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Profit based unit commitment for GENCOs using parallel NACO in a distributed cluster

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ABSTRACT

Deregulation process has created an intense competition with the participation of many generating companies (GENCOs) in a power market. Wholesale transactions (bids and offer) have to be cleared and settled in a shorter duration. Therefore, this necessitates for the system operator to quick and smarter decisions. In this problem formulation, profit based unit commitment (PBUC) problem aims in maximizing the profit of GENCOs. However demand satisfaction is not an obligation. Here, parallel nodal ant colony optimization (PNACO) approach mimicking ant's intelligence is used in the decision on committing generating units. The sub problem economic dispatch (ED) is carried out using parallel artificial bee colony (PABC) approach mimicking foraging behavior of bees. Profit based unit commitment (PBUC) must be obtained in less time even though there is a possible increase in generating units. Nowadays, as computing resources are available in plenty, effective utilization will be advantageous for reducing the time complexity for a large scale power system solution. The proposed approach uses a cluster of computers performing parallel operations in a distributed environment for obtaining the PBUC solution. The time complexity and the solution quality with respect to the number of processors in the cluster are thoroughly investigated. The effectiveness of the proposed approach for PBUC is first validated on a standard 10 unit system available in the literature and then analysis for computational efficiency using 1000 generating units, which is a duplicate form of standard 10 unit system.

1. Introduction

In the deregulated electricity power market, optimal economic operation and planning of electric power generation has always occupied an important position. The traditional unit commitment problem (UCP) generally focuses on committing the ON/OFF status of the generating units and optimally allocates the generation of power for the ON generating units [1,2]. The optimal allocation is obtained by solving the economic dispatch (ED) problem, which can be categorized as a sub problem of the UCP. This operation is to minimize total generation cost in a specified time zone (usually 24 h) [3,4]. However, the profit based unit commitment (PBUC) problem is generally solved by the GENCOs in a deregulated power market. The operation involves maximizing solely the GENCOs profit, where demand satisfaction is not an obligation.

In deregulated markets, generation companies (GENCOs) are usually entities owning generation resources and participating in the market without concern of the system unless there is an incentive for it. Hence, GENCOs consider generation planning for a period of, say 24 h in advance, based on the price forecast, generation unit characteristics, unit availability etc., and thereby determine the bidding strategy for each bidding period of the next day. To excel in the competition, GENCOs will acquire additional generating units with flexible operating capability which allows a timely response to the continuous changes in power system conditions. In the deregulated market, independent system operator (ISO) forecasts the demand and the price for the next day/hour. The GENCOs will send its bidding to the ISO, depending upon the demand and its generator coefficients. The ISO will accept and select the bidder whose price is less than or equal to its forecasted price. If the bidder's price is more than the forecasted one, then ISO will fix the forecasted price as the market clearing price (MCP). If any of the GENCOs fix the price below the forecasted price, the ISO will fix the lowest price as MCP.

1.1. Literature survey for solution techniques

The profit based unit commitment (PBUC) problem is a mixed integer and continuous nonlinear optimization problem, which is very complex to solve because of its enormous dimensions, nonlinearity and large number of constraints. Eric H. Allen first

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Nomenclature

AvgP	average of maximum profit ($) obtained in 10 simulations
D_t	total system demand at time t
E	all states that are eligible at time t
EW_h	efficiency of a cluster
fit_p	fitness value of the solution p
L_{gb}	maximum total profit incurred till the current tour
N	total number of generating units
n	number of units in each node
i	index for generator unit
N_{ants}	total number of ants
N_e	number of food sources which is equal to the number of employed bees n_e
$P_{(i,t)}$	power level of ith generator unit at tth hour (MW)
$I_{(i,t)}$	commitment state of ith unit at tth hour
maxiter	maximum number of iterations
$P_{i,min}$	minimum power output of ith generator unit (MW)
$P_{i,max}$	maximum power output of ith generator unit (MW)
PF	total profit ($)
$\Pr_{rs}^k(st)$	transition probability of kth ant from state r to s
RV	total revenue ($)
ST_t	startup cost ($)
SW_h	speedup factor for a cluster
TS	total number of states
t	index for time
$T^{on}(i)$	minimum up-time of ith generator unit
$T^{off}(i)$	minimum down-time of ith generator unit
T	dispatch period in hours
TC	total cost ($)
W	processor or worker
W_h	number of processors in cluster
W_t	execution time of one processor
W_{ht}	execution time of a cluster
$X^{on}(i,t)$	"on" duration of ith generator unit till time
$X^{off}(i,t)$	"off" duration of ith generator unit till time t
$x_{q\min}$ and $x_{q\max}$	the minimum and maximum limits of the parameter to be optimized.
C_i	production cost ($) $C_i(P_{(i,t)}) = a + b \times P_{(i,t)} + c \times P_{(i,t)}^2$
a	cost co-efficient of ith generator unit ($/h)
b	cost co-efficient of ith generator unit ($/MW h)
c	cost co-efficient of ith generator unit($/MW^2 h)
A	relative importance pheromone trail intensity
B	relative importance of heuristic function
C	constant
ρ	evaporation factor
σ_g	forecasted market price for energy at time t
σ_n	forecasted market price for non-spinning reserve at time t
σ_r	forecasted market price for spinning reserve at time t
τ_{rs}(st)	pheromone trail intensity of state (st) r to s
η_{rs}	(st) Heuristic function of state (st) r to s
$\Delta\tau_{rs}$	change in pheromone deposition
ϕ_{pq}	random number between [−1, 1]
LC	limit count
HC$_i$	hot cost of the ith generator ($/h)
CC$_i$	cool cost of the ith generator ($/h)
T^{cold}	permissible cool hour of the ith generator (h)
Ini-state	initial status of the ith generator

proposed the price based decision mechanism for GENCOs to schedule their reserve based on spot market power [5]. The Lagrange Relaxation method can provide a fast solution by properly adjusting the Lagrangian multiplier [6,7]. But if the problem is a non-convex, then it suffers from numerical convergence. In LR gradient method this problem is eliminated. However, the solution obtained from gradient-based method suffers from getting local optimum solutions. In order to overcome these complex mathematical problems, there are other methods of computational methodologies shared by popular intelligent systems such as genetic algorithm and evolutionary programming. Charles W. Richter et al. presented a PBUC formulation using genetic algorithm (GA) which considers the softer demand constraints and allocates fixed and transitional costs to the scheduled hours [8].

Pathom Attaviriyanupap et al. proposed a Hybrid LR-EP to solve profit based unit commitment for scheduling both power and reserve simultaneously [9]. However, the reserve is scheduled based on reserve probability value. Here, evolutionary programming (EP) is used for the proper adjustment of lagrangian multiplier. H.Y. Yamin et al. proposed an auxiliary hybrid model using LR and GA to solve UC [10]. Here, GA is used to update the Lagrangian multiplier. T.A.A. Victoire et al. proposed Tabu-search based heuristic technique to solve PBUCP involving both energy and reserve schedule [11]. Here, for different values of reserve probability, the variations of energy and reserve schedules are observed in terms of profit. A mixed integer programming method which provided better solution than LR method is proposed by Tao Li and et al. [12]. This approach took higher computation time for convergence.

In [13], Chandram et al. proposed an Improved Pre-prepared Power Demand (IPPD) table and the Muller's method as a means of solving the Profit Based Unit Commitment (PBUC) problem. Here, the PBUC problem is solved by the proposed approach in two stages. Initially, information concerning committed units is obtained by the IPPD table and then the sub problem of Economic Dispatch (ED) is solved using the Muller's method. In [14], variable neighborhood Tabu search parallel enhanced particle swarm optimization with island model (VTS-PEPSO) is used to solve the PBUC problem. Christopher et al. implemented parallel artificial bee colony algorithm (PABC) for solving PBUC problem using parallel computation [15]. Though the computational time taken has reduced, the accuracy of the solution could have been improved. They had also applied nodal ant colony optimization (NACO) for solving PBUC [16] and found that the convergence of getting near optimal solution is encouraging. However, the inherent limitation is the computation time. Therefore, considering the strength and weakness of ACO [16–21] and ABC [3,15,22–24], this paper focuses on suitably combining both ACO and ABC solving PBUC in the parallel environment. Here, ACO is used to get the discrete status of the generating units and ABC is used to solve economic dispatch sub problem producing the optimal dispatch of the committed generating units.

2. Proposed work

ACO is an intelligent optimization algorithm that searches the optimal solution mimicking real ants [17,18]. Existing literatures [16–21] prove ant colony optimization (ACO) techniques are found to be competent in solving combinatorial optimization problems. It is on this basis that ACO is suitable for PBUC which is also hard combinatorial in nature. An analogy can be drawn between ants finding the shortest path from source (nest) to its