An Improved Integer Coded Genetic Algorithm for Security Constrained Unit Commitment.

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ABSTRACT

This paper presents a novel approach to solve the security constrained unit commitment problem using decomposition technique. The method applies an improved integer coded genetic algorithm (ICGA) to schedule the commitment states of units. ICGA technique reduces the size of chromosomes and computation time significantly. Here, the proposed ICGA has been enhanced by using perturbation operator. Simulation results for six-bus test system exhibit the effectiveness of the proposed approach.

(Keywords: integer coded genetic algorithm, ICGA, security constrained unit commitment, SCUC, perturbation operator)

INTRODUCTION

The principal object of UC in conventional power systems is to schedule the status of generation units in order to serve the load demand at minimum operating cost while meeting all plant and system constraints. While in new power markets the financial aspect is one of the most important objects in power generation scheduling, the secure operation of the system is essential. Therefore in some competitive electricity markets a centralized Security Constrained Unit Commitment (SCUC) determines the generation schedule. SCUC provides a financially viable unit commitment (UC) that is physically feasible.

The UC problem as a part of SCUC is considered as a large scale nonlinear, nonconvex, and mixed integer problem. In order to overcome the complexity of the UC problem, several methods have been proposed to obtain exact optimal solution.

Tabu search [8], simulated annealing [4], priority list based methods [3], simplex method [4], Lagrangian relaxation [6], dynamic programming [10], and mixed-integer programming [9] are some techniques have been used to solve UC problems. As it will be discussed in the next section, SCUC is much more complex than UC problem.

Decomposition of the problem is a good simplification technique to divide the main complex problem of SCUC into a master problem (UC) and network security check sub-problems [17, 18]. Reference [12] shows the advantages of benders decomposition technique to solve the SCUC problem in power system. References [5, 11, and 13] use benders decomposition technique to solve SCUC problem in new deregulated power systems. In these works Lagrangian relaxation and dynamic programming are used for unit commitment scheduling and linear programming is applied to solve sub-problems.

In [1] the authors developed and implemented an integer coded genetic algorithm (ICGA) to solve the UC problem. ICGA is able to find a better unit commitment schedule in a comparatively lower amount of time because of the power of GA in optimization problem. Therefore this paper presents a method based on ICGA which have improved with perturbation operator. Numerical studies on 6-bus system show the advantages of proposed algorithm. Final schedule have a lower operating cost in comparison with previous mentioned methods.

PROBLEM FORMULATION

Decomposition Technique

Problem decomposition is a popular optimization technique. In applying the decomposition algorithm, the original large-scale optimization problem is divided into a master problem and several sub-problems.

Master Problem

For the proposed problem, the master problem includes unit commitment which can be formulated by (1)-(7) without considering reactive power generation and network constraints. The objective is to minimize the cost of supplying the load as formulated below [5, 11]:

$$\text{Min} \sum_{i=1}^{NG} \sum_{t=1}^{NT} [F_{ci}(P_{it}) * I_{it} + SU_{it} + SD_{it}] \quad (1)$$

where,

I_{it}	Commitment state of unit i at time t;
$F_{ci}(.)$	Production cost function of unit i;
N_G	Number of units;
N_T	Number of periods of time under study (24 h);
P_{it}	Generation of unit i at time t;
SD_{it}	Shutdown cost of unit i at time t;
SU_{it}	Startup cost of unit i at time t;

Function (1) is composed of production costs of generators and startup and shutdown costs of individual units over the given period. The optimal amount of power generation for each generator will be determined by economic dispatch.

$$\sum_{i=1}^{N_G} P_{it} * I_{it} = P_{D,t} + P_{L,t}$$
$$\sum_{i=1}^{N_G} R_{S.it} * I_{it} \geq R_{S,t} \quad (t = 1, \ldots, N_T) \quad (2)$$

$$P_{it} - P_{i(t-1)} \leq [1 - I_{it}(1 - I_{i(t-1)})]\, UR_i + I_{it}(1 - I_{i(t-1)}) P_{i,min} \quad (i = 1, \ldots, N_G) \quad (3)$$

$$P_{i(t-1)} - P_{it} \leq [1 - I_{i(t-1)}(1 - I_{it})]\, DR_i + I_{i(t-1)}(1 - I_{it}) P_{i,min} \quad (i = 1, \ldots, N_G) \quad (4)$$

