Jemal Mohammed Amin et al., J Electr Eng Electron Technol 2020
DOI: 10.37532/jeeet.2020.9(4).178

Journal of electrical engineering and electronics technology

Research Article

A SCITECHNOL JOURNAL

Study of Reliability of Power Distribution System and Improvement Options at Awash7 kilo Substation, Ethiopia

Jemal Mohammed Amin[1] and Getachew Biru Worku (PhD)[2]

Abstract

This paper presents a study of reliability of power distribution system and improvement options at Awash7 kilo substation in Ethiopia. Basically, power distribution reliability has been a major challenge in Awash7 kilo city. The existing substation has encountered frequent and long power interruptions problems. The interruptions are caused mainly by the short circuit (SC) and earth fault (EF). There are also planned outages for operation and maintenance purpose. Thus, the objective of the study is to assess the reliability of the existing distribution system and suggest solutions for reliability improvement in heuristic techniques. To limit the scope of the study, 15 kV Awash7 kilo city feeder of the substation has been chosen for the reliability improvement measures. In the study, four different mitigation scenarios have been assessed using the heuristic method to improve the system reliability. From the mitigation scenarios with the lowest SAIDI, SAIFI and Expected Energy Not Supplied (EENS) has been selected as an optimal one. The simulation results have been done with the help of Electrical Transient Analysis Program (ETAP 16.0) software. The result of this study reveals that the overall reliability of Awash7 kilo city feeder has been improved by 86%, 85.4% and 92.94% for SAIFI, SAIDI, and EENS respectively as compared with the existing system by incorporating a mitigation technology in to the network model. The economic analysis shows that the selected solution results in a cost saving of 20,229.47 USD per year from the unsold energy of one feeder only with three years payback period investment for the implementation of the reliability mitigation technology.

Keywords: Distribution System, Power Reliability, Reliability Indices, ETAP Software, SAIFI, SAIDI.

Introduction

The electric power system is basically set up to supply electricity with little or no interruptions to its customers. Nowadays, Ethiopian Electric Utility (EEU) Power system has 400 kV, 230 kV, 132 kV primary transmission systems and 66 kV, 45 kV as sub-transmission system and 33 kV and 15 kV as a distribution system. Awash7 kilo substation receives electric power from Koka power plant at 132 kV from the interconnected system (ICS). The 132 kV transmission line is stepped dawn to 66 kV/15 kV with two parallel connected transformers as shown in Figure1. The distribution system in the city has a primary voltage of 15 kV and stepped down further to 400/220V to supply the various consumer loads [1]. The network topology of Awash7 kilo substation is radial. Awash7 kilo substation consists of five outgoing feeders. The nominal voltages of the three feeders are 15 kV and the remaining two feeders are 66 kV. As per the data found from the south-east region billing office, the south-east region has a total of 9,823 customers and out of which, 4,819 customers are living in Awash7. From the outgoing feeders, 15 kV feeder city line is serving customers found in the center of the city and is extended to Argoba Wereda and Awash Park, which are located at 35 km away from the Awash7 kilo substation. Commercial businesses like hotels, small and micro industries, banks, most administrative offices, telecommunication center, schools and a large number of residential customers get electricity from this feeder. City line is represented by L1 as depicted in Figure 1.

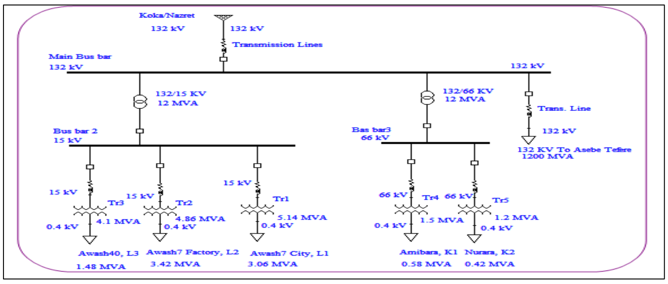

Figure1.Single line diagram of Awash7 kilo Substation

2. Substation Collected Data and Analysis

This part briefly deals with the methodologies used for data collection and data analysis for the existing system. Reliability analysis needs data on interruption duration, interruption frequency, a total number of customers served, customers interrupted, loads connected and so on. So, under this section, the collected failure data and basic electrical data of power system equipment which are necessary for reliability analysis are presented. These data are used to analyze the current reliability status of the substation and to distinguish the main problems of interruption. Primary data have been collected from the Ethiopia Electric Utility (EEU) of Awash7 kilo.

