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A Solution to The Unit Commitment Problem Using Hybrid Genetic and particle swarm optimization Algorithms

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Abstract: The solution of the unit commitment problem (UCP) is a complex optimization problem. The exact solution of the UCP can he obtained by a complete enumeration of all feasible combinations of generating units, which could be a huge number. The objective is to find the generation scheduling such that the total operating cost can be minimized, when subjected to a variety of constraints. This also means that it is desirable to find the optimal generating unit commitment in the power system for the next hours. This paper presents a hybrid genetic and particle swarm optimization algorithms (HGAPSO) to solve optimal Unit Commitment Problem (UCP). The HGAPSO is applied to the widely used ten-unit test system and its multiples (10-100). Comparing our results with those of many UC solving methods demonstrate that not only the HGAPSO procedure consider is the constraints very well, but also has some advantages, such as good convergence, fast calculating speed and high precision.

Key words: hybrid genetic and particle swarm optimization algorithms (HGAPSO), Power System, Unit Commitment Problem (UCP), System Constraints,

INTRODUCTION

In all power stations, Investment is quite expensive and the resources needed to operate them are rapidly becoming more sparse. As a result, the focus today is on optimizing the operating cost of power stations. In the present world, meeting the power demand as well as optimizing generation has become a necessity. Unit commitment in power systems refers to the optimization problem for determining the on/off states of generating units that minimize the operating cost for a given time horizon. The solution of the unit commitment problem is a complex optimization problem. The exact solution of the UCP can be obtained by complete enumeration of all feasible combinations of generating units, which could be a huge number. The unit commitment is comnionly formulated as a nonlinear, large scale, mixedinteger Combinational optimization problem. Several solution techniques have been applied to this problem, either by using deterministic, meta heuristic, and hybrid approaches. Deterministic approaches include priority list (PL) (A. J. Wood, *et al*. 1996), dynamic programming (DP) (C. K. Pang, *et al*. 1976), Lagrangian Relaxation (LR) (S. J. Wang, *et al*. 1995), integer mixed-integer programming (T. S. Dillon, *et al*. 1999), and the branch-and-bound methods The priority list is the simplest and fastest but achieves poor final solution (A. I Cohen, *et al*. 1983). Meta-heuristic approach, such as genetic algorithm (GA) (H. Ma , *et al*. 1994), evolutionary programming (EP) (Juste *et al*. 1999), simulated annealing (SA) (F. Zhuang & F. D. Galiana, *et al*. 1990), tabu search (TS) (A. H. Mantawy *et al*. 1999), particle swarm optimization (PSO) (Lee, T., & Chen, C. 2007), greedy random adaptive search procedure (GRASP) (Viana, A *et al*. 2003) are also being widely investigated to solve the UC problem. These meta-heuristic methods optimization methods attract much attention, because of their ability to search not only local optimal solution but also global optimal solution and can easily deal with various difficult nonlinear constraints. However, these meta-heuristic methods require a considerable amount of computational time to find the near-global minimum especially for a large-scale UCP. Hybrid Genetic and Particle Swarm Optimization Algorithms (HGAPSO) is proposed in this paper to solve the UCP. It combines the advantages of the genetic algorithm and the social behavior-based PSO algorithm with such characteristics as simple concept, fewer parameters adjustment, prompt formation, great capability in global search and easy implementation .This paper is organized as follows. Section II provides the mathematical formulation of the UCP. Section III introduces the basics of HGAPSO. Section IV proposes an optimization strategy of HGAPSO method for solving UCP. Section V gives the numerical example. Section VI outlines the conclusions.

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II. Uc problem formulation:
II.1. objective function:

In this paper it is assumed that the schedule periods are 24 hours and divide into 24 time-steps. The total cost is the sum of the running cost and start up cost for all units over the whole scheduling periods. Accordingly, overall objective function of the UC problem is:

$$Min\,F(U_{it},P_{it}) = \sum_{t=1}^{24}\sum_{i=1}^{G}[U_{it}F_{it}(P_{it}) + U_{it}(1-U_{it-1})S_i] \tag{1}$$

Generally, the running cost, per unit in any given time interval is a function of the generator power output. The cost function is usually in the form of:

$$F_i(P_{it}) = a_iP_{it}^2 + b_iP_{it} + c_i \tag{2}$$

The generator start up cost depends on the time the unit has been off prior to the start up. Time-dependent start up cost is represented as follows:

$$S_i = S_{0i} + S_{1i}(1 - e^{-T/\tau_i}) \tag{3}$$

The shut down cost is usually given a constant value for each unit. The shut down cost has been taken equal to 0 for each unit.

