WELL-BEING ANALYSIS FOR GENERATING UNIT PREVENTIVE MAINTENANCE SCHEDULING

Bipul Kumar Talukdar[1], Bimal Chandra Deka[2]

[1]Assistant professor, Dept. of EE, GIMT, Guwahati, India
[2]Associate Professor, Dept. of EE, Assam Engineering College, Guwahati, India[2]

ABSTRACT

Preventive maintenance scheduling of generating units is an important requirement in generating system's planning and operation. Due to outage of generating unit(s) for scheduled maintenance, the reliability of the system is affected significantly. In this paper, reliability of a generating system is evaluated incorporating scheduled maintenance using well-being framework. 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. This paper presents an analytical technique which gives enough information to system planners or operators about the health status of the system under preventive maintenance consideration.

Keyword: *maintenance scheduling, well-being analysis, system health analysis, preventive maintenance.*

---

1. INTRODUCTION

Generating units in a power system require periodic maintenance activities during which the unit under maintenance is detached from the grid and can no longer produce electricity. It influences the system by increasing the production cost and deteriorating the reliability. In a vertically integrated power system, the process of maintenance scheduling is organized by the system operator while keeping in mind that the aforementioned impacts should be limited as much as possible.[1] For most systems, there are two classes of maintenance: preventive maintenance and corrective maintenance. In preventive maintenance, units or components are replaced, lubricated, changed or adjusted before failure occurs. The objective is to increase the reliability of the system over the long term. In contrast, repair or corrective maintenance is performed after failure has occurred in order to return the system to service as soon as possible. Although the primary criterion for judging preventive maintenance procedures is the resulting increase in reliability, a different criterion is needed for judging the effectiveness of corrective maintenance. The criterion most often used is the system availability which is defined as the probability that the system will be operational when needed. The amount and type of maintenance that is applied depends strongly on its costs as well as the cost and safety implications of system failure. [2]

There are two main aspects of scheduled maintenance studies. The first is to ascertain a schedule for maintenance and the second is the effect of maintenance scheduling on the system's health. The value of system risk probability increases when scheduled maintenance is considered because of the reduced and variable reserve capacity at different times of the year. The load model and the generation model are changed during the whole operating period. In this paper the contingency enumeration (CE) approach is used to determine the well-being indices on a period basis. In this approach, for each maintenance period, a generation model is built. All possible combinations of the existing generating units' states are listed in the CE model with their corresponding probabilities. The available reserve for each state is then compared with the capacity of the largest unit of that state to determine the state probability. [1]

2. WELL-BEING FRAMEWORK

System well-being analysis [3, 4, 5, 6] is an approach to power system reliability evaluation which incorporates deterministic criterion in a probabilistic framework and provides information about the system's operating condition as well as risk assessment. This approach provides a new perspective to generation adequacy studies and can also be useful in those situations in which conventional probabilistic techniques are not normally accepted, such as in system operating capacity reserve assessment and in small isolated system planning. 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]

System well-being analysis utilizes three well-being indices, 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. [1, 5]

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 the loss of the largest generating unit while all the equipment 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. [1, 4, 5]

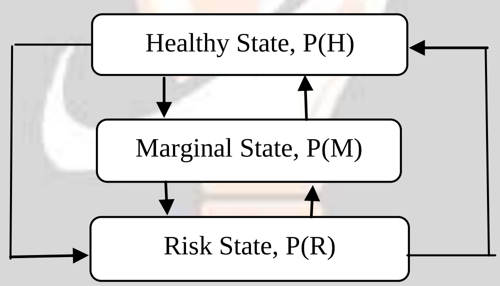

Fig.1: Model for well-being analysis of a system

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.

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. [3] The probability of health, margin and risk are collectively known as the basic well-being indices. The model [5, 7] for well-being analysis of a system is shown in Fig. 1.

