

Thermal Unit Commitment using Extended Priority List Algorithm

UDAY KISHAN R¹, KRISHNA MOHAN TATIKONDA², V ANANTHA LAKSHMI³

ASSISTANT PROFESSOR, DEPT OF EEE, ANDHRA LOYOLA INSTITUTE OF ENGG. &TECH, VJA.¹

ASSISTANT PROFESSOR, DEPT OF EEE, ANDHRA LOYOLA INSTITUTE OF ENGG. &TECH, VJA.²

HEAD OF DEPARTMENT, DEPT OF EEE, ANDHRA LOYOLA INSTITUTE OF ENGG. &TECH, VJA.³

ABSTRACT

The Unit Commitment Problem is to determine a minimal cost turn-on and turn-off schedule of a set of electrical power generating units to meet a load demand while satisfying a set of operational constraints such as power generation-load balance, spinning reserve, operating constraints, minimum up time & minimum down time, etc. The production cost includes fuel, startup, shutdown, and no-load costs. Several conventional methods are available to solve the unit commitment problem. This paper describes the application of EPL algorithm for determining short term commitment of thermal units in electrical power generation. This method allows a qualitative description of the behavior of the system, the system characteristics and response without the need for exact mathematical formulations. It is demonstrated through a numerical example that a EPL based approach achieves a logical and feasible economic cost of operation of the power system, which is the major object of Unit commitment. The results obtained from EPL based approach are compared with the priority list method solution to unit commitment problem.

Index Terms— Unit Commitment problem (UCP), EPL Algorithm, Priority List Method

INTRODUCTION

There have been several mathematical programming techniques proposed so far to solve unit commitment problems. They include Priority List, Dynamic Programming, Branch and Bound, Lagrangian Relaxation, Simulated Annealing, Expert Systems, Artificial Neural Networks [7]. The most commonly used method being simple and fast by electricity utilities is the priority list method. This method is used to rank generating units in a heuristic with increasing operation cost. EPL Logic Algorithm provides a solution to UCP working with a population of individuals each representing a possible solution. Together with a set of the main genetic operators of crossover and mutation this method provides a powerful global search mechanism, whose computation code is simple. EPL is useful in reducing the need for complex mathematical models in problem solving. EPL is used to describe uncertainty, which is applicable to the UCP. Loading of generators, start up cost, incremental cost and production cost are considered to be EPL variables with the UCP. EPL is useful in reducing the need for complex mathematical models in problem solving. EPL is used to describe uncertainty, which is applicable to the UCP. Loading of generators, start up cost, incremental cost and production cost are considered to be EPL variables with UCP.

THERMAL UNIT COMMITMENT PROBLEM FORMULATION

Fuel cost (FC)

For a given set of N committed units ($i = 1 \dots N$) at hour H ($j = 1 \dots H$), the total fuel cost at that particular hour, is minimized by economically dispatching the units subject to the following constraints: [1]

- (i) The total generated power must be equal to the demand.
- (ii) The power produced by each unit must be within certain limits.

This problem can be stated as follows.

$$\text{Min FC} = \sum_{h=1}^H \sum_{i=1}^N U_{ih} (\text{FC}_i) P_{ih} \quad \dots (1)$$

where, U_{ih} is the status of the unit i at hour $h=1$ (ON) or 0 (OFF)

P_{ih} is the Power output of unit i at hour h in MW

Start-up cost (ST)

As, the temperature and pressure of thermal unit must be changed slowly, a certain amount of energy will be expended to bring the unit online. This energy, does not result into any MW generation from the unit, is called

start up cost. There are two approaches to treat a thermal unit in down period namely cold start and banking. The first allows the unit's boiler to cool down and then heat back up to operating temperature in time for a schedule turn on. The second requires that sufficient energy be input to the boiler to just maintain the operating temperature. The exponential function for the start up cost is given by

$ST_i = b1 [1 - \exp(-b3 * X_i)] + b2 \dots$ (2) $b1, b2$ and $b3$ are start-up cost parameters and X_i the number of consecutive hours for which the unit i has been down [4].

