

# Dynamic Programming Based Unit Commitment Methodology

C.Nagarajan S.Madhusudan

Professor&Head, Department of EEE, Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

PG Scholar, Department of EEE, Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

**ABSTRACT:** In dynamic programming-based power scheduling algorithms, thousands of hourly economic dispatches must be performed to consider every possible unit combination over all the stages of the optimization interval. If the unit commitment problem is constrained to observe a minimum system spinning reserve and an economic dispatch of a combination of units does not comply with this requirement, necessary and sufficient conditions have been established to guarantee that the dispatch of these units will meet the constraint. However, these conditions can only be checked for feasibility after a dispatch is performed. In this paper, we present necessary and sufficient conditions for the feasibility of unit combinations that can be checked off-line. That is, before the start of the unit commitment algorithm, and thus before any economic dispatches are performed, thereby rendering a very efficient unit scheduling algorithm in terms of computer memory and execution time. Moreover, these feasibility conditions are independent of the problem formulation and thus can easily be applied to other unit commitment algorithms. Examples are provided to illustrate the efficiency attainable by the implementation of these conditions.

## I. INTRODUCTION

Unit commitment is one of the decision-making levels in the hierarchy of power system operations management. The optimization problem is posed over time horizons that vary from 24 hours to one week. The objective is to determine the set of generating units, among those owned by a utility that should be connected to the power grid on an hourly basis to supply the demand at minimum operating cost over the scheduling horizon. This optimization problem is constrained by the unit characteristics and other operation limitations. Since the objective of the unit commitment is to determine a cyclic schedule that will meet the system constraints at minimum cost, the economic operation of a power system may be formulated as a dynamic optimization problem. The problem is dynamic in the sense that decisions to startup and/or shutdown units at any stage cannot be made without considering the states of the system at some other stages.

Generally, unit commitment is a computationally intensive algorithm, since thousands of hourly economic dispatches must be performed to consider every possible unit combination over all the stages in the optimization interval. Therefore, any effort toward the elimination of any unfeasible unit combinations performed off-line, that is before the start of the commitment algorithm and thus before any dispatches are considered, will handsomely the commitment problem is constrained to observe a minimum system spinning reserve and a dispatch of a unit combination does not comply with the requirement, the problem may still be solvable by the re-dispatch of these units, as long as the conditions prescribed by W.G. Wood<sup>10</sup> are satisfied. However, these feasibility conditions can only be checked after a dispatch has been performed and, as a consequence, many dispatches that turn out to be unfeasible are needlessly computed in the process

### Scope

In this paper we present the off-line conditions that a unit combination must satisfy to not only meet the minimum system spinning reserve constraint, but also the power balance constraint, the unit capacity limits, and all the other pertinent constraints as well. These conditions are shown to be necessary. We further show that these conditions turn out to be both necessary and sufficient when the spinning reserve constraint is to be met by re-dispatch. Clearly then, when these conditions are not fulfilled by a unit combination, that combination can be discarded as unfeasible by the scheduling algorithm, thereby reducing drastically the number of decisions to be considered in the solution space.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

The net result is a very efficient commitment algorithm as illustrated by examples. Furthermore, these feasibility conditions are independent of the problem formulation and thus can easily be implemented in other unit commitment algorithms.

## II. OBJECTIVES OF STUDY

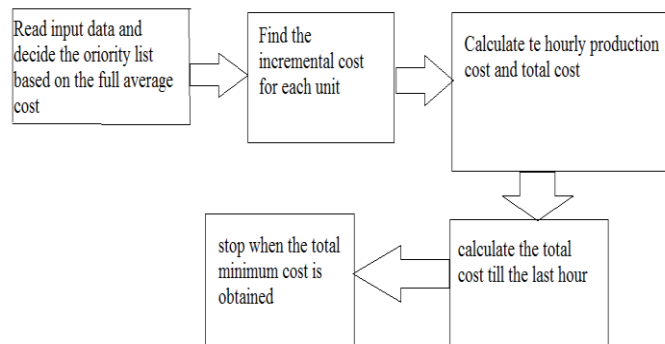
### Existing System

The Lagrangian Relaxation Method has been successfully applied in unit commitment scheduling of power systems.. This can then be done through creation of the relaxed problem by including the constraints into the objective function. By multiplying the constraints with the Lagrange multipliers,  $\lambda$  and  $\mu$ , respectively, and including them in the objective function; the primal problem is transformed into an unconstrained optimization problem, called the relaxed problem. Two basic models, one for the power production problem and one for the heat production problem, are used. The total system cost is minimized and the model includes start-up costs. For the heat production problem heat storage is included. Minimum operation and shut-down times are also considered

