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Electrical power projects: the role of risk management and reliability

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ABSTRACT

The management of power outages caused by severe weather disasters such as earthquakes, tornadoes, and weather disturbances is critical in power transmission and distribution systems. The transmission system is the key to any power system and can trigger severe or significant effects if it fails. Different causes of fires, extreme weather conditions, ageing components, poor maintenance and malfunctions, human error, mal-operative procedure, and high operating network variables may cause transmission components to fail. System reliability is the probability that, despite component failures, a system remains available or functional. Risk management of the failures describes it. There are several methods to predict the failure rate, including exponential and Bayesian distributions. In this study, Poisson distribution forecasted the outage patterns for transmission and distribution networks for one and five years. A probability distribution function generated this pattern. Moreover, previous data were obtained from National Electric Power Regulatory Authority (NEPRA). On comparing the acquired results with previous outage data, it was reported that the average outages in the transmission system were 567.The average outages in the distribution system stood at 37 for five years with a 100% confidence level. However, the probability of getting 620 transmission outages and 50 distribution outages was highest in the probability distribution function for five years. Poisson distribution proved to be a useful tool to assess the transmission and distribution system reliability by estimating the failure rate over the years. It would allow the risk professionals to schedule, reduce, and track the systems' risks. It would also help to improve the system's reliability.

1. Nomenclature

Λ	Number of Failures in The Given Time
CL	Confidence Level
ETA	Event Tree Analysis
FTA	Fault Tree Analysis
K	Maximum Number of Failures Input
K-Electric	Karachi Electric
KV	Kilo Volts
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
NEPRA	National Transmission and Dispatch Company
P	Probability

PDF	Probability Density Function
R	Number of Failures in Time (T)
R	Reliability
Q	Quality
T	Time Considered for Probability Distribution.
T	Failure Time in Reliability
TTF	Time To Fail.
Dpss	Distributed Power Systems

