# UNIT COMMITMENT SOLUTION USING GENETIC ALGORITHM BASED ON PRIORITY LIST APPROACH

[1]SARJIYA, [2]ARIEF BUDI MULYAWAN, [3]ANDI SUDIARSO

[1] Department of Electrical Engineering and Information Technology, Universitas Gadjah Mada, Yogyakarta, Indonesia

[2] Department of Electrical Engineering and Information Technology, Universitas Gadjah Mada, Yogyakarta, Indonesia

[3] Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

E-mail: [1]sarjiya@ugm.ac.id, [2]arief.abm@gmail.com, [3]a.sudiarso@ugm.ac.id

## ABSTRACT

This paper presents the completion of unit commitment (UC) problem using genetic algorithm based on priority list (GABPL) approach. The UC problem is divided into two sub problems. The problem of unit scheduling is solved by using GABPL method. The lambda iteration method is used for solving the economic load dispatch problem. The proposed method is tested on 10-units-system case study as well as its duplication. The priority list which is used in this paper can make genetic algorithm to converge faster and better. The results of the proposed method are compared to other methods referred in this paper.

**Keywords:** *Unit Commitment, Economic Dispatch, Genetic Algorithm, Priority List, Lambda Iteration*

## 1. INTRODUCTION

The consumption rate of electrical energy whose value varies over time will create systematic problems in generation system. This problem involves which generating units have to be turned on or off and how much power that has to be generated by each generating units to fulfill different load demands in each period. In electrical power system, it is classified as optimization problem, one of the prominent problem that has to be done. This kind of problem is well known as unit commitment (UC). UC is a generation scheduling problem with the objective is to obtain minimum cost without violating limits that are already set in a period of time [1]. The time period for UC can be chosen as 24 hours, seven days, etc. In this problem, the cost which should be minimized consists of fuel cost, start-up cost, and shut-down cost that come from the generating units.

In solving the UC problem, there is sub problem that also has to be solved. This sub problem is called economic load dispatch (ELD). The ELD distributes loads which are asked from each online generating unit economically by ensuring that every online generating unit is used minimally at below capacity limit to fulfill load demands.

In its development, many optimization methods have been developed to solve the UC problem. The previous work on UC problem and its solution techniques have been reviewed by [2]. At first, the optimization methods are in the form of conventional iteration methods, like Lagrange relaxation (LR), integer programming, dynamic programming [2], priority list (PL) [2], [3], etc.. These methods are often trapped in local optima if UC modeling is getting complex. Because of its weakness, other optimization methods are begun to be introduced, i.e. artificial intelligence methods (AI) that is based on metaheuristic like fuzzy methods [2], genetic algorithm (GA) [2], [4], ant-colony optimization (ACO) [5], particle swarm optimization (PSO) [6], shuffled frog leaping algorithm (SFLA) [7], etc.. These methods use multi-searching point to look for optimal solution so that the produced output can approach optimal global point.

The process of finding a method that can produce a better solution is continued to be sought by researchers. Many researchers combine some methods to solve this UC problem i.e. priority list based evolutionary algorithm (PL EA) [8], extended PL (EPL) [9], and hybrid genetic algorithm (HGA) [10]. These methods use PL as initial population from metaheuristic method and can produce a better solution than before.

From the previous works, it can be concluded that most researchers use GA with additional operator to solve the UC problem. GA method is used because it is easy to be implemented and has good convergence level. Another advantage of GA is its character uses multi-searching-no-single-point to look for solution from generated population, so that GA can give many solution options [11]. However, GA method sometimes can also be trapped in local optima solution because there are too many possible solutions to be tried [7]. In order to overcome this weakness, researcher use improved PL method [12] as one of the initial population from GA. The GA method used in this paper also apply some additional operators [13] to produce optimal solution and there are new additional operators presented in this paper to achieve a better solution. Parameters from GA are also optimized by using design of experiment (DOE) [12].

## 2. PROBLEM FORMULATION

### 2.1 Notations

The notations used in this paper are,

| | |
|---|---|
| N | total generating units, |
| t | time, |
| i | generating unit |
| T | total period of time, |
| *TOC* | total operating cost of generating units, |
| $U_{it}$ | the on/off status of the *i*-th unit at *t*-th hour, if unit is up $U_{it}$=1, if unit is down $U_{it}$=0, |
| $F_{it}(P_{it})$ | fuel cost function of *i*-th unit, with generation output, $P_{it}$, at the *t*-hour, |
| $S_{it}$ | start-up cost of *i*-th unit at *t*-th hour, |
| $a_i$, $b_i$, $c_i$ | fuel cost coefficient of *i*-th unit, |
| $P_{it}$ | the generation output of the *i*-th unit at *t*-th hour, |
| $HSC_i$ | hot start-up cost of *i*-th unit, |
| $CSC_i$ | cold start-up cost of *i*-th unit, |
| $MDT_i$ | minimum down time of *i*-th unit, |
| $MUT_i$ | minimum up time of *i*-th unit, |
| $Toff_i$ | total time of *i*-th unit during down, |
| $Ton_i$ | total time of *i*-th unit during up, |
| $Tcold_i$ | cold start-up time of *i*-th unit, |
| $load_t$ | load demand at *t*-th hour, |
| $SR_t$ | spinning reserve at *t*-th hour, |
| $Pmax_i$ | maximum generated output power of *i*-th unit, |
| $Pmin_i$ | minimum generated output power of *i*-th unit, |
| $UR_i$ | up ramp of *i*-th unit, |
| $DR_i$ | down ramp of *i*-th unit, |
| $M_i$ | priority index of average production cost, |
| $x_i$ | multiplier factor of *i*-th unit, |
| $\lambda$ | incremental cost value of all units. |

