Journal of Renewable Energy and Smart Systems Vol.1, No.1, 2024: 33-41

Renewable Energy and Smart Systems

journal homepage: https://sanad.iau.ir/journal/res

Investigating the Failure Rate and Restoration Time of Medium Voltage Distribution Network to Use in Reliability Studies (Case Study)

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Article info

Keywords:
Distribution Network,
Reliability,
Failure Rate,
Restoration Time,
Mean Time to Repair (MTTR)

Article history:
Received: 3 Apr 2024
Accepted: 10 Jul 2024

Abstract

Reliability assessment in complex systems, particularly in electric power distribution networks, fundamentally depends on the accurate estimation of input parameters. These parameters, which include outage frequency, duration, failure causes, and affected network components, form the basis of analytical reliability indices and operational decision-making. Inaccurate or poorly structured data can therefore lead to misleading reliability evaluations and suboptimal planning strategies. Within Iranian power distribution companies, event record databases are routinely used to log detailed information related to network outages, including fault locations, outage durations, restoration times, and operational actions. These databases primarily support dispatching operations and emergency response management. However, the historical data stored in such systems are often not directly suitable for reliability analysis due to issues such as incomplete records, inconsistent classifications, redundant entries, and the presence of non-relevant events. As a result, direct utilization of raw outage data may compromise the accuracy of reliability studies. To overcome this limitation, data mining and information extraction techniques are required to preprocess, filter, and restructure the recorded data into meaningful and reliable datasets. These techniques enable the identification of hidden patterns, elimination of noise, correction of inconsistencies, and extraction of key parameters necessary for calculating standard reliability indices. This paper focuses on systematic methods for extracting useful reliability-related information from large-scale outage databases. The proposed approach includes data cleaning, event classification, normalization of failure causes, and statistical analysis of outage characteristics. The methodology is applied to the event record database of the Gilan Power Distribution Company (GPDC) as a representative case study. The extracted reliability parameters and calculated indices are then compared with international benchmarks and reference values to evaluate the performance of the distribution network and to identify potential gaps in data quality and system reliability. The results demonstrate that applying structured data mining techniques significantly enhances the usability of historical outage data and improves the accuracy of reliability assessments. The findings of this study provide valuable insights for utility companies, system planners, and researchers by highlighting the importance of data-driven approaches in modern reliability studies and supporting more informed decision-making in power distribution systems.

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1. Introduction

The reliability is an important issue in various engineering fields and based upon the context, different approaches are used in order to quantitatively analyze it. According to [1], the reliability of a system is the probability of a system performing its purpose adequately for the period of time intended under the operating conditions encountered. The power system is complex, highly integrated, and very large. Thus, its analysis as a whole system is overwhelming. Therefore, a hierarchical structure is defined for the reliability studies of the power systems in which the distribution networks are in the third level of the structure [2].

The newest standard of the reliability for the distribution systems has introduced a variety of indices to analyze the electric distribution network reliability [3]. The standard proposes methods to separate the intense and scarce events which are studied within the resilience scope [4] from the usual and frequent ones considered for the reliability analysis. In order to calculate and analyze the reliability indices, it calls for simple and accurate analytical models or simulation-based modeling as Monte Carlo method, respectively studied in detail in [2], [5] and [6]. The input parameters to use these models are failure rate (λ) and restoration time (r) of the equipment.

In the Iran's electric power distribution company, the power outages are registered in the *event record* database. However, these data cannot be used directly for the analytical reliability studies. In order to turn the registered data into useful ones, data mining is required. In [7-8] methods have been suggested to classify and refine the distribution network data. In this paper, in order to extract the useful information, steps of the so called data mining standard Cross-Industry Standard Process for Data Mining (CRISP-DM) will be adopted and implicitly presented in the next sections of the paper. The second part of the paper is dedicated to literature reviews. Finally, the summary and conclusions of the paper will be presented in the fifth section.

2- Literature Review

In the fourth chapter of [5], there are numerous information about reliability of devices based on historical data of companies, test data of producers, specialized organizations such as IEEE and CIGRE and technical journal and conference papers. Within the reference, there is no distinction between different overhead lines; however, three maximum and minimum values based on different and conventional researches are introduced for overhead lines and ground networks. The up and low figures, largest and lowest found mean values are in the published researches.

