Journal of Energy Storage 18 (2018) 380–388

Contents lists available at ScienceDirect

Journal of Energy Storage

journal homepage: www.elsevier.com/locate/est

Management of charging cycles for grid-connected energy storage batteries

Mohammed Jasim M. Al Essa

Faculty of Engineering, University of Kufa, P.O. Box (21), Najaf Governorate, Iraq

ARTICLE INFO

Keywords:
Battery energy storage systems
Distribution grids
Energy management
Load flow
Optimization
Voltage control

ABSTRACT

The use of renewable energy requires a certain level of energy management in electricity distribution grids. Grid-connected energy storage batteries (ESBs) can be utilized to keep this level of management by charging and discharging them accordingly. Grid-connected ESB users schedule their usage based on time-of-use tariffs to follow economic charging cycles. However, charging several grid-connected ESBs during off-peak tariff interval may cause a decline of grid voltage below its limit. Therefore, this paper suggests a management scheme to maintain voltage-sag magnitude within its threshold, while minimizing the aggregated cost of charging the grid-connected ESBs. A sequential quadratic programming technique is employed to solve the objective function, considering an IEEE test system of 37 node. According to optimization results, the management scheme reduces the operational cost of different ESB penetration in the test system, taking into consideration ESB state of charge and grid voltage.

1. Introduction

Grid-connected energy storage systems were reported in the literature [1] as emerging technologies that have an impact on revenues considering their ability of increasing demand side flexibility, while implementing scheduling algorithms in electricity grids [2]. A sustainable low-carbon electric pattern can be achieved in power grids using backup energy systems to contain intermittent renewable energy efficiently. Energy storage systems (ESSs) are able to enhance the management of power grids in order to improve efficiency and reduce cost. The de-carbonization of energy sector needs an adequate electricity market of renewables to maintain acceptable variations of voltage and frequency [3]. Fig. 1 shows different combinations of electrochemical energy storage batteries (ESBs), which were used to provide grid support in transmission and distribution power systems based on their capacity and discharging timescale [4].

Grid-integrated ESSs were presented in [5] considering their applications and services for connecting variable energy resources to distribution grids. ESSs were surveyed in [6] as a promising entity to increase the flexibility of energy sector with high penetration of renewable resources. For example, ESSs were investigated in [7] to increase the deployment of solar panels in low-voltage distribution grids using their ability of load clipping, peak shaving and energy shifting. Stationary batteries of ESSs were assessed in [8] to decrease peak demand in low voltage grids. It was concluded that the grid-integrated ESSs have the capability of providing quick and economic reserves, as compared to traditional load shifting ones [9]. A simplified algorithm was proposed in [10] to increase the revenue of grid-scale ESSs while participating in a particular reserve market.

Grid-level ESBs were discussed in [11] to investigate their impact on power management and voltage control based on field-trial results across different distribution grids. High numbers of grid-integrated renewable sources (e.g. residential solar panels) can cause voltage fluctuations. Grid-integrated ESBs were used in [12] to maintain grid voltage within its boundaries using quadratic programming of scheduling their charging cycles. Distributed control strategies were proposed in [13] to mitigate the impact of solar panels on grid voltages, considering energy storage. ESSs were presented in [14] to facilitate demand response of residential users based on electricity prices, while connecting solar panels and plug-in hybrid electric vehicles to distribution grids. It was conclude in [14] that a utility corporation has a good control on peak load with a compromised level of consumer comfort considering time-of-use tariff and real time price. An energy management scheme of charging batteries was implemented in [15] based on genetic algorithm to reduce energy costs, accommodating solar panels and plug-in electric vehicles in distribution grids. Re-chargeable batteries were studied in [16] to evaluate their impact on a distribution feeder. A quadratic convex optimization of optimal energy storage scheduling was addressed in [16] to accomplish an efficient use of solar panels and batteries, considering transformer losses and voltage variations. Energy management algorithms of valley-filling and peak-shaving methods were developed in [17] to achieve an intelligent scheduling framework of three-phase ESSs in a low-voltage distribution grid, embedding a day-ahead forecasting model.

E-mail address: mohammedj.alisa@uokufa.edu.iq.

https://doi.org/10.1016/j.est.2018.05.019
Received 23 January 2018; Received in revised form 12 May 2018; Accepted 28 May 2018
2352-152X/ © 2018 Elsevier Ltd. All rights reserved.

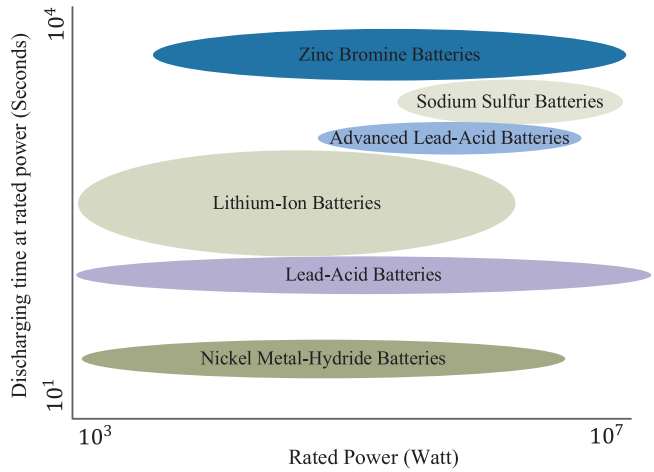

Fig. 1. Electro-chemical batteries for grid-support applications in transmission and distribution power systems based on their capacity and discharging time-scale (adapted from [4]).

