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

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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.

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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Nomenclature

Symbols and parameters

A_s	state matrix
B_s	input matrix
C_s	output matrix
D_s	feed-forward matrix
D_m	static friction coefficient
E_{fd}	excitation voltage (p.u.)
E'_{fd}	transient voltage behind x'_q (pu)
E'_q	internal voltage behind 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_{P1}	proportional gain of active power controller
K_{P2}	proportional gain of reactive power controller
K_{I1}	integral gain of active power controller
K_{I2}	integral gain of reactive power controller
K_{DC1}-K_{DC6}	gain of stabilizer
K_1-K_{12}	gain of stabilizer
m	counter of gain of stabilizer
n	counter of gain of stabilizer
M	system inertia (Mj/MVA)
P	active power (w)
P_e	electrical power (pu)
P_m	mechanical power (pu)
Q	reactive power (var)
P_{ref}	reference active power (w)
Q_{ref}	reference reactive power (var)
r	counter of time constants of stabilizer
T_1-T_{48}	time constants of stabilizer (s)
T_a	regulator time constant (s)
T'_{do}	time constant of excitation circuit (s)
u	input signals in state-space model
V_{ref}	reference voltage (pu)
V_t	voltage on network (pu)
$\dot{x}$	vector of states in state-space model
y	output signals in state-space model
$\dot{\delta}$	differential of rotor angle (Rad/Sec)
ω	rotor speed (pu)
$\dot{\omega}$	differential of rotor speed (pu)
ω_0	reference rotor speed (pu)

Abbreviations

BESS	Battery energy storage system
CPSS	Conventional power system stabilizer
ESS	Energy storage system
ITAE	Integral of time and absolute error
MPSS	Multiband power system stabilizer
PI	Proportional integral
PSO	Particle swarm optimization
PWM	Pulse width modulation

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