Objective function

The objective (or cost) function (OF) of the UCP is to determine the state of the units U_{ih} (0 or 1) at each period H , so that the overall operation cost is a minimum within the scheduling time span.

$$\text{Min OF} = \sum_{h=1}^H \sum_{i=1}^N U_{ih} (FC_i) P_{ih} + ST_i U_{ih} (1 - U_{i, h-1}) \dots \text{ (3)}$$

Subjected to the constraints [1]

(i) Total power generated should meet the load requirement and system losses,

$$P_G = P_D + P_L \dots \text{ (4)}$$

Where P_G is power generated, P_D is the power demand and P_L is the power losses.

(ii) Spinning reserve at each hour must be satisfied to cover any shortfall in generation,

$$P_G = P_D + \text{Reserve} \dots \text{ (5)}$$

(iii) Each generator must operate within its minimum and maximum power output limits,

$$P_{MIN} < P_G < P_{MAX} \dots \text{ (6)}$$

(iv) The consecutive number of hours for which a generating unit must remain on (minimum up time, MUT) or off (minimum down time, MDT) should not get violated,

$U_{ij} = 1$ for $T_{i\text{on}} < MUT_i$ and $U_{ij} = 0$ for $T_{i\text{off}} < MDT_i$ where, $T_{i\text{on}}$ and $T_{i\text{off}}$ is the consecutive number of hours for which the unit is on and off till the end of last hour respectively.

Test System

In order to prove effectiveness of EPL for solving UCP, it is applied to test system of four units ($n=4$) over time period of eight hours ($H=8$).

Table 1

Load Demand & Reserve requirement of Test System.

Period	Demand	Reserve + Demand
1	400	450
02	470	530
03	520	600
04	510	540
05	360	400
06	240	280
07	240	290
08	450	500

Table 2

Generating Unit Characteristics of Test System.

					Start Up Cost Parameters				
Unit	Max Cap	MUT	MTD	I.C	b1	b2	b3	SDC	AFLC
1	80	3	2	-1	350	158	0.4	0	20.8
2	250	2	1	-2	400	162.6	0.9	0	18
3	300	4	2	1	1100	421.1	0.48	0	17.4
4	60	2	3	-4	0.02	0.02	0.01	0	23.8

Short Term Thermal UCP by Priority List Method

Priority List Method

From a modelling point of view, Priority listing is the simplest method. The calculation time for this method is small, even for large systems. This makes the methods eligible for our purposes. An important disadvantages of this method is that it is not consider accurate. Also state transition costs are not taken into account.

Implementation detail

The simplest unit commitment solution method consists of creating a priority list of units, a simple shut –down rule or priority –list scheme could be obtained after an exhaustive enumeration of all unit combinations at each load level. The priority list could be obtained in a much simpler manner by noting the average full load production cost (AFLC) which is simply the net heat rate at full load multiplied by the fuel cost. At each hour when the load is dropping, determine whether dropping the next unit on the priority list will leave sufficient generation to supply the load plus spinning reserve requirements. If not, continue operating as is; if yes, go to the next step.

- Determine the number of hours, H, before the unit will be needed again. That is assuming that the load is dropping and will then go back up some hours later.
- If H is less than the minimum shut –down time for the next step; if not, go to next step.
- Calculate two costs. The first is the sum of the hourly production costs for the next H hour s with the unit up. Then recalculate the same sum for the unit down and add in the smart-up cost for either cooling the unit or banking it, whichever is less expensive. If there is sufficient savings from shutting down the unit, it should be shut down, otherwise keep it on.

Repeat this entire procedure for the next unit on the priority list. If it is also dropped, go to the next and so forth.

Result of Test system with Priority List Method

Table 3
Result for Test system with Priority List Algorithm based
Approach

Hr	Units ON/OFF Schedule				P _G MW	Total Cost
	1	2	3	4		
1	0	1	1	0	550	9978
2	0	1	1	0	550	9738
3	0	1	1	1	610	11166
4	0	1	1	1	610	11166
5	0	1	1	0	550	9738
6	0	0	1	0	300	5238
7	0	0	1	0	300	5238
8	0	1	1	0	550	9968
Cumulative Cost in Indian Rupees (INR) 72,240						
EXPLANATION OF THE EPL METHOD						

