Power System Reliability
POWER SYSTEM RELIABILITY

Today’s electric power system networks are comprehensively multifaceted and are volatile in operational behaviour with large interruptions. From the power system reliability point of view, a consumer aspires for an uninterrupted power supply with optimum unit cost from the DIS Cos. The higher investments lead to more availability of power generation and improved continuity of the power supply to the consumers. This chapter provides a general theoretical background to the research and the related literature survey. The statement of problem, thesis objectives and main contributions were also presented.

2.1 BACKGROUND OF POWER SYSTEM RELIABILITY

Owing to huge number of power projects under construction, controllers and other stakeholders are in the industry for inspection of essential arrangements and extensive needs. Many strategies propose associated routes which raise questions for decision makers about the maximum use of limited transmission corridors. Modern power system consists of number of utilities interconnected together and power exchanged between utilities over tie-lines by which they are connected [10]. In order to achieve interconnected operation system, an electric energy system must be maintained at a desired operating level with proper planning having frequency limits, voltage profiles of load bus, reactive power limits at generating bus with minimum line losses.

The planning of power system can be achieved by proper scheduling the power generation during the normal and adverse conditions for stable operation. The ability of power flow in an electric power system is possible with controlled operation and without generations reschedule or topology changes can improve the power system performance. The main function of an electric power system is to satisfy the system load demand requirement 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 of reliability [11].

The concept of power-system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. Electric power system is extensively complex and possesses unpredictable operational behaviour of interruptions. Ideally, power system reliability in viewpoint of consumers means uninterrupted supply of
power from the generation, transmission, or distribution systems to consumers. Electrical engineering is divided into three separate groups of specializations: generation, transmission, distribution of Power to the consumers. The operation of power system network with stable and good response characteristics in a closed loop system is the concern of the control area of specialization, which are typically represented in a line diagram of power flow from higher level to lower level at various stages as shown in Figure 2.1.

The aim of traditional electric power generation system is to generate the electrical energy with sufficient amount at appropriate locations and to pass on it to the various load centers with the good quality and reliability. In this revision the idea is to study the electrical transmission system reliability assessment for continuity of the power flow is main concern, which consists of high voltage and high capacity transmission lines which carry the generated energy through long distances in order to make the energy available nearest to the load centers [12]. The voltage level of this transmission system varies from 132kV to 750kV or 765kV. Regulating transformers are used to control the active and reactive components of the energy. Also various VAR controlling devices are preferable in this transmission system.

SECTION BREAK UP

- 2.2 Functional zones and hierarchical levels
- 2.3 Deterministic versus probabilistic approaches
- 2.4 Transmission Expansion Plan (TEP)
- 2.5 Forecasting of future needs
- 2.6 Factors influencing the long-range transmission plan
- 2.7 Deregulated utility environment
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2.2 FUNCTIONAL ZONES and HIERARCHICAL LEVELS

Power system adequacy assessment can be conducted in all the three basic functional zones of generation, transmission and distribution. Three hierarchical levels (HL) can be structured by combining the functional zones shown in Figure 2.2. In a hierarchical level I (HL-I) study, the total system generation including interconnected assistance is examined to determine its adequacy to meet the total system load demand.

![Hierarchical Levels Diagram]

Figure 2.2 Hierarchical levels for power system reliability assessment [10].

Reliability assessment at HL-I is normally defined as generating capacity adequacy estimation. At level II (HL-II) includes both the generation and transmission assessment of the integrated ability of the composite system to deliver energy to the majority offer points [10, 16]. This analysis is usually termed as composite system reliability assessment. Adequacy evaluation at hierarchical level III (HL-III) includes all of the three functional zones and is not easily conducted in a practical system due to the computational complexity and scale of the problem. These analyses are usually performed only in the distribution functional zone. Such as generation stations transmission lines, substations, switching stations and distribution systems.

2.3 DETERMINISTIC versus PROBABILISTIC APPROACHES

Essentially, reliability studies provide predictions. In general, the basic activities associated with reliability assessment can be divided into the two fundamental segments of measurement, i.e. based on (i) Past performance. (ii) Predicting future performance.
Prediction is not a certainty, but they are probabilistic in nature. In most of the engineering system design techniques, prediction of future performances is also involved. However in real time application, most of the methods are deterministic only. This also applies to the older methods used in the reliability studies [10, 16].

2.3.1 Traditional Approaches (deterministic)

In this approach, system design and operating polices are based on pre selected tests: failure criteria are defined so that certain combinations of the system and load conditions must not represent immediate system breakdown or even excessive component stress. Make sure that these criteria are met, “worst–case conditions” are analysed and the computed stresses and strengths for the case are set apart by a “safety – factor”. The drawbacks of the traditional methods

- Variations in the input data is ignored
- Selection of “worst–case conditions” is arbitrary. Important conditions may be omitted, unlikely conditions may be included.
- The assumption of failure risk in the designs satisfying traditional criteria is misleading. In fact, the approach provides no idea how safe the design actually is the effort to stay on the safe side on design.

2.3.2 The probabilistic approach

In this approach, the system design and operating must not exceed pre-selected limits. While the probabilistic approach requires far more sophisticated analysis, the concept of limiting the risk of system failure can be very clearly interpreted, the impact of failures can be assessed, and the method avoids the potential disparities inherent in the traditional approach. “Indices used in the probabilistic approach”, are serve as reliability measures. Such indices are measurable quantities i.e. they have numerical values. Typically the indices used in this method are probability of failure, frequency of failure, mean durations of failures and expected amount of energy per year is unable to supply.

2.4 TRANSMISSION EXPANSION PLAN (TEP)

Transmission system is one of the major components in the electric power industry. Therefore as electric loads grow, transmission expansion planning should be carried out in timely and proper way to facilitate and encourage competition. The main goal of power system planning in regulated power systems is to meet the demand of loads, while
maintaining power system reliability. Transmission expansion planning is centralized and coordinated with generation expansion planning. Therefore, planners can design the least cost transmission plan based on the certain reliability criteria. The long term transmission plan objectives are:

1. The expected future needs must meet with the delivery of energy and to build easy energy to do business across the regions.
2. Minimization of environmental values and its impact on network spreading out.
3. Is malleable to a broad scope of future conditions as much extent as possible.
4. Is not deliberately overbuilt, while recognizing that transmission growth is lumpy.
5. Present forecast guidance for near-term judgment making [13].