### 2.2 Objective Function

The objective function of UC problem can be formulated as **(1)** [3].

$$Min\ TOC=\sum_{t=1}^{T}\sum_{i=1}^{N}\left(U_{it}.F_{it}\left(P_{it}\right)+U_{it}.S_{it}\right)\quad(1)$$

There are two cost functions involved in **(1)**. The first one is fuel cost which is the cost incurred per generated MW that generated by generating units and can be formulated as **(2)**.

$$F_{it}\left(P_{it}\right)=a_iP_{it}^{\ 2}+b_iP_{it}+c_i\qquad(2)$$

The second one is start-up cost from the generating units that can be formulated as **(3)**.

$$S_{it}=\begin{cases}HSC_i, & if\ MDT_i<T_{off,i}\le MDT_i+T_{cc}\\ CSC_i, & if\ T_{down,i}>MDT_i+T_{cold,i}\end{cases}\qquad(3)$$

### 2.3 Constraints

In minimizing the objective function, these constraints must be satisfied.

#### 2.3.1 Power balance constraint

In this constraint, the total power generated by generating units must be equal to the total load demanded by consumers. The mathematical equation can be seen in (4).

$$\sum_{i=1}^{N}\left(U_{it}.P_{it}\right)=load_t\ ,\ 1\le t\le T.\qquad(4)$$

#### 2.3.2 Spinning reserve constraint

The total capacity of the committed generating units must be bigger than or equal to the load and the specified spinning reserve. The formulation can be seen in (5).

$$\sum_{i=1}^{N}\left(U_{it}.P\max_i\right)\ge\left(load_t+SR_t\right),\ 1\le t\le T.\qquad(5)$$

#### 2.3.3 Power generating limit

The active powers that can be generated by the generating units have minimum and maximum values defined as (6).

$$P\min_i\le P_{it}\le P\max_i\ ,\ P\in R.\qquad(6)$$

### 2.3.4 Minimum up/down time

Before turning on or off the generator, the minimum down time (MDT) or minimum up time (MUT) from that generator must be fulfilled. The mathematical formulation of these constraints can be seen in (7) and (8).

$$T_{on}(i,t) \geq MUT(i) \quad if \;\; U(i,t+1) \; should\; be \;\; turned \;\; off, \tag{7}$$

$$T_{off}(i,t) \geq MDT(i) \quad if \;\; U(i,t+1) \; should\; be \;\; turned \; on. \tag{8}$$

### 2.3.5 Ramp up/down constraints

One of the characteristic of the thermal generating unit is the generated power can't be changed drastically at a short time interval because the increasing or decreasing of thermal energy must be done gradually. Mathematically, these constraints can be formulated as (9) and (10).

$$P_{i,t} - P_{i,t-1} \leq UR_i, if \;\; generation \;\; increases \tag{9}$$

$$P_{i,t-1} - P_{i,t} \leq DR_i, if \;\; generation \;\; decreases \tag{10}$$

### 2.3.6 Initial status

The on/off time of the generating units at initial status must be considered too.

## 3. PROPOSED METHOD EXPLANATION

GA is firstly founded by John Holland and developed by his student, David Goldberg. This GA method utilizes the natural selection process. In this process, each individual will have some gene changes continuously to adapt to its environment through the process known as the selection process. In this process, there are several processes to get the new population i.e. parents search using roulette wheel, cross over, and mutation.

In solving the UC problem, this problem is divided into two parts. The first part is the generation scheduling problem or this UC problem itself. The second part is the ELD problem. The details of how to solve these problems can be seen in the next section.

