Chapter 2

Literature Survey

2.1 Introduction

The reliability assessment is an integral part of the power systems when generation transmission distribution networks are studied either individually or compositely. This thesis is mainly associated with the reliability assessment, and reliability improvement of the conventional and renewable energy integrated electrical systems. The reliability improvements can be observed for electrical network planning and operation when the integration of renewable sources, including Electric Vehicle (EV), WTG, BESD, and SPV are incorporated into the electrical power system [23–26]. However, due to the proliferation of renewable sources, an increase in the uncertain parameters as well as the severity of uncertainty (also referred to as unreliability) in power systems is observed. Wind power, solar power, EV's charging and discharging behaviors and their allocation, and BESD incorporate the uncertainty parameters [27,28]. These parameters affect the restructuring of the power system. Thus, a thought process develops among the researchers regarding the uncertainty analysis for reliability assessment of a distribution system. It is observed from [29] that the research trend on reliability assessments is increasing tremendously since the last decade. The optimal and reliable working conditions during the three operational stages, including generation, transmission, and distribution, are the prerequisites. Thus, the study on the handling of uncertainty parameters for the reliability analysis is required. In this context, [30] has given a Monte-Carlo simulation method for evaluating the reliability indicators.

The reliability indicators include ASAI, Average Service Unavailability Index (ASUI), Customer Average Interruption Duration Index (CAIDI), Customer Average Interruption Frequency Index (CAIFI) SAIDI, SAIFI, EENS, AENS. These indicators are being evaluated at load points. The calculation of these indices is accomplished by simulating the random behaviors that exist in the systems. These behaviors are classified as failures of control systems, communication systems, and protection systems, and disturbances like human errors and lightning of the electrical power systems. The significance of reliability is thus described in [31]. A load-based reliability index is introduced to implement a reward and penalty scheme for utility companies to improve the system's reliability. This chapter also gives a proper understanding to the readers about unreliability and its handling approaches. The reliability improvement and assessment methods and models are also described for the readers. In this regard, Table 2.2 is given to analyze the literature available on reliability assessment and its improvement methods for the renewable integrated Distribution Systems. On the other hand, data on customer-related failures indicate that they contribute the most to the unavailability of supply as determined by the electrical utilities. Table 2.1 is showing the mean unavailability of customers index per year. This table is also referred to as the customer unavailability statistics.

Table 2.1: Usual unavailability index of customers

Contributor	**Mean unavailability per customer per year**	
	Time (minutes)	**Percent (%)**
Transmission and Generation	0.5	0.5
LV	10.9	12
11 kV and 6.6 kV	59.5	61
66 kV and 33 kV	7	8
132 kV	2.1	2
Planned Shutdowns	16.9	16.5
Total	96.90	100

2.2 Unreliability in Electrical Power Systems

Table 2.2: Important attributes of research work on RE in an electrical power system.

S. No.	Work consideration(s)	Method(s)	Remarks	Ref.
1	To regulate the annual reliability performance of utilities	Advanced metering infrastructure architecture	The feeder reliability performance is evaluated by a proposed utility reward/penalty scheme	[31]
2	Distribution system reliability by Outage Management System study, Expansion Planning, Cold Load Pick-up events	MC Simulation, Sequential Monte-Carlo method, Novel 2-step Algorithm, Lightning Search Algorithm, Genetic Algorithm	SAIFI, SAIDI, CAIDI, AENS, ASAI are calculated, load curtailments and cost in power system is minimised to improve the reliability of the distribution system	[32], [33], [34], [35], [36], [37]
3	Reliability improvement using Parking Lot, EV's Parking Lot allocation, stochastic traffic flow and charging load of EVs	Vehicle to Grid programs, non-MC Simulation, car following models, MC method, Markov Chain theory, Fuzzy Logic system, Dynamic traffic flow model	The Parking Lots are utilized in reliability improvement, effect on reliability improvement by integrating lots, suppression of stochastic disturbances, EV charging load benefits, reliability cost and SAIDI are minimized	[38], [39], [40], [41], [42]

4	Reliability during grid outages	Sequential MC method, optimization function to minimize the Energy Not Supplied (ENS)	Reliability of Electrical Power Distribution Network (EPDN) is improved with Vehicle to Grid and Vehicle to Home centralised and dispersed EV charging respectively	[32]
5	reliability assessment with Mobile BESD integration	Markov models verified by MC method, an Accelerated MC method, Chance Constrained Programming	Modeling of MBESD and EPDN, EENS and CAIDI are applied to reliability assessment, BESD is integrated to get the efficient reliability	[43], [44], [45]
6	Improving reliability by reducing peak demand and electricity charges for consumers	Power Management Strategy algorithm	Algorithm for an integrated residential SPV and energy storage unit is proposed to improve the reliability	[46]

7	Wind Energy Conversion System (WECS) uncertainty and reliability improvement	MC Simulation, Power law process, reliability assessment approach, Condition Monitoring System, Demand Side Management, MC Simulation, Column and Constraint Generation algorithm	Reliability analysis of Wind Turbine (WT) components is performed, power system reliability with or without intermittency consideration, cost of monitoring	[47], [48], [49], [50], [37], [51]
8	Reliability analysis of the hybrid system	Analytical process	Reliability indices Loss of Load Expectation (LOLE) and Loss of Energy Expectation (LOEE) are calculated for a hybrid system	[52]
9	To schedule the conventional generator outputs in response to increase in renewable energy penetration	Generation Rescheduling Algorithm	Transmission system reliability with renewable energy penetration is given	[53]
10	Electrical power system incorporates Dynamic Thermal Rating and WF to enhance reliability	Sequential MC method, Autoregressive Moving Average model	The higher penetration of wind energy may be allowed on rating consideration	[54]

