Power Distribution System Reliability Assessment and Improvement Case of Jimma Town, Ethiopia

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Abstract. A frequent and long lasting power interruption has become a serious problem in Ethiopia. This problem has highly affected the life and economic activity of the society. The cost of power interruption to the power utility and also to the industry is very significant. This research has made an assessment of this problem and explored potential mitigation techniques. The reliability assessment has been done on the 15 kV city feeder. The interruption data of years 2010 to 2015 has been evaluated to determine the customer interruption indices. The study has evaluated different mitigation alternatives to look at the possibilities of reliability improvement. ETAP software has been used to test the improvement potential of the reliability indices for the distribution system. Various alternatives have been assessed using heuristic method. Reliability indices such as SAIFI, SAIDI and EENS have been reduced by 84.75%, 85% and 88.651% respectively as compared with the base year average values.

Keywords: Power distribution system · Power reliability · Protection system coordination · ETAP software

1 Introduction

Jimma is the oldest city of Oromia region in Ethiopia. It is located at the geographical coordinates of 7° 40′ 22.1″ N and 36° 50′ 32.9″ E and is 354 km away from Addis Ababa, capital of Ethiopia. The life of the people is highly dependent on electricity. Electricity is needed for lighting, cooking, water supply, educational activities, health sectors, etc. Assessment of the power reliability problem and exploration of cost effective problem mitigation techniques are the focus of the research. Many researches had been worked in different areas of the globe, to improve power distribution system reliability. The author of this research has been reviewed many researches and has got many ideas and techniques of solving such real existing problems.

Koval and Chowdhury [1] recommended a basic new restoration methodology for distribution system configurations that maximizes the amount of load that can be restored

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after a grid blackout, substation outage and distribution feeder line section outages and evaluates the cost of load point interruptions considering feeder islanding and substation capacity constraints. Several case studies with restoration procedures are presented and discussed to clearly reveal the impact of distribution system capacity constraints on load point reliability indices and the cost of load point interruptions.

Merlin and Back [2] proposed a branch and bound type heuristic method to determine the network configuration to enhance distribution system reliability and for minimum line losses. Its solution scheme starts with a meshed network by initially closing all switches in the network. The switches are then opened one at a time until a new radial configuration is reached. In this process the switch to be opened at each stage is selected in order to enhance distribution system reliability and to minimize line losses of the resulting network.

2 Distribution System Reliability Assessment

The old and simple radial power distribution system topology is used in Ethiopia dominantly. The primary distribution system of Jimma town takes 132 kV and steps down to 15 kV and 33 kV. There are seven outgoing feeders (two 33 kV and five 15 kV) which supplies the town and surrounding Woredas. This study focuses on the one, 15 kV feeder, with the highest rate of interruption and supplies the largest part of the town (Fig. 1).

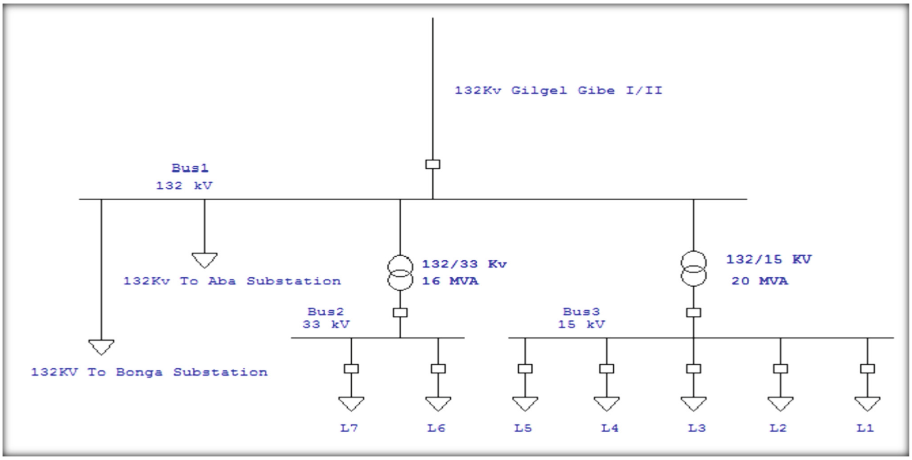

Fig. 1. Single line diagram of Jimma old substation distribution feeders and incoming line

The power distribution system reliability of the case study area is assessed by using different reliability indices. The indices for power distribution system analysis include customer-oriented indices and energy-oriented indices as defined in IEEE Standard 1366™-2012 [3].