Transmission system planning includes detailed evaluation of transmission facilities over a period of 20 years. As distribution load forecasts are considered, it is feasible that projections signify that one or more reliability criteria would not be met at some date in the future. In such belongs, corrective actions are developed and remedial measures are developed and assured system planning continues to comply with reliability criteria. The various feasible actions that can address system reliability deficiency are:

1. Large transmission lines on the existing right-of-way (ROW) or new ROW.
2. Increasing the capacity of existing transmission components by re-conductor of existing transmission line with higher ampere capacity conductor or the use of high temperature low sag conductor (HTLS) and Installation of parallel transmission transformer.
3. Upgradation of existing facility to a higher voltage.
4. Installation of transmission capacitor banks in various transmission lines as well as in distribution stations and/or combinations of the above.

Interconnection of new generation resources reliability criteria can be met in some cases only. Latest generation resources aren't solely a supply of extra real power, however, they are supplies of reactive power, all of that facilitate bring the system into compliance with reliability criteria. Resources closer to load will provide greater reactive support than those supplementarily away. At some purpose, the interconnection of latest generation resources is required to satisfy reliability and provides needs. In reality, the key indicators of a power system’s reliability for consumers are the frequency and duration of interruptions at their point of utilization (i.e. Load point). From an engineering point of
view, the question is how to mathematically determine the load point interruptions and energy not supplied to the utilities then how to, assess the electrical power production (generation), transport of power (transmission) and to supply distribution system.

2.5 FORECASTING OF FUTURE NEEDS

To achieve planning, it largely requires the following forecasting needs:

- Must predict future demand for electricity, generation capability and acceptable reserves needed to fulfill the forecast load
- Must create assumptions regarding future load growth, the temporal arrangement and site of future generation additions and different connected assumptions
- Must create associate degree assessment of the transmission facilities needed to supply for the economical and reliable access to jurisdictions outside the country.
- May, if the ISO considers it necessary to try to do, build associate degree assessment of the contribution of a projected transmission facility to any of the following:
  - Increasing the transmission system reliability.
  - An enthusiastic competitive market.
  - Transmission system efficiency must be improved.
  - Operational benefits for flexibility.
  - Transmission system expansion for long term [13].

At planning level and maintenance stage, the transmission system should have followed these steps for the past 20 years:

i. Forecasting of load on the interconnected electrical system, together with exports of electricity.

ii. Generation Capacity Expansion (GCE).

iii. Detection of timing and position of future generation.

iv. The transmission facilities required to meet load forecasted must be finalised and also need to satisfy the requirement of imports and exports.

v. Must provide efficient and reliable access power for jurisdiction of transmission facilities.

vi. Other matters related to the items described above in sub-clauses (i) to (v) which the Central Electricity Regulating Authority has to (CERA)

- The transmission system plan must update periodically as required.
• Construct the transmission plan which includes the assumptions and supporting data on which the plan is developed, available to the community, and file copies of them with the Commission and the Minister for information

2.6 FACTORS INFLUENCING THE LONG-RANGE TRANSMISSION PLAN

Which the various factors will affect the plans are as follow [13]

i. The need to modify reliability requirements.

ii. The economic load forecasts Changes and the effect of demand side management (DSM) programs.

iii. State’s energy regulating program effects.

iv. Other state and national policies such as the Regional Greenhouse Gas Initiative.

v. Latest business in generation and transmission.


2.7 DEREGULATED UTILITY ENVIRONMENT

During the years of 1970 to 80s, almost all the electric power utilities throughout the world were operated with an traditional power system structure and the generation, transmission and distribution are owned by a single entity called as ‘Vertically Integrated Electric Utility’ (VIU) that supplies power to the customers with Motto of service to the Nation. It is operated with a governmental model in which one controlling authority, i.e. the utility operated as a fixed geographical area and it refers to as Vertically Integrated Electric Utilities (VIEU). There was a fragment of hesitation that whether the monopoly organization was efficient.

There is quick change in philosophies in respect of resources line information technology, communication technology, smart metering system and SCADA etc. which brought a revolution in power sector. In a vertically integrated power system, it is equipped with bulk generating units. There was a small piece of doubt whether the monopoly organization was efficient. There is a deep change in philosophies in respect of Telecom, Air Lines and IT Sectors, which brought a revolution in power sector also. The vertically integrated electric utilities have their own generation, transmission and distribution
systems which supply power to the customers at regulated and subsidy rates are shown in the Figure 2.3.

<table>
<thead>
<tr>
<th>Monopoly model</th>
<th>Single buyer</th>
<th>Wholesale completion</th>
<th>Wholesale/retail competition</th>
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<td>Public utility</td>
<td>Generation1</td>
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<td>Generation2</td>
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<td>Transmission</td>
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<td>Transmission/MO/SOE</td>
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<td>Distribution</td>
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<td>Consumers</td>
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Vertical Integration Monopoly Model

Figure 2.3 Vertically Integrated Utility Structure.

Vertical integration is at the heart of the economics of organization. Monopoly model Each IPP (Independent power producers) contract PPAs (Power purchase arrangement) with public utility of government only. Single buyer competition was introduced only to the electricity whole sale sector. The market where the independent single buyer produces wholesale electric power based on fixed contracts with the power producers through competitive bidding. Whole sale competition market introduces only to the electricity wholesale sector. Wholesale/retail competition market is introduced to both electricity wholesale and retail electric power sector.

