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Improved gravitational search algorithm for unit commitment considering uncertainty of wind power

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ABSTRACT

With increasing wind farm integrations, unit commitment (UC) is more difficult to solve because of the intermittent and fluctuation nature of wind power. In this paper, scenario generation and reduction technique is applied to simulate the impacts of its uncertainty on system operation. And then a model of thermal UC problem with wind power integration (UCW) is established. Combination of quantum-inspired binary gravitational search algorithm (GSA) and scenario analysis method is proposed to solve UCW problem. Meanwhile, heuristic search strategies are used to handle the constraints of thermal unit for each scenario. In addition, a priority list of thermal units based on the weight between average full-load cost and maximal power output is utilized during the optimization process. Moreover, two UC test systems with and without wind power integration are used to verify the feasibility and effectiveness of the proposed method as well as the performance of the algorithm. The results are analyzed in detail, which demonstrate the model and the proposed method is practicable. The comparison with other methods clearly shows that the proposed method has higher efficiency for solving UC problems with and even without wind farm integration.

1. Introduction

With the high requirements and strict quality control for managing electricity restructuring, great changes are occurring in the electric power industry. One of the major aspects is that the impact of this industry on energy, environment, and economy requires more efficient, less pollutant, and less costly means of power generation. As wind energy is friendly to environment and it has renewable nature, more and more efficient, reliable and economical wind turbines have been developed to solve this problem. And wind power is considered one of the most mature renewable energy generation techniques, which is also regarded as the most effective energy in economic benefits. However, the wind power is a kind of energy also has the nature of fluctuation and unpredictability. Due to those uncertainty characteristics, the ever-increasing level of wind penetration to power system makes the system operation a challenging task. As the supply and demand on power grid should be kept balance to guarantee the stability of the power frequency and user requirement. And this balance is relatively easy to be satisfied in traditional thermal power system as the generation output of thermal unit is controllable. However, in thermal-wind power system, the fluctuant power output produced by wind turbines should be compensated by thermal units. To avoid wind power waste or dissatisfaction of user requirement, the adjustment ability of thermal units should be kept in an appropriate level according to the security demand of power grid. To ensure the security, some measures should be taken. One aspect of them is the set of additional power reserve capacity. Due to the inaccuracy of wind power prediction, emergence spinning reserve is indispensable for system reliability. And the system spinning reserve should not only consider the up spinning reserve but also take the down spinning reserve into account. In addition, the system should have enough ramping capacity to compensate the wind power fluctuations. To investigate the impact of huge wind penetration on power system operation, we take unit commitment (UC) [1–4] as the model which plays an important role in the operation planning of power systems.

To solve the UC problem, many methods have been proposed, such as mixed-integer linear programming (MILP) [5,6], second-order cone programming (SOCP) [7], memetic algorithm (MA) [8], genetic algorithm (GA) [9],binary particle swarm optimization [10,11], bacterial foraging (BF) [12], discrete differential evolution approach [13] and so on. But those models only took the thermal generation into account and did not consider the impact of wind

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Nomenclature

a_i, b_i, c_i	fuel cost coefficients of thermal unit i
Gi	thermal unit i
Si	scenario i
N_s	number of scenarios after scenario reduction
T	number of time intervals in the planning horizon
N_g	number of thermal units
N_w	number of wind units
NP	population number of QBGSA
U_{np}	candidate solution of each agent in QBGSA
$f(P_{i,t}^s)$	fuel cost function of thermal unit i at time t in scenario s ($)
$S_{i,t}$	start-up cost of thermal unit i at time t ($)
F_N	total cost of objective ($)
FC^s	total fuel cost of scenario s ($)
S_i^{hot}	hot startup cost of thermal unit i($)
S_i^{cold}	cold startup cost of thermal unit i ($)
USR_t^s	up spinning reserve at time t in scenario s (MW)
DSR_t^s	down spinning reserve at time t in scenario s (MW)
UR_i	ramp-up capacity of thermal unit i(MW/h)
DR_i	ramp-down capacity of thermal unit i (MW/h)
MUT_i	minimum up time of thermal unit i (h)
MDT_i	minimum down time of thermal unit i (h)
P_i^{max}	maximum generation limit of thermal unit i (MW)
P_i^{min}	minimum generation limit of thermal unit i (MW)
$T_{i,t}^{on}$	continuously on time of thermal unit i up to time t (h)
$T_{i,t}^{off}$	continuously off time of thermal unit i up to time t (h)
$P_{d,t}$	system load demand at time t (MW)
$P_{i,t}^s$	generation output of thermal unit i at time t in scenario s (MW)
$W_{f,t}$	forecasted wind power at time t (MW)
$W_{j,t}^s$	generation output of wind unit j at time t in scenario s (MW)
$W_{d,t}^s$	total wind power output at time t in scenario s (MW)
η	minimum reserve level to support generator outages and forecast errors in electrical demand
us%	percentage of wind generation contributing to up spinning reserve requirements
ds%	percentage of wind generation contributing to down spinning reserve requirements
rand	random number in the interval [0, 1]
p_s	probability of scenario s
Sce(s)	performance index of scenario s
π_i	priority index of thermal unit i

