Chapter 1

Introduction

1.1 General

1.1.1 Historical Background

After World War II, reliability theory was initially used in the electronics, nuclear, and space sectors, where great reliability was required for these increasingly complex systems. The established reliability theory was primarily relevant to these areas. Because the initial failure is the most critical in such an application, reliability theory was developed primarily for non-repairable systems. Reliability analysis techniques for repairable systems are still being developed at a snail's pace. In the area of electronics engineering, a huge quantity of component failure data has been gathered, evaluated, and published at the same time as the development of reliability features. Reliability studies are being conducted in virtually every engineering discipline. In all domains, such research provide applications for both repairable and non-repairable systems.

The roots of reliability theory development may be traced all the way back to World War II. When an explanation for the poor performance of the German V-1 and V-2 missiles was sought, the first official reliability evaluation was claimed to have taken place. These were made up of a huge number of components that were thought to be very reliable. Lack of data, computational resource constraints, a lack of realistic reliability techniques, aversion to probabilistic approaches, and a misunderstanding of the significance and meaning of probabilistic criteria and risk indices are the main issues that arise when evaluating the reliability of components or systems. These arguments are no longer relevant since most utilities now have meaningful and usable data, reliability assessment methods have advanced significantly, and most engineers have a basic knowledge of probabilistic approaches. The goal of this thesis is to demonstrate the reliability of different power systems that include renewable energy sources, as well as to explain why the suggested reliability evaluation is important. As a result, a variety of reliability indices have been assessed [1].

1.1.2 Electrical Power System

Electrical power systems are becoming more complicated all the time. This may be due to a variety of factors, including its physical scale, scattered geography, interconnections, system behavior uncertainty, vast distances, and so on. The majority of the causes, whether linked to generation, transmission, or distribution, have an impact on the reliability of the power systems. As a result, it's critical to talk about why and how to evaluate power systems' reliability.

Customers in the residential, industrial, commercial, and agricultural sectors all rely on power systems to provide reliable and cost-effective energy. As a result, the level of redundancy must be proportional to the need for a reliable and cost-effective supply. The primary point of contention is cost and redundancy. As a result, the risk of consumers being disconnected for any cause, as well as the cost of over and under investments, result in a trade-off between reliability and cost. These issues are likely to cause disruptions in operations and planning management.

Despite the fact that a number of criteria have been established to account for errors that happen at random. The probabilistic or stochastic character of system behavior, such as demand, component failures, wind speed, solar irradiation, battery charging, and traffic flow rate of electric cars, was not taken into account by these criteria. Thus, the following common probabilistic features are defined.

- Forced outage rate (or repair time)
- The failure rate

Failures of components, generation plants, and systems occur randomly; the frequency, duration, and impact of failures vary from one year to the next. In general, electrical utilities save these details as they occur and produce a set of performance measures, which include the following.

- System unavailability

- Estimated energy not supplied
- Number of incidents
- Number of hours of interruptions

The important point to note is that these measures are statistical indices. They are not deterministic values but at best are average or expected values of a probability distribution. So the power system reliability indices can be calculated using analytical and simulation approaches. The analytical approach represents the system by a mathematical model and evaluate the reliability indices. This approach generally provides expected indices in a relative short computational time. Unfortunately, assumptions are frequently required for this method. Thus, simulation approach estimate the reliability indices by simulating the actual process and random behaviour of the system [2, 3].

Finally, it can be depicted that due to randomness of the power systems, there is no solution, which provide perfect reliability analysis of the power systems. However, there are some methods and indices available, through which approximate excellent reliability can be obtained. In subsequent sections, it has been discussed that how to evaluate the power systems' reliability by formulating some reliability indices?

1.2 Concept of Reliability

"Reliability is the probability of system performing its function adequately for an intended period of time under the operating conditions intended".

In engineering and technology, reliability is both an ancient idea and a modern subject. For centuries, things, processes, and individuals have been labeled as reliable if they have met specific expectations and unreliable if they have not. A trustworthy individual will never fail to deliver on his promises. The kinds of expectations used to assess reliability have all been linked to the execution of a certain job or task. The reliability of a device is high if it has consistently fulfilled its functions successfully, and low if it has a tendency to fail in repeated trials. Experience has allowed people to make educated guesses about how much faith they could put in achievement and how much they had to dread failure [4].