2.1 Customer Oriented Indices

System Average Interruption Frequency Index (SAIFI): It is the average frequency of sustained interruptions per customers over a predefined area. Total number of customer interruptions per year divided by the total number of customers served.

$$\mathrm{SAIFI} = \frac{\sum \mathrm{N_i}}{\mathrm{N_t}} \tag{1}$$

Where, Ni is the number of interrupted customers for each interruption event i during the reporting period, N_t is the total number of customers served in the area.

System Average Interruption Duration Index (SAIDI): It is commonly referred to as customer minutes of interruption or customer hours and provides information as to the average time the customers are interrupted.

$$\mathrm{SAIDI} = \frac{\sum \mathrm{r_i N_i}}{\mathrm{N_t}} \tag{2}$$

Where, $\mathrm{N_i}$ is the number of interrupted customers for each interruption event i during the reporting period, N_t is the total number of customers served in the area and $\mathrm{r_i}$ is outage duration for event *i*.

Customer Average Interruption Frequency Index (CAIFI): This index gives the average frequency of sustained interruptions for those customers experiencing sustained interruptions. It is the value of total number of customer interruptions divided by total number of customers affected.

Customer Average Interruption Duration Index (CAIDI): It is the average time needed to restore service to the average customer per sustained interruption. It is the sum of customer interruption durations divided by the total number of customer interruptions.

$$\mathrm{CAIDI} = \frac{\mathrm{SAIDI}}{\mathrm{SAIFI}} \tag{3}$$

Average Service Availability Index (ASAI): This index represents the fraction of time (often in percentage) that a customer has power provided during one year or the defined reporting period.

2.2 Load or Energy Oriented Indices

Expected Energy Not Supplied Index (EENS): This index represents the total energy not supplied by the system.

$$\mathrm{EENS} = \sum_i \mathrm{L_i r_i} \tag{4}$$

Where L_i the average load is connected to load point i and r_i is the outage duration for event i.

Table 1. Summary of reliability indices of city feeder for years 2010–2015

Reliability indices	Unit	2010	2011	2012	2013	2014	2015	Average of six years
SAIDI	Hrs./customer/yr.	237	181	238	203	302	471	272
SAIFI	Int./customer/yr.	241	302	480	424	461	705	435.5
CAIDI	Hrs./Interruptions	0.9	0.6	0.49	0.48	0.66	0.67	0.62
EENS	MWH	311	335	441	721	851	1458	686.2

The summary of the reliability indices for the years from 2010 to 2015 for the site are selected as base years and shown in Table 1.

In Jimma, each interruption, interruption duration and loads of each feeder per hour is recorded in the substation but the causes of interruptions are not recorded. As per the information from the technicians at the substation, the most common causes of interruptions are: overload, trees, windy rain, lightning, accidents, animals, scheduled operational interruptions, human error, grid outage, equipment malfunction and others. Among the causes, feeder overloading ranked first followed by tree contact and windy rain with operational scheduled interruptions and unknown causes ranked fourth and fifth place respectively.

The power outage frequency is as high as 435 and service restoration duration is as long as 272 h per year for the selected feeder. The data clearly indicates that power interruption per day is a common phenomenon in the case study area and due to this problem day to day activities of the society are highly affected and hence the customers' complaints to the utility have been strong and frequent.

To predict the reliability indices of a distribution system, values of failure rates and mean time to repair for each component are necessary. To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length (Kilo meters) as indicated in Eq. (5). The average mean time to repair (MTTR) of each failure is computed using Eq. (6).

$$\mu_A = \frac{\text{Total Number of Interruptions}}{(\text{Total feeder length(km)}) \times (\text{Number of years})} \tag{5}$$

$$\text{MTTR} = \frac{\text{Total Repair Time}}{\text{Total Number of Interruptions}} \tag{6}$$

Where, μ_A is active failure rate of a component.

