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Optimal allocation, sizing of PHEV parking lots in distribution system

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ABSTRACT

The emerging of plug-in-hybrid electric vehicles (PHEV) results in the increase in the utilization of vehicles batteries for grid support. This paper presents a multi-objective algorithm to optimally determine the number of parking lots to be allocated in a distribution system. In addition, the algorithm optimally selects the locations and sizes of these parking lots. The proposed algorithms determine also the corresponding energy scheduling of the system resources. The objective of the proposed algorithm is to minimize the overall energy cost of the system. The problem is formulated as an optimization problem which is solved using artificial bee colony (ABC) and firefly algorithm taking into consideration the power system and PHEV operational constraints. The proposed algorithms are applied to a 33-bus radial distribution network. The test results indicate an improvement in the operational conditions of the system.

Introduction

The rapid industrial and modernization growth resulted in a rapid growth of hydrocarbon-based energy consumption. This has been one of the most significant challenges for the environment and human life [1]. In addition, the decrease of fuel quantity, volatility price and the need to decrease the dependency on fossil fuels caused the electric vehicles (EVs) to be considered as an effective resource in transportation and power system [2]. EVs include plug-in-hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs). However, electrification of the transportation sector brings more challenges and offers new opportunities to power system planning and operation. The possibility of using the energy stored in the gridable EVs batteries to supply power to the electric grid is commonly referred to as vehicle-to-grid (V2G) [3]. Integration of V2G as distributed energy sources when the vehicles are parked requires an appropriate site selection of optimized on-grid parking lots and an optimal energy resource scheduling.

In recent years, many researchers have addressed the integration of V2G in power system. In [4], authors proposed an algorithm for optimally managing a large number of PHEVs charging at a municipal parking station. They tried to optimally allocate energy to PHEVs while maximizing the average state-of-charge (SOC) of the batteries. As the power flow in the presence of PHEVs can be bidirectional, the PHEVs can aid to improve grid efficiency and reliability. The increase of power quality of the grid by using coordinated charging and discharging of PHEVs was presented in [5]. Authors in [6], proposed a practical model for the assessment of the contribution of V2G systems as a support to energy management within a small electric energy systems. In the same context, authors in [3] presented a day-ahead energy resource scheduling for smart grids considering the use of gridable vehicles. The main objective was to minimize the operation cost of the system.

In addition to energy management of PHEVs in pre-located parking lots, the optimal locations and sizes of these lots attracted the attention of many researches too. Optimal allocation of parking lots can reduce the network loss such as other distributed generation (DGs), enhance reliability, improve voltage profile and consequently bring economical benefits for distribution system companies. In [2], authors proposed an algorithm for optimal allocation and sizing of parking lots. Few buses of the system were considered as candidate buses for allocating parking lots. However, the researchers ended up with only determining the optimal size of the allocated parking lots as they placed parking lots at all of the candidate buses. Furthermore, the vehicles were set to charge during off-peak hours and discharge during peak hours. Hence, no energy management approach was applied. Authors in [1] proposed a solution of the optimal DGs siting and sizing problem. Thereafter, they selected the predetermined optimum site of DG to be a location of a parking lot. To satisfy the size of the parking lot an on-grid hybrid renewable energy system was chosen. The energy management algorithm considered an optimum charging