Table 1. Shows the basic data for the 15 KV feeders (bus bar 2) and 66 KV feeders (bus bar 3). L1, L2 and L3 represent the outgoing feeder lines from 15 KV bus bar and K1 and K2 represent the outgoing feeder lines from 66 KV bus bar. The total number of distribution transformers connected to the substation is 76 with a total rating of

***Corresponding author:** Getachew Biru Worku (PhD); Department of Electrical and Computer Engineering, Adama Science and Technology University, Ethiopia

Received: 27 July, 2020 **Accepted:** 24 Aug, 2020 **Published:** 10 September, 2020

16.36 MVA. Out of this, Awash7 kilo city has a total of 34 distribution transformers with a total capacity 9.9 MVA connected to feeder L1 and L2.

Table 1. Summarized data for Awash7 kilo substation feeders [4]

Feeder Name	Total No of Distribution Transformer	No of Customers	Total capacities of Distribution Transformer (KVA)	Total Length of Feeders (km)
Awash7 city L1	26	4,819	4555	35
Awash7 Factory L2	8	8	5345	0.6
Awash 40 L3	22	2,242	3450	10
Amibara K1	10	1,405	1680	18
Nurara K2	12	1,349	1330	16
Total	76	9,823	16360	79.6

Table 2, shows the frequency interruption due to non-momentary (unplanned) and planned interruptions in the existing Awash7 substation system from 2015/2016 G.C to 2017/2018 G.C. [4]

Table 2: Frequency Interruptions from 2015/16 G.C to 2017/18 G.C. [4]

Feeder	2015/2016 G.C			2016/2017 G.C			2017/2018 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total	Unplanned	Planned	Total
L1	198	183	381	245	165	410	288	163	451
L2	125	78	203	98	128	226	130	95	225
L3	285	165	450	191	108	299	270	115	385
K1	213	155	368	245	125	370	188	175	363
K2	182	155	337	141	128	269	158	112	270
Total	1,003	736	1,739	920	654	1,574	1,034	660	1,694

Table 3 shows the duration of interruptions due to non-momentary (unplanned) and planned interruptions in the existing Awash7 substation system from 2015/2016 G.C to 2017/2018 G.C. [4] Table 3: Duration Interruptions from 2015/16 G.C to 2017/18 G.C

Feeder	2015/2016 G.C			2016/2017 G.C			2017/2018 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total	Unplanned	Planned	Total
L1	171	141	312	181	127	308	187	152	339
L2	18	65	83	62	73	135	31	84	115
L3	168	82	250	132	112	244	128	110	238
K1	105	110	215	176	79	255	105	89	194
K2	128	145	273	87	168	255	153	102	255
Total	590	543	1,133	638	559	1,197	604	535	1,141

Table 4 shows annual average frequency and duration of interruptions from 2015/2016 G.C to 2017/2018 G.C.

Table 4. Average frequency of interruptions and average duration of interruptions

Feeder	Frequency Interruption (Int/year) 2015/16 to 2017/18 G.C			Duration Interruption (Hour/year) 2015/16 to 2017/18 G.C		
	Unplanned	Planned	Total	Unplanned	Planned	Total
L1	243.67	170.3	413.97	179.67	140	319.67
L2	117.67	100.3	217.97	37	74	111
L3	248.7	129.3	378	142.7	101.3	244
K1	215.33	151.67	367	128.7	92.67	221.37
K2	160.33	131.67	292	122.7	138.3	261
Total	985.7	683.24	1,668.94	610.77	546.27	1,157.04

According to the data collected from Awash7 kilo substation, the causes of faults include Distribution Permanent Earth Fault (DPEF), Distribution Permanent Short Circuit (DPSC), Distribution Temporary Earth Fault (DTEF) and Distribution Temporary Short Circuit (DTSC). Table 5 and Table 6 shows percentage ratings of the fault types in terms of interruption duration and interruption frequency; whereas o Other faults includes overload, blackout (total loss of power to an area), under frequency, transmission line fault etc

