# POWER SYSTEM RELIABILITY

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## ABSTRACT

*This Paper discusses several philosophical aspects concerning power-system reliability. It puts the reliability aspects in perspective, describes a hierarchical framework of analysis and discusses how the economics of reliability should be compared.*

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## INTRODUCTION

A power system serves one function only and that is to supply customers, both large and small, with electrical energy as economically as possible and with an acceptable degree of reliability and quality. Modern society, because of its pattern of social and working habits, has come to expect that the supply should be continuously available on demand. This is not physically possible due to random system failures which are generally outside the control of power-system engineers, although the probability of customers being disconnected can be reduced by increased investment during either the planning phase, operating phase or both. It is evident therefore that the economic and reliability constraints can conflict, and this can lead to difficult managerial decisions at both the planning and operating phases. These problems have always been widely recognized, and it is not suggested that they have only recently come to the fore. Design, planning and operating criteria and techniques have been developed over many decades in an attempt to resolve and satisfy the dilemma between the economic and reliability constraints. The criteria and techniques first used in practical applications, however, were all deterministically based. The essential weakness of deterministic criteria is that they do not respond to nor reflect the probabilistic or stochastic nature of system behaviour, of customer demands or of component failures.

### NEED FOR POWER-SYSTEM RELIABILITY EVALUATION

The economic, social and political climate in which the electric power supply industry now operates has changed considerably during the last 20-30 years. During the period following the Second World War, and prior to the end of the 1950s, planning for the construction of generating plant and facilities was basically straightforward because it could be assumed that the load would at least double every 10 years (7-8% annual growth rate). Therefore past trends provided a relatively simple guide for the future. In addition, plant construction was relatively uncomplicated. The lead time for a coal-fired station was perhaps 3-5 years with only a relatively small period of that time associated with planning and environmental inquiries. The timing of unit construction and the development of quantitative methods for determining the correct amount of spare capacity in both single and highly interconnected systems became more important. The problems were still manageable, however, because of the continued growth in consumer demand. This situation changed abruptly in the mid-1970s. Inflation and the astronomical increase in oil prices created a rapid increase in consumer tariffs. This was a reversal of a longstanding trend. Their combined effects introduced considerable uncertainly in predicting future demand. Also conservation became a major issue which created a further reduction in forecast demand. Therefore construction plans had to be modified to recognize the new scenario.

## Definition of power-system reliability

The function of an electric power system is to satisfy the system load requirement as economically as possible and with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term reliability. The concept of power-system reliability, however, is extremely broad and covers all aspects of the ability of the system to satisfy the consumer requirements. The term reliability has a very wide range of meanings and cannot be associated with a single specific definition such as that often used in the mission-oriented sense. It is therefore necessary to recognise its extreme generality and to use it to indicate, in a general rather than specific sense, the overall ability of the system to perform its function. A simple but reasonable subdivision of the concern designated as system reliability is shown in Fig.l. This represents the two basic aspects of a power system: system adequacy and

system security. These two terms can best be described as follows. Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. Adequacy is therefore associated with static conditions which do not include system disturbances. Security relates to the ability of the

system to respond to disturbances arising within that system. Security is therefore associated with the response of the system to whatever perturbations it is subject.

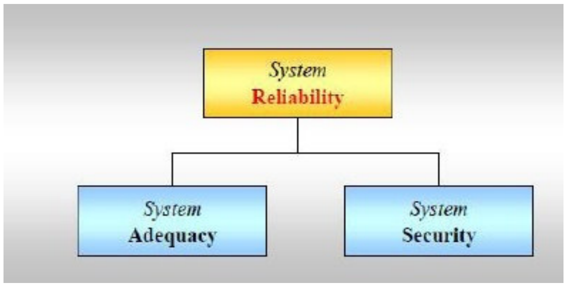


**Figure 1.1 Components of system reliability**

System Security, on other hand, relates to the ability of the system to withstand sudden perturbations arising within it. This includes the conditions associated with both local and widespread disturbances and loss of major generation and transmission facilities. In terms of generation, generation system security is the capability of the generators in enduring unexpected contingencies involving frequency and voltage any time during system operation. Security is a dynamic measure of response to the unforeseen events. Security, therefore, involves the analysis of both static and dynamic conditions. Together, adequacy and security provides the overall reliability description of the Power system, which can be broadly described as the ability to supply the quantity and quality of electricity desired by the customer when it is needed.