Summation of all the healthy state probabilities in a maintenance period, i , is called the probability of health Pi(H) of that period. Similarly, Pi(M) and Pi(R) be the probability of margin and risk of i^{th} maintenance period which are the summation of all marginal state probabilities and risk state probabilities respectively. The total P(H), P(M) and P(R) for the whole period are calculated by using the following equations.[1]

$$P(H) = \sum_{i=1} [P_i(H). (period_i / total\_period)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$P(M) = \sum_{i=1}^{n} [P_i(M). (period_i / total\_period)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$P(R) = \sum_{i=1}^{n} [P_i(R). (period_i / total\_period)] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where, i : the maintenance period number
n : the total number of maintenance period
periodi: the duration of the i^{th} maintenance

3. ALGORITHM FOR DETERMINING THE BASIC WELL- BEING INDICES

Based on the contingency enumeration approach [1], 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.

Step 5: Calculate the system well-being indices using equations (1), (2) and (3) respectively.
Step 6: Stop.

4. 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) [10] is considered here. The RBTS is a small but powerful education based reliability test system. 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.

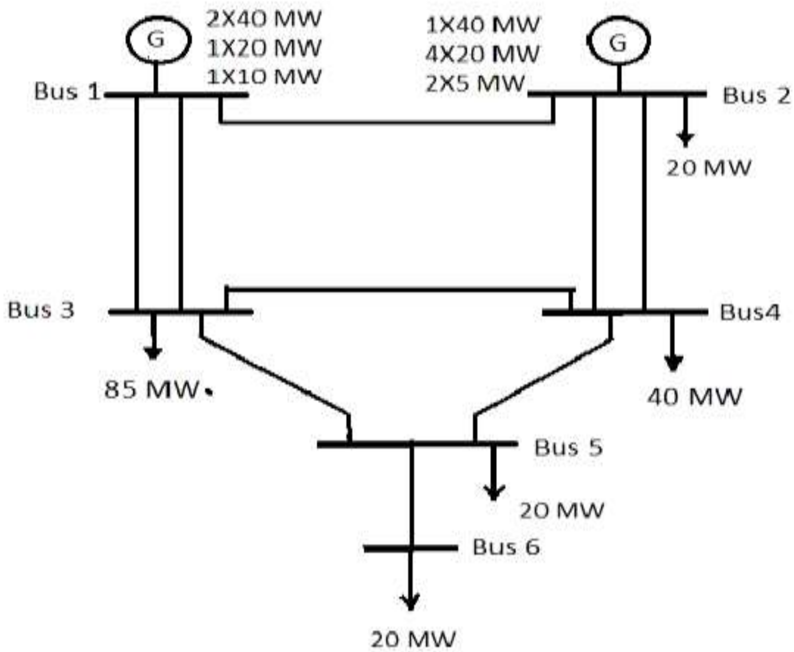

Fig.2: Single line diagram of the RBTS

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

Bus No.	No. of units	Capacity (MW)	MTTF (hr)	MTTR (hr)	Scheduled maintenance (week/yr)
1	2	40	1460	45	2
1	1	10	1752	45	2
1	1	20	4380	45	2
2	4	20	3650	55	2
2	2	5	4380	45	2
2	1	40	2920	60	2

5. CASE STUDIES

In the fig 1, it shows the graph of time Vs throughput of receiving packet. Throughput is the average rate of successful message delivery over a communication channel. In order to incorporate preventive maintenance in the well-being analysis, well-being indices are evaluated on a period basis. The maintenance scheduling for each unit of the RBTS is shown in the Table 2. Each unit takes a period of 2 weeks per year for maintenance. The unit out for maintenance in a particular period of a year is taken arbitrarily here. Again, it is assumed that maintenance of any unit is carry out only once in a year and only one unit is scheduled for maintenance at a particular period. Once the maintenance of that unit is over, only then the next unit is brought for maintenance. [1, 8, 9]

