Evaluation and Improvement of Reliability Indices of Electrical Power Distribution System

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***Abstract*— 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. Two approaches to reliability evaluation of distribution systems are normally used; namely, historical assessment and predictive assessment. The distribution system is an important part of the total electrical supply system. This is due to the fact that the distribution system provides the final link between a utility's transmission system and its customers. It has been reported that more than eighty per cent of all customer interruptions occur due to failures in the distribution system.**

Distribution System Strengthening and Distribution Automation (DA) system are being increasingly implemented under Restructured Accelerated Power Development and Reforms Programme (R-APDRP)/Integrated Power Development Scheme (IPDS) by the electric utilities to reduce the operational problems of distribution networks. System strengthening and the Distribution Automation (DA) system not only provides system wide status and health monitoring but also helps in coordinated controls required to enhance quality and reliability of the supply.

In India, the Utilities calculate Reliability Index and the same thing submitted to Regulatory commission and Central Electricity Authority. The data base is not available to calculate all the Reliability indices as per IEEE 1366-2012. An attempt has been made in this paper to calculate Reliability indices which includes, System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Frequency Index (CAIFI), Customer Average Interruption Duration Index (CAIDI), Energy Not Supplied (ENS), Average Energy Not Supplied (AENS), etc.

Keywords—Reliability; Indices ; Distribution System

I. INTRODUCTION

The economic growth and development of a country depends heavily on the reliability and quality of the electric power supply. Generally, rigorous planning is done for addition of generation and expansion of the transmission networks. However, the distribution systems have generally grown in an unplanned manner resulting in high technical and commercial losses in addition to poor quality of power. Efficient operation and maintenance of distribution system are hampered by non-availability of system topological information, current health information of the distribution components such as distribution transformers and feeders and historical data etc. Other reasons include lack of efficient tools for operational Planning and advanced methodology for quick fault detection, isolation, and service restoration. All these lead to the increased system losses, poor quality and reliability of power supply in addition to the increased peak demand and poor return of revenue.

The IEEE- 1366-2012 [13] Standard has formulated broad methods to assess statistically the performance of distribution network and has defined various indices with respect to reliability of the distribution system. In India, as a part of electricity reforms, electricity regulatory bodies have been formed. Attempts are being made at present by the regulatory bodies to assess the performance of utilities and they are in the process of bringing out uniform methods for statistical analysis of Reliability Indices and their implementation.

The utilities evaluate reliability index regularly on monthly basis and then it is sent to Central Electricity Authority (CEA) and corresponding regulatory commission. In other countries like USA, electric utilities carry out Predictive Reliability assessment and Reliability Assessment. They have huge data base to calculate Reliability Indices and Reliability assessment[7,9,10].

A. Importance of Reliability Parameters

- Customer is demanding uninterrupted (24x7) Power Supply
- The Reliability Parameters became one of the benchmark Parameters for evaluating the performance of Utility.
- It is mandatory as per National Electricity Policy 2005 (NEP 2005) [11] to submit regular Reliability Index reports to the Central Electricity Authority (CEA) and respective Regulatory Commission.
- It creates healthy competition to compare reliability parameters with different electrical utilities.
- The brand image of the utility will improve with the better Reliability parameters

B. Reliability Parameters in Indian Context

The Distribution reforms initiated during the year November 2001 . Prior to 2001, the sufficient data base of interruptions and duration data in the Electricity Boards of India is not available to evaluate Reliability performance. The Ministry of Power, Government of India initiated the reforms programme

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namely Accelerated Power Development and Reforms Programme (APDRP). The main objective of APDRP is System strengthening of Sub Transmission and Distribution Network and Capacity building exercise. The programme initiated in the year 2001 and completed by the year 2010. During this period, utilities started collecting data in terms of Interruption and duration. This data submitted to Ministry of Power, Govt. of India on monthly/annual basis. The interruptions data and duration of interruption data has evolved one of the benchmark parameters for Electric utility. As per Electricity Act 2003/ Electricity (Amendment) Act, 2014 [8], the State Electricity Boards were unbundled into generation, Transmission and Distribution companies. In few states, the distribution company was divided into DISCOMS/ESCOMS based on geographical locations.

After unbundling, the majority of Distribution Companies started maintaining data base in terms of interruption and duration, the electric utilities started calculating SAIDI, SAIFI and Reliability Index.

