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Reliability Analysis Techniques in Distribution System: A Comprehensive Review

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Abstract: Quality of electricity with continuity is the reliability of the power system which is inversely proportional with the duration of power supply interruption. It depends on some expected or unexpected faults/failures on the systems, speed of protecting systems, preventive maintenance, and motivation of technical staffs. The detailed study of the distribution system is more crucial as its reliability is the concern of utility's fame, service, customers' satisfactions and reflects to the overall revenue. The relevant articles from the various sources have been collected and analyzed different reliability indices with their significance. Also, to realize the methodology related with reliability analysis, a comparative study among its different components has been carried out and the best techniques for maintaining system reliability are suggested.

Index Terms: Distribution System, Distribution System Reliability, DSR, Power System Analysis, Electric Distribution

1. Introduction

In Electrical Power System (EPS), all the generated electricity is consumed by the end consumers through the distribution system, which is also defined as the final stage in the electric power delivery and is responsible to feed the electrical demand of the individual consumers. In this sense, we can also say that it is the vital part of the electric power system and is final connecting bridge between a transmission system and the consumers. As electricity has become the vital part of the human society and we cannot imagine the sustainability of the modern age without it. Hence, any interruption in the electric distribution system results great loss to the consumers. The term defined for the regularity or continuity of distribution system is termed as distribution system reliability and is studied as the major branch of power system dealing with the trustworthiness or the consistency of the system. The major factors that affects the reliability of the distribution system are the different causes of faults in the line, failures of distribution system components, interruption in the power system, physical factors like rain, wind, landslides, floods, etc. and the demand of the system. The reliability of the distribution system is also the measure of service quality of that utility company and to make the system more reliable, they should be able to maintain the minimum outages as far as possible, regular system maintenance, implementation of fast acting protecting systems etc. For the shake of maintaining good reliability of the system, the distribution systems can be also redesigned or reconfigured overcome the problems faced due to overloading, low voltage regulation, frequent system trips due to physical factors like wind, landslides etc. [1-3].

Reliability and quality of the electricity is mostly affected on country development & economic growth and it is also directly related with satisfaction of customers. Capacity shortages and Faults & failures are the factors that affect the reliability of system [4, 5]. Nowadays, substantial changes with respect to structure, function, and regulation are applied by the electric power industry for power quality and reliability [6]. So, we can say that DSR is quite complex than Generation & Transmission System Reliability. And reliability analysis must be done during the design phase and development of complex components, equipment & systems to eliminate reliability weaknesses [7]. To understand reliability, we should focus on below three terms adequacy, quality and security [8, 9].

This article mainly focuses on identifying the major reliability analysis tools and techniques used in power system. A comparison of different reliability analysis techniques is presented and analyzed to identify the most efficient techniques based on the different scenarios. The section 2 of this article discusses the relevant literatures which gives the theoretical background of the topic and makes the comparison of the major results from the relevant literatures. Section 3 of this article highlights the insights of the different reliability indices used in power system and finally section 4 discusses on the results obtained and finally presents the conclusion. As this article presents the review of the relevant articles and suggests the effective tool for reliability analysis in distribution system, this lacks the field data collection and their reliability evaluation.

2. Research Methodology

Systematic Literature Review has been carried out to identify the best approaches used in DSR. This included proper identification of the related works, evaluate different approaches used in this area and finding the best solutions to the field. This research is based on the detailed survey of research works with the same scope and their critical analysis in methodologies and taking all together in the comparative tables to evaluate and compare their performances and area of applications. This article has made followed following literature review planning protocol.

A. Research Questions

Q1. What is the methodology that is being used for evaluation of the distribution system reliability?
Q2. What are the advantages/disadvantages of the existing reliability indices?
Q3. What is the best suited approach to identify the reliability indices?
Q4. What is the effectiveness of studying reliability of the distribution system?

B. Databases for Literature Survey

This study was conducted on two well-known literature databases with scientific scope, namely IEEEXplore Digital Library[1], ScienceDirect[2] and also, contains the study from relevant articles obtained from the GoogleScholar[3] literature using the keywords: "distribution system reliability", "DSR", "electric distribution", and "power system reliability".

