INTERNATIONAL JOURNAL OF ENHANCED RESEARCH IN SCIENCE TECHNOLOGY & ENGINEERING
VOL. 1, ISSUE 2, NOV. 2012 ISSN NO: 2319-7463

A Case Study of Various Constraints Affecting Unit Commitment in Power System Planning

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ABSTRACT: In fact, the problem of Unit Commitment is a complicated decision making operation on account of various operational constraints affecting the economical scheduling of units in an electrical power system. These constraints could not be violated while determining the optimal or near optimal commitment schedule. This paper presents a detailed study of various operational constraints which directly or indirectly have a great impact on power system optimization problems. The knowledge of choosing various variables with the appropriate operational constraints is absolutely a good deal in electrical power system planning and optimization problems**.**

KEYWORDS: Electrical Power System, Unit Commitment (UC), Operational Constraints.

INTRODUCTION

One of the most important problems in electrical power system planning and optimization is Unit Commitment. It has a significant influence on secure and economic operation of power systems. The UC problems involve scheduling the on/off states of generating units, which minimizes the operating cost, start-up cost and shut-down cost for a given horizon under various operating constraints. It is the problem of determining which units and how many should operate to meet a particular load level while satisfying specified operating criteria. To reach an economic operation, some units should be considered for shutdown over a part or all of the scheduling time period.

In Power Systems, the investment is quite expensive, and the resources in running them are substantially becoming sparse of which the focus turns to optimizing the running cost of the power systems. In today's world, it becomes an extreme necessity to meet the demand as well as optimize the generation. In the UC problem, the decisions are the selection of the time for each unit to be on and/ or offline (binary variables) as well as the unit's economic generation level (continuous variables). Unit commitment problem is a non-linear, large scale, mixed integer constrained optimization problem. The number of combinations of different variables grows exponentially for a large-scaleunit commitment problem, which makes it difficult to solve in practice. Over the past decades, many salient methods have been developed for solving the UC problems. The exact solution to the problem 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.

The corresponding author gratefully acknowledges the guidance given by Prof. R. K. Sharma (HOD, Electrical Engineering., Lovely Professional University, Punjab, India.). He also acknowledge the valuable suggestions given by Er. Ashutosh Bhadoria (Asst. Prof., Electrical Engg. at Lovely Professional University, Phagwara, India).
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UNIT COMMITMENT PROBLEM FORMULATION

The Power System Unit Commitment Problem can be stated as follows:
For an electrical utility with N generating units and given a certain price profile, it is required to determine the start up/ shut down times and the power output levels of all the generating units at each time interval t over a specified scheduling period T, so that the generators total profit is maximized , subject to the unit constraints.[1]

In the UCP under consideration, an interesting solution would be minimizing the total operating cost of the generating units with several constraints being satisfied. The major component of the operating cost, for thermal and nuclear units, is the power production cost of the committed units and this is given in a quadratic form in the equation below[2] :

$$\mathbf{Fi(P_{it}) = A_i + B_i.P_{it} + C_i.P_{it}^2} \qquad \textbf{(i)}$$

where,

$Fi(P_{it})$ is production cost of unit i at a time t (Rs/hr),
A_i, B_i and C_i are cost coefficients of unit i (Rs/MWh, Rs/h)
P_{it} is its output during hour t (MW)

The start-up cost S_{it} of unit i depends on the number of successive hours, $Toff_i$, prior to the start-up hour, t, during which it had been shut down. If SO_i is its cold start-up cost, Td_{ni} is its minimum down time (to be defined later in this section) and di and e are its start-up cost coefficients, then S_{it} is given by[5]:

$$\mathbf{S_{it} = SO_i\{1 - d_i[\exp(-Toff_i / Td_{ni})]\} + e_i} \qquad \textbf{(ii)}$$

Start-up cost is incurred only at OFF-ON transitions. Hence, if binary variable v_{it} has a 1 value only if unit i is started at hour t, then the total operational cost F_T of the system of N units over T hours is given by[8]:

$$\mathbf{F_T = \sum_{t=1}^{T} \sum_{i=1}^{N} [F_i(P_{it})u_{it} + S_{it}.V_{it}]} \qquad \textbf{(iii)}$$

where u_{it} has a 1 value if the unit i is ON in hour t, and a 0 value if it is OFF in hour t. It is to be noted that u_{it} and v_{it} are not independent, since $v_{it}=1$ iff $u_{i,t-1}= 0$ and $u_{it} = 1$.