### Disadvantages

- Due to Dual Solution Optimization is difficult
- Oscillation occurrences are non Removed
- Quality of Feasible Solution is not satisfactory

### Block diagram of dynamic programming method



Block diagram of dynamic programming method

Generation operators, transmission owners, and load serving entities must

Provide accurate and current information to those performing the planning and dispatch functions. Those performing planning and dispatch must provide accurate and current dispatch instructions to generation operators, transmission operators and load serving entities.

Inadequate or incomplete communications affects the level of costs of the economic dispatch.

- Software tools for dispatch and information

Reliable and secure computer software is essential for rapidly responding to system changes to maintain power system reliability, while selecting the lowest cost generators to dispatch. Obsolete software affects the level of costs achieved by the economic dispatch.

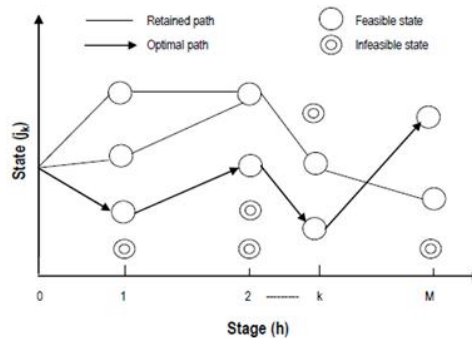
- Coordination of dispatch across regions

Where there are multiple, independently performed, dispatches in a region, the effectiveness of coordination agreements and their implementation affect the level of costs of the economic dispatch.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015



dynamic programming optimization method

Therefore, any effort toward the elimination of infeasible unit combinations, or states, performed offline, that is before the start of the commitment algorithm and thus before any dispatched are considered, will handsomely pay off in the efficient use of computer resources. In this paper, closed-form dispatch strategies and state feasibility conditions are established to eliminate infeasible unit combinations thus rendering a very efficient commitment algorithm. The state transfer or recursion function required to solve this optimization problem using dynamic programming is given by

## Dynamic Economic Dispatch

Economic dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, while serving power to the public in a robust and reliable manner. The Economic Dispatch Problem is solved by specialized computer software which should honor the operational and system constraints of the available resources and corresponding transmission capabilities. This is defined as "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities

## Concept of Economic Dispatch

The Economic Dispatch is the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities. Most electric power systems dispatch their own generating units and their own purchased power in a way that may be said to meet this definition

There are two fundamental components to economic dispatch:

Planning for Tomorrow's Dispatch Scheduling generating units for each hour of the next day's dispatch

- Based on forecast load for the next day
- Select generating units to be running and available for dispatch the next day (operating day)
- Recognize each generating unit's operating limit, including its:
  - Ramp rate (how quickly the generator's output can be changed)
  - Maximum and minimum generation levels
  - Minimum amount of time the generator must run
  - Minimum amount of time the generator must stay off once turned off

Recognize generating unit characteristics, including:

- Cost of generating,
- Its variable operating costs (fuel and non-fuel),
- Variable cost of environmental compliance,
- Start-up costs,

Next day scheduling is typically performed by a generation group or an independent market operator

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

## Reliability Assessment

- Analyze forecasted load and transmission conditions in the area
- To ensure that scheduled generation dispatch can meet load reliably.
- If the scheduled dispatch is not feasible within the limits of the Transmission system, revise it.
- This reliability assessment is typically performed by a transmission operations group

