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Dynamic Programming Model based on Cost Minimization algorithms for Thermal Generating Units

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Abstract: Electricity companies normally run various units and they need to be committed because electrical energy cannot be stored in a wide-scale systems and load demand is a random variable process fluctuating with the time of the day and the day of the week. This problem generates a term called "Unit Commitment". DP is one of the advanced techniques to solve the problem of unit commitment. It reduces the dimensionality of the combination and saves time, memory for the computation. It is the most refined algorithm and a powerful tool to solve various optimization problems. In this paper, a DP model is designed for thermal generating units which includes operating cost as the most imperative parameter to optimize. A chunk of unit output ranges is extracted and optimized operating cost is achieved corresponding to various load demands. Load is increased in small step sizes and no. of unit combinations to be derived for particular plant output is reduced in significant manner. A lot of computation time is saved while doing simulation as compared to enumeration technique. Simulation studies reflects different combination units against different load demands and operating cost is minimized for the total loads.

Keywords: Unit Commitment (UC), Dynamic Programming(DP), Operating Cost (OC)

Nomenclature

N	Number of units
Pd	Power Demand
PG_{max}	Maximum limit of Unit
PG_{min}	Minimum Limit of Unit
PG	Power Generation

1. INTRODUCTION

UNIT commitment (UC) problem involves scheduling the on/off states of generating units, which minimize the operating cost, start-up cost and shut-down cost for a given horizon under various operating constraints. In addition to fulfill a large number of constraints, the optimal UC should be met the forecasted load demand calculated in advance, plus the spinning reserve requirement at every time interval such that the total cost is minimum[1]. Unit commitment is a mixed-integer nonlinear optimization problem. It involves determining the economical operation schedule subject to all constraints. However, this problem has integer and continuous variables and moreover has many constraints. It is difficult to determine the economical operation schedule for that reason. The exact optimal solution can be obtained by complete enumeration which cannot be applied to realistic power systems due to its computational burdens. Adequate operating reserve is required in an electric power system to maintain a desired level of reliability through a given period of time. The traditional unit commitment is one of difficult scheduling problems for minimizing operation cost of units while satisfying the constraints on generators and system characteristics. However, in recent years, power systems become deregulated and competitive so that the power system operation requires the problem reformulation that reflects the changes under new environment. So attempts are being continuously made to solve this problem by reliable iterative and heuristic methods. A number of such methods has been developed so far such as [2]:

- Dynamic Programming
- Integer Programming
- Lagrange Relaxation
- Genetic Algorithm
- Neural Networks
- Simulated Annealing
- Evolutionary Programming
- Particle Swarm Optimization

I. Load Cycle of Unit Commitment

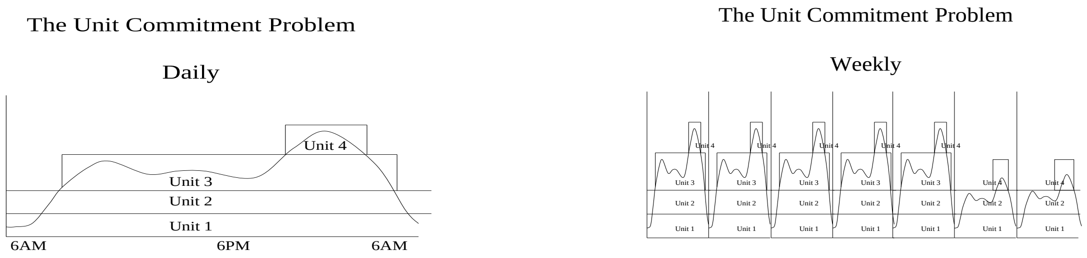


Fig 1.Load Cycle of 24 hrs and weekly Unit Commitment Schedule of four units **[3]**