11	To avoid the volatility of wind power integration	time-based Demand Response Program, contingency-based Demand Response Program	The proposed approach examines the effect of Demand Response Programs on Loss of Load Probability (LOLP), LOEE, ECOST, Operational Cost, and Expected Total Cost	[55]
12	reactive power optimization problem in active distribution networks formulated	Column and Constraint Generation algorithm	To address the uncertainties in WP output, a two-stage robust reactive power optimization model is proposed	[56]
13	An increased probability of undesirable interactions between multiple System Integrated Protection Schemes	Markov modeling, Sequential MC method	Procedure to assess the risk of System Integrated Protection System maloperations and undesirable interactions between different Protection Systems is implemented	[57]
14	Computation time in evaluating power system reliability	MC method with Multi-Label K-Nearest Neighbour	The reliability indices are evaluated for accuracy and analysis time is obtained for reducing computational burden	[58]

In electrical power systems, it is essential to consider the uncertain parameters of renewable energy sources. It is also mentioned that why uncertainty parameters are needed to be analyzed? 'Uncertainty' which leads to the unreliability of the system, requires possibilistic and probabilistic handling approaches. In a possibilistic approach, fuzzy membership functions represent the uncertain parameters, and it is solved with fuzzy arithmetic. In the probabilistic approach, the modeling of uncertain parameters is performed by Probability Density Function (PDF)s and then analyzed with Monte-Carlo Simulation and Point Estimate methods. Figures 2.1 and 2.2 show the classification of uncertainties and their dealing approaches respectively [59].

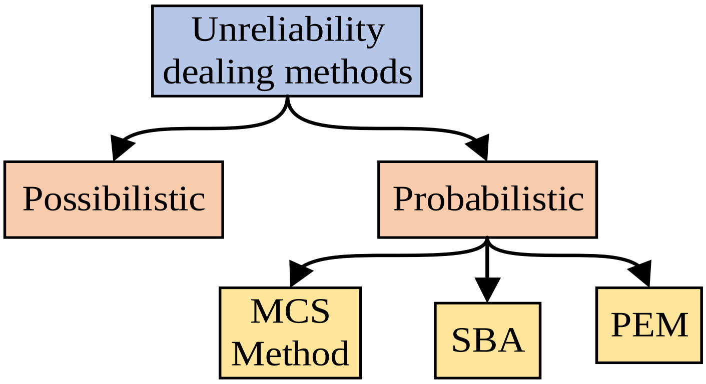

Figure 2.1: Flow chart of unreliability dealing methods.

MCS = Monte-Carlo Simulation, PEM = Point Estimate Method, SBA = Scenario-Based Approach

2.2.1 Possibilistic approach

In [60], Zadeh has mentioned the concept of Possibilistic modeling of uncertain parameters. The idea is mainly aimed at the uncertain input parameters for their fuzzy membership function representation. First, the membership function of the input variables is applied to get the output membership function variables by using the α-cut method. Then, after getting the membership function, a centroid method for defuzzification is applied to defuzzify the variable outputs and produce the crisp output values. In [61], it is seen that the possibilistic methods are applied to handle the uncertainty parameters of the electrical power system.

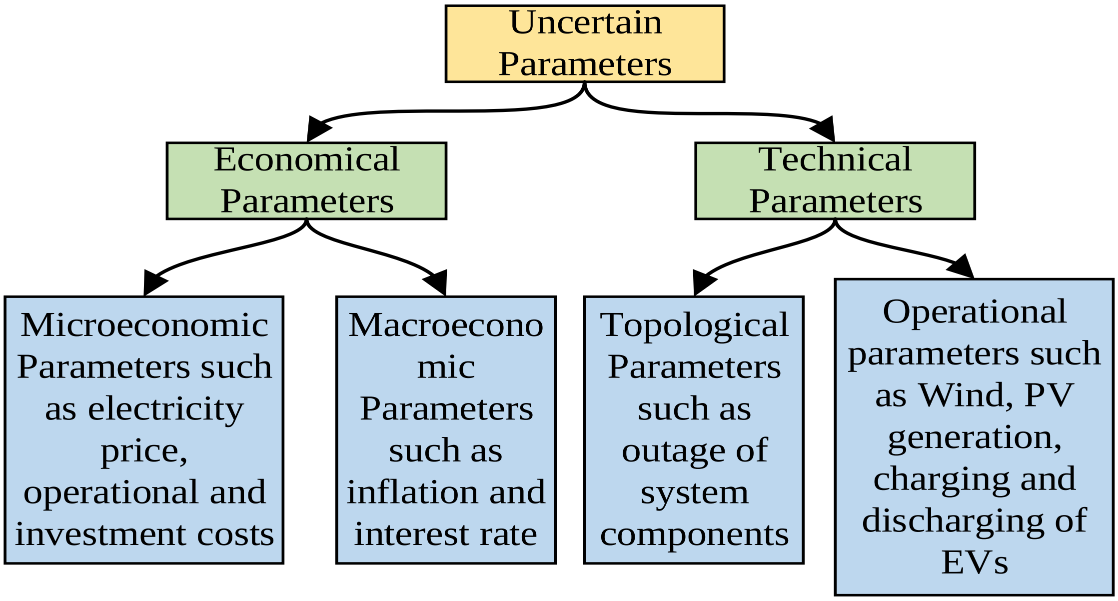

Figure 2.2: Sources of unreliability parameters.