Table 5. Percentage average interruption duration of each type of fault

Causes	DPEF	DPSC	DTEF	DTSC	Operational	Others
Percentage of interruption types	10%	17%	9%	10%	47%	7%

Table 5 shows that 47% (Hr.) of the interruption duration of the overall system are due the operation and maintenance, 17% is due to distribution permanent short circuit, 10% is due to a distribution permanent earth fault, and the remaining other faults account for around 7% (power transformer overloading, transmission line fault, etc.).

Table 6 shows that 41% of the interruption frequency is due the operation and maintenance, and 19% are due to a distribution temporary earth fault, 15% is due to distribution permanent short circuit, 6% is due to others (power transformer overload, transmission line fault, etc).

Table 6: Percentage of each type of fault in terms of interruption frequency

Causes	DPEF	DPSC	DTEF	DTSC	Operational	Others
Percentage of interruption types	13%	15%	19%	6%	41%	6%

Table 7 shows the annual average energy and power consumption of each feeder bus bar. The annual average energy is calculated using the recorded data from 2015/16 -2017/18 G.C.

Table 7: Annual average energy and power consumption of each feeder [4]

Feeder Name	Average apparent power consum. (MVA)	Average Power Consumption		Average Energy Consumption	
		Average Active Power (MW)	Average Reactive Power (MVAr)	Average Active Energy (kWh)	Average Reactive Energy (kVArh)
Awash7 city L1	3.06	2.448	1.7748	21,444,480	15,547,248
Awash7 Factory L2	3.42	2.736	1.9836	23,967,360	17,376,336
Awash40 L3	1.48	1.184	0.8584	10,371,840	7,519,584
Amibara K1	0.58	0.464	0.3364	4,064,640	2,946,864
Nurara K2	0.42	0.336	0.2436	2,943,360	2,133,936
Total	8.96	7.168	5.1968	62,791,680	45,523,968

Based on Table 7, the average power factor (PF) of the substation can be calculated as;

$$\mathrm{PF} = \mathrm{Cos}(\tan^{-1}(\mathrm{Q/P})) \qquad (2.1)$$

$$\mathrm{PF}=\mathrm{Cos}\ (\tan^{-1}\left(\frac{45{,}523{,}968}{62{,}791{,}680}\right) = 0.8$$

Whereas;

PF= Power factor

Q= Reactive Power in (MVAr)

P= Active Power in (MW)

3. Distribution Reliability Indices Calculation

Most reliability indices are average values of a specific reliability characteristic of an entire system, operating region, or feeder. The indices for the power distribution system analysis include customer-oriented indices and energy-oriented indices as defined in IEEE standard 1366-2012 [2].

3.1. Customer Oriented Indices

1. System Average Interruption Frequency Index (SAIFI): The index represents the average number of sustained interruptions experienced by a customer in a unit time (generally one year) [2].

$$\mathrm{SAIFI} = \frac{\text{Total number of Customer Interruptions}}{\text{Total number of Customers served}} = \frac{\sum_i N_i}{N_T} \qquad (2.7)$$

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

2. System Average Interruption Duration Index (SAIDI): The index indicates the average time a customer has an interruption during a time cycle (one year) [2].

$$\mathrm{SAIDI} = \frac{\text{Total Customer Interruptions Durations}}{\text{Total number of Customers served}} = \frac{\sum_i r_i N_i}{N_T} \qquad (2.8)$$

Where ri is the outage time.

3. Customer Average Interruption Duration Index (CAIDI): It is determined by dividing the sum of all customer interruption duration by the number of customers experiencing one or more interruptions over a one year period. The index is the ratio of SAIDI to SAIFI as given in Equations (2.9). It represents the average time taken to restore service to the customers [2].

$$\mathrm{CAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total number of Customer Interruptions}} = \frac{\mathrm{SAIDI}}{\mathrm{SAIFI}} \qquad (2.9)$$

4. Customer Average Interruption Frequency Index (CAIFI): Customer average interruption frequency index (CAIFI) gives the average frequency of sustained interruptions for those customers experiencing interruptions as given in equation (2.10) [2].

$$\mathrm{CAIFI} = \frac{\text{Total number of Customer Interruptions}}{\text{Total number of Customer Interrupted}} = \frac{\sum_i N_i}{C_n} \qquad (2.10)$$

Where Ni is the total number of customer interruption, Cn is the total number of customers facing an interruption during the reporting period.

