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Original article

An optimization method for sizing a solar/wind/battery hybrid power system based on the artificial immune system

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ABSTRACT

This study proposes a novel technique to obtain the optimum size of a Solar/Wind/Battery hybrid power system (HPS) using Clonal Selection Algorithm (CLONALG). The objective of the proposed method is to find the optimal size of the HPS to utilize its output with small fluctuation rate and minimum cost. The system is designed with the optimal size of PV arrays, wind turbines, and batteries so that it can satisfy the demand requirement with the least percentage of load interruptions. Loss of Power Supply Probability (LPSP) is considered as a reliability index of the HPS, and the optimization process is supposed to get the least LPSP as it could. To verify the proposed algorithm, it is applied to a case study located in Troyes Barbery Station- France and the results are compared with those obtained by Genetic Algorithm (GA). Then the CLONALG is used to get the optimal size of an HPS located in Qena AL-Gadida city-Egypt. The results proved that the proposed method is effective for the sizing process and can achieve the system objectives.

Introduction

The global concern about the environmental pollution and the large demand of electrical energy to feed the rapid expansion of population and industry give renewable energy sources (RES) the big portion in the studies and the development of the energy map. Solar/wind hybrid power system (HPS) takes its part in the studies as it represents a good choice for the off-grid remote areas. Such HPS has the advantages of non-fuel cost, non-CO2 emissions, ease of extensibility, modularity and the suitability for the off-grid remote areas. The main drawback of this HPS is the unpredictability and intermittency nature of solar and wind RES due to their dependency on climate and weather conditions [1]. To ensure the reliability of the HPS, a backup energy source should be intended to supply the load in times of lack of solar and wind energy. Batteries can fulfil such role by storing excess energy when available for times of deficit energy [2]. Disadvantages of batteries are the expensive cost, short lifetime compared to PV panels and wind turbines (WT), self-discharge rate and their own efficiency during the charging/discharging process [1]. However, an appropriate sizing of PV/WT/battery HPS is sufficient to diminish the disadvantages of its components and improve its reliability and efficiency. The intention of this study is to provide an effective methodology for better sizing of the PV/WT/battery HPS based on the usage of wind, solar and battery technologies regarding to the least cost criterion while satisfying the actual demand requirements of a certain site with the least percentage of interruptions [3]. Using the proposed methodology is capable of providing an optimum solution once the HPS components parameters are known such as wind speed, solar irradiation, load demand and economic variables. This methodology is derived by using the new Clonal Selection (CLONALG) optimization method.

Many optimization methods were presented in the literature to obtain the optimal size of the HPS [4]. These techniques can be classified as artificial intelligence (AI) techniques [2–12], conventional analytical methods [13–17], and software packages [18,19]. The non-convexity of the problem makes it hard for the conventional methods to obtain a global optimum. AI methods are more efficient than conventional methods because they can handle the non-linear, non-convex optimization problem of the components sizing of the HPS [7]. The main limitation of these methods is that they may be stuck with local minima. The CLONALG has the ability to get out local minima. It avoids the worst results and starts the search for the optimal solution from the best result of the last iteration [20].

Nowadays, there are a variety of AI techniques used as optimization tools. These techniques include Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), and Ant Colony. Genetic Algorithm (GA) is one of the optimization methods which operates in terms of the genetic process for biological mechanisms; it has the ability to present a problem-solving method for difficult real-world

