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Solution of unit commitment problem using quasi-oppositional teaching learning based algorithm

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ABSTRACT

In this article, quasi-oppositional teaching learning based algorithm (QOTLBO) is proposed to solve thermal unit commitment (UC) problem. Teaching learning based algorithm (TLBO) is a recently developed meta-heuristic algorithm based on the effect of the influence of a teacher on the output of learners in a class. The objective of UC is to economically schedule generating units over a short-term planning horizon subjugating to the forecasted demand and other system operating constraints in order to meet the load demand and spinning reserve for each interval. The proposed method is implemented and tested using MATLAB programming. The tests are carried out using 10-unit system during a scheduling period of 24 h for four different cases. Additionally, the QOTLBO algorithm is also carried out for large scale power systems viz. 20, 60, 80 and 100 units to prove the scalability of the algorithm. The results confirm the potential and effectiveness of the proposed algorithm after comparison with various methods such as, simulated annealing (SA), genetic algorithm (GA), evolutionary programming (EP), differential evolution (DE), particle swarm optimization (PSO), improved PSO (IPSO), hybrid PSO (HPSO), binary coded PSO (BCPSO), quantum-inspired evolutionary algorithm (QEA), improved quantum-inspired evolutionary algorithm (IQEA), Muller method, quadratic model (QM), iterative linear algorithm (ILA), binary real coded firefly algorithm (BRCFF) and basic TLBO.

1. Introduction

Over the years power demand has increased globally due to rapid industrialization and as well as due to domestic consumer needs. Also, the varying load demand has been a major problem for most of the electricity generating companies and power system. Moreover, in order to maximize the profit, the total fuel cost is to be minimized for a considerable period of time considering large number of constraints. For a particular system load pattern may exhibit large differences between maximum and minimum demand. Therefore, enough power must be generated to meet the prerequisite demand. So, it is uneconomical to run all the units since the load varies continuously with time and the optimum condition of the units may alter during any period. Therefore, the problem of determining the units of a plant that should operate for a given load is the problem of unit commitment (UC). UC is used to economically schedule generating units over a short-term planning horizon subject to the forecasted demand and other system operating constraints [1,2]. The UC problem determines hourly start-up and shut-down schedule and the real power outputs of the generating units over a scheduled time period of a day. In this context UC is an important optimization task in operations and planning of modern power systems since improved UC schedule may save millions of dollars per year in production cost. Mathematically, the UC problem is defined as a non-linear, large-scale, mixed-integer combinatorial problem. Several aspects are associated with it which is difficult to solve such as fuel availability, load forecast variable costs affected by the loading of generator units. Main considerations in solving the UC problem are "unit commitment" decision and the "economic dispatch" decision. The UC decision determines the number of the generating units to be running during each hour of the planning horizon considering the system capacity requirements and the economic dispatch decision allocates the system demand and spinning reserve capacity among the operating units during each specific hour of operation [3].

A survey of literature on the UC problem reveals that various numerical optimization techniques such as priority list (PL) [4,5], Branch-and-bound (BB) methods [6], Lagrangian relaxation (LR) methods [7,8], dynamic programming (DP) [9] and constraint logic programming [10] were employed to approach the UC problem. Tumuluru et al. presented a formulation of UCP for scheduling