**Functional Zones and Hierarchical Levels**:

Modern power systems in developed countries are usually very large highly integrated and complex. The numerous numbers of components and the complex interrelations between them makes evaluation of the overall system extremely tricky as it would require very complicated analytical models. These models are not impossible to build but they are extremely difficult to develop and would require excessive computing time. Furthermore, the results obtained are likely to be so vast that meaningful interpretation will be difficult. Due to these characteristics, power systems are normally divided into three main functional zones, namely generation, transmission and distribution system. Typically, the zones are evaluated separately for better measures of reliability in terms of making appropriate assumptions and flexibility in failure criteria selection. They can then be combined into higher hierarchical levels to convey a more wholesome performance of the system. Power system can be divided into three hierarchical levels which are shown in figure 1.2 they are:

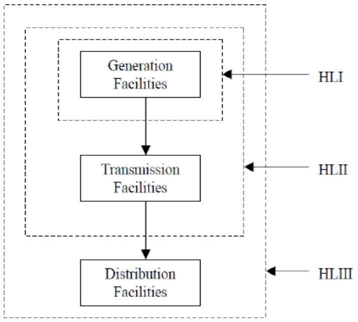


**Figure 1.2 Functional Zones and Hierarchical Levels**

First level (HL I) containing the equipment and units generating electricity;

Second level (HL II) containing both the units and equipment for generation and transmission of electricity
Third level (HL III) containing whole system, including distribution.

## SYSTEM RELIABILITY EVALUATION

Analytical methods or Monte Carlo simulation can be used to calculate the reliability indices. Analytical techniques represent the system by analytical models and evaluate the indices from these models using mathematical solutions. Monte Carlo simulations, on the other hand estimate the indices by simulating the actual process and random behavior of the system, treating the problem as a series of experiments. The reliability indices obtained indicate the ability of the generating facilities to meet the system demand. In the analytical method, the generating system model used for generation capacity adequacy assessment is a *Capacity Outage Probability Table* (COPT) which can be created using the recursive technique which will be explained later in this chapter. As for the load model, the daily peak load or hourly load for a period of one year is normally used to form the *Load Probability Table* (LPT).

The process of evaluation of power system reliability starts by creating a mathematical model of a system or a subsystem and then proceeding with a numerical solution, summarized in the following general steps :

- Define the boundary of the system and list all the components included.
- Provide reliability data such as failure rate, repair rate, repair time, scheduled maintenance time, etc., for every component.
- Establish reliability models for every component.
- Define the mode of system failure, or define the criterion for normal and faulty systems.
- Establish a mathematical model for the system reliability and its basic assumptions.
- Select an algorithm to calculate the system reliability indices.

### Conventional Generating Unit Reliability Model

The most important input quantities required in generation system reliability analysis are the capacity and the failure probabilities of individual generating units. If a simple two-state model is assumed for the operation of a unit, its failure probability is given by its unavailability U, which can be expressed in terms of the unit failure rate $\lambda$ and repair rate $\mu$ in given equation.

$$U = \frac{\lambda}{\lambda + \mu} \qquad (2.1)$$

Where,

λ = unit failure rate

μ = unit repair rate

U= unit unavailability

Unit unavailability is also known conventionally as "forced outage rate" (*FOR*), although the value is not a rate. The *FOR* is defined in Equation 2.2 below

$$FOR = \frac{Forced\ outage\ hours}{IN{-}service\ hours + forced\ outage\ hours} \qquad (2.2)$$

The *FOR* calculated for a long period of time (e.g. 365 days), is the same index as the unavailability defined in Equation 2.1. The *FOR* is a good approximation for the 2 state approximations. The next step in building a generation model is to combine the capacity and availability of the individual units to estimate available generation in the system. The result of this combination will be a capacity model, where each generating unit is represented by its nominal capacity, Ci and its unavailability, Ui (or *FOR*). The capacity or the outage capacity, *X* is considered to be a random variable in power system reliability analysis. The capacity or outage capacity is discrete and obeys an exponential distribution. The unit model is the probability table of a generator unit's capacity state.

The probability model of a two-state generator model has only two states; in operation or on outage. There are 2*n* possible different capacity states. The individual state probability can be described in Equation 2.3

$$P(X = xi) = \begin{cases} 1 - q, & xi = Ci \\ q, & xi = 0 \end{cases} \qquad (2.3)$$

The cumulative state probability (the distribution function) can be obtained by summing up the individual state probability for all capacity less than *xi*. Equation 2.4 gives the cumulative state probability.

$$P(X = xi) = \begin{cases} 0, & xi < 0 \\ q, & 0 \le xi \le Ci \\ 1, & xi \ge Ci \end{cases} \qquad (2.4)$$

There will be a forced outage rate for every capacity Ci, and the individual state probability and cumulative state probability are summarized in Equation 2.5 and 2.6 respectively.

