Dynamic Programming Method Approach to Unit Commitment for Electricity Generation Schedule in Yangon Division

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Abstract: This paper presents a Dynamic Programming (DP) method based an algorithm to solve the Unit Commitment (UC) scheduling of the thermal generation units in Yangon. Electricity demands are in its peak in Yangon, it has become very difficult for operators to fulfill the demand in the present. The main objective of Unit Commitment is to determine a minimum 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. The total production costs include fuel, startup, shutdown, and no-load costs. There are many conventional and evolutionary programming methods used for solving the unit commitment problem. Dynamic programming method is one of the successful approaches to unit commitment problem. Dynamic Programming has many advantages over the enumeration scheme, the chief advantage being a reduction in the dimensionality of the problem. It is one of the refined algorithm design standards and is powerful tool which yields definitive algorithm for various types of optimization problems. To implement the unit commitment problem into an optimization program, the MATLAB® software is used. The results obtained from Dynamic programming method in consideration of various start up cost functions were found satisfactory.

Key Words: Dynamic Programming (DP) method, Unit Commitment (UC), minimum cost, startup cost.

1. INTRODUCTION:

In the Yangon Electricity Supply Corporation (YESC) networks, there are two types of generating resources like hydro and thermal. Also, the load demand varies during a day and attains different peak values. Although hydro generation unit is operated constantly for base load, it is required to decide which thermal generating unit to turn on and at what time it is needed in the power system network and also the sequence in which the units must be shut down keeping in mind the cost effectiveness of turning on and shutting down of respective units.

The entire process of computing and making these decisions is known as unit commitment (UC). The unit which is decided or scheduled to be connected to the power system network, as and when required, is known to be committed unit. Unit commitment in power systems refers to the problem of determining the on/off states of generating units that minimize the operating cost for a given time horizon. UC problem is a non- linear, large scale, mixed integer constrained optimization problem and happens to belong to combinatorial optimization problems [1].

Dynamic programming (DP) is effectively employed to solve the problem of unit commitment for a system having larger number of units. This is mainly because DP constitutes the enumeration of viable schedules or solutions to the unit commitment problem which becomes tedious and difficult to do manually and it has to be done using a digital computer to make it fast and easier. DP approach hourly evaluates possible unit commitment schedules associated with decision made in the proceeding step by considering all constraints before searching for a schedule that yields the minimum cost. There are certain data requirements while using DP [4]. These data include cost characteristic of the units under consideration along with the maximum and minimum load limits and various other constraints. DP method follows absolute enumeration of feasible alternatives of schedule and their comparison on the basis of operating costs. The main advantage of DP approach is that once the operating schedule of n units is evaluated, the optimal schedule for n + 1 unit can be easily determined. Thus DP reduces the dimensionality of the considered problem.

2. UNIT COMMITMENT PROBLEM:

The demand for electricity is higher during the daytime and lower during the late evening and early morning.

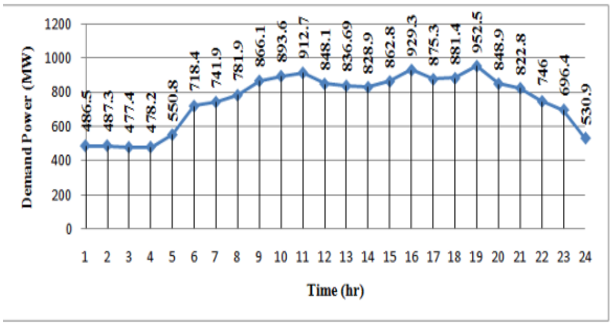

Fig. 1 The daily load cycle for Yangon Distribution Network

Source:[8]

The problem is first to decide which of the available units to turn on, and then to determine a schedule of the units.