Consumers can select power providers other than conventional power company. The present power systems operation has assumed commercial significance and technical considerations like availability, demand and generation, transmission adequacy, which weigh against the economic background of the countries. The electric utility introduced new concept of deregulation in this sector in order to improve availability, efficiency and derive the economic benefits. Many electrical utilities and power network companies’ worldwide have been coerced to change their ways of doing business from vertically integrated mechanism to open market system. This kind of process is called as deregulation or restructuring or unbundling. At present, electricity market has been restructured as separate entities of generation, distribution and transmission are carried by different bodies like GEN. Cos (Generation Companies), TRANS CO’s (Transmission
Companies) AND DISCOs (Distribution Companies) as shown in the Figure 2.4. These changes in the structure of electric utilities and the creation of free markets for energy trading are bringing about a redefinition of power system operation and forcing a re-examination of the design concepts for control centers.

Many utilities over the world are on the threshold of system operation as they enter into the arena of a free electricity market. Of late, several improvements have been achieved in power system operation. The evolution was mainly in the development of computational and communication systems. But, now-a-days, a Disco has the freedom to contract with any Gen. Co, in its area or in any other area for transaction of power. This is called “Bilateral Transaction”. The other structure is open access in which bilateral contracts transactions are directly organized between generator and consumer.

2.8 TRANSMISSION RELIABILITY ANALYSIS IN DEREGULATED UTILITY ENVIRONMENT

2.8.1. The economic perspective

An important issue in today’s deregulated utility environment is reliability. Customers demand high level of service and desire the lowest possible cost. It seems easiest way to improve the reliability by designing new infrastructure that is much more reliable than the old depreciating system. Due to capital cost of building new facilities and budget constraints, it is not however a realistic solution to build new infrastructure [9-12]. The existing infrastructure must, therefore be modified to improve its reliability and performance.

Eventually the reliability issue should decide whether to go for building new or modify the existing infrastructure. Most of the large electric utilities had become
completely vertically integrated i.e. single companies controlled not only the bulk of the generation facilities but also the transmission and distribution lines that represented the only link to the final customers. The resulting development of a complex, vertically integrated inter-state electricity marketplace meant states no longer had clean jurisdiction over these national entities.

The combination of regulatory failure at the state level, and the simultaneous expansion of the inter-state electricity market called for government intervention and subsequent unbundling of power utilities. The prohibitive approach of the states from opening up the retail electric market to competition through “unbundling”, the process of separating into its three distinct components viz. generation, transmission, and distribution, in order to allow consumers to buy electricity from generators of their own choice, resulted in more confusion because of power system complexities.

In generally restricting inter-state integration and expansion, state by state restricting efforts become difficult, since the unbundling process might serve to create new monopolistic companies and thereby create a vicious circle of regulatory and legal battles among intra-state and inter-state policymakers. It will harm consumers by discouraging the development of competitive opportunities in those areas in where the government power providers remain active because these entities are accorded favourable treatment relative to private power providers.

In other words, if legislation attempts to open electric markets to competition without simultaneously privatizing the transmission and distribution wings, a most uneven playing field will be the result, that will diminish the beneficial effects of liberalization for consumers. Moreover, unfair and anti-competitive subsidies remain in the electricity marketplace must be eliminated if deregulation is to be a success. Independent power producers proved they make better use that of resources and also help to reduce costs.

In addition to that, mandating the private companies to use specific alternative technologies which have not yet proved themselves feasible in the open market could set the original goals of deregulatory legislation. If solar, wind, hydrothermal or other forms of alternative power production as their own prematurely mandating their use, however, could prove uneconomical to companies struggling to complete in newly liberalized markets, and it could drive up consumer prices extensively as benefit of fight to hold.
2.8.2 The technological perspective

Emergent control technologies making rigorous use of Information and Communication Technologies (ICT) appear to be potentially useful for dealing with this new situation. But the entire request will insist a new approach to design and operation. Indeed, their integration within existing control infrastructures and practices is a real challenge. These factors contribute to increase in power system vulnerabilities, in a worldwide scenario where malicious threats against large and complex infrastructures are increasing [9]. The application of various ICTs in power system is to monitor, control, protection, and other vital functions. The potential of further improving system operation, flexibility, security margins and overall cost, they are subjected to threats not fully understood; especially those derive from the interaction with the power system infrastructure.

This introduces further vulnerabilities that should be accurately assessed. Deregulated power systems are undergoing an in-depth restricting so as to implement open access and cope with enlargement, progressive integration of the state electricity market and intensification of interstate trade [9]. Growing demand, hectic transactions, growing number of stockholders, complexity of controls are all the factors which contribute to an increased vulnerability of the electrical infrastructure as made patent by the major blackouts in recent years. In that context, the state power utilities must keep and expected to enhance current standards about security of supply. The basic actions to reach the goals,

- Improved network security through increased collaboration and exchange of information between transmission system operators
- Defining and agreeing on common security and reliability standards
- Developing and implementing common standards, measures to protect physical infrastructures.

Recent blackouts and power shortages which occurred in different parts of the world with unprecedented widespread effect and frequency have showed growing vulnerabilities of present power system. Today’s power systems are getting more complex, with sometimes unpredictable behaviour, and they become more difficult to master. During disturbances, communication and information systems failures may be detrimental to power system integrity and security. It is recognized that innovation based on ICT for security improvement, while optimizing system performance and control, is a key factor in this context.
Power system controls also need to restructure so that to cope with a worldwide scenario where malicious threats against large infrastructure are intensifying. However, emergent control technologies including wide area monitoring and adaptive controls, which could potentially participate positively in providing a response to such difficulties and barriers, are difficult to integrate with the existing control architectures and legacy systems. Indeed, they imply a change of paradigm in the way power system controls are to be organized and interact with human operators. They also imply extensive use of broadband communication facilities, thus increasing the exposure of the power infrastructure to accidental failures and malicious threats.

2.8.3 Different effects of ICT system failure at grid level

- Loss of information or corrupted observability
- Corruption of emergency management system functions
- Loss of generation capacity
- Loss of lines and/or corridors
- Malfunction of protection or power control devices
- Power system instability

Direct effects on distribution grids or on generation plants may also have immense indirect impact on transmission grids.

2.8.4 The benefits of deregulating the market

The benefits of deregulating the electricity market fall into seven principal concepts

- Increased competition, lower prices
- Lower operating costs for business and regional cost differences
- Increased reliability of service, a cleaner environment, More jobs.