$$[X^{on}{}_{i(t-1)} - T_i^{on}] * [I_{i(t-1)} - I_{it}] \geq 0 \quad (5)$$
$$[X^{off}{}_{i(t-1)} - T_i^{off}] * [I_{it} - I_{i(t-1)}] \geq 0 \quad (t = 1, \ldots, N_T) \quad (i = 1, \ldots, N_G)$$

$$P_{i,min} I_{it} \leq Pit \leq P_{i,max} I_{it} \; (t = 1, \ldots, N_T)(i = 1, \ldots, N_G) \quad (6)$$

$$F_{FT}^{min} \leq \sum_{t=1}^{N_T} \sum_{i \in FT} [F_{fi}(P_{it}) * I_{it} + SU_{f,it} + SD_{f,it}] \leq F_{FT}^{max} \quad (7)$$

where,

DR_i	Ramp-down rate limit of unit i;
$F_{FT}{}^{min}$	Minimum fuel consumption of type FT;
$F_{FT}{}^{max}$	Maximum fuel consumption of type FT;
$P_{i,min}$	Lower limit of active power generation of unit i;
$P_{i,max}$	Upper limit of active power generation of unit i;
$P_{D,t}$	System demand at time t;
$P_{L,t}$	System demand at time t;
$R_{s,it}$	Spinning reserve of unit i at time t;
$R_{S,t}$	Total system spinning reserve requirement at time t;
$SU_{f,it}$	Startup fuel consumption of unit i at time t;
$SD_{f,it}$	Shutdown fuel consumption of unit i at time t;
T_i^{on}	Minimum up time of unit i;
T_i^{off}	Minimum down time of unit i;
UR_i	Ramp-up rate limit of unit i;
X_{it}^{off}	OFF time of unit i at time t;
X_{it}^{on}	ON time of unit i at time t;

The above mentioned constraints are the system power balance (2), system spinning reserve requirements (3), ramping up/down limits (4), minimum up/down time limits (5), real power generation limits (6), and fuel consumption limitations (7).

Sub-problem

Limitations on reactive power generation (8), constraints on power flow through transmission lines (9) and bus voltage limits (10) are considered and met in sub-problems (11) and (12) are constraints on tap changing and phase shifting transformers. A power flow problem will be solved to check the system constraints.

$$Q_{i,min} I_{it} \le Q_{it} \le Q_{i,max} I_{it} (t=1,\ldots,N_T)(i=1,\ldots,N_G) \quad \textbf{(8)}$$

$$-PL_{l,max}^{t} \le PL_{l}^{t} \le PL_{l,max}^{t} (t=1,\ldots,N_T)(l=1,\ldots,N_L) \quad \textbf{(9)}$$

$$V_{b,min}^{t} \le V_{b}^{t} \le V_{b,max}^{t} (t=1,\ldots,N_T)(b=1,\ldots,N_B) \quad \textbf{(10)}$$

$$T_{min} \le T^{t} \le T_{max} (t=1,\ldots,N_T) \quad \textbf{(11)}$$

$$\gamma_{min} \le \gamma^{t} \le \gamma_{max} (t=1,\ldots,N_T) \quad \textbf{(12)}$$

where,

$PL_{i,max}$ Maximum capacity of line i;
$Q_{i,min}$ Lower limit of reactive power generation of unit i;
$Q_{i,max}$ Upper limit of reactive power generation of unit i;
V_b Voltage magnitude at bus b;
$V_{b,min}$ Minimum voltage magnitude at bus b;
$V_{b,max}$ Maximum voltage magnitude at bus b;
γ_{min} Lower limit vector of phase shifter angle;
γ_{max} Upper limit vector of phase shifter angle;
T_{min} Lower limit vector of transformer tap;
T_{max} Upper limit vector of transformer tap;

INTEGER-CODED GENETIC ALGORITHM

Chromosome Definition

Each chromosome consists of NG genes corresponding to NG units. The schedule for each unit can be demonstrated by a 5 digit string so that each digit shows the period of time that the unit remains in up or down state. Positive/negative numbers indicate up/down state. Due to the limitations of plants in startup and shutdown it seems to be rational to restrict 5 transitions for each unit during 24 hours of a day. Figure 1 shows the concept clearly and Equation (13) describes it.