3. Related Works

Capacity building exercise and Distribution Automation (DA) system by Accelerated Power Development and Reforms Program (APDRP)/ Integrated Power Development Scheme (IPDS) [4]. The India the utilities of USA carry out Predictive Reliability assessment But in Nepal these types of practice is not carrying out. If a utility tries to evaluate RI, there is more difficulties due to we have no more data base as other countries like USA. Data for evaluating RI (mainly related to interruption) are the benchmark parameters of Utility. In Nepal there is no specific regulation are found in contrast of RI till now but some of them are found in the context of power quality [10]. India and other countries like USA have more acts, policies, commission, rules, regulation, planning for maintaining power quality and reliability. So, in the scenario of Nepal, there needs to be some specific guidelines for maintaining proper system reliability with consideration of geography and environmental conditions.

Optimal Capacitors Placement (OCP) method is used to improve reliability of DS. For this RI is evaluated by state space method for both uncompensated and compensated system. This method finds the optimization value between investments of capacitors and the cost of losses. It also helps to improve losses & voltage of DS [11, 12]. Nowadays smart electrical distribution systems are needed to achieve higher levels of reliability. Due to some weakness of conventional program for reliability improvement like there is inappropriate for providing desired reliability of customers at different load points. It based on Utility-Based Reliability Planning (UBRP), Value-Based Planning (VBP), Performance-Based Rates (PBR) & Reliability Insurance Scheme (RIS) etc. [13].

Performance of DS is depending on efficiency, reliability, quality of supply. So, reliability is the major entity for PS and the reliability can be improve by increased investment on planning & operating phase, proper maintenance strategy and redesign/improved structure of DS [14]. Reliability or RI can be improved by DG by the fulfillment of power demand by its backup generation. AET & MC Simulation method have disadvantage that it cannot find weak system components. Due to this disadvantage Bayesian network (BN) Model which is based on probability theory and it is easy for uncertainty knowledge expression and inference like causal, diagnosis and explaining inference. It is noted that we have to make the perfect balance between low cost of DG injection & the maximum reliability achieved [15, 16].

By some reliability parameters we can found the best generator states & the parameters/ reliability indications are LOLP (most used), LOLE, EENS, and ECOST. This type of parameters is used to determine the reliability of the multi-energy carrier system [17]. Difficulties on this job is the optimal number & location of DG to be connected and if it is properly done than it helps to catch the reliability cost and worth requirements for utility. It has more advantages like it reduces loss in DS, it has more efficiency, quality of supply, better VR, less pollution, no need of construction power plant for a time, reduce capacity of line due to it is connected near load center. In this paper GA is used for optimization and Back Propagation Algorithm (BPA) is used for carrying out network training [6]. Proper DG or renewable energy (wind, PV, etc.) or PVDG can improve DSR. Proper rating & position helps to enhance reliability. DSR also affected by demand side management (DSM) & demand response (DR). DSM reduces the load on distribution lines during peak times without load shedding and it deters the consumers for turning off unwanted loads. So, we can say that proper

[1] https://ieeexplore.ieee.org/Xplore/home.jsp
[2] https://www.sciencedirect.com/
[3] https://scholar.google.com/

locating, proper size DG plays a vital role in DSR [18-22]. Latin Hypercube sampling (LHS) and MC sequential simulation method is used for reliability evaluation of DS with DG. It is based on random sampling. It can increase sampling speed and stratified sampling is the main idea for this [23].

These days, some topologies are used during designing of DS to achieve most reliable from least reliable system. They are simple radial, primary auto loop, Reliability is directly related with service and revenue. So we are ready for adequate planning, monitoring of system performance and putting in place effective control actions which helps in reduction in operation and maintenance costs also [24]. For reliability issues with power quality, traditional circuit analysis-based method can be used which is the combination of short circuit algorithm, Current Summation Method (CSM) & Sequential Monte Carlo Simulation (SMCS) algorithm. First one is used to find short circuit current, second is used for evaluating voltage & third one is used to show probabilistic conditions of power flow & short-circuit. SMCS is powerful tools for performing evaluations & used for reliability assessment of DS which is based on random number [25, 26].

Reliable electric supply with quality should be maintained with low cost and is a difficult task. So, we have to do some task with a certain optimization level by some optimization tools. In this paper, on the basic of evaluation of interruptions risks method of finding losses due to interruption is classified into three categories these are the methods of interview of customers, analytical, & simulation methods. Further three cases are taken like calculation of losses & reliability by MC methods and for optimization of no & locations of some equipment which are used in distribution systems and compare results [27]. DS is a Vital but the weakest link between supply & load because almost DS is a radial type feeders and lateral type distributors. DS is a customer load point oriented and generation and transmission are system oriented. Mainly reliability of power system is depending on DS due to it is the weakest link and 80% interruption is caused by DS. So, we have to focus on DSR to maintain power system reliability [4, 28, 29].