5. Average Service Availability Index (ASAI): The average service availability index (ASAI) gives the fraction of time the customer has power during the reporting time. Higher ASAI values reflect higher levels of reliability. Equation (2.11) is used to calculate the value of ASAI for a given service area [2].

$$\mathrm{ASAI} = \frac{\text{Customer hours service availability}}{\text{Customer hours service demand}} = \frac{N_t x\ 8760 - \sum_i r_i N_i}{N_t x\ 8760} \qquad (2.11)$$

Where Ni is the total number of customer interruption, Nt is the total number of customers served and ri is the restoration time for each interruption event i.

6. Average Service Unavailability Index (ASUI): This index is the complementary value of the average service availability index (ASAI) [2].

ASUI=1-A

(2.12)

Load or Energy Oriented Indices:

1. Energy Not Supplied Index (ENS): This index represents the total energy not supplied by the system [2].

$$\mathrm{ENS} = \sum_i L_a(i) r_i \qquad (2.13)$$

The unit is (Watt-hour)

Where, L_a(i) is given by:

$$\mathrm{ENS} = \sum_i L_a(i) r_i \qquad (2.14)$$

$$\mathrm{L_a(i) = L_p(i) \, x \, L_F(i)} = \frac{\mathrm{E_d(i)}}{\mathrm{t}} \qquad (2.15)$$

Where, Lp(i) is a peak load demand,

Lf(i) is the load factor and

Ed(i) is the total energy demanded in the period of interest t.

2. Average Energy is Not Supplied (AENS): This index represents the average energy not supplied by the system [2].

$$\mathrm{AENS} = \frac{\text{Total Energy not suplied}}{\text{Total number of Customers served}} = \frac{\sum_i L_a(i) U_i}{\sum_i N_i} \qquad (2.16)$$

The reliability indices of the Awash7 kilo city feeder can be calculated using equations (2.7) to (2.15). The following substation input data's are taken in order to calculate the existing reliability indices.

The utility cost for the utility during the outage is calculated as:

$$\text{Interruption cost} = \text{Unsupplied energy (in kWh) x } 0.4409\,\frac{\text{ETB}}{\text{kWh}}$$

Table 8: Calculated reliability indices of Awash7 kilo city feeder for year 2015/16-2017/18 G.C

Feeder Name	Reliability Indices	2015/16 G.C	2016/17 G.C	2017/18 G.C	Average
Awash7 kilo City Feeder line, L1	SAIFI	381	410	451	414.0
	SAIDI	312	308	339	319.67
	CAIDI	0.819	0.751	0.752	0.772
	ASAI	0.964	0.965	0.961	0.963
	ASUI	0.036	0.035	0.039	0.037
	EENS	763.776	753.984	829.872	782.552
	AENS	0.158	0.156	0.172	0.162

The utility cost for the utility during the outage is calculated as:

$$\text{Interruption cost} = \text{Unsupplied energy (in kWh) x } 0.4409\,\frac{\text{ETB}}{\text{kWh}}$$

Whereas, the tariff 0.4409 is taken from the average of the first block tariffs of residential and commercial customers, which most Ethiopian electricity customers are assumed to be grouped [3]. For Awash7 kilo city feeder (L1), 763.8 MWh energy was unsupplied in the year 2015/16 as indicated in Table 6. Thus, the interruption cost is =763.8 kWh x1000 x0.4409 ETB/ kWh=336,748.8 ETB. Based on the exchange rate of the Commercial Bank of Ethiopia (CBE) on 05-May-2018, (l $= 27.5151 ETB), the interruption cost in USD becomes 12,238.69. By the same procedure the interruption cost for the 3 years, that is, from 2015/16 to 2017/18 G.C is calculated and summarized in Table 9.

