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# A Novel Unit Commitment Technique Considering Prohibited Operating Zones

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**Abstract:** The aim of this study is to show the effectiveness of prohibited operating zone. Generation scheduling is a crucial challenge in power systems especially under new environment of liberalization of electricity industry. This study is focused on the economical aspect of unit commitment problem. Since, the generating units may have certain ranges where operation is restricted based upon physical limitations of machine components or instability. Therefore, Prohibited Operating Zones (POZ) as a redundant constraint is considered, while the next load demand as a very important issue is deliberated. In this study generation scheduling of each hour is conducted by considering the next load demands to increase reliability of scheduling. The impact of hot/cold start-up cost is taken in to account in order to get an efficient generation scheduling via genetic algorithm. Case studies and numerical analysis presents significant outcomes, while it demonstrates the effectiveness and robustness of the proposed method.

**Key words:** Economic dispatch, generation scheduling, genetic algorithm

## INTRODUCTION

Fast growing load in power systems associated with a large gap between heavy load and light load periods, generation scheduling and Unit Commitment (UC) problem has become a crucial issue in operation time horizon and unit commitment problem has always been an important research challenge in power systems especially under restructured environment. In a vertically integrated power system, unit commitment determines when to start-up or shut-down units and how to dispatch online generators over a given scheduling horizon in order to minimize the operating costs, satisfying the prevailing constraints such as load balance, system reserve requirement, ramp rate limits, minimum up/down time limits (Tsung and Chen, 2007; Afshar *et al*., 2007; Yamin *et al*., 2007; Dieu and Ongsakul, 2008). Since, the unit commitment is a mixed integer programming, it is very hard to get an exactly optimal solution and it has been viewed as a very complex optimization problem and variant methods have been implemented to solve such a complicated problem either using classical optimization or heuristic as well as hybrid techniques. Dynamic Programming (DP) is the earliest conventional optimization method that can be applied to solve the dissimilar size UC problem. The other classical optimization methods are as follows: Priority List (PL) (Senjyu *et al*., 2003) Lagrangian Relaxation (LR), mixed integer programming (Daneshi *et al*., 2008) and Branch and Bound (B and B). The classical optimization techniques, in general, might not be able to find a solution within a significant computational time for the medium or large scale UC problem. These limitations have been redounded to introduce the heuristic optimization methods (Padhy *et al*., 1997). With the emergence of metaheuristic and evolutionary algorithm in modern optimization technique such as: Simulated Annealing (SA), Tabu Search (TS), fuzzy logic, Genetic Algorithm (GA), Artificial Neural Network (ANN) (Padhy, 2004) and Ant Colony (AC) (Sum-Im and Ongsakul, 2003) have been used to solve the UC problem. Moreover, in some methods more than one algorithm has been incorporated together and forms a hybrid technique to meet the industry requirements. The hybrid methods are also applied to handle more complicated constraints and are claimed to have a better performance. In one hand, evolutionary algorithms may seem simple but their solution might be suboptimal and on the other hand, they might be complicated with more accurate results (Padhy *et al*., 1997). The hybrid methods such as fuzzy dynamic programming and neural network (Daneshi *et al*., 2003), genetic-based neural network, Lagrangian relaxation associated with genetic algorithm (Yamin and Shahidehpour, 2003) and annealing genetic algorithm (Cheng *et al*., 2000a) are experienced to tackle to the UC problem.

In this study a new approach considering next hours demand by minimizing the operating costs considering

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prohibited zones is presented. The generating units may have certain ranges where operation is restricted based upon physical limitations of machine components or instability, e.g., due to steam valve or vibration in shaft bearings. Therefore, prohibited operating zones as a prominent constraint must be considered. By including next hours demand at a scheduling horizon the online units that are not optimal to be turned off kept continuing. On the other hand, in the proposed formulation a new objective function that comprises start-up cost is used in order to select the best chromosomes to get better results. So, at first units with less start up cost are selected and then generation units with higher start-up cost may have a chance to be turned on in order to minimize total scheduling horizon costs.

## MATERIALS AND METHODS

Unit commitment involves determining generation outputs of all units from an initial hour to satisfy load demands associated with a start-up and shut-down schedule over a time horizon. The objective is to find the optimal schedule such that the total operating costs can be minimized, while satisfying the load demand, spinning reserve requirement as well as other operational constraint.

