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An Approach to solve Unit Commitment Problems considering Reliability as a Constraint

Bipul Kumar Talukdar[1*]
Department of Electrical Engineering
Girijananda Chowdhury Institute of Management & Technology, Azara, Guwahati, India
bipul_ee@gimt-guwahati.ac.in

Bimal Chandra Deka[2]
Department of Electrical Engineering
Assam Engineering College
Guwahati, India
deka_bimal@rediffmail.com

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Abstract— Unit commitment is an important task in power system operation and control. Depending on the system's load demand, the available generating units of the system are scheduled for operation so that optimum economy over the period is achieved. In addition to the economy, reliability of the system is also an important constraint in preparing the unit commitment schedule. In this paper, reliability concept is incorporated in unit commitment problems and the well-being framework is used for this purpose. The well-being analysis of a system provides the opportunity to consider both deterministic and probabilistic approaches and alleviates the weaknesses associated with the deterministic approach or interpreting a single risk index.

Key words—Unit commitment, well-being analysis, reliability, system health analysis, system risk analysis

I. INTRODUCTION

Unit commitment (UC) problem is problem of operational planning. The purpose of planning is to determine a schedule which tells us beforehand where and which unit to start and shut down during the operation over a pre-specified time horizon. For this one must be able to foresee the future operating condition, i.e. load demand. The problem is actually a selection of proper combination of units to be run to achieve optimum economy of operation over the whole period. The purpose of unit commitment is to gain economy but certainly the commitment must fulfill the necessary operational constraints. Unit commitment can be performed considering economic as well as reliability criterion. In the first case, the scheduling of units is done such that the overall cost of generation and operation is minimized. The objective function of such commitment problem is the overall cost minimization. But in the second case, the reliability of the system should be given more importance than overall cost. The objective function of such commitment problem is reliability maximization.

A more reliable system may not be economical. In the same way, a more economical system may not have high reliability. Therefore, it is more practical and useful to solve the unit commitment problem considering both economic and reliability criteria so that a cost effective reliable UC schedule can be obtained.

II. RELIABILITY CONSIDERATION IN UC PROBLEM

In order to meet the load demand under forced outage of a generator or its derating caused by minor effect, static reserve capacity is always provided at a generating station so that the total installed capacity exceeds the yearly peak load by a certain margin. This is a planning problem and can be studied under well-being framework.

In arriving at the unit commitment decision at any particular time, the constraint taken into account is merely the fact that the total capacity online is at least equal to the load. If under actual operation, one or more of the units were to fail perform (random outage) it may not be possible to meet the load requirements. To start a spare (stand by) thermal unit and to bring it on steam to take up the load will take several hours so that the load cannot be met for intolerably long periods of time. Therefore, to meet contingencies the capacity of units online must have a definite margin over the load requirements at all times. This margin which is known as spinning reserve ensures continuity by meeting the load demand up to a certain extent of probable loss of generation capacity.

Since the probability of unit outage increases with operating time and since a unit which is to provide the spinning reserve at a particular time has to be started several hours ahead, the problem of security of supply has to be treated in totally over a period of one day. Furthermore, the loads are never known with complete certainty. Also spinning reserve has to be provided at suitable generating stations of the system and not necessarily at every generating stations of the system. This is a complex problem which can be explained in a simplified way as follows.

A unit during its useful life span undergoes alternates periods of operation and repair. The lengths of individual operating and repair periods are random phenomenon with operating periods being much longer than repair periods. When a unit has been operating for a long time, the random phenomenon can be described by the following parameters.

Mean cycle time = T (up) + T (down)

Inverse of these times are defined as,

Failure rate (λ) = 1/T (up) (failures per year)

Repair rate (μ) = 1/T(down) (repairs per year)

Failure and repair rates are to be estimated from the past data of units by using the above equations. Sound engineering judgment must be exercised in arriving at these estimates. The failure rates are affected by preventive maintenance and the repair rates are sensitive to size, composition and skill of repair times.

If we know the failure rates (λ) and the repair rates (μ) of the units, the availability and unavailability or forced outage rate (FOR) can be calculated as follows.

Availability (A) = $\mu / (\mu + \lambda)$

Unavailability (F.O.R) = $\lambda / (\mu + \lambda)$

Once the units to be committed at a particular load level are known from purely economic considerations, the reliability consideration is implemented to the system to provide a certain degree of continuity and quality of service to the consumers. For this a deterministic criterion can be applied by taking judicial judgment by the operator. One such criterion is that the system risk probability P_r must not exceed a certain tolerable insecurity level (MTIL). MTIL for a given system is a management decision which may guided by past experience. If the value of P_r exceeds MTIL, the economic unit commitment schedule is modified by bringing in the next most economical unit as per the UC table. P_r is then recalculated and checked. The process is continued till P_r is less than or equal to MTIL.