Electric power systems are an excellent example of a system that requires a high level of reliability. Adequacy and security are two types of reliability. Adequacy refers to whether or not the system has enough facilities to meet the clients' load demand. These facilities include the equipment needed to produce enough energy, as well as the transmission and distribution infrastructure needed to get the energy to the actual consumer load points. For various elements of the power system, such as load and generation, adequacy evaluation typically necessitates probabilistic models. The capacity of a system to react to internal disruptions is referred to as security.

Concepts must have numerical measurements in engineering applications; that is, methods must be accessible. As a result, before reliability can be used in engineering applications, it must be transformed into one or more quantifiable quantities using appropriate functions. Probability is a mathematical notion that defines reliability. Electric power systems are supposed to be very reliable. The typical length of interruptions that a customer encounters in many power systems is 2-3 hours per year. For certain industrial clients, a high level of reliability is required. As a result, one of the most important considerations in the planning, construction, operation, and maintenance of electric power systems is reliability.

The quality constraint refers to the need that the power supply's frequency and voltage stay within specified limits. Customers' perceptions of reliability will, of course, differ from one place to the next. Furthermore, reliability of various elements of the power network, such as the generating, transmission, and distribution systems, vary.

The presence of adequate facilities inside the system to meet customer demand include those needed to produce sufficient energy that deliver the energy to real consumer load locations. As a result, adequacy is thought to be linked to static circumstances that do not contain system disruptions. Security, on the other hand, is thought to be linked to a system's capacity to react to disturbances inside that system. As a result, security is linked to the system's reaction to any disruptions it encounters.

Generation systems, composite generation and transmission (or bulk power) systems, and distribution systems are all examples of systems functioning zones. The chance of finding the unit in a forced outage at some point in the future is the basic generating unit parameter utilized in the static capacity assessment. The likelihood was formerly known as the unit forced outage rate in power system applications, and it was specified as the unit unavailability in engineering systems.

The operational environment, time of operation, and quality of service provided by the system must be considered in the reliability study. Because any qualitative assessment is useless for any engineer building or planning a system, the usefulness or quality of the system must be evaluated not quantitatively, but numerically, using a numerical measure based on probability theory known as the reliability index. This environment will have an impact on the system's failure rate. A power system built in adverse region vs the system in the region with favorable weather conditions, for example, would have different failure and repair rates, and therefore a varied chance of success and failure. As a result, any reliability modeling must take the operational environment into consideration.

Naturally, the operating time of a repairable or non-repairable component is a major consideration. With an increase in the planned period of operation of a system, the likelihood of successful operation diminishes. The quality of service requires particular attention since although it may help, it may not please the customer. For example, although power may be accessible at certain customers' homes, the supply voltage and frequency may be insufficient for usage in a manufacturing operation. As a result, the traditional definition of reliability is the likelihood of a component executing its necessary function sufficiently throughout the specified duration of operation in a particular operating environment.

1.3 Reliability Functions

The reliability assessment is performed by evaluating the reliability or survival function ($R(t)$), cumulative distribution function ($f_c(t)$), failure density function ($f(t)$), and hazard rate function ($H(t)$). The method for representing failure probability of a component is its reliability, viz. the probability that the system or equipment would not fail within time (0, t). To express this relationship, Equation (1.1) has been formulated.

$$R(t) = Pr\{T \geq t\} \tag{1.1}$$

Where

- R(t) $\geq$ 0
- R(0) = 1
- $Lim_{t \Rightarrow \infty}$ R(t) = 0

Cumulative distribution function (or unreliability) $f_c(t)$ is defined in Equation (1.2), which is the failure probability occurs before time ‘t’.

$$f_c(t) = 1 - R(t) = Pr\{T < t\} \tag{1.2}$$

Where

- f_c(0) = 0
- $Lim_{t \Rightarrow \infty}$ f_c(t) = 1

Then $f(t)$ is described as the derivative of $f_c(t)$, as given in Equation (1.3) and the area under the complete $f(t)$ is obtained as 1.

$$f(t) = \frac{df_c(t)}{dt} = -\frac{dR(t)}{dt} \tag{1.3}$$

$R(t)$ depends on the term failure rate function or hazard rate function (H(t)), as given by Equation (1.4), which implies that the higher $H(t)$ will lead to the decrease in $R(t)$.

$$R(t) = e^{-\int_0^t H(t)dt} \tag{1.4}$$

Where

- H(t) = $Pr\{t \leq T \leq t + \Delta t | T \geq t\} = \frac{R(t) - R(t+\Delta t)}{R(t)}$

