ASSESSMENT OF POWER RELIABILITY AND IMPROVEMENT POTENTIAL BY USING SMART RECLOSERS

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ABSTRACT

This paper presents the use of smart reclosers for improving reliability of a distribution system of one of the major cities of Ethiopia. As frequent power interruptions are posing a huge problem to the life of the people and the economy, finding a solution to the problem is very essential. Electric reliability has affected social well being, public health, water supply, communication service, and economic growth in the country. This study presents the assessment result of the power distribution reliability for the city and the possibility of using smart reclosers for improving the urgent and pressing power interruption problem. The smart reclosers are key elements for fault detection, isolation and restoration.The WindMilsoftware has been used to verify the improvement of the reliability indices for the distribution system. The simulation result of the designed model with three reclosers in each feeder and tie-recloser between connected nearby feeders shows that the application of smart reclosers improves the reliability of the distribution network by 75% in comparison with the reliability of currently existing system.

Keywords*: Power Reliability, Power distribution system, Smart grid, WindMil.*

INTRODUCTION

Adama is the second largest city in Ethiopia and is located at 8.54°N 39.27°E at an elevation of 1712 meters, 99 km southeast of Addis Ababa. Adama has been supplied from the national grid. With the growth of the city and the high demand of electricity, providing a reliable power supply becomes a formidable task to the power utility. Frequent power interruptions have posed serious problems to the city and mitigating the problem is very critical to improve the livelihood of the population.

D. Haughton and G. T. Heydt’s paper [9], entitled “Smart Distribution System Design: Automatic Reconfiguration for Improved Reliability” describes the concepts of reliability indices, reliability improvement methods, smart grid concepts and components of smart grid. Another paper, by Greg Rouse and John Kelly, entitled “Electricity Reliability: Problems, Progress and Policy Solutions” [6] discusses smart grid as a solution for the reliability problems of the existing grid. It also discusses different design philosophy of smart grid to accomplish continuous reliability improvement. This paper presents the application of these concepts for assessing practical and pressing problem of power reliability in Ethiopia.

DISTRIBUTION SYSTEM RELIBAILITY ASSESSEMNT

The network topology for Adama city is a radial grid. The primary distribution system takes 132 kV from the transmission line and converts it to 15 kV by using two parallel connected transformers as shown in Fig. 1. 295 distribution transformers are used to further step-down the voltages to customer-level voltage of 380/220 volts at the load points.

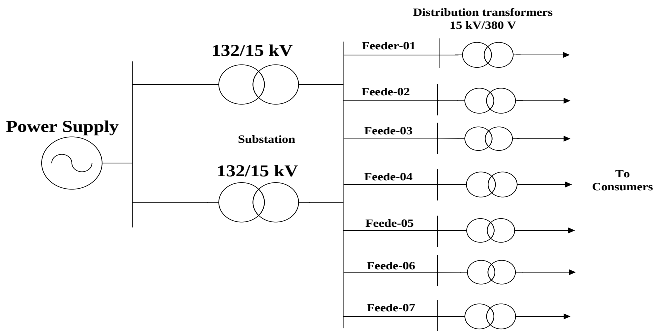

Figure 1 Single-line diagram for the power distribution system at Adama City

The reliability of the power supply is assessed using the known reliability indices. The indices for distribution system analysis include customer-oriented indices and load or energy-oriented indices as defined in IEEE Standard 1366 [1, 2, 3].

A) Customer-Oriented Indices

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

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

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

4) *Customer Average Interruption Duration Index (CAIDI)*: It is the average time needed to restore service to the average customer per sustained interruption.

5) *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.

6) *Average Service Unavailability Index (ASUI):* This index is the complementary value to the average service availability index (ASAI).

B) Load or Energy-Oriented Indices

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

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

3) Average Customer Curtailment Index (ACCI): This index represents the total energy not supplied per affected customer by the system.

4) Average Load Interruption Frequency Index (ALIFI): This factor is analogous to the System Average Interruption Frequency Index (SAIFI) and describes the interruptions on the basis of connected load (kVA) served during the year by the distribution system.

5) Average Load Interruption Duration Index (ALIDI): This factor is analogous to the System Average Interruption Duration Index (SAIDI) and describes the number of hours on average that each kVA of connected load was without service.

The following Adama city substation data are used as input in calculating the reliability indices.

- The number of customers;
- The connected load;
- The duration of the interruption in hours;
- The amount of power (kVA) interrupted; and
- The frequency of interruptions.