Table . I Thermal Generation Data for Production Cost Function

Thermal Unit (4)		*Thermal Unit (5)*	
fuel Input (MBTU/hr)	*Power Output (MW)*	*fuel Input (MBTU/hr)*	*Power Output (MW)*
1070.136	*89.1*	*1010.33*	*84.3*
1082.952	*90.8*	*1014.6*	*85.5*
1100.752	*91.6*	*1018.16*	*86.6*
1102.888	*92.5*	*1023.86*	*87.4*
1110.72	*92.8*	*1029.55*	*88.6*
Thermal Unit (6)		*Thermal Unit (7)*	
833.04	*110.85*	*1241.728*	*80.5*
847.28	*115.84*	*1308.656*	*99.4*
854.4	*118.62*	*1314.352*	*99.8*
865.792	*121.11*	*1319.336*	*99.9*
875.76	*124.51*	*1323.608*	*100.5*
Thermal Unit (8)		*Thermal Unit (9)*	
184.408	*9.6*	*605.2*	*53.5*
931.296	*52.1*	*609.88*	*55.2*
935.568	*53.5*	*619.44*	*56.5*
943.4	*55.5*	*633.112*	*58*
1107.16	*56*	*640.8*	*59.4*
Thermal Unit (10)		*Thermal Unit (11)*	
412.342	*24*	*273.408*	*21.5*
430.048	*26*	*276.256*	*22*
459.952	*29*	*284.088*	*22.5*
471.344	*30*	*289.072*	*23*
480.6	*31*	*292.42*	*24*
Thermal Unit (12)		*Thermal Unit (13)*	
312.69	*39.2*	*160.2*	*14*
323.66	*44.8*	*186.544*	*17.9*
329.48	*46.15*	*199.36*	*18.9*
334.94	*47.2*	*210.04*	*19.5*
340.57	*48.3*	*225.704*	*20.6*
Thermal Unit (12)			
435.15		*45*	
439.72		*46*	
442.225		*46.5*	
450.925		*47.5*	
457.816		*48*	

Source:[8]

This cyclical demand requires that utility operation plan for generation of power on an hourly basis. The daily load cycle for Yangon Distribution Network is shown in figure 1.There is two major power generating types to distribute in Yangon network. They are hydroelectric generating stations and thermal power generating stations. The number of total generation is fourteen. Among these generation units, three units are hydro power generation and remaining are thermal power generation units. The base load is considered as 450MW operated with hydro generation units. Above 450MW of power demand is regarded as average and peak load considered with thermal units.

Although hydro generation has no variable production cost, thermal generation is to be consider the production cost depending on output power generation within the generation constraint. The consideration of cost function for thermal unit is fuel consumption and power output. These data are described in table.I for all thermal units. The production cost function, CFi for unit i at any given time interval

$$CF_i = a_i + b_i P_i + c_i P_i^2 \quad (1)$$

$$P_i^{min} \leq P_i \leq P_i^{max} \quad \text{for } i=1\ldots\ldots\ldots NG \quad (2)$$

Where, a_i, b_i, c_i are the unit cost coefficients.

The following notation is used for unit commitment problem [5].

System parameters:

CFi(p) : Cost of producing p units of power by unit i

SUi : Start up cost of unit i

u(t) : Load at time t (demand)

r(t) : Power reserve at time t (in case of unit failures)

Decision variables:

$P_i(t)$: Amount of power produced by unit i at time t

$v_i(t)$: Control variable of unit i at time t

$$v_i(t) = \begin{cases} 0 & \text{if unit i is off at time t} \\ 1 & \text{if unit i is on at time t} \end{cases} \tag{3}$$

Auxiliary variables:

xi(t) : Consecutive time that unit i has been up (+) or down (-) at time t

I(x) : Logic function defined by

$$I(x) = \begin{cases} 0 & \text{if x is false} \\ 1 & \text{if x is true} \end{cases} \tag{4}$$

The objective of the standard UCP is to minimize the sum of two cost terms. The first term is the cost of the power produced by the generating units, which depends on the amount of fuel consumed [6]. The second term is the start-up cost of the generating units, which for thermal units, depends on the prevailing temperature of the boilers.

Fuel Cost:

For a given set of *N* committed units at hour *t*, the total fuel cost, at that particular hour, is minimized by economically dispatching the units subject to the following constraints:

a) The total generated power must be equal to the demand (also called load).

b) The power produced by each unit must be within certain limits (minimum and maximum capacity).

Start-up Cost:

The start-up costs relate to turning a unit on. If the thermal unit has been off for a long period, a cold start-up cost will be incurred. If the unit has been recently turned off (temperature of the boiler is still high), a hot start-up cost is applied. Three types of functions are commonly used to model start-up costs as cold startup cost function, a function of the temperature: two-step (cold/hot) and exponential functions.