2.2.2 Probabilistic approach

It is a general method to address the uncertainties including wind power generation, EV dynamics, load, SPV generation, and electric rate in reliability assessment of the power system. The Equations (2.1)–(2.5) are the PDFs of uncertain parameters, including load, wind power, solar power, and electricity price, respectively. The uncertain parameters are first modeled into PDF and then solved by probabilistic methods, including Monte-Carlo Simulation, Point Estimate Method, and Scenario-Based Approach. According to applications, the MC Simulation method is further studied as Accelerated, Sequential, Non-sequential, Bayes, and Quasi Monte-Carlo Methods, as discussed in [33, 38, 39].

$$PDF(L) = \frac{1}{\sqrt{2\pi\alpha}}\left[\exp(-\frac{(L-\beta)^2}{2\alpha^2})\right] \tag{2.1}$$

Where

- L denotes the apparent power of the load
- α is the forecasted load mean value
- β is the apparent power's standard deviation

$$PDF(V) = (\frac{S_h}{S_c})(\frac{V}{S_c})^{S_h-1}\exp{(-\frac{V}{S_c})^{S_h}} \tag{2.2}$$

Where

- S_h and S_c are termed as shape and scale parameters respectively and wind speed is denoted by V and P(V) is the wind power generated

$$P(V) = \begin{cases} 0; V \leq V_{in}^c \geq V_{out}^c \\ \frac{V - V_{in}^c}{V_{rated}^c - V_{in}^c}; V_{in}^c \leq V \leq V_{rated}^c \\ P_r; \text{Otherwise} \end{cases} \tag{2.3}$$

Where

- V_{in}^c and V_{out}^c are referred as to cut-in and cut-out speeds respectively
- V_{rated}^c refers as rated speed of WT
- P_r is power rated for WT

$$PDF(S) = \begin{cases} \frac{\Gamma(k'+c')}{\Gamma(k')(c')} S^{k-1}(1-S)^c - 1; \text{if } 0 \leq S \leq 1 \\ 0;\ \text{Otherwise} \end{cases} \tag{2.4}$$

Where

- k' and c' are the parameters of Beta distribution
- ‘S’ is the solar irradiation power

$$PDF(P_E) = \frac{1}{\sqrt{2\pi\alpha_p}} \left[\exp(-\frac{(p_E - \beta_p)^2}{2\alpha_p^2}) \right] \tag{2.5}$$

Where

- P_E denotes electricity price
- α_p and β_p are referred to standard deviation and the expected value of the electricity price

The Gaussian PDF representation of uncertain loads, which is modeled as an expected value equals the forecasted value as seen in Equation (2.1). As it is known that the wind power generated is completely dependent on the wind speed [62–64]. The modeling of wind speed data is performed as a Weibull function mentioned by Equation (2.2) [65, 66]. The photovoltaic power is mainly dependent on the solar irradiation [67, 68]. The solar irradiation is generally modeled as the Beta Distribution Function as represented in Equation (2.4). The last-mentioned uncertain parameter is electricity price [69]. It is also modeled as Gaussian Distribution Function whose mean value equals the forecasted price [70]. The uncertain parameter modeling is performed by common PDF. Then, probabilistic methods are applied and analyzed for handling the uncertainty, as described in [71–73]. In the upcoming sections of this chapter, the latest researches are explored and presented for reliability assessment in the electrical power systems.

2.3 Reliability Assessment of Power Systems

The reliability assessment of the distribution systems have been thoroughly reviewed in this thesis.[1] Probability Density Functions are utilized in handling the uncertainty parameters as described in Section 2.2. Reliability function of any system is defined by using PDF, as given in Equation (2.6) [74]. The Electrical Power Distribution Networks are the significant individual contributors to the unreliability of customer power supply [69]. As the EPDNs are mainly recognized as the part of highest occurring failure events. The reliability with economical cost must be included in optimal dynamic expansion planning of EPDN with the proliferation of Renewable Energy Sources [34]. The failures in the Electrical Power Distribution Networks have limited effects. Therefore, the quantitative analyses on the adequacy of other EPDN's designs are of less concern. Hence, the efforts devoted are still less till date. On the other side of the analysis, it is observed that the statistics of customer-related failures showing the maximum contribution to the unavailability of supply as set by the electrical utilities.

$$R(t) = \int_{t}^{\infty} f(t).dt \tag{2.6}$$

Where

- R(t) and f(t) are the reliability function and probability density function, respectively at a time 't'

The essential aspects in reliability assessment of EPDN are balanced Generation, Transmission, and Distribution operation, Outage Management System, Expansion Planning, Allocation of backups, and Maintenance Policy. However, due to outage events like Cold Load Pick-up

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[1] Sachin Kumar, R.K. Saket, D.K. Dheer, J.B. Holm-Nielsen, P. SanjeeviKumar, "Reliability Enhancement of Electrical Power System Including Impacts of Renewable Energy Sources: A Comprehensive Review", IET Generation, Transmission & Distribution. Vol. 14, No. 10, pp. 1799–1815 (2020)

during the Outage Management System study, time-based reliability indices are evaluated and improved using various optimization methods.

The reliability parameters, including failure rate, annual outage time (or unavailability), and outage time, are defined for reliability assessment. But these indexes are unable to show the significance or severity of an electrical power system outage. Therefore, extra customer-related reliability indices, including ASAI, ASUI, CAIDI, CAIFI, SAIDI, and SAIFI, are frequently defined for further system's reliability assessment. While Energy Not Supplied, AENS, and Average Customer Curtailment Index are the load and energy-related indices. All indices are helpful, and Table 2.3 shows that the previous researchers have used different reliability indices in the evaluation of power system reliability.

The power system network is well known for its complexity. The complexity of a power system increases with the integration of renewable sources into it. The reliability assessment becomes more critical for the renewable integrated power system. The reliability is analyzed by the adequacy and security of the power system. As security is defined by the dynamic state of the system. Hence, in most of the cases, adequacy is considered for the power system reliability assessment [78]. The adequacy is described as the supply fulfillment for the load connected. So the adequacy of the system is analyzed by using LOLP index for Reliability Evaluation. Transmission line flow constraints and generator outage are accounted for in the LOLP calculation. Thus, to assess the reliability of the hybrid power system, MC Simulation with Multi-Label K-Nearest Neighbour algorithm is used as a state classifier [58].