power on system operation. In order to investigate this impact, some researchers have put forward models to solve thermal UC problem with wind power integration (UCW). Refs. [14,15] proposed different methods to solve UCW and special reserve constraints were established to protect the system security in a required level which was mainly affected by the wind fluctuation. But they didn't take the influence of wind fluctuation on system operation into account, and the imposed constraints on system operation will result in an increase of operation cost. In Refs. [16,17], the possible wind power outputs which decided by the wind fluctuation rule were represented by a scenario tree, but it was considered asinefficiency because of this method creating numerous variables even for a small scenario tree. Authors in Refs. [18,19] applied a chance constrained programming formulation to deal with the wind volatility assuming the wind power output obeyed a certain distribution. However, the constraints which contained wind power output should be described as probability inequalities in this method and the system reliability was too much affected by the predetermined probability level. In Refs. [20,21] authors presented an energy storage system to solve the negative effects of the wind fluctuation on system operation, but it also added extra cost on energy storage equipment.

To avoid the disadvantages of the models introduced above in simulating the impact of wind power fluctuation, this paper utilizes an efficient method which combines Latin hypercube sampling (LHS) with Cholesky decomposition (LHS-CD) to generate huge different scenarios to simulate the wind uncertainty. In this method, scenarios are generated according to the forecasted wind power and its prediction error at each time stage. Each scenario has a certain possibility and contains several numbers of wind power outputs which have a one-to-one relationship with the time intervals. In other words, each scenario represents a possible set of wind power outputs over the whole time intervals. In addition, an efficient simultaneous backward scenario reduction technique based on probability metrics is utilized to decrease the number of scenarios to a smaller scale as a tradeoff between calculation time and simulation accuracy. With this technique, the simulation accuracy of wind fluctuation is well guaranteed by the scenarios and the calculation complexity is controlled significantly by using LHS-CD compared with those of scenario trees.

To overcome the imperfection of traditional methods in solving some high-dimension complex problems, some new methods have been proposed to substitute the existed algorithms. In recent years, a new optimization method known as gravitational search algorithm (GSA) [22] proposed by Esmat Rashedi et al. in 2009 has become a candidate for optimization application due to its flexibility and efficiency, which is based on the Newton's law of gravity and law of motion. GSA has been verified good quality performance in solving different optimization problems, such as future oil demand forecasting [23] and synthesis gas production [24], parameter identification [25] and optimal reactive power dispatch [26] in power system. However, application of GSA in combinatorial optimization problem is still limited. The major obstacle of successfully applying GSA to combinatorial problem is due to its continuous nature. To remedy this drawback, binary coding GSA (BGSA) [27] has been proposed as a feasible tool to deal with the discrete problems. And the merit of the BGSA has been tested for solving various nonlinear benchmark functions. But the standard BGSA has its disadvantage of easily trapping into local best solution especially for large-scale problems, which is resulted from its imperfect internal searching rule. And this deficiency has been relieved in some degree by the newly proposed quantum-inspired binary gravitational search algorithm (QBGSA) [28], which has been utilized to solve the optimal PQM placement problem in power systems. Motivated by these studies and the special situation of this wind integrated UC problem, this paper has made an attempt to propose a method for UCW by means of the QBGSA and scenario analysis method. Considering the reliability of the system operation, which is affected by the wind power fluctuation, as well as the economic operation of the system, the proposed method is aimed at optimizing a unit state combination which can satisfy all of the constraints under different scenarios with the least average operation cost. Then a unique scenario with the best merit for system operation is selected as a representation of wind power output. Finally, the power generation scheduling is achieved on the basis of the unit state combination and the selected scenario. What's more, the