In [10], despite classifying the overhead lines into cross-armed (bare wire and covered conductors) and uncross-armed (Aerial Bundled and Spacer cables), the failure rates of both classes are claimed to be the same. Thus, this only figure is adopted as enough for the overhead network. Within the same reference, there are, of course, distinctions between overhead lines and ground networks in one hand and urban and rural networks on the other.

In reliability analysis, it is customary as well as practical to measure the failure rate in terms of the length unit. In order to achieve this goal, tables of the mentioned references will be concluded as follows: 1) data registered in terms of the length unit are adopted without any changes; 2) failure rate of other data (assumed to be equal to the Gilan Power Distribution Company (GPDC) for the purpose of correct comparison) is multiplied by their frequency in a unit length; 3) results of the steps (1) and (2) are aggregated; 4) the unit length has been changed from mile into kilometer. The overall results of the studies are concluded in table 1.

Table 1: Conclusive Results of Failure Rates Data reported in [5] and [10]

Failure Rate in Ground Network (f/yr.km)	Failure Rate in Overhead Network (f/yr.km)	Studies Description
0.672	0.383	Maximum values in literatures [5]
0.104	0.126	Conventional Values in [5]
0.013	0.038	Minimum Values in [5]
0.063	0.172	Values for Urban Areas according to [10]
0.073	0.189	Values for Rural Areas according to [10]

The study of the network equipment restoration time is more intricate than that of the failure rate. Throughout the primary references [2], [5] and [10], in order to compute this time, such concepts as repair time and switching time or more accurately Mean-Time-To-Repair (MTTR) and Mean-Time-To-Switch (MTTS) have been used. In standard [11] values of repair time of equipment in the industrial areas are gathered. These values are too high and sporadic to be applicable to the electric distribution networks.

The more recent studies within the real distribution networks have shown that the restoration time (The time interval from the moment power outage occurs until the moment service turns back) throughout the distribution networks is also of high dispersion, even though it is lower compared to the industrial areas. In [12] it has been shown that despite classification of various faults, the restoration time for each class again is highly dispersed, thus, choosing a typical representative for the whole data is practically impossible; there, researchers proposed using the log-normal distribution instead of a scalar value to represent the data; this method is typical and useful in approaches based upon repetition to some extent without applicability of the analytical methods. The proposal in [3] for separating the major event days from other days in order for reliability analysis is useful with respect to elimination of very large and sporadic events, however, as mentioned in [13-14], data of restoration time are still of very high dispersion and become even more intense in the presence of adverse weather conditions.

The more recent studies mostly present modeling patterns and in case of need for input parameters, they make use of previous researches summarized in [5] and [10]. The summary of the restoration times is given in table 2.

Table 2: Summary of the Restoration Times in [5] and [10]

Typical Restoration Time (hr.)	Maximum Restoration Times (hr.)	Minimum Restoration Times (hr.)	Studies Description
4	240	0.5	Reference [5]
2	24.5	-	Reference [10]

In [5], the minimum, typical and maximum values of restoration times are, respectively, 0.5, 4 (related to typical restoring of overhead line) and 240 (related restoration of Gas Insulated Substation) hours. In [10], the typical and maximum values of restoration times are reported to be, accordingly, 2 (associated with restoration of customers' service through replacing fuses) and 24.5 (associated with repairing the underground cable in rural areas) hours.

3- Failure Rate

Analysis of the power outages in [15] points out that over a 5-year time interval, the annual pattern of unscheduled power outages in the medium voltage networks are approximately similar as depicted in fig. 1.

If the momentary outages are eliminated and assuming that momentary break lead to operation of cut-out fuses which can be re-fused without any repair [16], the pattern of sustained power outages will be as in fig. 2.

