



A new approach for optimal sizing of battery energy storage system for primary frequency control of islanded Microgrid



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ABSTRACT

This paper presents a method for determining optimal size of a battery energy storage system (BESS) for primary frequency control of a Microgrid. A Microgrid is assumed to be portion of a low voltage distribution feeder including sources such as microturbine, diesel generator, fuel cell and photovoltaic system with slow response for frequency control. A BESS due to its very fast dynamic response can play an important role in restoring balance between supply and demand. In this paper, overloading capacity of the BESS is employed for fast handling of the primary frequency control of a MG. To achieve this purpose, by considering overloading characteristics and limitations of the state of charge (SOC) of battery, a control scheme of dc/ac converter for the BESS is developed. Based on this scheme, overloading capacity of the BESS and its permissible duration for participating in primary frequency control is determined. Simulation studies are carried out using PSCAD/EMTDC software package to evaluate the performance of the proposed control scheme.

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1. Introduction

Due to the increased demand for energy and environmental benefits of the renewable distributed generation (DG), DG sources such as fuel cells, wind turbine and photovoltaic arrays have a large utilization nowadays [1]. The increase in DG penetration depth and the presence of multiple DG units in electrical proximity to one another have brought about the concept of Microgrid (MG) [2,3]. A MG may consist of multiple distributed energy resources (DERs), customers, energy storage units and can be defined as a small electric power system being able to operate physically islanded or interconnected with the utility grids [4,5]. In the interconnected mode, the frequency and the voltage of the MG are controlled and maintained within a tight range by the main grid [6,7]. In the islanded mode, a MG mainly suffers from load-generation unbalance especially at the moment of disconnection and consequently its frequency may undergo rapid change due to the low inertia and small time constants of microsources present in the MG. Therefore, in the islanded mode primary frequency control is a critical issue which requires sufficient and fast reserve. A MG without adequate reserve may be under the risk of blackout [8]. Primary frequency control appears as a vital task for controlling and stabilizing MG during islanded operation [6,7,9].

For handling frequency problem of a MG, energy storage devices such as batteries, sodium–sulfur (NaS) batteries, flywheel

energy storage (FES), super-capacitor, superconducting magnetic energy storage (SMES) and finally load-shedding are the key to guarantee the frequency control and smooth transition of MG into islanded mode [10,5]. In a MG, the energy storage devices with fast response play the role of the spinning reserve in the conventional power systems for preserving the balance between supply and demand especially during islanded operation [11].

Since renewable energy resources (RES) are naturally intermittent so, an energy storage system (ESS) is required to optimize their energy utilization [12–14]. The main role of ESS in a MG is to maintain stability, facilitate integration of the renewable energy and improving power quality. Fast response ESS can effectively damp electromechanical oscillations in power systems because they can provide storage capacity in addition to the kinetic energy of generators with the ability for sharing sudden changes in power requirement [15]. In [16], a cooperative control strategy for microsources and ESS during island operation is presented in which the ESS is responsible for the primary control of frequency and voltage, while the secondary control of MG management system returns the power output of the ESS to zero.

Battery energy storage system (BESS) is composed of static elements and has a very fast dynamic response compared to typical generators or other energy storage devices [17]. Battery energy storage systems (BESS) can cover a wide spectrum of applications ranging from short-term power quality support to long-term energy management [18]. The BESS technologies with fast response is able to perform multitask functions (e.g., load leveling, peak shaving, spinning reserve, black-start capability, uninterrupted power

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supply (UPS), flicker compensation, voltage sag correction, and area regulation) with the same device [19,20]. In fact, the future of the BESS certainly lies into multitasking, where a single modular and flexible unit can do peak shaving, load leveling, frequency control, load management, and so on [18]. Even if frequency control is not the primary task of a BESS, it is still economically attractive to assign a certain battery reserve to perform this particular task [18]. In [21], a dynamic model of BESS is derived for stability study of a large-scale power system and attempting to damp torsional oscillations of turbo generator.

In recent years, several BESS have been mainly installed worldwide for load leveling and peak shaving [18]. The BESS can satisfy the technical requirements for primary frequency control by absorbing power from the grid and injecting power to the grid during high and low frequency excursions respectively with respect to the nominal set point. Additionally, since the BESS is composed only of static elements, it has a very fast dynamic response compared to typical generators or other storage devices [18,17]. The great potential of BESS for frequency regulation has been demonstrated in [19]. The effect of BESS on the load–frequency control of an isolated power system is presented in [22] by promising improvement. Concerning investment cost for battery storage technologies, determination of optimal capacity for BESS for long term energy management performance is very important. In [23], an optimization method for dimensioning BESS for primary frequency control using a control algorithm based on the fixed SOC is developed for large interconnected power systems. In [24], for primary frequency control of an isolated power system an incremental model of the BESS has been implemented into the load–frequency control with improved performance. In [18], a method for optimal sizing and operation of BESS for use as spinning reserve in a small isolated power system is presented. The methods dealt with optimal sizing of BESS for frequency control have mainly considered the nominal capacity of BESS for primary frequency control.