For the minimization of $F_{T,}$ some major constraints that must be taken into account includes[4]:

- The total power output must meet the load demand plus system losses.
- There must be enough spinning reserve to cover any shortfall in generation.
- Energy constraints must he met.
- The generation of each unit must be within its minimum and maximum allowable power output range.
- The minimum up- and down-times of thermal generation units must be considered.
- Ramp rates limits for thermal generation units must not be violated.

Hence, unit commitment [7-9] is a nonlinear, non-convex, large scale, mixed integer problem to determine a start-up and shut-down schedule of generating units at minimum operating cost. In this problem, the demand and reserve requirements and the constraints of the generating units must be satisfied. It should be mentioned that solving this problem can be computationally expensive in large power systems. An improved formulation for the unit commitment problem is especially valuable for advanced and computationally demanding problems such as stochastic formulations or transmission switching. Even though the UC model was developed in an era of monopolistic producers, it remains important today, even after the deregulation of the power industry. Unit commitment problem can easily be extended to generate production schedules in a competitive market environment.

CONSTRAINTS IN UNIT COMMITMENT

Many constraints can be placed on the unit commitment problem. The list presented here is by no means exhaustive. Each individual power system, power pool, reliability council, and so forth, may impose different rules on the scheduling of units, depending on the generation makeup, load-curve characteristics, and such[5-6].

SPINNING RESERVE CONSTRAINTS

It can be defined in many ways according to:

- Wood and Wollenberg [6]: the total synchronised capacity, minus the losses and the load;
- British Electricity International [3]: "the additional output which is part-loaded generating plant is able to supply and sustain within 5 minutes. This category also includes pumped-storage plant [10] operating in the pumping mode, whose demand can be disconnected within 5 minutes
- Zhu, Jordan and Ihara [12]: "the unloaded section of synchronized that is able to respond immediately to serve load, and is fully available within ten minutes";
- Hirst and Kirby [9]: "generators online, synchronized to the grid, that can increase output immediately in response to a major outage and can reach full capacity within 10 minutes

In order to get a general definition of spinning reserve, it seems to be essential to remove the idea of time. In fact, each system has its particularities. However, in any system, there is a system operator. Therefore, this concept can be used within the proposed definition [13]:

*"**the spinning reserve is the unused capacity which can be activated on decision of the system operator and which is provided by devices which are synchronized to the network and able to affect the active power**".*

In the literature, one of the first attempts to utilize probabilistic SR determination that considers reliability of generators is made by Billinton and Chowdhury [2]. They define the system risk at time t to be R(t):

$$\mathbf{R(t) = \sum_{i} P_i(t).Q_i(t)} \qquad \textbf{(iv)}$$

Here $P_i(t)$ is the probability that the generation system is in state i at time t and $Q_i(t)$ is the probability that the system load will be equal to or greater than the generation in state i at time t. The generators can be in one of three states: up, derated (reduced capacity), or failed. Additional states are also considered such as cold reserve (state where the generator has to go through a complete start up), hot reserve (state where the generator has to go through a partial start up process which takes a shorter time), etc. With this formulation it is possible to incorporate the reliability of the generators into the SR calculation.

LOAD BALANCE CONSTRAINTS

The power balance constraint requires that the total output power of available plants be equal to demand, PD_t. The real power generated must be sufficient enough to meet the load demand and must satisfy the following factors given in [14]:

$$\sum_{J}^{N} P_J(t).U_J(t) = PD_t \quad \text{(v)}$$

Where,

PD_t = system peak demand at hour t (MW);
N = number of available generating units;
U(0,1) = uniform distribution with parameters 0 and 1;
UD(a,b) = discrete uniform distribution with parameters a and b.

