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Application of the Hybrid Big Bang–Big Crunch algorithm for optimal sizing of a stand-alone hybrid PV/wind/battery system

Saeedeh Ahmadi [a,*], Shirzad Abdi [b]

[a] Department of Process and Equipment Technology Development, Research Institute of Petroleum Industry (RIPI), Tehran, Iran
[b] Faculty of Engineering and Technology, Imam Khomeini International University (IKIU), Qazvin, Iran

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ABSTRACT

In this paper an efficient method based on Hybrid Big Bang–Big Crunch (HBB–BC) algorithm is presented for optimal sizing of a stand-alone hybrid power system including photovoltaic panel, wind turbine and battery bank. The optimization is carried out to continuously satisfy the load demand with minimizing the total present cost (TPC) of the system. TPC includes all the costs throughout the useful life of the system, which are translated to the initial moment of the investment. In the optimization problem, the reliability index of energy not supplied (ENS) is also considered to have a reliable system. The HBB–BC algorithm is an effective and powerful method that has high accuracy and fast convergence as well as its implementation is easy. This algorithm using the Particle Swarm Optimization (PSO) capacities improves the capability of the Big Bang–Big Crunch (BB–BC) algorithm for better exploration. In addition, the HBB–BC uses a mutation operator after position updating to avoid local optimum and to explore new search areas. This study is applied to a village in Qazvin, Iran that still lacks access to grid electricity due to economic and geography issues. The performance of the proposed algorithm is compared with PSO and Discrete Harmony Search (DHS) algorithms. Simulation results confirm that HBB–BC algorithm with high accuracy can find the optimal solution and it has the best performance in comparison with two mentioned algorithms.

1. Introduction

The need for energy-efficient and reliable electric power in remote rural villages is a driving force for research in this area. Fuel transportation problems, high operating costs, fluctuation in fuel cost, the depletion of the fossil fuel resources and environmental problems have forced many utilities to explore hybrid energy systems for inexhaustible energy development and environmental pollution prevention. Photovoltaic (PV) panels and Wind turbines (WTs) are the most promising technologies for supplying load demand in remote areas. Because of unpredictable nature of these power sources and dependence on environmental conditions, hybrid energy systems must be used by combining the wind and solar energies along with battery storage. Hybrid systems have greater reliability and lower cost than a PV-only system or a wind-only system. In order to have a cost-effective hybrid system, optimal sizing is necessary.

In previous studies, different methods have been presented for the optimal sizing of hybrid power systems. Kellogg et al. (1998) presented a simple numerical algorithm for generation unit sizing. It has been used to determine the optimum generation capacity and storage needed for a stand-alone, wind, PV, and hybrid wind/PV system for an experimental site in a remote area in Montana with a typical residential load. Dufo-López and Bernal-Agustín (2005) have developed a program that uses the Genetic Algorithm (GA) for sizing and operation control of a PV–Diesel system. The program has been developed in C++. Nelson et al. (2006) performed an economic evaluation of a hybrid wind/photovoltaic/fuel cell (FC) generation system for a typical home in the Pacific Northwest. In this configuration the combination of a FC stack, an electrolyser, and hydrogen storage tanks is used as the energy storage system. A new method for optimization of a wind–PV hybrid system for a specific location employing an iterative scheme has been addressed by Prasad and Natarajan (2006). Yang et al. (2008) presented an optimal sizing method for a stand-alone hybrid solar–wind system employing battery banks Based on the genetic algorithm. This method can achieve the desired loss of power supply probability (LPSP) with a minimum annualized cost of system. A triple multi-objective design of isolated hybrid systems minimizing, simultaneously, the total cost throughout the useful life of the installation, pollutant emissions (CO_2) and unmet load is presented

* Corresponding author.
E-mail addresses: ahmadis@ripi.ir (S. Ahmadi), sh.abdi@edu.ikiu.ac.ir (S. Abdi).