$P\ (X = xi) = P\ (xi)$ Where i = 0,1,2,…….  (2.5)

$P\ (xk) = (X \geq xk) = \sum_{i\geq k} (xi)$  (2.6)

From these equations, the *Capacity Outage Probability Table* (COPT) that represents the probability of different capacity outages of the system can be generated.

We can also use binomial distribution $(U + A)^n$ for calculation of probability of different outage states

$$P(j) = \frac{N!}{j!N-j} X A^{N-j} X U^{j} \qquad (2.7)$$

Where,

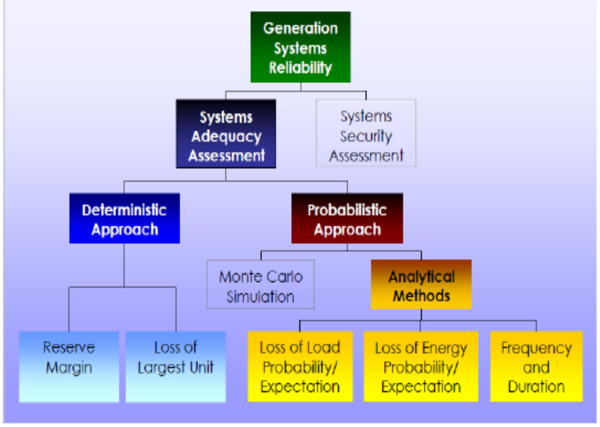
| | |
|---|---|
| U | unit unavailability |
| A | unit availability |
| N | no: of units |
| j | outage state |
| P(j) | Probability of outage state j |

**SYSTEM RELIABILITY INDICES:**

Commonly used probabilistic reliability indices are Loss of Load Probability (LOLP), Loss of Load Expectation (LOLE), Loss of Energy Expectation (LOEE), and Loss of Load Frequency (LOLF) and Loss of Load Duration (LOLD). Most of these indices are basically expected values of a random variable. Expectation indices provide valid adequacy indicators which reflect various factors such as system component availability and capacity, load characteristics and uncertainty, system configurations and operational conditions, etc. Typical reliability indices used in power system evaluations and their categorizing is shown in Figure 1.3

There are several problems with the use of the LOLP for power system reliability evaluations.

- LOLP does not provide any indication of the frequency or duration of shortages and the extent of load shedding in MW or severity of potential shortages which are important reliability measures. As an expected value, it does not differentiate between one large shortfall and several small, brief ones.



- Different LOLP calculation techniques can result in different indices for the same system. Some utilities calculate LOLP based on the hour of each day's peak load (i.e., 365 computations), while others model every hour's load i.e., 8760 computations.
- LOLP does not include additional emergency support that one control area or region may receive from another, or other emergency measures that control area operators can take to maintain system reliability.
- Major loss-of-load incidents usually occur as a result of contingencies not modeled by the traditional LOLP calculation. Often, a major bulk power outage event is precipitated by a series of incidents, not necessarily occurring at the time of system peak (when the calculated risk is greatest) .
- The LOLP, in days per year, mainly indicates the number of days in the year in which the generation system would not be able to meet the load. The frequency of load shedding may be higher than this figure in case of double peaked daily load curves and in systems which employ units with higher failure rates but short repair duration.
- Since the load model used in the loss-of-load method is most often the cumulative curve of daily peak loads, the variations of load within a day are not recognized in it. This makes the LOLP value obtained by that method a rather crude approximation of the true system failure probability, and prevents the calculation of the system failure frequency.
- It is not very useful for comparing the reliabilities of different utilities or national systems, particularly if they have different shapes of the load curve and peak duration.
- It is argued that for the same system the use of the LOLP index would be adequate and correct for investigating different expansion plans and annual maintenance scheduling. This is only correct if the duration peak demand is static over years of the

study. This is not the case in many systems with the continuous increase in the middle of the day load being experienced in most cases, particularly in developing countries

## CONCLUSION:

The framework described in the paper is one on which the discussions within the power industry and with external groups can be ideally based. The need for such a framework is already evident due to the growing number of people and organisations wishing to effect the planning

Decisions of power systems and this trend will expand as the future progresses.

- There should be some conformity between the reliability of various parts of the system, and a balance is required between generation, transmission and distribution. This does not mean that the reliability of each should be equal. Reasons for differing levels of reliability are justified, for example, because of the importance of a particular load, or because generation and transmission failures can cause widespread outages whereas distribution failures are very localised
- There should be some benefit gained from any improvement in reliability. The most useful concept for assessing this benefit is to equate the incremental or marginal investment cost to the incremental or marginal consumers' valuation of the improved reliability. The main difficulty with such a concept is the present uncertainty in the consumer’s valuation. Until this problem is fully resolved, it is still beneficial for individual utilities to arrive at some consistent criterion by which they can assess the benefit of expansion and reinforcement schemes.

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