System constraints:

Many constraints can be applied on the unit commitment problem. Each individual power system, power pool, reliability council,…, may impose different rules on the scheduling of the units, depending on the generation makeup, load-curve characteristics. Spinning reserve describes the total amount of generation available from all units synchronized on the system, minus the present load supplied and losses being incurred. Spinning reserve must be carried out in such a way that the loss of one or more units does not cause too far a drop in the system frequency. Spinning reserve must obey certain rules which will specify that reserve must be capable of making up the loss of most heavily loaded unit in a given period of time. Reserve requirement also calculated as a function of the probability of not having sufficient generation to meet the load, by making people (A. Safari, *et al*. 2010).

1)Power balance constraint

$$\sum_{i=1}^{G}U_{it}P_{it} = P_{Dt}, t = 1,2,3,... \tag{4}$$

P_{it} is calculated by the running units at time-step t according to equal loss incremental rate principle and met:

$$\frac{dF_{1t}}{dP_{1t}} = \frac{dF_{2t}}{dP_{2t}} = ... = \frac{dF_{it}}{dP_{it}} = \lambda \tag{5}$$
$$t = 1,2,...,24, i = 1,2,...,G$$

2) Spinning Reserve

If spinning reserve needs to be more than 7% of the total load at each time interval, it must met:

$$\sum_{i=1}^{G}U_{it}P_{i\max} \geq 1.10P_{Dt}, t = 1,2,3,...24 \tag{6}$$

Unit Generation Output Limitation

$$P_{i\min} \leq P_i \leq P_{i\max} \tag{7}$$

$$t = 1,2,...,24, i = 1,2,...,G$$

Start Up- and Down Times Limitation

$$\sum_{t=1}^{24}\left|U_{it}-U_{it-1}\right| \le M_i \tag{8}$$

Minimum Up and Down-Time Constraints

$$TO_i \ge \underline{TO_i} \tag{9}$$

$$TS_i \ge \underline{TS_i} \tag{10}$$

HGAPSO ALGORITHM (Optimization Algorithm and Implementation):

The genetic algorithm can handle any kind of objective functions and constraints without much mathematical requirements about the optimization problems. GA has been touted as a class of general-purpose search strategies for optimization problems. In GA, variables of a problem are represented as genes in a chromosome and the chromosomes are evaluated according to their fitness values. GA starts with a set of randomly selected chromosomes as the initial population that encodes a set of possible solutions. Through natural selection and genetic operators, mutation and crossover, chromosomes with better fitness are found. The genetic operators alter the composition of genes to create new chromosomes called offspring. The selection operator is an artificial version of the natural selection, a Darwinian survival of the fittest among the population, to create populations from generation to generation and chromosomes with better fitness have higher probabilities of being selected in the next generation (Paterni, *et al*. 1999).

The PSO method is a population-based one and is described by its developers as an optimization paradigm, which models the social behavior of birds flocking or fish schooling for food. Therefore, PSO works with a population of potential solutions rather than with a single individual. It has also been found to be robust in solving problem featuring non-linear, non-differentiable and high-dimensional. The PSO starts with a population of random solutions ''particles'' in a D-dimension space. The *i*th particle is represented by $X_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$. Each particle keeps track of its coordinates in hyperspace, which are associated with the fittest solution it has achieved so far. The value of the fitness for particle *i* (pbest) is also stored as $P_i = (p_{i1}, p_{i2}, \ldots, p_{iD})$. The global version of the PSO keeps track of the overall best value (gbest), and its location, obtained thus far by any particle in the population. The PSO consists of, at each step, changing the velocity of each particle toward its pbest and gbest according to (11). The velocity of particle *i* is represented as $V_i = (v_{i1}, v_{i2} \ldots v_{iD})$. Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and gbest. The position of the *i*th particle is then updated according to (12):

$$\begin{aligned} v_{id} &= k \times v_{id} + c_1 \times rand(\,) \times (P_{id} - x_{id}) \\ &+ c_2 \times rand(\,) \times (P_{gd} - x_{id}) \end{aligned} \tag{11}$$

