ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Website: www.ijareeie.com

Vol. 7, Issue 12, December 2018

Reliability Assessment of Debre Tabor Town Electrical Power Distribution System

Biks Alebachew Taye

Lecturer, department of Electrical and computer Engineering, Debre Tabor University, Debre Tabor, Ethiopia

ABSTRACT: The basic aim of every electric power utility is to meet its energy and load demand at the lowest possible cost. However the power interruption statistics of utilities show that most of the customer service interruptions are caused due to failure in distribution system. Distribution system reliability assessment gives an opportunity to know the cost or losses incurred by the utility and its customers as a result of power interruption. The main goal of this study is to identify the main causes of interruption, assess duration and frequency of power interruption, indicate the power interruption influences on economy of customers and utility, valuate the reliability of the present distribution system and give recommendations based on performance evaluation, of Debre Tabor electric power distribution system. To achieve the goals the steps to be performed are: secondary data like cause of interruption, duration and frequency of interruption, number and type of customer, etc were collected from Woreta substation and Primary data were collected by observation, participating with maintenance team and interview, and also two type of questioners (for residential, and commercial and industrial customers) was prepared to assess cost of power interruption in customer side.The main causes for interruption of the system are identified. The collected data were analyzed based on IEEE Guide for Electric Power Distribution Reliability Indices. Distribution reliability indices such as SAIFI, SAIDI, CAIDI, and ASAI have been analyzed thoroughly on the Debre Tabor distribution using on data collected from EEU and the values are 540 interruption/year, 1259.36 hours/customer per year, 2.33hours/ interruption and 85.65% respectively. The average unsupplied energy of town in a year is 308.16 MWh/year; for the cost of this energy the utility loses in average 2.033 million Birr/year. The calculated distribution reliability indices values have been compared with standard benchmark values and comparison clearly indicates that Debre Tabor distribution system is extremely unreliable. Therefore, the reliability of Debre Tabor distribution system could be improved by installation of load break switch, auto recloser and built new substation near to Debre Tabor at reasonable cost.

KEY WORDS: Power Distribution System, Reliability Indices, Reliability Assessment, Power Interruption Cost.

I. INTRODUCTION

Electric power utilities should provide uninterrupted power supply to their customers at the lowest possible cost with acceptable levels of quality. The main problem facing by electric power utilities in developing countries is that, no sufficient technical research have been carried out in the distribution network, it may be due to lack of technical expertise in the utility. Presently, Ethiopia electrical power system is facing a lot of challenges as a whole, from generation to distribution. The power interruption statistics of utilities show that most of the customer service interruptions are caused due to failure in distribution system.Reliability is the most rational standard for deciding which design is the best in terms of minimum total life cost of electrical systems. Reliability can be evaluated and analyzed using Reliability Indices. Performing distribution system reliability assessment is used to identify the relevant improvement techniques to get better reliability of the system. As different researchers agreed there are different distribution system reliability assessment approaches and techniques[1] .
The main objective of this study is to evaluate and analyze electrical power distributionnetwork in Debre Tabor town to determine system reliability and customer satisfaction; and suggest relevant improvement techniques. Assess and Evaluate reliability conditions of the existing distribution system, Computing present fault rates and durations of power outages, Identify the major causes of power outage and suggest methods of improvement and evaluate the cost of customers and utility due to power outages, are also the objectives of the study.

