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# Optimal scheduling of renewable micro-grids considering plug-in hybrid electric vehicle charging demand

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ABSTRACT

In this paper, the optimal energy management of MGs (micro grids) including RESs (renewable energy sources), PHEVs (plug-in hybrid electric vehicles) and storage devices is studied by a new stochastic framework that considers the uncertainties in modelling of PHEVs and RESs using the well-known Monte Carlo simulation. In order to see the influence of different charging behaviours of PHEVs in the MG, three different charging patterns including uncontrolled, controlled and smart charging schemes are investigated. To study the optimal operation of the MG including the natural stochastic behaviour of the uncertain parameters, a new robust and powerful SOS (Symbiotic Organisms Search) algorithm is applied too. SOS simulates the interactions observed among natural organisms relying on other organisms to survive. In addition, a new modified version of the SOS algorithm is suggested to increase its total search ability in the local and global searches successfully. The performance of the proposed method is examined on two typical MG test systems with different scheduling time horizons. The results of applying the proposed method on the case studies are compared to other algorithms in different conditions with and without the PHEV charging effects.



## 1. Introduction

The recent tendencies in the power systems has been toward the socioeconomic growth and avoiding environmental concerns, aiming at higher power quality, more reliable services and increased energy efficiency especially in the distribution level [1–3]. The response to these issues necessitates the use of alternative energy sources particularly the energy which can be renewed including PVs (photovoltaics) and WTs (wind turbines). Moreover, other types of DGs (distributed generations) such as FCs (fuel cells) and MTs (micro turbines) have opened new insights for having active power systems with higher efficiencies in the near future [4,5]. Considering these into account, MG which consists of several alternative sources can be considered as a principal device to attain the favourable targets while distributing electricity more efficiently, successfully and securely. The MG concept undertakes a cluster of loads and Micro-Sources operating as a single controllable module that can offer either power or heat locally [6]. In other words, MG idea considers and manages part of the challenges and benefits generated by the application of DGs in the new smart grids. As a result, in recent years, the investigations on MG have widely and rapidly appeared in the literature. Hafez et al. investigated a renewable MG from the planning, design and operation perspective in order to minimise the expenses during the MG lifetime [7]. Pipattanasomporn et al. studied the practical application of an agent-based technique for flexible operation of a MG that has PV system joined with battery storage [8]. In Ref. [9], Morais et al. implemented an optimal operation technique for a renewable MG to optimise the performance of the supply using a mix-integer linear programming by applying the right timing. In Ref. [10] an optimal energy management of a renewable MG laboratory over a seven day period was investigated and an intelligent deterministic minimisation method was implemented. In Ref. [11] MG in interconnected mode of operation was studied to optimize the local production and exchanged power under various market policies. Chen et al. minimised the MG cost by planning forecast, storage and optimisation modules and application of a real-coded genetic algorithm [12]. Dukpa et al. proposed a contribution policy to participate in the day-ahead unit commitment in a MG based on WT and storage battery [13]. In Ref. [14] the improvement in the life