As per National Electricity Policy 2005, NEP 2005[16] and Electricity Act 2003[8,11], Central Electricity Authority (CEA) requested all State Electricity Regulatory Commission (SERC) to furnish Reliability Index (RI) of all the distribution licensees under their jurisdiction covering all cities and towns up to the District Headquarter towns as also for rural areas.

KERC Guidelines, 2008 are available for determination of Reliability Index of supply of power to consumers [12]. These guidelines are issued subject to the provisions of the Electricity Act - 2003, section 57 as per which the State Electricity Regulatory Commissions are required to specify standards of performance of utilities. However, presently as per the schedule - II of the KERC (Licensees standards of performance) Regulations – 2004, the utilities are required to compute only the Reliability Indices.

C. Drawbacks in the Earlier Work

The Indian Electric utilities were collecting data manually and they are computing reliability index manually/MS office excel software. The customised /Application Software package was not used for reliability Analysis. There are 12 Reliability Indices as per IEEE-1366 -standard 2012[1,13] which can be evaluated in the Distribution Network. The attempts are not made to evaluate 12 Reliability indices due to non-availability of data and software tools.

Under Distribution Reforms, the Rural Electrification works carried out by Rajiv Gandhi Grameena Vidyut Karana Yojana (RGGVY) in 10th plan, 11th plan and 12th plan . This RGGVY is now renamed as Deena Dayal Upadhya Gram Jyothi Yojana (DDUGJY). Under DDUGJY, the rural electrification of Distribution network is being established in India.

Another Distribution reforms, Restructured Accelerated Power Development and Reforms Programme (R-APDRP) was initiated during the year 2010. Now, the R-APDRP renamed as Integrated Power Development Scheme (IPDS). Under IPDS Programme, the Distribution Automation, IT Applications and Data center is being established for all towns in India. The automatic downloading facility is available [2-6].

D. Activities Proposed

The following activities are proposed in this paper:

1. Reliability Indices are calculated for three Identified Practical Feeders namely Urban feeder, Industrial feeder and Rural feeder which are chosen from practical distribution Network of Bangalore Electricity Supply Company Ltd. (INDIAN ELECTRIC UTILITY), Bangalore.
2. The feeder Networks have been modeled and simulated by using CYMDIST-Reliability Assessment Module (RAM) Software.
3. The Test case has been validated with IEEE-RBTS (Roy Billinton Test System) Bus 2 Network.
4. The Historical Reliability Assessments of Three feeders have been evaluated and the results are compared to benchmark performance and operation of the practical distribution system.

II. METHODOLOGY

A. Proposed Methodology for Reliability Assesment

The methodology of present work involves different steps such as selection of network, time schedule for study, identification of preliminary and detailed work to be executed, processing and analyzing the interruption data with CYMDIST software and discusses the results of the analysis. The various steps of methodology are discussed in detail in the following sections.

The Distribution Network selected for the study is from Indian Electric Utility, The Details of Distribution Network selected is as presented in Table I.

B. Preliminary work

The following are the preliminary work carried out for study

- Identification of Urban feeder, Industrial feeder and Rural feeder from Indian Electric Utility
- Walkover survey of the Identified feeders in Indian Electric Utility
- The time schedule for present work is from April 2011-March 2012, one year data to cover all seasonal variations
- Data of sample 11kVfeeders obtained from Indian Electric Utility and the same was cross verified with that obtained from Power Transmission Corporation Ltd.
- Detailed power outage measurements at 11kV outgoing feeders of Master Unit Sub Station (MUSS) under study obtained from Transmission line and Sub-station, Division (TL&SS), PTCL (scheduled interruptions and incoming supply failure data Indian Electric Indian Electric Utility (unscheduled interruptions on 11kVfeeders).
- As per IEEE 1366-2012, all the reliability parameters are evaluated for Sample feeders of Indian Electric Utility.

C. *Detailed work*

Electric utilities have maintained a log book to enter the interruption details for all the feeders which are coming out from a particular substation and LC (Line Clearance) data book to enter the line clearance data. Collected the interruption details for a period of one year for urban feeder, industrial feeder and rural feeder, which includes the number of interruptions, duration of the interruptions, and cause for interruption and equipment's failure data for the industrial feeder. Single line Diagrams (SLD) of the feeder is collected from the substation, verified and then network is modeled in the CYMDIST software. Interruption details of the components are entered in the Reliability Assessment Module (RAM) of the software at specific places and simulation results are obtained.[2-6]

This minimal cut set method based on FMEA technique reduces computation time by focusing on the system contingencies which are relevant for the selected load points and not for the entire system. Components of a minimal cut set behave like they are connected in parallel i.e. all have to fail to cause system failure and several minimum cut sets behaves as connected in series.

