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Intelligent energy management of optimally located renewable energy systems incorporating PHEV

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ABSTRACT

The recent interest in plug-in-hybrid electric vehicles (PHEV) results in the increase in the utilization of vehicles batteries for grid support. In addition, the integration of renewable energy systems (RES) into electricity grid is a promising technique for addressing the environmental concerns. This paper presents a multi-objective algorithm to optimally allocate a number of renewable energy systems including parking lots for PHEV in a distribution system. The proposed algorithm determines the number, locations and sizes of the RES and parking lots. In addition, a rule based expert system is used to find 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) algorithm taking into consideration the power system and PHEV operational constraints. The proposed algorithm is applied to a 45-bus distribution network of Alexandria, Egypt. The test results indicate an improvement in the operational conditions of the system.

1. Introduction

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 [1]. In addition, 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 [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 Ref. [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 [7], an energy management strategy of a plug-in hybrid electric vehicle (PHEV) was developed where a rule-based optimal controller selected the appropriate operation mode. An energy management and control study of an electric vehicle charging station was presented in [8]. The authors considered energy management needs for charge and discharge of multiple electric vehicles simultaneously in a dynamic price framework. For vehicle-to-grid (V2G) frequency regulation services, authors in [9] proposed an aggregator that makes efficient use of the distributed power of electric vehicles to produce the desired grid-scale power. The cost arising from the battery charging and the revenue obtained by providing the regulation were investigated and represented mathematically. In [10], an intelligent method for scheduling usage of available energy storage capacity from plug-in-hybrid electric vehicles (PHEV) and electric vehicles (EV) was proposed. A scalable parking lot model was developed with different parameters assigned to fleets of vehicles. The size of the parking lot was assumed to be

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Nomenclature

x_i	the position of the *i*th onlooker bee
bi	the iteration number
θ_i	the position of the *i*th 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]
$\theta_{ij}^{\min}, \theta_{ij}^{\max}$	the minimum and maximum limits of the *i*th parameter
t	index of time periods running from 1 to *N*
a, *b*, *c*	fuel cost coefficients of diesel generators
C_{loss}	the cost of energy loss
C_{grid}	the cost of energy imported from the main grid
C_{UG}	the cost of energy obtained from utility owned generating units
C_D	the cost of energy obtained from diesel units
C_{PV}	the cost of energy obtained from PV units
C_W	the cost of energy obtained from wind 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
$P_{DS\text{-}i}(t)$	the power obtained from the *i*th diesel unit at time t
$P_{PV}(t)$	the power obtained from the PV unit at time *t*
$P_W(t)$	the power obtained from the wind unit at time *t*
$P_{UG}(t)$	the power obtained from utility owned diesel units at time *t*
$P_{UG\text{-}i}(t)$	the power obtained from the *i*th utility owned diesel unit at time *t*
$P_{DS}(t)$	the power obtained from placed diesel units at time *t*
$P_{DG}(t)$	the power obtained from DG units at time *t*
$P_{DG\text{-}i}(t)$	the power obtained from the *i*th 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 *i*th 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 *i*th bus
$V_i^{\max}, V_i^{\min}$	the maximum and minimum limits of bus voltage magnitude
S_{ij}	the power capacity in the *i*th distribution line
$S_{ij}^{\max}$	the maximum power capacity of the *i*th distribution line
$P_{DG\text{-}i}^{\min}$	the minimum output power of the *i*th DG unit
$P_{DG\text{-}i}^{\max}$	the maximum output power of the *i*th 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
NUG	the number of utility owned diesel units
NDS	the number of placed diesel units

large enough to accommodate the number of vehicles performing grid transactions. In addition, binary particle swarm optimization was applied to find the appropriate charge and discharge times throughout the day. Plug-in hybrid electric vehicles are a midterm solution to reduce the transportation sector's dependency on oil. However, if implemented in a large scale without control, peak load increases significantly and the grid may be overloaded. Two algorithms based on dynamic programming were proposed in [11] to address this problem. The first optimizes the charging time and energy flows. The latter also takes into account vehicle to grid support as a means of generating additional profits by participating in ancillary service markets. All the PHEVs have in common the batteries, which provide storage capability that can be used to effectively integrate wind power into the grid. By nature, wind power is intermittent which raises many challenges for the grid operator. The utilization of the storage from the PHEVs enables the power system operator to smooth out the output of the wind farms by storing energy when the wind power output is too high and releasing such energy when the power output is too low. Authors in [12] developed a probabilistic model to take into account the effect of the variability in the PHEV owner behavior and the fact that the PHEVs are not always plugged into the grid to show the positive levelization impact PHEVs can have on wind power operations when grouped in aggregations of large size.

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 Ref. [1], 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 [2] proposed a solution of the optimal DGs sitting and sizing problem. Thereafter, they selected one of the predetermined optimum sites 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 to be placed at the same site. The energy management algorithm considered an optimum charging 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. In addition, a number of distributed generation (DG) units are also optimally sited and sized. The DG units include PV, wind and diesel units. 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