Electrical Power and Energy Systems 56 (2014) 42–54

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Optimal sizing of battery energy storage for micro-grid operation management using a new improved bat algorithm

Bahman Bahmani-Firouzi *, Rasoul Azizipanah-Abarghooee

Department of Electrical Engineering, Marvdasht Branch, Islamic Azad University, Marvdasht, Iran

ARTICLE INFO

Article history:
Received 5 March 2013
Received in revised form 11 September 2013
Accepted 12 October 2013

Keywords:
Battery energy storage sizing
Distributed generation
Improved bat algorithm
Micro-grid
Operation management
Renewable energy sources

ABSTRACT

In recent years, due to large integration of Renewable Energy Sources (RESs) like wind turbine and photovoltaic unit into the Micro-Grid (MG), the necessity of Battery Energy Storage (BES) has increased dramatically. The BES has several benefits and advantages in the MG-based applications such as short term power supply, power quality improvement, facilitating integration of RES, ancillary service and arbitrage. This paper presents the cost-based formulation to determine the optimal size of the BES in the operation management of MG. Also, some restrictions, i.e. power capacity of Distributed Generators (DGs), power and energy capacity of BES, charge/discharge efficiency of BES, operating reserve and load demand satisfaction should be considered as well. The suggested problem is a complicated optimization problem, the complexity of which is increased by considering the above constraints. Therefore, a robust and strong optimization algorithm is required to solve it. Herein, this paper proposes a new evolutionary technique named improved bat algorithm that is used for developing corrective strategies and to perform least cost dispatches. The performance of the approach is evaluated by one grid-connected low voltage MG where the optimal size of BES is determined professionally.

1. Introduction

Micro-Grid (MG) is the corner stone and indispensable infrastructure of smart grid [1]. Nowadays, with increasing concerns and challenges about the fluctuation and intermittency of Wind Turbine (WT) and Photo-Voltaic (PV) units as Renewable Energy Sources (RESs) in the MG system, the Micro-Grid Central Controller (MGCC) needs to implement Battery Energy Storage (BES). Combination of the BES can buffer the power output of RESs by storing excess energy throughout times of high availability and inject it to the MG during a power shortage. So, in recent years, the studies of researchers have been compulsorily gravitated to determine the appropriate capacity or size of BES for an optimized Operation Management of MG (OMMG). Lee and Chen [2] introduced the first BES sizing formulation for two industrial customers in Taiwan Power Company System. Mitra proposed a suitable technique of selecting the size of a BES in such a manner as to satisfy a reliability index [3]. Le and Nguyen presented the BES sizing approach for wind turbine systems to guarantee the peak load demand [4]. Kaldellis et al. offered a selection method of the most cost-efficient BES in order to match an inconstant solar-based energy system in [5]. Chen et al. focused on determining the size of BES for a MG system in Singapore using a modeling language for mathematical programming [6]. Mohammadi et al. [7] investigated an optimized design of MG containing PV array, Fuel Cell (FC) and BES in the presence of other Distributed Generators (DGs) under pool and hybrid electricity market model. Ekren and Ekren Banu [8] investigated the size optimization of a PV/WT hybrid energy conversion system with BES using Simulated Annealing (SA) algorithm. Aghamohammadi and Abdolahinia [9] presented a new method for determining optimal size of a BES for primary frequency control of a MG consisting of Micro-Turbine (MT), diesel generator, FC and PV system. Jia et al. [10] proposed a statistical model based on Monte Carlo to determine the capacity of BES-super capacitor hybrid energy storage system in an autonomous MG.

Consequently, the study about BES sizing and its role in MG system has become a topic of interest in many literature. According to the previous sentences, the OMMG is implemented to MG by the MGCC for obtaining optimum generation cost while at the same time the BES with optimal and appropriate size can decrease generation cost and that is why the study of OMMG in the presence of BES sizing has become a common topic subject of discussion. In this regard, an appropriate method on the basis of cost model of BES is proposed in this study in order to determine optimal size of BES for the OMMG problem.

The OMMG problem is one of the backbone optimization tools for smart energy manager or MGCC in which the optimal power set points of BES and DGs are determined while all of the quality,

* Corresponding author. Address: Department of Electrical Engineering, Marvdasht Branch, Islamic Azad University, P.O. 73711-13119, Marvdasht, Iran. Tel.: +98 917 7154688; fax: +98 728 3311172.
E-mail address: bahman_bah@yahoo.com (B. Bahmani-Firouzi).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.10.019

Nomenclature

Indices

a	velocity updating strategy index
i_{PV}, i_{WT}	photo-voltaic (PV) and wind turbine (WT) indices, respectively
$iter$	iteration index of the proposed Improve Bat Algorithm (IBA)
BES, $grid$	Battery Energy Storage (BES) and grid indices, respectively
FC, MT	Fuel Cell (FC) and Micro-Turbine (MT) indices, respectively
m	bat index
t	time index