The derived functions R(t), $f_c(t)$, and f(t) are reproduced in Figure 1.1.

$$H(t) = \frac{f(t)}{R(t)} = -\frac{dR(t)}{dt} \times \frac{1}{R(t)} \tag{1.5}$$

From Equation (1.3), $H(t)$ describes as the early life failures, which is defined as the infant mortality, the system’s life is constant which is an actual useful life and finally, wearout failures in which failure rate drastically increases. Figure 1.2 may be used to demonstrate this. H(t) is a different method of expressing a failure distribution. When H(t) is rising, decreasing, or constant, failure rates may be described as increasing, decreasing, or constant, accordingly. To simulate equipment lifetime, any distribution may be utilized. In reality, distribution functions with monotonic hazard functions seem to be the most realistic, and there are a handful within that class that are widely considered to offer the most plausible models of system reliability. It is important to note that the following distributions can be used to obtain a life distribution of electrical power system or component.

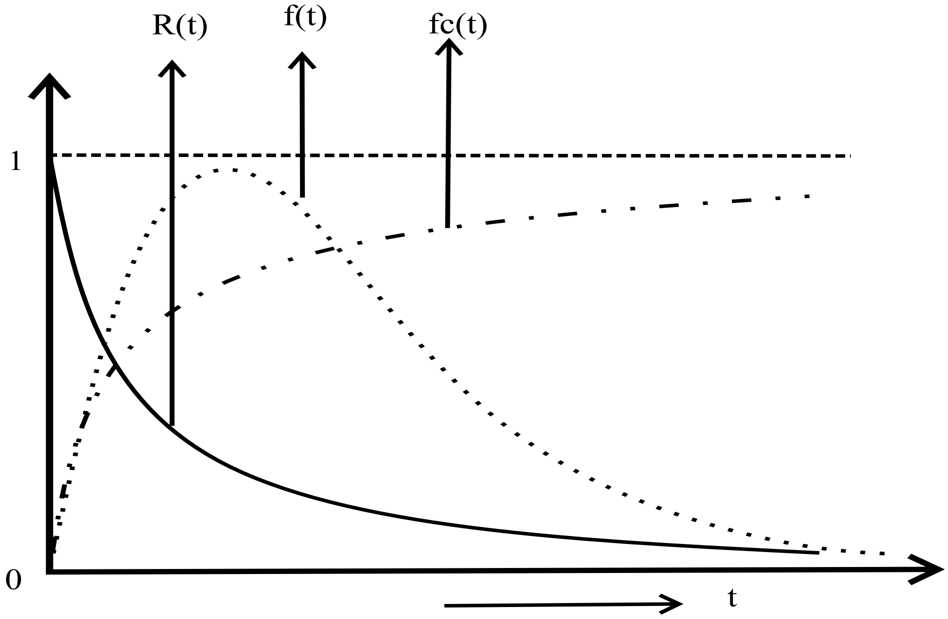

Figure 1.1: Functions related to reliability assessment.

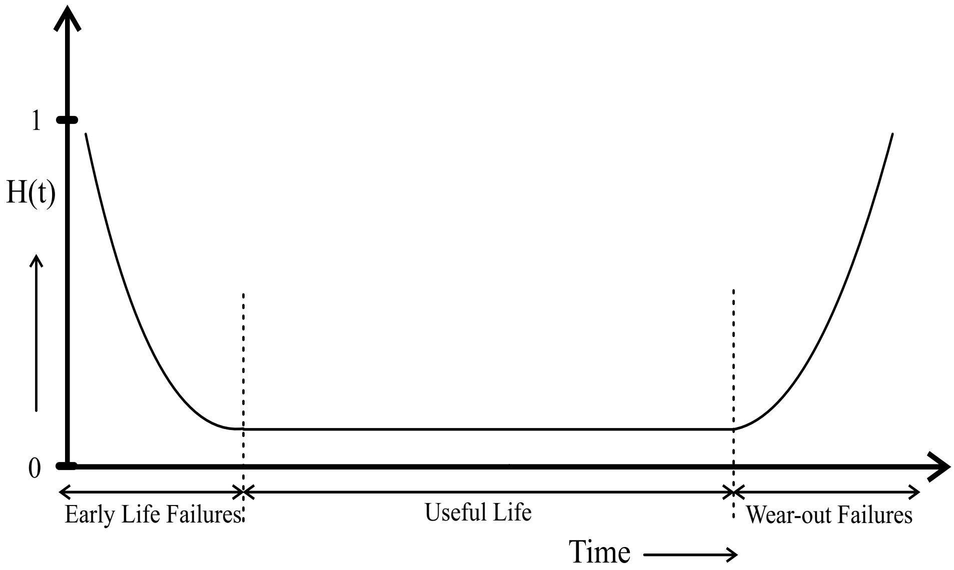

Figure 1.2: Bathtub curve.

