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Value Based Reliability Evaluation of Primary Power Distribution System

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Abstract: Distribution system reliability is concerned with the availability and quality of power supply at each customer's service entrance. Analysis of customer failure statistics shows that failure in distribution system contribute as much as 90% towards the unavailability of supply to a load as compared with each part of electric systems. These statistics reinforces the need for reliability evaluation of distribution systems. In recent years with the advent of smart grids the significance of distribution system has enhanced because of the importance of co generation and distributed generation. The different causes and duration of failures are analysed season wise. The failure rate of the different feeders of the system under study was calculated and the reliable feeders were identified. Suggestions are given to improve the reliability of the feeders. This type of analysis will help the operation and maintenance engineers to maintain the quality service to the customers and schedule the maintenance services.

Index Terms: Distribution Systems, Reliability Indices, Failure Rate, Availability.

I. INTRODUCTION

The economic progress and living standards of people in a country is influenced by the energy production and its proper utilization. So both the developed and developing countries in the world give significant importance for energy production. The proper utilisation of the produced energy is also an important factor. Power systems are complex, non linear, stochastic, dynamic systems. The quality and reliability of a power system determined when it's satisfactory operating level characterized by a nearly constant frequency, voltage profile at a very low level outage. The reliability of a power system is depending on the number of outages or power failures that will occur in the service period and outage duration [1]. The reliability of a power system is the probability of it performing its intended purpose adequately for the duration in which it has to operate under the conditions encountered.

Power distribution system reliability is a major consideration in system operation and planning. Utilities have the mission to maintain the highest level of service reliability to customers, and have the obligation to improve service reliability consistently by planning, operations, construction and maintenance with their limited resources. Historically, electrical utilities were continuously building more facilities to satisfy the growing demand of the load. There is an increasing awareness among distribution system planners and operators regarding numerical evaluation of the reliability cost. The majority of outages seen by customers are caused by failures in the distribution systems. It is therefore important to objectively assess the relative benefit of alternative distribution system schemes in computing customer service reliability. The reliability targets and the means to achieve them should be based on the customers' needs and his willingness to pay for a desired level of reliability so that the total cost (power supply cost plus customer outage costs) is minimized [2]. The objective is then to select an alternative that will satisfy a customer's desired level of reliability and is also within the budgeted funds. The alternatives available to a utility engineer and to a customer may include design modifications, reinforcements, allocation of spares, improvements in repair and maintenance policies, and alternate operating policies. The benefit per monetary unit expended and the merits of such alternatives may be compared by utilizing quantitative reliability techniques. The goal of modern power distribution system planning is to satisfy the growing and changing system load demand during the planning period and within operational constraints, economically, reliably and safely, by making optimized decisions on the following: voltage levels of the distribution network; locations, sizes, servicing areas, loads and building or expanding schedules of the substations; routes, conductor types, loads and building schedules of the sub transmission lines and feeders; other important issues such as the types and locations of switching devices, load voltage levels, and network and load reliability levels. etc[3,11]. This paper analysed the failure modes of overhead power distribution system and evaluated the reliability at Thrissur district in Kerala, India. The different reliability indices were evaluated. Section I discusses the fundamentals of reliability, terms and definitions, the system reliability indices and the data needed for reliability analysis. Section II presents data of area under study. Section III presents the data collected for reliability assessment of primary power distribution system and the results. The summery of investigations made and recommendations to improve reliability are presented in section IV. Section V presents the conclusion and future work.

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II. FUNDAMENTALS OF RELIABILITY

Distribution system reliability is concerned with the availability and quality of power supply at each customer's service entrance [3]. Traditionally, reliability analysis of electrical distribution systems was considered as a tool for the planning engineer to ensure a 'reasonable' quality of service and to choose between different.

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System expansion plans that cost wise were comparable considering system investments and cost of losses.

In some cases the cost of non-delivered energy and power (NDE, NDP) were included in the planning objective, but this approach was hampered by disputes concerning the levels of specific values of NDE in various sectors. Market based purchase of electrical energy allows for a deregulated and a competitive structure in the energy markets. In the framework of distribution system planning these new terms of delivery combined with recent developments in metering technology is leading to:

- An increased interest in demand-side management by variation in quality of service.
- An increased acceptance of cost estimates of customers' willingness-to-pay for quality of service.