2. Introduction

In the power grid, the system operates near its design limits through a large number of power transfers. This makes the power system vulnerable to potential faults, jeopardizing the system's stability. Moreover, system reliability is constantly at risk because of system events, unexpected load changes, operational problems, increasing network complications, high customer service demand, etc[1].Therefore, to calculate, track, and improve power system efficiency, new methods and tools need to be developed. In conjunction with modern machine learning methods, recent statistics show that control and communication technology improve the reliability of the system. In order to improve and maintain quality today, many more process monitoring tools and experimental designs are used. Extending quality to reliability is a revolution to focus, which is defined as "quality over time".[2]. A survey related capital development projects (transmission, generation, and distribution) conducted and confirmed that, other than previously recorded risks, there is a more drive towards thorough assessment and complex electrical projects with potential cost overrun. Risk perception is considered to be an important aspect of risk management [3] . Reliability is a power system's capacity to return from sudden disturbance to a stable state condition. The principal parameters are voltage and deviations in frequency. Therefore, the efficiency of the generation, transmission, and distribution systems must be taken into account from the planning stage. Thus, various parameters should be assessed for improving the distribution system efficiency, including operating costs, interruption of supply, load reduction policies, maintenance time, load shedding, and equipment problems. The general method of determining the reliability of a given system entails measuring reliability indices under a variety of operating conditions[4]. Reliability analysis is suitable for all engineering systems; a few of researchers finding confirms that the main objective for energy system and designing power is reliable supply of load, with the minimum cost, maximum reliability and changing weather conditions [5] Reliability Assessment Methods of Power Systems are divided into four categories: Deterministic methods, Probabilistic methods, Intelligent methods and Simulation methods (Tools)[6] Power system planning has used deterministic technology like the contingency criteria *n-1*initially. It examines the system's reliability under the expected fault. It explores the system output in the context of a given scenario while ignoring the system state and uncertainties in the power system. It considers that all states are known and constant. This is only efficient with fewer fault conditions and does not allow damage, necessitating several situations with set parameters to ensure the analysis's effectiveness. In most power system studies, the worst-case framework is investigated and long-term decisions are taken to maintain the system's operational integrity and reliability [7]. On the other hand, probabilistic approaches generate quantitative indices for decision-making during preparation and operation, both in the long and short term [8]. They obtain the likelihood of different events. They are more extensive than deterministic methods using risk indicators and diverse statistics, thereby substituting deterministic methods. Probabilistic risk evaluation can be divided into an analytical approach and a method of simulation [9]. The reliability evaluation of transmission systems is the key to system investment, repair, design, and service decision-making. This has become crucial for the decision-making process because it offers ample precision in evaluating reliability. It determines cascade outage, blackout, transmission capacity, load flow, contingency analyses, thermal line rating etc. Cascading failure is one or more events, resulting in a series of component failures and causing major electricity disruption [8]. There are several elements in the power grid. The root cause of the system failure is component breakouts. In a system risk assessment, this parameter is identified. It is divided into independent and dependent failure. The outage model further classifies each group. However, ageing failures are not included in the conventional risk assessment. Then the probability of network failure states is selected and measured. Lastly, analyzing and evaluating the effects of system failures is carried out [11]. The transmission system is the key to any power system and can trigger severe or significant effects if it fails. Different causes of fires, extreme weather conditions, ageing components, poor maintenance and malfunctions, human error, mal-operative procedure, and high operating network variables may cause transmission components to fail. The probabilistic security assessment approach focuses on solving the drawbacks of the simple deterministic method. Inputs and outputs of the power system represented by the probabilistic approach are determined using Probability Density Function (PDF). This takes into consideration the various operating conditions of component failures. Reliability in quantity power systems' modelling is generally challenging work. This is due to the high redundancy and reliability of the components. This has been linked to dependent extinguishing incidents [12]. Reliability and statistical inferences are widely used to obtain discrete random variables. Negative Binomial and Poisson distributions are often used to perform reliability studies, in addition to Binomial distribution[13]. Overhead transmission lines are vulnerable to lightning, storms, hurricanes and severe weather conditions and are exposed to nature. It has a close relationship with the external meteorological conditions, which is why weather factors needs to be part of reliability consideration over assessment of overhead transmission lines securing economic decision-makings [14]

2.1 Reliability Risk Management

Risk evaluation involves using an experience of failures to detect flaws in a specific design. Failure mode and impact analysis, exploration tests, and environmental and stress assessments are a few methods for assessing system reliability. Design, manufacturing, transportation, installation, service, repair, and retirement of systems are included in the domain. In reliability engineering, organizations also work closely with sourcing, vendors, marketing, finance, and customers [15]. The risk prioritization and reliability engineering characteristics categorize the most serious and likely failure conditions. There is no one way to achieve enhanced product reliability [15]. Focus has been on reliability in power system engineering. This has distinguished system reliability, assessment, and evaluation depending on the project process. There are two levels of reliability: component level and system-level reliability. Bottom-up and top-down techniques are used in these stages and are included in reliability methods [16]. The approach primarily adopted in the fault tree analysis (FTA) is in a top-down manner. It includes a risk management methodology defined by a fault tree diagram. The incident or loss is at the top of the tree, followed by immediate, mild, and critical factors. To characterize the relationship between bottom events and the top event, AND and OR logical gates are mostly used [17].A risk management strategy that involves implementation from the bottom up, in the opposite direction, is an event tree analysis (ETA). This uses failure as a first step in evaluating possible event sequences that may arise due to the initial incident. Analyzing the system reliability by systematically conducting risk management and integrating residual risks is reliability risk management. The risk response and treatment methodologies increase the system's reliability and reduce failure. The main responsibilities in reliability risk management are: (i) Understand the dynamics of the bulk power system; (ii) Risk identification and assessment; (iii) Analyze efficiency to evaluate the performance of the system at its current state; and (iv) Reliability evaluation. Reliability risk management analyses incidents and discusses the threats[18].