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II. RELIABILITY ANALYSIS OF AN ELECTRIC POWER DISTRIBUTION SYSTEM

Reliability in power system can be divided in two basic aspects; system adequacy and system security. Adequacy relates to the capacity of the system in relation to energy demand and security relates to the dynamic response of the system to disturbances (such as faults). Since distribution systems are seldom loaded near their limits, system adequacy is of relatively small concern and reliability emphasis in on system security[2]. The two main approaches applied to reliability evaluation of distribution systems are[3, 4]: Simulation methods based on drawings from statistical distributions (Monte Carlo) and Analytical methods based on solution of mathematical models. The Monte Carlo techniques are normally very time consuming due to large number of drawings necessary in order to obtain accurate results [2].
Reliability evaluation of a distribution system is associated with the continuity of supply energy from the supply points to the individual customer load points. The basic parameters used to evaluate the reliability of a distribution system can be categorized as load point indices and system indices. The load point failure rate, the average outage time and the average annual outage time are the basic load point indices[5]. The system indices can be obtained from these three load point indices and information on the number of customers and load connected at each load point in the system. The set of system reliability indices can be further classified into customer-oriented indices and load-oriented indices. Customer-oriented indices include the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Index of Reliability (IOR), Customers Experiencing Multiple Interruptions (CEMI), and Customers Experiencing Longest Interruption Duration (CELID). Load-oriented indices include Average System Interruption Frequency Index (ASIFI), Average System Interruption Duration Index (ASIDI), and Energy not supplied Index.
Systems reliability indices indicate the annual average performance of the network in terms of interruption frequency and duration. They are weighted by the number of customers or energy supplied. Quantitative reliability evaluation of a distribution system can be divided into two basic segments; measuring of the past performance and predicting the future performance[2]. Some of the basic indices that have been used to assess the past performance are[2]: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), The Average Service Availability (Unavailability) Index (ASAI), Momentary Average Interruption Frequency Index (MAIFI) and Energy not supplied (ENS)

III. PERFORMANCE EVALUATION OF DEBRE TABOR DISTRIBUTION SYSTEM

A. Existing Structure of Debre Tabor Electric Power Distribution System

Debre Tabor town is the capital city of south Gonder zone in Amhara region, Ethiopia and its geographical and environmental conditions are suitable for living. Debre Tabor town is accessed electrical power from nearby distribution station Woreta distribution substation.At present Woreta Substation has two 33kV outgoing feeders (Debre Tabor and Ebinat), three 15kV outgoing feeders (Saba, Addis Zemen and Woreta) and two 66kV incoming feeders (Bahir Dar I and Gonder II). There are two power transformers having 1*6.3 MVA (66/15KV) + 1*8.4/8.4/4.2MVA (66/33/15), with mixed customers (i.e. industrial, commercial and residential). Again for this substation there are no feeders dedicated for industrial, commercial and residential customers separately. The number of electric power customer in Debre tabor town is increasing day to day continuously. In 2017 the total number of customers in Debre Tabor town was 10560 (10310 single phase and 250 three phase).
The power distribution system in the Debre Tabor town get its source from Woreta substation by 2 feeders with radial distribution system. The two feeders are Debre Tabor feeder and Saba feeder with their voltage levels are 33kV and 15 kV respectively, and are configured radially. The average total distance of these feeders from Woreta distribution station is about 42 Km.the length of run of medium voltage (15kV and 33kV) in the town is about 50km whereas the length of run of low voltage (380V and/or 220V) in the town is about 630km in 2017 [6]. In existing system, 33kV line is used mainly for almost all customers in the town and nearby rural areas and 15kV lines are usually used mainly for Saba Engineering factory, partial part of Debre Tabor University and small part of the town areas (north- east part). The various size of distribution transformers are used. The transformers from 16kVA-250kVA are usually mounted either on a single pole or a double pole for both urban and rural areas. Beyond 250kVA transformers are mostly mounted on the ground with some height from the ground by concrete basement.

