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Well-being Analysis for Generating System Expansion Planning

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***Abstract---* One of the most important decision making parameters associated with generating system expansion planning is the reliability of the system. As the demand of electricity is increasing day by day, the generating capacity of the system must also be increased to meet the demand. This paper illustrates a technique to evaluate the reliability of a generating system for capacity expansion planning. The well-being framework is used for the purpose. The well-being analysis of a system provides the opportunity to consider both deterministic and probabilistic approaches of reliability evaluation and alleviates the weaknesses associated with the deterministic approach or interpreting a single risk index. The presented technique will give enough information to the system planners or operators about the health status of the system during the planning period of capacity expansion.**

***Key words*— Generation expansion planning, Well-being analysis, System health analysis, Reliability assessment.**

I. INTRODUCTION

Power system planning is a part of energy and economic development planning. Its objective is, therefore, to determine a minimum cost strategy for long-range expansion of the generation, transmission and distribution systems adequate to supply the load forecast within a set of technical, economic and political constraints. Power system planning has been mainly related to generation expansion planning. This is due to the fact that investment in transmission lines is a relatively small fraction of the investment in the construction of power stations and that investment in the distribution of electric energy to customers, although sizeable, is to a large extent independent of the generation and transmission system.[1]

One of the basic objectives of generation expansion planning is to determine the sequence of generating unit additions required for an economic and reliable supply of the predicted system demand. A fundamental problem in system planning is the correct determination of reserve capacity. Too low a value of reserve capacity means excessive interruption in supply; while too high a value of reserve capacity results in excessive cost. A higher reliability level requires system reinforcements, which in turn results in higher customer rates. Therefore, the responsibility of system planners/designers is to achieve the best possible trade-off between reliability and cost, recognizing the uncertainties with respect to load growth and equipment availability. [2, 3]

The term ‘reliability’ has an extremely wide range of meaning. The one most often used is that “reliability is a measure of the overall ability of a system to perform its intended function"[4]. To determine the reliability of a system, a wide range of deterministic and probabilistic criteria are required. Deterministic techniques provide a reliability analysis with information on how a system failure can happen or how system success can be achieved. These techniques are also often referred to as engineering judgment. The drawback of deterministic techniques are that these do not account for the stochastic nature of system behaviour and are not responsive to many of the parameters such as load and risk nature, which actually influence system reliability. Therefore, these approaches are inconsistent and cannot be used for comparing alternate equipment configurations and performing economic analyses. The alternative to the deterministic approach is the probabilistic approach, in which the stochastic aspects of the system are explicitly represented [5]. These approaches provide quantitative indices, which can be used to decide if system performance is acceptable or if changes need to be made. However, there is considerable reluctance to using probabilistic techniques in many areas due to the difficulty in interpreting the resulting numerical indices. Although deterministic criteria do not consider the stochastic behaviour of system components, they are easier for system planners, designers and operators to understand than a numerical risk index determined using probabilistic techniques. The dilemma between the deterministic and probabilistic approaches can be alleviated by including accepted deterministic criteria in a probabilistic framework using an approach known as 'well-being analysis' [6, 7] which bridges the gap between these two approaches.

II. WELL-BEING FRAMEWORK

System well-being analysis is an approach to power system reliability evaluation which incorporates deterministic criterion in a probabilistic framework and provides system operating information in addition to risk assessment. In this approach, the reserve margin is determined using probabilistic techniques and compared to an accepted deterministic criterion to measure the degree of system comfort. The most common deterministic criterion dictates that specific credible outages, e.g., single contingency or two critical components will not result in system failure [7].

In well-being analysis of a system, three indices, namely, the probability of health P(H), the probability of margin P(M) and the probability of risk P(R) are determined. These three indices, known as well-being indices, reflect the three states in which the system can reside. The model for system well-being analysis is shown in Fig.1. [8]

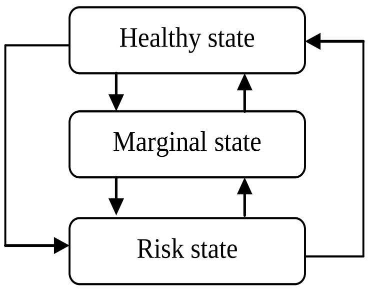

Fig.1: Model for system well-being analysis

The probability of health P(H) is the probability of the system being in the healthy state where the system has enough reserve capacity to meet the specified deterministic criterion such as the loss of the largest generating unit. In other words, the available reserve capacity is equal to or greater than the required reserve capacity so that the demand meets the generation at any condition.