2.2 Poisson distribution

Reliability is the probability that a system will not fail in a given period. Simon Denis invented the Poisson distribution in 1837, used in reliability analysis. It is one of three discrete distributions that use integers as random variables (binomial, hyper geometric, and Poisson) [19,20]. Decades passed since the probabilistic transmission planning and risk assessment been used where key components amongst others is the historical outage data computing failure rates of transmission lines individually which are used in the modelling of transmission system. With an Exponential distribution of time between failures, amongst others the most common type is Poisson distribution for calculating transmission line outages probabilities [21]. The events in the Poisson distribution occur at a constant average rate. At any interval, the number of occurrences is independent of the number of occurrences. The probability mass function for Poisson distribution is:

$$P(r) = \frac{(\lambda t)^r}{r!} e^{-\lambda t} \tag{1}$$

In Eq. (1), 'λ' is total outages per unit time, a time considered for the probability distribution is 't', the number of failures in the given time is 'r', and $P(r)$ is the probability of 'r' outages in time 't'[22]. The probability that each failure occurs within the same time interval must be determined in an attempt to estimate the probability of 'k' or fewer failures during 't'. Failure probability is:

$$P(r \leq k) = \sum_0^k P(r) \tag{2}$$

The confidence level (CL) of the sample based on $r \leq k$ failures during time 't' having failure rate 'λ' is:

$$CL = 1 - P(r \leq k) \tag{3}$$

Most experts in the field of electrical engineering influenced and considered Distributed power systems (DPSs) under two general approaches: system adequacy and system security respectively. Where the security of its power system includes reliability and availability [23]. Poisson distribution assesses system reliability and availability for power system components. It helps to schedule preventive maintenance, hire the repair crew, and to buy replacement parts [22].

2.3 Reliability Analysis

Reliability is simply the probability that the device will continue to operate. Mathematically:

$$R(t) = P(T > t) \tag{4}$$

Where 't' is the period in the operating conditions and *'T'* is a failure time in Eq. (4). If probability density function (PDF) is *'f(x)'*, the reliability function is:

$$R(t) = \int_0^\infty f(x)\, du \tag{5}$$

Reliability function *R(t)*for the probability of failures *F(t)*, corresponding to *f(x)*in terms of cumulative distribution function (CDF) is written as:

$$R(t) = 1 - F(t) = 1 - \int_0^\infty f(x)\, du \tag{6}$$

The reliability function provides a cumulative reverse probability distribution of the components' failure time. Failure time is the period the component has been retained in operation until the end of service, referred to as a time to fail (TTF). Since generators function constantly, availability is used [24].The possibility that the device will be operational in the future is availability [25]. Many reliability methods are used in research and industry, owing to the availability of historical databases and low computational costs. Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) of electrical power systems are used to determine key factors influencing overall system reliability [24, 26, 27].ETA describes all possible accident sequences and chains associated with specific event initiations in a bottom-up manner. One of the research studies collected data on the efficiency of generators based on ETA [28].FTA is a malfunction and outage analysis. It detects the failure event and combinations of failures in a top-down flow. It evaluates forced outages in which the system observes failures [29]. Electrical and mechanical devices can be reparable or non-reparable. The life of a non-repairable component lasts until it becomes non-feasible to repair [30].The Poisson distribution finds the likelihood that a single failure occurs for a non-repairable device. Moreover, reparable components can have a useful life following events of failure. The life of the repairable components consists of the time for operation as well as the time required for maintenance. Reliability risk management is a measure of the probability and consequence of events that could disrupt system efficiency [30].Risk evaluation responds to three questions: (*i*) What can go wrong?; (*ii*) What are the chances of a failure?; (*iii*) What are its implications?[32]The risk factors that decrease the system reliability are identified and assessed using risk management tools and practices [33]. They have a significant impact on project success. The identified risk factors from the literature[34]are mentioned in Table 1.

Table 1

Risk factors identified from the literature.

