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Review

Optimal scheduling for distribution network with redox flow battery storage

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ABSTRACT

There are many advantages to utilize storages in electric power system. Peak shaving, load leveling, load frequency control, integration of renewable, energy trading and spinning reserve are the most important of them. Batteries, especially redox flow batteries, are one of the appropriate storages for utilization in distribution network. This paper presents a novel, heuristic and practical method for optimal scheduling in distribution network with flow battery storage. This heuristic method is more suitable for scheduling and operation of distribution networks which require installation of storages. Peak shaving and load leveling is considered as the main objective in this paper. Several indices are presented in this paper for determine the place of storages and also scheduling for optimal use of energy in them. Simulations of this paper are based on real information of distribution network substation that located in Semnan, Iran.

Contents

1. Introduction

The need for energy storage and their utilization in electric power system has long been discussed [1]. The distributed electricity generation is an appropriate option for a sustainable development [2]. Hybrid systems with energy storage such flow batteries have received considerable attention for last decades [3]. Flow batteries consist of two electrolyte tanks which the electrolytes are circulated by pumps through an electrochemical cell [4]. Some of the main advantages of flow batteries are long life, complete discharged, high power, power rating and the energy rating are decoupled and electrolytes can be replaced simply [5]. High capacity flow batteries can be like a power plant [6]. They can eliminate the need for use of expensive generation and distribution additions [7]. In a typical power system, any time that a consumer demands a power, it should be provided by network immediately. According to variable nature of loads, energy production must be a function of these variations. In demand curve, whatever the demand factor become lower, the network peak increases giving a constant amount of energy. This power peak is account as a negative parameter for power grid; because all the equipment should be promoted based on it [8]. Moreover, according to restructuring in power system, cost of energy in peak hours and cost of access to transferring systems are expensive than non-peak hours, which this issue can cause an increase in imposed costs on distribution systems. Nowadays, utilization of storages has solved this problem slightly. Consumption peak is decreased by storing the energy in non-peak hours and using it in peak hours [9]. Batteries, one of the most appropriate storage for this work [10]. In addition to peak shaving, utilization of storages in network would bring economic efficiency

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as well. Because, price of the energy in peak hours is several times more than energy price in non-peak hours [11]. Although technological evolution of some storages is not fulfilled yet and construction cost of some others is high [12], many advantages like load leveling, peak shaving, load frequency control, voltage control, integration of energy production units with uncertainty, spinning reserve and ..., which are acquired by storage, justify the utilization of them in network [13]. Peak shaving and load leveling are one of the most important subjects in electric networks [14]. This issue is more important in radial networks [15]. Now peak shaving more done with pumped storage power plants but the use of batteries is also growing [16]. Flow batteries like Vanadium Redox Flow Batteries (VRFB) are capable to store energy from 100 kW h up to 100 MW h. With this volume of energy storage, VRFB are suitable for applications like peak shaving and load leveling in distribution substations [17]. Various methods of allocation and sizing have been studied. A novel methodology is developed by Kroposki et al. [18] that sizing and placement distributed energy source on electrical feeders. Alexandre et al. [19] present a sizing methodology and optimal operating strategy for a battery energy storage system to provide a peak load shaving. Biswas et al. [20] considered the Optimum distributed generation placement with voltage sag effect minimization. Ghosh et al. [21] are presented a simple conventional iterative search technique for optimal sizing and placement. In [22] optimal allocation of energy storage in microgrid is presented. In [23] a method of locating and sizing to improve the voltage stability margin is expressed. Several models and methods have been suggested for the solution of the optimal placement problem by Georgilakis and Hatziargyriou [24]. Gözel and Hocaoglu [25] presented an analytical method for the sizing and siting of distributed generators in radial systems. Bahmani-Firouzi and Azizipanah-Abarghooee [26] propose a new evolutionary technique that is used for developing corrective strategies and to perform least cost dispatches for optimal sizing of battery energy storage. In [27], an off-grid hybrid system (PV/diesel/wind/battery) is considered, modeled and optimally sized. Fossati et al. [28] propose a genetic algorithm-based method for sizing the energy storage system in microgrids. In [29] presents a mixed-integer linear programming method to solving the problem of optimal placement in radial distribution systems. In [30] the taxonomy of the reviewed optimal placement is presented. In this paper, a new and practical method is presented for optimal placement and sizing of storage and also planning of optimal charging and discharging of redox flow battery storage for peak shaving and load leveling and earning income by energy trading. The innovation of this paper is definition of two new indices for determination of storage installation location and definition of a new index for prioritization of charging/discharging hours and storage charge/discharge rate. This paper would be more practical and could be utilized for distribution networks that intend to perform a study for storage installation and its production planning. Distribution substations of Semnan city located in Semnan state of Iran, is the under study system in this paper.

