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Predictive Reliability Assessment in the Power Distribution System

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The electrical utilities are facing market conditions and therefore have to plan and operate their distribution systems in a cost effective way. This implies that the customer's requirement on reliability i.e. availability has to be balanced towards the cost for obtaining the same. An effective way to solving this issue is by the use of quantitative assessment of reliability, i.e. reliability indices, which is based on probability theory. However these methods require input data that defines the condition for the system and its components. is to predict the future behaviour based on collected data and measured performance.

The reliability assessment is normally used to evaluate performance of the distribution system network. The reliability of power Distribution system can be calculated by different reliability indices.This paper describes the reliability indices for two feeders of one is an industrial feeder and another one is an urban feeder. A software module (Reliability Assessment Module-RAM) has been used and the results of two practical distribution feeders are compared to benchmark the performance and operation of the power distribution system.

Keywords: *Distribution System, Reliability Indices, Reliability Sassements Module.*

1.0 INTRODUCTION

The distribution system is an important part of the total electrical supply system, as it is provides the final link between a utility's bulk transmission system and its customers. It has been reported in some literature that more than 80% of all customer interruption s occur due to the failure in the distribution system Though a single distribution system reinforcement scheme is relatively inexpensive compared to a generation or a transmission improvement scheme, an electric utility normally spends large sum of capital and maintenance budget collectively on a huge number of distribution improvement projects [6].

Directly and indirectly customer satisfaction is concerned with this improvement and modernization schemes of the transmission and distribution network. Reliability assessment which was rarely an issue some time back is now generating waves in the management of utilities. The customers who were tolerant earlier has become demanding more. Customers are becoming conscious about the interruptions free service. They are started realizing that how should get electricity in which they are also stakeholders of the entire system.

Reliability of a power distribution system is defined as the ability to deliver uninterrupted service to customer. Distribution system reliability indices can be presented in many ways to reflect the reliability of individual customers, feeders and system oriented indices related to substation. To evaluate reliability in distribution system, two

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different approaches are normally used; namely, historical assessment and predictive assessment. Historical assessment involves the collection and analysis of distribution system outage and customer interruption data [4]. It is essential for electric utilities to measure actual distribution system reliability performance levels and define performance indicators in order to assess the basic function of providing cost effective and reliable power supply to all customer types.

Historical assessment generally described as measuring the past performance of a system by consistently logging the frequency, duration, and causes of system component failure and customer interruptions. The historical data is very useful when analyzed to ascertain what went wrong in the past and therefore correct it, and also as input to predict future service reliability [2]. Historical models summarize the actual performance of a distribution system during some time period, for example, quarterly, half-yearly or annually. The basic data item in this case is a system failure, which is a component outage or a customer interruption. Each failure event is taken into consideration and analyzed according to causes of failure, duration of outage, area of the system affected. A variety of customer and load oriented system performance indices can be derived by analyzing the recorded data.

The reliability indices are very useful for assessing the severity of interruption events Assessment of past performance is useful in the sense that it helps to identify weak areas of the system and the need for reinforcement [6]. It enables previous predictions to be compared with actual field experience as well as it can serve as a guide for acceptable values in future reliability assessments. The predictive reliability assessment can also help to predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system.

2.0 RELIABILITY INDICES

The most commonly used system indices are [1].

- System Average Interruption Frequency Index (SAIFI)

$$\text{SAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers served}}$$

SAIFI is the average number of interruptions per customer served.

- System Average Interruption Duration Index (SAIDI)

$$\text{SAIDI} = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customers served}}$$

SAIDI is the average duration of a customer interruption, per customer served.

- Customer Average Interruption Duration Index (CAIDI)

$$\text{CAIDI} = \frac{\text{Sum of customer interruption durations}}{\text{Total number of interrupted customers}}$$

CAIDI measures the average duration of a customer interruption within the class of customers that experienced at least one sustained interruption.

- Momentary Average Interruption Frequency Index (MAIFI)

$$\text{MAIFI} = \frac{\text{Total no. of customer momentary interruptions}}{\text{Total number of cutomers served}}$$

- Average Service Availability Index

$$\text{ASAI} = \left(1 - \left\{\frac{\text{SAIDI}}{8760}\right\}\right) * 100$$

ASAI is the ratio of total customer hours that service was available, divided by the total customer hours in the time period for which the index is calculated.

This paper describes the reliability indices SAIFI, SAIDI, CAIDI, MAIFI and ASAI etc., for two practical feeders (industrial feeder & urban feeder) of an Indian utility.

