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Evaluation of different initial solution algorithms to be used in the heuristics optimization to solve the energy resource scheduling in smart grids

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ABSTRACT

Over the last years, an increasing number of distributed resources have been connected to the power system due to the ambitious environmental targets, which resulted into a more complex operation of the power system. In the future, an even larger number of resources is expected to be coupled which will turn the day-ahead optimal resource scheduling problem into an even more difficult optimization problem. Under these circumstances, metaheuristics can be used to address this optimization problem. An adequate algorithm for generating a good initial solution can improve the metaheuristic's performance of finding a final solution near to the optimal than using a random initial solution. This paper proposes two initial solution algorithms to be used by a metaheuristic technique (simulated annealing). These algorithms are tested and evaluated with other published algorithms that obtain initial solution. The proposed algorithms have been developed as modules to be more flexible their use by other metaheuristics than just simulated annealing. The simulated annealing with different initial solution algorithms has been tested in a 37-bus distribution network with distributed resources, especially electric vehicles. The proposed algorithms proved to present results very close to the optimal with a small difference between 0.1%. A deterministic technique is used as comparison and it took around 26 h to obtain the optimal one. On the other hand, the simulated annealing was able of obtaining results around 1 min.

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1. Introduction

Presently, the planning and operation of the power systems deal with diversity of distributed energy resources, due to the increasing use of distributed generation (DG) units, mainly based on renewable sources [1]. In the future, the integration of storage units, demand response (DR) programs on the consumers side and namely the increasing penetration of electric vehicles (EVs) will also influence the power systems planning and operation [2]. The integration of these new distributed resources in power systems will require specific technical conditions to be satisfied. The introduction of new players in a smart grid context [3] is expected to help in the fulfilment of those conditions. The smart grid and all its related elements are the adequate environment to deal with the new changes in the power system and new uncertainties related with the distributed energy resources [4]. Smart grids are intended to co-ordinate the needs and capabilities of resources, network operators, consumers, aggregator player and electricity market stakeholders to operate the power system as efficiently as possible, minimizing costs and environmental impacts while maximizing the power system reliability, resilience and stability [5].

The intermittent power generation of renewable sources based DG units is one of the problems that affects more the planning and operation of the power systems [6]. The integration of EVs with vehicle-to-grid (V2G) technology [7] (i.e. ability to discharge from the EV battery to the network) can help to deal with this

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Nomenclature

Parameters

α	Cooling rate
η_c	Grid-to-vehicle efficiency
η_d	Vehicle-to-grid efficiency
B	Imaginary part in admittance matrix [S]
c_A	Fixed component of cost function [m.u./h]
c_B	Linear component of cost function [m.u./kW h]
c_C	Quadratic component of cost function [m.u./kW h^2]
c	Resource cost in period t [m.u./kW h]
E	Stored energy in the battery of vehicle at the end of period t [kW h]
$E_{Initial}$	Energy stored in the battery of vehicle at the beginning of period 1 [kW h]
E_{Trip}	Energy consumption in the battery during a trip that occurs in period t [kW h]
G	Real part in admittance matrix [S]
L^i	Set of lines connected to bus i
N	Total number of resources
S_{Lk}^{max}	Maximum apparent power flow in line k [kVA]
T	Total number of periods
$\overline{U}$	Voltage in polar form [V]
$\overline{y}$	Series admittance of line that connects two buses [S]
$\overline{y_{sh}}$	Shunt admittance of line that connects two buses [S]

Variables

θ	Voltage angle
P	Active power [kW]
Q	Reactive power [kVAr]
S	Apparent power [kVA]
V	Voltage magnitude [V]
X	Binary variable

Indices

B	Bus
BatMax	Battery energy capacity
BatMin	Minimum stored energy to be guaranteed at the end of period t
Ch	Charge process
Dch	Discharge process
Deg	Battery degradation
DG	Distributed generation unit
DGForecast	Forecast power of distributed generation unit in period t
DR_A	Demand response program for loads with continuous regulation
DR_B	Demand response program for loads with discrete regulation (on/off)
EV	Electric vehicle
GCP	Generation curtailment power
i , *j*	Bus i and bus j
L	Load
Max	Upper bound limit
Min	Lower bound limit
NSD	Non-supplied demand
SP	External supplier
ST	Storage unit
Stored	Stored energy in the battery of the vehicle
TFR_HV_MV	Transformer that connects from high voltage to medium voltage
TFR_MV_LV	Transformer that connects from medium voltage to low voltage

intermittent behaviour of the renewable sources [8]. EVs are parked approximately 96% of the time and in only 4% of the time the vehicles are travelling [7]. Thus, EVs can be used most of the time to store in their batteries the surplus of energy produced by renewable sources. In the following periods, EVs can use this extra stored energy to inject in the network, which will compensate the intermittency of the renewable sources. On the other hand, the network operators must guarantee a minimum amount of stored energy in the EVs batteries with the goal of supporting their daily trips [9].

In future scenarios of intensive distributed resources penetration (e.g. DG and EVs), the power system is expected to have a more complex planning and operation, in which the day-ahead optimal resource scheduling problem is of utmost importance. The optimal resource scheduling is characterized by obtaining the optimal dispatch of the available resources considering a certain objective function while satisfying the forecasted consumer demand. Typically, the minimization of the operation cost is used as objective function [10]. The increasing number of energy resources makes the optimal resource scheduling a large dimension and complex problem with several local optima, in which the task of obtaining the global optimum will be more difficult [11]. For these large dimension and complex problems, a deterministic technique can take several hours or even days to determine the optimal dispatch [12]. Therefore, artificial intelligence (AI) techniques, mainly metaheuristics, have been applied to deal with large dimension and complex optimization problems. Metaheuristics like tabu search, simulated annealing (SA), genetic algorithm (GA), particle swarm optimization (PSO) and artificial immune system have been used to solve many power system problems, as it is discussed in Ref. [13]. In Refs. [14,15] the use of PSO to handle unit commitment related to EVs penetration is proposed. Ghanbarzadeh et al. [16] also applied PSO for dealing with the resource scheduling problem (based on a unit commitment perspective) with EVs penetration in the network. On the other hand, authors in Ref. [17] implemented GA to optimize the EVs charging considering the minimization of the operation cost while taking into account the network constraints. Although these techniques cannot ensure finding the global optimum [18], they use less memory and execution time than deterministic approaches. However, these metaheuristic techniques can be conveniently improved by adjusting the different parameters of each technique and, most importantly, by using good initial solutions in order to reduce the convergence effort of the optimization methods [19]. Proper initial solutions can provide solutions near the optimal one with a low execution time, solving some of the drawbacks of the metaheuristics [20]. In the initial solution, it is possible to incorporate other techniques (AI or deterministic) leading to a hybrid metaheuristic, which combines the best features of both techniques, therefore providing better results than traditional metaheuristics used to solve individually the optimization problem [21].

The main contribution of this paper is the evaluation of the SA algorithm effectiveness and efficiency considering different initial solution algorithms. Five different algorithms are developed to find the initial solution namely: (1) random solution (base case); (2) Ant colony optimization; (3) Naive-scheduling heuristic; (4) Pre-scheduling heuristic; (5) Mixed-integer linear programming. The pre-scheduling and mixed-integer linear programming heuristics are two new algorithms applied for this optimization problem that are proposed in this paper. The second and fifth algorithms turn the SA algorithm into a hybrid heuristic. This aspect of incorporating good strategies in the initial solutions is even more important in local-based metaheuristics, like the SA algorithm. In fact, these techniques do not have the same characteristics as population-based algorithms (e.g. GA and PSO) which use several individuals

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