III. IMPLEMETATION OF WELL-BEING FRAMEWORK

Both deterministic and probabilistic approaches can be used to establish spinning reserve requirements. The most common deterministic criterion relates the reserve margin to the size of the largest unit or to some percentage of the peak load. Deterministic criteria do not incorporate any explicit recognition of the actual risk and subsequently probability methods were developed to incorporate this requirement. Probabilistic approaches generally base the design and operating constraints on the criterion that the risk of the certain events must not exceed preselected limits. Many utilities still prefer to use a deterministic technique due to the difficulty in interpreting the numerical risk index and the lack of sufficient information provided by a single index. A practical way to overcome these difficulties is to embed deterministic consideration into the probabilistic framework in the form of system well-being analysis. The system well-being is described by a set of mutually exclusive, exhaustive operating states designated as healthy, marginal and risk. In this approach, the capacity reserve is evaluated using probabilistic techniques and compared to an accepted deterministic criterion, such as the loss of the largest unit, in order to measure the degree of system comfort. [1, 2, 3]

System well being analysis utilizes three indices, namely, the probability of health P(H), the probability of margin P(M) and the probability of risk P(R). These three probabilities reflect the three states in which the system can reside. [4]

The probability of health is the probability of the system being in the healthy state. In this state, the system has enough reserve capacity to meet the deterministic criterion such as

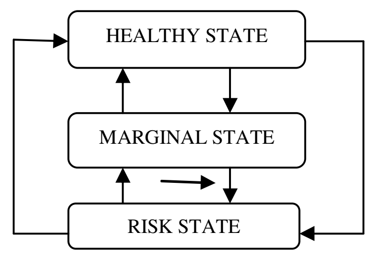

Fig.1: Model for well-being analysis of a system

the loss of the largest generating unit while all the equipments and the operating constraints are within limits. In other words, the available reserve is equal to or greater than the required capacity reserve so that the demand meets the generation at any condition.

The probability of margin is the probability of the system being in the marginal state. The system operates in the marginal state when it has no difficulty but does not have sufficient margin to meet the specified deterministic criterion, that is withstand the loss of any single generating unit or branch. If the individual load is either equal to (emergency) or greater than (extreme emergency) the available capacity of the component, the system will enter the state of risk. [4,5]

The probability of risk, also known as the loss of load probability (LOLP), is the probability of the system being in the risk state. In this state, the load exceeds the available generation. [6]

A system can enter at the risk state or marginal state from the healthy state due to the loss of certain operating capacity or due to a sizable increase in the system load. The probability of health, margin and risk are collectively known as the basic well-being indices. The model for well-being analysis of a system is shown in Fig. 1

. The probability associated with the healthy or risk states can be considered as operating criteria where both deterministic, i.e. healthy state definition and probabilistic criteria are covered. The system operators can choose any one of the following criteria.

A. Single criterion: When the single criterion is used it means that the capacity of spinning reserve must be scheduled in such a way that the probability of system being in the risk state cannot be greater than a specified system risk that is determined by system operators.

$P_r \leq$ MTIL,

where MTIL is the maximum tolerable insecurity level.

B. Multiple criteria: This operating criterion might be to operate the system such that the probabilities of the healthy state and the system risk state are both at acceptable levels. In this case, the capacity of spinning reserve should first be determined to meet the acceptable healthy state probability that exceeds or equals the specified value.

$P_r \leq$ MTIL & $P_h \geq$ MTHL,

where MTHL is the minimum tolerable health level.

IV. ALGORITHM FOR DETERMINING THE BASIC WELL- BEING INDICES

Based on the contingency enumeration approach, the following algorithm is developed for calculating the well-being indices for a generating system considering scheduled maintenance.

Step 1: Read the system's information i.e. number of generating units, capacity, mean time to failure (MTTF) and mean time to repair (MTTR) of each unit. Also, read the contingencies (i.e., units' up or down states) as well as system load.

Step 2: Determine the probability and available capacity for each contingency state. Also, determine the capacity of the largest unit (CLU) for each state.

Step 3: Determine reserve capacity for each contingency state as,

Reserve capacity = Available capacity – System load.

Step 4: For each state,

a. If reserve capacity ≥ CLU, assign the probability of that state as healthy state probability.
b. If reserve capacity < CLU, but greater than zero, assign that state's probability as marginal state probability.
c. If reserve capacity < 0, assign that state's probability as risk state probability.

Step5: Calculate the system well-being indices using equations (1), (2) and (3) respectively.

Step 6: Stop.

V. DESCRIPTION OF THE TEST SYSTEM

To illustrate the concept of health analysis of generating system considering unit maintenance scheduling, the Roy Bilinton Test system (RBTS) is considered here. The RBTS is a small but powerful education based reliability test system. [7]. This system was developed by Roy Billinton for use in the power system reliability research program. The aim of designing this system was to conduct a large range of reliability studies with relatively low computation time requirements. The single-line diagram for this system is shown in Fig.2.

