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Augmented Lagrange Hopfield network based Lagrangian relaxation for unit commitment

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ABSTRACT

This paper proposes an augmented Lagrange Hopfield network based Lagrangian relaxation (ALHN-LR) for solving unit commitment (UC) problem with ramp rate constraints. ALHN-LR is a combination of improved Lagrangian relaxation (ILR) and augmented Lagrange Hopfield network (ALHN) enhanced by heuristic search. The proposed ALHN-LR method solves the UC problem in three stages. In the first stage, ILR is used to solve unit scheduling satisfying load demand and spinning reserve constraints neglecting minimum up and down time constraints. In the second stage, heuristic search is applied to refine the obtained unit schedule including primary unit de-commitment, unit substitution, minimum up and down time repairing, and de-commitment of excessive units. In the last stage, ALHN which is a continuous Hopfield network with its energy function based on augmented Lagrangian relaxation is applied to solve constrained economic dispatch (ED) problem and a repairing strategy for ramp rate constraint violations is used if a feasible solution is not found. The proposed ALHN-LR is tested on various systems ranging from 17 to 110 units and obtained results are compared to those from many other methods. Test results indicate that the total production costs obtained by the ALHN-LR method are much less than those from other methods in the literature with a faster manner. Therefore, the proposed ALHN-LR is favorable for large-scale UC implementation.

1. Introduction

Unit commitment (UC) which is considered as a large scale, nonlinear, mixed-integer optimization problem plays a very important role in optimal operation of power systems. Solving the UC problem is a complex decision making process since multiple constraints must be satisfied and a good UC solution method can substantially contribute to annual savings of production cost. The objective of the UC problem is to minimize the total cost of thermal generating units while maintaining sufficient spinning reserve and satisfying the operational constraints of generating units over a given schedule time horizon. An optimal solution to the UC problem in power system operation can be obtained by a complete enumeration. However, the requirement of the excessive computational resource is impossible to be implemented in practice. Therefore, many research efforts have been focused on efficient UC algorithms for lower total production cost and computational time.

Many conventional methods were applied to solve the UC problem such as priority list (PL) [1], branch and bound method (BB) [2], dynamic programming (DP) [3], mixed-integer linear programming (MILP) [4], Lagrangian relaxation (LR) [5]. Among these methods, the PL method is one of the earliest and simplest approaches to solve the UC problem. Most priority list schemes are built around a shut down algorithm based on the relative efficiency of each unit. However, the PL method can not deal with the systems of moderate size since the large number of combinations can not be properly handled, leading to relatively higher operation cost. The BB and DP methods suffer from the "curse of dimensionality" if the size of a system is too large or scheduling period is too long. When applying a MILP problem formulation, solving large-scale problems requires a large amount of computing effort and can result in relatively high computational time. The LR method is considered to be the most realistic and efficient method among the conventional methods for large-scale systems. The LR method is superior to the DP method due to its higher quality solution and faster computational time. However, due to the non-convexity of the UC problem, the optimality of the dual problem does not guarantee the feasibility of the primal UC problem. An enhanced adaptive Lagrangian relaxation (ELR) to overcome the drawback of the LR method has been proposed in [6] based on adaptive Lagrangian relaxation enhanced by a heuristic search for identical units. ELR is favourable for large scale implementation in terms of the total production costs and computational times.

Recently, meta-heuristic techniques have been widely used for solving the UC problem such as artificial neural network (ANN)

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Nomenclature

C_i^t	on/off decision criterion of unit i at hour t
DR_i	ramp down rate limit of unit i (MW/h)
ER^t	excessive spinning reserve at hour t (MW)
$F_i(P_i^t)$	quadratic fuel cost function of generating unit i $F_i(P_i^t) = a_i + b_iP_i^t + c_i(P_i^t)^2$ ($/h)
$F_{i,high}^t$	upper limit frame of power output of unit i at hour t (MW)
K_{max}	maximum allowable number of iterations for LR
N	total number of generating units
$P_{i,max}$	maximum power output of unit i (MW)
$P_{i,min}$	minimum power output of unit i (MW)
P_i^t	generation power output of unit i at hour t (MW)
$P_{i,high}^t$	highest possible power output of unit i at hour t (MW)
$P_{i,low}^t$	lowest possible power output of unit i at hour t (MW)
$P_{i,fwd}^t$	highest forward power output of unit i at hour t starting from the first committed hour (MW)
$P_{i,bwd}^t$	highest backward power output of unit i at hour t starting from the last committed hour (MW)
P_D^t	system load demand at hour t (MW)
P_R^t	system spinning reserve at hour t (MW)
SD_i^t	shut down cost of unit i at hour t ($)
SDH_i	start up time of unit i to increase its output power from zero to $P_{i,min}$ or above (h)
SDR_i	shut down ramp constraint of unit i (MW/h)
SU_i^t	start up cost of unit i at hour t ($)
SUH_i	shut down time of unit i to decrease its output power from $P_{i,min}$ or above to zero (h)
SUR_i	start up ramp constraint of unit i (MW/h)
T	time horizon for UC (h)
$T_{i,down}$	minimum down time of unit i (h)
$T_{i,off}^t$	continuously off time of unit i up to hour t (h)
$T_{i,on}^t$	continuously on time of unit i up to hour t (h)
$T_{i,up}$	minimum up time of unit i (h)
$T_{i,fwd}^t$	continuously forward on time of unit i starting from the first committed hour up to hour t (h)
$T_{i,bwd}^t$	continuously backward on time of unit i starting from the last committed hour up to hour t (h)
U_i^t	status of unit i at hour t (on = 1, off = 0)
UR_i	ramp up rate limit of unit i (MW/h)
β^t	penalty factor in Lagrangian relaxation function
ΔP^t	power shortage at hour t (MW)
λ^t	Lagrange multiplier for power balance at hour t ($/MWh)
π^t	Lagrange multiplier for spinning reserve at hour t ($/MWh)
ψ	updating factor of power balance constraint
ϕ	updating factor of spinning reserve constraint
χ_i, δ_i, τ_i	start up coefficients of thermal unit i

