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# Optimal placement and schedule of multiple grid connected hybrid energy systems

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ABSTRACT

This paper presents an artificial bee colony (ABC) based algorithm to optimally solve the problem of allocation and the problem of design and schedule of multiple hybrid photovoltaic (PV)-diesel distributed generation in distribution systems. Both problems are solved simultaneously. The objective of the proposed algorithm is to minimize the overall investment, replacement and operation and maintenance costs of each located hybrid photovoltaic-diesel system (HPVDS). As the hybrid energy systems are grid connected, the algorithm considers also the minimization of the distribution system power loss, the amount of imported power from the transmission grid and the un-served load in case of emergency. Meanwhile, the algorithm aims to maximize the excess generated power by the HPVDS that may be injected into the distribution network. These objectives are to be achieved while satisfying the operational constraints of the system. The proposed algorithm is applied to two test systems to validate its effectiveness.



## Introduction

Distributed generation (DG) has been considered as an important alternative to centralized energy resources. As the penetration of DG systems into distribution and transmission networks increase, they are more likely to be grid connected. These DG systems are located in close proximity to energy users. The DGs and their loads can operate as grid connected or in a stand-alone (islanded) mode [1,2]. Therefore, these systems are to be rated and designed as if they are to operate in stand-alone mode but scheduled for being grid connected as introduced in this paper.

The interest in DGs increases because it can provide reliable, secure, efficient and sustainable electricity from renewable energy resources [3]. The deregulated energy environment has encouraged the usage of DG sources near the energy consumers. These sources comprise many technologies such as diesel engines, wind turbines, photovoltaic, microturbines, and hydroturbines [1]. Hybrid energy systems are recognized as a viable alternative to grid supply or conventional fuel-based power supplies [4].

Optimal design of various combinations of these technologies has been studied in stand-alone and/or grid connected modes. In [5], a probabilistic approach to design an optimal size of PV distributed generators in a distribution system to only minimize the active power loss was presented. Optimal design of single stand-alone hybrid PV/wind/diesel systems was presented in [6,7] in order to minimize the total cost of the system. Likewise, the economic analysis of the stand-alone hybrid energy systems has been proposed in [8,9] while the economic analysis of such system in grid connected mode was also presented in [10]. In [11], the feasibility of hybridization of diesel power plant with a photovoltaic (PV) system was investigated whereby the performances of each part have been simulated. Investigating economic feasibility of a PV/diesel HPS in various climatic zones within South Africa was reported in [12].

Many optimization algorithms have been reported to solve the hybrid energy systems design problem [13]. However, all of these researches addressed the design of hybrid energy systems which, when grid connected, were at fixed locations of the grid and did not consider the optimal placement of such systems. Nevertheless, when the locations of these systems change, their ratings, design and schedule change too.

Other researches addressed the optimal siting and sizing of DG units or microgrids without dealing with the detailed design of these systems. In order to optimally allocate DG units some researchers used analytical methods [14] and others used evolutionary computational methods such as genetic algorithm [15], tabu search [16] and particle swarm optimization [17,18].