Constants

$\mathrm{Bid}_{grid,t}$, $\mathrm{Bid}_{BES,t}$, $\mathrm{Bid}_{MT,t}$, $\mathrm{Bid}_{FC,t}$, $\mathrm{Bid}_{i_{PV},t}$, $\mathrm{Bid}_{i_{WT},t}$	Bid of utility, BES, MT, FC, PV, WT at time t, respectively (€ct/kW h)
FC_{BES}, MC_{BES}	fixed and maintenance cost for BES, respectively (€ct/kW h)
$f_m^{\max}, f_m^{\min}$	maximum and minimum pulse frequency for bat m, respectively
IR	interest rate for financing the installed BES
$Iter\_\max$	maximum number of iteration for the proposed IBA
LT	lifetime of the installed BES (year)
$NPOP$	number of bats in the population of IBA
$N_1^{iter}, N_2^{iter}, N_3^{iter}, N_4^{iter}$	number of bats which select the velocity updating strategy 1, 2, 3, and 4, respectively
NT	operation time horizon (h)
nv	number of variables of each bat
OR_t	minutes operating reserve requirements (kW)
OM_{DG}	fixed operation and maintenance cost of Distributed Generators (DGs) (€ct)
OM_{FC}, OM_{MT}, $\mathrm{OM}_{i_{PV}}$, $\mathrm{OM}_{i_{WT}}$	fixed operation and maintenance cost of FC, MT, PV and WT, respectively (€ct/kW h)
$P_{grid,\max}$, $P_{grid,\min}$	maximum/minimum limits of power production for the utility, respectively (kW)
$P_{Demand,t}$	electrical load demand at time t (kW)
$P_{BES,\max}$, $P_{BES,\min}$	maximum/minimum producible power of BES, respectively (kW)
$P_{FC,\max}$, $P_{FC,\min}$	maximum/minimum producible power of FC, respectively (kW)
$P_{MT,\max}$, $P_{MT,\min}$	maximum/minimum producible power of MT, respectively (kW)
$rand(.)$	random function generators in the range [0, 1]
$rand_m(1, nv)$	random vector with the dimension of $1 \times nv$ relating to the mth bat
$Shut_{FC}$, $Shut_{MT}$	shut-down cost coefficient for FC and MT, respectively (€ct)
$Start_{FC}$, $Start_{MT}$	start-up cost coefficient for FC and MT, respectively (€ct)
tax	tax rate of utility power grid
$X_{\min}, X_{\max}$	minimum and maximum boundary vectors of the control variable X, respectively
α_{BA}, γ_{BA}	constants parameters for the Bat Algorithm (BA)
Δt	time interval duration
$\eta_{\text{discharge}}$, η_{charge}	discharge and charge efficiency of BES, respectively
ε	random function generators in the range [−1, 1]
θ	learning rate to control the learning speed in

Variables

A_{mean}^{iter}	mean of the pulse loudness for all bats in iteration $iter$
$ACUM_a$	accumulator parameter for velocity updating strategy a
$C_{BES,\min}$, $C_{BES,\max}$	minimum and maximum size of BES
$C_{BES,t}$	energy stored in the BES
$Cost_{grid,t}$	cost of trade with the up-stream grid at time t (€ct)
$Cost_{DG,t}$, $Cost_{BES,t}$	cost of fuel and operating power of DGs and BES at time t, respectively (€ct)
$f_m^{iter}, A_m^{iter}, r_m^{iter}$	pulse frequency, loudness and emission rate for bat m in iteration $iter$, respectively
$Gbest^{iter}$, $Worst^{iter}$	best and worst position among all bats in iteration $iter$
F	total costs (€ct)
$Mean^{iter}$	mean population vector in iteration $iter$
$P_{grid,t}$, $P_{BES,t}$, $P_{MT,t}$, $P_{FC,t}$, $P_{i_{PV},t}$ and $P_{i_{WT},t}$	power of utility, BES, MT, FC, PV and WT, respectively (kW)
$\overline{P}_{BES,t}, \underline{P}_{BES,t}$	maximum discharge and charge rates of BES at time t, respectively (kW)
$Pbest_m^{iter}$	personal best position of bat m in iteration $iter$
$prob_a$	probability of velocity updating strategy a
$SDC_{FC,t}$, $SDC_{MT,t}$	shut-down cost for FC and MT at time t, respectively (€ct)
$SUC_{FC,t}$, $SUC_{MT,t}$	start-up cost for FC and MT at time t, respectively (€ct)
$TCPD_{BES}$	total cost per day of BES (€ct)
X_m^{iter}, V_m^{iter}	position and velocity of bat m in iteration $iter$, respectively
$u_{BES,t}$, $u_{MT,t}$, $u_{FC,t}$	status (On or Off) of BES, MT and FC at time t, respectively
WF_m	weighting factor for the mth bat

Subscript

t	tth time step (h)

Abbreviations

ABC	Artificial Bee Colony
BA	Bat Algorithm
BES	Battery Energy Storage
DG	Distributed Generator
FC	Fixed Cost
FC	Fuel Cell
FSAPSO	Fuzzy Self Adaptive Particle Swarm Optimization
GA	Genetic Algorithm
GENCO	Generating Company
IBA	Improved Bat Algorithm
IR	Interest Rate
LT	Lifetime
MC	Maintenance Cost
MG	Micro-Grid
MGCC	Micro-Grid Central Controller
MT	Micro-Turbine
OMMG	Operation Management of Micro-Grid
OR	Operating Reserve
PSO	Particle Swarm Optimization
PV	Photo-Voltaic
RES	Renewable Energy Source
RWM	Roulette Wheel Mechanism
SA	Simulated Annealing
SMES	Superconducting Magnetic Energy Storage
SP	Successful Performance
Std	Standard deviation
TLBO	Teaching–Learning-Based Optimization
TCPD	Total Cost Per Day
WT	Wind Turbine