3.0 METHODOLOGY

3.1 Historial Reliability Assessment

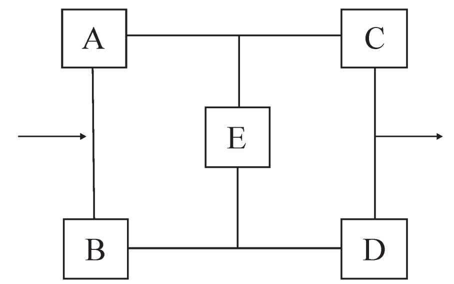
The basic techniques used inpower system reliability evaluation can be divided into two types-analytical technique and numerical simulation technique. Analytical techniques represent the systemby a simplified mathematical model and evaluate the reliability indices from this modelusing direct mathematical solutions. In numerical simulation techniques; it estimates there liability indices by simulating theactual process and random behavior of the system. The method therefore treats the problemas aseries of real experiments conducted in simulated time. Ites timates tyandotherindices by counting the number of times an event occurs. The solution time for analytical techniques is relatively short; as compared with numerical simulation techniques this is usually extensive. This disadvantage has been partially over come by the development of recent computational facilities. To evaluate reliability indices in power system, some of the following methods are listed below

- Network reduction
- Markov modeling
- Cut-Set method
- Monte Carlo simulation

In this paper Cut-Set method based on failure modes, has been used to evaluate the reliability indices. The cut-set method is a powerful one evaluating the reliability of a system for two main reasons.

- It can be easily programmed on a digital computer for the fast and efficient solution of any general network.
- The cut-sets are directly related to the models of system failure and therefore identity the distinct & discrete ways in which a system may fail.

It can be defined as, a cut-set is a set of system components which, when failed, causes failure of the system. In terms of reliability network or block diagram, the above definition can be interpreted as a set of components which must fail in order to disrupt all paths between the input and output of the reliability network.



MINIMAL CUT SET OF THE SYSTEM

The minimum subset of any given set of components which causes system failure is known as a minimal cut-set. It can be defined as, minimal cut-set is a set of system components which, when failed, causes failure of the system but when any one component of the set has not failed does not causes system failure. The definition means that all components of a minimal cut-set must be in the failure state to cause system failure.

TABLE 1

MINIMAL CUT-SET OF THE FIG.1

Number of the of minimal cut-set	Components the cut-set
1	AB
2	CD
3	AED
4	BEC

3.2 Predictive Reliability Assessment

Predicting distribution system reliability performance is normally concerned with the electric supply adequacy at the customer load point. The basic indices used in practice are load point average failure rate (λ), average outage duration (r), and the average annual outage time (U). For a radial system, the basic equations for calculating the reliability indices at each load point "p" in a radial circuit are [2]

$$\lambda_p = \sum_{i=1}^{n} \lambda_i \quad failures/year$$

$$U_p = \sum_{i=1}^{n} \lambda_i \times r_i \quad h/year$$

$$r_p = \frac{Up}{\lambda_p} \quad h/failure$$

Where n is the number of outage events affecting load point "p." The steps associated with the predictive reliability calculation approach are summarized as follows

Calculate the reliability of each load point being serviced by a given distribution system configuration considering all interruption events and system constraints contributing to its unreliability for each year of the system.

Calculate the system reliability indices with the help of calculated load point average failure rate, average outage duration and the average annual outage duration.

Repeat both the stepsfor all load points of the distribution system configuration under study and obtain the all the system indices SAIFI, SAIDI, CAIDI, ASAI, ENS, AENS etc.

4.0 CASE STUDIES

4.1 Industrial Feeder Network

The practical distribution feeder which is taken from one of the Indian utility. This feeder network has been modeled and simulated using CYMDIST-RAM software. It is an industrial feeder starting from 220/66/11kV substation, consisting of 74 Distribution transformers (DT's) having 140 number of total customers served with a total feeder length of 8.64 km.

4.2 Urban Feeder Network

This urban distribution feeder is taken from one of the Indian power distribution utility which is modeled and simulated using CYMDIST-RAM software.It is an urban feeder starting from 66/11kV substation, consisting of 118 Distribution transformers (DT's) having 6966 number of total customers served with a total feeder length of 17.78 km.

