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# Comparative Study of Reliability Assessment Techniques for Composite Power System Planning & Applications

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***Abstract***
Reliable electric power supply is essential for modern society. The extensive use of electricity has led to a high susceptibility to power failure. Reliability is a key aspect of power system design and planning. Therefore fast and accurate power system reliability assessment techniques are important. This paper proposes the probabilistic techniques such as, analytical technique & Monte Carlo Simulation technique for reliability assessment of composite power system. Another technique, fault tree analysis technique has also discussed. This paper gives a comparison of all proposed techniques.
***Keywords***- Composite power system; Reliability; Basic indices, Reliability Assessment techniques: Analytical technique, Monte Carlo Simulation Technique, faults Tree Analysis.

## I. Introduction

Electric power systems throughout the world are undergoing considerable change in regard to structure, operation and regulation. Technological developments and evolving customer expectations are among the driving factors in the new electricityParadigm. Competition and uncertainty in the new deregulated electric utility industry are serious concerns. Electric power utilities also face increasing uncertainty regarding the political, economic, societal and environmental constraints under which they have to operate existing systems and plan future systems. All these conditions have created new electric utility environments that require extensive justification of new facilities, optimization of system configurations, improvements in system reliability and decreases in construction and operating costs. New planning criteria with broader engineering considerations of transmission access and consistent risk assessment must be explicitly addressed. The likelihood of the occurrence of worst possible scenarios must also be recognized in the criteria and acceptable risk levels incorporated in the decision making. Within this competitive environment, fast and accurate power system reliability assessment techniques play an important role in shaping the criterion for judging the robustness of delivered service.

The term reliability measures the ability of a system to perform its assigned function, where past experience helps to form advance estimates of future performance.

The term reliability when used in a power system context has a wide range of meaning. In order to be more specific it is usual to divide the term into the two aspects of adequacy and security shown in fig1

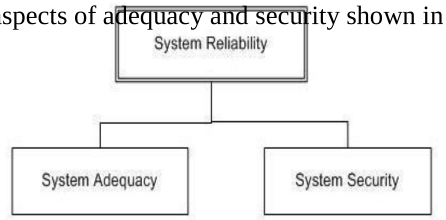



Figure 1

Adequacy considers the system in static conditions which does not include system disturbances. It relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. System Security, on other hand, relates to the ability of the system to withstand sudden perturbations arising within it.

Assessments methods in power system are mainly applied to different hierarchal levels [5] 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. These levels are described in fig.2.

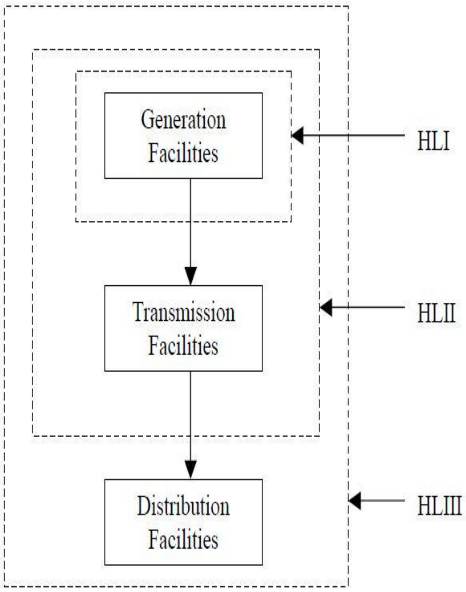



Figure 2

Adequacy evaluation at HL1 is concerned with only the adequacy of generation to meet the system load requirement and this area of activity is usually termed as generating capacity reliability evaluation. Both generation and associated transmission facilities are considered at HLII adequacy assessment and is sometimes referred to as composite system or bulk system adequacy evaluation. HLIII adequacy assessment involves the consideration of all three functional zones in an attempt to evaluate customer load point adequacies. Therefore, Evaluation of HLIII is therefore termed as overall power system adequacy assessment. The reliability indices calculated at each hierarchical level are physically different. System reliability is usually predicted using one or more indices which quantify expected system reliability performance and is implemented using criteria based on acceptable value of these indices. This paper focus on reliability assessment in composite system.