Electric vehicle has two modes of operations, including centralized and dispersed EV charging. The authors suggest these modes in [32]. In these two modes, residential demands are fulfilled by Vehicle-Home or/and Vehicle-Grid during the islanding condition. Further, as a part of planning, the reconfiguration of electrical network for the power system reliability improvement is presented in [79]. The implementation of EVs' Vehicle-Grid programs is effectively considered in [36] for reliability and adequacy analysis of EPDNs. A comparative analysis is performed and mentioned in [32], where it is observed that the reliability improves with EVs proper mode of scheduled operations. The reliability assessment techniques and models are defined as follows.

- Traffic flow model of EV

- Monte-Carlo method for EV charging

Table 2.3: Insight on reliability indices and energy resources utilized in literature for reliability assessment of Electrical Power Distribution Network

Ref	Reliability Indicator/Reliability Improvement Method	Energy Resource
[23]	EENS	Wind, SPV, Battery
[25]	LOLP, LOEE	Wind
[32]	SAIDI, SAIFI, EENS, ASAI	Conventional
[34]	SAIDI, EENS	Conventional
[35]	SAIDI, SAIFI, CAIDI, ENS	Conventional
[36]	AENS	EV
[37]	SAIDI, SAIFI, ENS	Wind, SPV
[41]	Information Reliability	EV
[42]	LOLE, LOEE, EWEB	Wind, SPV
[43]	EENS, CAIDI, ASAI, ASUI	Mobile BESD
[44]	FMEA	BESD
[45]	Optimal scheduling	Mobile BESD
[49]	LOLE, LOLF, LOLP, LOEE, EDNS	Conventional
[52]	LOLE, LOEE	Wind, SPV, Battery
[75]	EENS	Mobile BESD
[76]	ENS	Wind, SPV
[77]	LOLP	Plug-in EV

- Markov chain process and fuzzy theory for EVs' charging state
- Monte-Carlo method for EV dynamics
- Vehicle-Home and Vehicle-Grid

An integration of different Distributed Generation technologies is considered in the adequacy study of EPDNs. This can be achieved when the EV's Vehicle-Grid programs with their associated charging load are successfully implemented. The probabilistic model of the uncertainties associated with wind power generation offers available energy from Vehicle-Grid programs. It is also observed that the Vehicle-Grid capability of Plug-in EVs enhances Microgrid reliability. [77] has proposed mixed-integer nonlinear programming to obtain the optimal planning of Microgrid when Plug-in EVs are present. Reliability is improved at a reduced cost by implementing a suitable charge and discharge strategy of Plug-in EVs.

The interfacing between energy consumers, and transportation infrastructure, and generating units are the different forms of energy in an energy hub. To model the interactions between various DG technologies, a renewable-based energy hub is considered. The related reliability indices SAIDI and EENS during grid-connected and islanded conditions are obtained [80].

Reliability improvement of EPDN:

The integration of Mobile BESD and BESD are described in [43] and [44], respectively and a stochastic model is proposed by [39], which are developed for reliability improvement and support the microgrids in Outage Management System during contingency events. The effect of Mobile BESD is observed on reliability indices, as shown in Figure 2.3 [43]. EENS and CAIDI are measured in kilowatt-hour and hour, respectively. The reliability improvement techniques and models are as follows.

- Energy Storage System (ESS) as spinning reserve
- Integrated Residential ESS Unit and Solar Photovoltaic system
- Modelling and Markov process of BESD

2.4 Reliability Analysis Considering Lightning Impulse

The DC, AC, and impulse high voltages are needed in several electrical engineering high voltage applications. One of the applications is to simulate the overvoltage and overcurrent phenomena occurring naturally in the power system. Transient overvoltages due to lightning and switching action cause the steep build-up of voltage on transmission lines and other electrical apparatuses. Because of this, a modified Agrawal coupling overhead line model was developed to estimate the LIV on the EPDN [81]. In continuation, a macro-model based on the Agrawal model has been developed to estimate the LIV on the overhead power lines [21]. The macro-model has been applied to three configurations of overhead lines to calculated the LIV on the three-line conductors. The LIV estimation can also be performed by simulating and developing the Rogowski coil [82]. The Rogowski coil was developed to achieve accuracy and economical than other LIV measuring sensors. The LIV estimation becomes crucial when the breakdown strength of solid, liquid, and gas dielectrics are computed [83]. Simultaneously, the influence of lightning current models on overvoltages has been observed for overhead transmission systems [84]. High impulse voltages and currents are required for the testing purpose of the electrical apparatuses. A comparative analysis of the lightning phenomena results in overvoltage in the AC connected, and VSC based HVDC connected WFs has been performed [88, 89]. Lightning strokes at six Wind Turbine were analyzed for four cases to obtain better results in less overvoltage and the rate of rising of valve voltage. The study is further extended in [90] to analyze the influence of lightning overvoltage phenomena on six pulse converters. The operating voltage is brought within the limit to ensure the reliability and efficiency of the converter-based system [91, 92].

Further, to assess the reliability of a HVDC system under the action of Lightning Impulse (LI) phenomena, a test has been performed on a high voltage divider. In addition to these analyses, several researchers in [93, 94] have assessed LI voltage phenomena in mixed HVDC transmission lines in 110 kV double circuit line insulators. The overall performance analysis of a power system exposed to LI phenomena leads to the system components' failure analysis and maintenance strategy, as discussed in [95]. In [96,97], authors have suggested lightning impulse test and cable fault of SPV modules, respectively, and grid fault diagnosis is made in [98, 99]. Also, authors in [100] have described the parametric analysis and transient response of the WT model under voltage dips. A comprehensive literature comparison has been illustrated in Table 2.4.

