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Analysis of Economic Load Dispatch & Unit Commitment Using Dynamic Programming

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ABSTRACT: The modern power system around the world has grown in complexity of interconnection and power demand. The focus has shifted towards enhanced performance, increased customer focus, low cost, reliable and clean power. In this changed perspective, scarcity of energy resources, increasing power generation cost, environmental concern necessitates optimal economic dispatch. In reality power stations neither are at equal distances from load nor have similar fuel cost functions. Hence for providing cheaper power, load has to be distributed among various power stations in a way which results in lowest cost for generation. Practical economic dispatch (ED) problems have highly non-linear objective function with rigid equality and inequality constraints. In this paper, a unit commitment problem is being described & its solution using dynamic programming for multi unit system over 24 hour time horizon is being presented. This also means that it is desirable to find the optimal generating unit commitment (UC) in the power system for the next H hours. The main objective of this paper is to reduce the total production cost includes fuel cost, maintenance cost etc.

KEYWORDS: Economic Load Dispatch, Unit Commitment, Power System, Production Cost.

I.INTRODUCTION

Many utilities have daily load patterns which exhibit extreme variation between peak and off peak hours because people use less electricity on Saturday than on weekdays, less on Sundays than on Saturdays, and at a lower rate between midnight and early morning than during the day. If sufficient generation to meet the peak is kept on line throughout the day, it is possible that some of the units will be operating near their minimum generating limit during the off peak period. The problem confronting the system operator is to determine which units should be taken offline and for how long. In most of the interconnected power systems, the power requirement is principally met by thermal power generation. Several operating strategies are possible to meet the required power demand, which varies from hour to hour over the day. It is preferable to use an optimum or suboptimum operating strategy based on economic criteria. In other words, an important criterion in power system operation is to meet the power demand at minimum fuel cost using an optimal mix of different power plants. Moreover, in order to supply high-quality electric power to customers in a secured and economic manner, thermal unit commitment (UC) is considered to be one of best available options. It is thus recognized that the optimal UC of thermal systems, which is the problem of determining the schedule of generating units within a power system, subject to device and operating constraints results in a great saving for electric utilities. So the general objective of the UC problem is to minimize system total operating cost while satisfying all of the constraints.

Various approaches have been developed to solve the optimal UC problem. These approaches have ranged from highly complex and theoretically complicated methods to simple rule-of thumb methods. The scope of operations scheduling problem will vary strongly from utility to utility depending on their mix of units and particular operating constraints. The economic consequences of operation scheduling are very important. Since fuel cost is a major cost component, reducing the fuel cost by little as 0.5% can result in savings of millions of dollars per year for large utilities. A very important task in the operation of a power system concerns the optimal UC considering technical and economical constraints over a long planning horizon up to one year.
However, the generating companies (GENCOs) share of this remaining demand may difficult to predict since it will depend on how its price compares to that of other suppliers. The GENCO's price will depend on the prediction of its share of this remaining demand as that will determine how many units they have switched on. The UC schedule directly affects the average cost and indirectly the price, making it an essential input to any successful bidding strategy.

There may be a tendency to think that maximizing the profit is essentially the same as minimizing the cost. This is not necessarily the case. We have to remember that since we no longer have the obligation to serve the demand, the GENCOs may choose to generate less than the demand. This allows a little more flexibility and makes the problem complex in the UC schedules under the deregulated environment. Finally, the profit depends, not only on the cost, but also on revenue. If revenue increases more than the cost does, the profit will increase. So for the next-generation UC problem, researchers have to still play an important role. If the bid functions are non convex or non differentiable in nature, which is commonly seen in both regulated and deregulated power industry, then the above problem becomes complex. Further, the complexity increases if the competition is encouraged in both suppliers and buyers side including emission constraints. So it has been observed that the hybrid models, which are the combination of both classical and non classical methods, can handle the present day complex UC problem commonly seen within developed countries. With the available standard software products, electric utilities have to enhance, evolve, and upgrade or add new applications such as UC solutions for modern deregulated power industry in conjunction with energy management systems.

II.UNIT COMMITMENT

The scope of the operations scheduling problem will vary strongly from utility to utility depending on their mix of units and particular operating constraints. The economic consequences of operations scheduling are very important. Since fuel cost is a major cost component, reducing the fuel cost by as little as 0.5 percent can result in savings of millions of dollar per year for large utilities. The time horizon of operations scheduling depends on a number of factors. Large steam units take several hours to start up and bring on-line. They also have minimum up and down-time constraints and start up costs which require that they be scheduled over a period of several days. The Schedule of the thermal units is also influenced by preventative maintenance schedules, nuclear refuelling schedules, or long-term fuel contracts which involve making decisions on a yearly or multi-year timeframe. Hydro scheduling also, in general, involves a yearly or multi-year time frame due to the large capacity of many hydro reservoirs. Many hydro or pumped hydro reservoirs have daily or weekly cycles. Typically the commitment and generating schedule is output on an hourly basis.