## II. Basic Indices for Composite System Assessment Planning

Both the load point & system indices are necessary to provide complete assessment of Composite system adequacy and can be categorized as annualized and annual indices. Reliability of composite system calculating over one year referred as annualized indices. Over other annualized indices require less computing time and can provide satisfactory indication when compared with different other alternatives. Annual reliability indices, However are calculated are based on the actual time varying load throughout the year. The basic indices [1, 2] used in composite system are as follows:

1. Probability of Load Curtailment (PLC)

$$PLC=\sum_{i \in S} p_i$$

2. Expected Frequency of Load Curtailment (EFLC)

$$EFLC=\sum_{i \in S} (F_i - f_i) \text{ occ. /yr}$$

The expected no. of Load Curtailments (ENLC) is often used to replace EFLC

$$PLC=\sum_{i \in S} F_i \text{ occ. /yr}$$

Fi can be calculated by the following equation:

$$Fi = p_i \sum_{k \in N} \lambda k \text{ occ. /yr}$$

3. Expected duration of load Curtailment (EDLC)

$$EDLC = PLC \times 8760 \text{ hrs/yr}$$

4. Average duration of load Curtailment

$$ADLC = EDLC/EFLC \text{ hrs/disturbance}$$

5. Expected load Curtailment (ELC)

$$ELC = \sum_{i \in S} C_i F_i \text{ MW/yr}$$

6. Expected demand not supplied (EDNS)

$$EDNS = \sum_{i \in S} Ci F_i \text{ MW}$$

7. Expected energy not supplied (EENS)

$$EENS = \sum_{i \in S} Ci F_i D_i = \sum_{i \in S} 8760 \text{ Ci Pi MWh/yr}$$

8. Expected damage cause (EDC)

$$EDC = \sum_{i \in S} Ci F_i D_i W \quad \text{k\$/yr}$$

9. Bulk power interruption index (BPII)

$$BPII = (\sum_{i \in S} C_i F_i)/L \text{ MW/MW-yr}$$

10. Bulk power/energy curtailment index (BPECI)

$$BPECI = EENS/L \text{ MWh/MW-yr}$$

11. Bulk power-supply average MW curtailment index (BPACI)

$$BPACI = ELC/EFLC \text{ MW/disturbance}$$

12. Modified bulk energy curtailment index (MBECI)

$$MBECI = EDNS/L \text{ MW/MW}$$

13. Severity Index (SI)

SI = BPECI× 60 system min/yr

## III. Analytical Technique For Reliability Assessment Of Composite Power System

The most common analytical methods for reliability assessment are described in this section:
1. State space method
2. Contingency enumeration method
3. Minimal cut set method

**STATE SPACE METHOD**

In this the most important parts of the state space method are presented. For further details, references [5] and [6] are recommended. The modeling of a component is typically based on an Up and a Down state. The relationship between m (up-time or mean time to failure: MTTF), r (down-time or mean time to repair: MTTR) and T (cycle time which is the sum of the up-time and down-time), is illustrated by Figure 3. The state space is a set of all possible systems states, and can be described using a state space diagram. For a single component system, the state space diagram would look like shown in Figure 4, where λ and μ are the systems transition rates (failure rate and repair rate, respectively).

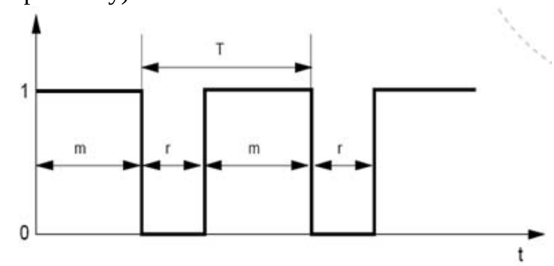



Figure 3

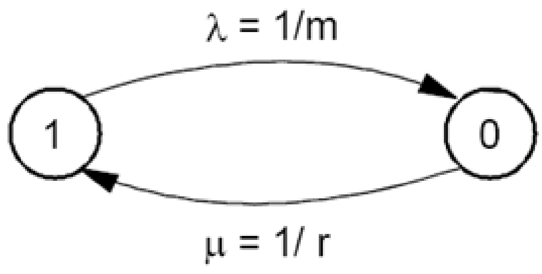



Figure 4

**Contingency Enumeration Method**

The contingency enumeration method (sometimes called the state enumeration method) is another analytical method, which, as the name implies, assesses the reliability through analysis of a selected number of contingencies. A good description of the contingency enumeration method can be found in references [3], [8] and [9]. In reliability evaluation of distribution systems, simplified contingency enumeration methods may be used. One such method is the RELRAD (RELiability in RADial systems) method [11], where the radial structure of the distribution systems is utilised to perform efficient reliability analyses.

For HL II reliability evaluation, the contingency enumeration method can be structured in four steps, see Figure 5, which are further described in this section.