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B. Maintenance activities in Debre Tabor distribution system

Basically there are two type of electrical maintenance practice; thus are: Preventive maintenance and Corrective maintenance. The concept of preventive maintenance is to reduce failure probabilities by maintenance before failure or significant degradation has occurred. Corrective maintenance is performed after fault recognition and is intended to put the component in a state it can perform a required function. In Debre Tabor's distribution system preventive maintenance is seldom performed; in site visit it was found that most of equipment needs preventive maintenance in order to improve unexpected power interruption and failure of equipment. This preventive maintenance is highly required on transformer and related switch gears. Equipment like surge arrestors, drop out fuses and High Rupture Capacity (HRC) fuses are seemed to be uninspected. For equipment's with random occurring instant failures corrective maintenance might be the only option. Maintenance activities in Debre Tabor distribution system in most instances are not carried out as planned due to unplanned and unforeseen circumstances within the distribution system and most of the time only corrective maintenance is embarked, and this result not to meet the scheduled activities of preventive maintenance. The eventual ageing of the electrical network, the extent of damage experienced, conduction of repeatable repairs in the same areas and lack of maintenance leads to deterioration of the distribution network.

C. Major Causes of Interruption in Existing Distribution System

Abnormality in the system can either be a malfunction of a system component, a fault or a system operation due to maintenance or repair. Most of the time, interruptions occur because the system is reacting to a fault. Over-loading, earth fault and short circuits are the major cause of interruptions in Debre Tabor distribution system. In Debre Tabor distribution system there are different factors which affect the reliability of the system, depending on physical appearance and two years monthly report statistical data the main factors which affect reliability performance of the system can be discuss as follow.

1. Dirt and Dust Accumulation in Switching Stations:
2. Lightning, Wind, Vehicles and Animals
3. Trees or Limbs and Structures (Clearance)
4. Presence of Moisture and Loose Connection:
5. Usage of Equipment and Devices beyond their Ratings: Equipment used in electrical power distribution system must be installed depending on their name plate or their manufacturing policy. In this case study, some transformers are found to be over loaded due to many customers being installed on a single transformer covering wide area and/or HRC fuses being installed beyond the rating of the transformer. This over loading is mainly due to the improvement of the living standard of the customers.
6. Inappropriate use of protective device: The function of protective devices (fuses) is to open the circuit when the magnitude of controlled value is more than the rated value. But, if it is placed where it is not in designed values, it will not give the required function. These will be caused for the burning of other components which affect the reliability performance of the system and economy of the country.For example here are the data taken on a transformer in somewhere in study area.
   KVA rating = 630
   I rated = 909A (maximum possible line current)
   Two out goings for the customer
   Box 1: 300A, thin wire, thin wire (fuse ratings)
   Box 2: 300A, thin wire, 250A (fuse ratings)
   Here besides over loading, the fusing devices are of different ratings and this leads to transformer failure. For a transformer over loading can be examined by the above data, is totally out of design and apart from science.
7. Inappropriate Crossing of distribution lines: In some parts of the town including the main roads there are so many cross lines. These cross lines make short circuit during windy conditions.
8. Improper maintenance: While I visiting the distribution of Debre Tabor, has observed that some transformers are without preventive and control equipment. Out of 40 transformers checked out about 34 transformers were incomplete of all the following components or at least one of these: Arrestor, Body ground, Drop out fuse or at least a link, Usage of inappropriate fuse (below and above rating) and usage of inappropriate size of wire/ broken wire.85% of the inspected transformers are incomplete and not yet in safe condition i.e. exposed for power failure and further more damages.

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Vol. 7, Issue 12, December 2018

9. Substation distance from load center: Woreta substation is far from Debre Tabor (load center) about 42 kilo meter; this makes a high voltage drop and power loss. As researcher checked from customer side, the voltage reached to each customer is below 190V in single phase (220). This under voltage is difficult to run industrial motors and other loads, makes difficulty for customers to perform their works properly.

IV. RELIABILITY ANALYSIS OF THE EXISTING DISTRIBUTION SYSTEM

A. Data collection

For this study data are collected from north-west region EEP, Woreta distribution substation (EEU) and from the customers of the town. The collected data are a recorded data that includes peak load, type of faults, frequency and duration of interruption of both medium voltage (33kV and 15kV) outgoing feeders of the distribution system.To collect data from customers, questionnaires are prepared for two types of customers for residential and for industrial and commercials. Systematic random sampling technique is used to select the sample. Primary dataare obtained through questioner, direct observation and Participating with the maintenance team. Secondary dataare collected from monthly power interruption report of Woreta distribution substations and North-Western region Ethiopia electric utility office; and literatures.Based on the primary data and secondary data, Analytical method is applied to assess the overall behavior of the distribution system reliability and cost/worth indices.