**Objective function:** The outage cost as well as fuel cost of generation units should be considered in power system operation as an objective function of a UC problem. The objective function is a function that comprises the fuel costs of generating units, the start-up costs of the committed units and shut-down costs of decommitted units. The start-up cost is presented in two schemes: hot start-up costs and cold start-up costs, while the shut-down cost is assumed to be fixed. Nevertheless the objective function in common form is expressed by Eq. 1.

$$\begin{aligned}\text{Minimize } \{&\sum_{t=1}^{T}\sum_{i=1}^{N}F_{i,t}(p_{i,t}^{o})*u_{i,t} \\ &+\sum_{t=1}^{T}\sum_{i=1}^{N}SUC_{i,t}*u_{i,t}*(1-u_{i,t-1}) \\ &+\sum_{t=1}^{T}\sum_{i=1}^{N}SDC_{i,t}*u_{i,t-1}*(1-u_{i,t})\}\end{aligned} \quad (1)$$

where, $P_{i,t}^{o}$ is power output of unit i at hour t, $u_{i,t}$ is on or off status of unit i at hour t, $SUC_{i,t}$ and $SDC_{i,t}$ are start-up cost and shut-down cost of unit i at time t, respectively, N is number of units and T is unit commitment horizon.

The fuel costs of generating units and the major component of the operating costs for thermal units are generally given in a quadratic form as it is shown in Eq. 2. Operating cost coefficients can be given or they might be estimated using bidding strategies (Badri *et al*., 2008):

$$F_{i,t}(P_{i,t}^{o}) = a_i + b_i P_{i,t}^{o} + c_i (P_{i,t}^{o})^2 \quad (2)$$

where, $a_i$, $b_i$ and $c_i$ are fuel cost coefficients for unit i:

The start-up cost is defined as follow:

$$SUC_{i,t} = \begin{cases} HSC_i, & \text{if } T_{i,t}^{D} \le MD_i^{ON} \le T_{i,t}^{D} + CST_i \\ CSC_i, & \text{if } MD_i^{ON} > T_{i,t}^{D} + CST_i \end{cases} \quad (3)$$

where, $HSC_i$ and $CSC_i$ are hot start-up cost and cold start-up cost, respectively, $T_{i,t}^{D}$ is minimum down-time of unit I, $MD_i^{ON}$ is duration during which the ith unit is continuously on and $CST_i$ is cold start time of unit i.

**Operational limitation and constraints:** The minimization of the objective function is subjected to a number of system and unit constraints such as: power balance, spinning reserve capacity of generating units, prohibited operating zones, minimum up/down time limit as well as spinning reserve requirement. Initial conditions are needed to be considered in scheduling problem:

- **Initial condition:** Initial conditions of generating units include the number of hours that a unit consequently has been on-line or off-line and its generation output at an hour before the scheduling
- **Power balance constraint**

$$\sum_{i=1}^{N}(P_{i,t}^{o})*u_{i,t} = D_t \quad 1 \le t \le T,\ i \in N \quad (4)$$

where, $D_t$ is demand during hour t

- **Unit output limit:**

$$\begin{aligned}&\underline{P}_{i,t}*u_{i,t} \le P_{i,t}^{o}*u_{i,t} \le \overline{P}_{i,t}*u_{i,t} \\ &1 \le t \le T,\ i \in N\end{aligned} \quad (5)$$

where, $\underline{P}_{i,t}$ and $\overline{P}_{i,t}$ are minimum generation and maximum generation of unit i, respectively.

- **Spinning reserve:**

$$\sum_{i=1}^{N}(\overline{P}_{i,t})*u_{i,t} \ge D_t + SR_t \quad 1 \le t \le T,\ i \in N \quad (6)$$

where, $SR_t$ is spinning reserve requirement at time t

- **Unit ramp-up constraint:**

$$\begin{aligned}&P_{i,t}^{o} \le \overline{P}_{i,t} \\ &\overline{P}_{i,t} = \text{Min}\{P_{i,t-1}^{o} + RUR_i, \overline{P}_i\} \\ &1 \le t \le T,\ i \in N\end{aligned} \quad (7)$$