2.9 POWER SYSTEM ADEQUACY versus SYSTEM SECURITY

Today’s new operating environment for electrical power system is to supply its customers with electrical energy as economically as viable possible and with an acceptable level of reliability. The prerequisite of reliable electric power supply enhance the significance of dependence of modern society on electrical energy. Electric power utilities therefore must provide a reasonable assurance of quality and continuity of service to their customers. The plan of assurance depends on the desires of the consumer and the allied cost of providing the overhaul [10, 14].
In general, additional reliable systems engross huge economic investment. It is unrealistic to undertake to design a power system with 100% reliability. The power system planners and engineers have at all times attempted to reach a sensible level of reliability at an inexpensive cost. It is quite clear that reliability and related cost/worth evaluation are important aspects in power system planning and operation reliability of a power system is defined as the ability of power system to supply consumers' demand continuously with acceptable quality.

The concept of power-system reliability is extremely broad and covers all the aspects of the ability of the power system to satisfy the customer needs. The perception of power system reliability may be reasonable involves the security and adequacy and can be recognized a healthy, marginal (alert) and emergency (at risk) concerned and designated as “system reliability”. System reliability can represent in two basic aspects one is system adequacy and system security are indicated in below Figure 2.5.

![Figure 2.5 Sub-division of System Reliability](image)

**System Adequacy**: It relates to the existence of sufficient facilities within the system to satisfy the consumer load demand or operational constraints. 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 don’t include system disturbance.

**System Security**: It 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 perturbations it is subjected to. These include the conditions associated with local and widespread disturbance of major generation, transmission, services etc.
2.10 POWER SYSTEM ADEQUACY METHODS

2.10.1 Deterministic approach

In this, no measure of reliability exists. Criteria are set in terms of pre-determined tests. Example: The system must retain its ability to supply all loads during [10]. The loss of the largest generating unit and loss of selected loads cause inadequacy. As this approach follows predetermined norms, this methodology is being constantly phased out as it is not suitable to dynamic nature of the present day complex systems.

2.10.2 Probabilistic approach

Reliability is measured with the help of probabilistic indices. For example, the probability or the frequency of failures or the expected number of days per year when peak load is not met may be required in a typical assessment of power system reliability. The probabilistic reliability criteria are predetermined index values which separate the regions of the acceptance and rejection. For example, a design requirement may be that the index of expected number of days in year when the peak load demands is not met should be less than 0.1 day/year (one day in ten years).

2.11 POWER SYSTEM SECURITY METHODS

2.11.1 Deterministic approach

It is unfeasible to protest against all sudden contingences. This approach can be implemented by setting and operating at security limits for the line loadings. Which are lower than the thermal limits, generally used in adequacy studies for operating the power system network. The operating limits are determined by stability tests for the above set of contingencies [10].

2.11.2 Probabilistic approach

In this approach, the following indices are proposed based on system security

- Probability that the next disturbance will result in an unstable
- Mean time to instability
- Probability and frequency of a stable state reached after limited.
- Probability and frequency of system collapse

Based on the above calculations, the following are typical applications to be carried out for ensuring system security:

- Determination of reliability trends
- Comparison of alternatives
- Assessment against reliability criteria and balancing costs and benefits

Reliability analysis can be made based on the following time frames:

- Time frame A (from the present to a few hours or days)
- Time frame B (up to 1 yr)
- Time frame C (up to the end of the operating time horizon - 2 to 4 years)

For the safe operation of the power system, planning studies are carried out in the above time frames. Another aspect of reliability is system integrity, the ability to maintain interconnected operations. Integration is violated causes an uncontrolled separation occurs in presence of severe disturbance. Most of the probabilistic techniques presently available for power system reliability evaluations are in the domain of adequacy assessment.

There are two basic and conceptually mythologies are present for evaluation of power system reliability shown in above Figure 2.6. An analytical approach represents the system by a mathematical model and evaluates the reliability indices from this model using analytical solutions. The Monte Carlo simulation approaches, however, estimate the reliability indices by simulating the actual process and random behaviour of the system and treats the problem as a series of real experiments. Monte Carlo simulation usually requires longer execution time a conventional methods.

2.12 POWER SYSTEM DATA AVAILABILITY AND ITS IMPORTANCE IN FAILURE ASSESSMENT [9]

Failures in transmission facilities affect large sections of the system and therefore can have widespread and may cause catastrophic consequences. Unavailability of transmission line, extra high tension substation or a failure of important components such as potential transformers, current transformers or capacitive voltage transformers etc. will lead to reduced transmission reliability. In the absence of comprehensive and complete
data, an individual power utility is forced to arrive at some consistent criterion based on experience and judgment of few individuals in higher positions.

As this criterion is human knowledge sensitive, extensive computerization of data is required for assessing the benefit of expansion and reinforcement/augmentation schemes for obtaining improved availability. Different utilities apply different failure criteria in developed and developing countries. So, it is not possible to present uniform rules for defining failures. Also different policies exist for taking corrective action when a system problem is encountered. What is considered a correct action by one utility may be considered a failure by another.

System disturbance data are needed to monitor actual performance and compare with similar and closely identical utilities as a means of assessing performance. Past performance assessed is needed to develop predictive models which are needed to analyze complex system behaviour to delineate planning and operational issues, i.e. system adequacy and security requirements. Failures of substation components such as transformers, circuit breakers and disconnecting switches etc., are to be tabulated chronologically for statistical data collection for review as outage statistics.

Frequency and duration of interruptions caused by transmission lines are to be meticulously recorded for analysis. A reliable substation design has an ultimate impact on the overall system performance. The immediate consequence of poor substation design is the failure to contain simple disturbances. Hence, there is strong economic incentive to review the reliability of sub-station designs. Sub-Station reliability can’t be detached from grid/transmission reliability. It is the overall transmission system reliability with crucial concern.