Table 9. Summary of estimated interruption cost from 2015/16 to 2017/18 G.C

Years	EENS (MWh)	Interruption Cost (ETB)	Interruption Cost (USD)
2015/2016 G.C	763.776	336,748.83	12,238.69
2016/2017 G.C	753.984	332,431.54	12,081.79
2017/2018 G.C	1358	598,742.2	21,760.5
Max.	1358	598,742.2	21,760.5

Based on the data analysis, the following conclusion can be drawn.

• The power reliability of the Awash7 kilo city feeder line, L1 does not meet the requirements set by the Ethiopian Electric Agency (EEA) and the international reliability indices of other benchmarked countries.

4. Evaluation of Reliability Improvement Techniques

This part presents the explanation of the modeling and simulation of the existing system with different mitigation alternative scenarios to improve the system reliability of the Awash7 kilo city feeder line at a reasonable cost. The simulation focuses on evaluating the impact of using reclosers and reconfiguration of the feeder on the reliability of the system.

Scenario- 1: Using one Recloser: A Recloser R1 has been placed on the major feeder (SL19) as shown in figure 2. Input quantities like power rating of the load, number of customers, feeder length, failure rate and repair rate are entered in the ETAP software as input. The interruption data of years from 2015/16 to 2017/18 G.C are used as a base year.

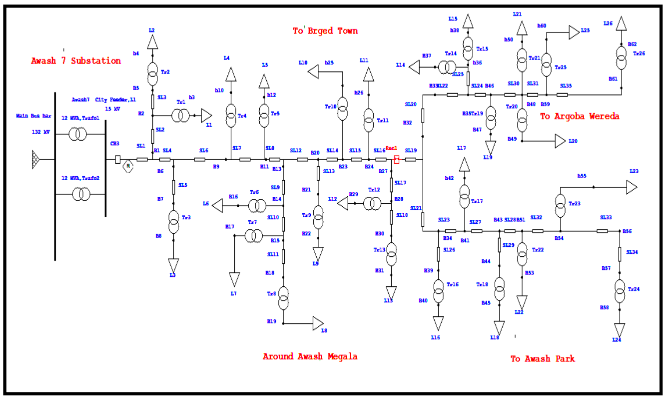

Figure 2. Single line diagram using with one Recloser on major feeder using ETAP Software

Table 10. Simulation result of reliability indices for Scenario-1 using ETAP Software

Project: Power Reliability Improvement | ETAP | Page: 1
Location: Awash7 Kilo, Afar, Ethiopia | 12.6.0H | Date: 26-05-2018
Contract: 0914352253 | SN:
Engineer: Jemal Mohammed Amin | Study Case: Scenario 1; RA | Revision: Base
Filename: Reliability | Config.: Normal

SUMMARY

System Indexes

SAIFI	234.0079 f / customer.yr
SAIDI	229.6079 hr / customer.yr
CAIDI	0.981 hr / customer interruption
ASAI	0.9738 Pu
ASUI	0.02621 Pu
EENS	334.470 MW hr / yr

SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied

Table 10 is the screenshot for the simulation with one Recloser in the feeder. As can be seen from the result of the simulation, the expected number of outages per year has been reduced from 414.0 to 234.0 (43.47% reduction), the annual outage duration has been reduced from 319.7 to 229.6 hours (28.2% reduction) as compared with the existing system through the additional Recloser in the main feeder. In this case, the reliability of Awash7 city feeder is improved by 43.47%, 28.2% and 59.2% for SAIFI, SAIDI and EENS respectively.

Scenario- 2: Using two Reclosers on the feeders: In this particular Scenario, the effect of using two Reclosers on the feeders has been presented in figure 3. One of the two Reclosers has been placed on the major feeder (SL19) as revealed in Scenario-1, and second Recloser (R2) has been placed in the existing Awash7 kilo city to Argoba Wereda line (SL30) which is 15 Km far away from the substation and with serious power reliability problem.