where, $RUR_i$ is ramp up rate limit of unit I

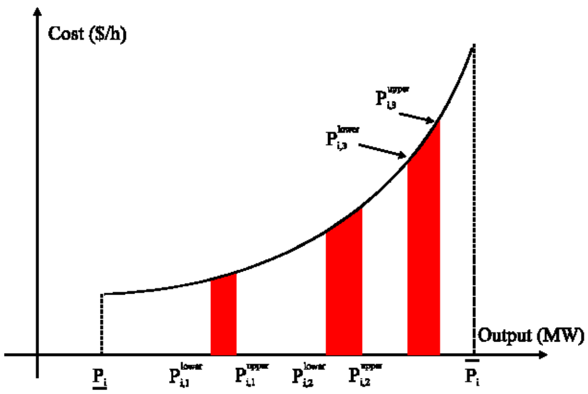


Fig. 1: Prohibited operating zones and output limit of a generator

- **Unit ramp-down constraint:**

$$\begin{aligned}&\underline{P}_{it} \le P_{i,t}\\&\underline{P}_{it} = \mathrm{Max}\{P^{o}_{i,t-1} - RDR_i, \underline{P}_i\}\\&1 \le t \le T,\ i \in N\end{aligned} \tag{8}$$

where, $RDR_i$ is ramp down rate limit of unit i:

**Prohibited operating zone:** Some on-line generating units have their generation limit, which cannot be exceeded at any time (Saber *et al*., 2009). Moreover, a typical thermal unit may have a steam valve in operation, or a vibration in a shaft bearing, which may result in interference and discontinue inputBoutput performance-curve sections, called prohibited operating zones, as shown in Fig. 1.

Therefore, in practical operation, adjusting the generation output of a unit must avoid all capacity limits and unit operations in prohibited operating zones. The feasible operating zones of a unit can be described as follows:

$$\begin{cases}\underline{P}_i \le P^{o}_i \le P^{Lower}_{i,1}\\P^{Upper}_{i,j-1} \le P^{o}_i \le P^{Lower}_{i,j}, \qquad j = 2,..PZ_i\\P^{Upper}_{i,PZ_i} \le P^{o}_i \le \overline{P}_i\end{cases} \tag{9}$$

where, $P^{Lower}_{i,1}$ and $P^{Upper}_{i,j-1}$ are lower and upper bounds of the jth prohibited zone of unit i and $PZ_i$ is the number of prohibited zones of unit i.

**Minimum up time limit:** Minimum number of hours that a unit must be continuously on-line since it has been turned on:

$$MD^{ON}_i \ge T^{U}_i \tag{10}$$

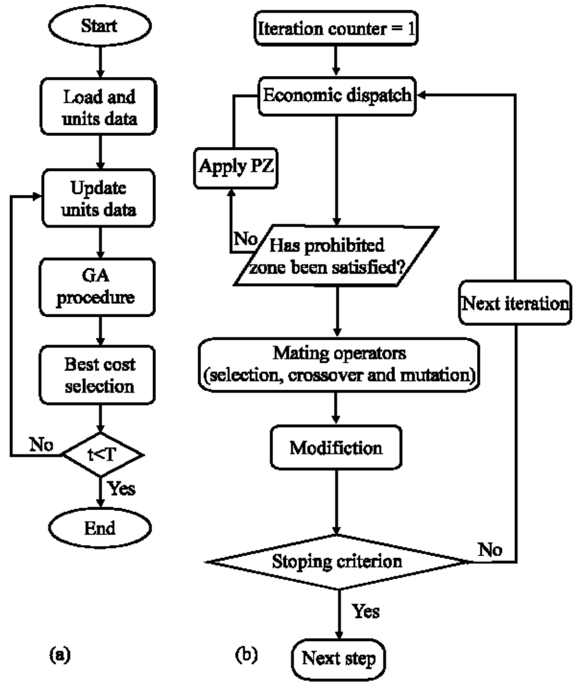


Fig. 2: (a) Main flowchart of proposed Method (UCPOZ) and (b) GA procedure considering POZ limit

where, $MD^{ON}_i$ duration during which the ith unit is continuously on.

**Minimum down time limit:** Minimum number of hours that a unit must be continuously off-line since it has been turned off

$$MD^{OFF}_i \ge T^{D}_i \tag{11}$$

where, $MD^{OFF}_i$ duration during which the ith unit is continuously off.

**Solution methodology:** The optimization technique consists of some steps that is shown in Fig. 2a: Main flowchart of proposed Method (UCPOZ) b: GA procedure considering POZ limit are explained in the following steps. In each step, related constraints are taken into account while finally the objective function associated with all constraints is minimized via Genetic Algorithm (GA).