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, average outage duration (r), and the average annual outage time (U).

where n is the number of outage events affecting load point "p" .The steps associated with the predictive reliability calculation approach are summarized. 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 steps for all load points of the distribution system configuration under study and obtained the all the system indices SAIFI, SAIDI, CAIDI, ASAI, ENS, AENS etc.

- Case 1: RBTS Bus-2 network has been taken as a test case for validation
- Case 2: Urban feeder modeled and Reliability Assessment/parameters is evaluated
- Case 3: Industrial feeder has been modeled and Reliability Assessment/parameters is evaluated
- Case 4: Rural feeder has been modeled and Reliability assessment/parameters is evaluated
- Case 5: Comparison of Urban feeder/Industrial feeder/Rural feeder results

D. *Sampling Procedure*

It is highly appreciated if the Reliability Assessment is carried out for complete Indian Electric Utility Area. It needs lot of investment, survey, data collection, skilled man power and time duration.

However, in view of the practical feasibility and time span required for the exercise to be completed, in this study, different sample selection procedure is followed which shall comprise of different load patterns that are important for general performance study of any distribution system. The sampling strategy in INDIAN ELECTRIC UTILITY system, three 11Kv feeders different load patterns are only selected. They are shown in Table I.

TABLE I. 11KV FEEDERS UNDER STUDY

S. No.	**Feeder Name**	**Name of the Sub-station**	**Type of feeder**	**No.of DT's**	**No.of Consumers**	**Length (km)**
1	KIADB	Antharasanahalli	Industrial	73	140	8.64
2	Vemgal	Vemgal	Rural	108	2440	45.08
3	Devanoor	Melekote	Urban	129	7273	21.45

III. RBTS NETWORK

The RBTS Bus-2 network has been taken as a test case for validation. This is a typical network coming from 33/11kV substation as a source point and having 4 feeders, 22 load points and 1908 customers (like residential, commercial and government organization/institutional customers). All feeders are radial in nature but connected as mesh through normally open sectionalizing point to provide alternative supply. The single line diagram and system configuration of RBTS Bus-2 network is shown in Fig. 1.

The reliability indices of the RBTS-test system are standardized by IEEE working group. These simulated results achieved by CYMDIST software module and has been taken as a validation case for practical network. This is more significant to evaluate the performance of practical industrial feeder, Domestic feeder and Rural feeder. The reliability indices of RBTS network shown in Table II.

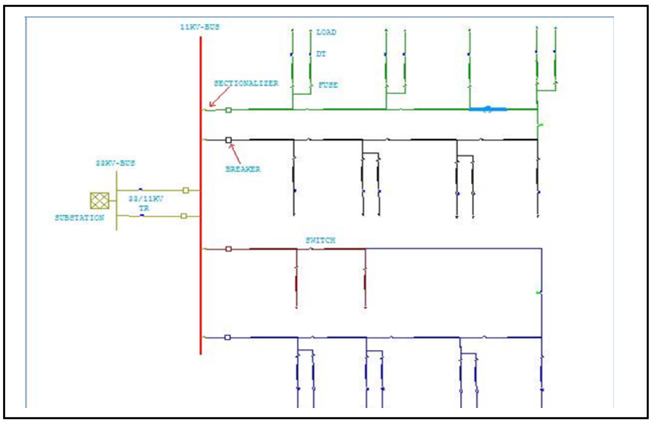

Fig. 1. Single line diagram of the RBTS TWO-BUS SYSTEM

TABLE II. RELIABILITY INDICES OF RBTS NETWORK

Feeder	SAIFI Intr/cust-yr	SAIDI hrs./cust-yr	CAIDI hr./cust-Intr	ASAI	ASUI	ENS kWh/yr	AENS kWh/cust-yr
F1	0.248	3.76	15.16	0.99957	0.000430	13862	21.26
F2	0.140	0.57	4.06	0.99994	0.000060	1217	608.69
F3	0.250	3.76	15.07	0.99957	0.000430	11845	18.74
F4	0.247	3.75	15.17	0.99957	0.000430	12983	20.87

A. Industrial Feeder

The practical Industrial distribution feeder, KIADB Industrial feeder is taken from INDIAN ELECTRIC UTILITY, Karnataka state which is modeled and simulated using CYMDIST RAM software. It is an industrial feeder starting from 66/11kV substation, consisting of 74 Distribution Transformers (DTs) having 140 number of total customers served with a total feeder length of 8.64 kms. Interruption details of the feeder have been collected for duration of one year from available Load Dispatch Centre (LDC), log books and LC (Line Clearance) books at the substation. The single line diagram and system configuration of KIADB Industrial feeder, are shown in Fig. 2 respectively.