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Nomenclature

$A_i^{(k,j)}$	ith component of the jth candidate generated in the kth iteration
$A_i^{c(k)}$	ith component of the center of mass in the kth iteration
$A_i^{gbest(k)}$	the global best position up to the iteration k
$A_i^{lbest(k,j)}$	the best position of the jth particle up to the iteration k
$A_{i\max}$	upper limit for the ith control variable
$A_{i\min}$	lower limit for the ith control variable
C_{BA}	unit cost of battery bank ($)
$C_{BA,M}$	annual maintenance cost of battery ($/year)
C_{CON}	unit cost of converter ($)
C_{INV}	unit cost of inverter ($)
C_{PV}	unit cost of PV panel ($)
$C_{PV,M}$	annual maintenance cost of PV panel ($/year)
C_{REC}	unit cost of rectifier ($)
C_{REG}	unit cost of charge regulator ($)
C_{WT}	unit cost of wind turbine ($)
$C_{WT,M}$	annual maintenance cost of wind turbine ($/year)
$CPV(\,)$	cumulative present value
DOD	maximum depth of discharge
ENS	energy not supplied during the year (kW)
$ENS(\%)$	percentage of energy not supplied during the year
$ENS_{\max}(\%)$	allowable percentage of energy not supplied during the year
f_j	fitness function value of candidate j
G	perpendicular radiation at array's surface (W/m^2)
$InfR$	inflation rate
$IntR$	interest rate
$INVESTC$	investment cost ($)
m	number of control variables
$MAINC$	maintenance cost ($/year)
N	population size
N_{BA}	number of battery bank
N_{CON}	number of converter
N_i	number of component i
$N_{i\text{-max}}$	maximum number of the component i
$N_{i\text{-min}}$	minimum number of the component i
N_{INV}	number of inverter
N_{PV}	number of PV panel
N_{REC}	number of rectifier
N_{REG}	number of charge regulator
N_{WT}	number of wind turbine
P_{BA}	charge quantity of the battery bank (kW h)
$P_{BA\text{-max}}$	maximum charge quantity of battery bank (kW h)
$P_{BA\text{-min}}$	minimum charge quantity of battery bank (kW h)
P_{Load}	load demand (kW)
P_m	mutation probability
P_{PV}	output power of each photovoltaic panel (kW)
$P_{PV\text{-rated}}$	rated power of each PV panel (kW)
P_{WT}	output power of each wind generator (kW)
$P_{WT\text{-rated}}$	rated power of each wind generator (kW)
r_j	random number from a standard normal distribution
$REPLACEC$	replacement cost ($)
S_{BA}	nominal capacity of battery bank (kW h)
T	economic life cycle of the hybrid system (year)
TPC	total present cost of the system ($)
v	wind speed (m/s)
V_{ci}	cut-in speed of the wind turbine (m/s)
V_{co}	cut-out speed of the wind turbine (m/s)
V_r	rated speed of the wind turbine (m/s)
α_1	parameter for limiting the size of the search space
α_2, α_3	adjustable parameters
η_{BA}	charge efficiency of the battery bank
η_{CON}	efficiency of the converter
η_{INV}	efficiency of the inverter
η_{MPPT}	efficiency of MPPT system
η_{REC}	efficiency of the rectifier
σ	hourly self-discharge rate

by Dufo-López and Bernal-Agustín (2008). For this task, a multi-objective evolutionary algorithm (MOEA) and a genetic algorithm have been used in order to find the best combination of components of the hybrid system and control strategies. An advanced variation of Particle Swarm Optimization algorithm is used by Kashefi Kaviani et al. (2009) to optimal design of a hybrid wind/photovoltaic/fuel cell generation system to reliable supply of the demand. The aim of the design is minimization of annualized cost of the hybrid system over its 20 years of operation. Hakimi and Moghaddas-Tafreshi (2009) used the particle swarm optimization algorithm for optimal sizing of a stand-alone hybrid power system. This study is performed for Kahnouj area in south-east Iran. Ekren and Ekren (2010) performed Simulated Annealing (SA) algorithm for optimizing size of a PV/wind integrated hybrid energy system with battery storage. The proposed methodology is a heuristic approach which uses a stochastic gradient search for the global optimization. Mohammadi et al. (2012) presented an optimized design of microgrid in distribution systems with multiple distributed generation units under different market policies such as pool/hybrid electricity market. Proposed microgrid includes various energy sources such as photovoltaic array and wind turbine with energy storage devices such as battery bank. The particle swarm optimization algorithm has been implemented for the optimization of the microgrid cost. A discrete simulated annealing algorithm (DSA) for finding the optimum design of hybrid PV/wind system is presented by Askarzadeh (2013b). The DSA algorithm is then expanded by using the merits of two other heuristic algorithms, namely, harmony search and chaotic search. Kazem et al. (2013) presented a method for optimal sizing of a standalone PV system for remote areas in Sohar, Oman. PV array tilt angle as well as the size of the system's energy sources are designed optimally for better performance and lower energy cost. A methodology based on iterative technique is presented by Smaoui et al. (2015) to perform the optimal sizing of a stand-alone hybrid photovoltaic/wind/hydrogen system supplying a desalination unit which feeds the area's inhabitants with fresh water. The methodology aims at finding the optimal technical–economic configuration among a set of systems components. Fetanat and Khorasaninejad (2015) employed ant colony optimization (ACO) for continuous domains based integer programming for size optimization in a hybrid photovoltaic–wind energy system. The objective function of this system design is the total design cost. The optimal sizing and tilting of a hybrid photovoltaic/battery/diesel generator system are performed by Jeyaprabha and Selvakumar (2015) for the remote locations in India, using artificial intelligence techniques (AIT) without the metrological data. Maleki et al. (2015) evaluated the performance of different variants of particle swarm optimization algorithms on the sizing problem of PV/wind/battery systems. The optimal size of system components has been studied under various performance conditions using real-time information and meteorological data from each of Iran's southern, north-west, and north-east regions.

The Big Bang–Big Crunch (BB–BC) optimization algorithm is a global optimization method that relies on one of the theories of the evolution of the universe, namely, BB–BC theory. It has several advantages over other evolutionary methods: the inherent