**Call load and units data**

**Initialization:** At this step an initial population is generated according to Eq. 5, 7, 10 and 11 such that some information for first hour is obtained from initial condition. In order to have an efficient program the demands of next $T^{D}_i$ hours should be taken into consideration. When a unit is turned off its status cannot be changed for $T^{D}_i$ hours, while satisfying the next $T_i^D$ hours demand excluding this unit should be examined. If it is not satisfied for any next $T_i^D$ hours, scheduling will be referred to the previous hour for re scheduling in which the later unit should kept online (Pourakbari-Kasmaei *et al.*, 2008).

**Update units data:** Here, units' data like the time that a unit continuously has been on/off according to the previous hour's scheduling is updated.

**GA procedure:** Genetic algorithm is a random and robust search technique that guides a population towards an optimum using the principles of natural evolution. This process is facilitated through a fitness evaluation procedure, which determines the fitness value of each member of the population the so-called chromosome. Each chromosome contains a number of gens. In this simulation the chromosome is corresponds to a plant and a gen is corresponds to a unit. The robustness of GA and its capability across a broad range of problems make GA as general problem solving techniques in many applications (Swarup and Yamashiro, 2002). So, in this study according to the complexity of unit commitment considering prohibited operating zones (UCPOZ), GA is used to solve this complicated and non-convex optimization problem. The flowchart of the proposed GA-based solution approach for UCPOZ is shown in Fig. 2b that includes the following steps:

**Initialize the iteration counter as stopping criterion:** In this study according to the number of units the number of iterations is set to 80 and at first the iteration counter is set to one.

**Economic dispatch:** Economic dispatch determines the output of all online units with the objective of minimum total operating costs at a given hour, which is subjected to the power balance constraint Eq. 4 and output limits Eq. 5. For each chromosome of the generated population in step 2 of the main flowchart the ED is applied and the output power of each gens of chromosome is obtained. A lambda iteration method is applied in this study to determine the optimal economic dispatch.

**Prohibited zone check:** After ED, for each gens of chromosome, the prohibited operating zone check is taken into consideration. If any of gens violated the POZ, the POZ is applied to that gen and ED is repeated for the aforementioned chromosome.

**Fitness evaluation:** Here, the fitness value of each chromosome should be calculated. In order to accelerate the convergence of the proposed method the fitness function is adopted as follows:

$$\text{Adopted fitness function} = \frac{A}{1 + \text{Cost}(\text{chr}, \text{itr})} \tag{12}$$

where, A is the big positive number (assumed 1E+4), chr and itr are chromosomes and iteration counter, respectively.

Since, in scheduling problems the objective is to minimize the operating costs, those units with more expensive start-up costs may have no chance to be turned on before they must be, while they may impose less total operating costs. So, in this study a modified cost function with Modified Start Up Cost (MSUC) that is shown by Eq. 13 is used in order to select the best chromosomes for crossover and mutation and then generate new chromosomes to get an optimum scheduling.

At IEEE 10 unit test system the cold start-up cost (CSC) is held twice of hot start-up cost (HSC) but at this paper Eq. 14 is used, if $T_i^D \le MD_i^{OFF} \le T_i^D + CST$ changing of HSC to CSC is not as sharp as a step, at this case the change is sluggish.

$$\text{Cost}(\text{chr}, \text{itr}) = \text{Min}\sum_{t=1}^{T}\sum_{i=1}^{N} F_{i,t}(p_{i,t}) * u_{i,t} + MSUC_{i,t} * u_{i,t} * (1 - u_{i,t-1})\} \tag{13}$$

Where:

$$MSUC_{i,t} = \begin{cases} CSC_{i,t} & \text{if } MD_i^{OFF} > T_i^D + CST_{i,t} \\ (1 + \dfrac{MD_i^{OFF}}{T_i^D + CST_{i,t}})HSC & \text{if } T_i^D \le MD_i^{OFF} \le T_i^D + CST_{i,t} \end{cases} \tag{14}$$

- **Mating:** The mating process consists of three operators: selection, crossover and mutation (Haupt and Haupt, 2004)
- **Modification:** After crossover and mutation processes for achieving feasible chromosomes two following tasks should be handled
- **Chromosomes elimination:** Infeasible chromosomes that can not satisfy the SRR constraint will be eliminated as redundant
- **Chromosome modification:** Since, the number of chromosomes must be remained constant, chromosomes with the best fitness are replaced instead of eliminated chromosomes

**Stopping criterion:** For stopping GA Procedure it is needed to have a criterion, in this study a constant number of iteration has been used.