A .Cold startup cost function

$$S_c = C_c(1 - \varepsilon^{-t/\tau}) \times F + C_f \tag{5}$$

where,

C_c = cold start cost
F= fuel cost
C_f = fixed cost
α = thermal time constant for the unit
t = time (h) the unit was cooled

$$S_h = C_t \times t \times F + C_f \tag{6}$$

where,

C_t = cost of maintaining unit at operating temperature

B. Two-step function (cold/hot)

$$S(t) = \begin{cases} S_c & \text{if } -x(t) \le t_{\text{cold start}} \\ S_h & \text{otherwise} \end{cases} \tag{7}$$

$t_{\text{cold start}}$ is the number of hours that it takes for the boiler to cool down. The S_c and S_h costs are the start-up costs incurred for a cold and hot start, respectively.

C. Exponential function

$$S(t) = b_0\left(1 - e^{\frac{-\max(0, -x(t-1))}{\tau}}\right) + b_1 \tag{8}$$

Start-up costs are incurred only when a transition from state off to on occurs, which can be expressed as follows:

$$CS(t) = S(t)v(t)(1 - v(t-1)) \tag{9}$$

Objective function:

Consequently, the objective function of the unit commitment problem for *N* generating units and *T* hours can be written as follows:

$$\min \sum_{t=1}^{T} \sum_{i=1}^{N} \left[CF_i(P_i(t)) v_i(t) + CS_i(t) \right]$$

Subject to the constraints

a) Demand

$$\sum_{i=1}^{N} v_i(t) P_i(t) = u(t) \qquad t=1,\ldots,T \qquad (10)$$

b) Capacity limits

$$v_i(t) P_i^{min} \le P_i(t) \le v_i(t) P_i^{max} \; t=1,\ldots\ldots,T; i=1,\ldots.,N \qquad (11)$$

c) Minimum uptime (MUT) and minimum downtime (MDT)

$$v_{i(t)} \ge I(1 \le x_i(t-1) \le t_{up} - 1) \; t=1,\ldots,T; i=1,\ldots.,N \qquad (12$$

$$v_i(t) \le 1 - I(-t_d + 1 \le x_i(t-1) \le -1) \; t=1,\ldots,T; i=1,\ldots.,N \qquad (13)$$

d) Power reserve

$$\sum_{i=1}^{N} v_i(t) P_i^{max} \ge u(t) + r(t) t=1,\ldots,T \qquad (14)$$

The total amount of power available at each hour must be greater than the load demanded. The reserve power available, denoted by $r(t)$, is used when a unit fails or an unexpected increase in load occurs [7].

3. DYNAMIC PROGRAMMING APPROACH TO UNIT COMMITMENT:

The basis for Dynamic Programming (DP) is the theory of optimality elucidated by Bellman in 1957. This method can be used to explain crises in which many chronological conclusions are to be taken in defining the optimum operation of a system, which consists of distinct number of stages. The searching may be in forward or backward direction. Within a time period the combinations of units are known as the states. In Forward Dynamic programming an excellent economic schedule is obtained by commencing at the preliminary stage amassing the total costs, then retracing from the combination of least accumulated cost starting at the last stage and finishing at the initial stage. The stages of the DP problem are the periods of the study horizon. Each stage usually corresponds to one hour of operation i.e., combinations of units steps forward one hour at a time, and arrangements of the units that are to be scheduled are stored for each hour.

Dynamic programming has many advantages over the enumeration scheme, the chief advantage being a reduction in the dimensionality of the problem. Suppose it have been found units in a system and any combination of them could serve the (single) load. There would be a maximum of 2^N - 1combinations to test [3]. However, if a strict priority order is imposed, there are only four combinations to try:

Priority 1 unit

Priority 1 unit + Priority 2 unit

Priority 1 unit + Priority 2 unit + Priority 3 unit

Priority 1 unit + Priority 2 unit + Priority 3 unit + Priority 4 unit

In the dynamic-programming approach that follows:

1. A *state* consists of an array of units with specified units operating and the rest off-line.

2. The start-up cost of a unit is independent of the time it has been off-line (i.e., it is a fixed amount)

3. There are no costs for shutting down a unit.

4. There is a strict priority order, and in each interval a specified minimum amount of capacity must be operating [2].

In its elemental form, the dynamic programming algorithm for unit commitment problem inspects every possible state in every interval. The dimensionality of the problem is significantly declined which is the chief advantage of this method. The postulations for structuring the step by step procedure for dynamic programming method are tracked below [4].

1) A state consists of a group of units with only precise units in service at a time and the remaining off-line.

2) While the unit is in off state the start-up cost of a unit is independent of the time specifically it remains fixed.

