The Journal of CPRI,
Vol. 10, No. 4, December 2014 pp. 687-694

Customers interruption cost estimation based on reliability in power distribution system

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Reliability assessment of distribution network is an important subject due to increasing demand for more reliable service with less interruption frequency and duration. An effective way to solving this issue is by the use of quantitative assessment of reliability, measure the reliability indices to find out the probability of availability and unavailability of supply. This paper describes the energy not supplied to the customers in terms of customer kWh loss and revenue loss to the customers and the revenue loss to the utility in profit making areas is presented for two practical networks by calculating the reliability indices. The software module CYMDIST Reliability Assessment Module (RAM) is used for the simulation and analysis.

Keywords: *Distribution system, customer cost of interruption, reliability indices, CYMDIST-RAM.*

1.0 INTRODUCTION

1.1 Reliability Survey

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.

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 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. 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.

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

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becoming conscious about the interruptions free service.

1.2 Customer Cost Survey

Finding a compromise between reliability and costs has been a subject of discussion for several decades now and will likely continue for years to come. Cost-estimation studies are an important tool to be able to estimate an optimal level of continuity of supply. The optimal continuity of supply can be different for different regions (urban versus rural) and for different types of customers (industrial versus domestic) and will certainly evolve with time as end user equipment, customer requirements and investment costs change.

In order to find the optimal level of continuity of supply from society's point of view, it is imperative to balance the various cost-elements towards each other, i.e. the costs associated with reducing the scope of interruptions must be compared to the possible reduction in the customer's costs resulting from the same actions.

The cost of an interruption varies widely from customer to customer and from country to country. Other important factors include duration, time of year, day of the week, time of day, and whether advance warning is provided. The cost of an interruption is highly dependent on its duration. Short interruptions can results in ruined processors and broken equipment's. Longer interruptions can results in lost production and lost sales.

The price that a customer is willing to pay for higher reliability is directly connected to the interruption costs created by power failures. If the price that a customer pays for increased reliability is less than the decreased in interruption cost, the customer could be expected to react favorable to the increased charge.

1.3 Reliability Indices

A variety of performance indices that express interruption statistics in terms of system customers are defined in the following.

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer is interrupted during a time period. In this paper, the time period considered in computing performance indices is one year. SAIFI is therefore determined by dividing the total number of customer interruptions in a year by the total number of customers served at the end of the year. A customer interruption is considered to be one interruption to one customer [1].

$$SAIFI = \frac{Total\ customer\ interruptions}{Total\ customers\ served} \quad ....(1)$$

The System Average Interruption Duration Index (SAIDI) is the average interruption duration per customer served. It is determined by dividing the sum of all customer interruption durations during a year by the number of customers served.

$$SAIDI = \frac{Total\ customer\ hours\ of\ interruptions}{Total\ customers\ served} \quad ....(2)$$

The Customer Average Interruption Duration Index (CAIDI) is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the total number of customer interruptions over a one-year period.

$$CAIDI = \frac{Total\ customer\ hours\ of\ interruption}{Total\ customer\ interruptions} \quad ....(3)$$

The Average Service Availability Index (ASAI) is the ratio of the total number of customer hours that service available during a year to the total customer hours demanded. Customer hours demanded is determined as the year-end number of customers served times 8760 hours. This is sometimes known as the Index of Reliability (IOR). The complementary value to this index, that is, the Average Service Unavailability Index may also be used. This is the ratio of the total number of customer hours that service was unavailable during a year to the total customer hours demanded.

$$ASAI = \frac{Customer\ hours\ available\ for\ service}{Customer\ hours\ demanded} \quad ....(4)$$

The results obtained from two surveys dealing with United States and Canadian utility activities in regard to service continuity data collection and utilization show that a large number of utilities calculate the customer-based indices of SAIFI, SAIDI and CAIDI for their systems.

2.0 METHODOLY

2.1 Historical Reliability Assessment

The basic techniques used in power system reliability evaluation can be divided into two types-analytical technique and numerical simulation technique. Analytical techniques represent the system by a simplified mathematical model and evaluate the reliability indices from this model using direct mathematical solutions. In numerical simulation techniques; it estimates the reliability indices by simulating the actual process and random behavior of the system. The method therefore treats the problem as a series of real experiments conducted in simulated time. It estimates probability and other indices 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 overcome by the development of recent computational facilities. To evaluate reliability indices in power system, some of the following methods are listed below

- Network Reduction Technique
- Markov Modeling
- Minimal 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 purposes.

- 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. Figure 1 and Table 1 gives the example of the minimal cut set method.