Average frequency of interruption and duration of interruption for Debre Tabor distribution system are analyzed and interpreted as shown in Tables 1 and 2 respectively. The power interruptions of each feeder is recorded when the outgoing circuit breaker is open means all customers connected to the feeder are interrupted.

Table 1:Frequency of Interruption for Debre Tabor Distribution System

Month	Frequency of Interruption (No./Year)
September	60
October	39
November	25
December	9
January	27
February	25
March	39
April	85
May	57
June	56
July	64
August	54

An average of 45 frequency of interruption per month occurs in the Debre Tabor distribution. This indicates that averagely within two days three power interruption is happened in Debre Tabor town.

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Table 2: Duration of Interruption for Debre Tabor Distribution System

Month	duration of Interruption (hours)
September	53:04:00 =53.07
October	17:58:00= 17.97
November	59:25:00= 59.42
December	7:20:00= 7.33
January	71:45:00= 71.75
February	46:06:00= 46.1
March	136:24:00= 136.4
April	229:42:00= 229.7
May	191:34:00= 191.57
June	150:14= 150.23
July	128:40:00= 128.67
August	167:09:00= 167.15

An average of 104.94 hours duration of interruption per month occurs in Debre Tabor distribution. This indicates that averagely complete power interruption is happened in Debre Tabor town for 3.5 hours per day.

B. Reliability Indices Evaluation for Debre Tabor

As one object of this study is to provide a more adopted method for determining distribution network reliability, this part of the study used IEEE1366 indices[7] to evaluate the reliability indices of Debre Tabor distribution system. The availability of power for customers from this substation is performed on the medium voltage side of the customer transformers (15kV and 33kV). The reliability is highly affected by outages occurred on the customer side secondary distribution lines which unable to collect data for analysis due to lack of resource, lack of organized data and advanced technology at the substation to view the performance of the customer side secondary distribution network. The utilities commonly use the following reliability indices for frequency and duration to quantify the performance of their systems[8].

System Average Interruption Frequency Index, $SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customer\ served} = \frac{\sum \lambda_i N_i}{\sum N_i}$ = (/yr)

System Average Interruption Duration Index, SAIDI= $\frac{sum\ of\ customer\ interruption\ durations}{Total\ number\ of\ customer\ served} = \frac{\sum u_{iN_i}}{\sum N_i}$ (hr/Yr)

Customer Average Interruption Duration Index, $CAIDI = \frac{sum\ of\ customer\ interrruption\ durations}{Total\ number\ of\ customer\ interruptions} = \frac{\sum u_{iN_i}}{\sum \lambda_i N_i} = \frac{SAIDI}{SAIFI}$ (hr)

Customer Average Interruption Frequency Index, $CAIFI = \frac{Total\ number\ of\ customer\ interrupted}{number\ of\ customer\ affected} = \frac{\sum UN_i}{N}$

Average Service Availability Index, $ASAI = \frac{customer\ hours\ of\ available\ service}{customer\ hours\ demanded} = \frac{\sum N_i x8760 - \sum u_i N_i}{\sum N_i x8760}$

Based on the recorded data the average reliability indices of the existing system are calculated and summarized in table 3.