### 3.1 Genetic Algorithm Based on Priority List Approach for Solving the Generation Scheduling Problem

For solving this UC problem, firstly, the PL method based on the average production cost (APC) [14] is used. The formulation to calculate this priority index can be seen in (11). Unit with the priority index value $M_i$ lower than the others will become the first priority to be turned on. In solving this UC problem, if there is only a MDT constraint violation, the 'hold on status' method will be used to fulfill this constraint [3], [12]. This "hold on status" works by turning on the generating unit in previous hours until the MDT is satisfied.

$$M_i = \left. \frac{F_i(P_i)}{P_i} \right|_{x_i.P\max_i} \tag{11}$$

where,

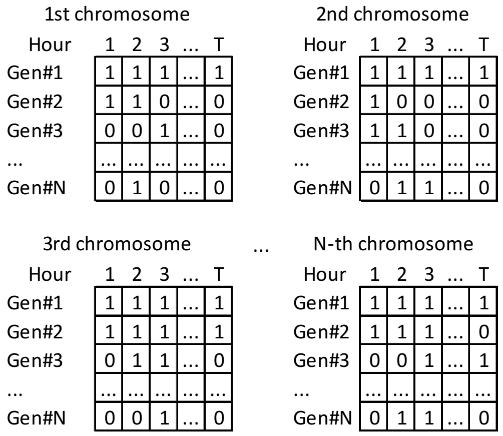
$$x_i = \frac{1}{2}\left(1 + \frac{P\min_i}{P\max_i}\right) \tag{12}$$

After the generating scheduling result from the PL method is obtained, this result will be used as one of initial population from GA. Then, GA with binary coded will be used to solve this UC problem. The binary coded used in this method are 0 and 1 value which indicate the status of generating unit (0 if the unit is down and 1 if the unit is up). The matrix used for solving this UC problem is three-dimensional matrix with rows represent the scheduling time, columns represent the number of generating units, and the last arrays represent the population size so that if n populations are used, then the last arrays will amount to n. The detail can be seen in Fig. 1.

To get the best individual through the selection process, besides the result from the PL, the initial population must be formed beforehand. This initial population is formed randomly. After the formation process is done, there will be a repaired scheduling to fulfill the minimum up/down time constraints so that the formed initial population is a viable solution. The repaired scheduling steps are as follows,

- If at *t*-hour the generating unit is down but at (*t*-1)-hour it is up, then the up time will be checked first. If the up time is over than or equal to the minimum up time of the corresponding unit, then the unit can be shutdown. However, if the minimum up time is not fulfilled yet, then the unit will still be up in the *t*-hour.
- If at *t*-hour the generating unit is up but at (*t*-1)-hour it is down, then the down time will be checked first. If the down time is over than or equal to the minimum down time of the

corresponding unit, then the unit can be started up. However, if the minimum down time is not fulfilled yet, then the unit will still be down in the *t*-hour.



1st chromosome

| Hour | 1 | 2 | 3 | ... | T |
|---|---|---|---|---|---|
| Gen#1 | 1 | 1 | 1 | ... | 1 |
| Gen#2 | 1 | 1 | 0 | ... | 0 |
| Gen#3 | 0 | 0 | 1 | ... | 0 |
| ... | ... | ... | ... | ... | ... |
| Gen#N | 0 | 1 | 0 | ... | 0 |

2nd chromosome

| Hour | 1 | 2 | 3 | ... | T |
|---|---|---|---|---|---|
| Gen#1 | 1 | 1 | 1 | ... | 1 |
| Gen#2 | 1 | 0 | 0 | ... | 0 |
| Gen#3 | 1 | 1 | 0 | ... | 0 |
| ... | ... | ... | ... | ... | ... |
| Gen#N | 0 | 1 | 1 | ... | 0 |

3rd chromosome

...

| Hour | 1 | 2 | 3 | ... | T |
|---|---|---|---|---|---|
| Gen#1 | 1 | 1 | 1 | ... | 1 |
| Gen#2 | 1 | 1 | 1 | ... | 1 |
| Gen#3 | 0 | 1 | 1 | ... | 0 |
| ... | ... | ... | ... | ... | ... |
| Gen#N | 0 | 0 | 1 | ... | 0 |

N-th chromosome

| Hour | 1 | 2 | 3 | ... | T |
|---|---|---|---|---|---|
| Gen#1 | 1 | 1 | 1 | ... | 1 |
| Gen#2 | 1 | 1 | 1 | ... | 0 |
| Gen#3 | 0 | 0 | 1 | ... | 1 |
| ... | ... | ... | ... | ... | ... |
| Gen#N | 0 | 1 | 1 | ... | 0 |

*Fig. 1. Representation of The Population in GA*

With this repaired scheduling, the initial population which satisfies the minimum up/down time constraints will be obtained. The next process is called the chromosomes evaluation. In this process, the constraints are checked. First, the spinning reserve constraint will be checked at each hour using the schedule from the initial population. If there is a violated spinning reserve in an hour, then the penalty count will be added to the penalty function.

Second, the minimum up/down time must be satisfied so that the individual can enter the ELD problem. If those constraints can't be satisfied, the individual will be given a penalty count. After the ELD problem is solved, each individual will enter the fitness function calculation process. The penalty count will be multiplied by penalty factor and the penalty function is expressed as in (13). This penalty function, start-up cost, and fuel cost which are obtained from the ELD problem will be summed to obtain the fitness value from each individual inside this population. The formulation can be seen in (14).

$$penalty\ \ function = penalty\ \ factor \times penalty\ \ count \cdot \qquad (13)$$

After calculation of the fitness function is done, the next is the selection process. In this process, there are several sub-parts of the process. The first one is the elitism process. In this process, the best individual will be duplicated so that it won't enter the next selection process which has the possibility to damage it. This best individual will be kept to be used in the next generation.