The calculated average failure rate of the line and average repair times per km of the existing feeder are 7.96 (Interruptions/(km·year)) and 0.62 (Hrs./interruption) respectively. By using the above two equations, the basic reliability parameters used in ETAP software for reliability analysis are calculated.

3 System Modeling

In this thesis, ETAP 12.6.0 has been used as a design, simulation and reliability assessment analysis tool. Figure 2 shows the project editor view, with the reliability page opened. Length of feeder, rating and type of each transformer, topology and layout of the system, conductor type, topography and others are used as input in modeling the system.

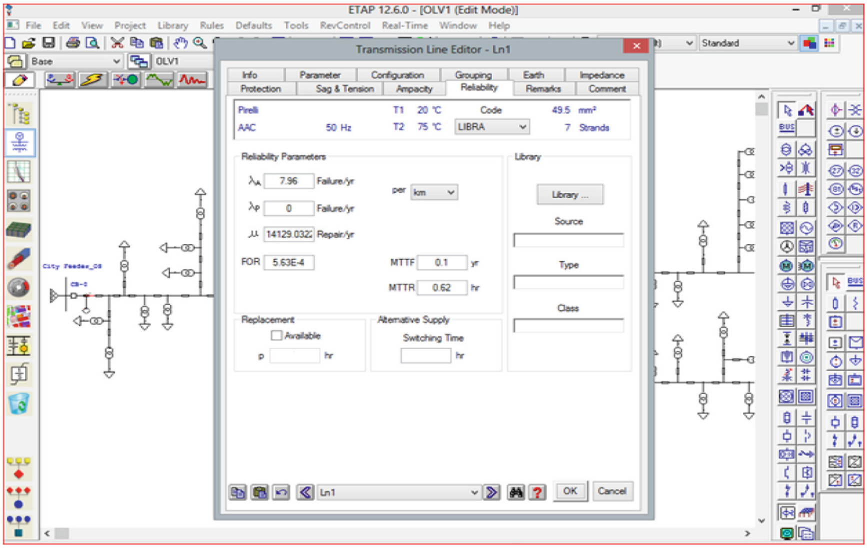

Fig. 2. Window of Etap 12.6.0 software as reliability page opened

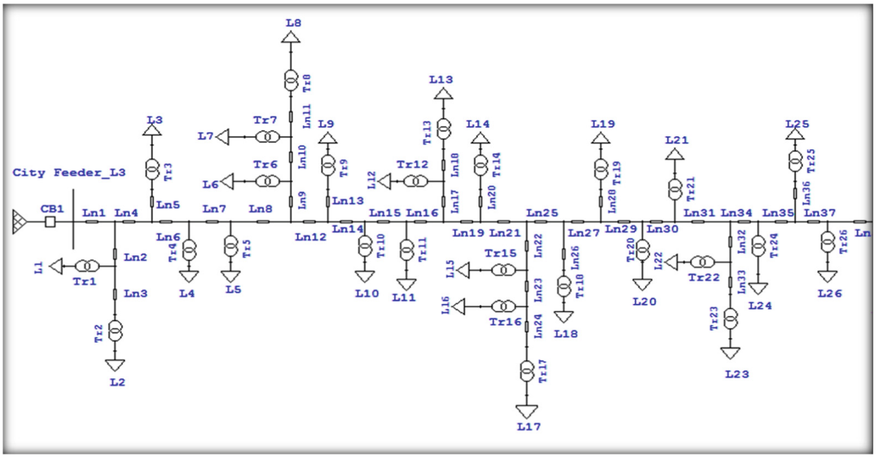

Fig. 3. Single line diagram of the existing system partially

Figure 3 shows single line diagram for some part of the existing feeder. In the diagram L1–L68 indicates Load Points on each transformer, Tr1–Tr68 are Transformers, Ln1–Ln90 represents Segmented Lines of the Feeder and CB is for Circuit Breaker.