2.13 LITERATURE SURVEY
(1) R.Biliinton et al. [17], presents on reliability issues on today’s electric power utility environment. This manuscript describes the changes, services creating them and the possible reliability issues linked with them. Today’s electric power utilities environment all over the world is undergoing substantial revolution in to size wise, structure, operation and regulation. This is particularaly true in those countries with highly developed and complex systems. The ‘unbundling’ of vertically integrated utilites has twisted a situation in which the overall dependability for serving the electrical energy needs of the individual
customers does not live in a utility and is hard to assign. In general, the new planning criteria should address the following issues:

- Maintain power flow continuity with the designed loading enlargement while being financially acceptable.
- Uncertainties linked with deregulation, wheeling and transmission access, and crumbling of the distribution systems
- Generation and transmission systems modelled as integrated

This results push towards privatization and deregulation of the electric utility industry and it will initiate an extensive range of reliability issues. These issues will need new system reliability criterion and methodical tools that identify the remaining fears related with power system planning and act.

(2) Haitao Liu et al. [18], describe the evaluation of power system reliability using selection technique based on fast sorting algorithm (FSA). In this technique the probabilities of few high level outage states may be superior to those of a few low level outage states because system equipment may not be the same. The amount of these large level outages causes huge probabilities for bulky practical power system. The effect on system reliability can vary considerably due to high level outage.

This method uses a pre-process for assemble system apparatus based on their probabilities in climbing order. The number of system states are measured, the precision of reliability index obtained using the proposed procedure is much higher than the existing methods. Further, the same correctness and the number of system states to be evaluated using the proposed method that is much less than that existing method. The anticipated technique has been developed for IEEE-RTS

(3) G. Hanoud & R. Billinton [19], presents an approximate and practical approach which include uncertainty concepts in Generating Capacity Reliability Evaluation (GCRE) based on the recursive algorithm and Fourier transform techniques for evaluation of LOLE index in single area system for The IEEE Reliability Test System considering the uncertainty. This paper also described about fairly accurate and practical to evaluate the effect of uncertainty associated with the generator forced outage rates and the forecast peak loads on the LOLE of single area system. The Fourier transform technique also provides a continuous distribution approximation of the discrete capacity outage
probability model. This approximation model may be valid in certain systems and generally improves as the system size increases. The results obtained in these cases are in reasonable agreement with those obtained using the recursive algorithm.

(4) Fang Yang et al. [20], focuses on the evaluation of a bulk power system reliability using the technique called systematic record of contingencies and the valuation of their effects on the system over a variety of system power demand levels. Contingencies and power demand states are represented, with Markov models. Reliability indices are calculated using these models. Both adequacy and safety approaches are used. In adequacy approach, an improved system simulation method is used based on the single-phase quadratized power flow. Corrective measures are also applied for the purpose of all the alleviating abnormal conditions and realistic operator actions. The applications of the adequacy approach on two test power systems are presented and evaluation results show the influence of remedial actions on system reliability.

(5) J. Endrenyi et al. [21] describes on various techniques for assessment of bulk power system reliability concepts and applications. The paper also presents concepts on probabilistic methods to assess’ bulk power system. In this report, the modelling and computational difficulties are investigated, and the stipulation of matching programme precision and computing effort is stressed. The main points in this paper are bulk power system reliability evaluations performed for many purposes. Changing political and economic factors, such as energy prices or demand growth rates, may change the importance of some of the program features and shift the emphasis from energy to capacity considerations or vice versa. The requirements of greater program accuracy and smaller computing effort are conflicting in each of application; a judicious balance must be established between the two factors.

(6) Jin-O. Kim and Chanan Singh [22], present an article on uncertainty includes in LOLE Calculation Using Fuzzy Set Theory. This manuscript presents an indefinable approach using fuzzy set theory to manage the uncertainties in the reliability input data of real power systems. The article develops an algorithm to calculate the possibilistic reliability indices according to the degree of uncertainty in the given data. In this algorithm, the transformation is performed by making a compromise between the transformation consistency and the human experience. The IEEE-RTS with 32-generating units is used to demonstrate the capability of the proposed algorithm.
The fuzzy set theory using Max-Min operation of fuzzy numbers has been introduced to manage the uncertainty, and the fuzzy classification theory is also applied to reduce the number of load data and computation time. Large number of load data used and has been clustered into small number of classes using fuzzy partition matrix and the cluster centers representing each class along with their membership have been used in fuzzy calculation to evaluate the reliability index. The computation time has been improved dramatically through the efficient fuzzy arithmetic operation, and economic usage of the computer storage area also shows the feasibility of algorithm.

(7) T. X. Zhu [23], assessed the Expected Energy Not Supplied (EENS) in bulk power system reliability enhancement. The analytical formula of EENS with respect to component reliability variables, such as component availability and unavailability, component failure rate and repair rate, component ability is proposed. The system EENS, can help us to identify the system “bottlenecks” effectively and provide essential information for power system planning and operation.

(8) Majid Moazzami et al. [24], presented an article on power system reliability enhancement using powerformer™, which is a high voltage generator without transformer connected to grid. It is a high-voltage generator is a novel type alternator with XLPE insulation for windings on recent days. The main noteworthy of these alternators has higher availability, and additional reactive power boundary, short period congestion capacity and removing the power transformer from the structure of the power plant. They investigated the installation effect of these generators on the bulk power system reliability.

The reliability indices evaluated using 6-bus IEEE-RBTS system replacing the conventional alternators by new powerformers. The reliability indices results obtained show that the expected duration of load curtailment (EDLC) and the expected energy not served (EENS) are improved. It shows that the more number of powerformers in the electric power system, the reliability indices were improved.

(9) W. Zhang et al. [25], focused on cost/benefit related reliability analysis for the estimation of bulk power systems. Today’s financial component plays a key position in the application of reliability concepts and it must achieve a satisfactory level of reliability. Insufficient reliability of power supply finally affects the costs and customers much more than good reliability. It is, therefore, significant to find out the optimal reliability level at
which the reliability investment achieves the most excellent results in minimizing the customer damage costs due to power supply interruption. The consumer damage cost (ECOST) is a function of interruption frequency, duration of interruption, load lost, position, other community and social effects.