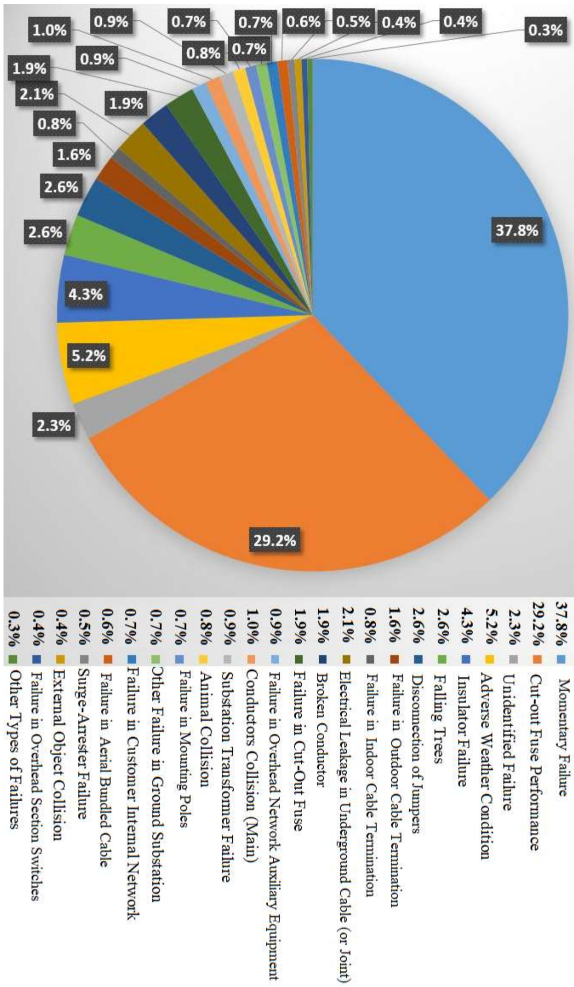

Fig. 1: Diagram of the Causes of Total Unscheduled Power Outages in GPDC [15]

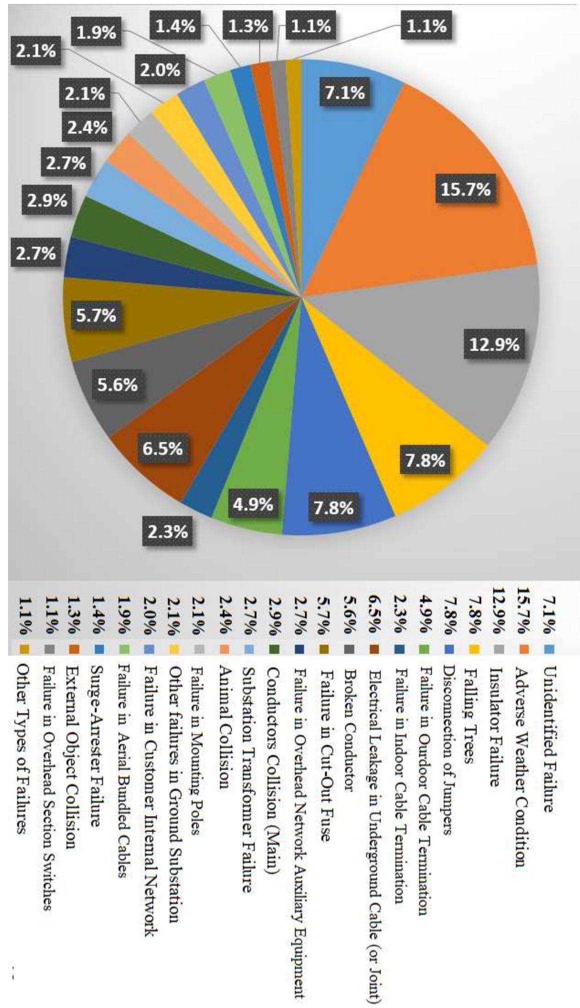

Fig. 2: Diagram of Causes of Sustained Unscheduled Power Outages in GPDC [15]

The details of the causes of sustained power outages and failure rates of equipment in the medium voltage network for the GPDC has been brought in table 3. In the last row of the table, the miscellaneous reasons, leading to outage of the medium voltage feeders, are classified in one class due to their very low percentage; their reasons, among others, include theft, fire, human errors, electrocution, etc.; the other reasons of power failure are classified based on definitions given in [17].

Based on table 3, the fig. 3 illustrates the annual failure rate of each kind of medium voltage network which has led to sustained power outage. It can be seen that contrary to expectation, the failure rates of aerial cable and ground network are more than bare wire overhead line. Comparing the results obtained here with those of conventional values of the world given in [5] and [10], the reason of such high failure rate would be more defective cable termination and joints in the network of GPDC compared to the conventional world's values which should be more analyzed and remedied.