4.3 Outage Data & Network Data Collection

Electric utilities have maintained LDC's (Load Despatch Centre) for schedule & to despatch generated power to the distribution utilities.The distribution Utilities are maintaining log books to interruption details for all the feeders which are coming out from a particular substation and LC (Line Clearance) book to enter the line clearance data.We have verified and collected the interruption details for a period of one year from respective LDC's and the substations, which includes the number of interruptions, duration of the interruptions, cause for interruption, Location of fault in the feeder and equipment's failure data for both Industrial and Urban practical distribution feeders.. Feeder network has been modeled in CYMDIST software module and Interruption details of the components are entered in the feeder network at appropriate places, simulation carried out successfully and results are obtained.

5.0 RESULTS AND ANALYSIS

The CYMDIST Reliability Assessment Module software is validated with IEEE-RBTS Bus-Two system network. This is more significant to evaluate the performance of our practical distribution feeders.

Table 2 result shows the reliability indices of practical industrial feeder, urban feeder and describes the performance of the practical distribution networks. These results are helpful to the local utilities to provide quality of power

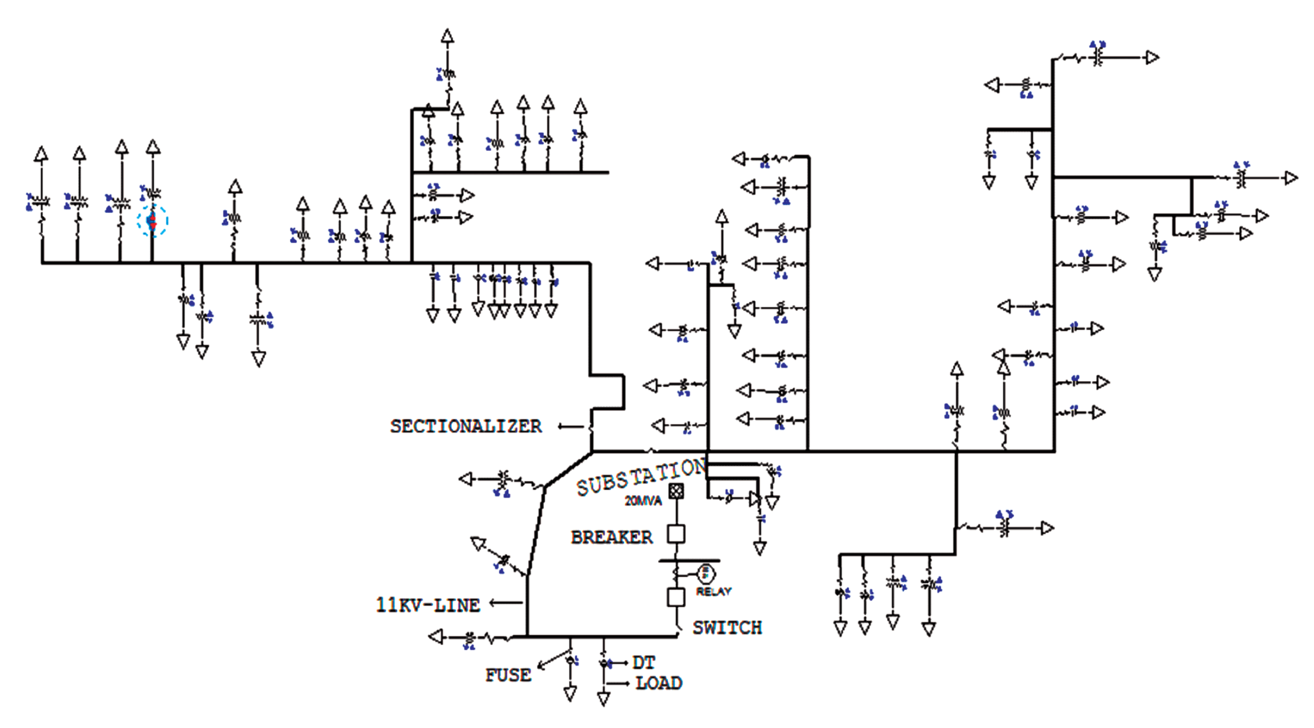