This manuscript presents a method to compute the calculation of the ECOST (expected customer damage cost) and the related IEAR (interrupted energy assessment rate) indices in composite power systems. These cost associated with the reliability index are estimated in the form of annualized values. Two reliability test system studies are conducted which result an insight into the discrepancy of the indicator with different system factors. The investment cost is deterministic in nature and can be obtained using well-established methods. The customer damage cost is probabilistic and is conceptually an aggregated value of the customers who are willing to pay to avoid the load interruptions or voltage standard violations.

(10) Nahid-Al-Masood et al. [26], concern about the operation of electric power generation is a major mission, i.e. operation, planning, design, and maintaining the power supply at acceptable level of reliability to its users. This article presents the assessment of power system reliability index for Bangladesh Power System (BPS) using recursive algorithm and considering the node-rated states of generators. In this paper reliability index ‘LOLP’ of BPS using recursive algorithm is evaluated for the period of last ten years considering maximum demand of BPS is about 5000 MW which has an total installed capacity of 5275 MW. During this period a considerably increasing in LOLP is observed due to poor reliability of the power system of Bangladesh. Thus the reliability analysis of BPS will help estimating the service quality of the system. It will also create awareness among the utility and the consumers of the system and will assist in planning and operation of BPS.

(11) David C. Yu et al. [27], presents an application of Bayesian networks (BN) to the problem of reliability assessment of power systems. Bayesian networks afford a flexible means of representing and reasoning with probabilistic information, the uncertainty and dependencies are easily incorporated in the analysis. Able probabilistic algorithms in Bayesian networks permit not only computation of the loss of load probability but also answering and it can be useful tools for reliability assessment of power systems. The
validation results show that the proposed model calculates the loss of load probability (LOLP) index with the same accuracy of other analytical methods.

The BN model is uniquely capable of directly computing the indices are most valuable for the enhanced system reliability assessment. The results of the case studies on the 4 area test system illustrate the robustness of the proposed model. Increase in the load uncertainty will increase the LOLP indices. The results shows that, decision can be made for reinforcing weak points in the power network to ensure the required reliability level of a power supply system.

(12) Roy Billinton and P. G. Harrington [28], proposed the limited generation capacity studies for considering the effect of unit forced outages and uncertain load requirements to examining the reliability associated with a generation configuration using an energy based indices. The concept is based on the Expected Loss of Energy Approach and extends the technique to include the consideration of energy limitations associated with generation facilities. The most obvious form of energy limitations is associated with hydraulic services and therefore the types of energy limitation considered have been formulated keeping these points in view:
(a) Units with no energy storage facilities such as run-of-the-river installations
(b) Units with facilities capable of storing energy until a peak load period
(c) Units whose energy supply makes them suitable for part base load and part peak saving
(d) Units with substantial storage facilities in which specified quantities of energy are available within certain periods.

(13) M. Fotuhi and A. Ghafouri [29], proposed the considerations of load demand uncertainty in the bulk power system reliability indices assessment using fuzzy logic method. Today’s Power systems are nonlinear and large-scale systems, extracting their reliability indices involve much uncertainty. This method is used to evaluate the reliability of composite power systems as a most accurate one and uses load flow results in different conditions. Thus, consecutive outage of each unit and transmission line is considered and then load flow equations are solved. The sensitivity and importance of the reliability of a given network conditions leading to system risk is determined and they will be taken into account in the calculation of reliability indices. Also on snowy days, because conducting wires of transmission lines get heavier, their failure rates increase. In this article the effects of such considerations into reliability calculations are imposed using fuzzy logic. Different
weather conditions and load changes were considered for reliability calculations performed for the effect of various conditions on reliability indices were examined.

(14) Paul F. Albrecht et al. [30], presented a load demand model, generation model, and transmission network for performance estimation. The objective is to define system sufficiently for wide range to provide a basis for reporting on analysis for combined composite reliability methods. The goal is to establish a core system which can be supplemented by individual with additional or modified parameters needed in a meticulous application. For illustrations, the reliability test system as reported in this article does not include data on the following:

- Substation pattern at generation/load buses
- Distribution system configuration
- Interconnections with other systems
- Protective relay configurations
- Future expansion, such as load expansion, future unit capacities and reliability.

(15) Jasmon, G.B. et al. [31], proposed a new technique in minimal path and cut set method for the evaluation of complex systems in reliability engineering. They introduced a strong idea of minimizing the entire number of minimal paths to its basic minimal path. The idea minimizes the evaluation time and storage capacity in finding the minimal cutsets. Various examples are considered for exhibiting the supremacy of the method in minimizing the computational necessities as compared to the conventional method and illustrate that the duty for analyzing huge systems now becomes important.

(16) Daniel Nack [32], Iowa State University in 2005 proposed the reliability evaluation of various sub-station arrangements based on the conventional method. Because the substations are the strongest points in an electric power system and carry bulk amount of electrical energy, it causes the failure of weak components such as breaker, line, transformer etc. or points of failure that would lead to loss of load. By knowing these indices for different substation setups, an engineer can use these indices to design a better substation configuration with the best overall efficiency of continuity. Determining the substation reliability can also be important for existing installations as it can help locate weak points that may be contributing to overall system unreliability. This article also presents an overview in determining substation reliability indices and then through the use of an example show how various configurations can be compared.
(17) Ahmed R. Abul’ Wafa et al. [33], presented an article on decision making process for cost effective and reliable substation solutions. The assessment of substation reliability is vital role in assessing the overall power system performance. Any components failure in substation can lead to numerous outages with possible cascading failures and extensive loss of customer load. In this a technique is developed for modeling, analyzing, and selecting appropriate configurations for sub-stations based on different criteria, such as power flow, interruption cost, reliability necessities, initial funds, function and maintenance. The article presents five different configurations of substation reliability estimation for operating characteristic of load point have been undertaken.

The criterion is coupled with the Life Cycle Costs (LCC) with allied interest rates and substation life cycle period. The tactic is implemented by utilizing specialized tools for calculating reliability and estimating cost efficiency. It is applied for comparison between the most commonly used sub-station/switching station configurations using conventional and alternative technologies. To execute this method the authors developed necessary logical software tools. The complete reliability considerations for various substation models are developed in this paper which can provide quantitative basis for decisions making on selecting the suitable arrangement of substation for meticulous kind of consumers.