The probability of the system being in the marginal state is called the probability of margin P(M). The system operates in the marginal state or alert state when it has no difficulty but does not have sufficient margin to meet the specified deterministic criterion. 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.

The probability of risk P(R) is the probability of the system being in the risk state. It is also known as the loss of load probability (LOLP). In this state, margin is negative, i.e. the system load exceeds the available generation.

A system can enter at the risk state or marginal state from the healthy state due to the failure of certain generating units or due to a sizable load growth. Again, a system can go to the healthy state from marginal or risk state due to the addition of new generating facilities or certain amount of load curtailment. From the basic probability theorem,

$$P(H) + P(M) + P(R) = 1 \qquad (1)$$

Well-being indices can prove useful in generation capacity planning of large systems that routinely use conventional probabilistic techniques, as these indices provide more flexibility to the system planners in decision making process.

III. ALGORITHM FOR DETERMINING THE BASIC WELL-BEING INDICES

Based on the contingency enumeration approach [9], the following algorithm is developed for calculating the well-being indices for a generating system.

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 the 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 well-being indices as,

$$P(H) = \Sigma \text{(Healthy state probability)}$$
$$P(M) = \Sigma \text{(Marginal state probability)}$$
$$P(R) = \Sigma \text{(Risk state probability)}$$

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Step 6: Stop.

IV. MODEL FOR GENERATION EXPANSION PLANNING

The generation capacity expansion planning model assesses the annual capacity requirements of a power system in order to satisfy specified reliability criteria. The main features of the model are:

- Only the generating units are considered in the model. The units may be in operating state (Up), derated state or failed (Down) state. Transmission lines are assumed to be 100% reliable.
- The existing system is taken as the starting point for the expansion analysis. It uses relevant number of units, types, capacities and forced outage rates (F.O.R).
- The capacity model and load model of the planning period are required to determine the P(H), P(M) and P(R) of the system.
- The evaluated P(H) and P(R) are compared with specified health level (SP_H) and specified acceptable risk level (SP_R) respectively. If P(H) is less than SP_H or /and P(R) is greater than SP_R, one unit is added at a time until the P(H) becomes equal to or greater than SP_H or/and P(R) becomes less than SP_R. This creates the expansion plan and the capacity model is updated for each addition.

V. DESCRIPTION OF THE TEST SYSTEM

To illustrate the concept of generation capacity expansion planning using well-being approach, the Roy Bilinton Test system (RBTS) [10] is considered. RBTS is a small but powerful education based reliability test system which was developed by Roy Billinton for use in the power system reliability research program. The purpose 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.

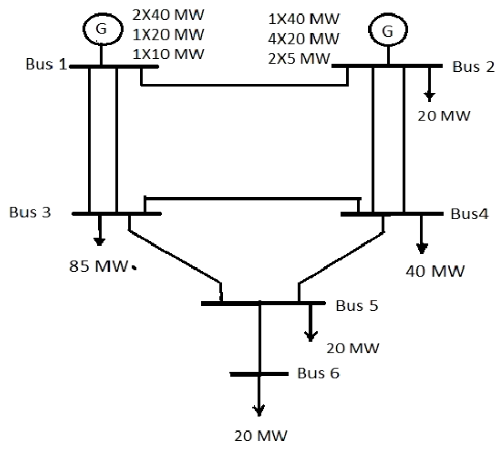

Fig.2: Single line diagram of the RBTS

The RBTS has six buses, nine transmission lines and eleven 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 generation data for 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)	F.O.R
1	2	40	1460	45	0.0299
1	1	10	1752	45	0.0250
1	1	20	4380	45	0.0102
2	4	20	3650	55	0.0148
2	2	5	4380	45	0.0102
2	1	40	2920	60	0.0201

VI. CASE STUDIES

A two state model for generating units is considered for the study. That means each unit may be either in operating state (Up) or failed (Down) state at a time. As there are 11 generating units in the RBTS, there will be total 2^{11} contingency states. The calculated well-being indices of RBTS for load 185 MW are as follows:

$$P(H) = 0.8597612904$$
$$P(M) = 0.1330252622$$
$$P(R) = 0.0072134474$$

The acceptable system risk level (SP_R) is assumed to be 0.01 in this study, i.e. the system is considered to be adequate if its P(R) is less than or equal to 0.01. Thus, the test system is found out of risk even at the peak load and can be operated satisfactorily. This is taken as the starting point for the expansion analysis of the system.