## Dispatching the Power System Today

- Monitor load, generation and interchange (imports/exports) to ensure balance of supply and load
- Monitor and maintain system frequency at 60 Hz during dispatch according to NERC standards, using Automatic Generation Control (AGC) to change generation dispatch as needed
- Monitor hourly dispatch schedules to ensure that dispatch for the next hour will be in balance
- Monitor flows on transmission system
- Keep transmission flows within reliability limits
- Keep voltage levels within reliability ranges
- Take corrective action, when needed, by:
  - Limiting new power flow schedules
  - Curtailing existing power flow schedules
  - Changing the dispatch
  - Shedding load

This monitoring is typically performed by the transmission operator

- Area Factors Limiting the Effectiveness of Dispatch in Minimizing Customer Costs Geographic area included the size of the geographic region over which the dispatch occurs affects the level of costs: that is, which generation resources and which transmission facilities are considered in planning and economic dispatch.
  - Generation resources included
  - Which generation resources in the area are included in the planning and economic dispatch, and whether they are included in the same manner,
  - Affects the level of costs.
  - Transmission facilities included

What transmission facilities are included in the planning and economic dispatch, and how the reliability security limits of the transmission facilities are incorporated into the economic dispatch?

## III. PROBLEM FORMULATION

To mathematically state the constrained unit commitment problem, we need the following definitions

### Definition 1

Let the time horizon be divided into  $M$  hourly stages.

Then the set of all stages is  $K = \{0, 1, \text{ and } 2... k... M\}$ . Assume that a utility has  $N$  generating units.

Then the set of all units, or the universal set, is  $I = \{1, 2, \dots, i, \dots, N\}$ . Since a generating unit may be on or off at stage  $k$ , let the status of unit  $i$ , or commitment variable, be defined by the binary set  $d_i k = \{0, 1\}$ .

At any stage  $k$ , the set of all units may be divided into two mutually exclusive sets:

$ION \in \{i \in I \mid d_i k = 1\}$ , the set of units on-line at stage  $k$ , and

$IOFF \in \{i \in I \mid d_i k = 0\}$ , the set of units off-line at stage  $k$ , that is, satisfying  $ION \cup IOFF = I$  and  $ION \cap IOFF = \emptyset$ .

Since the status of any unit is described by a digit in the binary set, then the set of all unit combinations at stage  $k$  is given by  $J_k = \{1, \dots, j_k, \dots, 2^N - 1\}$ .

Then, the set of all possible unit combinations over the entire time horizon  $M$  is defined as  $J = \{J_1, J_2, \dots, J_k, \dots, J_M\}$ .

Given the status  $d_i k$  of every unit  $i \in I$  at any stage  $k$ , the unit combination number at that stage may readily be obtained by the binary to decimal transformation

$ik_2 1 2 1 k \in K, j_k \in J_k$

If  $p_{i k}$  is the power allocated to each unit  $i$  in any unit combination  $j_k$ , then the production cost for this combination is  $(p_{i k})_{d_i k} N I C_i = j_k PCOST(\sum=1 \text{ where } C_i(.)$  is the production cost  $[\$/h]$  of unit  $i$  at stage  $k$ .

The transitional cost associated with the start-up and shut-down of each unit  $i$  in unit combination  $j_k$  relative to unit combination at previous stage  $j_{k-1}$  is

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Where  $TC_i(\cdot)$  is the transitional cost (start-up or shut down) [\$/h] of unit  $i$  from stage  $k-1$  to  $k$ , and  $t_{i, k-1}$  is the number of hours that unit  $i$  has been on or off up to stage  $k-1$ . Then the optimization function of the unit commitment problem can be stated as

$$TCOST(j_{k-1}, j_k) = \sum_{i=1}^N |d_{ik} - d_{i, k-1}| TC_i(t_{i, k-1})$$

$$PCOST(j_k) = \sum_{i=1}^N C_i(p_{ik}) d_{ik}$$

any constraints. Of interest here are the following

1. Power Balance Constraint.  $i$  at stage

$$PG(j_k) = PD_k \quad [MW] \quad \forall j, \forall k$$

where

$$PG(j_k) = \sum_{i=1}^N p_{ik} d_{ik}$$

on  $j$  at stage  $k$ , and  $p_{ik}$  is the generation allocated to unit  $i$  in that combination, and  $PD_k$  is the system demand plus transmission losses at any given stage  $k$ .  $MSR_i$  is the maximum spinning reserve for unit  $i$ ,  $MSSR$  is the minimum system spinning reserve

