Contents lists available at ScienceDirect

## Simulation Modelling Practice and Theory

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

### Nonlinear modeling and simulation of battery energy storage systems incorporating multiband stabilizers tuned by Meta-heuristic algorithm

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#### ARTICLE INFO

Article history: Received 29 April 2017 Revised 15 June 2017 Accepted 26 June 2017 Available online 28 June 2017

Keywords: Battery energy storage system Multiband stabilizer Nonlinear modeling Time domain nonlinear simulation

#### ABSTRACT

A new control strategy including multiband stabilizers is designed for battery energy storage system (BESS). The introduced control scheme includes two internal control loops equipped with internal proportional-integral (PI) type controllers for active and reactive power control. These control loops are also equipped with multiband stabilizers. All controllers (i.e., internal controllers and multiband stabilizers) are simultaneously tuned by Meta-heuristic optimization techniques. Several disturbances are applied and simulated. The viability and effectiveness of the introduced method is verified through various nonlinear simulations and comparative studies.

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#### 1. Introduction

Energy storage systems (ESSs) are one of the most proper technologies in electric power systems that provide technical and economic advantages. There are several methods for storing energy such as mechanical, electro-chemical, electrical, thermal, and chemical approaches [1]. Although, all the methods are applicable in electric power systems, however, electro-chemical storage techniques including batteries energy storage systems (BESSs) are the most relevant storage technologies in electric power systems [2,3]. BESSs consist of several benefits making them appropriate for connecting to the electrical networks [4]. BESSs are directly connected to the main grid through interfacing converter [5].

The BESSs can be successfully utilized to damp out wind fluctuations [6,7]. In order to utilize the BESSs for facing wind uncertainties, it is required to design appropriate controllers for BESSs [8]. In the control strategies, it is required to consider the BESS operation constraints such as state of charge, rated power, and lifecycle. Designing proper control on BESS allows wind unit to be dispatched on an hourly basis according to the anticipated wind speed [8].

BESSs can also be controlled to mitigate the photovoltaic (PV) system fluctuations [9]. In hybrid PV-BESS systems, the BESS is mainly utilized to deal with power imbalance and peak load demand during grid-connected mode and to compensate power shortage under standalone mode [10]. In such models, application of model predictive control for interfacing inverter enables faster dynamic response [10]. Voltage regulation can also be achieved by BESS in hybrid PV-BESS systems; where, charging-discharging states of BESS are controlled when voltage deviates from the acceptable zone. BESS can regulate the voltage of PV system under fluctuating and nonlinearities [11].

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http://dx.doi.org/10.1016/j.simpat.2017.06.003 1569-190X/© 2017 Elsevier B.V. All rights reserved.







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#### Nomenclature

$A_s$ state matrix $B_s$ input matrix $C_s$ output matrix $D_m$ static friction coefficient $E_{fgl}$ excitation voltage (p.u.) $E_{fgl}$ internal voltage behind $\dot{x}_q$ (pu) $E_q$ internal voltage behind $\dot{x}_q$ (pu) $E_q$ internal voltage behind $\dot{x}_q$ (pu) $E_q$ voltage of q axis (p.u.) $F$ frequency of the grid (Hz) $Fref$ reference of frequency (Hz) $i$ counter of proportional gain $j$ counter of integral gain $K_a$ regulator gain $K_p$ proportional gain of active power controller $K_{P1}$ proportional gain of reactive power controller $K_{P1}$ integral gain of reactive power controller $K_{D1}$ integral gain of stabilizer $m$ counter of time constants of stabilizer $n$ counter of time constants of stabilizer $r$ counter of time constants of stabilizer $r$ counter of time constants of stabilizer $n$ counter of state power (w) $Q_{ref}$ reference reactive power (w) $Q_{ref}$ reference reactive power (w) $Q_{ref}$ reference reactive power (w) $Q_{ref}$ reference rostants of stabilizer $T_{ras}$ time constant of excitation circui	Symbols and parameters	
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PIProportional integralPSOParticle swarm optimization		
PSO Particle swarm optimization		
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Voltage profile in residential distribution networks may also be improved through appropriate control of BESS [12]. In the residential distribution networks, voltage of low-resistance distribution feeders can be regulated by reactive power compensation from PV inverters. But PV system cannot support voltage profile in high-resistance feeders and it is required to install

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