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A solution to the generation scheduling problem in power systems with large-scale wind farms using MICA

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ABSTRACT

This paper presents a novel solution, based on the Imperialistic Competition Algorithm (ICA), in order to determine the feasible optimal solution of the Generation Scheduling (GS) problem, in power systems with large scale wind farms. The reserve requirement, load balance and wind power availability constraints are considered in this work. In order to solve a highly constrained GS problem, a modified version of ICA is introduced to improve the initialing new countries and assimilation operators of ICA. The proposed MICA is applied on different test systems, with different wind energy penetration level. The results are compared with other methodologies and the comparison demonstrates the validity and efficiency of the proposed method, which results in near optimal schedules, while considering different equality and inequality constraints.

1. Introduction

In recent years, due to the growing markets for electrical energy, and the rapid increases in fossil fuel costs, an immediate need is created to explore new energy sources for electricity generation. Wind and solar energy have been identified as the most favorable power sources, capable of converting to electricity. This paper considers electricity Generation Scheduling (GS) with large-scale wind farms to minimize the total cost during specific periods of time.

The GS is a complex problem, which consists of two main sub problems; the unit commitment and the economic dispatch. It involves the arrangement of the minimum operation cost plan for scheduling periods. In other words, the main aim of GS problem is to decide on the commitment and generation of available power resources, during a scheduling horizon, to minimize the overall generation costs. GS problem is constrained with system demands and reserve requirements [1]. Since the fuel cost is the most significant part in expenses of conventional generators, decreasing the required fuel amount results in savings a large amount of money per year for companies.

The most urgent mission in the operation of a power system, involves the optimal GS, is considering technical and economical constraints over a planning time, one hour up to a few years. Finding the absolute solution, for a long term GS, is almost impossible due to extreme calculating time and many constraints. On the other hand, figuring short-term GS, to long term period scheduling, is not suitable due to several neglected constraints.

GS problem can solve exactly by checking all possible solution in realistic power system [1]. GS problem is a very large-scale, nonlinear and mixed-integer problem due to several feasible plans. Also it is an inaccurate planning due to the prediction errors, especially in systems with highly wind energy penetration. Several mathematical programming and investigative approaches have been suggested such as dynamic programming [2], evolutionary programming [3], simulated annealing [4], genetic algorithm [5,6], lagrangian relaxation [7–10], Tabu search[11] and partial swarm optimization[12–16]. Researchers have used a fuzzy logic based method, as an efficient choice for solving UC problem [17–19].

Imperialistic Competition Algorithm (ICA) is introduced in 2007, by Atashpaz-Gargari and Lucas [20]. ICA starts with an initial population, as other evolutionary algorithms, such as PSO or GA. In this methodology, the population, which called countries, is in two types: colonies and imperialists. Each imperialist together with some colonies form empires. ICA is based on an Imperialistic competition among these empires and reaching a condition, in which there is just one empire and all the countries have same position. The last country is the best result and output of optimization problem. ICA validity has been proved by testing on different benchmark functions [20] and optimization problems, in power systems, such as DG placement [21,22], non-convex dynamic economic power dispatch [23], capacitor placement [24] and transmission expansion planning [25].

This paper presents a solution for GS problem with some extra constraints, due to large wind farm presence, using Modified

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Nomenclature

a_{gi}, b_{gi}, c_{gi}	cost coefficients
e_i, h_i	coefficients of valve-point effects for unit i
p_t^i	output power of unit i at time t
F_t^i	fuel cost of thermal unit i at time t
$(C_V)_t^i$	variable cost for unit i at time t
$OMVC_i$	operational and maintenance variable cost of ith generator
$(C_F)_t^i$	fixed cost of unit i at time t
P_{max}^i	maximum output of generation unit i
$OMFC_i$	fixed cost of operation and maintenance cost of ith generator
$(C_V)_t^j$	variable cost for jth *wind farm* at time t
N_{gwind}	number of wind generation units
$OMVC_j$	variable cost of operation and maintenance of jth wind units
P_t^j	output power of jth wind unit
T	number of scheduling time intervals
$U_i(t)$	the commitment state of ith thermal units at time t
$V_j(t)$	the commitment state of jth wind farms at time t
P_t^{demand}	power demand at time t
P_{min}^i	minimum power of ith thermal unit
P_{max}^i	maximum power of ith thermal unit
P_{max}^j	maximum output power of jth wind farm
WR	constant value for Wind Reserve
LR	constant value for Load Reserve
N_{Themal}	number of thermal generation units
$\left(P_{Wind}^j\right)_t$	the output power of jth wind farm at time t
$\left(P_{Thermal}^i\right)_t$	the output power of ith thermal unit at time t
$(P_{Diff})_t$	difference of demand and generators output power
$Rand$	random number, uniformly distributed in [0,1]
$\left(R_{Thermal}^i\right)_t$	the reserve power of ith thermal unit at time t
$(R_{Total})_t$	total reserve power of thermal units at time t
$(R_{demand})_t$	demanded reserve power of thermal units at time t
$T.C._n$	total power of nth empire
ξ	impact factor of colonies power
$\vec{\alpha}_1$, $\vec{\alpha}_2$	predefined constant values
$\vec{A}_1$	vectors from colony toward imperialist
$\vec{A}_2$	vectors from colony toward most powerful colony
x	random variable with uniform distribution