Overview

We explain the proposed method briefly. A flowchart of EPL method is shown in Fig. 1. The EPL method consists of two steps; in the first step we get rapidly plurality of initial solutions by PL method. Advantage of using PL method is to be obtained solution which forms base of unit commitment schedule close to optimal schedule, in addition to obtaining rapidly solution. That is, the schedule obtained by PL method decides that the more costly unit for generation cost is off status, whereas cheaper unit is settled on status. In this time all constraints are not satisfied but the PL method decides a rough framework which is a costly unit are off status and cheap units are on status. In the second step, we apply several heuristics to plurality of initial solutions. To apply heuristics to all solutions is a time consuming processes. Hence, in this paper using a proper condition, the pro-posed method carries out the reduction of number of solutions applying heuristics. Then, only the solutions which are not potentially improvement are reduced. The details of the generation techniques for plurality of initial solutions obtained by PL method and incorporation of several heuristics are explained below. Note that actual introduction order of the heuristics in programming is the same order as the explanation of heuristics, given in Sections III-B-D.

Generation of Initial Solution

The generation of initial solution is important, particularly, for the UC problem. The initial solution is usually generated at random. However, this technique is difficult to get feasible solution for the UC problem with many constraints, resulting in quality of solution obtained will go bad. In this paper, initial solution is generated using the PL method. However, as it is also in the above-mentioned, the solution which obtained by PL method cannot fulfill all constraints. Merely characteristics which costly units are off status and cheap units are on status, can be expected to obtain approximate solution close to optimal solution by modification of solution in after section.

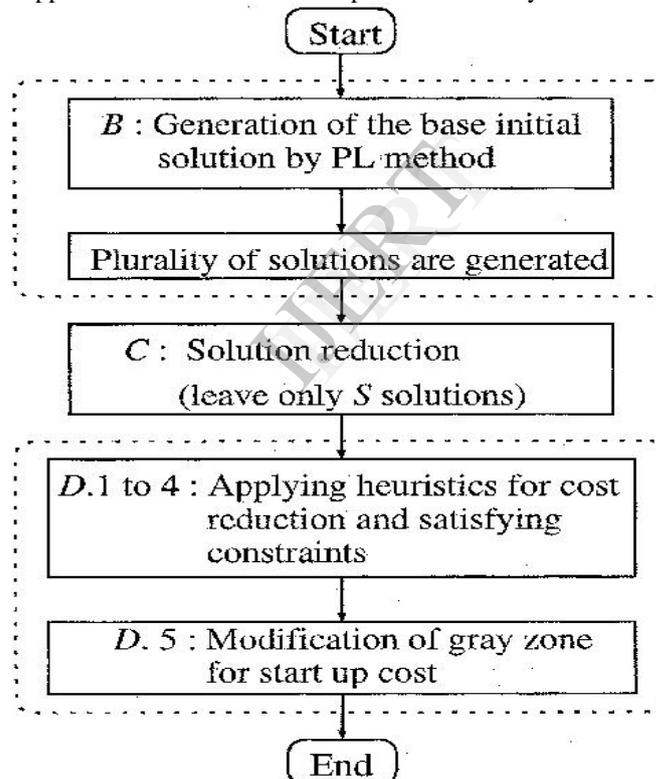


Fig. 1. Flowchart of EPL method in Section III.

First, priority list as shown in Fig. 2 is created based on each unit parameters. A unit, which is the highest of maximum output power, is located in the bottom of the list, and the other units are located in descending order of their maximum output power toward the top of the list. The most costly unit which is on the top of the list would have the lowest priority. Then, commit units until the load demand plus the spinning reserve requirements represented by (5) are fulfilled in the priority list order at every time interval. In addition, units of equal maximum output power are started up in ascending order of heat rate (hr), which means average fuel piece rate per output power given in Table I. The hr is given by the following formula:

$$hr = \frac{F_i(P_i(t))}{P_i(t)} \tag{7}$$

Finally, plurality of solutions are generated based on obtained one by PL method at this point as shown in Fig. 2. The technique of generating a solution sets up at random on/off status of X units located in a window (shaded area) shown in Fig. 3 at every time interval, and one solution is generated when a setup of the last period is completed. The same procedure is repeated several times and W initial solutions are generated.