3) For closing the unit there will be no cost involved.

4) The order of precedence is firm and a small quantity of power must be in operation in each interval. The flow chart for Dynamic Programming method is shown in Figure. 2.

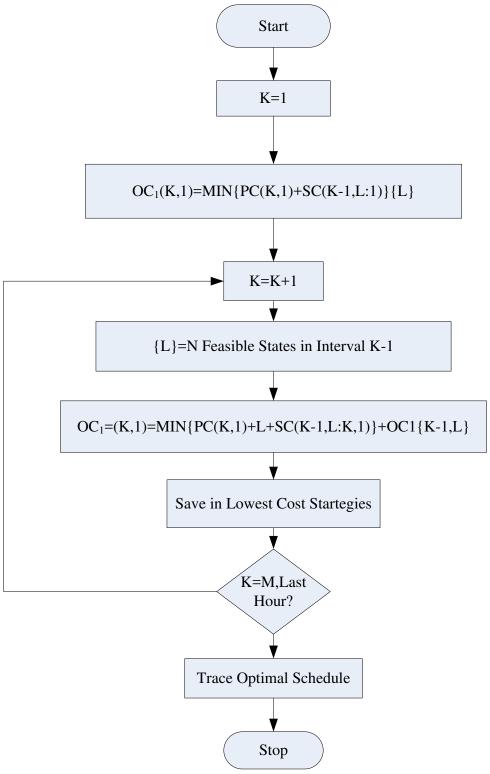

Fig. 2 Flow Chart Showing Unit Commitment by Dynamic Programming

Source:[3]

State ***(K , 1)*** is the Ith combination in hour ***K .*** For the forward dynamic programming approach, it can be defined a ***strategy*** as the transition, or path, from one state at a given hour to a state at the next hour.

Note that two new variables, *X* and ***N,*** have been introduced in Figure.2.

X = number of states to search each period

N = number of strategies, or paths, to save at each step

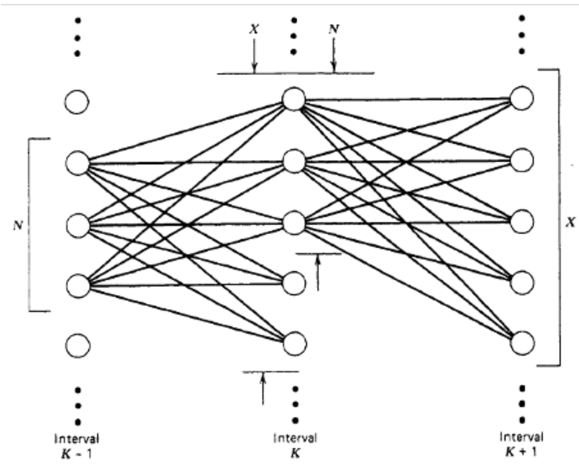

Fig. 3 Restricted search paths in DP algorithm

Source:[3]

These variables allow control of the computational effort in Figure. 3. For example, with a simple priority-list ordering, the upper bound on *X* is ***n,*** the number of units. Reducing the number ***N*** means that we are discarding the highest cost schedules at each time interval and saving only the lowest ***N*** paths or strategies. There is no assurance that the theoretical optimal schedule will be found using a reduced number of strategies and search range (the ***X*** value); only experimentation with a particular program will indicate the potential error associated with limiting the values of *X* and *N* below their upper bounds.

4. DATA DESCRIPTION FOR UNIT COMMITMENT PROBLEM IN YANGON:

According to collected data from YESC, the daily load cycle shown in Figure.1 is divided into two patterns as hydro and thermal unit consideration. Load demands pattern for 24 hours is shown in Figure.4. There are 3 hydro units and 11 thermal units in YESC.As hydro units have no variable and startup cost, it can be regarded as must run units in whole day. It is operated up to 450MW for all demands and extra remaining demands scheduled by thermal units.

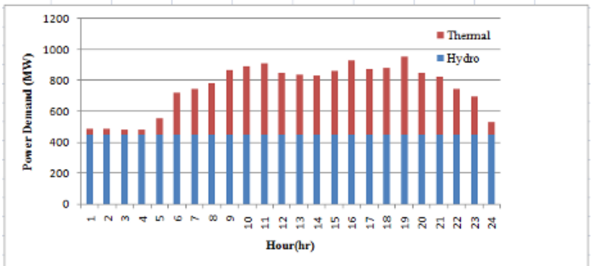

Fig.4 Load demands pattern for 24 hours for YESC

The production cost functions are evaluated with “polyfit(x,y,n)” in Matlab. The fuel consumptions values are assigned as “x” and output power values are assigned as “y”. The required order for cost equations is taken as “n”. After applying the required values in “polyfit(x,y,n)” , cost functions of thermal generations are achieved. In table .II, production cost functions and maximum and minimum limits of unit generations are described. The first three units are hydro unit generations and remaining are thermal units.