From the Table 2, it is observed that none of the units are scheduled for the maintenance periods 1, 5, 9 and 13. Therefore, all of the 11 units will be present during these periods. System's available capacity will be 240MW. System's peak load is 185 MW. The system well-being indices for these periods will be:

$$P(H) = 0.8597612904$$

P(M) = 0.1330252622

P(R) = 0.0072134474

Table 2: Unit Maintenance Scheduling

Maintenance Period No (i)	Unit out for maintenance	Maintenance period		Duration (week)
		From	To	
1	None	Jan 1	Feb 11	6
2	1	Feb 12	Feb 25	2
3	4	Feb 26	Mar 13	2
4	2	Mar 14	Mar 27	2
5	None	Mar 28	May 22	8
6	6	May 23	June 5	2
7	3	June 6	June 19	2
8	9	June 20	July 3	2
9	None	July 4	Aug 14	6
10	5	Aug 15	Aug 28	2
11	7	Aug 29	Sep 11	2
12	11	Sep 12	Sep 25	2
13	None	Sep 26	Dec 4	10
14	8	Dec 5	Dec 18	2
15	10	Dec 19	Dec 31	2

During maintenance period 2, unit 1 having capacity of 40 MW is out for maintenance. During this period (Feb'12 to Feb'25), only 10 units will be available in the system to meet the load. System's available capacity will be 200MW. System's peak load is 185 MW. So the well-being indices for the peak load during this period will be:

P(H) = 0.0000000000

P(M) = 0.8862604787

P(R) = 0.1137395213

During maintenance period 3, unit 4 having capacity of 20 MW is out for maintenance. Unit 1 will be available during this period. During this period (Feb'26 to Mar'13), 10 units will be available in the system to meet the load. System's available capacity will be 220MW. System's peak load is 185 MW. So, the well-being indices for the peak load during this period will be:

P(H) = 0.0000000000

P(M) = 0.9209505851

P(R) = 0.0790494149

Similarly, the well-being indices for the next maintenance periods can be calculated which are shown in Table 3. The well-being indices for the system for the whole year (52 weeks) can be calculated by using equations (1), (2) and (3) respectively. These are found to be as follows:

P(H) = 0.03305940677

P(M) = 0.00512398981

P(R) = 0.00027814188

Table 3: System Well-Being Indices for Different Maintenance Periods

Maintenance period No(i)	Unit out for maintenance	Well-being indices			Duration (week)
		P(H)	P(M)	P(R)	
1	None	0.8597612904	0.1330252622	0.0072134474	6
2	1	0.0000000000	0.8862604787	0.1137395213	2
3	4	0.0000000000	0.9209505851	0.0790494149	2
4	2	0.0000000000	0.8862604787	0.1137395213	2
5	None	0.8597612904	0.1330252622	0.0072134474	8
6	6	0.0000000000	0.9211369691	0.0788630309	2
7	3	0.8596746099	0.1331046466	0.0072207435	2
8	9	0.8595445762	0.1332237350	0.0072316888	2
9	None	0.8597612904	0.1330252622	0.0072134474	6
10	5	0.0000000000	0.9211369691	0.0788630309	2
11	7	0.0000000000	0.9211369691	0.0788630309	2
12	11	0.0000000000	0.8774274139	0.1225725861	2
13	None	0.8597612904	0.1330252622	0.0072134474	10
14	8	0.0000000000	0.9211369691	0.0788630309	2
15	10	0.8595445762	0.1332237350	0.0072316888	2
					Total=52

The system health, marginal and risk probabilities at different maintenance periods are plotted in Fig.3, Fig.4 and Fig.5 respectively.

