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Binary Grey Wolf Optimizer for large scale unit commitment problem

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ABSTRACT

The unit commitment problem belongs to the class of complex large scale, hard bound and constrained optimization problem involving operational planning of power system generation assets. This paper presents a heuristic binary approach to solve unit commitment problem (UC). The proposed approach applies Binary Grey Wolf Optimizer (BGWO) to determine the commitment schedule of UC problem. The grey wolf optimizer belongs to the class of bio-inspired heuristic optimization approaches and mimics the hierarchical and hunting principles of grey wolves. The binarization of GWO is owing to the UC problem characteristic binary/discrete search space. The binary string representation of BGWO is analogous to the commitment and de-committed status of thermal units constrained by minimum up/down times. Two models of Binary Grey Wolf Optimizer are presented to solve UC problem. The first approach includes upfront binarization of wolf update process towards the global best solution (s) followed by crossover operation. While, the second approach estimates continuous valued update of wolves towards global best solution(s) followed by sigmoid transformation. The Lambda-Iteration method to solve the convex economic load dispatch (ELD) problem. The constraint handling is carried out using the heuristic adjustment procedure. The BGWO models are experimented extensively using various well known illustrations from literature. In addition, the numerical experiments are also carried out for different circumstances of power system operation. The solution quality of BGWO are compared to existing classical as well as heuristic approaches to solve UC problem. The simulation results demonstrate the superior performance of BGWO in solving UC problem for small, medium and large scale systems successfully compared to other well established heuristic and binary approaches.

1. Introduction

The unit commitment problem comprises the efficient utilization of generation resources in power system operational planning. The UC problem is a cost minimization problem which is often expressed as optimization problem associated with various types of constraints with respect to system as well as operation of generation units. The UC problem is a complex optimization problem associated by many constraints like load, reserve balance constraints, power generation bounds, minimum up and down time constraints, ramp rate constraints etc. The complexity of UC problem is greatly affected by system dimension and constant thrust to better the solution quality is indispensable.

The earliest methods to solve the UC problem included classical optimization methods like mixed integer linear programming (MILP) [1], Dynamic programming (DP) [2], Priority list approach (PL) [3], branch and bound approaches (BB) [4]. Some of other approaches include dynamic programming with Lagrangian relaxation (DPLR) [5], extended Lagrangian relaxation (ELR) [5], extended priority list (EPL) [6], semidefinite Programming (SDP) [7] etc. The list of advantages of classical methods lies in their simplest forms of representation and application, fast convergence and integer solutions etc. However, suffer from major drawbacks with poor solution quality (PL approach), problems with system dimensionality (dynamic and linear programming), exponentially increasing execution time with system dimension (branch and bound) etc. The same resulted in origin of several nature/bio inspired evolutionary and heuristic approaches.

The evolutionary and heuristic approaches are developed by mimicking nature phenomenon. The same are adapted to solve UC problem successfully. Some of the heuristic approaches include genetic algorithm (GA) which functions on the principles of natural selection and biological evolution of offspring of every generation [8]. Whereas, approaches like particle swarm optimization (PSO) [9], ant colony optimization (ACO) mimics the social behaviour and coordination among the population [10]. In the similar lines of inspiration from nature, many other optimization approaches like

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Nomenclature

N	Number of units
H	Total number of scheduling hours
i	Thermal unit index (i = 1,2,3…. N)
h	Scheduling hour index (h = 1,2,3…. H)
F_c^i	Fuel cost function of i^{th} unit
γ_i^h	Status bit (0 or 1) of i^{th} unit for h^{th} hour
SU_i^h	Start-up cost of i^{th} unit for h^{th} hour
P_i^h	Scheduled power of i^{th} unit for h^{th} hour
SU_i^{hot}	Hot start-up cost of i^{th} unit
SU_i^{cold}	Cold start-up cost of i^{th} unit
T_i^{MD}	Minimum down time of i^{th} unit
T_i^{MU}	Minimum up time of i^{th} unit
$T_i^{h,off}$	Consecutive hours of de-committed state of i^{th} unit going into h^{th} hour
$T_i^{h,on}$	Consecutive hours of committed state of i^{th} unit going into h^{th} hour
P_i^{min}	Minimum generation limit of i^{th} unit
P_i^{max}	Maximum generation limit of i^{th} unit
P_d^h	System load for h^{th} hour
R_{sp}^h	Spinning reserve requirement for h^{th} hour
R_i^{DR}	Ramp down rate of i^{th} unit
R_i^{UR}	Ramp down rate of i^{th} unit