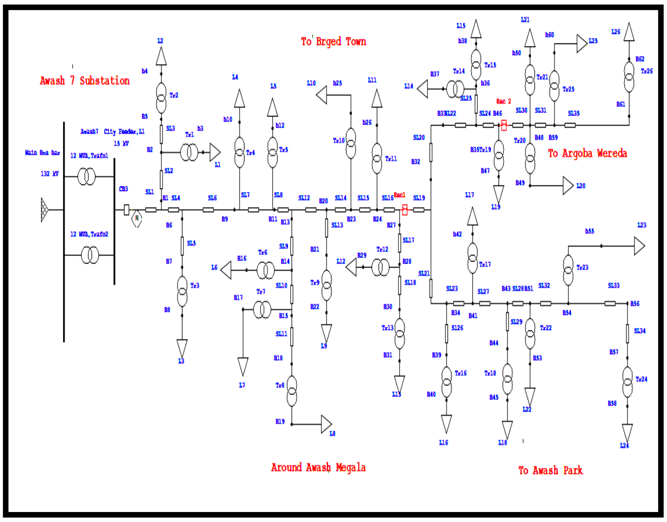

Figure 3: Single line diagram using two Reclosers on Distribution line for Scenario-2 using ETAP Software

Table 11. Simulation result of reliability indices for Scenario-2 using ETAP Software

Project: Power Reliability Improvement
Location: Awash7 Kilo, Afar, Ethiopia
Contract: 0914352253
Engineer: Jemal Mohammed Amin
Filename: Scenario 2

ETAP
12.6.0H

Study Case: **Scenario-2; RA**

Page: 1
Date: 26-05-2018
SN:
Revision: Base
Config.: Normal

SUMMARY

System Indexes

SAIFI 187.0951 f / customer.yr
SAIDI 170.8294 hr / customer.yr
CAIDI 0.913 hr / customer interruption
ASAI 0.9805 Pu
ASUI 0.01950 Pu
EENS 412.657 MW hr / yr
SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENSExpected Energy Not Supplied

Table 11 shows the reliability improvement of using two Reclosers in the feeders. As can be seen from Table 11, the two Reclosers significantly improve the reliability of the system. The expected number of outages per year has been reduced from 414 to 187.0951 (54.81% SAIFI has been improved), and the annual outage duration has been reduced from 319.67 to 170.8294 hours (46.56% SAIDI and 69.6% EENS) has been improved as compared to base years' average.

Scenario-3, System Reconfiguration using Tie-switch: In this Scenario, Awash7 kilo city feeder is reconfigured with diesel generator using normally open tie-switch as shown in figure 4. The tie-switch paves the way to transfer the load from the Awash7 city feeder to the existing diesel generator in case of power outage on the supply of the city. The diesel generator is intended for emergency cases (in case of the power outage of Awash7 city feeder line). The capacity of Awash7 diesel generator substation is assumed to be 15% (5.3/35*100%=15%) of the peak demand of the Awash7 city.

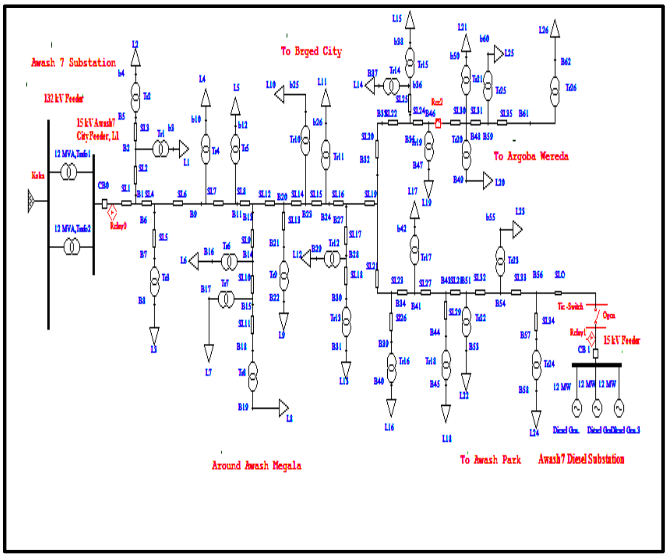

Figure 4. Single line diagram for Scenario -3 using ETAP Software [5]

Table 12. Simulation result of reliability indices for Scenario-3 using ETAP Software