Imperialist Competitive Algorithm (MICA). In the proposed MICA, two steps are modified, in order to handling different operating and technical constraints. The first modification is applied in generating new countries step, in order to initial new countries with feasible variables. The second modification is applied on assimilation part. The goal this modification is setting the variables based on their upper and lower limits while satisfying demand balance constraints. Due to large scale non-linear problem, a new assimilation mechanism is introduced to prevent local extrema trappings. The proposed methodology is applied on different test cases with different wind energy penetration levels. The results are compared with other methods, which have been applied to the GS problem. The results evaluate the proposed MICA capability in solving GS problem.

The remainder of paper is as follow. A brief review of wind turbine characteristic is presented in Section 2. Section 3 is about GS problem formulations and constraints. Introducing and Application of MICA for solving the GS problem is presented in Section 4. The simulation results of case studies are reported in Sections 5 and 6 concludes the paper.

2. Wind turbine

Each wind farm includes many wind turbines. The generated power by wind turbines varies as a function of the wind speed. Each wind turbine has its own power curve, which is the diagram of output generated power against the wind speed, as shown in Fig. 1. A turbine starts to power generation at the cut-in wind speed (V_{ci}) and shut down at the cut-out wind speed (V_{co}). When the wind speed is between the rated wind speed (V_r), and the cut-out wind speed, the turbine generates its rated power (P_r). The relationship between the output power and the wind speed is a nonlinear curve, when the wind speed is between the cut-in speed and the rated speed. The turbine output power at a given wind speed can be modeled as follows:

$$P_{out} = P_{rated} \times \left\{ \begin{array}{ll} 0 & 0 \leqslant WS < V_{ci} \\ A + B \times WS + C \times WS^2 & V_{ci} \leqslant WS < V_{rated} \\ 1 & V_{rated} \leqslant WS < V_{co} \\ 0 & V_{co} \leqslant WS \end{array} \right\} \tag{1}$$

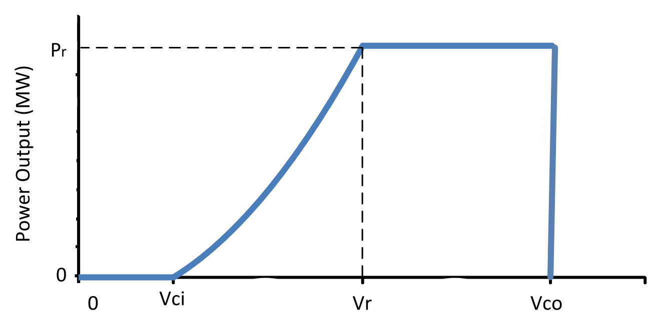

Fig. 1. Power curve of a wind turbine.

where A, B and C are constant values, which can be calculated as follows [26]:

$$A = \frac{1}{(V_{ci} - V_{rated})^2} \left\{ V_{ci}(V_{ci} + V_{rated}) - 4V_{ci}V_{rated}\left[\frac{V_{ci} + V_{rated}}{2V_{rated}}\right]^3 \right\} \tag{2}$$

$$B = \frac{1}{(V_{ci} - V_{rated})^2} \left\{ 4(V_{ci} + V_{rated})\left[\frac{V_{ci} + V_{rated}}{2V_{rated}}\right]^3 - (3V_{ci} + V_{rated}) \right\} \tag{3}$$

$$C = \frac{1}{(V_{ci} - V_{rated})^2} \left\{ 2 - 4\left[\frac{V_{ci} + V_{rated}}{2V_{rated}}\right]^3 \right\} \tag{4}$$

3. GS problem formulation

The objective of GS problem is minimizing the total operating cost of the generating units in a power system, along the scheduling periods, while the results satisfying number of operating constraints. Due to the monthly intervals (longer intervals), the ramp rate and minimum up/down constraints on the output of the generating units is ignored. The generation cost is the sum of