Condition for Solution Reduction

In order to reduce computational efforts, the plurality of solutions is reduced by adding following condition, only remaining solutions are applied heuristics. Actually, (8) is calculated about each solution and solutions are rearranged into the small order of Y . After rearrangement, each heuristics explained below is applied to the solution of S higher ranks

$$Y = \sum_{t=1}^T \left| \sum_{i=1}^N I_i(t) \cdot P_{i \max} - (D(t) + R^t) \right| \tag{8}$$

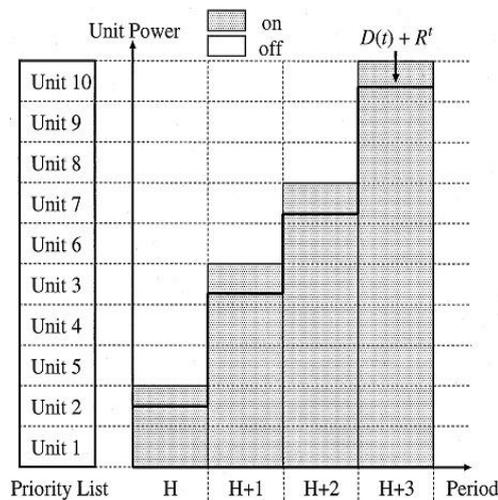


Fig. 2. Initial solution by priority list method

Unit group	HR [\$/MW]	Unit group	HR [\$/MW]
1	18.6	6	27.5
2	19.5	7	33.5
3	22.2	8	38.1
4	22.0	9	39.5
5	23.1	10	40.1

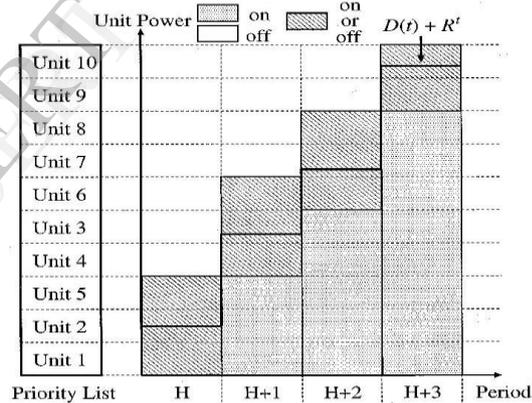


Fig. 3. Unit located in a window (case of $X = 3$).

Incorporated Heuristics

- 1) *Start Up of the Base Load Unit:* In power system, the units which must run at any time exists. We desire these units, which becomes the base of load, to start up at all scheduling pe-riod than repeating on or off because these units have relatively large output power. Since the solution by PL method is started up from the unit of a large output power, although most units used as a base will be in a on state, all base units does not be-come so. In the proposed method, for ten-unit systems, two units which are located from the bottom of priority list to toward the top are specified as the base load unit, these two units are fixed on status. Furthermore, when expanding the number of units, the base units were assumed to be 20% of all units.
- 2) *Consideration of the Minimum Up/Down Time at the Pe-riod Inserted Into the Load Peak:* In the period inserted into the load peak, how the constraint represented by (8) for rela-tively large units of minimum up/down time is satisfied poses an important problem. For example, when assuming that the min-imum up/down time of unit e shown in Fig. 5 is relatively large 5 h, since unit e does not need to generate electricity at hour ($H+2$), unit e is shut down usually but since it must restart in the next hour ($H+3$) unit e must start up also in a previous hour($H+2$) to satisfy the

minimum up time. On the contrary, it is also possible to satisfy minimum down time by shutting down the unit *e*. However, other costly units are started up instead of shutting down unit *e*, as a result the total cost will be high. Hence, this heuristic starts up units in large order of minimum up/down time (i.e., priority list order at the period inserted into the load peak). From prior simulation, we assume that started unit is until one that the total cost becomes more cheap.

- 3) Consideration of the Minimum Up/Down Times of all Units: At this moment in time, the minimum up/down times of all units has not considered. In order to be satisfied the minimum up/down times of all units, this heuristic looks for the hour changing from on status to off status between 1 to 24 h every unit, and corrects to on or off until the minimum up/down time is satisfied if the minimum up/down time is not satisfied at this hour. The example of operation in case the minimum up/down times is 3 h.
- 4) Commitment of the Excess Started or Deficient Units: When the above heuristic is completed, excess started or deficient units are generated at some periods. In order to reduce the total cost, their units must be committed certainly without violating the constraints. The procedure of commitment of the excess started or deficient units is explained below and the example of operation is shown in Fig. 6.

The priority order for shutting down the excess started units is decided by heat rate of each unit at maximum output powers as shown in Table I. The order of the unit shutdown is the large order of the heat rate. Then, the hours which satisfy (5) are searched and the excess started units are shut down every one unit in the above shutdown order. This heuristic judges whether the unit schedule can satisfy (5) and (6) every shutting down one unit. This heuristic keeps up remaining shutdown if the unit schedule can satisfy two equations, and the unit is started up again if not. The above operation is carried out as long as constraints are fulfilled.