**Best cost selection:** Here, the chromosome with the least cost is selected and the output power for all gens is kept as the best answer. All steps are repeated in scheduling time horizon.

## RESULTS AND DISCUSSION

The proposed methodology is implemented to a standard IEEE 10-Unit test system while at first the study is only about a commonly unit commitment problem and finally the prohibited operating zones is taken into consideration as a practical and redundant limitation. The POZ that is employed in the study is not an accurate representation. However, there is no great difficulty in making some changes in the formulations developed so that the proposed approach can employ different dispatch representation.

## CASE 1: STANDARD IEEE 10-UNIT TEST SYSTEM

The proposed method has been applied to solve a commonly UC problem that so-called 10-unit base system with the given data presented in the Table 5, where, in this case the POZ limitation is not considered. The result of the units output power is given in Table 1 and total cost comparison of several techniques is shown in Table 2.

The load demand of 10 unit base problem is given in Table 6.

## CASE 2: IEEE 10-UNIT TEST SYSTEM CONSIDERING POZ

In practice each generator has its generation limit, which cannot be exceeded at any time. Moreover, a typical thermal unit may have a steam valve in operation, or a vibration in a shaft bearing, which may result in interference and discontinue inputBoutput performance-curve sections, called Prohibited Operating Zones (POZ), so it seems be essential to study the POZ as a redundant limitation. As it can be seen from Table 1, at first hour both of units are generated in POZ and this is so difficult to change these generations according to POZ, but using GA is an efficient method for this purpose. The result of the units' output power is given in Table 3.

Table 3 for 24 h time horizon with a total operating cost 564714$. As the PZ is a practical constraint in the UC problem and has not been considered in the previous literatures, so by comparison of UCPOZ cost with the costs in Table 2. Total cost comparison of several techniques, it is clearly seen that there is no main difference between them which present the effectiveness of UCPOZ.

Table 1: Units output power for the 10 unit case

| | H | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U | 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 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 |
| 2 | 245 | 295 | 370 | 455 | 455 | 455 | 455 | 430 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 315 | 260 | 360 | 455 | 455 | 455 | 455 | 425 | 345 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 0 | 0 | 0 |
| 5 | 0 | 0 | 25 | 40 | 70 | 40 | 90 | 25 | 85 | 162 | 162 | 162 | 162 | 85 | 30 | 25 | 25 | 25 | 30 | 162 | 85 | 145 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | 20 | 33 | 68 | 80 | 33 | 20 | 0 | 0 | 0 | 0 | 0 | 33 | 20 | 20 | 20 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 25 | 25 | 25 | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 43 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 2: Total cost comparison of several techniques

| | Total cost of different methods | | | | | | |
|---|---|---|---|---|---|---|---|
| Method | SPL | EP | PSO | BPSO | PSO-LR | LR | LRGA |
| Cost | 564950 | 565352 | 574153 | 565804 | 565869 | 566107 | 564800 |
| | Total cost of different methods | | | | | | |
| Method | ALR | GA | BCGA | ICGA | DP | MA | PM |
| Cost | 565508 | 565825 | 567367 | 566404 | 565825 | 565827 | 564703 |

Table 3: Units output power for the 10-unit case considering POZ

| | H | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| U | 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 | **447.9999** | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455.00 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 | 455 |
| 2 | **252.0001** | 295 | 370 | 455 | 455 | 455 | 455 | 430 | 455 | 455 | 455 | 455.00 | 455 | 455 | 455 | 315 | 260 | 360 | 455 | 455 | 455 | 455 | 425 | 345 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 130 | 130 | 130 | 130 | 130.00 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 130 | 130 | 130 | 130 | 130 | 130 | 130.00 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 130 | 0 | 0 | 0 |
| 5 | 0 | 0 | 25 | 40 | 70 | 40 | 90 | 25 | 85 | 162 | 162 | 162.00 | 162 | 85 | 30 | 25 | 25 | 25 | 30 | 162 | 85 | 145 | 0 | 0 |
| 6 | 0 | 0 | 0 | 0 | 20 | 20 | 20 | 20 | 20 | 33 | 68 | **77.9999** | 33 | 20 | 0 | 0 | 0 | 0 | 0 | 33 | 20 | 20 | 20 | 0 |
| 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 25.00 | 25 | 25 | 0 | 0 | 0 | 0 | 0 | 25 | 25 | 25 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | **45.0001** | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 |
| 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 4: Abbreviation of UC solution techniques