Sometimes branches of reliability are also classified as i) Hardware reliability (Physical & Actuarial approach) ii) Hardware reliability & iii) Human reliability. Applications areas of reliability technology are mentioned as i) Engineering Design ii) Risk analysis iii) Environment Protection iv) Verification of reliability & quality v) Optimization of maintenance and operation [30]. Similarly, many methods are used to improve reliability of the DS like as i) Demand Response (DR) programs and smart charging/discharging of Plug-in Electric Vehicles (PEVs) which is used for radial systems & LOLE, EENS etc. are taken as RI [31]. Chronological Monte Carlo Simulation (MCS) is a probabilistic method and realistic system representation than other which is used for evaluating RI. This method is used to find the maximum number of mobile unit substations (MUS), optimal acquisition time within DG and spares to stock for a similar power transformer [32].

For evaluation of the RI, A path-based modeling framework is used. For line reconfiguration (DFR) to improve reliability & loss, a path-based mixed integer quadratic programming (MIQP) formulation is used [3]. To calculate reliability of the complex DS, a fast method based on the fault incidence matrix (FIM) is used. It has intuitive and extensible features [33]. RI of load points can evaluate by linear equation method with fast and accurate. Which uses only some algebraic equations. For this we required upstream and downstream node of lines to make linear equations. This method is network-dependent [34]. To evaluate the time-dependent reliability, a novel approach, known as time-dependent reliability analysis with response surface (TRARS) is applied [35]. Reliability evaluating Bayesian networks also can used in safety and risk assessments. It has features of flexible structure and it can reason under uncertainty [36]. To estimate reliability parameter, E-Bayesian and Hierarchical Bayesian estimations method is used. For exact estimation asymmetric loss function such as LINEX and Entropy loss function is found better than symmetric loss function [37]. To evaluate the real time reliability level of the feeders, an online reliability evaluation method is applied & which considers the time sequential load transfer procedure & MV feeders as the evaluation object [38].

Generally, Data for calculating/evaluating & analysis of RI is taken for a 12 month and of radial feeders. To achieve more accurate result on reliability more accurate & rigorous data should be collected.

Table 1. Comparison of relevant works with their major findings

Ref.	Problems	Required Data/Methodology	Result / Recommendation	Remarks
[39]	E/F & O/C fault	Fault type, Peak load, demand, outage duration & power loss due to outage	Reconfiguration of Distribution line with Ring system.	
[11]		Reliability indices and reliability cost mentioned	Presented an overview of useful methods used in reliability analysis.	
[40]	Weather Vegetation & Animals (50%) [50%=E/F, Maintenance/Unknown & Operation]	SAIFI, CAIDI, ASAI is used. [Note: The authors noted that large number of outages was reported in the data as unknown or other causes due to the inexperience of the utility workers.]	There should be standard way of reporting outage in utilities. But no justification.	33KV (O/G & U/G)
[41]		Analytical Technique which uses outage data. Also, study impact of alternative or complementary source like PV/inverter interconnected with the network in order to improve the reliability of the system by using ETAP software.	Reliability performance can be improved upon by introducing a complementary source and that by effectively utilizing solar technologies such as PV, there will be less erratic supply of power to consumers	

[15, 36]		Method based on Bayesian Networks by using test data from other.	The stochastic nature of failures of a distributed generation was analyzed and determined the availability, location and the no's of DG and the effect on the distribution system performance.	
[42]	Weather like lightning, wind, ice, flood, tree branch coming on lines	Failure rate due to cause is found using FUZZY model. Also found interruption type, duration, protection device used.	Failure rates are found	
[43]		The monthly reliability parameters for the 33kV distribution feeders were calculated using the daily outage data of the feeders for 16 months	System availability is low compared to the IEEE standard of ASAI which is 0.99989.	
[8]		Different reliability indices.	Result: different customers experience different levels of reliability and availability of supply even if they are under the same feeder and/or substation.	
[9]	Load Shedding	By customer-based indices & by Ekpoma network.	No	
[28]	Aging Components	Failure Mode and Effect Analysis (FMEA) was used to calculate the reliability indices. And a simple distribution network was generated for the research and the focus was on supply lines.	Presented the relationship between aging components and their limit age (time).	
[44]		Indices are found by NEPLAN simulation software which perform an offline simulation of the distribution network considering outage time, incoming energy, outgoing voltage rating & 3 phase current rating	It was recommended that the utility company should be keeping detailed account of data and records which contains component outage time, component failure rate and total energy consumed which will help compute reliability indices such as Energy Demanded Not Supplied (EDNS).	
[45]	Short circuit by animals like lizarda, rats etc.	Wavelet transform techniques & outputs of neural network in their work	By introducing hybrid approach that integrates AIS	Book
[46]		RELRAD (reliability in radial systems) and Markov Model.	Benefit of automation and remote control in a rural overhead system and the impact of reserve cable in an urban cable system	