- Binomial distribution
- Exponential Distribution
- Poisson distribution
- Geometric Distribution
- Weibull Distribution

- Normal Distribution
- Gamma Distribution

1.4 Power System Reliability

In an electrical power system: “Reliability is defined as providing adequate, stable, and reliable power for a particular distribution system”.

In power system planning, evaluating the reliability of a bulk linked combined generation, transmission, and distribution power system is crucial. Transmission lines, which link one electricity system to another, connect generating stations with the distribution system. It is possible to borrow electricity from a neighboring linked region in the event of a sudden rise in loads or loss of generation in one area. A reliability assessment of the overloaded electrical power system is required for the planning of operation, improvement, and growth of the bulk power system by a power system engineer. Interconnecting a power system to another power system improves the adequacy of its producing capacity. The actual interconnection advantages are determined by each system’s installed capacity, total tie capacity, tie line forced outage rates, load levels and residual uncertainty, and the kind of agreement between systems. One of the most important aspects of power system planning is calculating how much generating capacity is required to ensure that load needs are met in an acceptable manner.

The development of an appropriate transmission network to transport the energy of the customer load points is a second, but equally essential, step in the design process. The transmission network is split into two categories: bulk transmission and distribution. The difference between these two regions cannot be established only on the basis of voltage; it must also take into account the facility’s role in the system. Bulk transmission infrastructure must be linked with generating to allow energy to flow from these sources and to identify where distribution or sub-transmission facilities may offer a direct, frequently radial route to the consumer. In many systems, distribution design is nearly completely separated from the transmission system development process. Because of the location and size of the terminal station that emerges from the bulk transmission line, distribution system design becomes a distinct and independent procedure. The load point indices assessed for the bulk transmission system may be used as the distribution system’s input reliability indices to allow for coupling between the two systems in reliability assessment.

The issues that come with contemporary big interconnected power networks worry a power system engineer. The power system's steady-state analysis primarily concerns the control variables' base point setting in order to keep dependent variables within limitations (these may include line flows, load bus voltages, and reactive generation). Earlier research on power system reliability were limited to evaluating generating reserve capacity. Simultaneously, attempts were made to expand the studies to transmission and distribution systems, using more sophisticated analytical methods such as modeling the power systems of Markov processes.

In November 1965, the North-East United States and Eastern Canada were left without power for many hours. Nine coordinating entities, including the National Electric Reliability Council, were established as a direct result of this event. Investigations into virtually every element of power system reliability have spread out in the past 10 years. A growing number of papers have chronicled the evolution of power system reliability methodologies and procedures. The following are some of the most common words used in power system reliability assessments.

- Component
- System
- Outage
  - Forced outage
  - Scheduled outage
  - Transient forced outage
  - Permanent forced outage
- Exposure time
- Outage rate
  - Adverse weather permanent forced outage rate
  - Normal weather permanent forced outage rate
- Outage duration
  - Permanent forced outage duration

  - Transient forced outage duration
  - Scheduled outage duration
- Switching time
- Interruption
  - Scheduled interruption
  - Forced interruption
- Interruption duration
  - Momentary interruption
  - Sustained interruption
- Redundancy

The reliability assessment of an distribution network is as crucial as contrasted to other components and parts of the EPDN. The IEEE guide for EPDN reliability is adapted from standard number 1366-2012 [5]. According to the given standard, the reliability of an EPDN can be analyzed using some reliability indices. The reliability indices considered for EPDN reliability assessment include Expected Energy Not Supplied (EENS), Average Energy Not Supplied (AENS), System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Average Service Availability Index (ASAI). As described in [6], these indices are mainly classified in two categories, as elaborated in Equations (1.18)–(1.25c), which are calculated by using Equations (1.6)–(1.17).