(18) C. J. Zapata, A. Alzate and M. A. Ríos [34], focused the Reliability assessment of substations using Stochastic Point Processes and Monte Carlo Simulation, assuming that the failure and repair processes are stationary and making a great simplification on the protective systems modeling by the most important features are:

i. Manage time varying rates, a requirement for those scenarios development/weakening of element reliability, prophylactic maintenance and repair performance.

ii. It allows the explicit illustration of the custodial systems, its working sequence and the cause of failures.

iii. It does not need an extensive list of working states as other techniques do. It needs lengthy evaluation time for the simulation.

(19) Miguel Vega and Hector G. Sarmiento [35], presented an algorithm for evaluation of Substation Reliability using minimal Cut sets, Path Sets, graph method and frequency parameter method. This step by step procedure considers failures in breaker, breakers
blocked and breaker backup security to detach faults in a substation. Active and Passive outages are considered. Two estimate criterions are used for assessment of substation failures. One load point fails and the entire points of load fail substation fails. The rate of power not supplied is used to assess and compare economically for the substation reliability. The algorithm can be used to compare various substation designs based on their reliability. The algorithm can be used to justify investments considering the concept of ENS.

(20) J.J. Meeuwsen and W.L. Kling [36], presented the substation reliability indices based on the switching actions with disconnect switches. The simulation algorithms, which deduce the contingencies before and after switching actions with their corresponding reliability indices, are described in detail in the article. The manuscript reports on results obtained from analyzing six different busbar schemes with redundant components. The contingencies caused due to failures in substation configurations are most important aspect. For such simulations, a thorough understanding of system behaviour of operation is lot more essential.

(21) M. Z. A. Ab Kadir et al. [37], focused on Substation System Simulation Models for Transformer Risk Assessment Analysis. The paper revises a study to assessed lightning stresses on the 132 kV substations to improve its reliability in the event of active lightning behavior. The paper also detailed the modeling parameters of substation for this transient analysis in order to calculate the performance and to suggest such arrangement to minimize its design to be not only to withstand the stresses but to be more cost effective. The representation is based on single phase line model as it was recommended by the IEEE to be sufficient to symbolize the substation in transient analysis simulation.

The result of this manuscript would be the results of lightning stresses in term of voltage level measured at particular points in substation. The validation of the result was earlier compared with previous work done by Savic and Stojkovic to make sure the model was valid. The placement of arrester is crucially needed in order to optimize the substation performance in term of its reliability and cost effective. The arrester is best suited for optimized performance if it is installed near to the crucial point compared to the substation entrance. In this case, it is very important to have this surge arrester as close as possible to the equipment to be protected.
(22) R. Billinton et al. [38], present a time sequential Monte Carlo simulation approach for switching substation reliability assessment. The technique is illustrated by application to a sensible configuration associate degree accustomed judge the station dependability indices that square measure then compared with those obtained exploitation an analytical methodology. These results show that the simulation method can provide adequate indices. The simulation technique is also used to execute station sensitivity investigation by varying preferred station piece of parameters. This type of analysis can play a pivotal role in improving power system reliability and is essential and necessary in the selection of significant components. The Monte Carlo simulation technique is utilized to expand probability distributions associated with the station reliability indices. The article illustrates how the simulation method can provide additional indices which cannot easily be obtained using an analytical method.

(23) T. Lantharthong et al. [39], address the evaluation of distribution system reliability indices for planning studies and operation. The distribution systems reliability indices are plays an significant issue in power engineering for both utilities and customers. Reliability is a key concern in the design and operation of electric power distribution systems and load. Reliability evaluation of distribution Systems has been the subject of many recent papers and the modeling and evaluation techniques have improved considerably. This manuscript has reviewed some aspects of reliability research in distribution systems in the following three main topics:

- Introduction concepts of reliability in distribution system
- Reliability indices system
- Reliability Assessment of distribution system

The operation and maintenance costs due to low reliability can be reduced by adequate planning, monitoring system behaviour and taking proper control actions

(24) R.E.Brown et al. [40], presented the distribution system reliability evaluation based on the interruption profile and distribution system based on system topology and component reliability statistics. Many utilities do not have sufficient chronological section reliability records to carry out such estimation. The paper shows a way of gaining ample assurance in a reliability model by developing a validation method. Distributions system reliability models can be validated by adjusting default component reliability parameters so that predicted results match historical results. This has been demonstrated on a 4 feeder
test system by adjusting overhead line default parameters so that predicted values of MAIFI, SAIFI and SAIDI match historical values. This will facilitate the incorporation of the reliability into design and planning procedures which will aid in providing high levels of reliability in the lowest possible cost.

(25) Robert J. Rusch, David L. Metz and P. E. Stanley[41], identified customer oriented reliability indices based on the data collection only for Electric system reliability is being used for marketing as well as system engineering. They described that immense improvement is indeed for better customer services in the present situations. Reliability analysis gives that the real problem in the areas of important so as to effective action can be taken to improve customer service. This is followed by data collection and reduction. In this article the authors develop the calculations for the selection of relevant indices that are important to a given cooperative. The calculated indices should reflect actual customer perception based on the types of electric equipment the customer utilizes. Those indices then can be used as both a measure of customer satisfaction and a ‘report card’ to record progress in improving service. An improving ‘report card’ means that investment is being effectively utilized.

(26) L. D. Arya et al. [42] focused on probabilistic reliability indices evaluation of electrical distribution system accounting outage due to overloading and repair time omission. The article considers a technique for modifying failure rate and repair time of a distributor section accounting the outage due to overloading and omission of critical repair time termed as repair tolerance time. Essential associations have been derived for modification of failure rate and repair time of a distributor and these modified failure rate/repair time have been used to evaluate the average outage duration, annual outage duration and average failure as year for distribution systems. In this manuscript, the authors have measured two aspects for evaluate reliability index of distribution system,

(i) Secondary outage of the component owing to too much overload and

(ii) Repair time omission of a section. The effect of repair time omission is to increase ‘repair rate’ or decrease ‘average interruption duration’ at load point. Unavailability or average interruption duration per year also decreases. Average interruption duration and average interruption duration per year are of prime importance from consumer viewpoint.

