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Meta-heuristic framework: Quantum inspired binary grey wolf optimizer for unit commitment problem☆

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A B S T R A C T

This paper proposes a quantum inspired binary grey wolf optimizer (QI-BGWO) to solve unit commitment (UC) problem. The QI-BGWO integrates quantum computing concepts with BGWO to improve the hunting process of the wolf pack. The inherent properties of Q-bit and Q-gate concepts in quantum computing help in achieving better balance between exploration and exploitation properties of the search process. The position update processes of wolves at different hierarchy levels are replaced by Q-bit's individual probabilistic representation along with dynamic rotation angle and coordinate rotation gate. Therefore, solution approaches exploit the search properties of GWO and quantum computing using quantum bits, gates, superposition principle etc., to solve the unit commitment schedule efficiently. The results and statistical analysis demonstrates the effectiveness of proposed approaches in solving the UC problem and establishes the significance of proposed approaches among existing binary and quantum computing based heuristic approaches.

1. Introduction

Unit commitment (UC) is considered as one of the important tasks in efficient, reliable and optimal short term operation planning of power system. The UC problem is traditionally modelled as a cost optimization problem. The UC problem involves two steps namely commitment-decommitment (ON/OFF) schedules followed by economic dispatch of committed units. In past decades, many optimization approaches have been proposed to solve UC problem. The earliest methods in this paradigm are deterministic approaches like Legrangian relaxation (LR), priority list (PL), dynamic programming (DP), mixed integer linear programming (MILP), branch and bound techniques (BB). Each of these techniques are reported with their own advantages and disadvantages. While, the advantages being faster (LR), simple (PL), integer type solution (MILP) etc. Some of the disadvantages include high production cost (PL method), high dimensionality problems (dynamic programming

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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 ith unit
χ_i^h	Status bit (0 or 1) of ith unit for hth hour
SU_i^h	Start-up cost of ith unit for hth hour
P_i^h	Scheduled power of ith unit for hth hour
SU_i^{hot}	Hot start-up cost of ith unit
SU_i^{cold}	Cold start-up cost of ith unit
T_i^{MD}	Minimum down time of ith unit
T_i^{MU}	Minimum up time of ith unit
$T_i^{h,off}$	Consecutive hours of de-committed state of ith unit going into hth hour
$T_i^{h,on}$	Consecutive hours of committed state of ith unit going into hth hour
P_i^{min}	Minimum generation limit of ith unit
P_i^{max}	Maximum generation limit of ith unit
P_d^h	System load for hth hour
R_{sp}^h	Spinning reserve requirement for hth hour
R_i^{DR}	Ramp down rate of ith unit
R_i^{UR}	Ramp down rate of ith unit

and mixed integer linear programming), exponential rise in computational time with UC problem dimension (branch and bound), problems with numerical convergence (Legrangian relaxation method) etc.

The traditional deterministic approaches are followed by the heuristic approaches with most of them inspired from nature. Some of the heuristic and stochastic approaches for solving UC problem include genetic algorithm (GA) [1], evolutionary programming (EP) [2], simulated annealing (SA) [3], particle swarm optimization (PSO) [4], improved particle swarm optimization (IPSO) [5], firefly algorithm [6] etc. Many of the algorithms are based on natural phenomena and include a number of flukes searching for optimal solution with different mechanisms. For example, GA uses the biological evolution mechanisms like natural selection, crossover and mutation in solving the complex problems. Modified and hybrid variants of evolutionary approaches such as hybrid differential evolution with random search, ring crossover genetic algorithm (RCGA) [7] etc., have been developed in recent years to improve the solution quality and convergence of UC problem. However, complexity in basic evolutionary population based approaches limited the extension of these approaches to larger test systems. Whereas, PSO is based on coordination and social behaviour of particles amongst the group is used to optimize problems like UCP with high complexity. The other recent approaches developed to solve UC problem include hybrid variants such as grey wolf optimizer (GWO) with PSO (GWO-PSO) [8] using the hierarchical and social behaviour of grey wolf and swarm group, hybrid harmony search-random search (HHSRS) [9], fireworks algorithm (FWA), binary fireworks algorithm (BFWA) [10] that exploits the explosion principles of fireworks in sky. However, the exponential rise of fireworks/sparks in FWA approach with increasing system dimension may prove costly with respect to computational time. Other problem with the heuristic approaches is a parameter tuning for optimal performance. In this regard, GWO presents an effective mechanism in which all the parameters are evaluated in the run time in an adaptive manner. Therefore, the parameter tuning experiments can be avoided using GWO [11]. The motivation for BGWO development to solve UC problem is drawn observing the superior performance of GWO over other approaches like PSO, ACO, GA etc., on various problems.

In recent approaches, certain principles of quantum mechanics are used to model evolutionary computational techniques. These approaches employ principles like superposition, uncertainty and interference of quantum mechanics [12,13,25]. Han and Kim [14] proposed a popular evolutionary algorithm that deploys the use of concepts of quantum computing viz. quantum bits (Q-bits), quantum gates (Q-gates) and their superposition. The quantum inspired evolutionary algorithm attracted much importance due to its superior properties like balanced exploration and exploitation to converge to better solution compared to other evolutionary algorithms. The initial research involved the direct application of original QEA using Q-gates to direct best population towards the optimal solution of UC problem (QEA-UC) [15]. The conventional QEA is followed by advanced QEA approaches incorporating special initialization using Q-bit representation along with priority list to maintain diversity in the population [16,17]. The Q-bit and Q-gate concepts are also used to develop heuristic approaches like quantum inspired binary particle swarm optimization (QBPSO) [18]. In which, the velocity update operation of conventional PSO is replaced by Q-bit individual update based on probabilistic approach. Apart from these, many other approaches inspired by natural/biological phenomena are investigated [19].

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