1.4.1 Reliability Parameters

The basic parameter used in the evaluation of reliability is ‘forced outage’ at some distant time in the future. this probability parameter is defined as the system or component unavailability. In power systems, it is known as the forced outage rate (FOR), as mentioned in Equation (1.6) and (1.7).

$$\text{FOR (= Unavailability)} = \frac{\lambda}{\lambda + \mu} \tag{1.6}$$

$$\text{Availability} = \frac{\mu}{\lambda + \mu} \tag{1.7}$$

Where

- λ is expected failure rate = $\frac{1}{\text{Mean Time to Failure}}$
- μ is expected repair rate = $\frac{1}{\text{Mean Time to Repair}}$

The reliability indices are the function of reliability parameters mentioned in Equations (1.8)–(1.10). The reliability parameters have been calculated at load point 'P' as follows.

$$\text{Failure rate; } \lambda_P = \sum_{k \in n} num_k \times F_k \quad \text{failure per year} \tag{1.8}$$

$$\text{Outage duration; } U_P = \sum_{k=n} F_k D_{Pk} \quad \text{hour per year} \tag{1.9}$$

$$\text{Outage duration (or Repair Time; RT); } D_P = \frac{U_P}{\lambda_P} \quad \text{hour} \tag{1.10}$$

Where

- F_k is failure rate of the k_{th} element
- *n* is number of elements in the EPDN
- num_k is number of k_{th} elements in the EPDN
- D_{Pk} is duration of failure at P^{th} load point due to k_{th} failed element

From Tables 1.1 and 1.2 [7], failure rate, and unavailability can be determined, as given in Equations (1.11) and (1.12). The test systems' reliability indices are thus evaluated for all six scenarios using the values of λ_P and U_P, as illustrated in Equations (1.13)–(1.17).

$$\begin{aligned}\text{Failure rate, } \lambda_P = {} & (\text{no. of loads} \times \text{failure rate}_{(load)}) + (\text{no. of substations} \times \text{failure rate}_{(ss)}) \\ & + (\text{no. of feeders} \times \text{failure rate}_{(feeder)}) + (\text{no. of Gen} \times \text{failure rate}_{(DG)})\end{aligned} \tag{1.11}$$

$$\begin{aligned}\text{outage duration or unavailability, } U_P = {} & (\text{no. of loads} \times \text{failure rates} \times RT_{(load)}) \\ & + (\text{no. of substations} \times \text{failure rate} \times RT_{(ss)}) \\ & + (\text{no. of feeders} \times \text{failure rate} \times RT_{(feeder)}) \\ & + (\text{no. of DG} \times \text{failure rate} \times RT_{(DG)})\end{aligned} \tag{1.12}$$

Where

Table 1.1: Reliability data adapted for 33 bus

Component	**Reliability data for all loads, feeders, etc.**	
	λ_P(failure per year)	**RT(hr)**
Load@4	0.321	11.04
Load@(5, 7-12, 29, 30, 14, 16, 18-22, 25-28)	0.301	11.44
13, 15	0.314	11.17
17, 23, 24	0.208	1.75
31-33	0.327	10.96
substation	0.1	5
feeder (2, 3, 6)	0.2	3
DG	0.2	12

Table 1.2: Reliability data adapted for 118 bus

Component	**Reliability data for all loads, feeders, etc.**	
	λ_P(failure per year)	**RT(hr)**
Load	0.208	1.75
substation	0.1	5
feeder	0.2	3
DG	0.2	12

- $RT_{(load)}$, $RT_{(ss)}$, $RT_{(feeder)}$, and $RT_{(DG)}$ are the repair rates of load, substation, feeder, and distributed generation system.

$$\text{EENS} = \sum[(\text{Demand or load at } P^{th} \text{ load point}) \times (\text{Annual outage duration at } P^{th} \text{ load point})] \tag{1.13}$$

$$\text{AENS} = \frac{\sum(\text{EENS at } P^{th} \text{ load point})}{\text{Total number of customers at all load points}} \tag{1.14}$$

$$\text{SAIDI} = \frac{\sum[(\text{annual outage duration at } P^{th} \text{ load point}) \times (\text{Number of customers at } P^{th} \text{ load point})]}{\text{Total number of customers at all load points}} \tag{1.15}$$

$$\text{SAIFI} = \frac{\sum[(\text{average failure rate at } P^{th} \text{ load point}) \times (\text{Number of customers at } P^{th} \text{ load point})]}{\text{Total number of customers at all load points}} \tag{1.16}$$

$$\text{ASAI} = 1 - \frac{\text{SAIDI}}{8760} \tag{1.17}$$

1.4.2 System-Based Indices

The average failure rate, average outage duration, and average yearly unavailability or average annual outage time are the three main reliability indices that have been assessed using traditional ideas. Failure rate, outage duration, and yearly outage time are common terms for these indicators. They are not deterministic numbers, but rather the anticipated or average values of an underlying probability distribution, and therefore only reflect the long-run average values. Similarly, the other indices to be discussed will usually be devoid of the words ‘average’ or ‘anticipated’.