Although yearly or multi-year factors influence operations scheduling, the schedules actually produced are often useful for just several hours. This is because the scheduling requires forecast of many stochastic quantities such as loads, hydro inflows, and unit availabilities. If the actual values of these quantities differ greatly from the forecasts, then it is economical to resolve the operations scheduling problem. Since the determination of hourly hydro and thermal schedules over a period of several years is unrealistic and, As described above, unnecessary, past approach have developed a hierarchical approach to the overall operations scheduling problem .A typical hierarchy is shown in Fig 2.1 The Maintenance Scheduler solves for the time for preventive maintenance of the generating units. Typically, weekly schedules are generated over a period of one to three years. The Maintenance Scheduler coordinates with the long-Term Hydro Scheduler which produces hydro schedules over the same timeframe .This insures that the hydro energy is available, as needed, to replace units down for maintenance. The long-term maintenance and hydro schedules are inputs to the Unit Commitment and Short-Term Hydro Schedulers. Unit Commitment produces commitment and generation schedules or the thermal units while the Short-Term Hydro Scheduler produces generation schedules for the hydro units. The combined Unit Commitment and Short-Term Hydro scheduling problem often referred to as the Short-term hydro-thermal scheduling problem, produces hourly schedules over a period of several days.

Modern energy management systems often include unit commitment and, if appropriate, short-term hydro scheduling programs. These programs are run, at a minimum, daily to schedule the generating units of the systems. Differences between actual and forecasted loads, hydro inflows and unit availability will require that the implemented schedules differ from the ones generated by computer programs. Large errors between forecasted and actual data will often require that the unit commitment and hydro scheduling programs be rerun several times during a day. This paper will be mainly concerned with the shorter term aspects of operations scheduling. Methods for unit commitment and hydro scheduling will be described and in extensions to consider fuel constraints, losses, and transmission constraints will also be described. The operations scheduling methods that have been developed into production programs and which are based on optimization methods.

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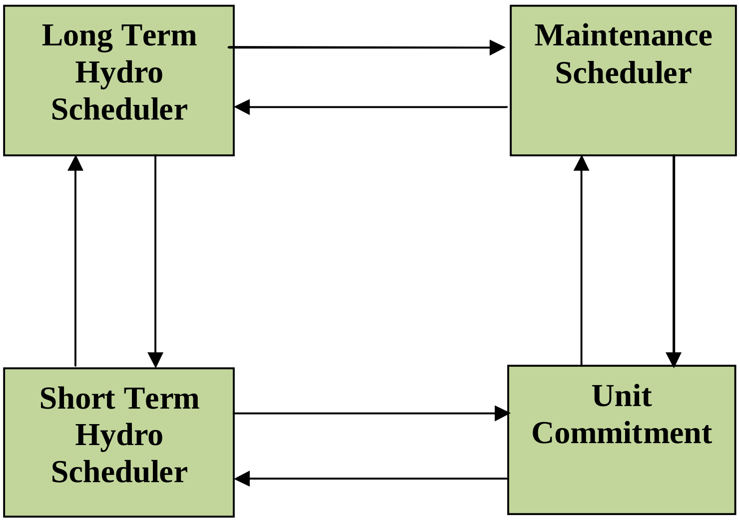

Fig 2.1. The typical hierarchy for overall operation of scheduling problem.

III. FORMULATION OF UNIT COMMITMENT

The objective of the UC problem is to minimize the total operating costs subjected to a set of system and unit constraints over the scheduling horizon. It is assumed that the production cost, *PCi* for unit '*i*' at any given time interval is a quadratic function of the generator power output, *pi*.

$$PC_i = a_i + b_i \rho_i + c_i \rho_i^2 \tag{1}$$

Where *ai, bi, ci* are the unit cost coefficients. The generator start-up cost depends on the time the unit has been switched off prior to the start up, *Toff*. The start-up cost *SCi* at any given time is assumed to be an exponential cost curve.

$$SC_i = \sigma_i + \delta_i\{1 - e^{\left(\frac{-T_{off,i}}{\tau_i}\right)}\} \tag{2}$$