Interruption of supply is occurred due to faults like lightning, switching, short circuit, and failures/damage of any electric components and also by routine maintenance. Cause of interruption is mostly animals & lightning. Mainly DS is affected by weather of environment. Loss of electricity to customer from energized conductors which is connected to the DS. Interruption of customer electric supply is mostly (80%) due to the distribution system among Generation, Transmission and Distribution [4, 29, 42, 47, 48]. The interruption/outages are based on type, frequency and durations.

A. Unplanned Interruption

It is the types of Forced interruption & which is caused by the following factors [40, 48].

- Human factors: Human errors, Improper operations, Electric structure gets collided by vehicles, excavation, mischief, destruction by worker, public etc.
- Intrinsic factors: manufacturing defects, ageing effects etc.
- Environmental factors: Earthquakes, Wind, flood, fires, icing, lightning, branches of trees or trees falls/touch on electric lines, by snakes/ birds/mice/fire ants/rats/gophers/ other animals etc.

This type of interruptions is classified as below according to cause and interruption duration.

- Momentary/Transient Interruption: Interruption/Loss of power supply for less than 5 minutes which is caused by mainly opening and closing of an interrupting device. By analytic and probabilistic method Momentary interruption indices can be found [49, 50].
- Temporary Interruption: Interruption/Loss of power supply for less than 80 mins. This time is different on different paper like up to 120min is taken as temporary interruption.
- Sustained/Permanent Interruption: Interruption/Loss of power supply from many hours (more than 80 mins) to last for day. It adversely affects for customer and utilities too [5, 43]. This type of faults is not self-clearing type.

B. Planned/Scheduled Interruption

It is a scheduled interruption/Loss of power supply for maintenance or any other works i.e. simply it is planned outage. It is the types of human factors.

C. Types of faults [39]

Many faults are appeared in power system like Single line to ground fault (LG), Line to Line fault (LG), Double line to ground fault (LLG), three phase fault (LLL), three phase to ground fault (LLLG).

Among them DS have almost the followings types of faults. Line to Line fault is the type of Over Current (O/C) Fault which occurred due to:

- Short Circuit bet lines
- Animals like Rats, Lizards shorts the line mainly in control panels
- Jumper/Line itself broken and touch another live line
- Wind collides the line to each other
- Over loading of lines
- Animals like Birds running and touch the 2 live lines
- Line to Ground fault is the type of Earth Fault (E/F) which occurred due to
- Live line is touched to ground by any causes.
- Jumper/Line itself broken/cut and touch the pole/ground live line
- Broken, Leakage insulators
- Branches of tree or Tree touched the line mainly during the wind.
- Broken wooden cross arms and other wooden structures,
- Leaking of underground and overhead cables/XLPE cables etc.
- Sagged line touched the tree, ground, building.

D. Terminologies

1. *Availability* (A):

The measure of the duration of power system is in fully operation at any time. That means it is the duration of operation of a component at any time.

$$A = \frac{MTBF}{MTBF + MTTR} = \frac{MTBF - MTTR}{MTBF}$$

2. *Unavailability (U):*

The measure of the duration of power system is in fully operation at any time.

$$U = \frac{\lambda}{\lambda + \mu} = 1 - \text{Availability (A)}$$

3. *Failure Rate (λ):*

$$\lambda = \frac{1}{MTTF} = \frac{\text{No of outage on component in a given period}}{\text{Total time component is in operation}}$$

4. *Repair Rate μ):*

$$\mu = \frac{1}{MTTR} = \frac{\text{No of operation on component in a given period}}{\text{Total time component is in operation}}$$

5. *Mean Time Between Failures (MTBF)*

In repairable systems, MTBF is the expected time between the occurrences of two consecutive fault/interruption and measures the reliability of these components. By which we know the total time of operation.

$$\text{MTBF} = \frac{1}{\omega F} = \frac{\text{Total system operating hours}}{\text{No of failures}} = \text{MTTF} + \text{MTTR}$$

Where, ωF = Frequency of system failures & which is the frequency of steady state of transition from functioning state to a failed state.