II. Literature Background

Dynamic programming is a powerful mathematical tool that utilizes the principle of optimality to solve optimization problems that can be characterized by sequential decision processes. It was first introduced by Dr. Richard Bellman in the late 1950, who described the way of solving problems where you need to find the best decisions one after another. The word "programming" in "dynamic programming" is a synonym for optimization and is meant as “planning or a tabular method”. It is basically a stage wise search method of optimization problems whose solutions may be viewed as the result of a sequence of decisions. Dynamic programming method which is based on priority list method is flexible. This method has many advantages such as its ability to maintain solution feasibility. Nevertheless, this method has dimensional problem with a large power system because the problem size increases rapidly with the number of generating units to be committed, which results in an unacceptable solution time. This algorithm would consistently evaluate a large number of possible decisions in terms of minimizing the overall cost in a multistage scheduling problem. In its fundamental form, the dynamic programming algorithm for unit commitment problem examines every possible state in every interval. Some of these states are rejected instantly because they are found infeasible. But even, for an average size utility, a large number of feasible states will exist and the requirement of execution time will stretch the capability of even the largest computers [4].

Dynamic programming has many advantages over the enumeration scheme, the chief advantage being a reduction in the dimensionality of the problem. Suppose we have four units in a system and any combination of them could serve the (single) load. There would be a maximum of $2^4 - 1 = 15$ combinations to test. However, if a strict priority order is imposed, there are only four combinations to try [5]:
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

The imposition of a priority list arranged in order of the full-load average cost rate would result in a theoretically correct dispatch and commitment only if [6]:
1. No load costs are zero.
2. Unit input-output characteristics are linear between zero output and full load.
3. There are no other restrictions.
4. Start-up costs are a fixed amount.

III. Theoretical Background

In dynamic programming based unit commitment algorithms, for each time interval (usually an hour), different combinations of units, which render feasible solutions to the scheduling problem, are considered. At each stage, economic dispatch is performed on every feasible unit combination to calculate its generation at equal fuel incremental costs. Taking into account transitional costs associated with the units' startup and shutdown, the algorithm could proceed in a forward direction to cover the entire scheduling horizon. The optimal schedule is obtained by tracing the path linking the successive decisions that rendered the least total cumulative cost. Since transitional costs are time dependent, forward dynamic programming must be used [7].
The dynamic programming (DP) method consists in implicitly enumerating feasible schedule alternatives and comparing them in terms of operating costs. Thus DP has many advantages over the enumeration method, such as reduction in the dimensionality of the problem. There are two dynamic programming algorithms [6,7]:

- Forward dynamic programming
- Backward dynamic programming

In Forward DP approach one could set up the algorithm to run forward in time from the initial hour to the final hour. Conversely, in Backward DP approach, one could set up a dynamic-programming algorithm to run backward in time starting from the final hour to be studied, back to the initial hour. The advantages of the forward approach are:
- Generally, the initial state and conditions are known.
- The start - up cost of a unit is a function of the time.

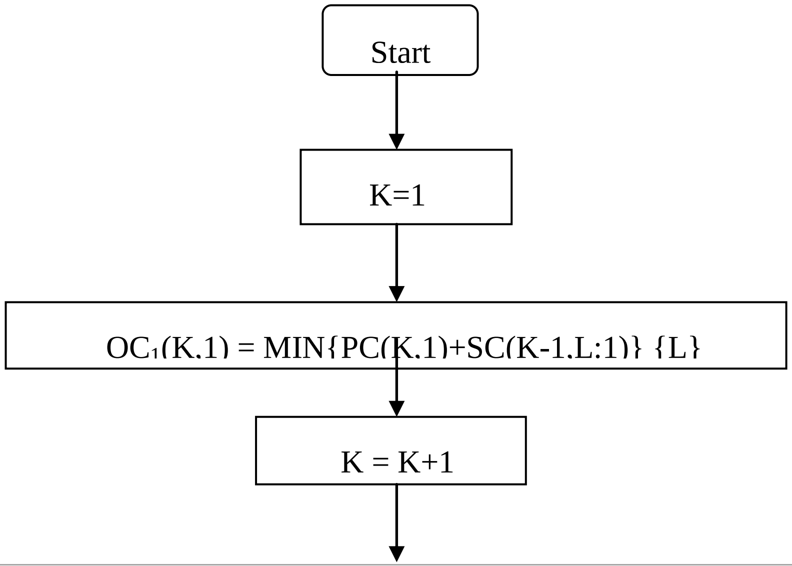
Thus the forward approach is more suitable since the previous history of the unit can be computed at each stage [8].

