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

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**A R T I C L E   I N F O**

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

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

**A B S T R A C T**

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].

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 compen-
Nomenclature

Symbols and parameters
\begin{align*}
A_s & \quad \text{state matrix} \\
B_s & \quad \text{input matrix} \\
C_s & \quad \text{output matrix} \\
D_s & \quad \text{feed-forward matrix} \\
D_m & \quad \text{static friction coefficient} \\
E_{fd} & \quad \text{excitation voltage (p.u.)} \\
E_{fd}' & \quad \text{transient voltage behind } x_q' \text{ (p.u.)} \\
E_{q} & \quad \text{internal voltage behind } x_q \text{ (p.u.)} \\
E_q & \quad \text{voltage of } q \text{ axis (p.u.)} \\
F & \quad \text{frequency of the grid (Hz)} \\
F_{ref} & \quad \text{reference of frequency (Hz)} \\
i & \quad \text{counter of proportional gain} \\
j & \quad \text{counter of integral gain} \\
K_a & \quad \text{regulator gain} \\
K_{p1} & \quad \text{proportional gain of active power controller} \\
K_{p2} & \quad \text{proportional gain of reactive power controller} \\
K_{I1} & \quad \text{integral gain of active power controller} \\
K_{I2} & \quad \text{integral gain of reactive power controller} \\
K_{DC1} \, \ldots \, K_{DC6} & \quad \text{gain of stabilizer} \\
K_{1} \, \ldots \, K_{12} & \quad \text{gain of stabilizer} \\
m & \quad \text{counter of gain of stabilizer} \\
n & \quad \text{counter of gain of stabilizer} \\
M & \quad \text{system inertia (Mj/MVA)} \\
P & \quad \text{active power (w)} \\
P_e & \quad \text{electrical power (pu)} \\
P_m & \quad \text{mechanical power (pu)} \\
Q & \quad \text{reactive power (var)} \\
P_{ref} & \quad \text{reference active power (w)} \\
Q_{ref} & \quad \text{reference reactive power (var)} \\
r & \quad \text{counter of time constants of stabilizer} \\
T_{1} \, \ldots \, T_{48} & \quad \text{time constants of stabilizer (s)} \\
T_a & \quad \text{regulator time constant (s)} \\
T_{do} & \quad \text{time constant of excitation circuit (s)} \\
u & \quad \text{input signals in state-space model} \\
V_{ref} & \quad \text{reference voltage (pu)} \\
V_t & \quad \text{voltage on network (pu)} \\
\dot{x} & \quad \text{vector of states in state-space model} \\
y & \quad \text{output signals in state-space model} \\
\dot{\delta} & \quad \text{differential of rotor angle (Rad/Sec)} \\
\omega & \quad \text{rotor speed (pu)} \\
\dot{\omega} & \quad \text{differential of rotor speed (pu)} \\
\omega_0 & \quad \text{reference rotor speed (pu)} \\
\end{align*}

Abbreviations
\begin{align*}
\text{BESS} & \quad \text{Battery energy storage system} \\
\text{CPSS} & \quad \text{Conventional power system stabilizer} \\
\text{ESS} & \quad \text{Energy storage system} \\
\text{ITAE} & \quad \text{Integral of time and absolute error} \\
\text{MPSS} & \quad \text{Multiband power system stabilizer} \\
\text{PI} & \quad \text{Proportional integral} \\
\text{PSO} & \quad \text{Particle swarm optimization} \\
\text{PWM} & \quad \text{Pulse width modulation} \\
\end{align*}

sation from PV inverters. But PV system cannot support voltage profile in high-resistance feeders and it is required to install BESS together with PV system [12]. In [12], droop-based BESS scheme is realized to support the voltage profile together with PV system. Application of BESS in electric vehicles is also one of the interesting topics [13].
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