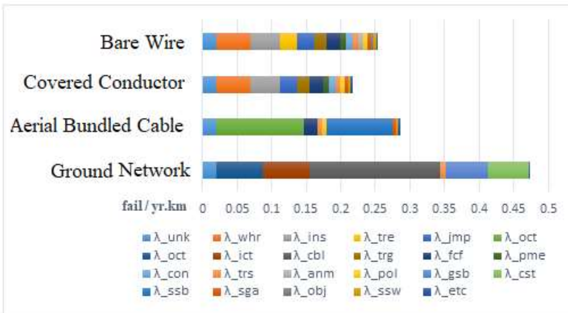

Fig. 3: Sustained Failure Rate in Different Types of Medium Voltage Network per km in GPDC Network [15]

4-Restoration Time Analysis

The main purpose of this section is to present a proposal for determination of restoration time in the non-automated (or non-complete automated) distribution networks. To this end, it has been assumed that the restoration time is the sum of times of call-out or dispatching repair crews, switching, fault identification and fault clearance; it should be noted that time for fault clearance, depending upon failure type and network topology, equals the time for repair of failed element or its replacement or even only disconnecting it and feeding the service to customers through a substituting low voltage network. Using such classification and resolution in restoration time, high dispersion of the restoration times are justified and more importantly, it can provide the required data for the study of distribution network's reliability indices.

4-1- *Fault Clearance Time*

Here, fault clearance time interval points out the time needed for repair or replacement or even disconnecting the failed part from the network such that upstream and downstream customers from the faulted point receive service. This time, according to [18], can be obtained through analysis of the data related to the scheduled emergency power interruptions registered in the event record database. This means a feeder based on a request from the repair crews is cut out, in order to emergently clear a fault to prevent occurrence of a bigger failure or spreading the power outage, with coordination of the dispatching control center and through a sub-transmission substation.

Fig. 4 illustrates details of time intervals related to scheduled emergency power interruptions which are registered in the event record database for various kind of reasons. The bar diagrams depict the minimum and maximum values of data, the box diagrams, the data between the first and third 4-quartiles and finally the rectangular diagrams, the mean values of the data.

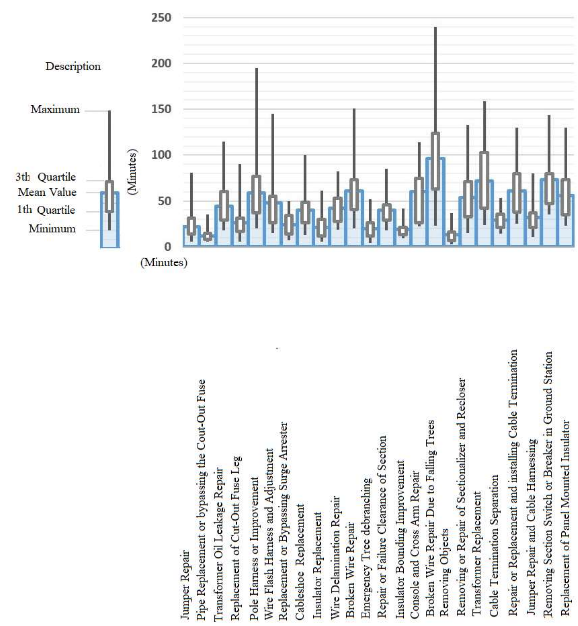

Fig. 4: Diagram of Pure Fault Clearance Time for each Type of Sustained Power Outages in Terms of #/min in GPDC [15]

In order to calculate the repair time, the sustained faults percentages shown in fig. 2 will be used as weighting coefficients to compute the weighted mean of the obtained times shown in fig. 4. In other words, given the number of each fault and its portion of the total faults along with the time for clearing each of them, value of mean Fault Clearance Time in each section (subsection of a feeder) under study will be equal to the weighted mean of Fault Clearance Time of individual failures. The value of this weighted mean (mean Fault Clearance Time of each section) for the overhead lines and ground networks have been obtained, respectively, 30 and 41 minutes. These time can be used in simple models in which a set of elements constituting a section of feeder operates as a single element. It goes without saying that when wide-spreading and accurate models are adopted for reliability analysis, direct use of the results as depicted in fig. 4 will increase the accuracy of the study.

4-2 – *Call-out (Dispatching) and Switching Time*

The dispatching time implies the time interval needed for sending out the repair crews for investigating the faulted feeder up to the first maneuvering point/s and opening the related switch (or switches) and subsequently sending request for empowering feeder when no faulty section is found. Here, it has been assumed that there is always a standby repairman who is not occupied with duties. The reason for such an assumption is priority of the medium voltage power outage over the low voltage, planning for adverse weather conditions and determining a watch list in the network operation departments. In cases where the repair teams are occupied, more complications will be involved which are addressed in [19-21].