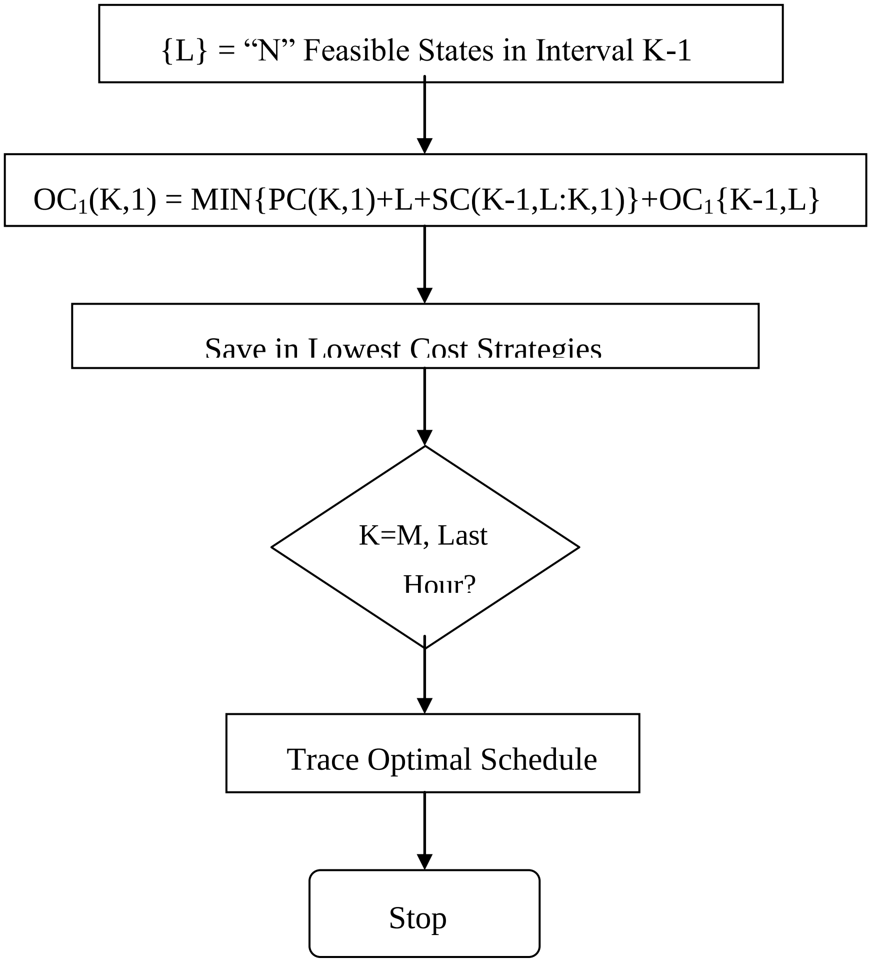
IV. Formulation of Optimal Operation

General working methodology for achieving solution using DP approach is given as [9]:

Split into Subproblems – The main problem is divided into a number of smaller, similar subproblems. The solution to main problem is stated in terms of the solution for the smaller subproblems.
Table Construction for Storage - The fundamental idea of dynamic programming is to avoid calculating the same stuff twice and usually a table of known results of subproblems is constructed for the purpose. Dynamic programming thus takes advantage of the duplication and arranges to solve each subproblem only once, saving the solution in table for later use. The key to competence of a dynamic programming algorithm is that once it computes the solution to a constrained version of the problem, it stores that solution in a table until the solution is no longer needed by any future computation. The initial solution is trivial. This tells us that we trade space for time to avoid repeating the computation of a subproblem.Combining using Bottom-up means - Combining solutions of smallest subproblems obtain the solutions to subproblems of increasing size. The process is continued until we arrive at the solution of the original problem.

