SPS and/or NPS *allow power systems planning* personnel to benefit from the following enhanced facilities.

— Automatic voltage regulators and turbine governor systems.
— Implementation of control systems by means of a dedicated macro language.
— Investigation of symmetrical or unsymmetrical network conditions, such as simultaneous occurrence of faults at different locations.
— Phasewise-controlled static VAr compensators.
— Different machine models.
— Transformers with automatic load tap changers.
— Different relay representations.

53.6. TOOLS FOR POWER SYSTEM STUDIES

For planning, designing and analysing power systems, various means are used. These are called the tools for analysis. Important tools, available today include the following :

1. DC Calculating Board
2. AC Calculating Board (Network Analyzer)
3. HVDC Simulator (Ref. Ch. 47)
4. Transient Network Analyser (TNA)
5. Special High Frequency Models.
6. Digital Computer (Sec. 24.5)

Transient Network Analyser (TNA0 is used for Transient analysis and simulation of AC Networks. Due to non-linearit and varying machine characteristics, some problems of AC systems cannot be solved by digital computer. TNA is a useful tool in which the AC Network can be closely represented.

The response of AC Networks to fast switching transients, lightning transients etc. is simulated on special *high frequency models.*

Problems on HVDC systems are analysed on *HVDC simulator.*

SUMMARY

Power system studies are generally aid to control room engineer, planning engineer, design engineer. The power system studies are carried out by means of Transient Network Analyser (TNA), HVDC Simulator, Digital Computer. The Network is represented by an equivalent physical or mathematical model. The studies include (1) steady state studies (2) Transient studies and also (1) Static studies (2) Real time studies.

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Power System Reliability Studies

Reliability — Quantitative Evaluation — Terms and Definitions — Rliability Indexes — Procedure of Evaluation — Service interruptions — Failure Mode and Effect Analysis FMEA — Types of Failures — Availability — Schedules Outage — Forced Outage — Summary

54.1. INTRODUCTION

The term 'reliability' is closely associated with *'outages', interruptions', 'failure', 'availability'* etc. and the reliability is closely associated with switchgear, protection and control. Absolute 100% reliability and availability of generating systems, transmission systems and distribution systems cannot be guaranteed. However, a very high level (99.99%) is aimed at and is being achieved in developed countries. High reliability (more than 99.8%) is possible with

— Availability of generation, transmission and distribution systems.
— Reserve capacity (margin) between installed capacities and expected maximum load.
— Design and quality aspects,
— Operation and Maintenance aspects.

An important aspect of power system studies involves *quantitative evaluation* or reliability, availability, security etc.

1. As required by the load.
2. To be supplied by the supply company ; proposed generating/transmission/distribution system.

Quantitative evaluation calls for precise definitions of terms, reliability indices, computer programs etc. the studies are based on set theory probability theory, combination analysis etc.

For quantitative evaluation, the *reliability performance* of constituent 'components' of the system should be known.

Alternative designs and alternative choice of components is considered while evaluating the service reliability. The choice of the following is based on the studies of reliability.

— Service reliability and cost of alternative components.
— Service reliability and cost of alternative system configuration.
— Maintenance requirements of components and subsystems.
— Operating practices and policy.
— Switching and protective schemes.

54.2. TERMS AND DEFINITIONS*

1. **Adequacy.** To have sufficient margin between generating capacity and maximum load.

2. **Availability.** A term which applies either to the performance of individual components or to a system. Availability is the long-term average fraction of time that a component or system is in service satisfactorily performing its intended function. An alternative and equivalent definition for availability is the steady-state probability, that a component or system is in service.

* *Courtesy* : IEEE.

3. **Component.** A piece of equipment, a line or circuit, or a section of a line or circuit, or a group of items which is viewed as an entity for purposes of reliability evaluation.

4. **Interruption.** The loss of electric power supply to one or more loads.

Interruption frequency. The expected average number of power interruptions to a load per unit time, usually expressed as interruptions per year.

5. **Outage.** The state of a component or system when it is not available to properly perform its intended function.

Repair time. The clock time from the time of component failure to the time when the component is restored to service, either by repair of the failed component or by substitution of a spare component for the failed component. It is not the time required to restore service to a load by putting alternate circuits into operation. It includes time for diagnosing the trouble, locating the failed component, waiting for parts, repairing or replacing, testing, and restoring the component to service. The terms *repair time* and *forced outage duration* can be used synonymously.

6. **Scheduled outage.** An outage that results when a component is deliberately taken out of service at a selected time, usually for purposes of construction, maintenance, or repair.

7. **Scheduled outage duration.** The time period from the initiation of a scheduled outage until construction, preventive maintenance, or repair work is completed and the affected component is made available to perform its intended functions.

8. **Scheduled outage rate.** The mean number of scheduled outages per unit of exposure time for a component.

9. **Switching time.** The period from the time a switching operation is required because of a component failure until that switching operation is completed. Switching operations include such operation.

10. **Expected interruption duration.** The expected, or average, duration of a single load interruption event.

11. **Exposure time.** The time during which a component is performing its intended function and is subject to failure.

12. Failure. Any trouble with a power system component that causes any of the following to occur.

1. Partial or complete plant shutdown, or below-standard plant operation.
2. Unacceptable performance of user's equipment.
3. Operation of the electrical protective relaying or emergency operation of the plant electrical system.
4. Deenergization of any electric circuit or equipment.

A failure on a public utility supply system can cause the user to have either of the following :

1. A power interruption or loss of service.
2. A deviation from normal voltage or frequency of sufficient magnitude or duration.

A failure on an in-plant component causes a forced outage of the component, that is, the component is unable to perform its intended function until repaired or replaced. The terms *failure and forced outage* are often synonymous.