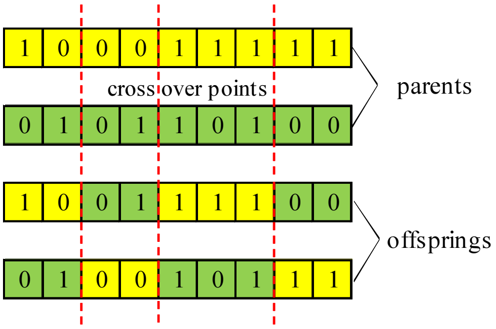


*Fig. 2 The Illustration of Crossover Process.*

$$Fitness = \frac{1}{startup\ \mathrm{cost} + fuel\ \mathrm{cos}\,t + penalty\ \ function} \qquad (14)$$

The next process is the reproduction process. In this process, there are three sub-processes i.e. parents search, cross over, mutation, and additional operator. The details of how to implement these operators into GA can be seen in the next section.

### 3.1.1 Parents search

The parents search in GA use the roulette wheel method. Individual whose fitness value bigger than the others will have a bigger chance to be selected.

### 3.1.2 Cross over

The cross over process is shown in Fig. 2. In this sub-process, the genes on both individual parents will be exchanged based on the cross over point. This sub-process will be run if the randomized number is less than or equal to the cross over probability.

### 3.1.3 Mutation

In this sub-process, the gene will be mutated if the randomized number is less than or equal to the mutation probability. If the gene is 1, then after this sub-process, it will be changed into 0 and vice versa. This mutation process can be illustrated in Fig. 3.

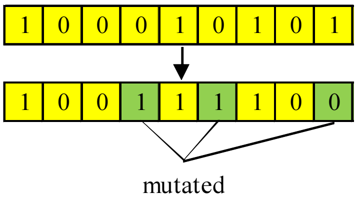


*Fig. 3 The Illustration of Mutation Process.*

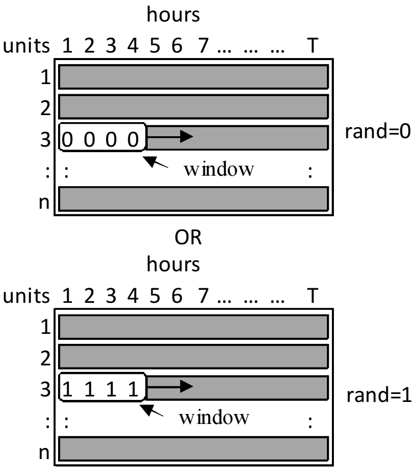

hours
units 1 2 3 4 5 6 7 ... ... ... T
1
2
3
:
n
0 0 0 0
window
rand=0
OR
hours
units 1 2 3 4 5 6 7 ... ... ... T
1 1 1 1
window
rand=1

*Fig. 4 Illustration of Window-mutation for Best Chromosome Operator*

### 3.1.4 Additional operator

Besides these three sub-processes, there are additional operators applied to the individuals i.e. swap-window, window-mutation, and the swap-mutation as well as the swap-window-hill-climb for the best chromosome [13]. These additional operators are used to produce a more optimal solution. Beside of these operators, there are two additional operators that run only for the best chromosome in every generation. These operators are introduced so that the optimal solution can be found. These operators, both for the best chromosome, are window-mutation and mutation-hour. The details of how to implement these operators into GA can be seen in the next sub-section.

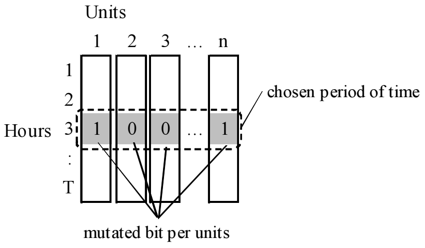


*Fig. 5 Illustration of Mutation-hour for Best Chromosome Operator*

#### 3.1.4.1 Window-mutation for best chromosome

The window-mutation operator is applied to the best chromosome with the probability of one. It generates a random value of 0 or 1 with equal probability. Then, it selects one unit at random and a "time window" of width w equal to MDT (if random value is 0) or MUT (if random value is 1) of the corresponding unit. After that, this operator is run from the 1st hour to the (T+1-w)th hour to mutate the bits in that window to 0s if w equal to MDT or 1s if w equal to MUT. If this task produces a better solution, this solution will be kept. Otherwise, it will be restored to the solution before this task is performed. The illustration can be seen in Fig. 4.

#### 3.1.4.2 Mutation-hour for best chromosome

This operator is also applied to the best chromosome with the probability of 0.7. It selects one of a period time randomly. After that, this operator is run from the 1st unit until the Nth unit to mutate one bit of each unit. If this task produces a better solution, this solution will be kept. Otherwise, it will be restored to the solution before this task is performed. The illustration can be seen in Fig. 5.