| Abbreviation | Solution techniques |
|---|---|
| SPL | Stochastic priority list (Senjyu *et al.*, 2006) |
| EP | Evolutionary programming (Juste *et al.*, 1999) |
| PSO | Particle swarm optimization (Zhao *et al.*, 2006) |
| BPSO | Binary particle swarm optimization (Gaing, 2003) |
| PSO-LR | Particle swarm optimization combined with lagrangian relaxation (Balci and Valenzuela, 2004) |
| LR | Lagrangian relaxation (Balci and Valenzuela, 2004) |
| LRGA | Lagrangian relaxation combined with genetic algorithm (Cheng, 2000b) |
| DP | Dynamic programming (Kazarlis *et al.*, 1996) |
| ALR | Augmented lagrangian relaxation (Ongsakul and Petcharaks, 2004) |
| GA | Genetic algorithm (Kazarlis *et al.*, 1996) |
| BCGA | Binary coded genetic algorithm (Sun *et al.*, 2006) |
| ICGA | Integer coded genetic algorithm (Ongsaku land Petcharaks, 2004) |
| MA | Memetic algorithm (Valenzuela and Smith, 2002) |
| PM | Proposed method |
| UCPOZ | Unit commitment considering prohibited operating zone |

Table 5: Unit characteristic and cost coefficient of 10-unit base problem

| Unit No. | $P_{max}$ | $P_{min}$ | a | b | c | $T^U$ | $T^D$ | HSC | CSC | CST | Initial condition | Prohibited operating zones |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 455 | 150 | 1000 | 16.19 | 0.00048 | 8 | 8 | 9000 | 4500 | 5 | 8 | [150 165], [448 453] |
| 2 | 455 | 150 | 970 | 17.26 | 0.00031 | 8 | 8 | 10000 | 5000 | 5 | 8 | [90 110], [240 250] |
| 3 | 130 | 20 | 700 | 16.60 | 0.00200 | 5 | 5 | 1100 | 550 | 4 | -5 | ------- |
| 4 | 130 | 20 | 680 | 16.50 | 0.00211 | 5 | 5 | 1120 | 560 | 4 | -5 | ------- |
| 5 | 162 | 25 | 450 | 19.70 | 0.00398 | 6 | 6 | 1800 | 900 | 4 | -6 | ------- |
| 6 | 80 | 20 | 370 | 22.26 | 0.00712 | 3 | 3 | 340 | 170 | 2 | -3 | ------- |
| 7 | 85 | 25 | 480 | 27.74 | 0.00079 | 3 | 3 | 520 | 260 | 2 | -3 | ------- |
| 8 | 55 | 10 | 660 | 25.92 | 0.00413 | 1 | 1 | 60 | 30 | 0 | -1 | [20 30], [40 45] |
| 9 | 55 | 10 | 665 | 27.27 | 0.00222 | 1 | 1 | 60 | 30 | 0 | -1 | ------- |
| 10 | 55 | 10 | 670 | 27.79 | 0.00173 | 1 | 1 | 60 | 30 | 0 | -1 | [12 17],[35 45] |

Table 6: Load demand of 10-unit base problem

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load | 700 | 750 | 850 | 950 | 1000 | 1100 | 1150 | 1200 | 1300 | 1400 | 1450 | 1500 |
| Hour | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| Load | 1400 | 1300 | 1200 | 1050 | 1000 | 1100 | 1200 | 1400 | 1300 | 1100 | 900 | 800 |

The POZ employed in the paper is not an accurate representation which is given in Table 5. However, there is no great difficulty in making some changes in the formulations developed so that the proposed approach can employ different POZ representation.

## CONCLUSIONS

In this study a reliable and efficient method using heuristic technique for unit commitment as well as scheduling problem has been presented. On the other hand it has been presented a new approach to select best chromosomes via GA, where the objective function in GA has been comprised start-up cost to give a chance to those units that have higher start-up cost and this yields a wide search area. On the other hand, in this paper prohibited operating zones as a practical constraint has been considered. The proposed method has been successfully applied to a standard 10-unit system and a 10-unit system considering POZ and the satisfactory results are compared with the other methods reported in literature. The results also can offer the usefulness of the proposed method which can consider as a practical technique. The results shown that the PM has the following merits in both UC problem and UCPOZ problem: efficient searching ability, robustness in result.

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