Risk Factors	
1.	Technical Risks
2.	Human safety Risks
3.	Financial Risks
4.	Regulatory Risks
5.	Reputational Risks
6.	Quality of Supply Risks
7.	Scheduling Risks

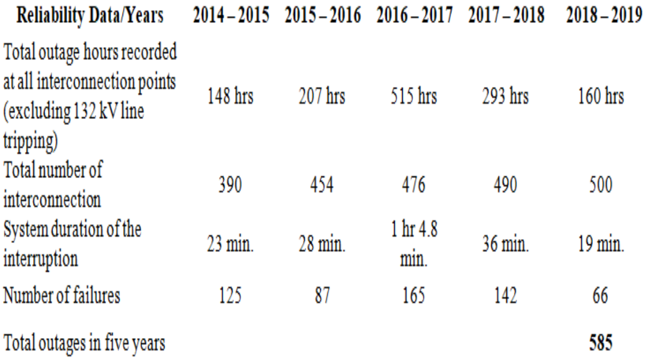
In this study, Poisson distribution is applied to test the reliability of the transmission and distribution system. The analysis is for one and five-year data and then compared with actual results.

3. Analysis

A power system includes numerous components such as power transmission lines, relays, fuses, circuit breakers, transformers, transmission poles, and so on. The failure of one component may affect the operation of the other elements. Therefore, the failure of each variable is considered independent of the others. MS Excel is used for analysis. Outage information of the transmission and distribution system is obtained by NEPRA for the years 2014 to 2018. The total number of 132 KV circuits in the National Transmission and Dispatch Company (NTDC) system was 500 and in the K-Electric distribution system was 35 in 2018 [35]. On average, there were125 outages in the transmission system and 10 power outages in the K-Electric distribution system for 2014 – 2015 [34].For NTDC transmission system, the failure rate is 125 per 8760 hours[37].The data obtained from NEPRA for NTDC and K-Electric over 5 years is presented in Table 2 and Table 3 respectively.

Table 2

Outage data provided by NEPRA for transmission network (NTDC)[31,32]



Reliability Data/Years	2014 – 2015	2015 – 2016	2016 – 2017	2017 – 2018	2018 – 2019
Total outage hours recorded at all interconnection points (excluding 132 kV line tripping)	148 hrs	207 hrs	515 hrs	293 hrs	160 hrs
Total number of interconnection	390	454	476	490	500
System duration of the interruption	23 min.	28 min.	1 hr 4.8 min.	36 min.	19 min.
Number of failures	125	87	165	142	66
Total outages in five years					**585**

Table 3

Outage data provided by NEPRA for distribution network (Karachi Electric)[31,32]

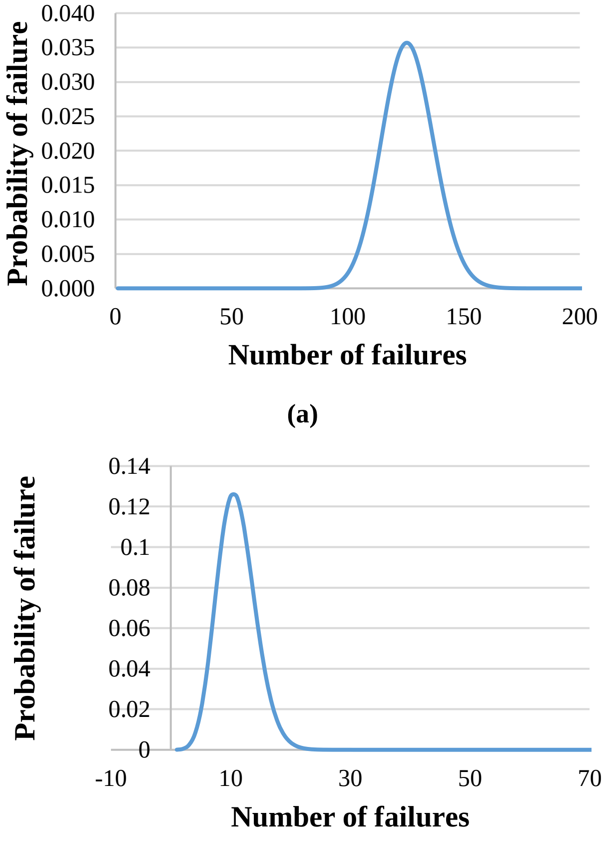
Reliability Data/Years	**2014 – 2015**	**2015 – 2016**	**2016 – 2017**	**2017 – 2018**	**2018 – 2019**
Total outage hours recorded at all interconnection points (excluding 132 kV line tripping)	11.06 hrs	10.32 hrs	7.10 hrs	3.37 hrs	4.27 hrs
Total number of interconnection	7	7	7	7	8
System duration of the interruption	01 hr 34 min	01 hr 28 min.	1 hr 6 min.	29 min.	37 min.
Number of failures	10	10	10	8	13
Total outages in five years					**51**