Table 2 reveals that the simulation result has given the reliability indices values with minimum deviation from the average of six years interruption data. The two basic reliability indices, system average yearly interruption duration and system average yearly interruption frequency are 272.02 and 435.5 respectively.

Table 2. Results of reliability indices for the existing system

Project:	Reliability on Distribution	ETAP	Page:	1
Location:	Jimma, Oromia	12.6.0H	Date:	11-05-2016
Contract:			SN:	
Engineer:	Eyasu Bechamu	Study Existing System: RA	Revision:	Base
Filename:	Main city		Config.:	Normal

SUMMARY

System Indexes

SAIFI	435.5062 f / customer.yr
SAIDI	272.0240 hr / customer.yr
CAIDI	0.625 hr / customer interruption
ASAI	0.9689 pu
ASUI	0.03105 pu
EENS	1483.348 MW hr / yr

4 Evaluation of the Reliability Improvement for Different Scenarios

The above analysis clearly shows how the power reliability of Jimma town is very poor and does not meet the requirements set by the Ethiopian Electric Agency (EEA). A new substation is under construction in Jiren about 8 km away from the center of **Jimma** town. The 230 kV incoming lines are from Gilgal Gibe I & II and also planned to get power from Fincha power plant via Nekemt - Bedele - Agaro HV power line during outages of Gilgal Gibe I & II. There are 40 MVA, 230/132 kV and 40 MVA, 230/15 kV large power transformers in the substation. The breakers are vacuum and SF6 types. The main purpose of the new substation is to upgrade the old 132 kV to 230 kV system.

The new substation is located on the other end of the town almost in the opposite side of the old substation, which will make reconfiguration of the existing distribution system simple and also uses mainly to overcome the overloading of the existing substation.

Starting from the existing system design and the reliability indices of the base years, the study has evaluated different mitigation alternatives to improve the system reliability at reasonable cost. Five different cases have been analyzed by computer simulation. The simulation focuses on evaluating the impact of using reclosers, tie switches and reconfiguration of the feeder on reliability of the system.

Recloser allows utilities to implement automatic back feed restoration (loop automation), fault finding and fault isolation. The device is also equipped with precise timing parameters allowing protection coordination time between devices to be minimized. Automatic circuit reclosers are designed for use on overhead distribution lines as well as distribution substation applications for different voltage classes like 15 kV, 27 kV and 38 kV [4].

Place and number of automatic re-closers are chosen by considering number of customers, feeder length, sensitivity of the area and economic benefits. The reliability indices SAIFI, SAIDI and cost benefits are the main drivers for comparison of the alternatives and this is done using heuristic technique.

For a fault occurred anywhere in the system, different protection devices may operate differently as a result of varying sensitivities, operating times and tolerances. When a fault occurs, the protection device closest to the fault should operate first to isolate the faulty circuit. If a protection device higher in the hierarchy trips first, multiple loads may unnecessarily lose service. To accommodate for the varying tolerances and to ensure that multiple protection devices do not unnecessarily trip for the same fault current, the protection devices should be coordinated to each other based on their settled pickup currents and tripping times [5]. The five alternatives are arranged as below, and their results are tabulated and compared.

Case-1: Using One Auto Recloser
Case-2: Using Two Auto Reclosers
Case-3: Reconfiguring the system using Tie switch
Case-4: Using Tie Switch and Isolating Dedo Woreda
Case-5: Using Two Auto reclosers, Tie Switch and Isolating Dedo Woreda

As a sample, the case-5 is shown with the reclosers and Tie-switch in Fig. 4. The model shows that two reclosers and a tie switch integrated in the system with the line to Dedo woreda is being isolated from the 15 kV city feeder. The two reclosers in both sides of the normally open tie-switch are placed by considering length of the feeder, number of customers and criticality of the location. Recloser (Rec-1) has been placed almost at a midpoint by considering the length and number of the customers connected to the new substation. The same thing was considered for Recloser (Rec-2) which has been placed at the old substation side.