$$x_{in}(t+1) = x_{in}(t) + v_{in}(t+1) \tag{12}$$

Where, P_{id} and P_{gd} are *pbest* and *gbest*. The positive constants c_1 and c_2 are the cognitive and social components that are the acceleration constants responsible for varying the particle velocity towards *pbest* and *gbest*, respectively. Variables r_1 and r_2 are two random functions based on uniform probability distribution functions in the range [0, 1]. The use of variable w is responsible for dynamically adjusting the velocity of the particles, so it is responsible for balancing between local and global searches, hence requiring less iteration for the algorithm to converge (A. Ratnaweera, *et al*. 2004). The considered optimization problem can be solved by either particle swarm intelligence or genetic algorithm. A combination of GA and PSO is utilized to overcome the drawbacks of using each of them solely, named HGAPSO optimization algorithm. Genetic algorithm has the capability of global optimum finding but low convergence speed near global optimum, on the contrary, PSO has high convergence speed but the probability of trapping on the local optimum. In the proposed algorithm, individuals are coded to a chromosome that contains variables of the problem.

On/Off statue can be easily represented by binary coding: 1 is on statue and 0 is off statue. If the scheduling period is divided into 24 time-steps and there are total *G* units. Then each unit has 24 bits (Figure1). i.e. 2nd bit of unit 1 represents the on/off statue of unit 1 at 2nd time step. One binary coding individual can be combined according to the order of units and each individual has total *G*×24 bits. Per bit of each individual in one population is produced randomly. This paper transforms the original constrained UC problem into unconstrained one by using penalty function.

$$MinF + \sum_{j=1}^{n_C} u_j R_j \tag{13}$$

Where, F is original objective function; n_c is the number of violation constraints; R_j and u_j are the violation value and penalty coefficient of jth constraint, respectively. Equation (13) only includes spinning reserve, start up and down times, minimum up and down-time constraints. The power balance and unit generation output limitation

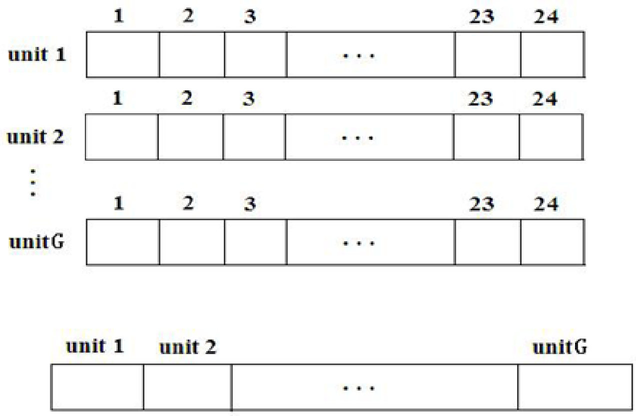

Fig. 1: The binary representation of unit commitment

is considered in the load dispatch. The Fitness Function is:

$$Fitness = \frac{1}{OF} = \frac{k}{F + \sum_{j=1}^{n_c} u_j R_j} \tag{14}$$

Constant K is proportional coefficient. The value of K and u_j should be selected according to the specific problem.

Optimization strategy:

The hybrid GA and PSO are applied to conduct searching optimum for the parameter set of the power system stability. The optimization process is given as:

Step1. Define the varying range of the parameters and objective function over the parameters.
Step2. Set generation gen=0.
Step3. Initialize population of the GA and particles of the PSO.
Step4. Evaluate population of GA and particles of PSO.
Step5. Perform selection operator of the GA.
Step6. Perform crossover and mutation operators of the GA.
Step7. Modify each particle's searching point by Eqs. (11) and (12).
Step8. Evaluate new population of the GA and new particles of the PSO.
Step9. If the termination criterion has satisfied, then stop; otherwise, gen=gen+1 and go to step 5.