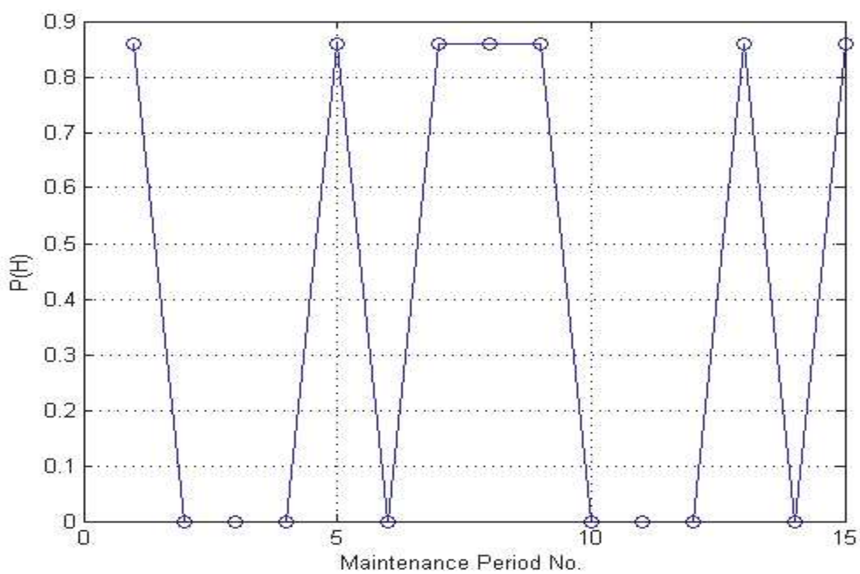

Fig.3: System's healthy state probability at different maintenance periods

It is seen from the Fig.5 that the system risk probability violates the maximum tolerable insecurity level (MTIL=0.01) if any one of the units 1, 2, 4, 5, 6, 7, 8, 11 is kept out for maintenance. Also from Fig. 3, it is seen that in some of the maintenance periods (Period no. 2, 3, 4, 6, 10, 11, 12, 14), probability of system health becomes zero. This may not be acceptable for some operations. It may be, therefore, preferable that unit maintenance be performed only when the system has sufficient margin to withstand further element outage. For this, either load curtailment should be done or stand-by unit should be added to the system to reach an acceptable healthy state probability.