6. Mean Time to Repair/Mean Down Time (MTTR):

It is the average time to be taken for repairing of an electric component before it is restored to normal operation if the component is out of service. It is also called Mean Down Time (MDT).

$$\text{MTTR} = \frac{FOR}{NF} = \frac{\text{Total duration of outage}}{\text{Frequency of outage}}$$

7. Mean Time to Failure/Mean Up Time (MTTF):

$$\text{MTTF} = \frac{SH}{NF}$$

Where,
Hours (H) = No of days * 24
Operation Hour (OH) = FOR+H
Service Hours (SH) = H-OH
No of times of forced outage = NF
Forced outage rate = FOR

E. Reliability indices

For a well-defined set of loads/customers, it can be defined as the statistical aggregations (specific reliability feature) of reliability data for an entire system. These are numerical parameters that reflect the capability of the system as required by consumers [45, 51]. Here we have indices as below:

1. Customer based or Sustained interruption indices:

System Average Interruption Duration Index (SAIDI): During a predefined time period, average interruption duration for an average customer is called SAIDI. It is expressed in minute/hours.

$$\text{SAIDI} = \frac{\sum \text{Customer Total Interruption or Outage Duration}}{\text{Total No of Customers Served or Supplied}} = \frac{\sum \text{R i N i}}{\text{Nt}}$$

System Average Interruption Frequency Index (SAIFI): During a predefined time period, average interruption time for an interrupted customer is called SAIFI. It is expressed in interruption per customer.

$$\text{SAIFI} = \frac{\sum \text{Total No of Customer Interrupted or Outage}}{\text{Total No of Customers Served or Supplied}} = \frac{\sum \text{N i}}{\text{Nt}}$$

Customer Average Interruption Duration Index (CAIDI): During a predefined time period, average interruption length for an interrupted customer is called SAIFI. i.e. It is the mean time to restore the system.

$$\text{CAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total No of Customers Interrupted}} = \frac{\sum \text{R i N i}}{\sum \text{Ni}} = \frac{\text{SAIDI}}{\text{SAIFI}}$$

Customer average interruption frequency index (CAIFI): The average frequency of the sustained interruptions for interrupted customers is called CAIFI [49, 50, 52-54]. In this case; number of times are not calculated for once counted customers.

$$\text{CAIFI} = \frac{\sum \text{Total No of Interruptions}}{\text{Total No of Customers Interrupted}} = \frac{\sum \text{N i}}{\text{C n}}$$

Average Service Availability Index (ASAI): During a predefined period, percentage of time in which power is avaible for customers is called ASAI.

$$\text{ASAI} = \frac{\text{Customer Hours Service Availability}}{\text{Customers Hours Service Demanded}} = \frac{\text{Nh} - \sum \text{R i N i}}{\text{Nh}} = \frac{\text{SAIDI}}{\text{SAIFI}} = \frac{8760 - \text{SAIDI}}{8760}$$

Average Service Unavailability Index (ASUI): During a predefined period, percentage of time in which power is unavailable for customers is called ASUI.

$$\text{ASUI} = \frac{\text{Duration of Outage in hours}}{\text{Total hours Demanded}} = 1 - \text{ASAI}$$

Customer Total Average Interruption Duration Index (CTAIDI): It is a hybrid of CAIDI except that those customers with multiple interruptions are counted only once.

$$\text{CTAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total No of Distinct Customers Interrupted}} = \frac{\sum \text{R i N i}}{\text{Cn}} = 1 - \text{ASAI}$$

Customers Experiencing Multiple Interruptions (CEMIn):

$$\text{CEMIn} = \frac{Total\ No\ of\ Customers\ that\ experiencd\ n\ or\ more\ sustained\ Interruptions}{\text{Total No of Customers Served}}$$

Customers Experiencing Long Interruptions Durations (CELID):
For single interruption Duration:

$$\text{CELID} = \frac{Total\ No\ of\ Customers\ that\ experiencd\ S\ or\ more\ hours\ duration}{\text{Total No of Customers Served}}$$

