment reduction of 11% from the first battery acquisition.

1. Introduction

With the advance of technologies that surround distributed generation (DG), there is a noted increase in the growth of electric energy production using PV panels. Brazil as well as other parts of the world show a constant and structured growth of DG together with the increasing access to such technologies. Along with consumer access, the so-called photovoltaic penetration has also developed considerably over recent years. This fact in turn has brought up new problems and challenges to electric energy distribution networks. Among such problems, one can cite the combination between the active power generated by renewable sources and the demand of consumers.

The moment that the excess of electric energy generated by micro-generators can be sold to electric energy distribution utilities, at particular periods of the day an imbalance of electric energy is identified between that generated by the consumer and that used by the same consumer in their systems.

As an example, the period of the day (sunny hours) that has the highest level of PV generation can be analysed.

If only the workdays of the week are considered, then such period is characterized by a low power demand from the residential consumers. This is explained since most people leave their homes to go to work and only some equipment (such as refrigerators) are left switched on and all other equipment (such as lightning and TV) is kept switched off or on stand-by.

This means that there will be an excess of PV energy being produced. The consumer usually injects the unused portion into the distribution network. Hence, for distribution systems with high PV penetration, or a high rate of clients subscribing to this type of DG, elevated levels of voltage on the network can be detected due to low demand request on the part of the consumer [1].

The inverse situation occurs during the period of the day the consumers are at home after returning from work. Taking into account

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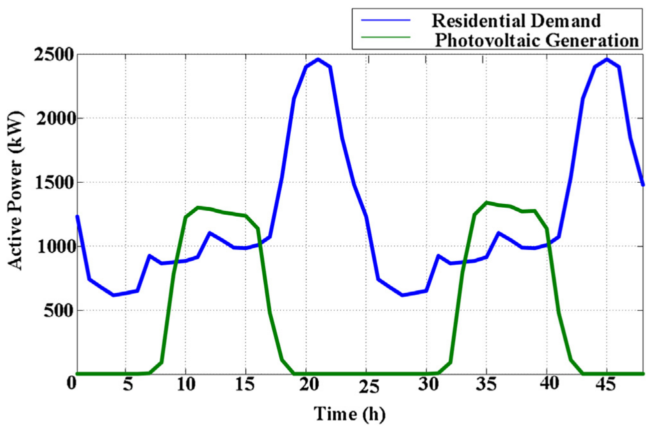

Fig. 1. Power demand versus photovoltaic generation.

the period between 17:00 h and 20:00 h (called the peak hours), when the solar irradiation starts to decline, it can be observed an increase in the power demand together with low generation from the PV panels. The profile of active power demand from residential consumers can be obtained in Ref. [2] and is shown in Fig. 1.

Another aspect that can be evaluated concerning PV generation is its intermittent nature. In other words, there is only available energy if there is sun irradiation. When the weather becomes cloudy, the supply is reduced, due to the decrease in solar irradiation on the PV panels, which can lead to undervoltage on the system onto which they are connected [1]. Another feature that needs to be taken into consideration is the operational temperature of the PV cell [3]. Therefore, for each previously specified period it is interesting that the same supply of energy is always maintained, since overvoltage and undervoltage are not desirable and its sensibility is directly linked to supply and consumption of electric energy from the consumers.

An increase in PV penetration leads to a decrease in the power flow from the main grid which results in a voltage level rise. When the PV generation is at its peak (at sunny hours), the residential power demand is usually at the lowest level. Thus, the PV energy is more than enough to attend the residential loads. This fact causes the distribution power flow to be reversed, from DG to main grid. The voltage profile will normally rise at the consumer bus with PV generation. Despite of reverse flow, there will be active power losses due to electrical current circulation. Otherwise, when there is no PV generation (at evening periods), the residential power demand is in its peak. Thus, the power flow is only from the main distribution grid. The distribution line currents will be high leading to a lower voltage profile and higher power losses [4,5].

Considering that in the next 20–30 years every type of sustainable energy should be based on rational use from traditional sources and greater use of renewable sources [6], one concludes that the development of techniques for the control of operational levels of distribution systems will be necessary.

One of the manners in which this can be currently performed is through the use of energy storage devices, thus facilitating the control of variables present at the insertion of DG.

Units for ESS use the electric energy conversion process of a power system to create an energy form that can be stored [7]. According to Ref. [8], there exists a number of applications of energy storage, among which the following can be highlighted:

- Control of voltage on demand peaks through load sharing, performed by use of electric energy storage over short periods of time, this results in positive aspects when it comes to voltage levels,
- Reduction in temporary outages,
- Frequency regulation in isolated systems,
- Reduction in losses on the system by increasing energy efficiency,
- Reduction of long duration outages when large electric energy storage systems is present.

The concept of ESS used in half of the means of transport have also been studied over recent years.

The Southeastern Pennsylvania Transportation Authority (SEPTA) has as one of its investment projects the integration of this technology with emergent technologies of smart grids into their electric train transit infrastructure. When these trains brake, their electric motors produce energy [9]. Different to hybrid vehicles (which use fuel and electricity), the trains are not designed with ESS. Without the capacity for storage, the energy generated when the train brakes can only be used if another train is accelerating in the same area. Putting it another way, the generated energy is usually wasted and being dissipated on the resistor banks that exist on the upper part of electric trains.

By installing banks of ESS units in parallel with traditional systems, SEPTA can use part of the DC energy generated. The device can store the energy originated from the electric train motors and make it available to the electric power system when necessary. It is estimated that this initiative returns more than U$250,000.00 per year in benefits to SEPTA [9].

The types of energy storage used on distribution networks, along with their constructive and operational features can be seen in Refs. [10–12].

Due to the simplicity of acquisition, installation and maintenance, as well as the advantage of low cost, the sizing and operation analyses here conducted are performed with lead–acid batteries which aim to reduce the technical losses on non-isolated electric energy distribution networks. The acquisition cost for this type of battery, according to the active power (kW) and electric energy (kWh) it provides, can be seen in Refs. [7,13].

2. Motivation and background

The role performed by the lead–acid batteries has been the object of interest of many researchers around the world. In Ref. [14], the author had already pointed to many applications for this type of energy storage, as well as its use in the reduction of active power peaks in electric energy distribution networks. In Ref. [15], a proposal for sizing is made based on the approach of the chemical kinetics of lead–acid batteries, in the attempt to overcome difficulties associated with already existing methods at the time of its publication. The method proposed by Manwell and Mcgowan, under the title of KBM (Kinetic Battery Model), has been widely used, as seen in the studies of Refs. [16] and [17]. However, the sizing of the capacity of ESS follows, essentially, the same process. In Ref. [18], a proposal is made for a sizing method for the minimum storage capacity required, by the yet to be installed ESS, across a number of locations on a low voltage network, considering high PV penetration. The researchers Ammar and Joós [19] propose a short-term sizing for supercapacitors energy storage, with the objective of improving the quality of voltage on a system with distributed wind generation. In Ref. [20], simulations were performed in order to analyse the reduction in technical losses on distribution networks with the addition of ESS. The authors in Ref. [21] offer an optimal ESS sizing method, taking into consideration the localization where they should be installed, along with the demand and DG encountered on the system under study. In Nazaripouya et al. [22], the authors also propose the allocation and optimal sizing for the battery type for ESS, with the aim of voltage regulation on an IEEE 14-bus system, under the pretext of PV penetration. Methods