2.5 Reliability Improvement with Wind-Solar-Battery

The incorporation of distributed energy sources in the Electrical Power Distribution Network can support the increasing load demands. To satisfy the increasing load demands, an extensive comparison and assessment have been performed on exploring the potentiality of the distributed energy sources, including the wind and solar energies [101, 102]. The EPDN is the combination of electrical loads and DG (especially, WTG and SPV) integrated with electrical storage system namely BESD [103]. In this regard, several comprehensive studies are available on sustainable energy production and management. The state policies, renewable energy plants, and the devel-

Table 2.4: Literature comparison for DFIG-based Wind Integrated Power System (WIPS)

Ref.	**System fault**	**Controller design**	**Natural lightning**	**Reliability study**	**Remarks**
[21]	×	×	✓	×	LI voltages with rise time of 0.7 μs, 0.8 μs, 1.2 μs, 1.65 μs, and 2 μs on transmission line
[82]	×	×	✓	×	Measurement of lightning current (100 kA, 8/20 μs)
[20]	×	×	✓	×	Monte-Carlo-based simulation of 230 kV transmission line's outage due to LI current (31.1 kA, 3.83/77.5 μs)
[85], [22]	×	✓	×	×	DFIG controller design and step responses
[86]	×	×	✓	×	Power controller operation under the impact of voltage lightning (1.2/50 μs)
[87]	×	×	✓	×	Standard LIV generation
This Thesis	✓	✓	✓	✓	**Generation of natural lightning impulse to study the impact on grid-connected wind power system**

opment of renewable energy sources, including solar energy, wind energy, small hydroelectric energy, biomass energy, tidal energy, and geothermal energy, have been analyzed for different states of India [104]. As the energy crisis deepens day by day, the EPDN accompanied by

RESs is a better solution and also it acts as a complement to the central power grid system [105]. Therefore, a study on renewable energy potential has been performed for five countries: China, Iceland, India, Sweden, and the United States of America. The strengths, weaknesses, opportunities, and threats related to green energy generation and use have been reviewed for these countries using a SWOT analysis [106, 107]. Sometimes an arrangement including the battery storage is needed due to the high penetration of renewable resources into an electrical network to fulfill the load demands [108, 109].

Thus, integration of BESD in the distribution system prevails as a better solution for obtaining a steady power output, especially from WTG and SPV owing to the uncertainties involved in the energy harvesting sources such as wind speed [101], solar irradiation, and ambient temperature [110]. Therefore, it is a requisite to determine the siting(s) and sizing(s) of WTG, SPV, and BESD. The system's reliability, stability, and power quality are thus, improved substantially. Therefore, to obtain improvements in the system's attributes, the multi-objective optimization methods for problems including operational cost, siting and sizing of distributed resources, Carbon Dioxide (CO_2) emission, total power loss, voltage deviation, demand-side management, charging-discharging of BESD, total harmonic distortion, and system reliability are established [111–113].

Moreover, improvement in power system reliability is observed when congestion management algorithms are implemented to identify the transmission line congestion [114]. The Distributed Generations and BESDs are scheduled optimally to alleviate the transmission line congestion. A two-step optimization approach is used for solving the congestion problem [115]. In this optimization method, the optimum location and the size of the SPV array are observed, and then the BESD size with location is determined for accomplishing a further reduction in electrical losses and voltage deviation. The authors in [116] have proposed an index to obtain the optimal siting of DGs in Electrical Power Distribution Network. This index is implemented to resolve the multiple problems, including total Electrical Power Loss Minimization, ENS, and voltage deviation. Another objective, such as loss of yearly energy minimization, is observed through the integration of Distributed Energy Resources (DER)s-based DGs and network reconfiguration [117].

Furthermore, a novel two-stage stochastic programming method is proposed, and the uncertainty considerations together with the load variation are also studied, especially for wind energy and solar power generation [118]. In this method, the total cost is reduced by incorporating BESD into the system and by considering the demand response programs in planning. Simultaneously, the enhancement of the power system reliability is achieved due to the obtained optimal BESD size and location. The reliability improvement and reduction in network losses are also observed using compound co-optimization strategic plan [119]. The reliability indices such as EENS, EIR, LOLE, and LOLP, are defined in the co-optimization strategy. Also, a moth-flame optimization [120], Olympic games ranking process [121], firefly algorithm [122], lightning search algorithm [123], crow search optimization [124], and an improved variant Particle Swarm Optimization (PSO) [125] techniques have been implemented and discussed in the literature so as to obtain the optimal site, optimal size, optimal parameters of DGs, and EPLM. An exhaustive literature comparison has been represented in Table 2.5. Where Loc is referred as Location of the DG and Vol is node voltage of the system.

Table 2.5: Literature comparison considering Wind-Solar-Battery

No. of Bus	**Parameters Considered**							**Ref.**
	Size	**Loc**	**Vol**	**Loss**	**Reliability**	**pf**	**DG**	
34, 69		✓	✓	✓		✓	SPV/WTG	[126]
33, 69, 119	✓	✓	✓	✓			SPV/WTG	[127]
33, 69	✓	✓	✓	✓			SPV	[16]
13	✓	✓	✓	✓			SPV/BESD	[115]
33, 118	✓	✓		✓			SPV/WTG	[117]
38	✓	✓					SPV/WTG	[123]
33, 69	✓	✓	✓	✓			SPV/ESS	[124]
38, 69	✓	✓	✓				Gas/Wind	[128]
33	✓	✓	✓	✓		✓	SPV/WTG	[129]
33	✓	✓	✓	✓	✓	✓	**SPV/WTG/BESD**	**This Thesis**

2.6 Integrating Wind Energy with Conventional Generation

This thesis also presents a view on reliability assessment and reliability improvement by focusing on WIPS. The main cause to focus on WIPS is the volatility, which includes, penetration, wake effect, output power correlation for WTs, effect of parameters, and environment. The above mentioned causes are incorporated in reliability assessment [47] because these are the major contributors for reduction in power system reliability.