Project: Power Reliability Improvement
Location: Awash7 Kilo, Afar, Ethiopia
Contract: 0914352253
Engineer: Jemal Mohammed Amin
Filename: Scebario-3

ETAP
12.6.0H

Study Case: Scenario-3; RA

Page: 1
Date: 01-06-2018
SN:
Revision: Base
Config. Normal

SUMMARY

System Indexes

SAIFI 115.3246 f / customer.yr
SAIDI 87.5822 hr / customer.yr
CAIDI 0.759 hr / customer interruption
ASAI 0.9900 Pu
ASUI 0.01000 Pu
EENS 212.657 MW hr / yr
SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied

In Scenario-3, as shown clearly in Table 12, the expected number of outages per year is reduced from 414.00 to 115.32 (72.14% SAIFI improvement). And also the annual outage duration has been reduced from 319.67 hours to 87.5822 hours (72.6% SAIDI) and EENS has been improved by 84.35% compared to base-data.

Scenario-4, Using two Recloser, Tie-Switch and Isolated Argoba Woreda line

In Scenario-4, two Recloser and a normally open tie switch, that connects the diesel generator to the load during power outage are included in the model. Recloser (Rec-1) is placed at Awash7 kilo substation city feeder line side and Recloser (Rec2) is placed at the Awash7 diesel generator substation. In this scenario, as clearly shown in Figure 5, the long line running to Argoba woreda has been permanently isolated from the existing city feeder at the exit of the Awash7 kilo city. The two substation circuit breakers of Awash7 kilo substation (CB-0) and Awash7 kilo diesel substation (CB-01) and the normally open tie switch have been coordinated and interlocked together.

In scenario-4, the 15 kV power line which goes to Argoba woreda is isolated from the existing system of Awash7 city feeder line and being replaced with separate 66 kV power line. Isolating Argoba line from Awash7 city feeder line has a significant advantage on increasing the reliability of the feeder on Awash7 city. With the emergence of small villages around and increment of electricity demand, replacing the 15 kV by 66 kV may help to solve the reliability problems in the Argoba woreda. For long distances, the power transfer capability of the 66 kV power line is better than 15 KV power lines. Argoba woreda Line, which consists of currently four transformers (2 with 315 kVA and 2 with 200 kVA ratings) and covers about 15 km outside of Awash7 city, should connect to the Amibara 66 kV feeder line. The Amibara 66 KV line is one of the two outgoing 66 kV lines from Awash7 Kilo substation. Its capacity is 4.0 MW, but the actual peak load of the feeder is 2.0 MW, which is only about 50% of its capacity.

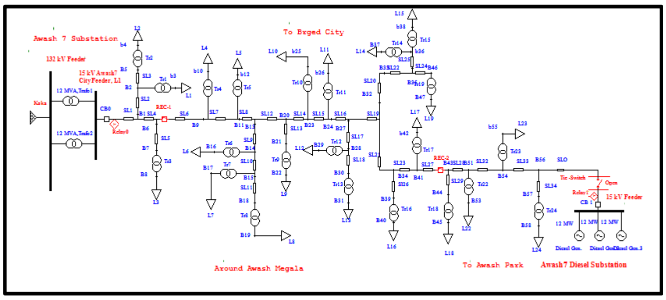

Figure 5. Single line diagram for Scenario-4 using ETAP Software

Table 13. Simulation result of reliability indices for Scenario-4 using ETAP Software

Project: Power Reliability Improvement
ETAP 12.6.0H
Page: 1
Location: Awash7 Kilo, Afar, Ethiopia
Date: 01-06-2018
Contract: 0914352253
SN:
Engineer: Jemal Mohammed Amin
Study Case: Scenario-4, RA
Revision: Base
Filename: Scenario-4
Config.: Normal

SUMMARY

System Indexes

SAIFI 58.0002 f / customer.yr
SAIDI 46.6805 hr / customer.yr
CAIDI 0.805 hr / customer interruption
ASAI 0.9947 Pu
ASUI 0.00533 Pu
EENS 95.946 MW hr / yr

SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied

As can be seen from Table 13, the two Reclosers together with the tie switch helped to enhance significantly the reliability of the system. The expected number of outages per year per customer has been reduced from 414.0 to 58.0 (86% SAIFI has been improved), and the annual outage duration has been reduced from 319.67 to 46.68 hours (86.4% SAIDI and 92.94% EENS) have been improved as compared with the selected base years.