FIG. 1 SINGLE LINE DIAGRAM OF TYPICAL INDUSTRIAL FEEDER NETWORK

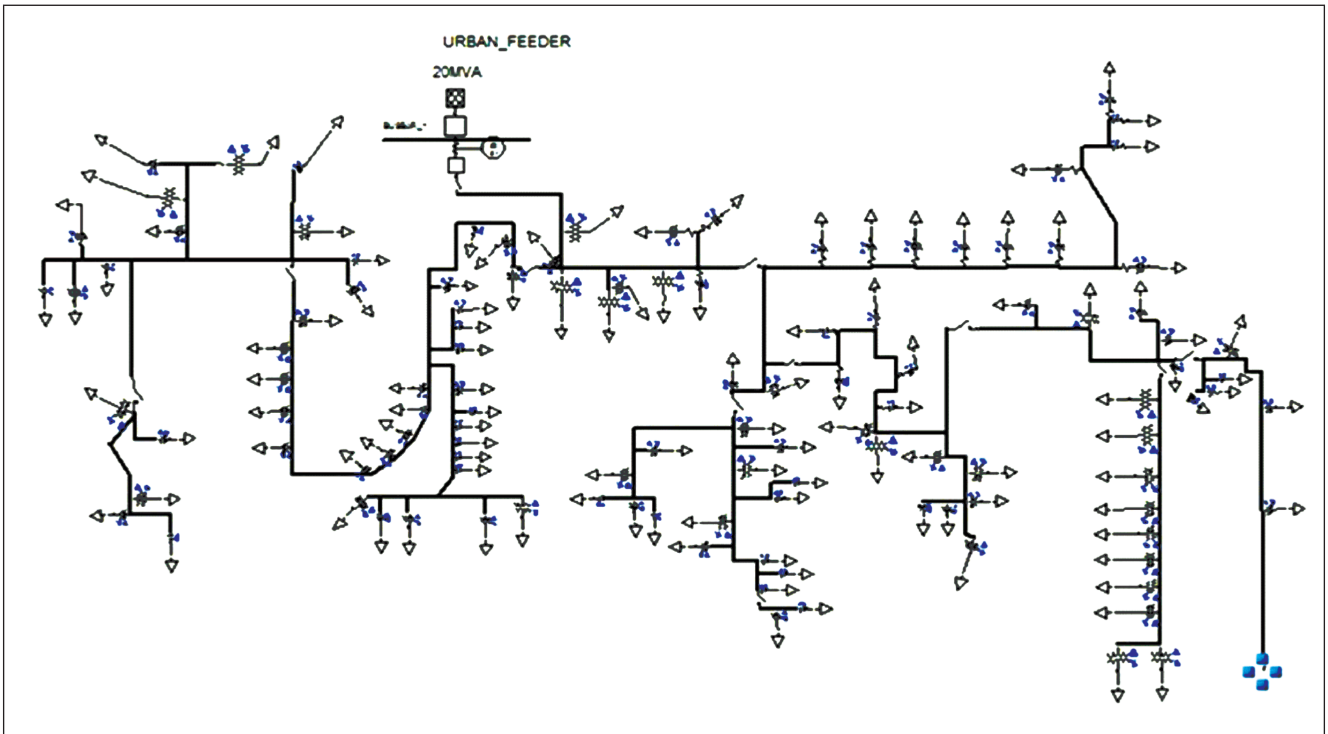


FIG. 2 SINGLE LINE DIAGRAM OF TYPICAL URBAN FEEDER NETWORK

supply at consumer end in reliable and cost effective manner. From Figure 6 the SAIFI, SAIDI values give the system frequency and duration of interruptions per year per customer basis. MAIFI gives the momentary average interruptions per year per customer. Average system availability Index (ASAI), Average energy not supplied (AENS) and energy not supplied (ENS) indices will be helpful to the utilities for proper energy and asset management with respective kilowatt hour (kWh) loss. Reliability indices can vary from one place to another place according to the network configuration, geographical and weather conditions [6].

TABLE 2

HISTORICAL RELIABILITY INDICES OF TYPICAL DISTRIBUTION FEEDERS.

Sl. No.	Historical Reliability Indices	Industrial Feeder	Urban Feeder
1	SAIFI (Intr/cust.yr)	403.430	757.441
2	SAIDI (hr/cust-yr)	375.159	587.148
3	CAIDI (hr/cust.Intr)	0.930	0.775
4	MAIFI (Intr/cust.yr)	119.238	612.739
5	ASAI	0.9572	0.93302
6	ENS(kWh/yr)	816178.9	704517.0
7	AENS (kwh/cust-yr)	5834.016	101.137
8	No.of Customers	140	6966
9	Line Length(km)	8.64	17.78

Table 3 shows the Predictive reliability indices for the Industrial and Urban feeder with the help of the historical data. One year historialinterruption data is used here to get the prédictive indices.