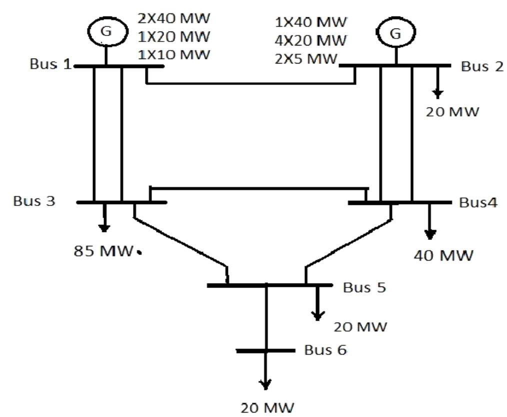

Fig.2: Single line diagram of the RBTS

The RBTS has six buses, nine transmission lines and 11 generating units ranging from 5 to 40 MW. The total installed generating capacity is 240MW and the annual peak load of the system is 185MW. The generating unit data for the RBTS is given in Table 1.

TABLE 1: GENERATING UNIT DATA OF THE RBTS

Priority loading order	Unit size (MW)	Failure rate (failure per year)	Repair rate (hr)	Bus No
1	40	3	60	2
2-3	20	2.4	55	2
4-5	40	6	45	1
6	20	5	45	1
7	10	4	45	1
8-9	20	2.4	55	2
10-11	5	2	45	2

VI. CASE STUDIES

A unit commitment schedule has been developed at different load levels of the RBTS. The generating unit reliability data for RBTS is given in Table 1.

Table 2 shows the required number of committed units and the corresponding probabilities of different operating states for 60, 80 and 100% of the system peak load for two different cases. In case 1, only a specified risk state probability of 0.01 (MTIL) is considered as the unit commitment criterion (single criterion). In case 2, in addition to the specified risk state probability of 0.01, a specified healthy state probability of 0.9 (MTHL) is added to the unit commitment criterion (multiple criteria).

TABLE 2: UNIT COMMITMENT SCHEDULE

Case	Load (MW)	Spinning reserve (MW)	Number of units	Probability of		
				Health	Margin	Risk
1	111	9	4	0.0	0.9937119	0.0062881
	148	12	5	0.0	0.9909901	0.0090099
	185	25	8	0.0	0.9931446	0.0068554
2	111	49	5	0.9909901	0.0089807	0.0000292
	148	42	7	0.9869216	0.0130205	0.0000579
	185	45	9	0.9847597	0.0151675	0.0000728

Let us consider a load level of 111 MW (60% of the system peak load). Generating units are taken from Table 1 until the total committed capacity is exactly equal to or greater than 111MW, i.e. four units. The total number of contingencies is 16 when 4 units are committed. The system has 9 MW spinning reserve and the outage of any single unit will result in load curtailment and therefore no contingency belongs to the healthy state. The probability of finding all units in service is 0.9937119 and belongs to the marginal state as the load is supplied and no single unit can be tolerated. All the other contingencies (with the cumulative probability of 0.0062881) belong to the risk state. The risk state probability is therefore less than 0.01 and no more units are required to be committed. In order to satisfy a healthy state probability of 0.9 (MTHL), a fifth unit is committed to the system to provide more spinning reserve. With five committed units, the total number of contingencies is 32 from which the first one (all committed units in service) belongs to the healthy state, six belong to the marginal state and 25 belong to the risk state. Table 2 summarizes the results for the two cases.

In this way the health analysis of generating system for unit commitment can be done in well-being framework.

VII. CONCLUSION

Almost all aspects of daily life in modern society depend on the use of electricity. The basic objective of an electrical power system is to generate and supply electrical energy to its consumers as economically as possible with an acceptable degree of reliability and quality. For this, a reliability based unit commitment is very essential for uninterrupted generation. Well-being approach for reliability evaluation has many advantages as it incorporates both probabilistic and deterministic criteria. This paper illustrates how this approach can be implemented to find a solution to unit commitment problem having reliability as a constraint.

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BIOGRAPHY

Bipul Kumar Talukdar was born in Assam, India. He received his B.E and M.E Degrees from Assam Engineering College, Guwahati in 2011 and 2014 respectively and presently he is pursuing Ph.D from Guwahati University. He is working as an assistant professor in the Department of Electrical Engineering of Girijananda Chowdhury Institute of Management & Technology, Guwahati, India. His area of interest is power system operation, security and reliability.

Dr. Bimal Chandra Deka received B.E Degree from Gauhati University, India, in 1989, M.Tech from I.I.T Kharagpur, India in 1997, and Ph.D from I.I.T Bombay, India, in 2004. Presently, he is working as an associate professor in the Department of Electrical Engineering of Assam Engineering College, Guwahati India.