Despite their importance, the three main indices may not always provide a full picture of the system’s behavior and reaction. For example, regardless of whether one customer or 1000 customers were connected to a load point, or if the average load at a load point was 1 kW or 1 MW, the same indices would be assessed. Additional reliability indices may be used to indicate the degree or importance of a system outage, and they are often done so. This section defines the various indices that are frequently used to assess distribution system reliability.

These indices are further categorized in load-oriented indices and customer oriented indices as given in Equations (1.18)–(1.19) and Equations (1.20)–(1.25c), respectively.

A. Load-Oriented Indices

Load-Oriented Indices have been calculated at load point ‘P’, as mentioned in Equations (1.18)–(1.19).

$$\text{EENS}_P = P_P U_P \quad \text{megawatt hour per year} \tag{1.18}$$

$$\text{AENS}_P = \frac{\sum_{P=1}^{n_P} \text{EENS}_P}{\sum_{P=1}^{n_P} N_P} \quad \text{megawatt hour per customer per year} \tag{1.19}$$

Where

- P_P is demand/load of the P^{th} load point

- EENS_P is expected *ENS* at P^{th} load or customer point
- n_P is total load points
- N_P is number of customers at P^{th} load point

'EENS' is defined as "the expected amount of energy demand, which is not served to the customers by the utility or system during the period when shortage or outage happens."
'AENS' is defined as "the average expected amount of energy demand, which is not served to the individual customer by the utility or system during the period when shortage or outage happens."

B. Customer Oriented Indices

These indices have allowed to enhance the EPDN's reliability related to the improvement of customer or load services. The two of the indices namely Expected Interruption Cost (ECOST) and Interrupted Energy Assessment Rate (IEAR) are related to the cost reliability and thus, termed as reliability worth of the system, which are described by Equations (1.20) and (1.21). Understanding the type and diversity of customer effects caused by electric service disruptions is a critical first step in evaluating reliability worth indices. From the consumers' viewpoint, the cost of an interruption is proportional to the degree to which the activities disrupted are reliant on electricity. Customers and interruptions, in turn, influence this dependence. Customer characteristics include customer type, nature of customer activities, size of operation, and other demographic data, as well as demand and energy needs, energy dependence as a function of time of day, and so on. The duration, frequency, and timing of interrupts are all features of interruptions.

$$\text{ECOST}_P = P_P \sum_{k=n} f(D_{Pk}) F_k \quad \text{\$ per year} \tag{1.20}$$

$$\text{IEAR}_P = \frac{\text{ECOST}_P}{\text{EENS}_P} \quad \text{\$ per megawatt hour} \tag{1.21}$$

Where

- ECOST_P is expected interrupted cost at P^{th} load point
- IEAR_P is Interrupted Energy Assessment Rate at P^{th} load point

- $f(D_{Pk})$ is system composite customer damage function ($ per kilowatt), as provided in Table B.5 of Appendix B

'EENS' is the expected cost incurred for the interruptions happen in the system. On the other side, 'IEAR' is the cost incurred for the interrupted energy, which was supposed to deliver to the customers served. Both the indices depend on the type of load served, e.g. residential, commercial, etc.

$$\text{SAIDI} = \frac{\sum_{P=1}^{n_P} U_P N_P}{\sum_{P=1}^{n_P} N_P} \quad \text{hour per customer per year} \tag{1.22}$$

$$\text{SAIFI} = \frac{\sum_{P=1}^{n_P} \lambda_P N_P}{\sum_{P=1}^{n_P} N_P} \quad \text{failure per customer per year} \tag{1.23}$$

$$\text{CAIDI}(= \frac{\text{SAIDI}}{\text{SAIFI}}) = \frac{\sum_{P=1}^{n_P} U_P N_P}{\sum_{P=1}^{n_P} \lambda_P N_P} \quad \text{hour per customer per interruption} \tag{1.24}$$