Table 14: Summary of the results of reliability improvement for all Scenarios

Customer Oriented Reliability Indices	**Scenarios**				
	Existing System	Scenario -1	Scenario -2	Scenario -3	Scenario -4
SAIFI (f/customer/yr)	414.0	234.00	187.1	115.32	58.00
SAIDI (hr/customer/yr)	319.67	229.61	170.8	87.58	46.68
CAIDI (hr/customer/Int.)	0.772	0.98	0.913	0.759	0.805
ASAI (Pu)	0.963	0.9738	0.9805	0.9900	0.994
ASUI (Pu)	0.037	0.02621	0.01950	0.0100	0.00533
% Reduction in SAIFI	0	43.47%	54.81%	72.14%	86.0%
% Reduction in SAIDI	0	28.2%	46.56%	72.6%	86.4%

From Table 14, it can be concluded that from the scenarios studied, the most optimal alternative for improving the power reliability of the study area was installing two Reclosers with tie switch at critically selected locations and permanently isolating the long which goes to Argoba woreda from the Awash7 city feeder (Scenario-4). Table 15, indicate that the summary of the result of energy oriented reliability indices.

Table 15: Summary of the result of energy oriented reliability indices

Energy-Oriented Reliability Indices	**Scenarios**				
	Existing System	Scenario-1	Scenario-2	Scenario-3	Scenario-4
EENS (MWhr/yr)	1358.4	554.470	412.657	212.657	95.946
ECOST (USD/yr)	21,766.9	8,884.788	6,612.386	3,407.601	1,537.432
% Reduction in EENS	0	59.18%	69.62%	84.35%	92.94%
% Reduction in ECOST	0	59.18%	69.62%	84.35%	92.94%

5.Conclusions

The study clearly has shown that the reliability of Awash7 kilo city feeder does not meet the requirements set by the Ethiopia Electric Agency (EEA). The average frequency of interruptions is 414.0 interruptions per customer per year (SAIFI) and also the average duration of the interruption is 319.67 hours per customer per year (SAIDI) for the city. This shows that there is huge unsupplied energy due to planned and unplanned outages. The average unsupplied energy is 1,358.4 MWh per year. This results in a loss of around 21,766.89 USD per year due to the power outage of the distribution substation.

By implementing the reclosers and replacing the city line and Argoba line by two separate feeders (Scenario-4) the overall reliability of the Awash7 kilo city feeder is improved by 86%, 85.4% and 92.94% in terms of SAIFI, SAIDI and EENS respectively. The proposed solution has the potential to save around 20,229.47 USD per year only from the unsold energy of the city feeder. The payback period for the investment will become 3 years for the proposed technology for improve the reliability to that level.

Acknowledgement

The author's great fully acknowledge the intake of the case study this research and the research park of Adama Science and Technology University of Ethiopia.

Conflict of interest

The authors declare that there is no conflict of interest for the publication of this article.

Reference

[1] G.C Dumakude, AG Swanson and Stephen, "Evaluation of Smart Technology for the improvement of Reliability in a Power Distribution System," Presented at South Africa Universities Power Engineering Conference (SAUPEC), Johannesburg, South Africa, January 2015.

[2] IEEE Guide for Electric Power Distribution Reliability indices, IEEE Std. 1366TM-2012, 31 May, 2012.

[3] Tesfaye Gebreegziabher, "Study on Smart Grid system for improvement of Power Reliability of the Distribution system," MSc Thesis, Submitted to Addis Ababa University, 173 pp, Addis Ababa, Ethiopia, October 2014.

[4] "Facts in Brief". EEP. Retrieved 4 April 2018.

[5] ETAP Software Version 12.6.

Author Affiliation

Top

[1]*Department of Electrical and Computer Engineering, Samara University, Ethiopia*

[2]*Department of Electrical and Computer Engineering, Adama Science and Technology University, Ethiopia*