Inversely, in case of no satisfying (5) at a period (i.e., deficient units exists, the units are started up every one unit in in-verse order for shutdown). This heuristic judges whether the unit schedule can satisfy (5) and (iv) every starting up one unit. This heuristic keeps up remaining startup if the unit schedule can satisfy two equations, and the unit is shut down again if not. This operation is ended when (5) is satisfied.

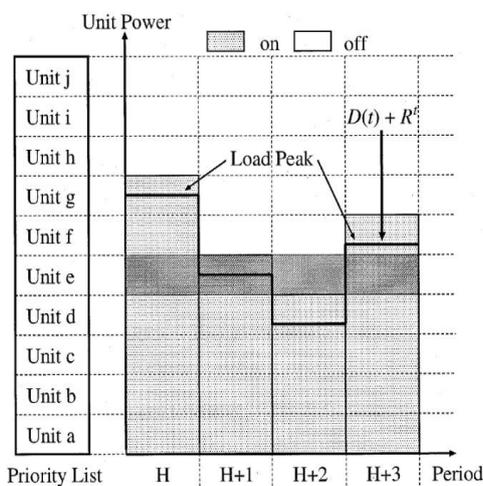


Fig. 5. Consideration of the minimum up/down Times of the period inserted into the load peak

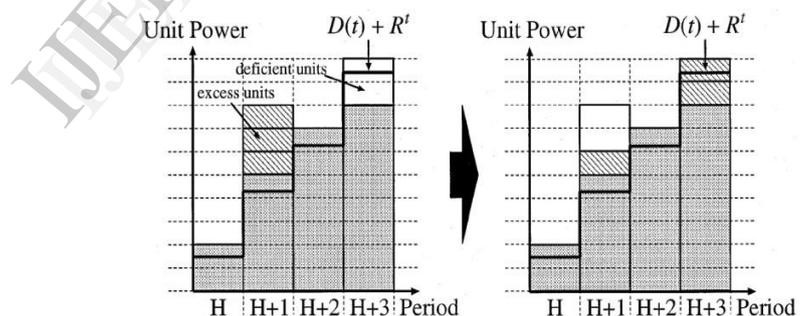


Fig. 6. Commitment of excess started or deficient units.

- 5) Modification of the Grey Zone for Start Up Cost: The grey zone for startup cost indicates the change point where changes from the cold start up cost to the hot start up cost. As shown in Table III, the cold start up cost is two times larger than the hot start up cost. Hence, it is desirable that the unit starts up with the hot start up cost if possible. To reduce the cost over de-tails, the grey zone modification algorithm, which searches the grey zone for start up cost and modifies schedule, is incorporated in this paper. In order to expedite the reduction of the cost, the unit schedule is modified by the specific unit order, that the start up cost is high whereas the fuel cost is low (i.e., proposed priority list order). The grey zone modification algorithm incorporated in this paper is explained briefly below.

Step 1) The total cost for the S solutions obtained by all heuristics mentioned above are calculated. The smallest cost in S solutions is set to as a incumbent value.

Step 2) At hours changing from off status at previous hour to on status at next hour, the grey zone is searched and modified.

Step 3) The total cost for modified solution is calculated if at least one grey zone exists. If the total cost is improved compare with a old incumbent value, the total cost is updated as a new incumbent value as well as modified solution is updated to a incumbent solution. Inversely, if the grey zone does not exist or modified solution is infeasible, modified part is returned.

ELD Calculation

In this paper, the economic load dispatch (ELD) calculation which uses the classical lambda-iteration method is performed only for feasible solution and is used in the portion where per-forms the cost calculation. The ELD calculation is stopped when the allowable error, which indicates that the sum of the all of on-line unit output minus the load demand, is less than the value that N is divided by ten. Compared with GA and TS which needs a lot of ELD calculations, the proposed method can attain short-ening of calculation time by leaps and bounds. Only the solutions which applied several heuristics will be-come feasible solution and these numbers will be about S . The number is represented as about S because all solutions which applied several heuristics are not necessarily possible to per-form.