In this paper, concerning overloading characteristics of BESS including overloading capacity and permissible overloading duration, a new algorithm is proposed for optimal sizing of the BESS for fast participating in primary frequency control of isolated MG. In fact, compared to the long term energy management performance of BESS, primary frequency control needs fast release of a relatively little energy which can be achieved by overloading characteristic of BESS.

For this purpose a control scheme is developed to implement overloading characteristics of BESS into primary frequency control. The energy exchange of the BESS during primary frequency control is not so much to violate the limits of the state of charge (SOC). Therefore, in the proposed approach, SOC limit violation is not so critical. However, in the proposed control scheme, limitations of the SOC of the BESS is considered. By using the simple and common method of column counting, the SOC is taken into account. Implementing the overloading characteristic of the BESS into primary frequency control will provide a chance for utilizing a BESS with very small size for restoring a relatively large unbalance power in a MG.

2. Study system

Fig. 1 shows single line diagram of the MG used for simulation studies. It consists of a 0.4 kV distribution feeder connected to a 20 kV distribution network through a 400 kV A transformer. The system structure and parameters are taken from the CIGRE low voltage distribution benchmark system [9]. The total installed capacity of the microsources is 79 kW. It consists of (1) a split-shaft microturbine (MT) with voltage–power ratings of 0.4 kV and

31.1 kV A equipped with an excitation system of the type of IEEE standard AC5A, (2) a diesel generator (DE) with voltage–power ratings of 0.4 kV and 31.1 kV A equipped with excitation system of the type of IEEE standard AC1A and governor control system, (3) a solid oxide fuel cell (SOFC) of 10 kW, (4) two photovoltaic arrays rating 10 and 3 kW respectively (PV), and (5) a BESS which is dedicated for primary frequency control and its capacity is supposed to be determined for this task. The split-shaft microturbine is based on the model of GAST turbine-governor presented in [25]. The diesel generator model used in the simulation is based on the model in the PSCAD/EMTDC software package used in [26]. The SOFC model is taken from the model used in [25]. Model description for photovoltaic array can be found in [16]. The BESS consists of a battery modeled as constant dc voltage source indirectly connected to the grid through power electronic converter. The details of the BESS converter are given in the next chapters. As shown in Fig. 1, the microturbine and diesel generator are connected directly to the MG and fuel cell, photovoltaics and BESS are connected through power electronics converters. The system and all microsources are properly modeled within PSCAD/EMTDC software.

3. Frequency and voltage control of MG

In the grid-connected mode, the voltage and frequency of MG are controlled by the main grid. However, in the islanded mode, its frequency and voltage may change rapidly due to the low inertia and small time constants of microsources. For proper operation of islanded MG, developing suitable control strategy is very important in order to maintain its frequency and voltage. If multiple microsources participate in the frequency and voltage regulation, frequency-droop and voltage-droop control strategies can be used to share power among microsources.

In this paper, BESS is considered as the main regulating unit for stable operation of a MG in the islanded mode. In fact, BESS due to its very fast dynamic response performs as a spinning reserve for primary frequency control. After stabilizing frequency of MG in the initial step of the primary control, active power-sharing among dispatchable microsources (microturbine, diesel generator and SOFC) is carried out based on their droop mechanism using Eq. (1) [27,28].

$$R_1 \times \Delta P_1 = R_2 \times \Delta P_2 = \dots = cte \quad (1)$$

where ΔP_i and R_i are active power variation and regulating droop of the i th microsource, respectively. Eq. (2) governs frequency change of the MG following a disturbance.

$$\frac{df}{dt} = \frac{f_0}{2 \sum_i H_i} \left(\sum_i P_{G_i} - \sum_i P_{L_i} \right) \quad (2)$$

where $\sum H_i$ is the sum of the inertia constants of all rotating machines. It is noteworthy that voltage of MG is controlled by the excitation systems of synchronous generators due to their fast responses. The process of the frequency control of MG is schematically illustrated in Fig. 2.

4. The proposed control scheme of BESS

The proposed control scheme of BESS is mainly based on the utilization of overloading capacity of the battery, including overloading capacity and permissible duration, for short term primary frequency control. Since the energy exchange of BESS during primary frequency control is low with respect to the energy excursion during long term energy management, the limit violation of SOC is not critical. However, in the proposed control scheme limitations

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