Thus, it is favourable to integrate Wind/SPV/Battery in the EPDN to enhance the system's reliability. Also, the effect of BESD is explained in the Wind Farm integrated electrical system under four scenarios, as given in Figure 2.3. Where

- Scenario 1: When intermittency and inertia of WT are not considered.
- Scenario 2: The spinning reserve requirement is considered.
- Scenario 3: Includes Scenario 2 with the inclusion of the wind penetration limit.
- Scenario 4: Large scale ESS is considered.

In Figure 2.4, LOLE is measured in hour/year, Loss of Load Frequency (LOLF) is in failure/year, Energy Demand Not Supplied (EDNS) is in MW/year, and LOEE is in MWh/year [49]. The pros and cons of WIPS reliability improvement methods are explained in Table 2.6. Where

- GRA is 'Generation Rescheduling Algorithm'
- CM is 'Condition Monitoring'
- ARMA is 'Auto-regressive Moving Average'
- DTLR is 'Dynamic Thermal Line Rating'
- DRP is 'Demand Response Program'
- DSM is 'Demand Side Management', which can further be implemented as WIPS reliability improvement methods

Table 2.6: Reliability improvement methods with their pros and cons

S. No.	**Method**	**Pros**	**Cons**

1	GRA	(i) Power flow variations are taken out from the transmission line. (ii) It minimises the probability of overburdening. (iii) Increases the transmission system reliability	Gives a flexible output power generation by ignoring the congestion in power, and stabilizes the wind energy resources with power system loads.
2	CM	(i) identifies the faults and degradation in semiconductor devices. (ii) It is cheap and limits the uncertain interruptions of power generation. (iii) Enhances generation reliability.	The assumptions such as upper-lower limits of voltage and current are taken on the characteristics of power electronics devices.
3	ARMA	(i) Years of big data are not needed. (ii) WECS is explained in the ARMA model.	(i) The noise changes in various ways even yet the equations of the system remain deterministic. (ii) Single reliable statistical test for chaoticity is not possible, incorporating multiple tests is a crucial aspect, especially when one is handling with limited and noisy data sets like wind speed and impedance loading.
4	DTLR	(i) More penetration of wind energy is supported due to current carrying capability of aerial lines. (ii) Raises the power system reliability.	(i) The DLR saturates after a particular stage of installed wind power. (ii) The maximum utilisation of power transmission capability is discontinued for long transmission lines.

5	DRP	(i) Eliminates the opposite impacts of wind energy volatility on power system reliability. (ii) Evaluates short term reliability of WIPS.	Real-world uncertainties influence the reliability enhancement feature of DRP.
6	ESS	(i) It includes reliability enhancement with analysing the power system service recovery. (ii) It utilises parking lot as a substitute for a disturbed zone.	(i) Energy loss in charging-discharging makes it inefficient. (ii) It is complex and not cheap and requires infrastructure and space.
7	DSM	(i) It evaluates the load side reliability. (ii) Reliability increases for the combined stage of hybrid energy and DSM.	(i) Users have a restricted resource to use the DSM. (ii) DSM is a better fit for greater energy consumers or those with complex energy demands.

The Distributed Generation integration in EPDN has considerable impacts on Distribution Systems' operation and planning strategy [130]. The previously addressed issues co-related to DG integration are defined as follows.

- Power loss minimization [131]
- Reduction in investment during system capacity enhancement [132]
- Improvement in bus voltage [133, 134]
- Mitigation of green house gases [135, 136]
- Improvement in voltage stability [137, 138]
- Improvement in system's reliability considering reliability indices [139]
- Enhancement in system security [140]
- Facilitate system restoration [141]

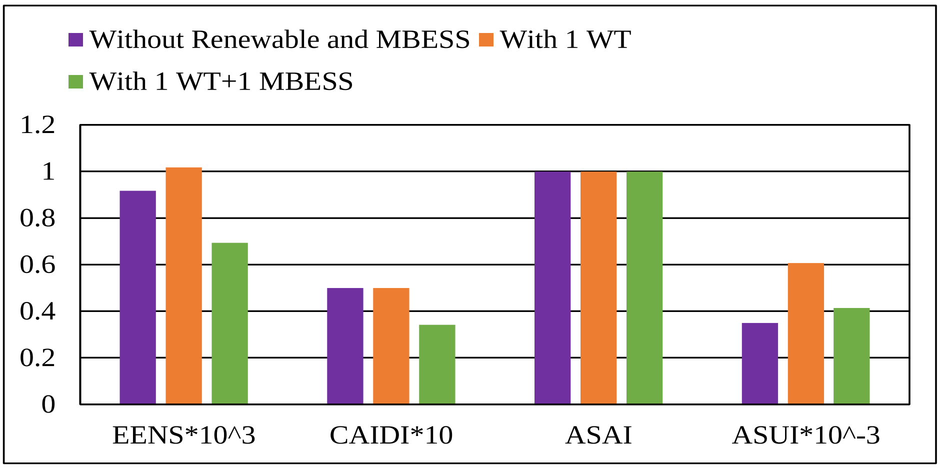

Figure 2.3: Approximate values of reliability indices.

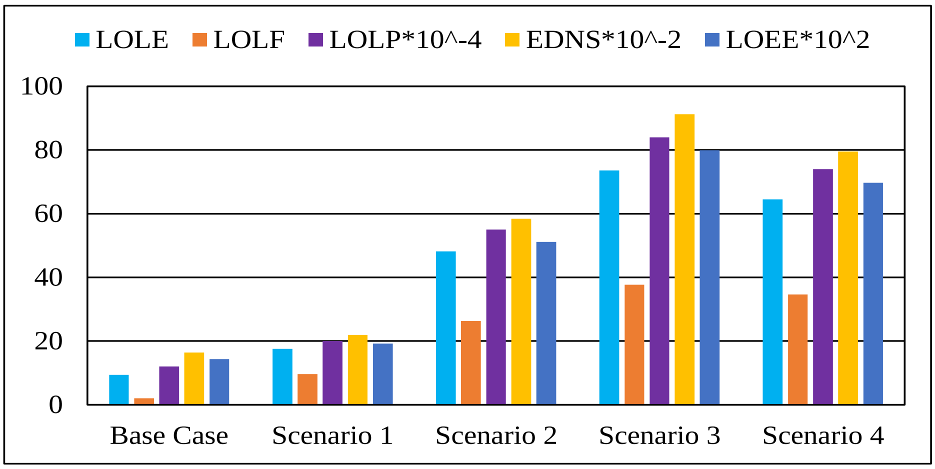

Figure 2.4: Reliability indices with 26 conventional generators and 43 WFs on IEEE RTS 69 bus system.