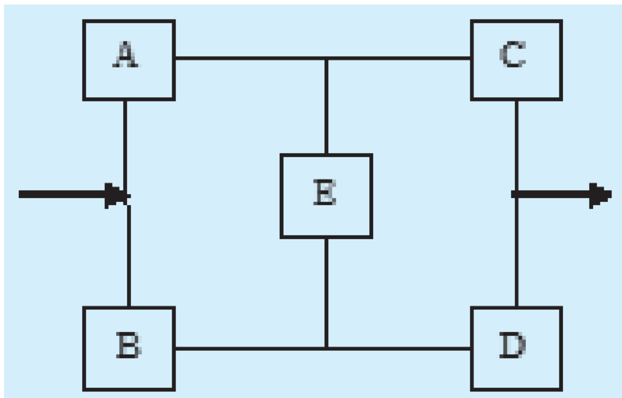

FIG. 1 MINIMAL CUT SET OF THE SYSTEM

TABLE 1

MINIMAL CUT-SET OF THE FIG.1

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

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 the “the 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.

2.2 Cost-Estimation Methods

Any System is said to be successful only when it's reliable and is provided to the customers with reasonable cost benefits. Hence economic evaluation of a system helps for a better functioning of a system. Economic evaluation or reliability worth of a system can be estimated and studied with the following concepts [4].

2.2.1 Direct Access Method

This method is commonly used to estimate the monetary costs of electricity interruptions, and the data collection is based on surveys. Customers are asked to estimate the expenses which they incur due to a hypothetical or experienced interruption or voltage disturbance. Usually, several scenarios are presented to the customer and the customer has to specify the economic costs according to predefined cost categories. The scenarios must be understandable, realistic and accepted by the respondent.

2.2.2 Contingent Valuation

Using Contingent Valuation studies, the respondent is presented with a hypothetical or experienced scenario of an electricity interruption or voltage disturbance, and asked for the willingness to pay to avoid it or willingness to accept compensation when it occurs, to be indifferent to the welfare losses in the scenario. The scenarios must be understand able realistic and accepted by the respondent.

2.2.3 Conjoint Analysis

This method is based on customers expressing their preferences for different hypothetical scenarios. Instead of asking directly for the costs, willingness to pay to avoid or willingness to accept certain interruptions, customers are asked to select the preferred option between pairs of hypothetical scenarios, or they may be asked to rank or rate a list of different hypothetical scenarios. Based on the choices, the costs are estimated indirectly through econometric models.

2.2.4 The Preparatory Action Method

Using this method, the customer is asked to choose from a list of hypothetical actions whichreduce the consequences of an electricity interruption or voltage disturbance. Each action is associated with a given cost.

2.2.5 The Preventative Cost Method

This method measures customer expenditures to prevent or counteract the consequences of interruptions or voltage disturbances. The value of such purchases can be seen as anestimate for the costs of an interruption or a voltage disturbance that they seek to avoid.

3.0 ASSESSMENT OF RELIABILITY INDICES

3.1 Case Studies

3.1.1 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.

3.1.2 Urban Feeder Network

This urban distribution feeder is taken from one of the Indian power distribution utility which is modeled and simulated using 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.

3.2 Outage Data & Network Data Collection

Electric utilities have maintained LDC's (Load Despatch Centre) for schedule & despatch generated power to the distribution utilities. The distribution Utilities are maintaining log books to store network data and 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 substations, which includes the number of interruptions, duration of the interruptions, cause for interruption and equipment's failure history for both the practical distribution feeders. Feeder network is modeled in software module based on geographical reference point of view. Interruption details of the components are entered in the feeder network at appropriate places and simulation has been done.

4.0 RESULTS AND ANALYSIS

4.1 Reliability Indices For Practical Feeders

The reliability indices of practical industrial feeder, urban feeder are tabulated in Table 2 which describes the performance of the practical distribution networks in terms of Reliability indices. The indices are obtained by considering both scheduled and unscheduled outages. These results are helpful to the local utilities to provide reliable supply at consumer end in cost effective manner. Reliability indices can vary from one place to another place according to the network configuration, geographical and weather conditions.

TABLE 2

RELIABILITY INDICES OF PRACTICAL DISTRIBUTION FEEDER NETWORK

Sl. No	Historical Reliability Indices	Industrial Feeder	Urban Feeder
1	SAIFI (Intr/cust.yr)	403.430	893.161
2	SAIDI (hr/cust-yr)	375.159	686.895
3	CAIDI (hr/cust.Intr)	0.930	0.769
4	MAIFI (Intr/cust.yr)	119.238	477.018
5	ASAI	0.957	0.922
6	ENS (kWh/yr)	816178.9	824202.7
7	AENS (kWh/cust-yr)	5834.016	118.318
8	No. of Customers	140	6966
9	Line Length (km)	8.64	17.78