THERMAL CONSTRAINTS

Thermal units usually require a crew to operate them, especially when turned on and turned off. A thermal unit can undergo only gradual temperature changes, and this translates into a time period of some hours required to bring the unit on-line. As a result of such restrictions in the operation of a thermal plant, various constraints arise, such as [15]:

a. **Minimum Uptime**: If the units have already been shut down, there will be a minimum time before they can be restarted and the constraint is given as:

$$Ton_j \geq Tup_j \quad \text{(vi)}$$

where,

Ton_j = duration for which unit j is continuously ON (in hours);
Tup_j = unit j minimum up time (in hours).

b. **Minimum down time:** once the unit is decommitted, there is a minimum time before it can be recommitted and the constraint is given as:

$$Toff_j \geq Tdown_j \quad \text{(vii)}$$

where,

$Toff_j$ = down unit i minimum down time (in hours);
$Tdown_j$ = off duration for which unit i is continuously OFF (in hours).

c. **Crew constraints:** if a plant consists of two or more units, they cannot both be turned on at the same time since there are not enough crew members to attend both units while starting up[1].

d. **Startup/Shutdown Costs:** A startup cost is incurred when a generator is put into operation. The cost is dependent on how long the unit has been inactive. While the startup cost function is nonlinear, it can be discretized into hourly periods, giving a stepwise function. Start up costs can be formulated as given in eq. (ii). Similarly, shut-down cost is incurred during shutting down generating units. In general, it is neglected from the unit commitment decision [21].

e. O&M Costs: Operation and maintenance cost is actually the labor cost of operating crews and the cost of plant maintenance. Typically, this cost depends on the amount of generating output [18].

$$OMC_i^t = nP_i^t \quad \text{(viii)}$$

GENERATION UNIT CONSTRAINTS

The power produced by each unit must be within its limits as indicated below[17]:

$$u_{i,t} P_{i,min} \leq P_{i,t} \leq u_{i,t} P_{i,max} \quad \text{(ix)}$$

where,

$P_{i,min}$ and $P_{i,max}$ are the minimum and maximum generation limits of unit i , respectively

GENERATION RAMPING CONSTRAINTS

If the ramping constraints are included, the quality of the solution will be improved but the inclusion of ramp-rate limits can significantly enlarge the state space of production simulation and when ramp-rate limits are ignored, the number of generators consecutive online/offline hours at hour t provides adequate state description for making its commitment decision at hour (t+1). When ramp-rate limits are modeled, the state description becomes inadequate. The operating range of all online units is restricted by their corresponding ramp-rate limits as follows [13]:

$$Rd_i \le P_{i,t} - P_{i,(t-1)} \le Ru_i \qquad (x)$$

where,

Rd_i and Ru_i are the ramp-down and ramp-up limits of unit i respectively.

OTHER CONSTRAINTS

In addition to system and unit constraints, there are other constraints that need to be considered in the UC decision. They are described as follows [16]:

A. **Fuel Constraints**: Due to the contracts with fuel suppliers, some power plants may have limited fuel or may need to burn a specified amount of fuel in a given time. A system in which some units have limited fuel, or else have constraints that require them to burn a specified amount of fuel in a given time, presents a most challenging unit commitment problem.
B. **Must Run Units:** Some units are given a must-run status during certain times of the year for reason of voltage support on the transmission network or for such purposes as supply of steam for uses outside the steam plant itself. The must run units include units in forward contracts, units in exercised call/put options, RMR units, nuclear power plants, some cogeneration units, and units with renewable resources such as wind-turbine units and some hydro power plants[11-15].
C. Must-off Units: Some units are required to be off-line due to maintenance schedule or forced outage. These units can be excluded from the UC decision [19,20].
D. Emission Constraints: There are some emissions like sulfur dioxide ($SO2$), nitrogen oxides (NOx), carbon dioxide ($CO2$), and mercury which are produced by fossil-fueled thermal power plants. The amount of emission depends on various factors such as the type of fuel used, level of generation output, and the efficiency of the unit. The production cost minimization may need to be compromised in order to have the generation schedule that meets the emission constraints[21,22].

CONCLUSIONS

This paper presents an approach to the unit commitment problem in an electrical power system when subjected to a variety of operational constraints. The additional constraints are easily generated and can have a significant effect on the quality of the UC formulation and the computational time required to solve it. While we study these formulations only in the context of the UC problem, it is straightforward to apply them to other scheduling problems [23].

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