Table 3 (Case-5) shows the value of reliability indices obtained from the simulation. As can be seen from the Table, the two reclosers together with the tie switch significantly enhance the reliability of the system. The expected number of outages per year per

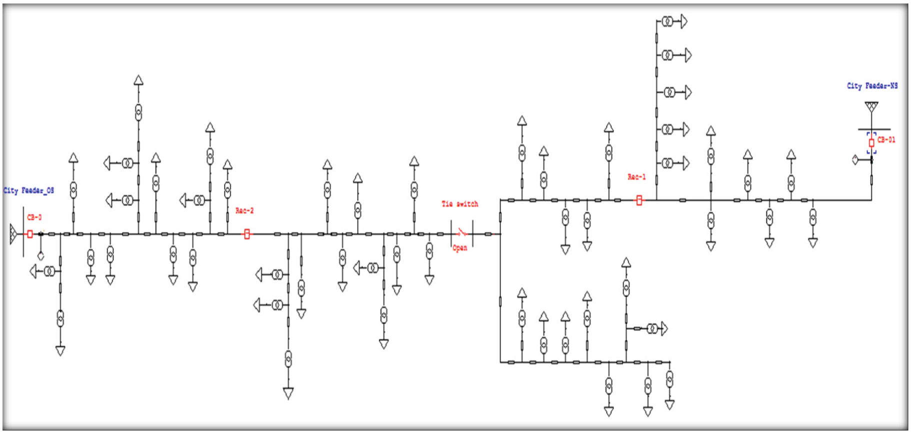

Fig. 4. Using two auto reclosers and tie switch with Dedo Woreda isolated (Case-5)

Table 3. Reliability indices of simulation results for case-5

Project:	Reliability on Distribution	ETAP	Page:	1
Location:	Jimma, Oromia	12.6.0H	Date:	22-02-2017
Contract:			SN:	
Engineer:	Eyasu Berhanu	Study Case: RA…Case 5	Revision:	Base
Filename:	Main city		Config.:	Normal

SUMMARY

System Indexes

SAIFI	66.4190	f / customer. yr
SAIDI	40.8441	hr. / customer. yr
CAIDI	0.615	hr. / customer interruption
ASAI	0.9953	pu
ASUI	0.00466	pu
EENS	168.339	MW hr. / yr

customer has been reduced from 435.5062 to 66.42 (84.75% system reliability improvement), and the annul outage duration has been reduced from 272 to 40.844 h (85% reduction in outage duration) as compared with the values at the selected base years. Table 4 summarizes reliability indices values for all the five cases mentioned above.

As it is observed from Table 4, both the SAIFI value in interruptions per year per customer and the SAIDI value in hours per year per customer of city feeder has been improved by almost 85% as compared with the values at the base years.

Table 4. Summary of reliability indices values for all cases

Cases	SAIFI	SAIDI	EENS (MWh/yr.)	ECOST (US Dollar)	% Reduction in SAIFI	% Reduction in SAIDI	% Reduction in EENS
Existing	435.5	272	1483.3	29406.7	0	0	0
Case-1	297.6	185.2	863.2	17112.3	31.7	31.9	41.8
Case-2	199.1	123.8	529.5	10497.9	54.3	54.5	64.3
Case-3	161.5	99.4	418.9	8305.1	62.9	63.5	71.8
Case-4	88.05	54.2	227.8	4515.4	79.8	80.1	84.6
Case-5	66.42	40.844	168.339	3337.246	84.75	85	88.651

5 Conclusion

In this research, the reliability assessment of Jimma distribution system has been done. Primary data from the field and secondary data from Jimma substation have been collected and analyzed. In order to explore reliability improvement options, the system is modeled and simulated using ETAP12.6.0 software for five different cases. SAIFI, SAIDI and cost have been used as driving parameters. From the cases, the system with two auto reclosers, tie switch and isolating the long line goes to Dedo woreda has been selected as an effective mitigation solution from the cases studied. For this case, SAIFI has been reduced by 84.75% as compared with the average reliability indices value of the base year. In the same case SAIDI and EENS have been reduced by 85% and 88.651% respectively. The proposed solution can save 579523.96 ETB per year from the unsold energy of the selected feeder with 2.03 years payback period for the recloser investment. Satisfaction of the society has been considered as a priceless advantage.

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