Where σ_i is the hot start-up cost, δi the cold start-up cost and τi is the cooling time constant.
The total operating costs, *OCT* for the scheduling period *T* is the sum of the production costs and the start-up costs.

$$OC_T = \sum_{t=1}^{T}\sum_{i=1}^{N} PC_{i,t}U_{i,t} + SC_{i,t}(1 - U_{i,t-1})U_{i,t} \tag{3}$$

Where *Ui,t* is the binary variable to indicate the on/off state of the unit i at time *t*. *Ui,t* =1 if unit i is committed at time *t*, otherwise *Ui,t*=0.
The overall objective is to minimize *OCT* subject to a number of system and unit constraints. All the generators are assumed to be connected to the same bus supplying the total system demand. Therefore, the networks constraints are studied above are as follows briefly.

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3.1 Power Balance Constraint

The total generated power at each hour must be equal to the Load of the corresponding hour, *Dt.*

$$\sum_{i=1}^{N} p_{i,t} U_{i,t} = P_{D_t} \tag{4}$$

3.2 Power Generation Limits

The generation of the unit is under its minimum and maximum limit

$$p_i^{min} \leq p_{i.t} \leq p_i^{max} \tag{5}$$

3.3 Minimum Up Time

This constraint signifies the minimum time for which a committed unit should be turned off and removed from online.

$$\mathbf{T_{i,t}^{on} \geq MUT_i} \tag{6}$$

3.4 Minimum Down Time

This constraint signifies the minimum time for which a de-committed unit should be turned on and brought on-line.

$$\mathbf{T_{i,t}^{off} \geq MUT_i} \tag{7}$$

3.5 Spinning Reserve Constraints

Spinning reserve is the term used to describe the total amount of generation available from all the units synchronized on the system minus the present load plus losses being incurred. Spinning reserve must be carried so that the loss of one or more units does not cause too far a drop in system frequency

$$\sum_{i=1}^{N} p^{\max}{}_{i,t} U_{i,t} \geq P_{D_t} + R_t$$
(8).

IV.UNIT COMMITMENT ALGORITHM

- **i)** Make the required combination of n no of generators,
  Combination = 2n-1
- **ii)** Select the feasible combination according to the given load.
- **iii)** Calculate the combination having least production cost.
- **iv)** Compute total cost, and do for all states.
- **v)** Save lowest cost strategies.
- **vi)** Trace optimal schedule

The flow chart of unit commitment is studied as under

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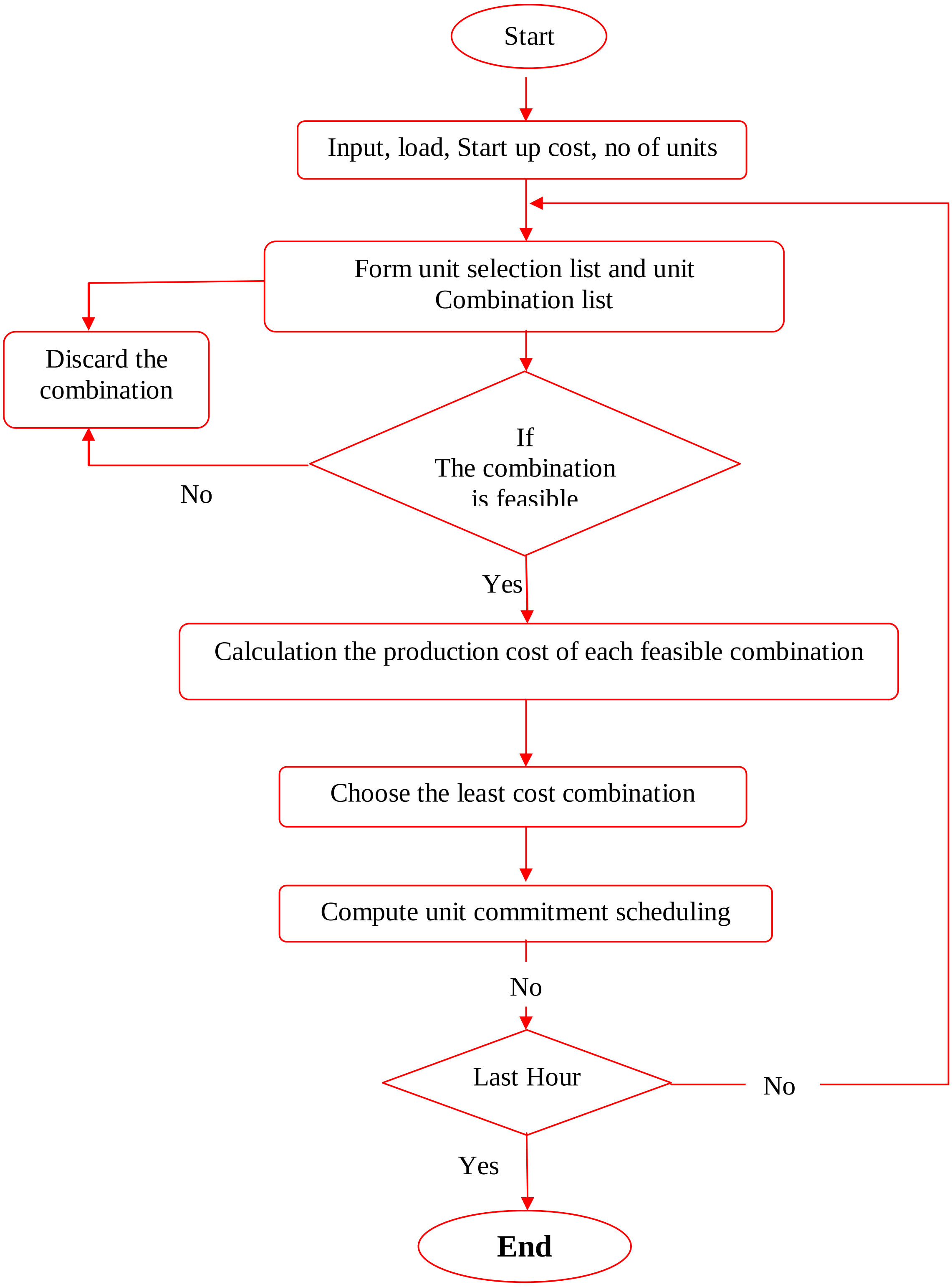