Based on the definition given in this paper, this time can be determined using the data from multi-level restoration of unscheduled power outages registered in the event record database. The time of first registered maneuver in such power outages equals the dispatching time. The data of the database for GPDC spans from 10 up to 45 minutes with mean value equal to 20 minutes.

The switching time interval includes those needed to visit and going from the maneuver point n^{th} to the maneuver point n + 1, given that no failure is observed throughout the desired section (part of a feeder); this encompasses the time duration for opening the installed switch at the $(n + 1)^{th}$ and connecting the installed switch at the point n. These kind of data also can be extracted from the registered multi-level restoration of unscheduled power outage records in the database. For the given case study of GPDC, these times span the interval 8 to 48 minutes with the mean value equal to 21 minutes.

4-3- *Fault Identification Time*

Determination of this time is more complicated than other times as there is no direct method to extract it from the registered data in the database. Reasonably, there are multitude of factors involved in the process. Type of the network (such as overhead Lines with covered or bare conductors, areial cables or ground network), time of day and night when failure occurs, types of failure, network observability from car road, the length of the line under investigation, and linemans' skill are a few of these factors; thus, accurate determination of this time duration calls for a separate study involving in data mining and usage of machine learning algorithms such as neural network which cannot be fully covered in the current research. In this paper, a simple approach will be proposed which is matched to the power outage data.

In order to compute this time interval, the multi-level restoration of power outages are considered for two classes of feeders, first totally overhead and second totally ground network. Then the time interval between the last performed switching and ending the power outages are extracted. In this time interval, three different times are hidden: 1) fault identification time, 2) fault clearance time and 3) switching time to power back to the customers under power outage during failure. Therefore, through subtracting the clearance time and switching time calculated before from the total restoration time, logically must give the Fault Identification Time. This is done in table 4.

4 – 4 - *Summary and Complementary Consideration of Restoration Time*

In this paper, it has been suggested that the total restoration time is the sum of calling-out or dispatching time, necessary switching time, fault identification time and fault clearance time. In order to achieve the minimum restoration time, the minimum registered times in each section must be taken into account. According to the previous sections, the minimum calling-out time is 10 minutes and that of the fault clearance time equals 3 minutes (related to minimum time needed to remove unwanted objects off the network). Assuming 2 minutes is needed for identification time, the total restoration time equals 15 minutes. This is the least required time to restore a given fault which led to a sustained power outage. Here, it has been assumed that there is no extra switching. Also, removing unwanted object off the network does not involve necessarily in securing the location and in some cases can be done remotely from the ground by the lineman.

Table 4: Estimation of the Sustained Fault Identification Time in GPDC [15]

Mean Identification Time per km (min/km)	Average Length of each Section (km)	Mean Identification Time in each Section (min/section)	Mean Fault Clearance Time (min)	Mean Switching Time (min/section)	Mean Restoration Time per Section (min/section)	Network Type
2.2	3.7	8	30	21	59	Overhead
2.3	1.3	3	41	21	65	ground

To determine the maximum restoration time, times for calling-out, fault identification, switching (considering 5 times switching with maximum 48 minutes for each switching) and fault clearance (related to maximum time required to repair broken conductor resulted from falling trees) are, respectively, considered to be 45, 30, 240 and 240 minutes. Also an extra 45 minutes time is considered for securing both sides of the faulty location; sum of these times, altogether, gives rise to 10 hours. This value here is the maximum theoretical time extracted from the studies. In practice, however, due to consistency of the distribution dispatching center, fast notification hierarchy and dispatching auxiliary repair crews, the restoration time is considerably lower than the maximum time. Exceptions to this are related to big storms, heavy snows and other disasters that according to definition, must be studied in the system resilience scope.

In order to calculate the typical (average) restoration time, times for dispatch, fault identification, switching (considering 2 switching for which 21 minutes is required) and fault clearance are, respectively, taken to be 20, 8, 42, and 30 minutes. The sum of these time plus 20 minutes for securing the area equals 2 hours which is typical for clearing a multi-level power restoration.