The load model of the system is assumed to be such that peak load is increasing by 5% per year. The study results are shown in Table 2 which shows the health, margin and risk probabilities for the RBTS for the increased loads.

Table 2 shows that as load increases, P(R) increases but P(H) decreases. Form the second year, P(H) will become zero and the system will go to the risk state as P(R) exceeds the limit SP_R. To reduce the risk level below SP_R, additional capacity should be added to the system or some amount of load should be curtailed.

TABLE 2: WELL-BENG INDICES FOR THE RBTS CONSIDERING 5% LOAD GROWTH PER YEAR

Year	Load (MW)	P(H)	P(M)	P(R)
1	194.25	0.8381466383	0.1528205558	0.0090328059
2	203.96	0.0000000000	0.9204181713	0.0795818287
3	214.16	0.0000000000	0.9188932954	0.0811067046
4	224.87	0.0000000000	0.8597612904	0.1402387096
5	236.11	0.0000000000	0.8212720101	0.1787279899

Let, an additional unit having capacity 40 MW and F.O.R equal to 0.02 is installed to the system at the start of the second year. Now, the total capacity of the system becomes 280 MW.

TABLE 3: WELL-BEING INDICES FOR THE RBTS IN ADDITION OF EXTRA UNIT

Year	Capacity (MW)	Load (MW)	P(H)	P(M)	P(R)
1	240	194.25	0.8381466	0.1528206	0.0090328
2	240	203.96	0.0000000	0.92041817	0.07958183
2	240 + 40	203.96	0.90200980	0.09423844	0.00375176
3	260	214.16	0.90051543	0.09557891	0.00390566
4	260	224.87	0.84256606	0.14755998	0.00987395
5	260	236.11	0.80484657	0.18133475	0.01381868
5	260+40	236.11	0.98255462	0.01672417	0.00072121
6	300	247.92	0.88394024	0.11041961	0.00564015
7	300	260.31	0.82571474	0.16146010	0.01282515
7	300+40	260.31	0.98394565	0.01531682	0.00073753
8	340	273.33	0.98098776	0.01809604	0.00091620
9	340	286.99	0.86626144	0.12589002	0.00784854
10	340	301.3	0.80920045	0.17474519	0.01605435

Table 3 shows that due to this addition of extra capacity to the system in the second year, the value of P(R) decreases significantly and becomes less than SP_R. Therefore, the system can be operated satisfactorily again and will remain in out of risk state up to fourth year. After completion of fourth year, system will again enter into the risk state as limit of SP_R will be violated. Therefore, the capacity of the system should be increased again. Let, another unit having capacity 40 MW and F.O.R of 0.02 is added to the system in the fifth year. This results in decrease in P(R) below the risk limit. Addition of this unit ensures that the system will be in out of risk state up to the end of sixth year. Figure 3 shows the P(R) values of RBTS for a period of 10 years. Due to the load growth, the system enters into the risk state in the second, fifth, seventh and tenth year. The addition of extra capacity to the system at the start of these years improves P(R) and brings the system out of risk state.

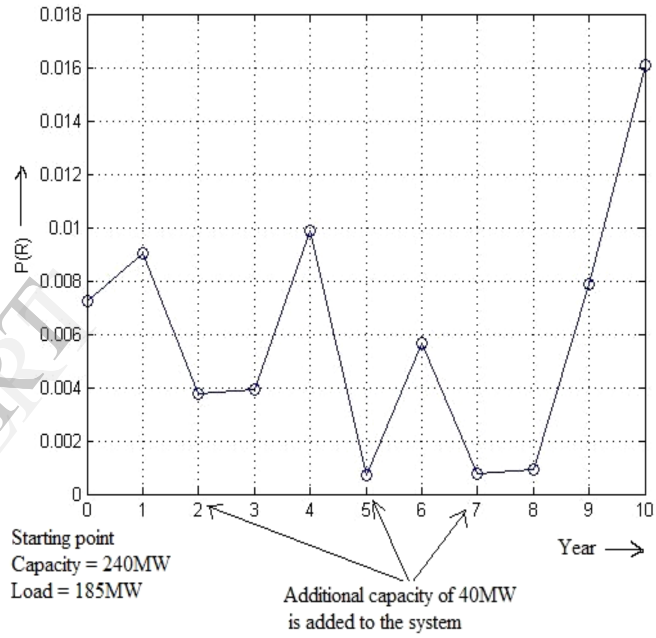

Fig. 3: P(R) vs. Time (year)

For operating the system more reliably, it is better to consider the healthy state criteria rather than risk state. Suppose, the system planner decides that the system should always remain in healthy state. For this, P(H) of the system must not be less than a specific limit SP_H. In this study, SP_H is assumed to be 0.84.