Flow Chart for Computer Simulation





V. Experimental Analysis and Simulation Results

A. Assumptions

- A state consists of an array of units with defined units operating and the off-line.
- There are no costs for shutting down a unit.
- The start-up cost of a unit is independent of the time it has been off-line (i.e., it is a fixed amount).
- There is a strict priority order, and in each interval a defined minimum amount of capacity must be operating.
- All the losses are neglected

B. Parameter setup

Operating cost equations for Units(U1,U2,U3,U4) in Rs/hr:

$C_i(P_{Gi)} = 1/2\, P_{Gi}^2+26P_{Gi}$ Rs/Hour(U1)…………………………..(1)

$C_i(P_{Gi)} = 1.5/2a_i\, P_{Gi}^2+28P_{Gi}$ Rs/Hour(U2)………………………(2)

$C_i(P_{Gi)} = 2/2a_i\, P_{Gi}^2+30P_{Gi}$ Rs/Hour(U3)…………………………(3)

$C_i(P_{Gi)} = 2.5/2a_i\, P_{Gi}^2+32P_{Gi}$ Rs/Hour(U4)……………………….(4)

N=4

Pd=40

Pgmin=[0 0 0 0]

Pgmax=[25 25 25 25]

C. Experimental Values

U1	U2	U3	U4
0	0	0	0
1	0	0	0
0	1	0	0
1	1	0	0
0	0	1	0
1	0	1	0
0	1	1	0
1	1	1	0
0	0	0	1
1	0	0	1
0	1	0	1
1	1	0	1
0	0	1	1
1	0	1	1
0	1	1	1
1	1	1	1

Table 1.Commited Schedule combinations of units
0-OFF,1-ON,U1-Unit 1,U2-Unit 2,U3-Unit 3,U4-Unit 4

Table.2 Experimental Variation of Operating Cost with Load demand and distribution of loads between generating units

U1	U2	U3	U4	Cost	Plantoutput(MW)
0	1	0	0	28.75	1
2	0	0	0	54	2
3	0	0	0	82.5	3
3	1	0	0	111.25	4
4	1	0	0	140.75	5
5	2	1	0	232.5	8
6	3	1	0	295.75	10
7	3	2	1	394.5	13
8	4	2	1	462.25	15
10	5	2	1	566	18
10	5	3	2	636.75	20
12	6	4	2	784	24
12	7	4	2	821.75	25
14	5	8	3	1016.3	30
18	10	7	5	1435.3	40

In table 2.,optimized value of OC is estimated under different load demands with subjected to optimium load distribution between four units.

D. Test Result

For load demand of 40 MW,OC comes out to be 1435.3 after so many iterations and load sharing happen to be U1-18,U2-10,U3-7,U4-5.Unit 1 shared the max load for minimizing OC and Unit 4 shared minimum load.

- *Graphical representation of Parameters*

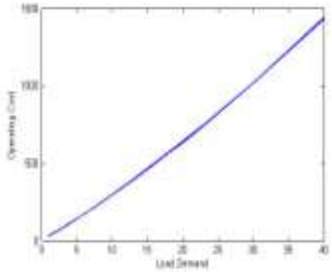


Fig 3.Variation of Operating Cost(OC) vs Plant output

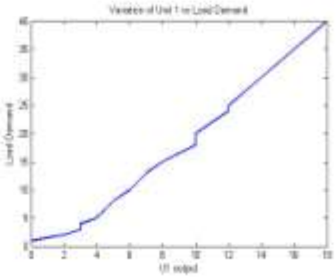
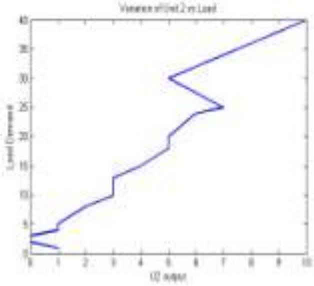
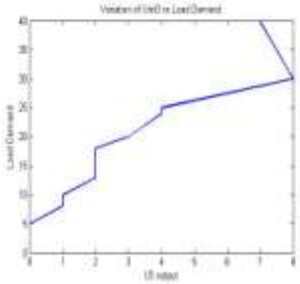