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**Nomenclature**

| | |
|---|---|
| $x_i$ | the position of the $i$th onlooker bee |
| $t$ | the iteration number |
| $\theta_i$ | the position of the $i$th employed bee which is selected by roulette wheel |
| $\theta_k$ | the position of a randomly selected employed bee |
| $u$ | a random variable in the range of $[-1,1]$ or $[0,1]$ as used in this paper |
| $S$ | the number of employed bees |
| $D$ | the number of parameters to be optimized |
| $MCN$ | the maximum number of iterations of the search process |
| $r$ | random number in the range of $[0,1]$ |
| $\theta_{ij}^{min}, \theta_{ij}^{max}$ | the minimum and maximum limits of the $i$th parameter |
| $A$, $B$ | the fuel curve coefficients |
| $P_{Ngen}$ | the diesel generator rated capacity |
| $Pr_{fuel}$ | the fuel price |
| $C_{O\&Mgen}$ | the diesel generator's hourly operation and maintenance cost |
| $C_{rep\ gen\ h}$ | the diesel hourly replacement cost |
| $C_{cycling\_bat}$ | the cost of cycling energy through the batteries |
| $C_{PV}$ | the PV panels cost |
| $C_{PV\text{-}inv}$ | the investment cost of PV panels |
| $C_{PV\text{-}rep}$ | the replacement cost of PV panels |
| $C_{PV\text{-}O\&M}$ | the operation and maintenance cost of PV panels |
| $C_{ds}$ | the diesel generators cost |
| $C_{ds\text{-}inv}$ | the investment cost of diesel generators |
| $C_{ds\text{-}rep}$ | the replacement cost of diesel generators |
| $C_{ds\text{-}O\&M}$ | the operation and maintenance cost of diesel generators |
| $C_b$ | the batteries banks cost |
| $C_{b\text{-}inv}$ | the investment cost of batteries banks |
| $C_{b\text{-}rep}$ | the replacement cost of batteries banks |
| $C_{b\text{-}ch}$ | the energy cost for charging the batteries banks |
| $C_{b\text{-}dis}$ | the energy cost for the discharge of the batteries banks |
| $C_{sh}$ | the cost of energy not served |
| $C_{loss}$ | the cost of energy loss of the distribution network |
| $C_{slack}$ | the cost of energy imported from the transmission grid |
| $C_{ex}$ | the cost of excess energy of HPVDS injected to the distribution network |
| $P_{PV}$ | the power generated by photovoltaic panels |
| $P_{ds}$ | the power generated by diesel generators |
| $P_{b\text{-}dis}$ | the batteries banks power discharge |
| $P_{b\text{-}ch}$ | the batteries banks power charge |
| $P_{sh}$ | the un-served (shed) power |
| $P_{slack}$ | the imported power from the transmission grid |
| $P_{loss}$ | the active power loss of the distribution network |
| $P_D$ | the load (demand) power |
| $P_{PV}^{max}$ | the PV maximum generation capacity |
| $P_{ds}^{max}, P_{ds}^{min}$ | the diesel maximum and minimum generation capacity, respectively |
| $P_S$ | the batteries banks power state |
| $P_S^{max}, P_S^{min}$ | the maximum and minimum batteries banks capacity limits, respectively |
| $P_{HDG}$ | the hybrid distributed generation capacity |
| $P_D^{max}$ | the maximum load power |
| $P_{slack}^{max}$ | the maximum limit of the slack bus power |
| $V_i$ | the voltage magnitude at the $i$th bus |
| $V_i^{max}, V_i^{min}$ | the maximum and minimum limits of bus voltage magnitude |
| nbus | the number of system's buses |
| $S_{ij}$ | the power capacity in the distribution line between bus $i$ and bus $j$ |
| $S_{ij}^{max}$ | the maximum power capacity of the distribution line between bus $i$ and bus $j$ |

However, up till now, these two problems of siting and sizing the hybrid energy systems and designing and scheduling them have been separately solved.

In this paper, both the siting and designing of multiple grid connected HPVDS in distribution networks are introduced. The proposed algorithm formulates the two problems as one optimization problem which is solved using artificial bee colony (ABC) algorithm. Moreover, in the proposed algorithm, neither the number of HPVDS nor their locations are specified. Hence, different designs for different locations are considered. The main idea of this paper is that, while sizing the hybrid DG systems, these systems are designed as if they will operate in stand-alone mode although they are grid connected. The systems are designed such that they totally support their local loads without the need of imported power from the distribution network to supply these loads. That is why each system located in the network is designed to include storage batteries.

Recently, many blackout incidences in many cities around the world such as the ones occurred in Newdelhi, India and Cairo, Egypt at the summer of 2012 were because of the overloading and tripping of one or more of the lines connecting the distribution network of the cities to the transmission grids. Therefore, the power taken by the distribution network from the transmission grid must be limited. In this paper, the HPVDS are considered to be grid connected only to support the distribution network by supplying it with their extra PV power. This support will reduce the purchased power from the main transmission grid (reduce the loading of upstream feeders) and reduce the amount of un-served (shed) loads once a loss of one or more of the upstream feeders occur. In order to achieve such purpose, an optimal scheduling of the HPVDS and other DG units of the system is considered in this paper. The distribution network is assumed to be connected to the transmission network through the slack bus. Therefore, in addition to including the slack bus power in the objective function to be minimized, the slack bus power is limited to certain percentage of the total demand of the distribution network.

The proposed algorithm is applied to two test systems to validate its ability to solve the problem. The two systems are the radial 33-bus test system and the Egyptian meshed 45-bus system of Alexandria.

This paper is organized as follows. Section 'Artificial bee colony optimization algorithm' describes the ABC optimization algorithm. Section 'Problem formulation' presents the problem formulation. Section 'ABC application to HPVDS siting and sizing problem' introduces the application of the ABC algorithm to the problem. Section 'Test results' presents the obtained results and the relevant discussion. Finally, the main conclusions are given in Section 'Conclusion'.

## Artificial bee colony optimization algorithm

The ABC optimization technique belongs to the group of swarm intelligence techniques. It was introduced in 2005 by Karaboga [19]. The performance of the ABC algorithm was compared with those of some well-known population based optimization algorithms such as genetic algorithm (GA) and particle swarm optimization (PSO). The results and the quality of the solutions matched or improved over those obtained by other methods [20]. The ABC algorithm is developed by simulating the behaviors of the real bees