## IV. SIMULATION RESULT

State No.	MW min		MW max			Units	
	1	2	1	2	3	4	
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	60.0	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	

Currently processing hour: 1  
 Currently processing hour: 2  
 Currently processing hour: 3  
 Currently processing hour: 4  
 Currently processing hour: 5  
 Currently processing hour: 6  
 Currently processing hour: 7

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Currently processing hour: 8

## HOURLY RESULTS:

Hour ON/OFF	Demand	Tot.Gen	Min MW	Max MW	ST-UP Cost	Prod.Cost	F-Cost	State	Units
0	-	135	550	0	0	13	0	1 1 0	
1	450	450	135	550	0	9208	9208	13	0 1 1 0
2	530	530	135	550	0	10648	19857	13	0 1 1 0
3	600	600	155	610	0	12450	32307	14	0 1 1 1
4	540	540	135	550	0	10828	43135	13	0 1 1 0
5	400	400	135	550	0	8308	51444	13	0 1 1 0
6	280	280	135	550	0	6192	57635	13	0 1 1 0
7	290	290	135	550	0	6366	64002	13	0 1 1 0
8	500	500	135	550	0	10108	74110	13	0 1 1 0

Elapsed time: 0.1380 sec.

## V. CONCLUSIONS

In this paper, we have derived the mathematical formulation for the unit commitment problem in power systems using dynamic programming techniques. Two conditions were presented, which can be checked offline to eliminate unit combinations that are guaranteed a priori to be infeasible combinations since they are both necessary for a successful solution. Furthermore, we have presented a theorem with necessary and sufficient conditions for unit feasibility that require re dispatch to meet the system spinning reserve requirement. Detailed examples on a 20-unit system showed specifically how the computational efficiency was attained. Therefore, when these conditions are checked as prescribed, they will always render very efficient solutions to unit commitment algorithms

## REFERENCES

1. Padhy, N.P., Unit Commitment- A Bibliography Survey, IEEE Trans. Power Systems, Vol. 19, no. 2, pp. 1196-1205, May 2004.
2. Hobbs, B.F and et al., The Next Generation of Electric Power Unit Commitment Models, Kluwer: Academic Publishers, 2001.
3. C.Nagarajan and M.Madheswaran - 'Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis"- Springer, Electrical Engineering, Vol.93, March 2011.
4. C.Nagarajan and M.Madheswaran, Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques", Taylor & Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, 2011.
5. C.Nagarajan and M.Madheswaran - 'Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter' - Journal of ELECTRICAL ENGINEERING, Vol.63 (6), pp.365-372, Dec.2012.
6. C.Nagarajan and M.Madheswaran - 'Analysis and Implementation of LLC-T Series Parallel Resonant Converter with Fuzzy controller'- International Journal of Engineering Science and Technology (IJEST), Applied Power Electronics and Intelligent Motion Control. Vol.2 (10), pp 35-43, December 2010
7. C.Nagarajan and M.Madheswaran - 'Performance Estimation of LCL-T Resonant Converter with Fuzzy / PID Controller' - International Journal of Computer and Electronic Engineering (IJCEE), Vol.2 (3), pp.534-542, June 2010
8. C. Nagarajan, M.Madheswaran and D.Ramasubramanian- 'Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model'- Acta Electrotechnica et Informatica Journal , Vol.13 (2), pp.18-31, April-June.2013
9. C.Nagarajan and M.Madheswaran - 'DSP Based Fuzzy Controller for Series Parallel Resonant converter' - Springer, Frontiers of Electrical and Electronic Engineering, Vol. 7(4), pp. 438-446, Dec.12.
10. C.Nagarajan and M.Madheswaran - 'Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis'- Iranian Journal of Electrical & Electronic Engineering, Vol.8 (3), pp.259-267, September 2012.
11. Beltran, C., Unit Commitment by Augmented Lagrangian Relaxation: Testing Two Decomposition Approaches, Journal of Optimization Theory and Applications, 112(2): 295-314; Feb 2002.