(27) Nagaraj Balijepalli et al. [43], found that customer power supply reliability is an important part of distribution system operation and planning. Monte Carlo simulations
square measure noticed the system of the reliability index, at the side of their mean and variance. Standard deviation of the reliability index provides distribution engineers with information on the anticipated range of the annual values. Analysis of outage data from a practical distribution system is performed to determine the failure and repair models appropriately using the Monte Carlo simulation.

Sensitivity studies presented in the paper to indicate that the SAIFI, SAIDI histograms are largely independent of the statistical model of the failure process while the SAIDI depends to a greater extent on the repair duration model. Depending on the connectivity and protection design, the SAIFI of individual feeders may exhibit multimodel behaviour. Such multimodel behaviour is usually absent in larger systems. In this paper, analysis of a practical distribution feeder is used to illustrate the nature of SAIFI.

(28) Fangxing Li, [44], focused on Reliability Index Assessment and Reliability-Based Network Reconfiguration in Power Distribution Systems. The article primarily shows a distributed processing approach of reliability index assessment (RIA) for distribution systems and proposes a balanced task partition approach to achieve better efficiency. Next, the distributed processing of RIA is applied to reliability-based network reconfiguration (NR) that employs an algorithm combining local search and simulated annealing to optimize system consistency. The results are demonstrated to the speeded execution of RIA and NR with distributed dispensation. It should be especially attractive for NR application.

(29) Lance A. Irwin [45], demonstrates the distribution reliability has always been the central focus of network operators. However, they must also focus on sustainability and efficiency. Maintaining the balance between quality, reliability and efficiency requires new tools for the network operator. This article describes a system that utilizes various methods for monitoring and reporting power quality information to help utilities maintain the balance of quality, reliability, and efficiency. Engineering technologies are available today to help utilities mitigate the impacts of outages but also to prevent the outages by monitoring their systems and evaluating the data. The innovation and adaptability of engineers at utilities will prove to be the key in taking power quality information and using that information to improve system reliability.
(30) ALDO ARRIAGADA et al. [46], proposed a methodology for the evaluation of reliability indexes in medium voltage radial distribution power systems. A universal reliability index is obtained as well as loss of frequencies and duration indexes for customers and individual installation. A linear optimization methodology is developed to identify networks element where investments allow increasing availability level for any customer in the system. A computer program was designed, developed, tested and used to evaluate several test electrical distribution systems. This manuscript also presented a methodology, an approach to evaluate the impact in the reliability indexes for a radial distribution system. The method will help find the adequate investments to reach adequate levels of customer service.

2.14 RESEARCH OBJECTIVES (THESIS OBJECTIVES)

From the above discussions and the literature reviewed to Carrey out the reliability evaluation of electric transmission systems, with the following main objectives

1. Reliability modelling and assessment of generating systems utilizing the uncertainty consideration in the load duration characteristics for index evaluation.
2. Evaluation of various EHVAC Substation configuration reliability indices for practically used configurations.
3. The evaluation of distribution system reliability indices for service continuity and average energy not supplied to consumer.
4. To improve the overall performance of the deregulated power system.
5. To model expansion plans.
6. To minimize the interruption costs and to review the maintenance schedules.

2.15 PROBLEM STATEMENT

Power system reliability indices play a major role in the planning and productivity performance operation of the polluted power system network. This is also a subject which has gained importance in the recent past, due to its robust activities in environmental conditions, because of the several interruptions, disturbances that take place in general operations. This disturbance could be of many types, like line outage, sudden loss of synchronism, abnormal operation, etc. The effective and efficient operation need to be developed for on-line monitoring at an earliest possible time. In view of the above adequate discussion and the applicable literature reviewed on power system reliability, the reliability evaluation of electric transmission systems mainly depend on three factors, such
as, evaluation of bulk power system reliability indices, EHT AC sub-station reliability indices assessment and computation of distribution system reliability indices.

Computation of these indices indicates the degree of reliability for the partial power system. Hence, the reliability examination is a well documented piece in the system risk and security studies. A number of power system reliability models have been developed and proposed for estimation of these indices for better planning. But, the power system network always subjected to uncertainty of operation due to disturbances. While considering the frequency of faults and duration of faults in the network, it is found that computation indices are a major concern for partial network. Similarly, for other faults cases, the cost, as well as efficiency gets influenced a lot.

In this thesis, the reliability evaluation of electrical transmission systems can recognize the sequential changes in system performance that will help to find the weak areas and suitable modifications/reinforcements. It is vital that, Collection of data is the most important stage for the computation of these indices. In the present study, data is collected from the AP TRANs Co., 220kV sub-station, Nellore, Andhra Pradesh and APSPDCL, 33/11kV Mangalam sub-station, Tirupati and Santha pet 33/11kV Sub-station, Chittoor maintenance and interruption registers.

**Research methodology and the contributions of the thesis:**

The main contributions of the thesis are summarized as follow:

- Evaluation of Bulk power transmission system reliability indices for (IEEE-RTS) considering the uncertainty in the load demand for adequacy
- EHT AC sub-station reliability assessment using the minimal cut-set algorithm and MCS technique for four sub-station configurations.
- Development of radial distribution feeder reliability evaluation for both rural and urban feeder considering the interruption data from records more precisely.

**2.16 SUMMARY OF THIS CHAPTER**

In this chapter, importance of theoretical backdrop on power system reliability assessment methods, transmission system planning, factors influencing the transmission system etc. have been discussed. The importance of this chapter 1 and chapter 2 is that, it presents domain knowledge to the readers, which enable to understand the research in an enhanced perception.
In this chapter, the object oriented literature review has been carried to provide in-depth knowledge of a research work. Hence, the problem statement and contribution of the thesis is also given. In the initial section of this thesis, a few research works done for computation of reliability indices have been referred, many of them, implementing deterministic, probabilistic methods and simulation technologies. The subsequent chapter, (Chapter-3) would discuss the computation of uncertainty concern in the bulk power system reliability indices assessment methodology for calculation of catastrophe.