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Nomenclature

Ppv	The PV's generated power
fpv	The derating factor
Ppv_r	The PV's rated generated power
G	The daily solar irradiation
GSTC	The solar radiation under standard test conditions
αT	The temperature coefficient of power
Tc	The actual cell's temperature
TSTC	The cell's temperature under standard test conditions
Ta	The ambient temperature
NOCT	The nominal operation cell temperature
PLmax	Maximum load demand
Vw	The upgrade wind speed at the hub height
Vi	The measured wind speed
hr	The reference height
h	The hub height
a	The power law exponent
Pw	Wind turbine's output power
Pr	Wind turbine's rated power
Vr	The rated wind speed
Vci	The cut-in wind speed
Vco	The cut-out wind speed
Cp	The power coefficient
ρair	The air density
A	The rotor swept area
V	The electric voltage
Vco	The open circuit voltage
R	The internal resistance
Pb	The maximum discharge quantity
Pbin	The maximum charge quantity
Nb	Number of batteries
Ich	The maximum charging current
Idch	The maximum discharging current
SOC(t)	Battery's state of charge at time t
SOC(t − 1)	Battery's state of charge at time t − 1
δ	The hourly self-discharge rate of battery
T	The optimization horizon
Pg	The total generated power
PL	The required load
Δt	The time step
Cbat	The capacity of the battery
C	The objective function (cost)
Cf	The fixed cost
Com	Operating & maintenance cost
CR	Replacement cost
S	Salvage cost
Cpv	The initial cost of the PV
Cw	The initial cost of the wind turbine
Cb	The initial cost of the battery
Npv	Number of PVs
Nw	Number of wind turbines
fd	The discount factor
Lt	The total lifetime of the project
r	The real interest rate
R	The nominal interest rate
f	The annual inflation rate
q	The lifetime of the HPS elements that differs from one to another
C1t, *C2t* & *C3t*	The total O&M cost of PV, wind turbine and battery over the project lifetime
Cpv-om	The operating and maintenance cost of PV
Cw-om	The operating and maintenance cost of wind turbine
Cb-om	The operating and maintenance cost of battery
Cpv-R	The replacement costs of PV
Cw-R	The replacement costs of wind turbine
Cb-R	The replacement costs of battery
Lrem	The remaining life of the component at the end of the project lifetime
Lc	The component lifetime
Lrep	The replacement cost duration
round	A MATLAB function that rounds to the nearest integer
LPSP	Loss of power supply probability
λL	The admissible LPSP
DL	The relative fluctuation rate
PLa	The average power of load
εL	A reference value
SOCmin	The minimum battery's state of charge
SOCmax	The maximum battery's state of charge
DOD	the depth of discharge of battery

problems [4]. Many published articles have used GA for optimum sizing of the HPS. Ogunjuyigbe et al. [2] presented a GA to design an off-grid HPS based on a tri-objective: decreasing the CO2 emissions, decreasing the life cost cycle (LLC) and decreasing the net dump energy. Also Ref. [5] developed a parallel GA using a total of 9 scenarios to compute the optimum configuration based on minimizing the LLC in addition to decreasing the loss of power supply probability (LPSP). Some other references used improved GAs for the same purpose such as Fulzele et el. [6] who introduced the Improved Hybrid Optimization by GA (IHOGA) and Abdelhak et al. [7] who used a Fuzzy-Adaptive GA (GA+) Algorithm compared to the standard GA for sizing a PV/WT HPS compared the cases of average and real battery service life.

Particle Swarm Optimization (PSO) is one of the improvement techniques, which involves shifting and swarm intelligence based on evolutionary calculation techniques. In comparison with GA-based methods, there is some similarity between them. The entry data of the PSO approach includes meteorological circumstances, the unit cost of the hybrid components such as installation and continuation costs, limitations and appropriateness of purpose and the principles of specific PSO factors [4]. For sizing a stand-alone HPS, Ref. [8] adapted an improved PSO optimization algorithm. The study derived the optimal size of batteries for systems with different penetration levels of renewables minimizing the dispatch cost and the levelised cost of electricity (LCOE). The results confirmed that the proposed method worked well in approaching different unit commitment and dispatch schemes for different system sizes. Economic aspects such as interest rate, inflation, capital recovery factor, sinking fund factor were demonstrated for every power source. For a smooth secure and stable system, an optimum design of a battery energy storage system (BESS) using PSO was implemented for a stand-alone HPS in Ref. [9], and for a system integrated to utility grids in Ref. [10]. The simulation results confirmed that the PSO method based on controlling of the frequency the MG improved the HPS's stability from the emergency to the normal state.

Simulated Annealing (SA) algorithm was performed in Ref. [11] for finding the optimum design of a PV/WT HPS. The DSA algorithm was then expanded by merging the SA with harmony search and chaotic search. The algorithms were applied to an HPS to find the optimum design. Simulation results proved that the proposed approach gave better results than other methodologies.

Ant Colony Optimization Algorithm (ACO) was derived in Ref. [12] for size optimization in a PV/WT HPS. The objective of the HPS design was the total cost that was the sum of the initial costs and the maintenance costs that should be decreased. The optimization was separately performed for three renewable energy systems including HPSs, standalone-PV and standalone-WT.