After this process is done, a new population with different chromosomes is formed. It will re-enter the fitness function process, the selection process, and so on until the maximum generation is reached. The best individual at the last generation will become the solution of this UC problem.

### 3.2 Lambda Iteration for Solving ELD Problem

In this ELD problem, the objective function is to minimize the fuel cost which is represented by quadratic function. The penalty function is added to the objective function by summing it with the fuel cost. This new function, after added by the penalty terms, is called the Lagrange function. The minimum condition will be obtained by (15) [1].

$$\frac{dF_i(P_i)}{dP_i} = \lambda, \quad \mathrm{i} = 1 \text{ to } n \tag{15}$$

$$P_i = {\lambda - b_i}\big/{2a_i}\,. \tag{16}$$

λ is the incremental cost value of all units. From (15), the formulation can be modified into (16) to get the value of the generated power from each unit. If there are generating units at their limits, this direct solution can't work well so that the lambda iteration method is used to solve this ELD problem. In lambda iteration, λ is searched using iteration. The method starts with two values of lambda, below and above the optimal value, then it will iterate until the absolute difference of two lambdas is less than the convergence tolerance. To include the inequality constraint i.e. the generating limits in lambda iteration, the formulation in (17) are used in each iteration [1].

$$\begin{aligned} P_i(\lambda) &= P_{\max,i}, \quad \text{for } P_i(\lambda) > P_{\max,i} \\ P_i(\lambda) &= P_{\min,i}, \quad \text{for } P_i(\lambda) < P_{\min,i} \end{aligned} . \qquad (17)$$

The flowchart to solve these problems can be seen in Fig. 6.

After the generated power results from the ELD problem are obtained, the fuel cost can be calculated and will be used in the calculation of the fitness function process.

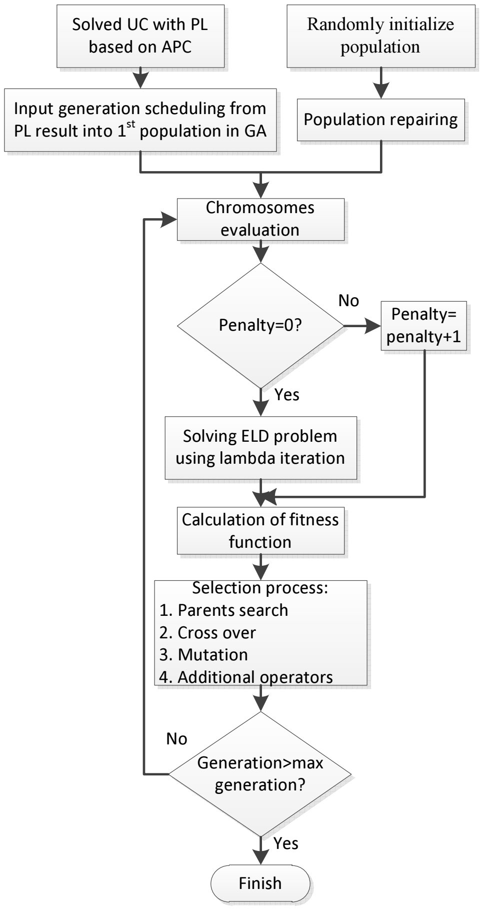

Solved UC with PL based on APC
Randomly initialize population
Input generation scheduling from PL result into 1st population in GA
Population repairing
Chromosomes evaluation
Penalty=0?
No
Penalty= penalty+1
Yes
Solving ELD problem using lambda iteration
Calculation of fitness function
Selection process:
1. Parents search
2. Cross over
3. Mutation
4. Additional operators
No
Generation>max generation?
Yes
Finish

*Fig. 6 Flowchart of The Proposed Method.*

## 4. SIMULATION RESULTS

This proposed method is implemented in Matlab program and tested on 10-units-system case study and its duplication.

### 4.1 Case 1: 10 Units System

*Table I: Comparison of GABPL Method among Other Methods on 10 Units System*

| Method | Total start-up cost ($) | Total fuel cost ($) | Total operational cost ($) |
|---|---|---|---|
| PSO [15] | - | - | 574,153 |
| DE [16] | 4780 | 568,262.6 | 573,042.6 |
| HPSOGA [17] | - | - | 568,960 |
| ICGA [4] | - | - | 566,404 |
| MA [18] | - | - | 565,827 |
| LR [13] | - | - | 565,825 |
| GA [13] | - | - | 565,825 |
| DPSO [7] | 2095 | 562,899 | 565,804 |
| SPL [19] | - | - | 564,950 |
| LRGA [20] | - | - | 564,800 |
| TSRP [21] | - | - | 564,551 |
| MRCGA [22] | - | - | 564,244 |
| DP combined with PL [23] | - | - | 564,049 |
| ACO [5] | - | - | 564,049 |
| UCCGA [24] | - | - | 563,977 |
| PL EA [8] | 4090 | 559,887 | 563,977 |
| MPL [3] | 4090 | 559,887 | 563,977 |
| HPSO [25] | - | - | 563,942 |
| SFLA [7] | 4090 | 559,847.7 | 563,937.7 |
| **GABPL** | **4090** | **559,847.7** | **563,937.7** |

In this case, the spinning reserve is specified as 10% from load [7]. The data is taken from [10] and can be seen in Table II and Table III. The GA parameters used in this case are optimized using DOE method [12]. The optimal values of these parameters are obtained for population size of 30 with maximum generation of 200, crossover probability 0.7, and mutation probability 0.12. With these parameters, the best obtained total cost is $563,937.7. This result is then compared to the total cost results from other methods in the reference papers shown in Table I.