TABLE 3

PREDICTIVE RELIABILITY INDICES OF TYPICAL DISTRIBUTION FEEDERS.

Sl. No.	Predictive Reliability Indices	Industrial Feeder	Urban Feeder
1	SAIFI (Intr/cust.yr)	391.470	757.488
2	SAIDI (hr/cust-yr)	578.761	731.342
3	CAIDI (hr/cust.Intr)	1.479	0.965
4	MAIFI (Intr/cust.yr)	48.064	612.723
5	ASAI	0.933398	0.91657
6	ENS(kWh/yr)	1259125.4	877447.1
7	AENS (kwh/cust-yr)	9000.181	125.961
8	No.of Customers	140	6966
9	Line Length(km)	8.64	17.78

Figure 3 indicates the comparison of SAIFI and SAIDI ofHistorical and Predictive Reliability assessment for Industrial feeder.

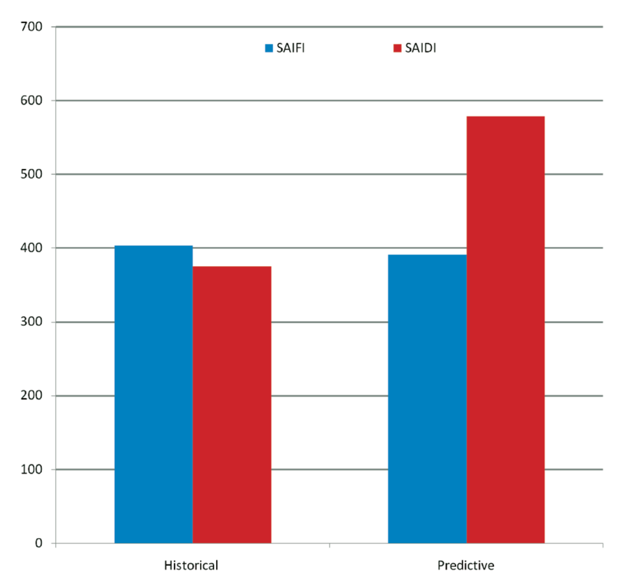


FIG. 3 COMPARISON OF SAIFI AND SAIDI FOR INDUSTRIAL FEEDER.

Figure 4 indicates the comparison of SAIFI and SAIDI of Historical and Predictive Reliability assessment for Urban feeder.

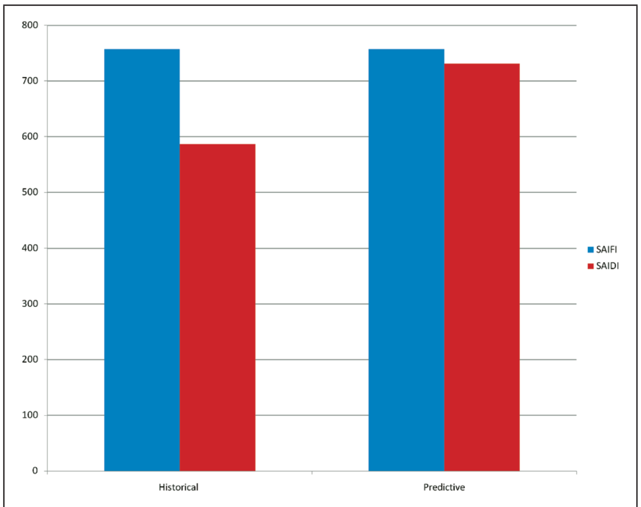


FIG. 4 COMPARISON OF SAIFI AND SAIDI FOR URBAN FEEDER

Figure 5 shows the Energy Not Supplied (ENS) of both the Industrial and Urban feeders in Historical and Predictive assessment. The results shows that the value of ENS in Industrial Feeder is higher than those of Urban feeder due to the higher MW rating of Industrial feeder even though the SAIFI and SAIDI of Industrial feeder is low when compared to the Urban feeder.

FIG. 5 COMPARISON OF ENS IN HISTORICAL AND PREDICTIVE RELIABILITY ASSESSMENT.

6.0 CONCLUSION

The study conducted can be very useful guidance to assess the performance of distributionnetwork. In general, interruptions have a negative impact on economy due to associated cost of interruptions. It will be of great importance for planners and managers of distribution networks if they could calculate the predictive indices. The predictive reliability Indices are calculated with the help of Historical data and the Predictive values obtained will helpful to find out the performance of the system in the near future. The performance can be improved by proper system planning and analysis studies to provide switches, sectionalizers and other protective devices at appropriate places.

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