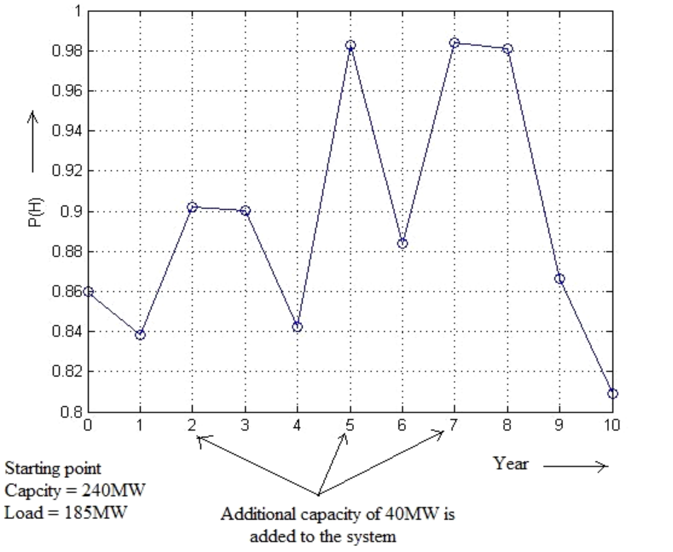

Fig. 4: P(H) vs. Time (year)

Figure 4 shows the yearly P(H) values for a period of 10 years for the RBTS considering that load growth is 5% per year and additional capacity of 40MW is added to the system if there is any violation of P(H) limit. It is seen from Table 3 that P(H) decreases to zero in the second year. Addition of 40 MW unit increases the P(H) above the SP_H and the system returns to the healthy state again. It will remain healthy up to the forth year. In the fifth year the P(H) limit will be violated again and more capacity should have to be added to the system. In the Fig. 4, it is shown that additional units having capacity 40MW are installed at the start of the second, fifth and seventh year to maintain the health level of the system above SP_H.

Addition of unit(s) increases the reserve capacity in the system. This results the increase in P(H). More reserve capacity means more healthy system for a long duration. But higher reserve capacity increases the cost of generation. Therefore, there should be a best possible trade-off between cost and reliability during the planning process. The task of the system planner is to determine the most effective and economic additions of generation capacity to the system at appropriate time in order to maintain the system reliability as high as possible and run the system economically.

VII. CONCLUSION

The well-being analysis of a generating system helps the operator or system planner to analyze the system's reliability easily. This paper illustrates a method for reliability assessment for generating capacity expansion planning by implementing the well-being framework. It will give information about the health status of the system during the load growth. It will also provide information to the management about how much and when additional capacity should be added to the system to maintain the system reliability above the specified level. This will help the system planner or operator to take decisions about the system for operation in the future.

REFERENCES

[1] A.J. Covarrubias, "Expansion planning for electrical power system", IAEA BULLETIN-VOL.21, NO.2/3
[2] Mario V. F. Pereira, Neal J. Balu, "Composite Generation/Transmission Reliability Evaluation", proceedings of the IEEE, VOL. 80, NO.4, April 1992
[3] R. Billinton, Fotuhi-Firuzabad M., "Reserve capacity assessment in small electric power generating systems", IEE power engg J 1996:10(2): 73-80.
[4] R. Billinton, R.N.Allan, "Reliability evaluation of Engineering Systems", Longman, London Plenum press, Newyork, 1983.
[5] Mario V.F Pereia and Neal J. Balu, "Composite Generation /Transmission Reliability Evaluation", IEEE proceedings, Vol. 80, no 4, April 1997
[6] L. Goel, C. Feng, "Well-being framework for composite generation and transmission system reliability evaluation", IEE prod-Gen, Trans, Distrib. Vol 146. No. 5, September 1999
[7] 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
[8] 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
[9] A. Abdulwhab, R. Billinton, "Generating system well-being index evaluation", Electrical Power and Energy System 26 (2004) 221-229
[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.

BIOGRAPHY

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