First, the GABPL result can be compared with the PL result on 10 units test system. The PL result on 10 units test system can be seen from Table IV and the GABPL best result can be seen in Table V. The total cost obtained by this PL result is $563,977. With this result, the GABPL method can decrease the total cost as much as $40 to become $563,937.7. Unit 5 at 23th hour with 25 MW generated power is turned off and unit 6 is turned on. Because the minimum generated power in unit 6 is 20 MW, 5 MW less than unit 5's, it can be generated by unit 2 so that the total generated power from unit 2, previously 420 MW, become 425 MW.

From Table I, it can be seen that the obtained total cost of the proposed method is lower than the other methods like differential evolution (DE), integer coded GA (ICGA), TS random perturbation (TSRP), memetic algorithm (MA), DP combined with PL, dynamic PSO (DPSO), hybrid PSO (HPSO), hybrid PSO and GA (HPSOGA), unit characteristic classification GA (UCCGA), stochastic PL (SPL), LRGA, LR, GA, PL EA, and methodological PL (MPL). This proposed method produces the most minimal total cost along with the SFLA [7]. This proposed method can get better solution because of better initial population. The improved PL as one of initial population can make GA to converge better compare to usual GA method. The proposed method has as much as 1,887.3$ reducing cost compare to usual GA method [13] in 10 unit system.

### 4.2 Case 2: The Duplications of 10 Units System

In this case, the generator and loads data are duplicated from the previous case study into 20, 40, 60, 80, and 100 units systems. The spinning reserve used in these test systems is specified as 10% from the load too. The maximum generations used in these systems are 300, 300, 500, 500, and 500 respectively. Because of the stochastic nature of metaheuristic method, this proposed method is run 10 times in every case study. The average total costs obtained in each case study as well as its comparison to other methods can be seen in Table VI. The average cost of proposed method on 20, 40, 60, 80, and 100 unit test systems are $563,941; $1,124,293; $2,246,375; $3,366,134; $4,488,750; $5,607,773 respectively. The obtained total cost on 20 unit test system is not twice more expensive than total cost on 10 unit test system, because there is other way to obtain lower total cost. It can be done by maximizing the power generated from cheaper generation unit or turning on cheaper generation unit so that lower total cost can be obtained.

From Table VI, it can be seen that, on 20 and 40 units systems, the total costs obtained by GABPL method is still higher than SFLA but lower than the other systems (60, 80, and 100 units system). Compared to PL EA method, the total costs obtained by GABPL method are lower on 10, 20, and 100 units systems. Overall, the application of the proposed method to large test system also gives better average total cost compared to other methods.

## 5. CONCLUSION

The UC problem is an important problem that has to be solved in electrical power system, especially in system generation. It consists of two sub problems, namely generation scheduling problem and economic dispatch problem. With optimizing the generation scheduling and economic dispatch problem, it can save great amount of cost. So, when optimization can decrease small amount of cost, it will be great advantage. Because of the inadequacy of conventional methods in solving large UC problem, metaheuristic methods are being studied. Researcher also developed hybrid method which combines several methods to get a better solution.

GABPL method with additional operator to solve the UC problem is presented in this paper. This is the hybrid method which is incorporating improved PL as one of initial population in GA. This approach can make GA obtain a better minimum value with faster convergence. Comparison of the results to other methods in 10 units test system indicates that the proposed method gives better solution than the other methods. In obtaining average total cost for large system, the proposed method can generate better average total cost than the other methods. It can be concluded that this proposed method is good in finding solution of the UC problem.

In this paper, GABPL method is only tested to common UC problem. There is no emission constraint, reliability constraint, or other constraint that can be included in the UC problem to make the UC modeling more realistic. In future work, we can include these constraints to UC problem to see the performance of this method.