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

LOAD DEMAND

	Unit1	Unit2	Unit3	Unit4	Unit5
P_{imax}	455	455	130	130	162
P_{imin}	150	150	20	20	25
a_i	1000	970	700	680	450
b_i	16.19	17.26	16.60	16.50	19.70
c_i	0.00048	0.00031	0.002	0.00211	0.00398
T_i^{on}	8	8	5	5	6
T_i^{off}	8	8	5	5	6
h-cost _i	4500	5000	550	560	900
c-cost _i	9000	10000	1100	1120	1800
c-s-hour _i	5	5	4	4	4
ini state	+8	+8	-5	-5	-6
	Unit6	Unit7	Unit8	Unit9	Unit10
P_{imax}	80	85	55	55	55
P_{imin}	20	25	10	10	10
a_i	370	480	660	665	670
b_i	22.26	27.74	25.92	27.27	27.79
c_i	0.00712	0.00079	0.00413	0.00222	0.00173
T_i^{on}	3	3	1	1	1
T_i^{off}	3	3	1	1	1
h-cost _i	170	260	30	30	30
c-cost _i	340	520	60	60	60
c-s-hour _i	2	2	0	0	0
ini state	-3	-3	-1	-1	-1

TABLE III UNIT CHARACTERSTICS AND COST COFFICIENTS

SIMULATION CONDITIONS

The unit characteristics and the load demand, which are used in this paper, are given in Tables II and III, respectively [5], [7]. In order to perform a simulation on the same conditions in [5] and [7], in all simulations the spinning reserve requirements was assumed to be 10% of the load demand and total scheduling period is 24 h. The simulations included test runs for 10-, 20-, 40-, 60-, 80-, and 100-unit systems. Expansion of the number of unit is based on 10-unit system, for the 20-unit system, the base 10 units were duplicated and the load demand was multiplied by 2. Similarly, other unit systems are expanded with same manner too.

number of initial solutions	W	20
number of unit inside the window	X	1
number of solutions applying several heuristics	S	5

SIMULATION PARAMETERS

In the Table III, “ini state” represents the initial unit state on scheduling period, and the positive sign indicates that the unit is on, whereas the negative sign indicates that the unit is off. For example, since initial state of unit 3 is 5, this indicates that unit 3 had kept starting up for 8 h. In this paper, the priority list was created so that the larger unit of output power could have a high priority. Hence, unit 1 has the highest priority, whereas unit 10 has the lowest priority. The simulation parameter used in the EPL, such as X , W , and S , are given in Table V. From several pretest simulations, we have confirmed that S mainly affects execution time and W mainly affects the total cost and X affects the both. The each values listed in Table V can yield satisfactory results for both the cost and execution time. The unit started in order of priority list mentioned in Section III-D-II is till unit 3. For 10-unit system, the units started in order of priority list are 5 units, in case of 100-unit system, it is 50 units. The simulation is performed for each unit systems with con-ditions given in Table V. Furthermore, for 40-unit system we ex-amine the effects on the total cost and execution time by varying X . Also, we simulate in two case of modifying grey zone (case 1) and without modifying grey zone (case 2) to examine the ef-fect on the total cost by modifying grey zone for startup cost. The all calculations are run on a Intel Pentium4 CPU(1.5 GHz), Linux version 2.2.18 and gcc version 2.91.66.

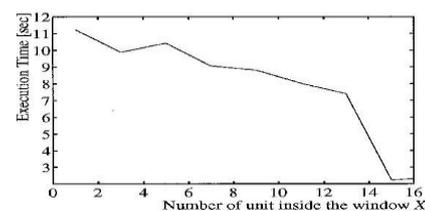
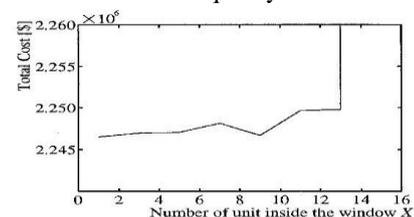
SIMULATION RESULTS

Table shows the comparison of proposed EPL method with GA and EP of total cost. In Table VI, the EPL method gives the lowest total cost of these method in all unit systems. Table VII shows the comparison of EPL method with GA and EP of exe-cution time. According to Table VII, the EPL method can obtain better solution rapidly even if the problem is large because the generation of the feasible solution is limited by the solution reduction, and the number of ELD calculation is reduced. In the proposed method, the generation of plurality of solutions is performed by setting up at random on/off status of X units in Fig. 3 at every time interval. Hence, we have an in-terest in the effects on the solution quality and execution time by varying X . Fig. 9(a) and (b) show the simulation results of the total cost and execution time for 40–unit system in the same conditions as Table V except varying X . In Fig. 9(a), the total cost is minimum as $X=1$, and it indicates that the quality of a initial solution obtained first by PL method excels very much.