13. **Failure rate (forced outage rate).** The mean number of failures per unit of exposure time for a component. Usually *exposure time* is expressed in years and *failure rate* is given in terms of failures per year.

14. **Failure Mode Effect Analysis (FMEA).** (Ref. Sec. 54.4).

15. **Forced unavailability.** The long-term average fraction of time that a component or system is out of service as a result of failures.

16. **Mean Time to Failure : MTTF**

Mean Time Between Failure : MTBF

17. **Reliability.** The term describes the ability of continuous service without outages/failure/interruptions. It is expressed as

$$\text{Reliability Index} = \left(\frac{\text{Total Service Hours} - \text{Interruption Hours}}{\text{Total Service Hours}}\right) \text{Per year.}$$

18. **Security.** Ability of the power system to continue to operate normally even with specified failures ; without cascade tripping and overall blackout.

19. **System.** A group of components connected or associated in a fixed configuration to perform a specified function of distributing power.

20. **Unavailability.** The long-term average fraction of time that a component or system is out of service caused by failures or scheduled outages. An alternative definition is the steady-state probability that a component or system is out of service. Mathematically, unavailability = (1 – availability).

54.3. RELIABILITY INDEXES

Various *Indexes have been considered in the past. Two types have proven useful for quantifying Reliability of Power Supply Systems.*

1. Loan interruption frequency.
2. Extended duration of load interruption events.

After computing these indexes for a supply system, the following other indexes are also computed.

1. Total expected average interruption time per year.
2. System availability or unavailability as measured at load supply point under consideration.
3. Expected energy demanded but not supplied, per year.

The disruptive effects of interruptions on the consumer are often non-linear with respect to the duration of interruption. Hence it is often desirable to compute :

1. Overall interruption frequency.
2. Frequencies of interruptions categorized by appropriate durations.

A typical example of simple Reliability Index for power supply at consumer's premises is given below :

Reliability Index of power system

$$= \left[\frac{\text{Total Hours} - \text{Interruption Hours}}{\text{Total Hours}}\right] \text{Per year.}$$

54.4. PROCEDURE OF SYSTEM RELIABILITY EVALUATION

The procedure for system reliability evaluation is described below :

1. Assess the service reliability requirements of the loads and processes supplied and determine appropriate service interruption definition or definitions.
2. Perform a failure mode and effects analysis (FMEA) identifying and listing those component failures and combinations of component failures which result in service interruptions and constitute minimal cut-sets of the system.
3. Computer interruption frequency contribution expected interruption duration, and the probability of each of the minimal cut-sets of (2).
4. Combine results of (3) to produce system reliability indexes.

54.5. SERVICE INTERRUPTION

The *service interruption* should be assessed as a first step in reliability studies. The clear definitions of service interruptions with respect to reduced voltage level (voltage dip) duration of voltage dip, loss of supply etc. should be determined in advance.

To simplify the analysis 'continuity' of supply or service, is used as a measure to calculate services interruptions. *Interruption in service continuity is generally used in computations of Reliability Indexes.*

54.6. FAILURE MODE AND EFFECT ANALYSIS (FMEA)

The failures or outages of *'component'* or *'combination of components'* (see Defn. 54.2.3.) is analysed and is called FMEA component outages are categorized as

1. Forced outages or failures
2. Scheduled (maintenance) outages
3. Overload outages.

Forced outages may be temporary outages or permanent outages. Permanent forced outages require repairs or replacements before restoration of service continuity. Temporary (transient) outages imply no permanent damage and no need for repairs/replacement.

In addition, component failure can be classified by physical mode or *type of failure.* This type of failure classification is important for switchgear and protective devices.

1. Faulted, must be cleared by back-up breaker
2. Fails to trip when required
3. Trips falsely
4. Fails to reclose when required. Each of the type will have different impact on service continuity and system performance. FEMA is a useful tool in reliability studies.

54.7. Availability

Availability means the equipment/plant/supply system is functioning satisfactorily and is in service. (Defn. 54.2.2.) Overall availability of generating, transmitting and distribution system depends on whether any part is out of service, due to any of the following :

1. Scheduled outage (for maintenance)
2. Forced outage (Due to fault or accident)

The *probability* of any plant or equipment being out of service as a result of (1) or (2) can be computed from statistical data of performance of existing plant and equipment.

54.8. Scheduled Outage

Planned preventive maintenance is carried out to avoid forced outage the plant and equipment.

Maintenance of switchgear and protection-gear consists of periodic checking of proper operation, condition of contacts and operating medium of circuit-breakers etc. Recent microprocessor based protective relays have self-checking feature or self-monitoring feature. The trend is towards maintenance free circuit-breakers and reliable protective gear.

54.9. Forced Outage

Statistical probability of any component of supply system being forced out of service due to its own failure is defined as proportion of a given period (exposure time) during which it is forced out of service.

$$\text{Forced Outage Rate } p = \frac{\text{Period of Forced Outage}}{\text{Given Period}}$$

$$\text{Given Period} = \text{Period of Forced Outage} + \text{Period Available for Service}^*$$

* (Excluding Scheduled outage).

The corresponding probability of the same component being 'available' for service is called 'Service Probability' or 'Service Rate'.

$$\text{Service Rate } q = \frac{\text{Period Available for Service}}{\text{Given Period}}$$

Note that $p + q = 1$.

SUMMARY

Reliability refers to continuing service without failure or outage. Reliability is calculated in terms of Reliability Indexes. Reliability of each component and group of components should be known before assessment of Reliability of Power System. In developed countries Reliability of 99.99% is generally achieved.

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