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*Table II: Generator Data of 10-Unit System*

| Unit | P min (MW) | P max (MW) | Fuel Cost Coefficients | | | MUT (h) | MDT (h) | Init cond. (h) | Hot SUC ($) | Cold SUC ($) | T Cold ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | a ($/MW$^2$) | b ($/MW) | c ($) | | | | | | |
| 1 | 150 | 455 | 1000 | 16.19 | 0.00048 | 8 | 8 | 8 | 4500 | 9000 | 5 |
| 2 | 150 | 455 | 970 | 17.26 | 0.00031 | 8 | 8 | 8 | 5000 | 10000 | 5 |
| 3 | 20 | 130 | 700 | 16.6 | 0.002 | 5 | 5 | -5 | 550 | 1100 | 4 |
| 4 | 20 | 130 | 680 | 16.5 | 0.00211 | 5 | 5 | -5 | 560 | 1120 | 4 |
| 5 | 25 | 162 | 450 | 19.7 | 0.00398 | 6 | 6 | -6 | 900 | 1800 | 4 |
| 6 | 20 | 80 | 370 | 22.26 | 0.00712 | 3 | 3 | -3 | 170 | 340 | 2 |
| 7 | 25 | 85 | 480 | 27.74 | 0.00079 | 3 | 3 | -3 | 260 | 520 | 2 |
| 8 | 10 | 55 | 660 | 25.92 | 0.00413 | 1 | 1 | -1 | 30 | 60 | 0 |
| 9 | 10 | 55 | 665 | 27.27 | 0.00222 | 1 | 1 | -1 | 30 | 60 | 0 |
| 10 | 10 | 55 | 670 | 27.79 | 0.00173 | 1 | 1 | -1 | 30 | 60 | 0 |

*Table III: 24-Hour Load Data of 10-Unit System*

| Hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Load (MW) | 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 (MW) | 1400 | 1300 | 1200 | 1050 | 1000 | 1100 | 1200 | 1400 | 1300 | 1100 | 900 | 800 |

*Table IV: Solution of UC Problem with Priority List Method on 10 Units System*

| Hour | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | Load (MW) | Fuel Cost ($) | Start-Up Cost ($) | Total Operational Cost ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 455 | 245 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 700 | 13,683.13 | 0 | 13,683.1 |
| 2 | 455 | 295 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 750 | 14,554.5 | 0 | 14,554.5 |
| 3 | 455 | 370 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 850 | 16,809.45 | 900 | 17,709.4 |
| 4 | 455 | 455 | 0 | 0 | 40 | 0 | 0 | 0 | 0 | 0 | 950 | 18,597.67 | 0 | 18,597.7 |
| 5 | 455 | 390 | 0 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1000 | 20,020.02 | 560 | 20,580.0 |
| 6 | 455 | 360 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1100 | 22,387.04 | 1,100 | 23,487.0 |
| 7 | 455 | 410 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1150 | 23,261.98 | 0 | 23,262.0 |
| 8 | 455 | 455 | 130 | 130 | 30 | 0 | 0 | 0 | 0 | 0 | 1200 | 24,150.34 | 0 | 24,150.3 |
| 9 | 455 | 455 | 130 | 130 | 85 | 20 | 25 | 0 | 0 | 0 | 1300 | 27,251.06 | 860 | 28,111.1 |
| 10 | 455 | 455 | 130 | 130 | 162 | 33 | 25 | 10 | 0 | 0 | 1400 | 30,057.55 | 60 | 30,117.6 |
| 11 | 455 | 455 | 130 | 130 | 162 | 73 | 25 | 10 | 10 | 0 | 1450 | 31,916.06 | 60 | 31,976.1 |
| 12 | 455 | 455 | 130 | 130 | 162 | 80 | 25 | 43 | 10 | 10 | 1500 | 33,890.16 | 60 | 33,950.2 |
| 13 | 455 | 455 | 130 | 130 | 162 | 33 | 25 | 10 | 0 | 0 | 1400 | 30,057.55 | 0 | 30,057.6 |
| 14 | 455 | 455 | 130 | 130 | 85 | 20 | 25 | 0 | 0 | 0 | 1300 | 27,251.06 | 0 | 27,251.1 |
| 15 | 455 | 455 | 130 | 130 | 30 | 0 | 0 | 0 | 0 | 0 | 1200 | 24,150.34 | 0 | 24,150.3 |
| 16 | 455 | 310 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1050 | 21,513.66 | 0 | 21,513.7 |
| 17 | 455 | 260 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1000 | 20,641.82 | 0 | 20,641.8 |
| 18 | 455 | 360 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1100 | 22,387.04 | 0 | 22,387.0 |
| 19 | 455 | 455 | 130 | 130 | 30 | 0 | 0 | 0 | 0 | 0 | 1200 | 24,150.34 | 0 | 24,150.3 |
| 20 | 455 | 455 | 130 | 130 | 162 | 33 | 25 | 10 | 0 | 0 | 1400 | 30,057.55 | 490 | 30,547.6 |
| 21 | 455 | 455 | 130 | 130 | 85 | 20 | 25 | 0 | 0 | 0 | 1300 | 27,251.06 | 0 | 27,251.1 |
| 22 | 455 | 455 | 0 | 0 | 145 | 20 | 25 | 0 | 0 | 0 | 1100 | 22,735.52 | 0 | 22,735.5 |
| 23 | 455 | 420 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 900 | 17,684.69 | 0 | 17,684.7 |
| 24 | 455 | 345 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 15,427.42 | 0 | 15,427.4 |
| **TOTAL** | | | | | | | | | | | | **559,887** | **4,090** | **563,977** |