$$\sum_{c=1}^{5} \left| T_i^c \right| = 24 \qquad i \in \{\text{Gen. units}\} \quad \textbf{(13)}$$

Fitness Function

The fitness function includes total operation cost for the scheduled unit commitment and related generation dispatch as described in (1). Start up/shot down cost should be considered for units (if any) using the following relations.

$$SU_{it} = \sum_{i=1}^{N_G} \sum_{c=2}^{5} V(T_i^c).SUi(-T_i^{c-1}) \quad \textbf{(14)}$$

$$SD_{it} = \sum_{i=1}^{N_G} \sum_{c=2}^{5} [1 - V(T_i^c)].SD_i \quad \textbf{(15)}$$

where
$V(.)$ Unit step function;

Chromosome Correction

If the chromosome which is defined in previous steps cannot fulfill sub-problems, chromosome correction improves the schedule of chromosome in a random manner. At first it finds hours which violation has been occurred. Then it breaks the chromosome and replaces another random schedule for these hours. Based on the new random schedule for mentioned hours, the chromosomes need to be modified to meet minimum permissible on/off time. As the other chromosomes, this new generated chromosome will be checked in sub-problems. If new modified chromosome cannot meet the system constraints, this procedure will be repeated. Numerical studies show that if the chromosome could not be corrected in 5 iterations it should be removed from the population.

GA Evolution

The evolution of a GA population is based on the natural selection [14, 16] and the survival of the best chromosome. In our implementation, this is achieved using the roulette wheel parent selection [16]. It means that the chance of a chromosome to be selected for reproduction is proportional to its fitness.

When two parents are selected, their symbol strings are combined to produce “offspring” solution using genetic-like operators. The common operators are crossover and mutation.

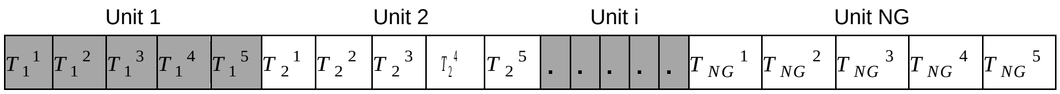

Figure 1: Chromosome Structure.

This paper uses perturbation in addition to common operators to achieve a lower operating cost. Test results show benefits of this new operator. It should be notified that in all GA Evolution stages, eq. (13) should be met.

Initial Population*:* To achieve the optimal solution it is better to produce a large initial population. In this problem probability of generating infeasible chromosomes is too high in random manner and it seems not to be rational to test all of constraints for each chromosome; therefore, it is better to reduce the number of initial population by checking the most important criterions which makes some of initial populations infeasible. The following constraints are made and used for this stage which is based on original constraints.

$$\sum_{i=1}^{N_G} \mathrm{P}_{\mathrm{i,max}} * \mathrm{I}_{\mathrm{it}} \geq \mathrm{P}_{\mathrm{D,\,t}} + \mathrm{P}_{\mathrm{L,\,t}} \quad \textbf{(16)}$$

$$\sum_{i=1}^{N_G} \mathrm{P}_{\mathrm{i,min}} * \mathrm{I}_{\mathrm{it}} \leq \mathrm{P}_{\mathrm{D,\,t}} + \mathrm{P}_{\mathrm{L,\,t}} \quad \textbf{(17)}$$

Crossover: The common way in crossover is to select one or more crossing points in the parent chromosomes and swaps the resulting pieces. There is one extra important restriction here for selecting cross point. We ought not to break the time schedule of one unit. It's only authorized to swaps one or more whole unit schedules. Figure 2 shows the crossover operator.

Mutation: While crossover operator exchanges the whole schedule of units between two parents, mutation operator influences the up/down schedule for one random unit in a portion of population. For each selected chromosome one random point and its related digit is chosen. If the integer is positive/negative it will be replaced with another random integer between its value and minimum up/down time of the unit. Equation (13) should be met by changing one another integer.

Perturbation Operator: Perturbation operator is a special case of proposed mutation. While in mutation, any selected digit can be replaced by any other acceptable digit; in perturbation, randomly selected digit will be added with ± 1. It means we decide to increase or decrease the previous on or off time. To meet (13) one another digit (e.g., adjacent integers) should be changed. This operator is applied to the best chromosomes with a suitable rate.