ACCI = Average Customer Curtailment Index

Where,
Ri = Repair/Restoration time for each interruption event
Ni = No of interrupted customers for each sustained interruption during the related period
Cn = No of total customers who experience a sustained interruption during the reporting period
Nt = Total no of customers
Nh = Total no of hours/year (8784 for leap & 8760 for leap yrs.)
λi = No of interruption
[Note: Replace S by T in above formula for total interruption duration]

2. *Load based indices:*

Average System Interruption Frequency Index (ASIFI): It is similar to SAIFI

$$\text{ASIFI} = \frac{\sum \text{Total Connected kVA of load Interrupted}}{\text{Total Connected kVA Served or Supplied}} = \frac{\sum \text{L i}}{\text{Lt}}$$

Average System Interruption Duration Index (ASIDI):

$$\text{ASIDI} = \frac{\sum \text{Connected kVA Duration of load Interrupted}}{\text{Total Connected kVA Served or Supplied}} = \frac{\sum \text{R iLi}}{\text{Lt}}$$

Where; LT = Total connected KVA load served/supplied
Li = Connected KVA load interrupted for each interruption event
B.1 Elementary RI [49] :
Average Failure (λ)
Average & Annual Outage Time (r)
Average Annual Outage Unavailability (U)
C.1 Other Indices (Momentary):
Momentary Average Interruption Frequency Index (MAIFI):

$$\text{MAIFI} = \frac{\sum \text{Total no of Customer Momentary Interruption}}{\text{Total no of Customer Served or Supplied}} = \frac{\sum \text{IMiNmi}}{\text{Nt}}$$

Momentary Average Interruption Event Frequency Index (MAIFIe):

$$\text{MAIFI}e = \frac{\sum \text{Total no of Customer Momentary Interruption Events}}{\text{Total no of Customer Served or Supplied}} = \frac{\sum \text{IMeNmi}}{\text{Nt}}$$

Customers Experiencing Multiple Sustained Interruption and Momentary Interruption Events (CEMSMIn):

$$\text{CEMSMIn} = \frac{\text{Total no of Customer Experiencing n or More Interruptions}}{\text{Total no of Customers Served or Supplied}}$$

Where,
IMi = No on momentary interruptions
IMe = No on momentary interruption events
Nmi = No of interrupted customers for each momentary interruption events during the reporting period

3. *C.2 RI Related to Load & Energy Oriented [49]:*

Energy Not Supplied (ENS): KWhr/yr
ENS = $\sum$ LiUsys,i
System Energy Not Supplied (EENS)
Average Energy Not Supplied/Served (AENS): in KWhr.yr /Customer

$$\text{AENS} = \frac{\sum \text{L}i \; \text{U}sys, i}{\sum \text{N}i}$$

Where,
Li = Average load connected to ith load point
Ni = No of customer at load point i.
Usys,i = Annual outage duration at ith load point

4. *Other indices that are related to reliability as:*

- Average outage duration
- Energy demanded but not supplied (EDNS)
- Loss of load probability (LOLP)
- Loss of load expectation (LOLE)
- Expected energy not supplied (EENS)[41]
- System expected outage cost (ECOST) : It is a type of Reliability cost worth indices.[41, 49]
- Interrupted Energy Assessment Rate Index (IEAR) : It is a type of Reliability cost worth indices.[41, 49]

5. *Factor affecting RI*

- Condition of environment, Strom and weather like wind, rain, flood, density of tree/branches coverage [45]
- Length of circuit: Longer circuit inversely effect on reliability.
- Types of Construction i.e. overhead or underground
- Types of line i.e. radial, ring, and network: Long Radial circuit more effect on reliability.
- Density of load & Voltage level
- Aging effect

6. *Importance of Reliability Parameters:*

- Performance of utilities are defined by RI or Reliability Parameters which is benchmark indication for utilities [39]. And it also makes the brand of utilities.
- It develops fair competitions different utilities to maintain reliability and power qualities of electricity.
- Continuous of electric supply is needed for Customer which is indicating by this type of parameters.

F. Techniques associated with reliability evaluation [46, 51] [52, 55, 56]

This type of methods is depending on maintenance time data & history of failures.
Analytical Evaluation Techniques (AET):

- It evaluates the reliability indices by analytically.
- This method is based on solution of mathematical models.
- Also based on assumptions w.r.t. statistical distributions of repair times and failure rates.
- It is the mostly used than SET
- It is sufficient to make results for objective decisions.
- By using direct numerical solutions we can found RI by a mathematical model [14]
- For this method Minimum Cut Set & Failure Mode Analysis is mostly used [57]
- It is properly used to evaluate the mean values of a wide range RI.