Where

- CAIDI is Customer Average Interruption Duration Index

'ASAI', 'SAIDI', 'SAIFI', and 'CAIDI' are used by electric power utilities. 'ASAI' is the average availability of the system during 8760 hours (1 year), 'SAIDI' 'is the average outage duration for each customer served. 'SAIFI' is the average number of interruptions that a customer would experience. 'CAIDI' is the average outage duration that any given customer would experience.

$$\text{ASAI} = \frac{8760 \sum_{P=1}^{n_P} N_P - \sum_{P=1}^{n_P} U_P N_P}{8760 \sum_{P=1}^{n_P} N_P} \quad \text{per unit} \tag{1.25a}$$

Also, *ASAI* can be derived as follows.

$$\text{ASAI} = 1 - \frac{\text{SAIDI}}{8760} \tag{1.25b}$$

$$\text{ASUI} = 1 - \text{ASAI} \quad \text{per unit} \tag{1.25c}$$

Where

- ASUI is Average Service Unavailability Index

1.5 Research Motivation

The fundamental methods for evaluating the reliability of electricity systems have been presented. The methods may be used to systems that are basic, complicated, or have a variety of architectures. The complexity of the electrical power system relies upon its ability to tackle unexpected load variations. The EPDN manages these load variations for continuous electrical power supply to the loads. This system is categorized into radial and loop structured distribution systems. Radial DS is preferred as it is simple, cheap, and mainly applicable to sparsely distributed loads. Furthermore, to meet the rapid growth in demand and promote sustainability, integration of RES in the distribution system is the desideratum. The RESs, including WTG and SPV, provide minimal electrical losses, improves system bus voltages, possess less operation costs, and more significantly, it emits less CO_2 emissions. Thus, the optimization of these parameters would ultimately improve the reliability of the electrical distribution system. Reliability in an electrical power system is defined as providing adequate, stable, and reliable power for a particular distribution system. Therefore, the study on reliability assessment and performance analysis of various distribution systems considering the optimal siting and sizing of conventional and renewable energy sources is crucial. It is also observed that the consideration of abnormal conditions on the distribution system muddles the system's reliability. Regarding the above discussion, some of the critical issues are mentioned as follows.

- Electrical loss minimization using system reconfiguration [8]
- Reduction in investment during system capacity enhancement [9]
- Improvement in bus voltage [10]
- Mitigation of greenhouse gases [11]
- Improvement in voltage stability [12]
- Improvement in system's reliability by considering the reliability indices [13]
- Enhancement in system security [14]
- Facilitate system restoration [15]
- Reduction in harmonic distortion [16]

- Optimal load management strategy [17]
- Reliability evaluation by considering wind farm layout [18]
- Assessment of wind energy potential under uncertainties [19]
- Monte-Carlo-based simulation of transmission line's outage due to LI current [20]
- Lightning voltages with various rise times on transmission line [21]
- DFIG controller design and step responses [22]

The mentioned issues have been analyzed individually without considering the effect on another issue(s). The concept of studying the impact of the mentioned issues motivates the scholar to carry out this thesis work. In the view of solid motivation, this thesis is concentrated on the reliability assessment of various distribution systems.

1.6 Objectives of the Thesis

Reliability evaluation of distribution systems is the sine qua non for any investigation and analysis of the electrical network system. However, the distribution system's reliability may not be evaluated as desired due to the following reasons.

1. The impacts of the system's ill conditions, including natural lightning and three-phase fault, must be considered for the reliability evaluation.
2. Distributed generations, including conventional generators and renewable energy sources, have not been considered in reliability evaluation of a distribution system.
3. The uncertain reliability parameters of various components are essential to incorporate while evaluating the reliability of a distribution system.
4. Commercial, industrial, and residential types of loads have not been considered in analyzing the effect of loads on a system's reliability.
5. A complete reliability assessment can be performed by evaluating the five indices, namely EENS, AENS, SAIDI, SAIFI, and ASAI.

The main objectives of the thesis are enumerated as follows.

1. To consider the effect of abnormal conditions on wind integrated electrical network to evaluate the distribution system's reliability.

2. To incorporate conventional generator, wind turbine generator, solar photovoltaic, and battery storage systems for the reliability evaluation of distribution systems.