For the initialization of GA, the initial population P is generated randomly and chromosomes encoded as the parameter set are encoded into binary string and the mapping from a binary string to a real number (r) is calculated as follows:

$$r = \min_r + binrep \times \frac{\max_r - \min_r}{2^l - 1} \tag{15}$$

Where, $\min_r$ is the minimum value of the input variable, $\max_r$ the maximum value of the input variable, and *binrep* represents the decimal value of length l. The traditional roulette selection with elitism is performed as the selection operator and it ensures that the best chromosome is selected into the new generation, for the GA. The two point crossover w ill act on parents to generate offspring. Mutation is keeping diversity in the

population for the PSO. the initial particles $p \in [\min_r, \max_r]$ are randomly generated and new particles are created by Eqs.
(11) and (12). The inertia weight, k is given by:

$$k = (k_1 - k_2) \times \frac{(MAXGEN - gen)}{MAXGEN} - k_2 \quad (16)$$

Where, k_1 and k_2 are the initial and final value of weight, respectively; *gen* is the current generation number and *MAXGEN* is the maximum number of generation. The fitness for the GA and PSO is computed by maximizing the inverse of the overshoot, defined as follows:

$$Fitness = \frac{1}{OF} = \frac{1}{F + \sum_{j=1}^{n_c} u_j R_j} \quad (17)$$

In our implementation, the size of the initial population for GA and PSO is 100. The crossover probability P_c=50, mutation Probability P_m=0.02, c_1=2.05, c_2=2.05, k_1=0.9, k_2= 0.4, l=10.

Numerical results:

This paper developed the HGAPSO program using visual C++. In order to verify the feasibility and effectiveness of the proposed HAPSO method for solving UCP, the proposed HAPSO method is tested on different system sizes based on a basic system of 10 units from the literature (Juste, K, *et al*. 1999). For the systems of 20, 40, 60, 80 and 100 units, the basic 10-unit system is duplicated and total load demands are adjusted proportionally to the system size. Table 1 gives the 24-h units outputs for the ten-unit case.

Test results and Comparing with other method results, are shown in Table 2 and Table 3, respectively. The obtained result in this paper represents a nearer global optimal solution to the problem and verifies the correctness of the proposed algorithm.

Conclusion:

In this paper, we proposed a hybrid genetic and particle swarm optimization algorithms (HGAPSO) to solve unit commitment problem. The proposed HGAPSO is a combination of particle swarm optimization with genetic algorithm. The simulated results obtained after solving several UCP instances with the number of units in the range of 10–100 show that HGAPSO is efficiently and effectively implemented for UCP.

The proposed algorithm considered various constraints successfully and the genetic operations are improved based on the characteristic of power system. The test results demonstrate the effectiveness of the HGAPSO in searching global or near global optimal solution to the UC problem. Also the results show a better convergence and higher precision.

Nomenclature

i	Index of units
t	Index of time-steps
G	Number of generating units
U_{it}	On/Off status of unit i at time-step t
P_{it}	Generation output of unit i at time-step t
$F_i(P_{it})$	Running cost of the unit i at time-step t
a_i, b_i, c_i	Running cost coefficients of unit I
S_i	Start-up cost of unit i
S_{0i}, S_{1i}, τ	Start-up cost coefficients of unit I
P_{Dt}	System load demand at time-step t
λ	Equal loss incremental rate
P_{Rt}	Spinning reserve
$P_{i\max}$	Unit i maximum generation output limit
$P_{i\text{mix}}$	Unit i minimum generation output limit
M_i	Start up and down times limitation

$\underline{TO_i}$ Minimum up time of unit *i*th

$\underline{TS_i}$ Minimum down time of unit *i*th

TO_i Duration during which unit is continuously on

TS_i Duration during which unit is continuously off

Table 1: Optimal Unit Commitment Result

Unit Number	On/Off Statue of Per Time-Step																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
4	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
5	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	0	0
6	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	0	0
7	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	0	0	0
8	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2: Total costs of the HGAPSO method for test systems.

No. of units	Best cost ($)	Average cost ($)	Worst cost ($)
10	564,312	564,489	565,646
20	1,124,871	1,125,109	1,125,390
40	2,247,973	2,248,267	2,248,693
60	3,370,412	3,370,828	3,371,329
80	4,487,637	4,488,233	4,489,231
100	5,616,102	5,616,992	5,618,069

Table 3: Comparison of the best total costs ($).

Methods	Number of Units					
	10	20	40	60	80	100
GA [7]	565,825	1,126,243	2,251,911	3,376,625	4,504,933	5,627,437
LR [7]	565,825	1,130,660	2,258,503	3,394,066	4,526,022	5,657,277
MA [10]	565,827	1,128,192	2,249,589	3,370,820	4,494,214	5,616,314
EP [21]	564,551	1,125,494	2,249,093	3,371,611	4,489,479	5,623,885
HGAPSO	564,312	1,124,871	2,247,973	3,370,412	4,487,637	5,616,102

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