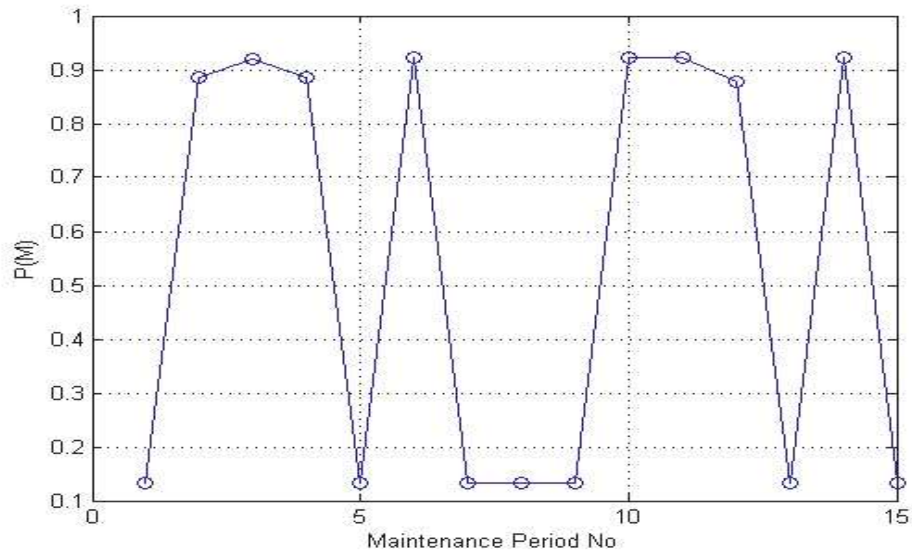

Fig.4: System's marginal state probability at different maintenance periods

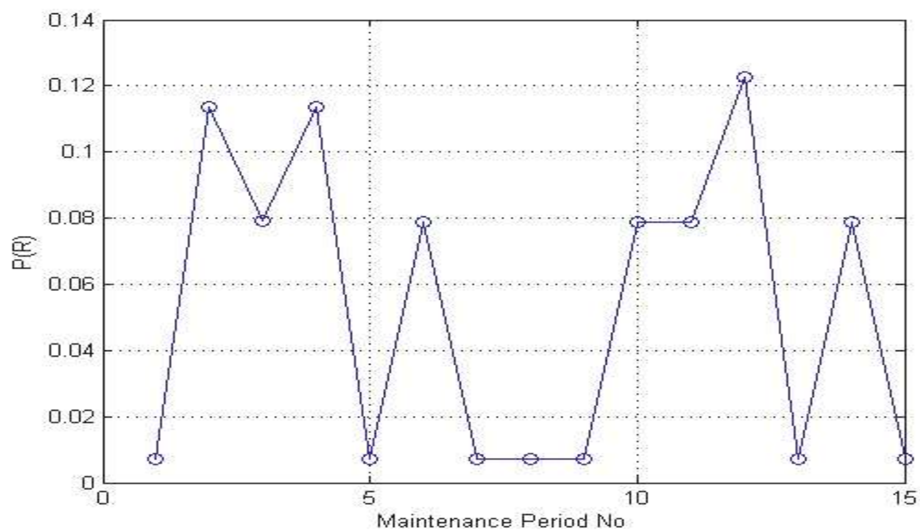

Fig.5: System's risk state probability at different maintenance periods

6. CONCLUSION

The well-being analysis of a generating system helps the operator or system planner to analyze the system's reliability easily. This paper presents a method for generating system's reliability evaluation incorporating scheduled maintenance of unit(s) by implementing the well-being framework. Preventive maintenance of unit is very essential for generating system's planning and operation. Due to shortage of unit(s) during maintenance period, the available capacity is reduced which results in decrease in reliability of the system. This paper illustrates how the reliability of a system is affected due to outage of unit(s) during the scheduled maintenance period. It also provides information to the management about when and how much additional capacity should be added to the system to maintain the system's reliability above the specified level. This will help the system planner to take decisions about the system for operation and prepare proper maintenance scheduling and planning.

7.REFERENCES

[1] A. Abdulwhab, R. Billinton, "Generating system well-being index evaluation", Electrical Power and Energy System 26 (2004) 221-229

[2] E. E. Lewis, "Introduction to Reliability Engineering", second edition, John Wiley & Sons Inc, Chapter 10.

[3] Mario V. F. Pereira, Neal J. Balu, "Composite Generation/Transmission Reliability Evaluation", proceedings of the IEEE, VOL. 80, NO.4, April 1992

[4] L. Goel, C. Feng, "Well-being framework for composite generation and transmission system reliability evaluation",IEEE prod-Gen, Trans, Distrib. Vol 146. No. 5, September 1999

[5] Saleh Abdulrahman Saleh Aboreshaid, "Composite Power System Well-Being Analysis", A thesis submitted to the college of graduate studies and research in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in the Department of Electrical Engineering, University of Saskatchewan, Saskatoon, 1997

[6] R. Billinton, Fotuhi-Firuzabad, M. and Aboreshaid, S., "An Approach to Evaluating System Well-being in Engineering Reliability Applications ", Journal of Reliability Engineering and System Safety, Vol. 50, No. 1, 1995, pp. 1-5.

[7] L. Goel, Z. Song, P. Wang, "Well-being analysis of spinning reserve in a bilateral power market", Electric power system research 69 (2004) 37-42

[8] Abdulwhab A, R. Billinton, " Generating facilities maintenance scheduling using a probabilistic technique", 35th University Power Engineering Conference, Belfast, September,2000

[9] R. Billinton, Abdulwhab A, "Application of probabilistic health analysis in generating facilities maintenance scheduling", Porto power tech conference, Portugal, 2001,p.10-3

[10] R. Billinton, S. Kumar, N. Choudhury, K. Chu, K. Debnath, L. Goel, E Khan, P Kos, G Nourbakhsh, J. Oteng-Adjei, "A reliability test system for educational purpose- basic data", IEEE Transitions power System, 1989; Vol. 4, No.3 ,August 1989.

8.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