3. To consider the uncertainty parameters for analyzing the effect on the reliability of the distribution system.

4. To formulate two methods for obtaining the optimal location/s and sizing/s of distributed generation/s to analyze the system's reliability.

5. To investigate the excellent reliability of the distribution system by evaluating all the related reliability indices.

The problem statement of the thesis is as follows. The reliability of the distribution systems has been assessed and improved by considering distributed generations and abnormal conditions.

1.7 Contributions of the Thesis

The present thesis has the following main contributions and the same have been illustrated in the upcoming chapters of this thesis.

1. The thesis reviews the uncertainty handling processes in electrical power systems discussed so far in the literature. After exposure to uncertainties operating analysis, the reliability evaluation in distribution systems is adequately described by including electric vehicle and battery storage. Then reliability improvement methods are discussed for various distribution systems.

2. Lightning Impulse Voltage, Lightning Impulse Current, and Rectangular Pulse Current waveforms are generated by proposing their equivalent circuits.

3. The impact of Lightning Impulse Voltage has been observed on on the parameters of Doubly-Fed Induction Generator-based Wind Integrated Distribution System.

4. A Three-phase fault is created and analyzed to compare the results with Lightning Impulse Voltage by a Particle Swarm Optimization technique, which has been implemented

to get optimal values of sixth order transfer function of DFIG gains, including k_p and k_i for better output system parameters' responses.

5. The reliability assessment of Voltage Source Converter interfaced DFIG system has been performed by using the Monte-Carlo method.

6. Distribution system performance is analysed, including minimization of I^2R loss and minimization of deviation in bus voltage, which is accomplished with and without distribution generations.

7. Two indexes, namely $index_1$ and $index_2$ have been formulated to obtain the optimal locations of one and multiple distributed generations includes conventional generator/s and renewable energy source/s.

8. Constriction Factor-based Particle Swarm Optimization technique has been implemented to acquire optimal ratings of distributed generations, which is compared with other nature-inspired techniques and the results have been utilized in assessing the system's reliability.

9. A brief study on system's reliability is performed by considering the uncertainties in DG's reliability data include failure rate and repair time.

10. The required indices of distribution system's reliability has been calculated for the commercial, industrial, and the residential type of loads.

1.8 Outlines of the Thesis

This thesis is organized into six chapters. The works performed in each chapter are briefly explained as follows.

- **Chapter 1:** This chapter describes the background and motivation for the thesis and provides an overview of the research work and objectives of the thesis.

- **Chapter 2:** The reliability analysis and improvement techniques for electrical power distribution systems and wind integrated power systems are discussed cumulatively in this chapter. First, the reliability improvement techniques of electrical power distribution systems using Electric Vehicle and BESD have been discussed exhaustively. Second, reliability improvement methods in wind integrated distribution systems have also been explored and reviewed. At last, reliability impacts on reactive power, unit commitment, and protection system have been elaborated briefly.

- **Chapter 3:** In this chapter, a DFIG-based WIPS is considered, and the reliability of the system has been assessed by implementing the MC method when the LIV acts as a significant cause of system failure. The generation of standard Lightning Impulse Voltage and Current waveforms has been accomplished by adapting the proposed equivalent realistic circuits. It is observed that the performance and reliability of the system improves by implementing the proposed method.

- **Chapter 4:** The work is further extended on DS of 33 bus by assuming Wind, Solar, and Battery, as distributed energy sources. An overview of SPV, WTG, and BESD is explained by using mathematical expressions. To determine the optimum location(s) and rating(s) of various energy sources, two indices and an optimization method are suggested. Furthermore, the results of several cases and scenarios are elucidated with supporting graphical depictions and tables. It is inferred that the reliability of the distribution system enhances by the proposed assessment method.

- **Chapter 5:** Following an extensive literature review, the thesis study will proceed as follows. For the reliability evaluation, two DSs of 33 bus and 118 bus are included. The three indices have been formulated and described as a more efficient way of determining the best bus number for DER(s) placement. The suggested optimization method was required to achieve the DERs' appropriate ratings for the system's lowest active and reactive power losses. Furthermore, by taking into account the uncertainty in DER's reliability data, the outcomes of several case studies are presented, and it is incurred that the system's reliability increases when the proposed approach of assessment is applied.

- **Chapter 6:** This chapter concludes the works accomplished in this thesis, enumerates benefits of the methods, and propose future scopes of the work.