Figure 4.1: Flow chart to solve Unit Commitment problem

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V. RESULT AND DISCUSSION

In this paper the committed generators are designated with "1" and non-committed generators are designated with "0".For each hour, program finds the potentially feasible states. Potentially feasible states are the states where demand (and reserve) can be supplied by the committed generators. If there are no potentially feasible states, program displays the error message and terminates. For each potentially feasible state, program takes all feasible states from the previous hour and checks if the transition to the current state (in current hour) is possible. If it is not possible, the corresponding transition (start-up) cost is set to Inf. However, if the transition is possible, calculated is the transition cost. Production for the current hour is calculated based on demand taking into account production at previous hour (ramp-up and down constraints). Finally, total cost is the sum of the transition cost, production cost, and the total cost at the state in previous hour. This procedure is repeated for all the states in previous hour. Total costs are then sorted and MN of them are saved (this is enhancement comparing to the classical dynamic program where only 1 previous state is saved). If the transition to a state in current hour is not possible from any of the states in previous hour, then current state is regarded as infeasible and is not considered anymore. If all the states in an hour are infeasible, program displays the error message and terminates.
The results obtained for the system using dynamic programming are summarized below in Table. I & II.

Table I

State No	MW min	MW max	Units
1	0.0	0.0	0 0 0 0
2	20.0	60.0	0 0 0 1
3	25.0	80.0	1 0 0 0
4	45.0	140.0	1 0 0 1
5	65.0	250.0	0 1 0 0
6	75.0	300.0	0 0 1 0
7	80.0	310.0	0 1 0 1
8	85.0	330.0	1 1 0 0
9	95.0	360.0	0 0 1 1
10	100.0	380.0	1 0 1 0
11	105.0	390.0	1 1 0 1
12	120.0	440.0	1 0 1 1
13	135.0	550.0	0 1 1 0
14	155.0	610.0	0 1 1 1
15	160.0	630.0	1 1 1 0
16	180.0	690.0	1 1 1 1

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Table II

Hour	Demand	Total Gen.	Min. MW	Max MW	Prod. Cost	Function Cost	State	Units ON/OFF
0	-	-	135	550	0	0	13	0 1 1 0
1	450	450	135	550	9208	9208	13	0 1 1 0
2	530	530	135	550	10648	19857	13	0 1 1 0
3	600	600	135	610	12450	32302	13	0 1 1 1
4	540	540	135	550	10828	43135	13	0 1 1 0
5	400	400	135	550	8308	51444	13	0 1 1 0
6	280	280	135	550	6192	57635	13	0 1 1 0
7	290	290	135	550	6366	64002	13	0 1 1 0
8	500	500	135	550	10108	74110	13	0 1 1 0