Table. II Unit Generation Data

$F1 = 30.69P_G - 20.47(\$/hr)$	$200 \le P \le 230(MW)$
$F1 = 30.69P_G - 20.47(\$/hr)$	$100 \le P \le 110(MW)$
$F1 = 30.69P_G - 20.47(\$/hr)$	$100 \le P \le 110(MW)$
$F4=2P_G^2 -308.5P_G +17013\ (\$/hr)$	$20 \le P \le 154.2(MW)$
$F5= 2P_G^2 -293.5P_G + 16792.5(\$/hr)$	$20 \le P \le 154.2(MW)$
$F6=0.19\ P_G^2 -29.321P_G + 5056.5(\$/hr)$	$20 \le P \le 125.6(MW)$
$F7= 2.5P_G^2 -426P_G + 24502(\$/hr)$	$20 \le P \le 120(MW)$
$F8= 1.668P_G^2 -17.68P_G +938.48(\$/hr)$	$5 \le P \le 120(MW)$
$F9= 2.2P_G^2 -216.49P_G +8300\ (\$/hr)$	$20 \le P \le 92(MW)$
$F10= 0.69\ P_G^2 +11.26P_G + 1392.03(\$/hr)$	$20 \le P \le 36.9(MW)$
$F11= 10.5\ P_G^2 -420.5P_G +5467.5\ (\$/hr)$	$5 \le P \le 33.4(MW)$
$F12= 1.57P_G^2 -121.59P_G + 3923.2(\$/hr)$	$20 \le P \le 53.6(MW)$
$F13= 5.75P_G^2 -148.74P_G + 1755.8(\$/hr)$	$15 \le P \le 26.7(MW)$
$F14= 9P_G^2 -787.5P_G + 19664(\$/hr)$	$20 \le P \le 52(MW)$

Then, thermal unit generation data are described in table.III detail. These data are taken from records of operating system at thermal generating stations in Yangon. Spinning reserve is taken as 20% of the demands for all hours [8].

Table .III Input Data for Thermal Unit Generation

Unit	MUT(h)	MDT(h)	start cost hot($)	Start Cost Cold($)	cold start hour(h)	In status (h)
4	3.25	3.25	222.5	445	2	-3.25
5	3.25	3.25	222.5	445	2	-3.25
6	1.5	1.5	73.375	146.75	1	-1.5
7	1	1	68.3	136.615	0.25	-1
8	1	1	68.3	136.615	0.25	-1
9	3	3	87.54	175.093	2	-3
10	0.5	0.5	34.36	68.72	0.25	-0.5
11	2	2	39.2	78.4	1	-2
12	0.5	0.5	23.955	47.91	0	-0.5
13	0.5	0.5	23.545	47.09	0	-0.5
14	0.33	0.33	20.485	40.97	0	-0.33

Source:[8]

5. SIMULATION AND RESULTS OF DYNAMIC PROGRAMMING METHOD:

This paper developed the dynamic programming method using MATLAB. The 3 units hydro generations are linear cost functions and the cost for 450MW of an hour is 13749$/hr. The total cost for 24 hours is 329976$. The total cost of 11 units for thermal generations is different upon the three types of startup cost functions. They have been described as Cold startup cost function, Two-step function (cold/hot) and Exponential function in previous section. Dynamic programming method is applied in all three types in this paper.