2. Peak shaving and load leveling

In power grid, the peak and its occurrence time is depended on type and behavior of consumers. Consumers usually are divided into several main groups like residential, commercial, industrial, agricultural and public. Peak shaving is removing the peak of consumption and load leveling is decreasing the difference between maximum and minimum amounts in demand curve [7,8]. Utilization of storage is one of the methods for peak shaving and load leveling. Some amount of energy could be stored in non-peak hours using storage and this amount is delivered to the network in peak hours. This work causes a decrease in network peak which can be useful for two reasons. First, existence of a peak doesn't have an economic efficiency, because all the power system equipment must be promoted according to power peak which these promoted equipment would be useless in other hours and only impose a cost to the network. Therefore, installation of storage could postpone the development of the network.

Second, consumers that are fed in peak hours should tolerate more cost and buy the energy more expensive. Accordingly, installation of storage for peak shaving and load leveling is a benefit for both producers and consumers of energy [6,9,10].

Hence, if the annual load demand increase with $\%\tau$ and the storage could reduce network peak by $\%\alpha$, the time (by year) that storage causes delay in network development is calculated by Eq. (1) [31]:

$$\Delta t = \frac{\log(1+\alpha)}{\log(1+\tau)} \tag{1}$$

3. Selection of the best substation for battery storage installation

In Iran electric power system, distribution system voltage in most places in equal to 20 KV which is transformed to 400 V in place of consumption. According to independency of substations in 63/20 KV substations, a proper planning for selection of battery installation location and planning of its charge/discharge could be performed.

The most appropriate substation for storage installation must be selected for optimal charge/discharge planning. In terms of peak shaving and load leveling indices, the best substation for storage installation is one that experiences the most variations in a period of consumption or would require capacity promotion in close future, such that the storage could reduce these variations or postpone its development. For this purpose, two indices are proposed for proper determination of installation location.

The first one is related to peak shaving and the second one is related to load leveling. It is supposed that 24 daily demand curve is available in peak day of all substations. Giving the daily demand curve in peak day, load duration curve is achieved which would be descending from maximum consumption hours to minimum consumption hours. According to various capacities of each substation and for more simplicity, consumption values of each substation are divided by maximum consumption value in that day, so that all load duration curves become per-unit.

3.1. Peak shaving indices

For this index, mean and standard deviation of per-unit load duration curve is calculated firstly. Afterward, K_{up} and H_{up} indices are defined according to load duration curve as follows:

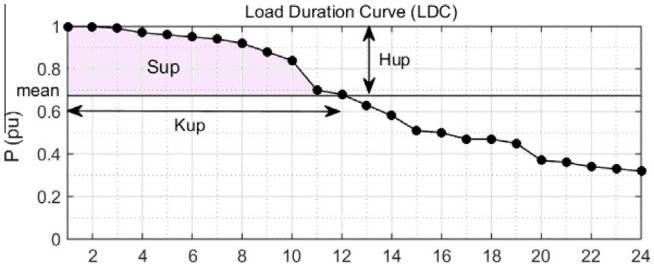

Fig. 1. Defined index for load duration curve.