Table 3: calculated average reliability indices

No.	Index	Value
1	SAIFI (interruption./cust./yr)	540
2	SAIDI (hr//cust./yr)	1259.36
3	CAIDI (hr/interruption)	2.33
4	ASAI (%)	85.62
5	CAIFI	0.051

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C. Comparison of Reliability Indices with Benchmark

Reliability benchmarks are the standards against which analyzed or measured reliability is judged. The benchmarks were calculated using the IEEE Guide for electric power distribution reliability indices – IEEE Standard 1366-2012. A benchmark of SAIDI, CAIDI, SAIFI and ASAI for nine countries is shown in Table 4. A lower number for SAIDI, SAIFI and CAIDI index indicates better reliability performance; i.e., a lower frequency of outages or shorter outage duration. A higher SAIDI, SAIFI and CAIDI index number indicates worse performance. Comparing the average SAIDI, SAIFI, CAIDI and ASAI value of Debre Tabor distribution with the benchmarks shows that has worse performance.

Table 4: Benchmarks for Reliability Indices[9]

No.	Country	SAIDI (Minutes/year)	SAIFI (Interruptions/Customer)	CAIDI (Minutes/outage)	ASAI (%)
1	US	240	1.5	123	99.91
2	Austria	72	0.9	112	99.97
3	Denmark	24	0.5	70	99.981
4	France	62	1	58	99.97
5	Germany	23	0.5	50	99.9999
6	Italy	58	2.2	106	99.9991
7	Netherland	33	0.3	75	99.97
8	Spain	104	2.2	114	99.968
9	UK	90	0.8	100	99.964
10	Debre Tabor	75562	540	140	85.65

D. Loss of Revenue due to Power Interruption

Interruption or outage costs can be broadly classified into direct and indirect costs. Direct costs are those arising directly from the electrical interruption and relate to such impacts such as lost industrial production, spoiled food or raw materials, personnel leisure time, injury or loss of life. Indirect costs are related to impacts arising from response to the interruption, such as crime during blackouts (short term) and business relocation (long term). Many direct impacts are relatively easy to identify and quantify, while such as injury and loss of life are easily identified but difficult to quantify. Till date, no single approach has been universally adopted, however, customer survey approach appears to be the method of choice widely used among the utilities around the world[10].

Power Outage Cost of utility: The cost of energy not supplied due to interruption for Debre tabor Electric power distribution is calculated by using equation below.

$$Cost\ of\ Energy = Power(in\ kW) * Time(in\ H) * Tariff\ for\ Electric$$

By considering an average price of 0.6 Birr/kWh for electricity in EEU[11], the average energy not supplied and average cost of energy not supplied due to power interruption for single months at Debre Tabor and Saba outgoing feeders are calculated and tabulated in table 5 below.

Table 5: average cost of energy not supplied due to power interruption for single month

No.	Feeder Name	Peak Load (MW)	Average Duration of interruption (Hr)	Energy Not Supplied (MWh)	Cost of Energy not Supplied (Birr)
1	Debre Tabor	5.115264	56.72	290.1420368	159578.12
2	Saba	0.37368	48.23	18.02103	9911.57
Total				308.1630662	169489.69

Therefore, the total average energy not supplied and average cost of energy not supplied due to power interruption for single month at Debre Tabor town (from the two outgoing feeders) are 308.16MWh and 169,489.69 Birr respectively.

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Vol. 7, Issue 12, December 2018

The total energy cost of energy not supplied due to power interruption per year in Debre Tabor town is 12*169,489.69= 2,033,876.28 Birr ($72,608).

Power Outage Cost of Customers: By preparing two types of questioners for customers the average cost incurred due to power outage for each type of customer is calculated. The power outage cost of residential customers are collected through questioners, from the result the average cost of residential customer is 24.74 Birr/hr for each customer with 20% difference due to power outage time and date. Total residential customers and small industries in Debre Tabor Town is 10310 and Average outage time of the system per year is 1259.36 hr. Then the total estimated cost = 10310 × 1259.36 hours/year × 24.74 Birr/hour = 321,224,200 Birr/year.