Table.IV Result Comparison of Various Startup Cost Function

	Cold startup		*Two step (cold/hot)*		*Exponential*	
hr	*Startup*	*Prod-cost*	*Startup*	*Prod-cost*	*Startup*	*Prod-cost*
1	*48*	*1577*	*48*	*1577*	*64*	*1577*
2	*0*	*1572*	*0*	*1572*	*0*	*1572*
3	*137*	*1706*	*137*	*1706*	*198*	*1706*
4	*78*	*2161*	*48*	*2839*	*111*	*2161*
5	*48*	*4755*	*147*	*4031*	*72*	*4755*
6	*322*	*11552*	*291*	*11296*	*474*	*11552*
7	*0*	*12679*	*78*	*12679*	*0*	*12679*
8	*445*	*15107*	*445*	*15555*	*665*	*15107*
9	*137*	*21199*	*68*	*20934*	*205*	*21199*
10	*78*	*22734*	*137*	*22782*	*89*	*22734*
11	*0*	*23852*	*0*	*23899*	*0*	*23852*
12	*137*	*19269*	*39*	*19269*	*202*	*19269*
13	*0*	*18418*	*0*	*18418*	*0*	*18418*
14	*0*	*17927*	*0*	*17927*	*0*	*17927*
15	*0*	*20599*	*0*	*20599*	*0*	*20599*
16	*137*	*24834*	*137*	*24834*	*202*	*24834*
17	*0*	*21615*	*0*	*21615*	*0*	*21615*
18	*0*	*21954*	*0*	*21954*	*0*	*21954*
19	*215*	*26529*	*176*	*26529*	*275*	*26529*

20	0	19335	0	19335	0	17335
21	0	17594	0	17594	0	17594
22	0	12966	0	12966	0	12966
23	0	10256	0	10256	0	10256
24	0	3616	0	3616	0	3616

Table. V UC Scheduled Obtained Using Dynamic Programming Method with Cold and Exponential Start up Function

hr	Load	Unit on/off	hr	Load	Unit on/off
1	486.5	11100000000100	13	836.69	11110101101100
2	487.3	11100000000100	14	828.9	11110101101100
3	477.4	11100001000000	15	862.8	11110101101100
4	478.2	11100001001000	16	929.3	11110111101100
5	550.8	11100001001100	17	875.3	11110110100100
6	718.4	11100101101100	18	881.4	11110110100100
7	741.9	11100101101100	19	952.5	11110111101100
8	781.9	11110100100100	20	848.9	11110101101100
9	866.1	11110110100100	21	822.8	11110101101100
10	893.6	11110110101100	22	746	11100101101100
11	912.7	11110110101100	23	696.4	11100101100100
12	848.1	11110101101100	24	530.9	11100001000100

Table. VI UC Scheduled Obtained Using Dynamic Programming Method with Cold/Hot Start up Function

hr	Load	Unit on/off	hr	Load	Unit on/off
1	486.5	11100000000100	13	836.69	11110101101100
2	487.3	11100000000100	14	828.9	11110101101100
3	477.4	11100001000000	15	862.8	11110101101100
4	478.2	11100001000100	16	929.3	11110111101100
5	550.8	11100100000000	17	875.3	11110110100100
6	718.4	11100101100100	18	881.4	11110110100100
7	741.9	11100101101100	19	952.5	11110111101100
8	781.9	11110100101100	20	848.9	11110101101100
9	866.1	11110101101100	21	822.8	11110101101100
10	893.6	11110111100100	22	746	11100101101100
11	912.7	11110111100100	23	696.4	11100101100100
12	848.1	11110101101100	24	530.9	11100001000100

Unit Commitment scheduled of on/off states are all equal for cold and exponential startup cost functions. But, there are differences in some hours i.e. 4, 5, 6 hr and 8,9,10 hr of cold/hot start up function. Depending on startup functions, the startup costs are different. Therefore, total fuel costs are not same. The detail simulation results of dynamic programming are shown in table. IV, V, VI and VII.

The result comparison of dynamic programming applied in different startup cost functions are described in table.VII.

Table. VI I Performance Comparison of Various Startup Function Considerations to Unit Commitment

Startup Function	*Thermal Fuel Cost($)*	*Hydro Generation Cost($)*	*Total Cost($)*
Cold Startup	*355585*	*329976*	*685561*
Two Step(cold/hot)	*355533*	*329976*	*685509*
Exponential	*356362*	*329976*	*686338*

6. CONCLUSION:

Dynamic Programming method is used for solving the UC problem in Yangon. This method provides the advantages of non-discrediting of generation levels and is proved to be efficient for thermal generation units with considerations of three types startup cost functions. According to result comparison with various startup cost functions, two-step function (cold/hot) is obtained the best result and on/off states scheduling are all equal in cold and exponential start up functions. All simulation result obtained by DP can find highly quality solutions with better than the current condition of generator scheduled in YESC and higher precision within in time horizon. Hence, this research will be helpful to achieve the generation scheduling for Yangon Distribution Network.

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