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Placement and sizing of battery energy storage for primary frequency control in an isolated section of the Mexican power system

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ABSTRACT

Increasing penetration levels of inverter-interfaced generation impose challenging frequency control problems to power system operation since frequency response capabilities are reduced as conventional generation is displaced by renewable energy sources. To face these challenges, alternatives such as Battery Energy Storage Systems (BESSs) are necessary to provide advanced and enhanced frequency support. However, improper location and size of BESSs may greatly affect the performance and economic cost of their particular application. Based on this, an approach for the placement and sizing of BESS for primary frequency support in an isolated power system is presented in this study. BESS location and size are determined according to the most severe contingency for generation outage and different penetration levels of converter based renewable generation in the test system. Under these considerations, the transmission system bus with the larger frequency decline is identified for BESS placement. On the other hand, BESS sizing is formulated as a constrained optimization problem, with a defined cost function to be minimized. An iterative process based on the Bat Optimization Algorithm (BOA) is used in this work to determine the selected parameters to be optimized. For comparison purposes, a Genetic Algorithm (GA) approach is also included to deal with the formulated optimization problem. Simulation results show that system frequency response can be improved with the approach proposed in this study. Besides, the use of BOA based alternative is seen to perform relatively better than the GA approach in this case.

1. Introduction

The high penetration of renewable energy sources in power systems can lead to many operational stability issues due to the intermittent nature and lack of inertia of converter based renewable energy systems. In particular, detrimental effects on system dynamic frequency response, due to the extensive replacement of conventional generators by renewable power supplies, have been reported [1]. The negative impact is especially critical in power systems with limited inertia, such as non-interconnected electrical networks, where the loss of a large generating unit may lead to unacceptable low frequency values due to very fast changes in the rotating speed of synchronous machines.

Although large-scale generation from renewable sources can be used to help in maintaining system frequency and stability requirements, inverter-interfaced generators are required to operate in a curtailed operation mode for this purpose. However, generation curtailment in this sense raises several concerns to electricity generation owners due to its impact on the economics of renewable energy projects [2]. Therefore, other possibilities such as the application of battery energy storage systems (BESSs) are being investigated and evaluated as interesting and advanced alternatives for frequency regulation in power systems with high penetration of renewables [3–12]. As for this, the placement and sizing of BESS units for effective impact on the particular service to be provided, with minimized power and energy requirements to reduce total BESS investment cost, are in general two fundamental problems in BESS deployment projects.

Considering BESS studies specifically related to power system frequency regulation services, an historic frequency data based method for minimizing BESS capacity in providing primary frequency reserve is presented in [4]. However, the BESS placement problem is not addressed in that study since a pre-defined location was considered. Using long-term wind power time series, a statistical methodology and optimal power flow formulations for optimal placement and sizing of BESS to mitigate wind power fluctuation during the interval between two Economic Dispatches are

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Nomenclature

List of symbols and abbreviations

a	constant
A	loudness
AGC	automatic generation control
BCS	Baja California Sur
BESS	battery energy storage system
BOA	bat optimization algorithm
CAO	power plant in BCS grid
CCO	power plant in BCS grid
CLC	power plant in BCS grid
COA	power plant in BCS grid
CPP	power plant in BCS grid
CVC	power plant in BCS grid
E_B	rated energy of BESS
f	frequency
f_{50s}	frequency at fifty seconds
f_{min}	minimum frequency
f_{ss}	steady-state frequency
GA	genetic algorithm
g_i	pulse frequency of ith bat
g_{max}	maximum pulse frequency
g_{min}	minimum pulse frequency
Hz	Hertz
Ip	active current injection
Ipcmd	active current command
Ipcmd′	output of active current control
Iq	reactive current injection
Iqcmd	reactive current command
Iqcmd′	output of reactive current control
J	cost function
K_1	droop control gain
kV	kilovolts
MEG	Mexican electric grid
MW	megawatts
P	active power
P_{aux}	supplementary active power
P_B	BESS power output
Pcmd	active power command
PFC	primary frequency control
Pgen	injected power
Pord	active power order
P_{PFC}	modulated active power for PFC
Pqflag	active/reactive power priority selection
Pref	reference active power
PV	photovoltaic
Q	reactive power
Qref	reference reactive power
r	pulse rate
REECC	BESS electrical control module
REGCA	BESS generator and converter/inverter module
s	seconds
S_B	rated power of BESS
SPVG	solar PV generation
t	time
t_a	starting time for PFC
t_b	ending time for PFC
TSAT	transient security assessment tool
t_{sim}	simulation time
UFLS	under frequency load shedding
v_i	velocity of ith bat
Vt	terminal voltage
x^*	current global best location of bats
x_i	position of ith bat
Δfl	absolute value of $(f - 59.41)$
α, γ	constants
η_c	charging efficiency
η_d	discharging efficiency
Δf	frequency deviation
β	random number

proposed in [5]. This approach involves a high computational effort since BESS power at all buses of the small study system is tried for possible placement, which can be impractical in power systems with a large number of nodes.

A comparative analysis of frequency support between a large scale bulk BESS and distributed BESS with the same capacity for an IEEE 16-machine network is presented in [6], but no information is provided about the technique used for the selection of BESS power and placement in the sample network. Using a 12-bus grid model, a BESS sizing methodology for both inertial response and primary frequency control is proposed in [7] using theoretically estimated values of target system inertia and power/frequency characteristics. However, neither the location where BESS was installed nor its placement method is revealed in the presented information. The effect of BESS for primary frequency control in a simple low order system frequency response model was also analyzed in [8], but BESS allocation and sizing problems were ignored.

These problems are also kept out of the scope of the studies in [9–12]. In [9], fast inertial response from BESS is investigated using a one machine power system model and considering several inertial controller gains, different sizes of disturbances and system robustness. Although interesting application experiences of BESS for frequency regulation are presented in [10], attention is focused mainly on BESS simulation models for system impact studies. Approaches for the modeling of BESS regulation strategies for primary control reserve are mainly addressed in [11], and new methods to analyze and assess the performance of energy storage systems (including BESSs), for frequency response services, are provided in [12].

Studies on the allocation and sizing of BESSs for frequency support using standard and small test systems, as used in most of the literature and whose structure and operation mode may not be in accordance with a practical and realistic situation to be solved, can lead to impractical and loosely supported research conclusions. On the other side, since strategic placing and sizing of BESSs are crucial to maximize the system operational benefit expected, some optimization approach might be adopted to determine their best location as well as minimal power and energy ratings according to the particular application. In this sense, population-based optimization algorithms may represent an interesting alternative since they provide a relatively simple process and strategy, free of derivatives, to search for optimal solutions even in complex problems [13]. As per this and to ensure that global optimality is achievable, a particular algorithm should appropriately combine two components: exploitation and exploration [14]. Besides, depending on the balance of these two components, some algorithms may perform better than others for a given specific problem and, therefore, be more suitable for global optimization.

Genetic algorithm (GA) offers a nonlinear optimization strategy widely applied in many areas of sciences and engineering. However, global optimality in GA is generally achieved at the expense of a slow convergence. Differential Evolution based optimization has some similarity to GA, but exhibits faster convergence. Unfortunately, its degree of population diversity largely depends on