The power outage cost of industrial and commercial customers are also collected through questioners. From the result the average power outage cost for these types of customers is 3807.5 Birr/hour for each customer. The industrial and commercial customers in Debre Tabor Town is 250 and Average outage time of the system per year is 1259.36 hours. Then the total estimated cost of industrial and commercial customers = 250 × 1259.36×3807.5 = 1,198,753,300 Birr/year. To buy stand by generators (buck up supply) the industrial and commercial customers invest in average 26833.33 Birr / customer, and to operate their stand by generator the running cost is in average 16333.33 Birr/ year per customer.

The costs calculated in above indicates how power outage is pain full to the economic cost of customers and utility.

V. RELIABILITY IMPROVEMENT STRATEGY OF THE DISTRIBUTION SYSTEM

A. Outage Mitigation Techniques

The mitigation techniques can be basically classified into two categories: electric and non-electric. Electric mitigation techniques have a direct impact on the distribution system and affect the distribution system analysis while non electric mitigation techniques do not have any impact on other engineering analysis tools and can be evaluated solely with reliability studies.Electric Mitigation Techniques includes: addition of protective devices (recloses and fuses) and switching devices (manual and automated switches), system reconfiguration and feeder reconductoring. Distribution automation is the way forward to improve system performance and reliability, reduce cost in long run and improve overall customer services.Building new substation from Bahir Dar – Alemata 230kV high voltage transmission linearound Debre Tabor is another option to reduced high power losses and operation costs. Non Electric Mitigation Techniques include; Vegetation management, Animal guards and Overvoltage protection

D. Design Solution

The Debre Tabor distribution system is mainly made up of radial network which is making things worse in case of line tripping. So it is better to convert radial networks to ring network for better reliability. Distribution transformers are without surge arrestors at the majority of locations. So, it is better the distribution transformer with their accessories are equipped with surge arresters. For better distribution reliability, low voltages feeders should be undergrounded. Loads or customers should be separated by specifying industrial, commercial and residential consumers.

It has been identified that the Woreta region distribution substations are overloaded and it has to be expanded to accommodate the increasing demands. Woreta distribution substation is supplying large power to Debre Tabor distribution system. In order to meet customers demand with greater capacity and reliability, it is necessary to upgrade the substation by designing the distribution substation with proper rating of distribution substation equipment or designing of new substation for Debre Tabor town. The power demand after 25 years will be approximately 24.12MW of active power and 30.2 MVA by considering a power factor of 0.9[12]. Therefore the power demand after 25 years will be approximately 30.2 MVA, which is above the total capacity (14.7 MVA) of Woreta substation.A design of 30.2 MVA (66/33kV, 27.5 MVA and 66/15, 2.7 MVA) distribution substation for Debre Tabor is carried out to upgrade the existing 66/33kV, 6.39MVA and 66/15kV, 0.5 MVA capacity.

VI. CONCLUSIONS

The aim of this study was to identify causes of interruptions and suggest possible solutions to the Debre Tabor distribution system. The Power interruption can be cause to extra costs to a backup supply, wastage of raw materials and products, loss of profits and payment of unused labor, suffering due to absent of light and communication, cause

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for water supply interruption, etc. From the substation fault record, it is concluded that most of the failures in the distribution system are due to short circuits, earth fault, overload, operation and system over load. To assess and evaluate reliability of the system analytical method is implemented for the feeders and the value obtained by analytical methods for SAIFI, SAIDI and ASAI are 540 interruptions, 1259.36 hours, and 85.65% respectively. From the data the average number of power interruption frequency is 540, and the average interruption duration is 1259.36 hours per year for the system, this indicates that the reliability of the system is low compared to the performance of other utilities distribution system and benchmarks. The cost suffered by the customers and utility in a year due to power outage is in average 1,519,977,500 and 2,033,876 Birr/year respectively which is very high and it has a great economical influence for development so, immediate solutions should be taken. The reliability improvement techniques suggested as predictive reliability can minimize the power outage frequency and duration. This improvement has a great impact socially and economically both for the utility and the consumers.

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