[7,8], genetic algorithm (GA) [9,10], simulated annealing (SA) [11–13], tabu search (TS) [14], evolutionary programming (EP) [15], particle swarm optimization (PSO) [16,17], constrained logic programming (CLP) [18], fuzzy optimization (FO) [19]. The GA, SA, TS, EP, and PSO methods can search not only local but also global optimal solutions. However, they are sensitive to the parameter settings and require a considerable amount of computational time for large problem size due to the large search space. In the CPL method, the number of the unit states required is still high and the ability to achieve the global optimal solution is not always guaranteed. In the FO method, the unit scheduling based on priority list and fuzzy optimization based "if-then" rules may not obtain the optimal solution. Therefore, the solution quality of this method is not much improved compared to some other classical methods. The Hopfield neural network (HNN) in [7] is based on minimization of energy function to solve unit commitment problem with linearized cost function and inequality constraints. However, the obtained result from this network is local optimum, which may be attributed to the inexact mapping of the UC problem to the neural network. An enhanced augmented Lagrangian Hopfield network (EALHN) has been proposed in [8] to overcome shortcomings of the HNN. The EALHN method is an augmented HNN including continuous and discrete Hopfield networks with its energy function based on augmented Lagrange relaxation enhanced by heuristic search based on merit order of generating units for handling minimum up and down time constraints. The EALHN is superior to the HNN and many other methods in terms of lower production cost and shorter computational time.

To reduce the search space in the large-scale problems, and therefore computational time, hybrid methods such as LR initialized augmented Hopfield network (LRAHN) [20], Hybrid GA including PL and GA [21], enhanced merit order and augmented Lagrange Hopfield network (EMO-ALHN) [22,23] have been recently used. These hybrid methods are much efficient than the single methods due to less production cost and faster computational time.

This paper proposes an augmented Lagrange Hopfield network based Lagrangian relaxation (ALHN-LR) for solving the UC problem with ramp rate constraints. ALHN-LR is a combination of improved Lagrangian relaxation (ILR) and augmented Lagrange Hopfield network (ALHN) enhanced by heuristic search. The proposed ALHN-LR method solves the UC problem in three stages. In the first stage, ILR is used to solve unit scheduling satisfying load demand and spinning reserve constraints neglecting minimum up and down time constraints. In the second stage, heuristic search is applied to refine the obtained unit schedule including primary unit de-commitment, unit substitution, minimum up and down time repairing, and de-commitment of excessive units. In the last stage, ALHN which is a continuous Hopfield network with its energy function based on augmented Lagrangian relaxation is applied to solve constrained economic dispatch (ED) problem and a repairing strategy for ramp rate constraint violations is used if a feasible solution is not found. The proposed ALHN-LR is tested on systems ranging from 17 to 110 units and the obtained results are compared to those from other methods reported in the literature.

The organization for the rest of the paper is as follows. Section 2 describes the UC problem formulation. ALHN-LR for UC problem is addressed in Section 3. Numerical results are shown in Section 4. Finally, conclusion is given.

2. UC problem formulation

The objective of the UC problem is to minimize

$$F(P_i^t, U_i^t) = \sum_{t=1}^{T}\sum_{i=1}^{N}[F_i(P_i^t) + SU_i^t(1 - U_i^{t-1})]U_i^t + \sum_{t=1}^{T}\sum_{i=1}^{N}SD_i^t(1 - U_i^{t+1})U_i^t \quad (1)$$

subject to

(a) Power balance constraints

$$P_D^t - \sum_{i=1}^{N}P_i^tU_i^t = 0, \quad t = 1, \ldots, T \quad (2)$$