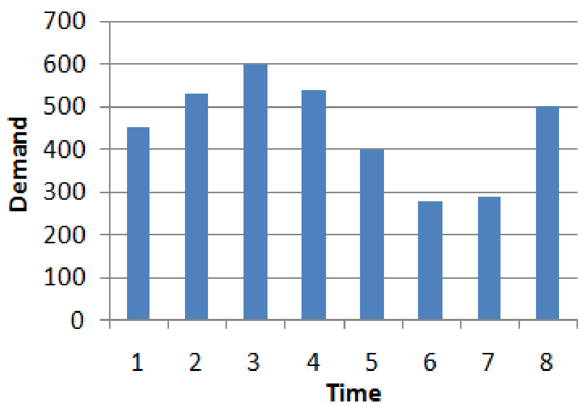

Figure 5.1 : Graph Between Demand of power and Time

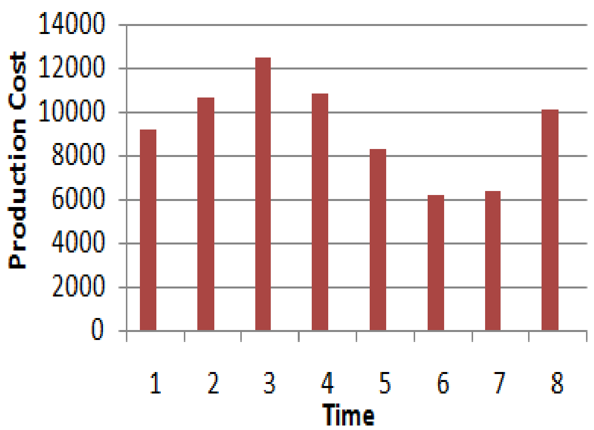

Figure 5.2 : Graph Between Production Cost and Time

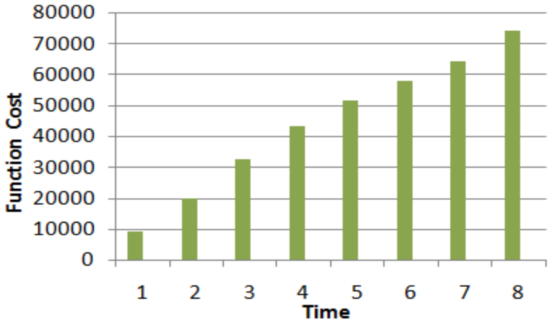

Figure 5.3 : Graph Between Function Cost and Time

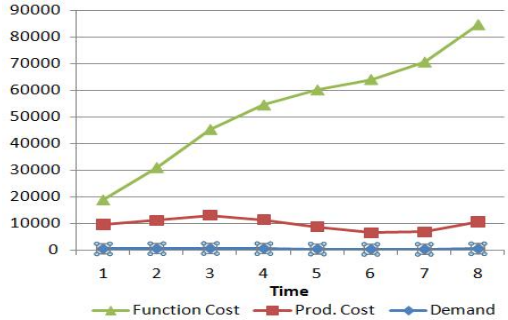

Figure 5.4 : Graph Between Production Cost, Function Cost, Demand and Time

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VI.CONCLUSION

It is recognized that the optimal unit commitment and economic load dispatch of power system results in a great saving for electric utilities. Unit Commitment is the problem of determining the schedule of generating units subject to device and operating constraints. The formulation of unit commitment has been discussed and the solution is obtained by dynamic programming method. The effectiveness of this algorithm has been tested on systems and analyses the behaviour of demand, production cost and function cost of the system with respect to time. It is found that the result obtained for the unit commitment and economic load dispatch using dynamic programming is minimum.

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BIOGRAPHY

Gaurav Belongs to Bihar Received his Bachelor of Technology degree from Allahabad Agriculture Deemed University, Allahabad in 2008. He is pursuing his M.Tech in Electrical Engg. (Power System) from SHIATS, Allahabad, UP-India.

Dr. Jyoti Shrivastava has done her graduation in Electrical Engineering and her post graduation in Design of Heavy Electrical Equipments. At present she is serving as an Senior Assistant Professor in Electrical Engineering department at college of Engineering and Technology, SHIATS, Allahabad, India. She has several international and National papers to her credit. Her field of interest and research are Power system control and operation, power quality improvement and condition monitoring of heavy electrical equipments. Her research aims to increase Transmission & Distribution system capacity and enhancing system reliability.