4. Results and discussion

4.1 Probability Density Function

4.1.1 Probability density function for 1-year

The probability density function (PDF) describes the event's continuous probability distribution. The PDF for the transmission and distribution system is calculated using Eq. (1).The probability of the outcome is represented by the region under the given range [38].The failure rate of 125 transmission and 10 distribution outages per 8760 hours (one year) is used in Eq. (1).The PDF for the transmission and distribution system is presented in Fig. 1(a) and Fig. 1(b) respectively. Y-axis represents failure probability, while the X-axis represents the failure numbers.



(a)

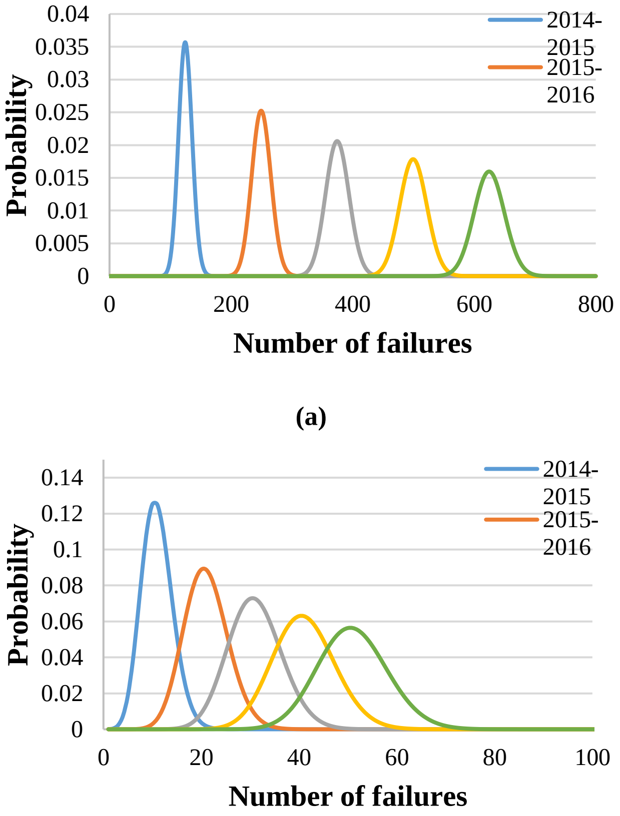
(b)

Fig. 1. PDF of (a) Transmission System and(b) Distribution System For 1 Year

In Fig. 1(a), the likelihood of 124 failures is the highest. Most likely, there will be 124 failures in one year on average. The probability of 124 or fewer failures in Fig. 1(a) is near one. The area under the curve represents the probability. The average number of failures is 124 in the transmission system in one year. Similarly, in Fig. 1(b), the probability of getting 10 failures is the highest. This shows that there will be 10 failures in a year in the distribution system on average.

4.1.2 Probability density function for 5 years

The PDF for transmission and distribution system failures measured for five years using the average data for one year is shown in Fig. s 2(a) and Fig. 2(b). The Y-axis estimates the failure probability. The X-axis represents failure numbers.