The annual average frequency and duration of interruptions for the years from 2009 to 2012 for the site are shown in Table 1 and 2, respectively. Table 1 and 2show sustained interruptions. 70% up to 80% of these faults are estimated to be originally temporary faults and become permanent faults, as the protection system of the distribution system is deficient to clear the temporary faults timely.

Table 1: Frequency of interruptions

Line	**Frequency of Interruption (interruptions/year)**		
	Non-momentary	**Planned**	**Total**
1	49.83	89.17	139.0
2	37.08	55.07	92.2
3	52.75	113.33	166.1
4	66.50	100.10	166.6
5	6.25	10.07	16.3
6	17.08	44.90	62.0
7	14.92	8.80	23.7
Overall System	**244.41**	**421.44**	**665.90**

Table2: Duration of interruptions

Line	**Duration of Interruption (hours/year)**		
	Non-momentary	**Planned**	**Total**
1	55.00	121.49	171.5
2	23.79	35.77	59.6
3	37.72	144.59	182.3
4	44.92	139.44	189.4
5	18.23	21.42	39.6
6	53.18	104.36	157.5
7	73.15	16.90	90.1
Overall System	**305.99**	**583.97**	**890.00**

Table 3shows the annual average energy and power consumption of each feeder. The annual average energy is calculated from recorded data of the years from 2009 to 2012.

Table3: Annual average energy and power supplied by each feeder

Line	Average Energy of Each Feeder		Average Active and Reactive Power	
	Active kWh	Reactive kVArh	P (MW)	Q (MVAr)
1	26,555,550.00	12,373,391.67	3.03	1.41
2	19,374,187.50	10,252,179.17	2.21	1.17
3	31,305,012.50	15,431,933.33	3.57	1.76
4	27,908,837.50	12,369,458.33	3.19	1.41
5	12,085,920.83	3,293,016.67	1.38	0.38
6	18,775,387.50	9,594,225.00	2.14	1.10
7	6,742,687.50	3,600,675.00	0.77	0.41
Overall System	**142,747,583.33**	**66,914,879.17**	**16.29**	**7.64**

The numbers of customers of the city distribution network are shown in Table 4.

Table 4: Number of customers on each feeder

Lines	**Type of Customers**			**Total**
	Residential	**Commercial**	**Industrial**	
1	599	30	-	629
2	392	-	-	392
3	4,949	112	1	5,062
4	7,567	407	15	7,989
5	-	-	1	1
6	3,129	620	11	3,760
7	70	5	-	75
Overall System	**16,706**	**1,174**	**28**	**17,908**

Table 5 and 6 show the average reliability indices of each feeder and the overall system which are calculated using the average frequency and duration of interruptions of the years from 2009 to 20012 by using equations defined in IEEE Standard 1366.

Table 5: Annual average customer-oriented reliability indices of the distribution network

Line	**SAIFI**	**SAIDI**	**CAIFI**	**CAIDI**	**ASAI**	**ASUI**
1	139	171.5	0.22	1.234	0.9804	0.020
2	92.2	59.6	0.24	0.646	0.9932	0.007
3	166.1	182.3	0.03	1.098	0.9792	0.021
4	166.6	189.4	0.02	1.137	0.9784	0.022
5	16.3	39.6	16.30	2.429	0.9955	0.005
6	62	157.5	0.02	2.540	0.9820	0.018
7	23.7	90.1	0.32	3.802	0.9897	0.010
Overall System	**141.3**	**176.8**	**0.04**	**1.251**	**0.9798**	**0.020**

Table 6: Annual average energy-oriented reliability indices of distribution network

Line	**ENS (kWh)**	**AENS**	**ALIFI**	**ALIDI**
1	519,645.00	826.14	139	171.5
2	131,716.00	336.01	92.2	59.6
3	650,811.00	128.57	166.1	182.3
4	604,186.00	75.63	166.6	189.4
5	54,648.00	54,648	16.3	39.6
6	337,050.00	89.64	62	157.5
7	69,377.00	925.03	23.7	90.1
Overall System	**14,498,100**	**809.59**	**118.03**	**145.33**

In general, based on the data collected and the analysis of its results, the following major points can be drawn:

1. The reliability of the power supply in Adamadoes not meet the requirements set by the regulatory body that is Ethiopian Electric Agency (EEA),

2. The reliability of Adama city power supply is not good enough as compared to the international reliability indices of best experienced countries such as Germany,

3. There is high unavailability of electric power in the network, and

4. There is also much loss of unsupplied energy due to sustained interruptions in the present power grid of Adama city.

Table 7 shows the comparison of the most commonly used reliability indices SAIFI and SAIDI of Adama city distribution network with the standards of Ethiopian Electric Agency (EEA) andother countries [5, 6]. Smaller values of the indices indicate better reliability, whereas larger values of the indices indicate poor reliability.