From this, it is obvious that the utilities have to pay more attention to reliability analysis of the distribution systems in order to ensure a quality of service that is in accordance with the customers' quality expectations reflected by their willingness-to-pay.

A. Reliability Indices

The basic reliability indices normally used to predict or assess the reliability of a distribution system are the three reliability indices [4,10].

- Load point average failure rate (λ)
- Average outage duration (r)
- Annual unavailability (U)

In order to incorporate the severity or significance of a system outage, using the three basic indices mentioned above, two expanded sets of indices listed below can be calculated. The two expanded sets of indices listed below can be calculated. The two expanded sets of indices are numbers and average load customers connected at each load point in the system, and the customer interruption cost. They are,

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- Average Service Availability Index (ASAI)
- Average Service Unavailability (ASUI)

These additional indices can be used to assess the overall behavior of the distribution system. The other set is the reliability cost / worth index are

- Expected Energy Not Supplied (EENS)
- Expected Interruption Cost (ECOST)
- Interrupted Energy Assessment Rate (IEAR)

The indices EENS, ECOST and IEAR can be those at each points or for the overall system [5]. All these indices can be used to evaluate the reliability of an existing distribution system and to provide useful planning information regarding improvement to existing systems and the design of new distribution systems. Moreover, in order to analyze the sensitivity of a reliability index EENS or ECOST with respect to failure rate of different elements, element contribution to that index and their ranking can be used. The rankings can be for a load point or the overall system.

B. Reliability Indices for Radial Distribution System.

The reliability indices are functions of the customer interruptions, customer interruption durations and the number of customers on the feeders. The customer interruptions are encountered when the electric components on the feeders fail in operation. Therefore, the customer interruptions depend on the equipment failure rates, while the customer interruption time is determined by both equipment failure rates and failure durations[6].

In a radial distribution system, the calculation of reliability indices involves a system consisting of series components from source to load [7]. The basic computing unit consists of two components in series. Suppose there are two components in series with failure rates λ_1, *and* λ_2, and failure durations r_1 and r_1 respectively. The system failure rate λ_s , will be[8]:

$$\lambda_s = \lambda_1 + \lambda_2 \tag{1}$$

and the system failure duration r_s will be

$$r_s = \frac{\lambda_1 r_1 + \lambda_2 r_2}{\lambda_1 + \lambda_2} \tag{2}$$

The overall system interruption time U_s, will be

$$U_s = \lambda_s r_s = \lambda_1 r_1 + \lambda_2 r_2 \tag{3}$$

In general, if there are *m* components in series, the system failure rate λ_m, will be:

$$\lambda_m = \sum_{i=1}^{m} \lambda_i \tag{4}$$

and the system failure duration r_m will be:

$$r_m = \frac{\sum_{i=1}^{m} r_i \lambda_i}{\sum_{1}^{m} \lambda_i} \tag{5}$$

The above formulae are based on the assumption that component failures are independent events and the failure rates are much smaller than the operating rates. When evaluating the failure rate at a load point on a feeder, only one fault is assumed to occur on a feeder and no multi faults are considered. Action of protective systems is not considered, assuming its effect in evaluation of reliability indices is minor as compared to the major fault duration on a feeder due to equipment failure. Momentary outages are not included in this study. The most commonly used reliability indices and their methods of calculations are given below [9].

- System Average Interruption Frequency Index (SAIFI)

This index gives an indication of the average number of sustained interruptions experienced by a customer in a unit time considered, normally one year. The system can be a feeder, a substation or a distribution system.

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$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ number\ of\ Customers\ Served} = \frac{\sum \lambda_i N_i}{\sum N_i} \quad (6)$$

Where $\lambda_i N_i$ is the number of interrupted customers for each interruption event during the time period considered and N_i is the total number of customers served in the area. To improve the value of this index, the number of interruptions should be reduced, and this can be achieved through a proper maintenance schedule, through the use of automation and improved protective equipment to sense the fault a clear the same before it leads to a permanent damage.