(a)

(b)

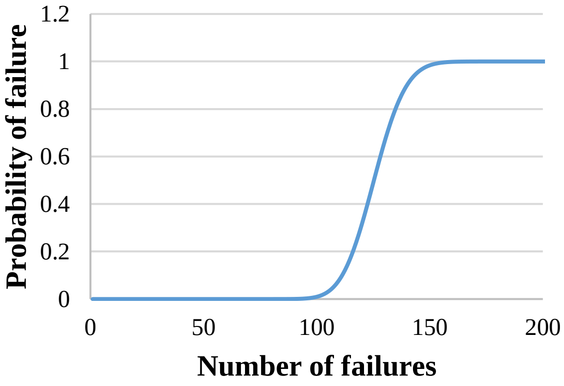
Fig. 2. PDF of (a) Transmission Outages and(b) Distribution Outages For 5 Years

Fig. 2(a) exhibits the PDF for transmission failures for five years. The highest cumulative probability for the first year is 124 outages, followed by 250,350, 500 and 620 cumulative outages for the subsequent years. Similarly, Fig. 2(b) shows the PDF for distribution failures for five years. The highest cumulative probability for the first year is 10 outages, followed by 20, 30, 40 and 50 cumulative outages for the subsequent years.

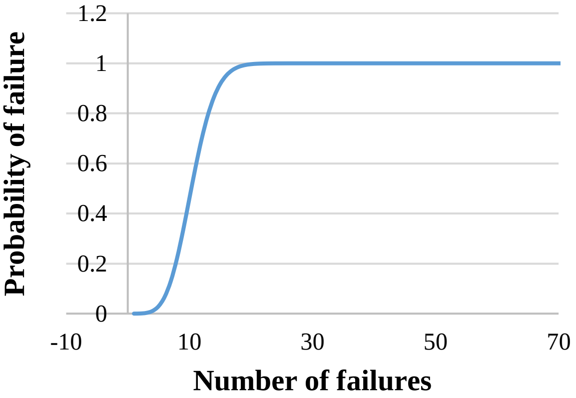
4.2 Probability Distribution Function

4.2.1 Probability distribution function for 1-year

The probability distribution function represents the probability for each outcome in a discrete manner. This is determined using Eq. (2) for one year. The probability distribution for the transmission and the distribution systems are shown in Fig. s3(a) and 3(b), respectively. The X-axis represents the probability of '*n*' failures occurring, and the Y-axis represents the probability.



(a)



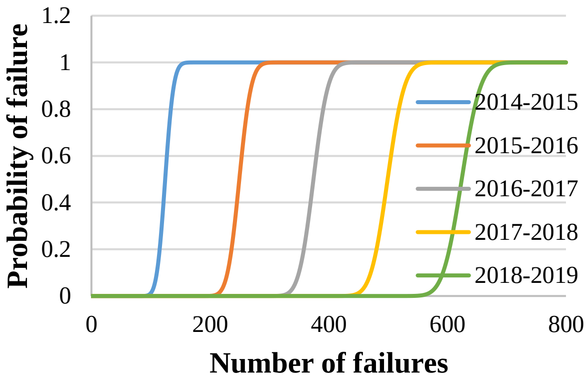
(b)

Fig. 3 Probability Distribution Function For (a) Transmission System (b) Distribution System

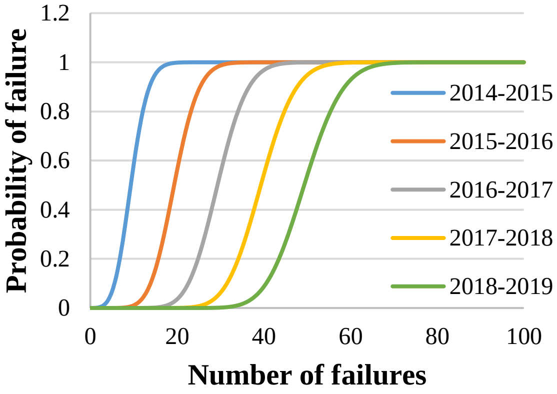
The function indicates the failure numbers and the related probabilities [33].Fig. 3(a) shows that the probability of getting 124 or more failures for the transmission system is near one. This verifies the results obtained through PDF and NTDC data. This means that there will be at least 124 failures in the distribution for 1 year. Fig. 3(b)shows that the probability of occurrence of 10 or more failures in the distribution system is near one. This also verifies the results obtained through PDF and K-Electric data.