It can be seen that there is a considerable difference between the results extracted here and those registered within the considered references. The most portion of this difference goes back, as explained in [11], to the way of defining the restoration time in different researches. Other factors can be related to repair crew dispatching or switching times, which are dependent upon the number of standby repair team against the extent of the area under consideration.

5- Conclusions

The input data are the main bases in analytical studies of reliability and researchers must not only consider the results of the global studies in his/her research. According to the findings of this paper, high level of failure in cable terminations and cable joints in GPDC is the main origin of highly unexpected failure rate (related to the reliability studies) of the aerial and ground cable network, which justifies the point just mentioned.

The high dispersion seen in restoration time of distribution power networks necessitates breaking down this time into smaller ones. This paper broke down the restoration time into times related to calling-out, network switching, fault identification and fault clearance; it also proposed solutions to determine each of these times given the facilities available to the Iran's electric distribution networks. Such a resolution in restoration time greatly help analytical studies related to reliability and would result in proposals and solutions to improve the non-complete automated distribution systems indices during the path to full-automated network.

6 - Appreciation

This paper was assembled based on data from the Gilan Power Distribution Company. The authors are obliged to appreciate PhD Muhammad Esmaeel Honarmand, the research office manager and MSE Seyed Hasan Ehsandoust, the dispatching and emergency affair manager of the GPDC due to providing access to their database.

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Table 3: Details of Reasons of Sustained Power Outage and Failure Rates of Medium Voltage Network Equipment in GPDC [15]

symbol	Failure Rate Caused by Failure in Overall Network (f/yr.km)	Mean Number of Equipment per km	Equipment Failure Rate (f/yr)	Total Number of Equipment in the Network	Total Length of The Effected Network	Type of Effected Network				Mean Annual Failure Rate	Type of Failure
						Ground	Overhead Line				
							Aerial Cable	Covered Conductor	Bare Wire		
λ_{unk}	0.019536	–	–	–	9674.6	*	*	*	*	189	Unidentified
λ_{whr}	0.050492	–	–	–	8239			*	*	416	Adverse Weather Condition
λ_{ins}	0.041615	83	0.000501	684111	8239			*	*	343	Failure in Insulator
λ_{tre}	0.025357	–	–	–	8202.9				*	208	Collision with trees
λ_{jmp}	0.024981	60.5	0.000413	498906	8239			*	*	206	Jumper Disconnection

λ_oct	0.127230	34.5	0.003688	34980	523.2		*			129	Failure in Outdoor Cable Termination
λ_oct	0.068225	18.5	0.003688	–	912.4	*					Failure in Outdoor Cable Termination
λ_ict	0.066636	17.7	0.003765	16203	912.4	*				61	Failure in Indoor Cable Termination
λ_cbl	0.189610	–	–	–	912.4	*				173	Electrical Leakage in Underground Cable (or Joints)
λ_trg	0.018206	–	–	–	8239			*	*	150	Broken Conductor
λ_fcf	0.019103	3.7	0.005163	29441	8762.2		*	*	*	152	Failures of Cut-Out Fuse

Table 3: Continued

λ_pme	0.008859	19.7	0.000450	162341	8239			*	*	73	Pole-Mounted Auxiliary equipment
λ_con	0.009346	–	–	–	8239			*	*	77	Conductors Collisions (or Bounding opening)
λ_trs	0.007433	2.6	0.002859	25185	9674.6	*	*	*	*	72	Substation Transformer Failure
λ_anm	0.007680	–	–	–	8202.9				*	63	Animal Collisions
λ_pol	0.006390	19.7	0.000324	172650	8762.2		*	*	*	56	Failure of mounted Poles
λ_gsb	0.060617	1.5	0.040411	1361	912.4	*				55	Other miscellaneous faults in Ground Substation
λ_cst	0.059185	–	–	–	912.4	*				54	Failure in Customer-side Network
λ_ssb	0.095566	–	–	–	523.2		*			50	Aerial Bundled Cable Failure
λ_sga	0.004239	9	0.000471	78564	8762.2		*	*	*	37	Surge Arrester Failure
λ_obj	0.004145	–	–	–	8202.9				*	34	External Objects Collisions
λ_ssw	0.003542	0.4	0.008855	3275	8762.2		*	*	*	29	Overhead Section Switches Failure (Except cutout fuses)
λ_etc	0.002894	–	–	–	9674.6	*	*	*	*	28	Other Types of Failures