Excessive-Power Elimination Operator: The existence of some units operating at minimum power during certain time intervals in a daily schedule may indicate commitment of excessive expensive units during these time intervals. Such a commitment schedule may be improved if some of the units operating at minimum are turned off while certain conditions are met. The excessive power elimination operator checks whether the rest of the online units satisfy demand requirements during the time interval that the unit is turned off. If the above requirements are satisfied, then the operator turns the unit off for this specific time interval and the new schedule is evaluated. If it is superior to the original, the new solution is encoded back to the chromosome. This operator can increase the rate of convergence.

TEST RESULTS

The proposed ICGA algorithm was implemented in MATLAB® program. The program is tested on a 6-bus system data described in Ref. [5]. Test results have been obtained considering population size of 50 for 300 generations with crossover and mutation rate of 0.8 and 0.2, respectively. In order to discuss the advantages of the proposed approach, 4 cases are studied and compared with the results of Ref. [5].

	Unit 1					Unit 2					Unit i					Unit NG				
Parent 1	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Parent 2	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Offspring 1	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Offspring 2	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5

Figure 2: Crossover Operator.

	Unit 1					Unit 2					Unit i					Unit NG				
Parent	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Offspring 1	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3-1	T_i^4+1	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Offspring 2	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4+1	T_i^5-1	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Offspring 3	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3+1	T_i^4-1	T_i^5	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5
Offspring 4	T_1^1	T_1^2	T_1^3	T_1^4	T_1^5	T_2^1	T_2^2	T_2^3	T_2^4	T_2^5	T_i^1	T_i^2	T_i^3	T_i^4-1	T_i^5+1	T_{NG}^1	T_{NG}^2	T_{NG}^3	T_{NG}^4	T_{NG}^5

Figure 3: Perturbation Operator.

Case 1: This case is scheduled without considering network constraints. Therefore the proposed schedule is the result of UC (master) problem. Table 1 shows the results.

Case 2: Consider ac transmission flow violations with the schedule obtained in case1. As it is shown in Table 2 violations occur in line 1-4 at hours 12, 20 and 21. The mentioned algorithm, proposes to incorporate unit 2. Incorporating unit 2 in mentioned hours will remove transmission flow violations. Table 3 shows the results.

Case 3: By considering case 1 as the base, Table 4 shows that bus voltage violations occur in bus 4 at hours: 10, 23 and 24. The proposed algorithm suggests committing unit 3 for these hours to eliminate violations. Because unit 2 is more expensive than unit 3, this commitment schedule has lower production cost in comparison with the solution of Ref. [5] which uses unit 2 to remove violations. Table 5 shows the proposed schedule.

Case 4: Transmission flow and bus voltage constraints shall be fulfilled in this case and it considers all ac network constraints. This case has also lower production cost in comparison with [5] which unit 2 removes violations instead of unit 3 at hours 10, 23 and 24. Table 6 demonstrates the results.

Table 1: Integer UC Schedule without Transmission and Voltage Constraints.

1	24	0	0	0	0
2	1	-11	7	-5	0
3	-10	12	-2	0	0

Table 2: Flow on Line 1-4 at Violated Hours.

Hours		12	20	21
No Cuts		102.16	102.72	102.7
T-Cuts	From bus 1	100	100	100
	To bus 4	98.45	98.40	98.41

Table 3: Integer SCUC Schedule with AC Transmission Constraints.

1	24	0	0	0	0
2	1	-10	10	-3	0
3	-10	12	-2	0	0

Table 4: Voltages on Bus 4 at Violated Hours (PU).

Hours		10	23	24
No Cuts		0.887	0.891	0.8914
V-Cuts	mag	0.991	0.999	0.999
	ang	-13.262	-12.422	-12.385

Table 5: Integer SCUC Schedule with AC Voltage Constraints Integer Schedule.

1	24	0	0	0	0
2	1	-12	6	-5	0
3	-11	13	0	0	0

Table 6: SCUC with AC Network Security Constraints Integer Schedule.

1	24	0	0	0	0
2	1	-10	10	-3	0
3	-9	15	0	0	0

CONCLUSION

ICGA strategy which have employed for representing chromosomes and encoding the problem search space is able to find a solution with minimum cost. It also ensures having at least one feasible solution during every stage of the GA simulation. Numerical studies on 6-bus system shows the abilities of the proposed algorithm.

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