- System Average Interruption Duration Index (SAIDI)

This index is an indication of the average time a customer has an interruption during one year. The specification is in customer hours or minutes of interruption per year.

$$SAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customer\ Served} = \frac{\sum U_i N_i}{\sum N_i} \quad (7)$$

Where, Ni is the number of customers and $U_i$is the annual outage duration at Load point i. The outage duration includes, the time taken to notice an outage, the time taken to locate and repair the fault.

SAIDI can also be improved by reducing the time of interruptions and time of interruption. In rural areas and in long feeders effective crew placement and automation are the methods to improve this index.

- Customer Average Interruption Duration Index (CAIDI)

It is the average interruption duration for those customers interrupted during a year. This is the ratio of SAIDI to SAIFI.

$$CAIDI = \frac{\sum Customer\ Interruption\ Durations}{Total\ Number\ of\ Customer\ Interruptions} \quad (8)$$

- Average Service Availability Index (ASAI)

This gives the fraction of time the customer has power during the time period considered. Higher value of this index is an indication of higher reliability. The ASAI for a given area can be calculated as,

$$ASAI = \frac{Customer\ Hours\ of\ Available\ Service}{Customer\ Hours\ Demanded} = \frac{\sum N_i * 8760 - \sum N_i U_i}{\sum N_i * 8760} \quad (9)$$

- Average Service Unavailability (ASUI)

$$ASUI = 1 - ASAI \quad (10)$$

C. Data Collected for Reliability Evaluation

Reliability evaluation requires both data on the performance of individual components together with the times required to perform various switching operations. System components data that are generally required are:

- Failure rates (forced outage rates) associated with different modes of component failure.
- Expected (average) time to repair or replace failed components.
- Scheduled (maintenance) outage rate of components
- Expected (average) duration of a scheduled outage event.

III. DETAILS OF DISTRIBUTION SYSTEM UNDER STUDY

Overhead distribution system is used for the distribution of electrical energy in the selected site. The study deals with 11 substations and their 11kV distribution feeders. The total number of feeders in the selected area is 64. Details are given in the table I.

Table. I

Substation under study	Number. of feeders	Substation under study	Number of feeders
I	8	VII	5
II	8	VIII	5
III	7	IX	7
IV	6	X	3
V	6	XI	3
VI	6		

IV. DATA ANALYSIS

The data include the outages of these substations for a period of 2.25 years, total number of failures for this period, total connected load in MVA in each feeder, total no. of consumers in each feeder and the length of feeder. Various causes considered for the study of interruption of supply are the following.

- Defective material
- Maintenance work
- Overload
- Weather
- External Agency
- Other

Defective materials include the defect of poles, conductors, insulators, cross arms and transformers. External factors affecting the supply are tree falling on the line, birds, vehicles colliding on the towers etc. The distribution system is greatly affected by weather. In some weather, snow and ice are big problems and in other lightning is a major cause of interruption in service. Weather causes many outages on distribution system. Utilities typically track weather items such as wind, rain, lightning, snow and tornados. Details of data collected for a typical substation is given in table II.

Table II

Name of Substation	Feeder	Total Failure hour for 2.25 Years	Total no of Failures for 2.25 Years	Total connected load in MVA	Total no. of consumers	Length of feeder in kM

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Sub. I	F1	181.55	572	5.34	9856	23.3
	F2	48.7	256	0.25	4785	25.4
	F3	279.41	824	13.214	4350	13.7
	F4	426.28	760	2.37	8215	41.4
	F5	99.166	294	5.1	single	4
	F6	235.95	635	4.5	9500	43.8

The failure details can be classified into different groups as mentioned above. Details of failures for a typical substation for one year are given below in Table III. The percentage distribution of each type of fault is represented in fig1.