*Table V: Solution of UC Problem with Proposed Method on 10 Units System*

| Hour | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | Load (MW) | Fuel Cost ($) | Start-Up Cost ($) | Total Operational Cost ($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 455 | 245 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 700 | 13,683.13 | 0 | 13,683.1 |
| 2 | 455 | 295 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 750 | 14,554.5 | 0 | 14,554.5 |
| 3 | 455 | 370 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 850 | 16,809.45 | 900 | 17,709.4 |
| 4 | 455 | 455 | 0 | 0 | 40 | 0 | 0 | 0 | 0 | 0 | 950 | 18,597.67 | 0 | 18,597.7 |
| 5 | 455 | 390 | 0 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1000 | 20,020.02 | 560 | 20,580.0 |
| 6 | 455 | 360 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1100 | 22,387.04 | 1100 | 23,487.0 |
| 7 | 455 | 410 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1150 | 23,261.98 | 0 | 23,262.0 |
| 8 | 455 | 455 | 130 | 130 | 30 | 0 | 0 | 0 | 0 | 0 | 1200 | 24,150.34 | 0 | 24,150.3 |
| 9 | 455 | 455 | 130 | 130 | 85 | 20 | 25 | 0 | 0 | 0 | 1300 | 27,251.06 | 860 | 28,111.1 |
| 10 | 455 | 455 | 130 | 130 | 162 | 33 | 25 | 10 | 0 | 0 | 1400 | 30,057.55 | 60 | 30,117.6 |
| 11 | 455 | 455 | 130 | 130 | 162 | 73 | 25 | 10 | 10 | 0 | 1450 | 31,916.06 | 60 | 31,976.1 |
| 12 | 455 | 455 | 130 | 130 | 162 | 80 | 25 | 43 | 10 | 10 | 1500 | 33,890.16 | 60 | 33,950.2 |
| 13 | 455 | 455 | 130 | 130 | 162 | 33 | 25 | 10 | 0 | 0 | 1400 | 30,057.55 | 0 | 30,057.6 |
| 14 | 455 | 455 | 130 | 130 | 85 | 20 | 25 | 0 | 0 | 0 | 1300 | 27,251.06 | 0 | 27,251.1 |
| 15 | 455 | 455 | 130 | 130 | 30 | 0 | 0 | 0 | 0 | 0 | 1200 | 24,150.34 | 0 | 24,150.3 |
| 16 | 455 | 310 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1050 | 21,513.66 | 0 | 21,513.7 |
| 17 | 455 | 260 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1000 | 20,641.82 | 0 | 20,641.8 |
| 18 | 455 | 360 | 130 | 130 | 25 | 0 | 0 | 0 | 0 | 0 | 1100 | 22,387.04 | 0 | 22,387.0 |
| 19 | 455 | 455 | 130 | 130 | 30 | 0 | 0 | 0 | 0 | 0 | 1200 | 24,150.34 | 0 | 24,150.3 |
| 20 | 455 | 455 | 130 | 130 | 162 | 33 | 25 | 10 | 0 | 0 | 1400 | 30,057.55 | 490 | 30,547.6 |
| 21 | 455 | 455 | 130 | 130 | 85 | 20 | 25 | 0 | 0 | 0 | 1300 | 27,251.06 | 0 | 27,251.1 |
| 22 | 455 | 455 | 0 | 0 | 145 | 20 | 25 | 0 | 0 | 0 | 1100 | 22,735.52 | 0 | 22,735.5 |
| 23 | 455 | 425 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 900 | 17,645.36 | 0 | 17,645.4 |
| 24 | 455 | 345 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 15,427.42 | 0 | 15,427.4 |
| **TOTAL** | | | | | | | | | | | | **559,847,7** | **4090** | **563,937.7** |

*Table VI: Comparison of GABPL Method among Other Methods on 10 Units System and the Duplications*

| **Number of units** | **Total Operational Cost ($)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **GABPL (average)** | **PL EA** [8] | **EPL** [9] | **SFLA** [7] | **GA** [13] | **LR** [13] | **ICGA** [4] | **EP** [8] | **BF** [7] | **SPL** [19] |
| **10** | **563941** | 563977 | 563977 | 564769 | 565825 | 565825 | 566404 | 564551 | 564842 | 564950 |
| **20** | **1124293** | 1124295 | 1124369 | 1123261 | 1126243 | 1130660 | 1127244 | 1125494 | 1124892 | 1123938 |
| **40** | **2246375** | 2243913 | 2246508 | 2246005 | 2251911 | 2258503 | 2254123 | 2249093 | 2246223 | 2248645 |
| **60** | **3366134** | 3363892 | 3366210 | 3368257 | 3376625 | 3394066 | 3378108 | 3371611 | 3369237 | 3371178 |
| **80** | **4488750** | 4487354 | 4489322 | 4503928 | 4504933 | 4526022 | 4498943 | 4498479 | 4491287 | 4492909 |
| **100** | **5607773** | 5607904 | 5608440 | 5624526 | 5627437 | 5657277 | 5630838 | 5623885 | 5611514 | 5615530 |