- Reduction in harmonic distortion [142]
- Reduction in power loss using system reconfiguration [143–145]
- Reduction in energy costs

The impact of DGs integration on EPDN performance is observed. Sometimes an arrangement including a battery energy storage system is needed due to the extensive incorporation of renewable resources into the electrical network [153]. However, system stability and power quality improvement are achieved, but it is not economical to add BESD. Thus, the multi-objective optimization problems, including DG location and size, CO_2 emission, total power loss, voltage deviation, demand-side management, charging-discharging of BESD, total

Table 2.7: Previously published work considering Conventional Generator

No.of bus	**Parameters Considered**									**Ref.**
	Size	**Loc**	**Vol**	**Loss**	**Rel**	**pf**	**Load**	**Pen**	**DG**	
37, 119	✓	✓	✓	✓		✓			CG	[130]
33, 69, 137, 205	✓		✓	✓					CG	[143]
33, 85	✓	✓	✓	✓	✓				CG	[146]
33, 69, 85	✓	✓	✓						CG	[147]
33, 69, 118	✓	✓		✓					CG	[148]
69, 118	✓	✓	✓	✓				✓	CG/Cap	[149]
33, 69, 118	✓	✓	✓	✓		✓			CG	[150]
28, 118	✓	✓	✓	✓					CG	[151]
33, 69		✓		✓		✓			CG	[152]
69	✓	✓	✓	✓					CG	[134]
12		✓	✓	✓					CG	[138]
33, 118	✓	✓	✓	✓	✓	✓	✓	✓	**CG/WTG**	**This Thesis**

harmonic distortion, and system reliability are established [144,147,154–156]. Improvement in network reliability is seen when congestion management algorithms to identify the transmission line congestion are implemented [157]. DGs and BESDs are scheduled optimally to alleviate this transmission line congestion. A two-step optimization problem is provided for the congestion problem [158]. The optimum siting and sizing of a SPV array are observed, and then the optimal size and location of BESD are determined to obtain the further reduction in loss of total power, and minimization of deviation in voltage have been observed. Authors in [146] have proposed an index to get the optimal siting of DGs in Distribution System. This index is implemented to resolve the multiple problems, including the minimization of total electrical power loss, ENS, and voltage deviation. Another objective, namely, loss of yearly energy minimization, is observed by integrating RESs-based DGs and network reconfiguration [159]. Further, two-stage stochastic programming has been proposed while uncertainty consideration, including wind energy and solar power generation and load variation, is studied [160]. In this method, the total cost is reduced by adding BESD in distribution system and considering demand response programs in planning. Simultaneously, enhancing the system's reliability is observed by obtaining an optimal BESD size and BESD location. The reliability improvement and reduction in network losses are also observed using compound co-optimization strategic plan [161]. The reliability indices, including expected ENS, EIR, LOLE, and LOLP, are defined in the co-optimization strategy. Further, to obtain the optimal site, optimal size of DGs and loss minimization, a moth-flame optimization [162], olympic games ranking process [163], firefly algorithm [143], lightning search algorithm [164], fast PSO [131], and crow search optimization [165] techniques have been implemented and discussed [166].

The reliability assessment provides a better evaluation of any power system's performance. For assessing the power system's reliability, several indices have been mentioned in the literature. The indices are categorized as energy-oriented and customer-oriented indices. The indices' values decrease if the aging of the sub-components is considered in reliability assessment [167]. Reliability is regarded as a primary requirement in the designing phase of DS. Thus, the optimal site and optimal size of three DGs for further reliability assessment has been considered. Three Conventional Generations are implemented as DGs in 33 bus and 118 bus DSs and observed an improvement in EPDN reliability. To fulfill the reliability assessment in EPDN, [155] has introduced a restoration strategy for ENS calculation. The optimization of reliability indices are considered [146, 161],, and the improvement in EPDN reliability is observed. Further, reliability improvement is made using congestion management and other techniques described earlier in this chapter.

The above literature focuses on optimal allocation and size of DGs obtaining a better power system performance. All proposed optimization techniques are proven to be better when compared with other methods. The system reliability assessment is discussed individually without analysing the impact of optimal DG integration. Thus, the PSO for optimal siting and sizing of DG for 33 bus DS is presented. Simultaneously, the parameters, as given in Table 2.7, which are not discussed in the previous literature, are also considered in this thesis. The comparison with other previous techniques shows the competitiveness of the Constriction Factor-based Particle Swarm Optimization (CF-PSO) technique. The comparative analysis for the reduction in electrical power loss and voltage deviation is performed by integrating the 1DG, 2DG, and 3DG in 33 bus and 118 bus DSs. The results are then obtained compared with the previously accomplished works, as described in Tables 2.8 and 2.9. After obtaining the reduced power

Table 2.8: Literature related to 33 bus distribution network considering distributed generations