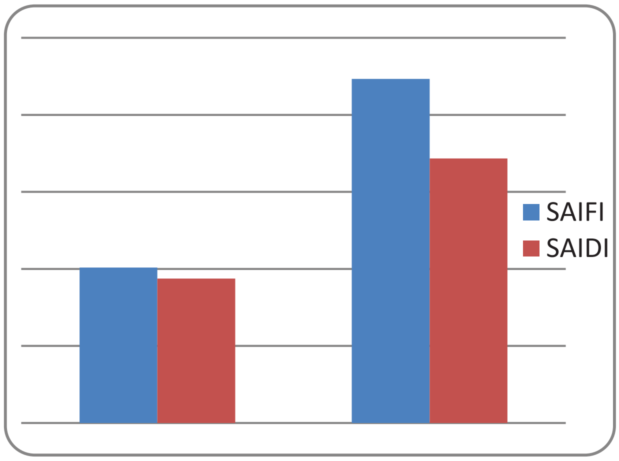

FIG. 4 COMPARISION OF SAIFI AND SAIDI VALUES FOR PRACTICAL

The SAIFI and SAIDI values for the Industrial feeder and Urban feeder is as shown in the Figure 4. The frequency of interruptions and duration of interruptions are higher in Urban feeder when compare to the Industrial feeder.

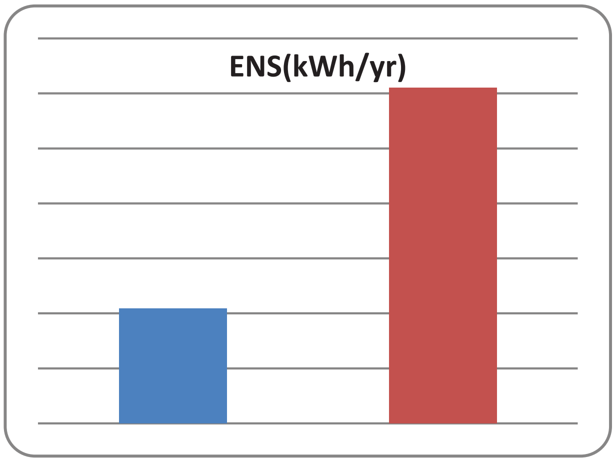

FIG. 5 COMPARISION OF ENS FOR THE PRACTICAL FEEDERS

4.2 Cost Of Interruption

4.2.1 Industrial Feeder

There are two types costs associated with power interruptions, which includes the revenue loss to the utility in profit making areas and the customer cost associated with interruptions. The Industrial feeder consisting of 57% of Industrial consumers, 30% of Commercial consumers and 13% of Residential consumers. The interruptions cost for utility is calculated based on the different tariff structure imposed on the various customers [2]. The customer cost of interruption is calculated based on the revenue loss accounted per kWh loss of supply. Different categories of customers are accounted different revenue loss per kWh loss of supply [3]. The total revenue loss is aggregated for all customers of Industrial feeder is calculated and is given in Table 3.

TABLE 3 COST OF INTERRUPTION FOR INDUSTRIAL FEEDER	
Type of feeder	**Industrial Feeder**
Energy Not Supplied (ENS) (kWh/yr)	816178.90
Interruption cost to Utility (Rs)	73,45,602.00
Customer cost of Interruption (Rs)	36,08,87,534.00

4.2.2 Urban Feeder

Urban feeder consists of 60% of Residential consumers, 33% of Commercial consumers and 7 % of Industrial consumers. The utility cost of interruption is calculated based on the tariff structure imposed on the different categories of the commercial consumers [2]. The customer cost of interruption is calculated based on the revenue loss per kWh loss of supply [3]. Table 4 gives the details of the interruption cost to utility and interruption cost to customers.

TABLE 4 COST OF INTERRUPTION FOR URBAN FEEDER	
Type of feeder	**Urban Feeder**
Energy Not Supplied(ENS) (kWh/yr)	824202.70
Interruption cost to utility(Rs)	53,57,313.00
Customer cost of Interruption(Rs)	8,08,75,459.00

The Energy Not Supplied (ENS) for both the feeders are drawn as Figure 5. The ENS for urban is high when compare to the Industrial feeder and the associated customer cost of interruption and interruption cost to utility calculated outlined in Table 3 and Table 4.

5.0 CONCLUSION

The Reliability Indices help in gauging the reliability of a system and improving the system's reliability for a better economical purpose whereas Cost analysis gives a precise idea on interruption costs and its effect on customers and utility. Here the Reliability Indices are calculated by collecting the required interruption data in the field and the interruption cost associated due to these interruptions also calculated for the selected feeders. Both the customer interruption cost and interruption cost to utility is calculated and is outlined for the two practical feeders.

6.0 ACKNOWLEDGEMENT

The authors are very thankful to the organization (CPRI) for permitting to do this research work. The authors thankful to the officers and associates of the Distribution Systems Division (DSD), who are directly or indirectly helped in execution of this project.

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