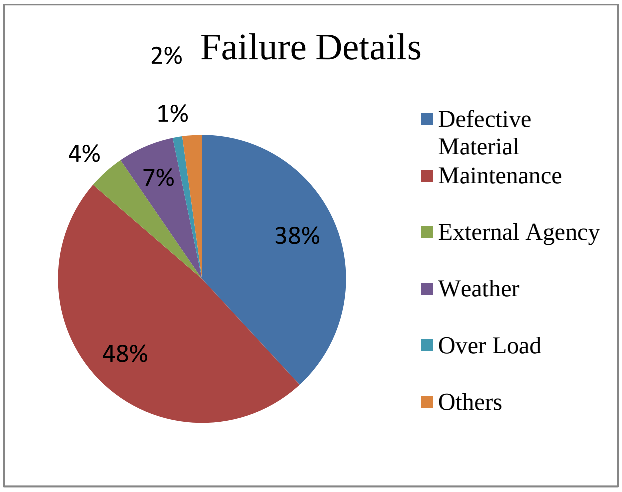

Fig. I. Failure details

Table III

Month	Defective Material in % of Total	Maintenance work in % of Total	External Agency in % of Total	Weather in % of Total	Over Load in % of Total	Others in % of Total	Total No. Of Failures
Jan	44.81	53.01	1.09	0.00	1.09	0.00	183
Feb	39.41	52.35	2.94	0.59	0.00	4.71	170
March	36.99	51.37	8.22	0.00	0.00	3.42	146
April	33.02	43.40	7.08	10.38	1.42	4.72	212
May	41.80	49.18	3.28	5.74	0.00	0.00	122
Jun	32.08	36.48	7.55	22.64	1.26	0.00	159
July	32.82	43.51	6.11	9.92	0.76	6.87	131
Aug	42.17	57.83	0.00	0.00	0.00	0.00	83
Sept	38.00	59.00	2.00	0.00	0.00	1.00	100
Oct	36.36	48.48	2.27	11.36	1.52	0.00	132
Nov	35.19	39.81	3.70	11.11	7.41	2.78	108
Dec	47.45	50.36	1.46	0.00	0.00	0.73	137

V. RESULTS

A. Reliability Indices for Substation I

a. System average interruption frequency index (SAIFI) = 0.282894 (interruptions per customer)

b. System average interruption duration index (SAIDI) = 7.500675 (hours per customer**)**

c. Customer average interruption duration index (CAID) = 26.5141(hours per customer interruption)

d. Average service availability index (ASAI) = 0.99914375

e. Average service unavailability index (ASUI) = 0.00085624

B. System Reliability Indices

By making use of the data collected the different reliability indices calculated for the primary power distribution in the selected area is tabulated as in the Table IV.

Table IV

System Reliability Indices
Average Failure Rate = 1.810664123
Average Frequency of Failure = 1.787366
Annual Outage Duration = 0.72962
Average Outage Duration = 0.402957119
System Average Interruption Frequency Index, SAIF = 1.810664125
System Average Interruption Duration Index, SAID = 0.729532212
Customer Average Interruption Duration Index, CAIDI = 0.402908635
Average Service Availability Index, ASAI = 0.99992
Average Service unavailability Index, ASUI = 0.00008
System Expected Energy Not Supplied Index, EENS = 219.44405
System Expected Interruption Cost Index, ECOST = 353.97968
Average Energy Not Supplied Index, AEN = 0.000507
System Interrupted Energy Assessment Rate Index = 1.61307486

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VI. CONCLUSIONS

The Value-based distribution reliability assessment is a valuable methodology for distribution planning, design, operations and construction. There is a wide variety of applications using this approach to enhance system service reliability. This procedure will help utilities to achieve their goal of providing quality energy service that their customers value. Reliability indices have been defined to monitor the duration and frequency of outages. The two basic types of indices are customer based indices and load based indices.

Customer based indices record the frequency and duration of outages for individual customers and are most informative mainly in residential areas. Load based indices monitor information on the duration and frequency of information of load and is relevant for circuits that are mostly industrial or commercial.

The majority of outages seen by customers are caused by failures in the distribution system. It is therefore important to objectively asses the relative benefit of alternative distribution system schemes in computing customer service reliability. The reliability targets and means to achieve them should be based on customer's needs and his willingness to pay for a desired level of reliability so that the total cost is minimised.

Here in this work the different reliability indices are evaluated and the reliable feeders which are having the failure rates less than 0.01per year (among the 64 numbers under study) are identified. To improve the indices the suggested method is redundancy and the cost for that is also evaluated and if the customer is ready to pay an additional amount of rupees 0.62per kWh they are able to get a reliable supply. The optimum location of protective devices, switches and fuses can be do as a future objective to reduce failure rate, SAIFI, SAIDI.

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