Fig 4.Variation of U1 output vs Load demand

In Fig.3,OC tends to vary linearly as the load demand increases. In Fig.4,U1 tends to vary non-linearly upto load demand of 25 MW and the increases linearly for minimum OC.





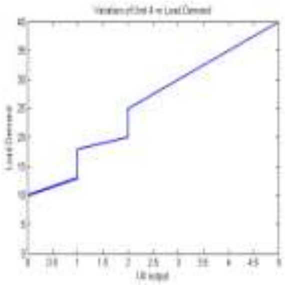


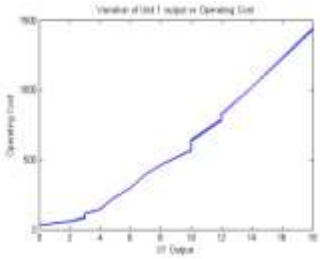
Fig 5.Variation of U2 output vs Load demand

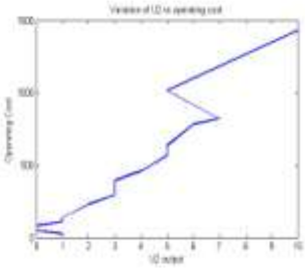
Fig 6.Variation of U3 output vs Load demand

Fig 7.Variation of U4 output vs Load demand

In Fig.5,U2 tends to vary non-linearly upto load demand of 30 MW and the increases linearly for minimum. In Fig.6,U3 tends to vary non-linearly upto load demand of 22 MWand reached its maximum sharing at 30 MW and then decreases. In Fig.7,U4 tends to vary non-linearly from online load demand of 10 MW upto load demand of 40 MW

- Variation of Unit output with OC





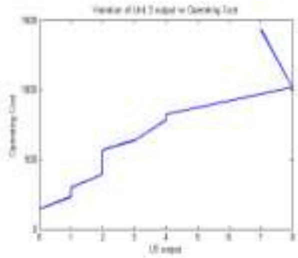


Fig 8.Variation of U1 output vs OC

Fig 9.Variation of U2 output vs OC

Fig 10.Variation of U3 output vs OC

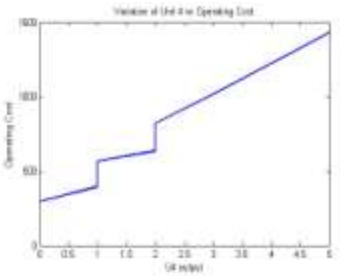


Fig 11.Variation of U4 output vs OC

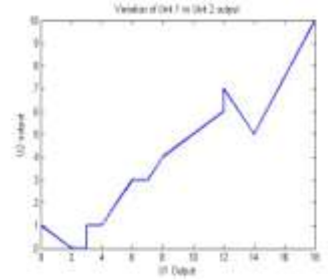


Fig 11.Variation of U1 output vs U2 output

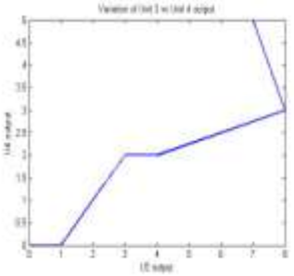


Fig 12.Variation of U3 output vs U4 output

CONCLUSION

In this paper, the optimized value of load sharing among 4 units and minimum OC is extracted using DP.A simple programming model is prepared for the computer simulation using MATLAB.Load sharing at different load demand is reflected in simulation studies with the computation of optimized OC value. This model can be extended to n no. of units and at different load demands. With small step size of load demand,more accuracy can be observed although computation time and memory are involved. Future work incorporates hybrid algorithms in this technique.

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