- Advantage: Less time consuming than SET and gives expectations indices. For a simple system it can be used as ideal.
- Disadvantage: In more cases it does not represent repair times adequately. For complex system to make simpler, assumptions to be done.

It has two types:

a. Network Technique:

- Reliability indices are determined by minimal cuts sets and groups of equations.
- This method is based on FMEA and it can be used as inductive method.
- Structural relationships between a system and its components are considered.
- System is considered as a network of its components (series, parallel, meshed & their combinations).
- Reliability indices are determined by minimal cuts sets and groups of equations.
- This method is based on a failure modes and effects analysis (FMEA) [For the generation sources are neglected]
- Challenge: Modeling the failure behavior of the system.
- The component which result in an interruption of service at the interesting point of load can find by this method.[57]
- Reliability of Substation can also be analyzed by this method, depending on outage data [5]

b. Markov Modeling Technique:

- It is a random process (Stochastic modeling) in which random variables are component failure and repair times etc.
- So, it can be said that a system behavior in each state is memoryless due to it works solely on the assumption.
- It does not consider the past event but take the present event to determine the future event.
- Large no of states are required in this method for modeling of system.[57]

SN	Methods	Advantage	Disadvantage
1	State Space	Accurate	Large Computation time
2	Contingency Enumeration	Less Computation time	Not applicable for an entire system
3	Minimum Cut Set	Less Computation & the best for specific load point	Not applicable for an entire system

AET can also be classified as State space method, contingency enumeration method, minimum cut set method [52].

c. Simulation Evaluation Techniques (SET):

It is a Sequential method and Stochastic techniques.

- Events are randomly chosen or in a given order.
- It requires a series of experiments and predicts the reliability indices by simulating the real process and the random behavior.
- This method is based on drawings from statistical distributions or probability statistics.
- In this method more nos of failure to simulate is needed so it is expensive
- The simulation process is intended for examining and predicting the stochastic behavior of a system in simulated time. It also may be time-sequential simulation process.
- For a specific period, simulation have an aim to make estimates of unknown parameters which will serve as real experiments.
- The common simulation method is Monte Carlo (MC) Simulation method.

d. Monte Carlo (MC) Simulation method

- It is called as Stochastic Simulation.
- It can be used as statistical simulation methods and use the sequences of random numbers.
- It has some charming properties like failure criterion being relatively easy to check without depending on the structural features of the system.
- It is collection of different methods.
- It has no simple mathematical model & equations, So it is not consider as an intellectually stimulating like AET [58].
- To predict the reliability it is used in a complex distribution system [49]
- Advantage: For complex system it is the more precise and powerful method.

- Disadvantage: For simple system it is computationally heavy i.e. More time consuming than AET. So, it is less used in specialized applications like complex system.
- It has some types like as Sequential Technique, Non-Sequential Technique, State Sampling Technique, and State Transition Sampling Technique.
- By this way we can classified the Reliability Evaluation as below:

Evaluation of Reliability is has two approaches as Histoptical Assessment & Predictive Assessment [4].

Reliability assessment is classified in to two groups as steady adequacy & transient security assessment. Evaluation of Reliability is also classified in to two groups as deterministic & probabilistic [18, 52].

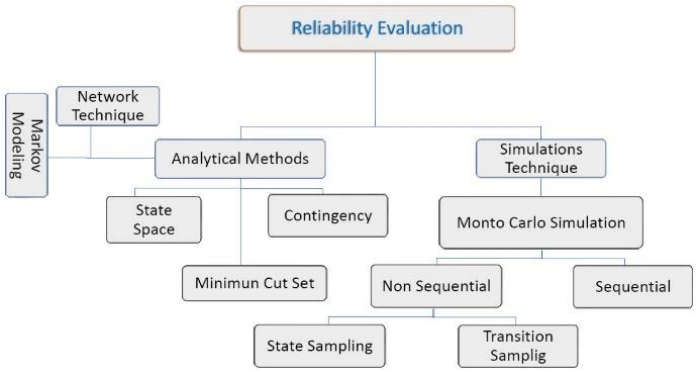

Fig. 1. Reliability Evaluation Approach

3. Reliability Assessment Methods and Major Findings

A. Cymdist

Reliability Assessment Module (RAM) Software: For feeder Network and Simulation & Modulation. In which RMEA technique based minimal cut set method is used to reduce computation time [4].