4.2.2 Probability Distribution Function for 5 years

The probability distributions for the transmission and distribution failures are calculated for five years. The results are presented in Fig. 4(a) and Fig. 4(b), respectively. The Y-axis represents the probability of getting 'n' failures or less. The X-axis represents the number of failures.



(a)



(b)

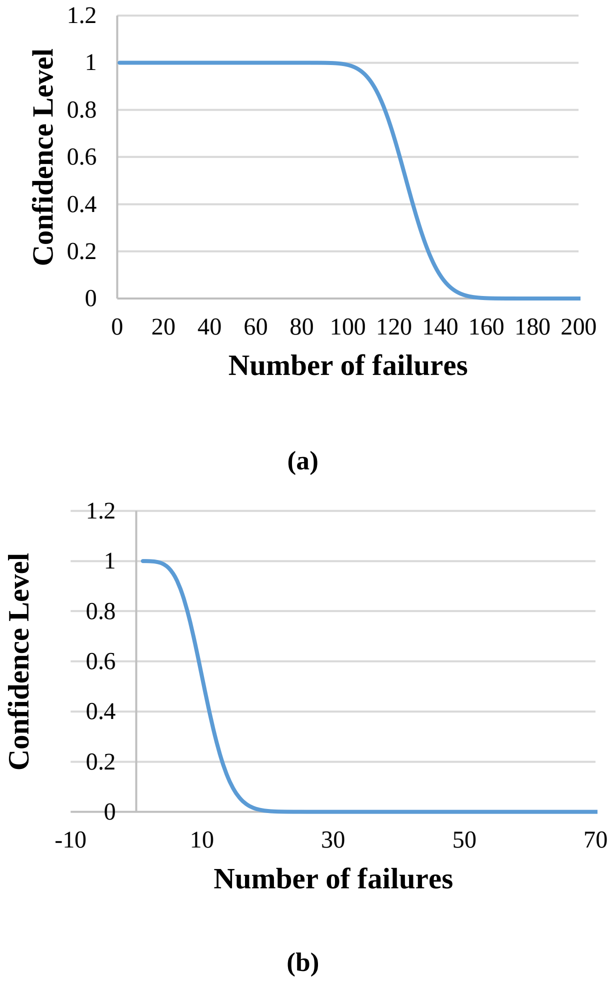
Fig. 4. Probability Distribution Of (a) Transmission Outages (b) Distribution Outages For 5 Years

In Fig. 4(a), the expected failures for the transmission system are 620. This validates the NEPRA data. The distribution shows the 5-year failure probabilities based on the failures having the highest probability in each year. This indicates that the expected failures for the first year are 124, followed by 248, 375, 490 and 620 for subsequent years. In Fig. 4(b), the expected failures for the distribution system are 50. This validates the NEPRA data. The expected average outages are 10 for the first year, followed by 20, 27, 39 and 50 for subsequent years. Since the data is different for both the transmission outages and distribution outages, which is why graphical view is different slightly.

4.3 Confidence level

4.3.1 Confidence level for 1-year

The CL estimates average system failures. The probabilities presented at the number of failures in Fig. s 1 and 3are analyzed through it. It is calculated using Eq. (3). Fig. 5(a) shows the CL for transmission outages whereas Fig. 5(b) represents the CL for distribution system failures.