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Nomenclature

x_i	the position of the ith onlooker bee
b	the iteration number
θ_i	the position of the ith employed bee which is selected by roulette wheel
θ_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]
θ_{ij}^{min}, θ_{ij}^{max}	the minimum and maximum limits of the ith parameter
γ	the absorption coefficient
β_0	the initial attractiveness
β	the attractiveness
α	the level of random noise
z	the distance between any two fireflies
I	the light intensity
J	the objective function
t	index of time periods running from 1 to N.
C_{loss}	the cost of energy loss
C_{grid}	the cost of energy imported from the main grid
C_{DG}	the cost of energy obtained from DG units
C_{gr}	the cost of garages charge/discharge energy
C_{s1}	the cost of energy imported from the main grid when the grid power is less than its maximum limit
C_{s2}	the cost of energy imported from the main grid when the grid power is greater than its maximum limit
$P_{loss}(t)$	the power loss at time t
$P_{grid}(t)$	the power obtained from the main grid at time t
$P_{grid\text{-}max}$	the maximum limit of the power obtained from the main grid
$P_{DG}(t)$	the power obtained from DG units at time t
$P_{DG\text{-}i}(t)$	the power obtained from the ith DG unit at time t
$P_{gr}(t)$	the garages charge/discharge power at time t
$P_{ch}(t)$	the garages charge power at time t
$P_{disch}(t)$	the garages discharge power at time t
$P_D(t)$	the demand power at time t
$SOC_i(t)$	the state of charge of the ith garage at time t
SOC_{max}	the maximum state of charge of a garage
SOC_{min}	the minimum state of charge of a garage
R_{ch}	the rate of charge of a battery
R_{disch}	the rate of discharge of a battery
V_i	the voltage magnitude at the ith bus
V_i^{max}, V_i^{min}	the maximum and minimum limits of bus voltage magnitude
S_{ij}	the power capacity in the ith distribution line
$S_{ij}{}^{max}$	the maximum power capacity of the ith distribution line
$P_{DG\text{-}i}^{min}$	the minimum output power of the ith DG unit
$P_{DG\text{-}i}^{max}$	the maximum output power of the ith DG unit
nbus	the number of system's buses
nline	the number of system's lines
ng	the number of DG units in the system

rate of PHEVs. However, the contribution of the PHEVs to support the grid with their stored energy was not addressed.

In this paper, an optimization algorithm is proposed to optimally determine the number of parking lots to be placed in a distribution system. The algorithm also determines the optimal locations and sizes of these parking lots taking into consideration two types of these lots, i.e. commercial and residential ones. The optimal charging and discharging scheme is also suggested so that the energy stored in the PHEVs support the network during heavy loading hours. The objective of the proposed algorithm is to minimize the overall cost of energy loss, energy transported from the main grid, energy supplied by the DGs and the net energy of charging/discharging the batteries of PHEVs. The problem is formulated as an optimization problem which is solved using artificial bee colony (ABC) algorithm and firefly algorithm (FA) taking into consideration the power system and PHEVs operational constraints.

The proposed algorithm is applied to a 33-bus radial distribution system. The test results show the effectiveness of the proposed algorithm to solve such complex problem. The results show also the improvement in the system operating conditions.

The remainder of this paper is organized as follows. Section 'Optimization algorithms' presents the background on the ABC and FA approaches. The problem formulation is detailed in Section 'Problem formulation'. In Sections 'ABC and FA application to the optimization problem' and 'Test results', the setup and optimization results obtained were commented, respectively. Finally, 'Section conclusion' concludes this paper briefly with remarks.

Optimization algorithms

This section describes the validated optimization approach. First, a brief overview of the ABC is provided, and then the FA is addressed.

Artificial bee colony optimization algorithm

The ABC optimization technique belongs to the group of swarm intelligence techniques. It was introduced in 2005 by Karaboga [7,8]. 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 [9]. The ABC algorithm is developed by simulating the behaviors of the real bees on finding food source, which is called the nectar, and sharing the information of food sources to the bees in the hive. The colony of artificial bees consists of three groups of bees which are the employed bees, the onlooker bees and the scout bees. Each of them plays different role in the process by flying around in a multidimensional search space representing the solution space. The employed bees randomly search for food source positions (solutions) and provide the neighborhood of the source in their memory. The onlooker bees get the information of food sources form the employed bees in the hive. Each onlooker bee selects one of the food sources exploited by the employed bees according to the quality of that food source. That means that good food source positions attract more bees. This phase of solution mimics the behavior of PSO in which each particle in the swarm uses the experiences and positions exploited by other particles. The last phase of ABC algorithm is the scout phase. The scouts control the exploration process where the scout bee is responsible for finding new food sources according to the foraging behavior of the honey bee. This phase of the algorithm mimics the mutation process of GA [9–11].

The ABC algorithm proceeds by setting one half of the colony size to be employed bees and the other half to be onlooker bees. Each cycle of the ABC algorithm consists of three steps [10,11]: