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Optimal power scheduling of thermal units considering emission constraint for GENCOs' profit maximization

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ABSTRACT

In this paper, authors propose a novel method to determine an optimal solution for profit based unit commitment (PBUC) problem considering emission constraint, under a deregulated environment. In a restructured power system, generation companies (GENCOs) schedule their units with the aim of maximizing their own profit by relaxing demand fulfillment constraints without any regard to social benefits. In the new structure, due to strict reflection of power price in market data, this factor should be considered as an important ingredient in decision-making process. In this paper a social-political based optimization algorithm called imperialist competitive algorithm (ICA) in combination with a novel meta-heuristic constraint handling technique is proposed. This method utilizes operation features of PBUC problem and a penalty factor approach to solve an emission constrained PBUC problem in order to maximize GENCOs profit. Effectiveness of presented method for solving non-convex optimization problem of thermal generators scheduling in a day-ahead deregulated electricity market is validated using several test systems consisting 10, 40 and 100 generation units.

Introduction

Along with the development of technological advances throughout the world, structure of different types of industries has been changed dramatically. To this end, power market which is one of the most vital industries has experienced significant changes in its structure. In previous power systems with traditional structure, unit commitment (UC) problem was determination of commitment statuses of thermal generation units so that summation of output power of ON units during certain periods of scheduling periods should meet load demand constraint while cost of operation should be minimized [1].

In order to obtain an optimal solution for nonlinear optimization problem of cost based unit commitment (CBUC), different methods like Lagrangian relaxation (LR) [2], mixed integer programming (MIP) [3], priority list (PL) [4], particle swarm optimization (PSO) [5], genetic algorithm (GA) [6] and imperialist competitive algorithm (ICA) [7] have been employed. These methods are different regarding total economic objective function and optimization techniques.

After deregulation of energy market, the electricity power industry has shifted from a vertically integrated structure to a parallel one. In fact, such the deregulation is decomposition of the vertically integrated power systems to several generating, transmitting and distributing companies. The main aim of this restructuring procedure is to raise a competition among different companies, specifically power generation companies (GENCOs), to provide cheaper as well as top quality choices for electricity customers. Consequently, in the new structure, employed strategies of market should metamorphose. In order to reach such the goal, GENCOs should run a novel profit based unit commitment (PBUC) that is different from traditional UC in terms of objective and demand constraint. In this new defined UC problem, load demand fulfillment is not mandatory anymore and the main purpose of PBUC is to maximize the GENCO's profit in which fuel price, energy selling price and ancillary services are the most highlighted signals for the commitment of thermal units [1].

Recently, numerous techniques have been utilized to reach an optimal solution for nonlinear optimization problem of PBUC under a competitive market. These approaches include: LR [1], Muller method [8], MIP [9], GA [10] and [11], tabu search algorithm (TSA) [12], PSO [13], ant colony optimization (ACO) algorithm [14], artificial bee colony (ABC) algorithm [15], parallel PSO

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Nomenclature

a_i	fuel consumption coefficient of unit i (\$/h)
a_{ei}	emission consumption coefficient of unit i (ton/MW^2 h)
b_i	fuel consumption coefficient of unit i (\$/MW h)
b_{ei}	emission consumption coefficient of unit i (ton/MW h)
c_i	fuel consumption coefficient of unit i (\$/MW^2 h)
c_{ei}	emission consumption coefficient of unit i (ton/h)
$Cost_n$	cost of country n
$C_i(\cdot)$	cost function of unit i (\$), $C_i(P_{(i,t)}) = a_i + b_i \times P_{(i,t)} + c_i \times P_{(i,t)}^2$
$\widehat{C}_i$	cost of imperialist i
$CSC_{(i)}$	cold start-up cost of unit i (\$/h)
$CST_{(i)}$	cooling constant of unit i (h)
DR_i	down ramp rate of unit i (MW/min)
E_{ci}	total mission consumption of unit i (ton/h)
$E_t^{\max}$	maximum allowance of emission at time t
f	objective function
$HSC_{(i)}$	hot start-up cost of unit i (\$/h)
i	index of generator unit
$Ini.\ S_i$	initial state of unit i (h)
$I_{(i,t)}$	commitment state of unit i at time t
N	total number of generating units
$Nd_{(.)}$	number of iterations of main/sub algorithm
N_{col}	number of colonies
N_{imp}	number of imperialists
$Noff_{(i)}^t$	number of continuous OFF states of unit i at transition time
$Non_{(i)}^t$	number of continuous ON states of unit i at transition time
N_p	number of particles (*i.e.* initial solutions) in PSO algorithm
$\widehat{N}_i$	number of initial colonies of imperialist i
$PD_{(t)}$	total system demand at time t (MW)
PF	total profit (\$)
Pos_C^d	positions of a colony at the current decade, in a specific empire
Pos_I^d	positions of an imperialist at the current decade, in a specific empire
Pos_C^{d+1}	positions of a colony at the next decade, in a specific empire
$\widehat{P}_i$	normalized power of imperialist i
$P_{(i)}^{g\max}$	maximum generation of unit i (MW)
$P_{(i)}^{g\min}$	minimum generation of unit i (MW)
$P_{(i,t)}$	generation of unit i at time t (MW)
r_i	a randomly generated numbers in (0, 1)
$R_D(t)$	total reserve at time t
RV	total revenue (\$)
SC_{col}	summation of costs of the colonies, existing in the territory of an empire
$ST_{(i)}$	start-up cost of unit i (\$)
t	index of time
T	dispatch period (h)
TC	total cost (\$)
$T\widehat{P}_i$	total power of imperialist i
$T_{(i)}^{off}$	minimum OFF time of unit i (h)
$T_{(i)}^{on}$	minimum ON time of unit i (h)
UR_i	up ramp rate of unit i (MW/min)
$X_{(i,t)}^{off}$	time duration for which unit i has been OFF at time t (h)
$X_{(i,t)}^{on}$	time duration for which unit i has been ON at time t (h)
β	assimilation weight factor
γ	deviation limit from the original direction
μr_i	prosperity value of ith empire
$\rho_{gm}(t)$	forecasted market price for energy at time t (\$/MW h)
$\hat{\sigma}_i$	probability of imperialist i
ξ	colonies' corporation factor in imperialist' power (*i.e.* a positive number which is considered to be less than 1)

in a shared memory model (PPSO) [16] improved pre-prepared power demand (IPPD) table [17] and parallel nodal ant colony optimization (PNACO) [18] ICA [19] (*i.e.* authors' previous contribution). A glimpse at researches in this area indicates superiority of the Lagrangian based methods. Despite the Lagrangian method enjoys high speed of convergence, LR based methods suffer from getting stuck in the local optimums besides the exponential increase of the problem scale versus increase of the scheduling horizon and number of units. To overcome these obstacles, some hybrid LR-evolutionary methods like combination of GA and LR [20], evolutionary programming (EP) and LR [21], PSO and LR [22], nonlinear programing (NLP) and dynamic programing (DP) [23] an evolutionary method based on priority list [24] are proposed. In [25], uncertainty in loads and availability of the thermal units are considered to solve a UC problem in a competitive market. In [26] an artificial neural network has been employed to model the uncertainty of generation resulted by spinning and non-spinning reserves.

Lately, due to sensitivity of public opinion to the environmental problems and air pollution, more optimal operation of the power generation units are being focused on. To this end, emission as an inseparable ingredient of thermal unit scheduling should be controlled, fuel sources should be exploited as less as possible while GENCOs' profit maximization should be maintained as the final goal. In such situations that several simultaneous objectives are considered, attempting to optimize one of them should not end up to sacrifice of the others. In this paper a compromise is accomplished so that profit of GENCO should be maximized besides maintaining emission table under a certain limit. To this end, Shuffled Frog Leaping Algorithm (SFLA) approach is also utilized to solve PBUC problem with the emission limitation for a case study with ten generation unit [27]. In [28,29] such obligation has been accomplished using PSO and a practical algorithm, respectively. Besides, newfangled heuristic algorithms have attracted considerable attention recently. These algorithms mostly enjoy high potential in terms of convergence speed and solution quality.

In this paper, the authors use a novel evolutionary algorithm which is called ICA to solve the UC problem under a deregulated power market. Considering numerous contributions in case of PBUC problem [20–26], only a small number of researches have been executed PBUC problem considering environmental obligations. To this end, minimization of emission consumption is regarded as the second objective function besides the maximization of GENCO profit. Moreover, a novel meta-heuristic strategy for constraint handling of PBUC problem is formulated in which new penalty factors are determined based on coordination of inherent features of the PBUC problem. As opposed to the traditional constrained handling methods presented in the literature review, this technique provides more optimality and superiority to the other contributions in cases of obtaining quality solutions and convergence speed. In this strategy, a meta-heuristic cascaded ICA–PSO is employed besides the main loop of ICA in order to determine optimal values of penalty factors. Then the optimization problem is solved using the ICA algorithm. By performing the