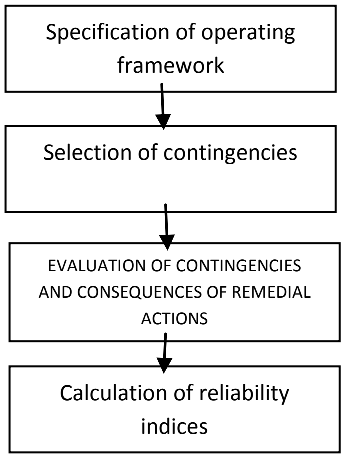



Figure 5

**MINIMAL CUT SET METHOD**

The basic functionality of the minimum cut set method is described. Reference [7] is recommended for further details. The minimal cut set method is a good tool to utilise when assessing the reliability of specific load points in the power system. The method reduces computation time by focusing on the system contingencies which are relevant for the selected load points and not for the entire system. The minimum cut set method is sometimes called the failure mode method, since the cut sets define the failure modes of a load point. A minimum cut set is defined as a set of system components which, if all are in failed state, causes outage at a selected load point. The logic minimum cut sets can be described as:

- Components of a minimum cut set behave like they are connected in parallel, i.e. all have to fail to cause system failure (see Figure 6).
- Several minimum cut sets behave as connected in series, i.e. failure of one minimum cut set causes
  system failure (see Figure 7).

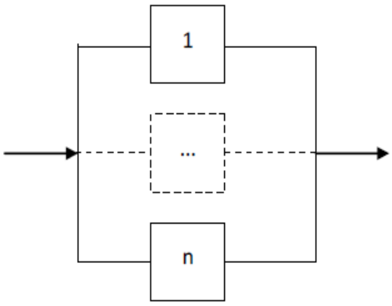



Figure 6

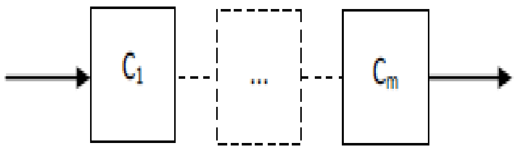



Figure 7

## IV. Reliability Assessment Using Monte Carlo Simulation Technique

Monte Carlo techniques solve difficult reliability problems using random numbers. Monte Carlo methods are non-deterministic, and they fall into the category of statistical calculations. It is based on transforming set of random numbers into another set of numbers (random variables) which have the same distribution of the variable considered. In each iteration, the result is stored and, at the end of all iterations, the sequence of results generated is transformed into a frequency distribution that permits the calculus of descriptive statistics such as mean and standard deviation. Monte Carlo simulation can provide information related to the probability distributions of the reliability indices in addition to their average values.

Monte Carlo Simulation comprises of two techniques.

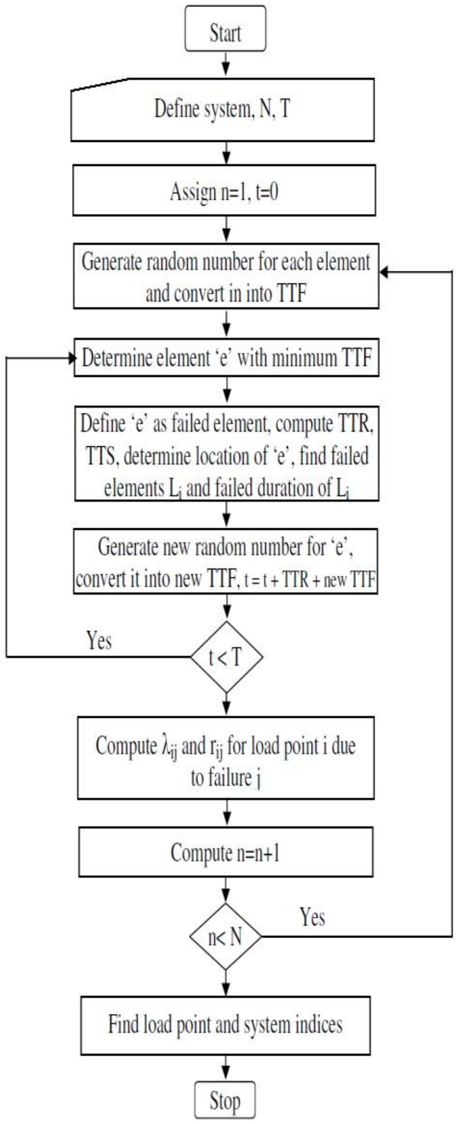
1. Non-Sequential technique
2. Sequential Technique

Non-sequential technique follows two steps

a. State Sampling method
b. State Transition method

The basic state sampling technique is relatively simple. It only involves the generation of uniformly distributed random numbers in the range of 0 to 1 instead of sampling distribution. Relatively little basic reliability data such as the component-state probabilities are required by the technique. The obvious disadvantage is that the state sampling technique estimates the frequency of load curtailments as the sum of load curtailments states. This not gives the actual frequency value.The state transition sampling method can be used to calculate exact frequency index without sampling the distribution function and storing chronological information as in the sequential technique. The restriction in this technique is that it only applies to exponential distribution component state durations.