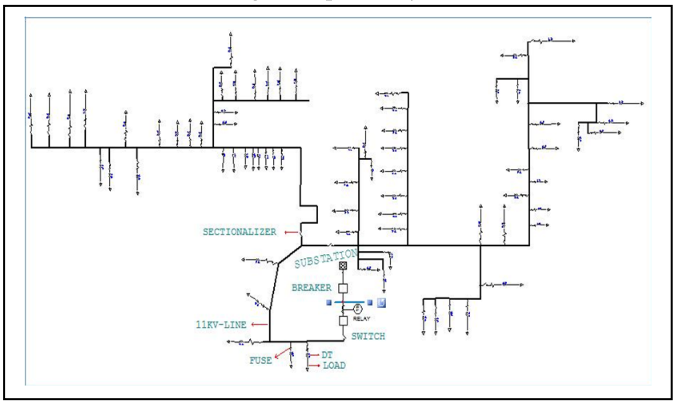

Fig. 2. Single line diagram and system configuration of KIADB Industrial feeder

In Table III, the reliability indices of practical industrial feeder are shown which describes the performance of the practical network. These results are helpful to the local utilities to provide quality of power supply at consumer end in reliable and cost effective manner. The SAIFI, SAIDI values give the system frequency and duration of interruptions per year per customer basis. Average System Availability Index (ASAI), Average Energy Not Supplied (AENS) and Energy Not Supplied (ENS) indices will be helpful to the utilities for proper 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.

All the indices are with respect to customer load point of view. The results of practical industrial feeder performance are shown in Table III. The performance can be improved by proper planning and automation in the distribution system which includes switches, sectionalizers and other protective devices at appropriate places.

TABLE III. RELIABILITY INDICES OF INDUSTRIAL FEEDER

Practical Feeder	Results
SAIFI Intr/cust-yr	403. 430
SAIDI hrs./cust-yr	375.159
CAIDI hr./cust-intr	0.930
MAIFI Intr/cust-yr	119.238
ASAI	0.9572
ENS kWh/yr.	816178.9
AENS kWh/cu	5834.016

B. Urban Feeder

This Devanoor urban distribution feeder is taken from Indian Electric Utility , Karnataka which is modeled and simulated using RAM software. It is an urban feeder starting from 66/11kV substation, consisting of 118 Distribution Transformers (DTs) having 6966 number of total customers served with a total feeder length of 17.78 km. The interruption details of the feeder have been collected for duration of one year from available Load Dispatch Centre (LDC), log books and LC (Line Clearance) books at the substation and KPTCL. The single line diagram and system configuration of Devanoor Urban feeder are shown in Fig. 3 respectively.

In Table IV shown the Reliability indices of urban feeder which describes the performance of the practical distribution networks. These results are helpful to the local utilities to provide quality of power supply at consumer end in reliable and cost effective manner. From Table. IV, 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.

All the indices are with respect to customer load point of view. The performance can be improved by proper planning and automation in the distribution system which includes switches, sectionalizers and other protective devices at appropriate places.

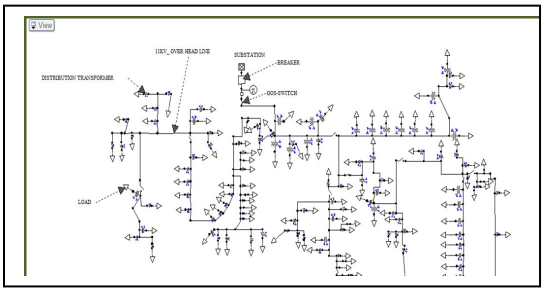

Fig. 3. Single line diagram and system configuration of Urban feeder

TABLE IV. RELIABILITY INDICES OF URBAN FEEDER

Practical Feeder	Results
SAIFI Intr/cust-yr	757.441
SAIDI hrs./cust-yr	587.148
CAIDI hr./cust-intr	0.775
MAIFI Intr/cust-yr	612.739
ASAI	0.93302
ENS kWh/yr.	704517
AENS kWh/cu	101.137

C. Rural Feeder

The Vemgal rural distribution feeder is taken from INDIAN ELECTRIC UTILITY which is modeled and simulated using RAM software. In Fig. 4, shown the single line diagram of rural feeder. It is starting from 66/11kV substation, consisting of 108 Distribution transformers (DT's) having 2440 number of total customers served with a total feeder length of 45.08 km. Interruption details of the feeder have been collected for duration of one year from available Load Dispatch Centre (LDC), log books and LC (Line Clearance) books at the substation and KPTCL. The single line diagram and system configuration of Vemgal Rural feeder, INDIAN ELECTRIC UTILITY are shown in Fig.4 respectively.