B. Game Theory Approach

It is a reliability improvement scheme which also can use in different sectors of power system. For categorization as a game, a problem should have three basic properties. i) For competition a commodity or subject is required ii) Objective functions is optimized by agent's iii) the agent's decision variables affect each other. Nash equilibrium concept is used to determine the output of the game [13].

C. Electrical Transient And Analysis Program (Etap)

This software is used for the analysis of the DS reliability or RI. It is also used to analyze the output by analytical methods [14, 41].

D. Genetic Algorithm (Ga)

It is used for optimization process by which optimal location and the power to be generated by DG is evaluated. It has five stages for this operation. The stages are generation of initial chromosome, fitness function, crossover, mutation, and termination. In genetic algorithm the initial process is generating initial chromosome. The initial chromosome is generated based on the requirement. GA with local search scheme known as Enhanced Genetic Algorithm (EGA) is applied for optimal placement & size of DG, and this action helps to improve reliability [6, 59].

E. Adaptive Fuzzy Modeling

Bad weather reduces the reliability of the system. The effects of trimming of trees, tree density, lightning and wind on the failure rates is predicted by this method. Input of this method is wind, size of conductor, protection device, tree trimming & density of tree. To direct this model Fuzzy Logic Toolbox of MATLAB was used [42, 60, 61]. Fuzzy fault tree analysis (FTA) be used for estimation of failure probability and it is based on interval type 2 fuzzy set (IT2FS). DS have both subjective and objective uncertainties and FTA It can consider both uncertainties [62].

F. Markov Models

It is used to evaluate RI. Detailed analysis of different failure modes of components is done by this method and used to find equivalent fault statistics of various components. This method is also proposed for the modular multilevel converter (MMC) [46, 63, 64].

G. Failure Modes And Effects Analysis (Fmea)

It is based on AET (Network Technique) & failure modes and it has complex system so it cannot be used normally. In that paper RBTS test system is also used. It is used to evaluate reliability of radial DS [4, 28, 33, 49, 58, 65].

H. Quantitative Technique

It gives the idea about historical performance of existing systems and used for data collection. In Series system one component leads to interruption so that Network Reduction method is used [5].

I. Lighting Search Algorithm (Lsa)

It is a nature-based optimization technique (search technique) & which is influenced by PSO & GA. At any load point, it is used to find the optimal sequence of restoration of each outage [66].

J. Teaching Learning Based Optimization (Tlbo)

This type of method is used to reconfigure radial DS. It is based on nature inspired population. It can decrease the combinatorial complex switching to solvable simpler switching [67].

K. Matlab

Some researchers applied this tool for load flow, simulations etc. By this Reliability assessment is calculated for energy hub [17, 68].

Similarly, many types of methodology, algorithm, tools etc. are used for reliability assessment/evaluating RI like as Modified Gbest Guided Artificial Bee Colony (MGABC) is based on meta-heuristic [19], Frequency Duration (FD) reliability techniques [64], particle swarm optimization (PSO) [68-70].

4. Discussion and Conclusion

From the paper studied above, the following conclusion is made for almost paper among them. Most of them is followed the steps mentioned below;

- First, they find out the problems, faults, types of interruption/failures of DS.
- The required data is taken from utilities, substations, logbooks/log sheets etc.
- By these data, analysis is carried out and finds the RI (like SAIDI, CAIDI, SAIFI, CAIFI, ASAI, LOLP, LOLE etc.) of DS.
- Analysis, evaluation and data taking are done by some methodology and software like CYMDIST, Game Theory Approach, ETAP, GA etc.
- Compare the RI with standard value (On IEEE base i.e. reliability benchmark) and find the reliability of DS is need to be improved or not?
- If improvement is necessary, they select the method by which RI or Reliability can be improved like Redesigning of line (using ring feeders), Using DG, Installing the Some equipment etc.

On the basic of problems arise in the distribution system, above papers give some ideas to improve DSR. By using fast sensing & operating protective devices, correcting faults faster, use the device like recloser to make interruption only for permanent faults, sufficient no & expert technical manpower, proper size of protective devices, adding of distribution substations if required as near as load centers, reducing faults, fault duration and no of affected customer/area [45]. And some paper also optimizes the cost for improving reliability by using MATLAB, FUZZY logic etc. for economy.

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