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the thermal generators in a day-ahead electricity market which is solved by *Lagrangian relaxation* (LR) method and then compared to *mixed integer linear program* (MILP) [11]. Quan et al. solved UC using tighter relaxation method (RM) based on second-order cone programming which is reformulation of traditional mixed integer quadratic programming and a convex hull description of a simple mixed integer [12]. Alemany et al. solved symmetry issues in mixed integer programming based UC where computational burden of the algorithm is reduced by adding appropriate inequalities into the mixed-linear formulation of the UC problem [13]. Dieu et al. provided solution of UC problem with ramp rate constraints using combined improved Lagrangian relaxation (ILR) and augmented lagrange hopfield network (ALHN) [14]. Rong et al. proposed a variant DP algorithm [15] for the solution of UC problem of combined heat and power systems. Mhanna et al. introduced a semi-definite programming relaxation based technique combined with selective pruning (SDPSP) to achieve faster convergence to a near-optimal solution of the UC problem [16]. Viana et al. used quadratic programming (QP) formulation of the standard thermal UC problem in power generation planning, together with a novel iterative optimization algorithm which considered piecewise linear approximation of the quadratic fuel cost function for its solution that are dynamically updated in an iterative way, converging to the optimum solution [17]. Amiri et al. proposed a solution of the UC problem by primary UC-modification process (PUC-MP) which solved the problem by using a simple and new priority based solution for operating the generating units in each hour, and then, using a modification process which enhanced the solution quality with lower cost [18]. Finardi et al. proposed a new mathematical optimization technique for hydro UC and loading problem for day ahead operation planning problem considering electrical and mechanical losses of the turbine generator [19]. However, for non-linear UC, these classical methods only provide local optimal solution with higher computational time. In order to revoke the above limitations and to solve non-linear UC problem various meta-heuristic methods are evolved by various researchers. Some of the well popular UC based meta-heuristic methods are differential evolution (DE), genetic algorithm (GA), tabu search (TS), evolutionary programming (EP), particle swarm optimization (PSO), ant colony optimization (ACO), harmony search algorithm (HSA), immune algorithm (IA). These are based on genetic and evolution mechanisms observed in natural systems and populations of living beings. The meta-heuristic methods are an iterative method which not only provides local optimal solution but also gives global or near global optimal solution in most of the times depending on the problem domain and time limit. Saber et al. solved UC with Vehicle-to-Grid (V2G) technology using PSO [20]. Pappala et al. solved UC problem by adaptive PSO technique (APSO) using adaptive penalty function approach [21]. Sum-im et al. proposed ant colony search algorithm (ACSA) to solve thermal UC problem [22] where UC was solved by ACSA and the economic dispatch sub-problem is solved by lambda-iteration method. Chandrasekharan et al. presented a binary/real coded artificial bee colony (BRABC) algorithm to solve the thermal UC problem with repair strategies [23] to obtain a feasible commitment schedule satisfying all the constraints. One of the most recent endeavours has been provided by Columbus et al. where nodal ACO [24] for solving profit based UC problem for the generation companies was proposed. Swarup et al. presented a UC solution methodology using GA [25]. Jalilzadeh et al. presented an improved GA (IGA) [26] for UC problem with lowest cost. Pavez-Lazo in his most recent endeavour proposed a deterministic annular crossover GA optimization for the UC problem [27]. Rajan et al. formulated improved GA utilizing varying quality function technique [28] to solve UC problem. Tokoro et al. solved UC problem by combining GA with continuous relaxation method [29]. Badekar et al. defined a new fitness function combining equal incremental cost and generation and load balance constraint using GA [30] to provide an optimum UC for thermal power plants. Rajan evolved a GA based simulated annealing (SA) method for solving UC problem in Utility system [31]. Some other meta-heuristic methods are also utilized to solve the UC problem. Datta et al. in his recent effort implemented a binary-real-coded DE for a complete solution of the UCP where some repairing mechanisms were associated in the DE for speeding up its search process [32]. Poujamal et al. recently proposed harmony search algorithm (HSA) to provide solution for UC problem [33]. Samiee et al. presented enhanced HSA (EHSA) [34] for solution of security constrained UC problem. Mohammed presented his paper in a conference where he solved the UC problem using biogeography based optimization (BBO) [35]. Roy in his most recent endeavour solved UC problem using gravitational search algorithm (GSA) [36]. Yang in his most recent research presented a UC model which gave optimal and feasible schedule to thermal units considering a precise ramping process for the implementation of the schedule [37]. Saravanan et al. solved UC problem using invasive weed optimization (IWO) algorithm for 10-unit system during a scheduling period of 24 h [38]. In order to provide global optimal solution of UC problem, some techniques are integrated with each other to form hybridized techniques. Senjyu et al. presented GA operated PSO [39] for solving UC problem for thermal units integrated with solar and wind energy systems. Research works on UC commitment problem using Fuzzy adaptive PSO have also been recorded in [40]. Duo et al. combined LR and evolutionary programming (EP) to provide a better solution for short-term thermal unit UC problem within a short computation time [41]. Lin proposed a hybrid taguchi-immune algorithm (HTIA) which integrated taguchi method (TM) and immune algorithm (IA) to provide a global optimal solution for the UC problem [42,43]. Mantawy et al. integrated simulated annealing (SA) and fuzzy logic methods to solve the UC problem where SA was employed to solve the combinatorial part of the UC problem and the non-linear part was solved by a QP [44]. Patra incorporated fuzzy and SA based unit selection procedure to produce a dynamic programming (DP) [45] for the solution of UC. Additionally, some Fuzzy UC models are also available in the literature [46–48].

All the above evolutionary and population based techniques in the literature survey are probabilistic techniques and necessitate some common controlling parameters like population size, number of generations, and elite size. Moreover, the algorithms also require finding of some of their own control parameters. GA involves determination of some algorithm-specific parameters such as crossover rate and mutation rate. PSO has its own parameters like inertia weight, social and cognitive parameters. In case of HS, determination of harmony memory consideration rate, pitch adjusting rate, and number of improvisations are necessary. The global solution of any function is only achieved with the proper tuning of these algorithm-specific parameters. Improper tuning may lead to local optimal solution or increase in convergence time.

In this paper, a recently developed heuristic algorithm named teaching–learning based optimization (TLBO) algorithm based on the effect of the influence of a teacher on the output of learners in a class, introduced by Rao et al. [49,50] is utilized for the solution of UC problem in this paper. This TLBO algorithm had been implemented in various problem domains of engineering and technology. Most recently, it has been utilized in solving a few areas of power system [51,52]. Unlike the other population based techniques, TLBO only requires determination of common controlling parameters like population size and number of generations for its functionality. In the present work, to increase the convergence speed of basic TLBO algorithm and provide global optimal solution, quasi-oppositional based learning (QOBL) is implemented on TLBO. The proposed quasi-oppositional TLBO (QOTLBO) along with basic