In Table V, shown the Reliability indices of rural feeder which describes the performance of the practical distribution networks. In rural feeder, the power supply has been given only 8-12 hours due to agricultural consumers in the feeder. The interruptions/outages and duration of outages are more compared to urban feeder and Industrial feeder. Under Niranthara Jyothi (NJY) Scheme of Karnataka state distribution reforms, the agricultural feeders and non-agricultural feeders are being separated in the rural area. There will be 24 hrs. supply for Non-agricultural feeders and 8-12 hrs, supply for agricultural feeders. Hence, the reliability will be improved in rural domestic feeders in future.

TABLE V. RELIABILITY INDICES OF RURAL FEEDER

Practical Feeder	Results
SAIFI Intr/cust-yr	1808.265
SAIDI hrs./cust-yr	6054.537
CAIDI hr./cust-intr	3.348
MAIFI Intr/cust-yr	109.384
ASAI	0.3093
ENS kWh/yr.	41236489.5
AENS kWh/cu	1930.548

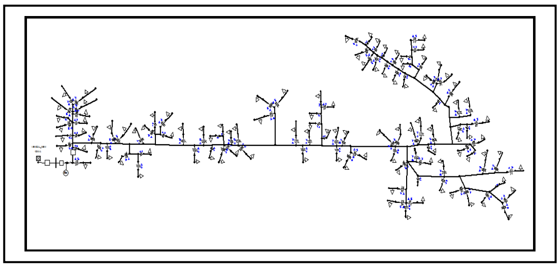

Fig. 4. Single line diagram and system configuration of Rural feeder

D. Comparison of Three Illustrative Feeders

In Table VI, the Reliability indices of Industrial Feeder, Urban feeder and Rural feeder are presented.

TABLE VI. RELIABILITY INDICES OF THREE FEEDER

Type of Feeder	Industrial (KIADB)	Urban (Devanoor)	Rural (Vemgal)
SAIFI Intr/cust-yr	403. 430	757.441	1808.265
SAIDI hrs./cust-yr	375.159	587.148	6054.537
CAIDI hr./cust-intr	0.930	0.775	3.348
MAIFI Intr/cust-yr	119.238	612.739	109.384
ASAI	0.9572	0.93302	0.3093
ENS kWh/yr.	816178.9	704517	41236489.5
AENS kWh/cu	5834.016	101.137	1930.548

The Industrial feeder has better SAIFI value and SAIDI value than urban feeder and rural feeder. The No. of Interruptions and duration of the interruption is less in Industrial feeder than urban feeder and rural feeder. The momentary interruptions are very less in Rural feeder as well as in Industrial feeder than urban feeder. The Average Service Availability Index (ASAI) /Reliability Index is 95.72% in Industrial feeder, 93.30% in Urban feeder whereas it is only 30.93% in Rural feeder. The Average Service Availability Index (ASAI) in rural area is 30.93 % because the utilities will supply Power only 8-12 hours in the rural area in Karnataka. The Energy Not Supplied (ENS) by the Electric utility is more in rural feeder than Urban feeder and Industrial feeder.

IV. CONCLUSIONS

Based on the Study Results

- The Reliability Parameters were calculated on three different load pattern distribution feeders' namely urban feeder, Industrial feeder and rural feeder of Bangalore Electricity Supply Company Ltd. (INDIAN ELECTRIC UTILITY).
- The Reliability parameters of three illustrative feeders were compared and the results were presented. It was observed that the Industrial feeder had better Reliability parameters than urban feeder and urban feeder had better Reliability parameters than rural feeder.

- The Energy Not Supplied (ENS) to the Customers and Revenue loss to the utility on three illustrative feeders were estimated.
- The Historical Reliability Assessment and Predictive Reliability Assessment were evaluated before and after proposal by adding new equipment.
- It is proved from the results presented that the accurate estimation of Reliability Parameters is beneficial in terms of Revenue generation and indirect benefits.

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