evolutionary programming (EP) [11], simulated annealing (SA) [12], shuffled leaping frog approach (SFLA) [13], imperialistic competition algorithm (ICA) [14], etc., are applied to solve UC problem. Later, hybrid approaches are developed integrating the expedient properties of classical and heuristic approaches to solve the UC problem. Some of them are Lagrangian relaxation genetic algorithm (LRGA) [15], Lagrangian relaxation particle swarm optimization (LRPSO) [16], IPPDTM [17], hybrid harmony search random search approach (HHSRSA) [18] are used to improve the UC problem solution quality. Recently, the principles of quantum computing viz. uncertainty, superposition and interference are successfully applied to UC problem through evolutionary approaches. The applicability of quantum evolutionary approaches [19] improved the exploration and exploitation of heuristic approaches at comparatively lower population size with respect to other evolutionary approaches used to solve UC problem. The harmony search algorithm with hybridization with random search has been used to solve UC problem [30]. Also, the hybrid approaches of nature inspired such as PSO-GWO are investigated with application to UC problem [22]. The overview and insights of some other recent nature inspired approaches for solving UC problem can be found in literature review presented in [47].

Recently, Seyedali Mirjalili [21] proposed a meta-heuristic approach named grey wolf optimizer (GWO) mimicking the specific hierarchical and hunting behaviour of grey wolves (Canis lupus). The earlier models of GWO are economic load dispatch problem in power system. Later, the GWO integrated with PSO is used to solve UC problem of different dimensions [22]. The GWO is also used to solve many other industrial/research problems successfully [23]. Recently, Binary Grey Wolf Optimizer is developed and successfully applied for optimal feature selection purpose [24]. Motivated by the successful application of GWO & BGWO to industrial and research problems, this paper presents a Binary Grey Wolf Optimizer application to solve complex, non-linear and constrained UC problem. The presented approach improves the solution quality of traditional GWO to solve UC problem efficiently.

The rest of the paper is organized as follows. The UC problem formulation and associated bounds, constraints are explained in Section 2. The principles of real valued grey wolf optimizer and Binary Grey Wolf Optimizer (BGWO) are presented in Section 3. Section 4 develops and describes the BGWO-UC approach. Section 5 presents the test system, parametric analysis and computational results for different dimensions of the test system. Comparison of proposed approach with the existing benchmarking algorithms in solving UC problem is also presented in Section 5. The performance and statistical significance of proposed BGWO models is also demonstrated in Section 5 using statistical tests. Finally, Section 6 concludes the paper with contributions.

2. Problem formulation

Leading into the solution procedure, the formulation of objective and constraints of the UC problems are explained before.

2.1. Objective function

The objective function of UC problem is modelled as a minimization problem of total cost which constitutes of fuel cost, start-up and shut down costs.

2.1.1. Fuel cost

All the committed thermal units incur fuel costs due to the minimum power generation limits and the committed units are dispatched economically so as to reduce the overall fuel cost yet satisfying the system, thermal unit constraints. The fuel cost is expressed as a quadratic equation given by,

$$F_c^i(P_i^h) = a_i + b_i(P_i^h) + c_i(P_i^h)^2 \;\forall\; h \in H; i \in N \tag{1}$$

where a_i, $b_i and c_i$ are the fuel cost coefficients of i^{th}unit.

2.1.2. Start-up cost

The objective function also includes the start-up cost which is incurred two the boiler temperature changes as a consequence of commitment and de-commitment events. When returning to the commitment status ($\gamma_i^h = 1$) from de-commitment state ($\gamma_i^h = 0$), the start cost depends on number of hours the unit is in de-committed state. If the unit is in de-committed state for more than or equal to cold start hours (T_i^{cold}) after minimum off time, cold start-up (SU_i^{cold}) cost is associated with its commitment event. However, if the units is in de-committed state after minimum off time but for less duration then cold start hours, then the hot start-up cost SU_i^{hot} is associated with the commitment event. Therefore, the start-up cost applicable for i^{th} thermal unit during h^{th} hour is given by,

$$SU_i^h = \begin{cases} SU_i^{hot} & if\ T_i^{MD} \le T_i^{off} \le T_i^{MD} + T_i^{cold} \\ SU_i^{cold} & if\ T_i^{off} \ge T_i^{MD} + T_i^{cold} \end{cases} \quad \forall\;\; h \in H; i \in N \tag{2}$$

A. *Shutdown cost:*In this paper, shut down costs are neglected which are often modelled as constant values per de-commitment status of the unit.

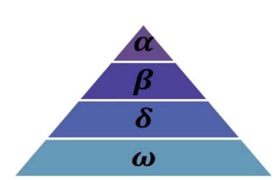

Fig. 1. Hierarchy of grey wolf pack [21].