No. of unit	Total cost[\$]		
	EPL	GA ^[5]	EP ^[7]
10	563977	565825	565352
20	1124369	1126243	1127257
40	2246508	2251911	2252612
60	3366210	3376625	3376255
80	4489322	4504933	4505536
100	5608440	5627437	5633800

($W = 20, S = 5, X = 1$)

Comparison of Total Cost



No. of unit	Total cost[\$]		Reduced cost[\$]
	Case 1	Case 2	
10	563977	563977	0
20	1124369	1124369	0
40	2246508	2246851	343
60	3366210	3366547	337
80	4489322	4490009	687
100	5608440	5609040	600

GREY ZONE MODIFICATION EFFECT

The total cost increases rapidly at $X > 13$ because the feasible solution does not exist. Please note that the proposed method adds large value as a penalty of the total cost to infeasible solution. In Fig. 9(b), transit of execution time is staying confined range when the feasible solution exists but the execution time decreases as well as non generating feasible solution at $X > 13$. As shown in Fig. 9(a) and (b), both of the execution time and total cost changes in confined range at $X \leq 13$, it indicates that the EPL method has a performance generates stably about 5 feasible solutions.

In order to verify effectiveness of the grey zone modification discussed before, we compare with case 1 and case 2. The grey zone modification for startup cost can modify the parts which cannot consider by the other proposed heuristics, as a result it gives more good unit schedule as shown in Table.

CONCLUSIONS

In this paper, we proposed a fast extended priority list method for the UC problem. The PL method is applied as a technique getting better initial solution rapidly. The effectiveness to use the PL method is clear from simulation results. The proposed condition for reduction of solutions in this paper can expedite reducing solution and as a result the number of the ELD calculation can be decreased. Hence, for a larger problem, the proposed method can get solution with practical calculation time. For operating more economically, to take modification of the grey zone for the start up cost into consideration is beneficial. For the units having the same characteristics, we have examined to use the concept of unit integration to reduce the further execution time. Among all units, some units with the similar unit parameters (e.g., the minimum up/down times and the maximum/minimum output power), are integrated, and is considered that it is equivalent to one unit. Hence, the original problem is reduced to the small problem, whereby the computational effort can be saved.

REFERENCES

- [1] H. H. Happ, R. C. Johnson, and W. J. Wright, "Large scale hydro-thermal unit commitment-method and results," IEEE Trans. Power Applicat. Syst., vol. 90, no. 3, pp. 1373–1384, 1971. IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 18, NO. 2, MAY 2003
- [2] A. Ohuch and I. Kaji, "A branch-and-bound algorithm for startup and shutdown problem of thermal generating units," Inst. Elect. Eng. Japan, vol. 95-B, no. 10, pp. 461–468, 1975.
- [3] G. S. Lauer, D. P. Bertsekas, N. R. Sandell Jr, and T. A. Posbergh, "Solution of large-scale optimal unit commitment problems," IEEE Trans. Power Appar. Syst., vol. PAS-101, pp. 79–86, Jan. 1982.
- [4] A. J. Svoboda, C.-L. Tseng, C.-A. Li, and R. B. Johnson, "Short-term resource scheduling with ramp constraints," IEEE Trans. Power Syst., vol. 12, pp. 77–83, Feb. 1997.
- [5] S. A. Kazarlis, A. G. Bakirtzis, and V. Petridis, "A genetic algorithm solution to the unit commitment problem," IEEE Trans. Power Syst., vol. 11, pp. 83–92, Feb. 1996.
- [6] H. Mori and O. Matsuzaki, "Application of priority-list-embedded Tabu search to unit commitment in power systems," Inst. Elect. Eng. Japan, vol. 121-B, no. 4, pp. 535–541, 2001.
- [7] K. A. Juste, H. Kita, E. Tanaka, and J. Hasegawa, "An evolutionary programming solution to the unit commitment problem," IEEE Trans. Power Syst., vol. 14, pp. 1452–1459, Nov. 1999.