Table 7: Summary of comparison of reliability indices

Country		**SAIFI**	**SAIDI**
United States		1.5	4
Australia		0.9	1.2
France		1.0	1.03
Germany		0.5	0.383
Italy		2.2	0.967
Spain		2.2	1.73
United Kingdom		0.8	1.5
Ethiopia		20	25
Adama City	Line-1	139	171.5
	Line-2	92.2	59.6
	Line-3	166.1	182.3
	Line-4	166.6	189.4
	Line-5	16.3	39.6
	Line-6	62	157.5
	Line-7	23.7	90.1
	Overall System	**141.3**	**176.8**

Comparative values for the other indices other than SAIFI and SAIDI could not be shown, as benchmark values are not available for them. The presentation of these indices helps to illustrate the integrity of the result and give also additional information on energy not supplied, average time needed to restore power supply service, etc.

In order to improve the huge power reliability gap, the use of smart reclosers as an integral part of the distribution automation is proposed and its possible impact on the reliability of the distribution system is simulated using WindMil Enterprise Student Version 8.1.1.717 software.

Reclosers provide automatic fault detection, fault interrupting and restoration capability including communication protocols for remote control. Smart reclosers open when a fault occurs on that part of the main in which they are connected; a timing device, however, enables them to reclose a predetermined number of times for short durations. If a fault is of a temporary nature, the recloser will remain closed and service will be restored; should the fault persist, the recloser will remain open and disconnect that part of the section from the circuit [6, 10].

EVALUATION OF THE RELIABILITY IMPROVEMENT USING THE SMART RECLOSERS

In order to improve the power reliability of the distribution systems, the feeders are sectionalized using reclosers in to smaller sections. In addition to that, respective two nearby feeders (Feeders 1 and Feeder 2, Feeders 3 and Feeder 4, and Feeders 6 and Feeder 7) have been connected through respective tie-reclosers to increase the redundancy of the power supply to the customers. But feeder 5 is not connected to any other feeder, as it is a dedicated line for only one big industry.

As a sample, Fig. 2 shows Line 1 and Line 2 with respective reclosers R_1 and R_3 and a Tie-recloser R_2. Line-1 and Line-2 represent the overhead lines, R_1 and R_3 represent normally closed smart reclosers whereas R_2 represents the normally opened tie-recloser. The reclosersare used to interrupt both load and fault currents.

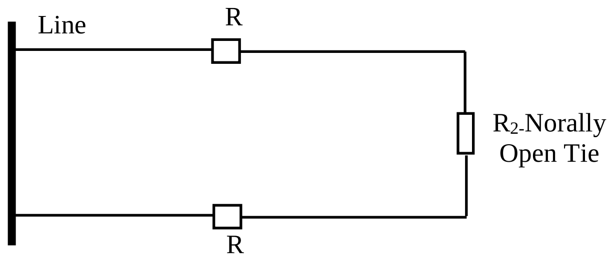

Figure 2 Single line diagram of sectionalized feeders with reclosers

The simulation focuses on evaluating the impact of sectionalized feeders on the power reliability of Adama power distribution system. The study has evaluated sectionalizing of each feeder in to two and three and then four smaller segment of equal customer number.

The result of the first simulation conducted using WindMil Enterprise Student Version 8.1.1.717 software by sectionalizing the feeder into two equal segments is shown in Table 8. As clearly seen, the outage rate has been reduced on the average by 50% compared with the reliability of the actual distribution system.

Note that in Table 8, FRE means Frequency of interruption (interruptions/year) and DUR means Duration of Interruptions (hours/year).

Furthermore the reliability indices have been computed for the sectionalized feeder using the mathematical equations defined in IEEE Standard 1366 and the results have been presented in Tables 9 and 10. The result clearly show50% reliability improvement for the sectionalized feeder compared to the actual feeder layout.