Whereas the sequential method can be used to accurately calculate the actual frequency indices and can incorporate any state residence time distribution. Compared to the relatively simple state sampling technique, this method requires considerable CPU time and storage [2].




Flow chart for Monte Carlo Simulation algorithm

## Fault Tree Analysis Technique For Reliability Assessment Of Power System

### A. METHODOLOGY

Events in a fault tree are associated with statistical probabilities. For example, component failures typically occur at some constant failure rate K (a constant hazard function). In this simplest case, failure probability depends on the rate K and the exposure time t:

$$P = 1 - \text{Exp}(-\lambda t)$$
$$P \approx \lambda t,\ \lambda t < 0.1$$

A fault tree is often normalized to a given time interval, such as a flight hour or an average mission time. Event probabilities depend on the relationship of the event hazard function to this interval. Unlike conventional logic gate diagrams in which inputs and outputs hold the binary values of TRUE (1) or FALSE (0), the gates in fault tree output probabilities related to the set operations of Boolean logic. The probability of a gate's output event depends on the input event probabilities.

An AND gate represents a combination of independent events. That is, the probability of any input event to an AND gate is unaffected by any other input event to the same gate. In set theoretic terms, this is equivalent to the intersection of the input event sets, and the probability of the AND gate output is given

$$P(A \text{ and } B) = P(A \cap B) = P(A)P(B)$$

An OR gate, on the other hand, corresponds to set union:

$$P(A \text{ or } B) = P(A \cup B) = P(A) + P(B) - P(A \cap B)$$

Since failure probabilities on fault trees tend to be small (less than .01), $P(A \cap B)$ usually becomes a very small error term, and the output of an OR gate may be conservatively approximated by using an assumption that the inputs are mutually exclusive events:

$$P(A \text{ or } B) \approx P(A) + P(B),\ P(A \cap B) \approx 0$$

An exclusive OR gate with two inputs represents the probability that one or the other input, but not both, occurs:

$$P(A \text{ xor } B) = P(A) + P(B) - 2P(A \cap B)$$

Again, since $P(A \cap B)$ usually becomes a very small error term, the exclusive OR gate has limited value in a fault tree.

### B. Fault Tree Analyses Steps

**1. Define the top event** - To define the top event the type of failure to be investigated must be identified. This could be whatever the end result of an incident may have been, such as a forklift overturning. Determine all the undesired events in operating a system. Separate this list into groups having common characteristics. Several FTAs may be necessary to study a system completely. Finally, one event should be established representing all events within each group. This event becomes the undesired event to study.

**2. Know the system** - All available information about the system and its environment should be studied. A job analysis may prove helpful in determining the necessary information.

**3. Construct the fault tree** - This step is perhaps the simplest because only the few symbols are involved and the actual construction is pretty straightforward. Principles of construction. The tree must be constructed using the event symbols listed above. It should be kept simple. Maintain a logical, uniform, and consistent format from tier to tier. Use clear, concise titles when writing in the event symbols. The logic gates used should be restricted to the AND gate and or gate with constraint symbols used only when necessary. An example would be the uses of the oval constraint symbol to illustrate a necessary order of events that must happen to have an event occur. The transfer triangle should be used sparingly if at all. The more the transfer triangle is used, the more complicated the tree becomes. The purpose of the tree is to keep the procedure as simple as possible.

**4. Validate the tree** - This requires allowing a person knowledgeable in the process to review the tree for completeness and accuracy.

**5. Evaluate the fault tree** - The tree should then be scrutinized for those areas where improvements in the analysis can be made or where there may be an opportunity to utilize alternative procedures or materials to decrease the hazard.

**6. Study tradeoffs** - In this step, any alternative methods that are implemented should be further evaluated. This will allow evaluators to see any problems that may be related with the new procedure prior to implementation.

**7. Consider alternatives and recommend action** - This is the last step in the process where corrective action or alternative measures are recommended.

## V. Conclusion

In this paper, Reliability Assessment Techniques are compared. It is observed that both Monte Carlo Simulation & Analytical Techniques are same in terms of solving power flow problems to identify system deficiencies & perform an important role in assessing Composite system Reliability efficiently and accurately, While differ with regard to process of selecting states and evaluating reliability indices. Major drawback of Monte Carlo Simulation is the long computational time while in analytical technique computational effort is much less.

It is observed that fault Tree analysis approach is more complex in comparison of analytical technique.

Comparison showed that the indices are calculated in lower time and more accuracy using analytical technique.

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