Technique	**No. of DG**	**At Node**	**DG Size (MW)**	**Loss (MW)**	V_{min}	**Ref.**
Base Case	-	-	-	0.2110	90.37	[168]
GA+AE	1	6	2.380	0.13264	NR	[169]
MINLP	”	”	2.590	0.11101	”	[170]
ELF	”	”	2.601	0.11110	”	[171]
IA	”	”	2.601	0.11110	94.25	”
LSF	”	18	0.743	0.14682	*NR	”
Mithulananthan	”	6	2.490	0.11124	”	[172]
RLFA	”	”	2.600	0.11110	”	”
LS	”	10	1.400	0.12382	”	[173]
VS	”	16	1.000	0.13675	93.18	”
IV	”	30	1.550	0.12515	92.75	”
SOS	2	6, 28	2.2861, 0.8363	0.10739	NR	[148]
	3	6, 28, 29	2.2066, 0.2, 0.7167	0.10426		
TLBO	3	12, 28, 30	1.1826, 1.1913, 1.1863	0.12469		[174]
PSO	3	13, 32, 8	0.9816, 0.8297, 1.1768	0.10535	”	[175]
GA	3	11, 29, 30	1.5, 0.4228, 1.0714	0.10630	”	”
HSA	2	18, 17	0.2012, 0.6932	0.14114	NR	[176]
	3	18, 17, 16	0.1913, 0.2133, 0.5927	0.13569		

*NR - Not reported

loss and improved bus voltages, the reliability assessment is accomplished. The performance analysis is performed for selected DSs, then after the system's reliability assessment is carried out with and without DGs' integration. Some of the literature in Table 2.10 showing the calculation of reliability indicators for reliability assessment of various Distribution System. Where, a Multi-Carrier Microgrid (MCMG), Roy Billinton Test System (RBTS), and Reliability Test Systemm (RTS) have opted for integration of DGs.

Table 2.9: Literature related to 118 bus distribution network considering distributed generations

Technique	DG	Node	DG Size (MW)	Loss (MW)	Ref.
Reconfiguration	1	71	2.979	1.0152	[159]
	2	71, 109	2.979, 3.120	0.08037	
SOS	3	70, 104, 68	2.3788, 4.7958, 1.2591	0.08752	[148]
PVSC	3	51, 74, 111	1.68, 1.82, 1.76	0.0711	[149]
QODELFA		20, 39, 47, 73, 80, 90, 110	1.7908, 2.7341, 1.8329, 2.4034, 1.7505, 2.2945, 2.7998	0.05186	[150]
Hybrid PSO-CSA with Reconfiguration	3	13, 52, 70	3 MW each	0.03444	[151]
QOTLBO	7	24, 42, 47	1.2463, 0.7322, 3.5352	0.05761	[174]
		74, 78	2.6792, 1.2483		
		94, 108	1.0865, 3.2432		
SA	5	75, 116, 56	2.1318, 0.7501, 1.1329	0.0858	[177]
		36, 103	4.5353, 4.9452		
KHA	7	48, 53, 74	1.7242, 1.3356, 1.8623	0.05747	[178]
		80, 96	1.8653, 1.6631		
		109, 112	1.9473, 1.1848		
SFSA	7	21, 42, 50	1.3757, 1.1997, 2.7418	0.05252	[179]
		71, 81	2.8915, 1.7025		
		97, 110	1.3321, 2.6674		
ACSA plus Reconfiguration	3	50, 73, 109	2.5331, 3.7043, 3.6819	0.05862	[180]
HSA-PABC	3	80, 30, 64	2.6, 6.8, 4.7	0.09043	[181]

Table 2.10: Reliability indices calculated in the literature for different Distribution Systems

System	Index	Value	No. of DG	Ref.	Remarks
33 bus	EENS	57.733	0	[146]	
	”	53.941	1		upf DG
85 bus	”	70.172	0		
	”	65.399	1		upf DG
MCMG	EENS	40.9	0	[161]	Microgrid is in islanding mode
14 bus	SAIDI	0.714, 0.222	No DG	[182]	Two values considering reward-penalty scheme or not
	EENS	8.694, 5.047	”		
33 bus	SAIDI	1.6287, 1.4802, 1.3257	3	[183]	First value is obtained considering 3 DGs without restructuring and other two values for two optimal structures of the distribution system
	SAIFI	0.2714, 0.2467, 0.2209	”		
	EENS	5.2968, 4.8795, 4.9412	”		
52 bus	SAIDI	5.013, 5.319, 3.791	3		
	SAIFI	0.824, 0.886, 0.632	”		
	EENS	26.719, 27.965, 23.177	”		
69 bus	SAIDI	1.776, 1.0279, 0.9684	3		
	SAIFI	0.1851, 0.1712, 0.1613	”		
	EENS	4.8623, 4.1928, 3.8498	”		
RBTS	EENS	9.841, 7.344, 5.920, 4.496	0, 1, 2, 4	[184]	Four values are obtained for 0, 1, 2, 4 DGs
IEEE RTS	”	1197.57, 932.97, 778.74, 600.35	0, 1, 2, 4		

2.7 Summary

Because the uncertainty factors make the EPDN untrustworthy, it was necessary to do a valuable research on the reliability assessment of such networks. This chapter focuses on the most important techniques for dealing with uncertainty parameters, such as reliability assessment and reliability improvement of EPDNs. When renewable energy sources are incorporated into electrical power networks, the probabilistic and probabilistic methods to dealing with uncertainty factors were explored. When dealing with modelling of unknown parameters, the probabilistic approach leads to the study of Monte-Carlo simulation, point estimate method, and scenario-based approach techniques. It was discovered that energy and customer oriented reliability indices such as AENS, ASAI, ASUI, CAIDI, CAIFI, EENS, SAIDI, SAIFI are critical to assess while conducting reliability analysis of the power systems. There was a brief investigation of the reliability assessment of Doubly Fed Induction Generator-based Wind Integrated Power System. The combination of Conventional Generations, Wind, Solar, and BESDs was also addressed in this chapter as a way to enhance the reliability of power systems. The existing literature was then contrasted with the contributions of this thesis in a comprehensive literature study.

The next chapter continues with reliability studies on DFIG-based WIPS. The power system's performance and reliability are assessed by considering three-phase and lightning faults on the adapted test system.