(a)

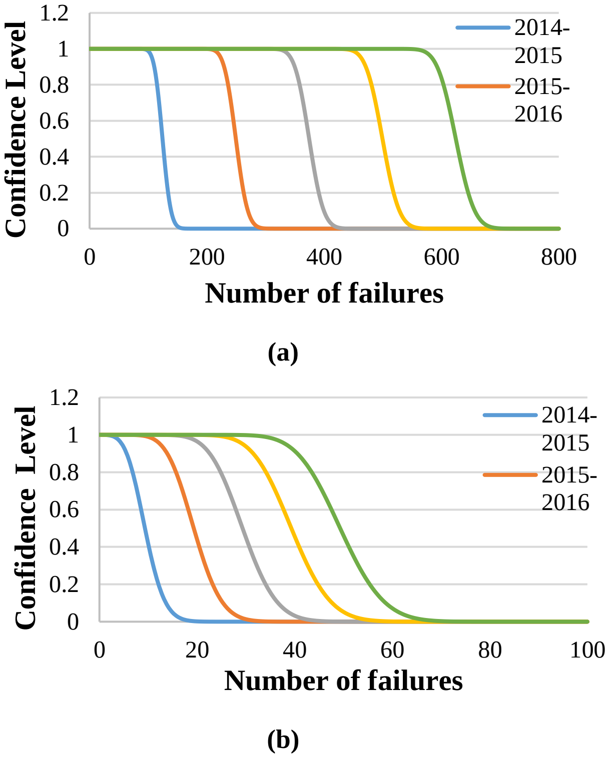
(b)

Fig. 5. Confidence Level Of (a) Transmission Outages and (b) Distribution Outages

Fig. 5(a) illustrates a CL of 100 failures in the transmission system. It is 100%. It means that the probability of getting 100 failures in one year is 100%. The CL of 140 failures is approximately 10%, which is consistent with the information provided. Fig. 5(b)illustrates the CL of five failures in the distribution system. This is also 100%. This means that the probability of getting five failures in one year is 100%. The CL of 14 failures is approximately 10%, which is consistent with the information.

4.3.2 Confidence level for 5 years

CL can help the professionals to forecast the system's reliability over a certain period. This will include the risk management techniques to maintain network reliability. The five-year CL for the transmission and distribution systems using one-year data is given in Fig. 6(a) and Fig. 6(b) respectively. The X-axis represents failure numbers, and the Y-axis represents the failure CL.



(a)

(b)

Fig. 6 Confidence Level Of (a) Transmission Outages and (b) Distribution Outages For 5 Years

In Fig. 6(a), there are about 100, 218, 337, 448 and 567 failures with a CL of 100% for the first five years respectively. Similarly, in Fig. 6(b) there are about 3, 11, 13, 20 and 35 failures with a 100% CL in the first five years respectively. These results are verified from the data available.

4.4 Verification of The Results

The results indicate that this approach effectively estimates the power system failures to assess the overall system efficiency. For a full analysis, situations like the influence of failure of a system on another sub-system failure, or triggering of power station line failure by any fabricated or natural event must be included [18].The study can also include an examination of individual components' mean time to failure (MTTF), mean time to repair (MTTR) and predict availability.

5. Conclusion

Poisson distribution is used to forecast transmission and distribution failures in power systems. The probability density function, probability distribution function and the confidence level are calculated. Both of the probability functions' results show that the highest probability for one year is 124 and 10 outages in the transmission system and distribution system, respectively. For five years, it is 620 and 50 respectively. The confidence level is calculated using the Poisson equation for five years. The results reveal that for a 100% confidence level, there will be at least 100 and 5 outages in the transmission and the distribution system respectively. For two years, there will be 218 and 11, for three years: 337 and 13, for four years: 448 and 20, and for five years: 567 and 35 outage failures in the transmission system and the distribution system, respectively. The results are verified from the data provided by NEPRA. It shows that Poisson distribution is useful for calculating the system reliability and forecasting the reliability of risk management. By Poisson distribution, the failure rate can be analyzed and precautions can be taken to improve the system's reliability. The role of risk management and reliability is an important factor worth considering in electrical industry. The global warming, disasters and most recent forecasts in Pakistan and internationally UAE for instance this weather had immense need of risk management and reliability avoiding huge disruption in personal assets and properties.

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