In this study, the impact of re-charging ESBs on voltage sag in electricity grids is highlighted. The business as usual scenario of the residential stationary ESBs is to charge them during low-price interval of electricity. The energy stored in the ESBs is later discharged over high-price term of electricity to gain revenue. However, this scenario leads to increase demand while delivering low-priced electricity because end-user customers tend to charge their ESBs utilizing low costs. To overcome such problem, this paper proposes a management scheme of charging ESB in residential grids using first principles and optimization techniques. Distribution grids were generally classified into interconnected and radial ones, focusing on the radial systems. A linear mathematical model of load flow calculations is developed considering radial feeders, while embedding synthesized ESB loads over a day. The problem is formulated using an objective function of cost reduction, which is thereafter solved with sequential quadratic programming.

This paper is structured as follows. Load flow calculations of electricity feeders are firstly developed considering an IEEE test system of 37 node. The raw data used in studying residential load profiles are then described. The algorithmic steps of generating ESB loads are afterwards demonstrated. Problem formulation was thereafter presented while explaining the installation of the proposed management scheme in electricity grids. Simulation results, conclusion and future work are later discussed.

2. Modelling of electricity feeders, residential appliances and batteries

Equations of load flow were presented in this section to accommodate diurnal load profiles of residential appliances and grid-scale batteries into a modified IEEE test system.

2.1. Electricity feeders

Fig. 2 shows the representation of an individual feeder in radial systems, considering the impedance of loads as indicated in Eq. (1) [18].

$$Z_n(t) = \frac{v_n^2(t)}{S_n(t)} \tag{1}$$

where $Z_n(t)$ is the load impedance at the node n in ohm at time step t. $v_n(t)$ is the voltage at the node n in Volt at time step t. $S_n(t)$ is the apparent power drawn by aggregated loads at the node n in kVA.

Kirchhoff's laws of voltage and current were used to evaluate load flows of the grid under study. The voltage is calculated at the node $(n-1)$ by the following formula:

$$v_{(n-1)}(t) = v_n(t) + z_{(n-1)n} \times \frac{P_n(t)}{v_n(t)} \tag{2}$$

where $v_{(n-1)}(t)$ is the voltage at the node $(n-1)$ at the time step t. $v_n(t)$ is the voltage at the node n at the time step t. $z_{(n-1)n}$ is the impedance of the line segment between the node $(n-1)$ and the node n. $P_n(t)$ is the power drawn by aggregated loads at the node n at the time step t [18]. Eq. (3) determines loading power of the distribution transformer at each time step t.

$$P_L(t) = \sum_{k=1}^{N_F} \left(\sum_{j=1}^{N} p_j(t) \right)_k \quad \begin{pmatrix} \{j = 1, 2, 3, ...,N\} \\ \{k = 1, 2, 3, ...,N_F\} \end{pmatrix} \tag{3}$$

where $P_L(t)$ is the aggregated power of customers at the distribution transformer in kW at time step t. N_F is the number of radial feeders. N is the number of residential customers per feeder. $p_j(t)$ is the power consumed by each customers in kW for a unity power factor at time step t.

$$i_n(t) = \frac{v_n(t)}{Z_n(t)} \tag{4}$$

where $i_n(t)$ is the current drawn by the connected load at the node n in Ampere at time step t. The branch current between the two nodes $(n-1)$ and n is calculated using Kirchhoff's current law as follows.

$$i_{(n-1)n}(t) = i_{(n-2)(n-1)}(t) - i_{(n-1)}(t) \tag{5}$$

Meanwhile, the voltage is calculated by the following formula [18]:

$$v_{(n-1)}(t) = v_n(t) + z_{(n-1)n} \times i_{(n-1)n}(t) \tag{6}$$

To start load flow calculations, the voltage at the node n is assumed to be equal to the nominal voltage. Then, the voltage at the source node (v_0) is calculated by initializing the calculations using the nominal value of voltage. Afterwards, correction factor (CF) is determined using Eq. (7) [18].

$$CF = \frac{V_0}{v_0} \tag{7}$$

where V_0 is the actual value of the voltage at the source node. The results of final voltages and final currents are determined along the feeder as follows [18].

$$V_x(t) = CF \times v_x(t) \quad \{x = 1, 2, 3, ...,n\} \tag{8}$$

$$I_x(t) = CF \times i_x(t) \quad \{x = 1, 2, 3, ...,n\} \tag{9}$$

where $V_x(t)$ and $I_x(t)$ are the voltage and current evaluated in load flow calculations using Eq. (1)–(9) at each node along the radial feeder for each time step t.

2.2. The grid under study

A modified IEEE test system of 37 node was used in this paper to study the impact of charging residential ESBs. The grid was adapted from [19] considering different feeders as shown in Fig. 3. A number of distribution transformers were indicated in Fig. 3, serving a finite number of residential customers.

2.3. Residential appliances

Residential loads are modelled considering diurnal load profiles of consumer electronics, cooking appliances, lighting components, space/water heating systems, wet appliances, and other miscellaneous. Smart-plug and circuit-monitoring instrument recorded these data over 10-min time steps [20]. Fig. 4 presents these diurnal profiles on a daily basis of 10-min time steps as reported by the source of data [20].

Download English Version:

https://daneshyari.com/en/article/7539850

Download Persian Version:

https://daneshyari.com/article/7539850

Daneshyari.com