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**Nomenclature**

| | |
|---|---|
| $AER$ | All-Electric Range is the maximum distance which a PHEV can travel on the battery |
| $B_{Gi}(t)$ | The bid of *ith* DG at time $t$ |
| $B_{Sj}(t)$ | The *jth* storage device bid at time $t$ |
| $BF_{1,2}$ | Factor indicating the mutual benefit to the organism $X_i$ |
| $B_{Grid}(t)$ | Utility bid at time $t$ |
| $C_{bat}$ | Battery capacity of PHEV |
| $Itr$ | Iteration number |
| $Levy$ | Levy flight movement in the optimization |
| $m$ | Daily driven mile of PHEV |
| $maxDOD$ | Maximum depth of discharge in PHEV battery |
| $MV$ | The relationship characteristic between organism $X_i$ and $X_j$ |
| $M_P$ | Column-wise mean value of the population |
| $n$ | Number of the state variables |
| $N_g$ | Number of generating units |
| $N_s$ | Number of storage devices |
| $N_L$ | Total number of load levels |
| $N_{PHEV}$ | Total number of PHEVs |
| $P$ | Rate of PHEV charger |
| $P_s$ | Vector including the active power of storage devices |
| $P_g$ | Vector including the power generation of all power units |
| $P_{G,i}(t)$ | Active power production of *ith* power unit |
| $P_{s,j}(t)$ | Active power of *jth* storage device at time $t$ |
| $P_{G,i,min}(t)$ | Minimum active power production of *ith* power unit at $t$ |
| $P_{G,i,max}(t)$ | Maximum active power production of *ith* power unit at $t$ |
| $P_{s,charge}(t)$ | Amount of active power charge of storage device at time $t$ |
| $P_{s,discharge}(t)$ | Amount of active power discharge of storage device at time $t$ |
| $P_{Grid,min}(t)$ | Minimum active power production of the grid at $t$ |
| $P_{Grid,max}(t)$ | Maximum active power production of the grid at $t$ |
| $P_{L,k}(t)$ | The amount of *kth* load value at time $t$ |
| $P_{PHEV,l}$ | The amount of *lth* PHEV power consumption at time $t$ |
| $P_{charge}/P_{discharge}$ | Permitted rate of charge/discharge during a finite time period ($\Delta t$) |
| $P_{charge,max}/P_{discharge,max}$ | Maximum permitted rate of charge/discharge during a finite each time period ($\Delta t$) |
| $rand$ | Random number in the range [0,1] |
| $S_{Sj}(t)$ | Start-up/Shut down cost of *jth* storage device at time $t$ |
| $S_{Gi}(t)$ | Start-up/Shut down cost of *ith* DG at time $t$ |
| $S_{Grid}(t)$ | Active power bought (sold) from (to) the utility at time $t$ |
| $SOC$ | State of the charge in PHEV battery |
| $t_{start}$ | Charging start time of PHEV |
| $t_D$ | Charging duration of PHEV |
| $T$ | Number of time intervals |
| $T_F$ | Random integer equal to 1 or 2 |
| $u_i(t)$ | State of the *ith* unit denoting ON/OFF statuses |
| $U_g$ | Vector including ON/OFF statuses of all power units |
| $W_{ess}(t)$ | Amount of stored energy inside the battery at time $t$ |
| $W_{ess,max}/W_{ess,min}$ | Maximum/Minimum stored energy inside the battery |
| $X$ | State variables vector |
| $X_i$ | *ith* organism in the ecosystem |
| $X_{best}$ | Organism with highest degree of adaptation in the ecosystem |
| $X_{inew}$ | The result of biological interaction on organism $X_i$ |
| $\eta$ | efficiency of PHEV charger |
| $\eta_{charge}/\eta_{discharge}$ | Battery efficiency during charge/discharge period |
| $\sigma/\mu$ | Log-normal pdf parameters for PHEV smart charging |
| $\sigma_m/\mu_m$ | Log-normal pdf parameters for PHEV daily mileage |
| $\varphi 1$ | Random number in range of [0,1] |
| $\omega$ | Constant parameter in the range [1,3]. |

*List of abbreviations*

| | |
|---|---|
| DG | distributed generation |
| FC | fuel cell |
| MG | micro-grid |
| MT | micro turbine |
| NiMH-Battery | Nickel-Metal-Hydride Battery |
| PV | photovoltaic |
| PHEV | plug-in hybrid electric vehicle |
| PDF | probability density function |
| RES | renewable energy source |
| SOS | symbiotic organisms search |
| MSOS | modified SOS |
| WT | wind Turbine |

of storage devices was investigated as part of cost optimisation in a typical MG. In Ref. [15] a novel technique based on the linear programming was devised to optimise the average production cost of a compound wind-solar MG. Nevertheless, in spite of the great efforts on the MG investigations, one of the deficiencies of the previous works is the lack of consideration of PHEVs as a fundamental part of future MG loads. It is worth noting that the recent improvements in the PHEV technology have attracted the attention of many researchers worldwide [16]. The recent reports show promising progress in the technology of PHEVs [17,18]. Some of the researches on PHEV charging demand and their integration in the power system can be found in Refs. [19–21]. Therefore, PHEVs will have a significant role in the future of MGs which requires accurate analysis to operate and schedule these systems optimally.

Based on the above discussion, this paper investigates the charging effect of PHEVs on the MG and their role in the MG operation. The high integration of PHEVs will affect the optimal operation of these vehicles in the MGs especially as a result of the high uncertainty injected from the driver behaviour for charging the vehicle. With this regard, Monte Carlo simulation method is applied to manage the uncertainties in the MGs in a reliable environment. Here we make use of proper probability density functions to model the uncertainties of the parameters. Considering these facts, finding the optimal solution of the operation management problem in the MG is a challenging problem in presence of the PHEVs. This situation necessitates the use of a capable optimisation algorithm to search for the global optimum in the wide search space. Consequently, the new SOS (symbiotic organisms search) algorithm is presented to globally solve the presented problem. SOS is a metaheuristic algorithm based on natural organisms' interaction to survive. Although the SOS idea is simple however it provides a proper balance between local and global search and can be