Table 8: Interruptions improvements using smart reclosers

Line	**Present Grid**		**Future Smart Grid** Number of Segments 2	
	FRE	DUR	FRE	DUR
1	139	171.5	69.5	85.75
2	92.2	59.6	46.1	29.8
3	166.1	182.3	83.05	91.15
4	166.6	189.4	83.3	94.7
6	62	157.5	31	78.75
7	23.7	90.1	11.85	45.05

Table 9: Customer-oriented reliability indices for feeder segmented into two parts

Line	**SAIFI**	**SAIDI**	**CAIFI**	**CAIDI**	**ASAI**	**ASUI**
1	69.5	85.75	0.11	1.234	0.9902	0.010
2	46.1	29.8	0.12	0.646	0.9966	0.003
3	83.05	91.15	0.02	1.098	0.9896	0.010
4	83.3	94.7	0.01	1.137	0.9892	0.011
5	16.3	39.6	16.30	2.429	0.9955	0.0045
6	31	78.75	0.01	2.540	0.9910	0.009
7	11.85	45.05	0.16	3.802	0.9949	0.005
System	**70.65**	**88.4**	**0.02**	**1.251**	**0.9899**	**0.0101**

Table 10: Energy-oriented reliability indices for feeder segmented in to two parts

Line	**ENS(kWh)**	**AENS**	**ALIFI**	**ALIDI**
1	259,822.5	413.07	69.5	85.75
2	65,858.0	168.01	46.1	29.8
3	325,405.5	64.28	83.05	91.15
4	302,093.0	37.81	83.3	94.7
5	54,648.00	54,688.00	16.30	39.60
6	168,525.0	44.82	31	78.75
7	34,688.50	462.51	11.85	45.05
System	**7,571,592.0**	**422.81**	**59.71**	**74.34**

Software Simulation of the Relaibility Indices

Figure 3 shows the simulation result of reliability indices-display of WindMil software for afeeder line segmented in to two smaller sections.This simulation result and the calcualted values of the reliability indeces shown in Table 9 and 10, are matching perfectly with the result of the software-simulation shown in Fig. 3, verifying the correctness of the methodology followed.The WindMil software computes the reliability indices based upon the number and distribution of customer and the predicted failure rates of lines wheras the results shown in Table 9 and Table 10 are directly computed by using the equations defeined in IEEE Standard 1366.

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                                                                                   Summary
                          Predictive Reliability Analysis Settings
                                          Source:

Database: C:\MILSOFT\SAMPLEEQDB\STUDENTEQDB\SMART GRID [2].WM\
Title:    Reliability Improvement Study of Adama City Power Supply Using Smart Grid
Case:     Simulation of the Future Power Grid                 12/09/2013  02:32  Page 1
--------------------------------------------------------------------------------------
Reliability Analysis Settings:
     Do Upline Fault Isolation
     Do Downline Fault Isolation
     Do NOT Include Coordination Failure
     If Fix Time is less than   0.00 hours then do not consider switching.
     1 Crew is avaliable to work each outage.
     Time to find trouble is   0.00 hours.
     Travel Time is fixed at   0.00 hours per trip.
     If calculated travel distance is less than   0.00 miles then travel time is set
     to    0.0 hours.
--------------------------------------------------------------------------------------
Source  Name      SAIFI     SAIDI     CAIDI     ASAI      ALIFI     ALIDI    Consumers    KVA
--------------------------------------------------------------------------------------
Line-5          16.3000   39.5927   2.4290   0.9955   16.3000   39.5927       1.0    1380.0
Line-6          31.0000   78.7400   2.5400   0.9910   31.0000   78.7400    3760.0    2140.0
Line-4          83.3000   94.7121   1.1370   0.9892   83.3000   94.7121    7989.0    3190.0
Line-2          46.1000   29.7806   0.6460   0.9966   46.1000   29.7806     392.0    2210.0
Line-3          83.0500   91.1889   1.0980   0.9896   83.0500   91.1889    5062.0    3570.0
Line-1          69.5000   85.7630   1.2340   0.9902   69.5000   85.7630     629.0    3030.0
Line-7          11.8500   45.0537   3.8020   0.9949   11.8500   45.0537      75.0     770.0
--------------------------------------------------------------------------------------
 Total System   70.6463   88.4160   1.2515   0.9899   59.7078   74.3515   17908.0   16290.0
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Figure 3 Simulation result of the designed smart grid model by segmenting each feeder into two parts

By increasing the numbers of segments from one to two and then three, the reliability indices have been further computed. Table 11 and Table 12 show the comparison of the indices for the exiting grid and the three conceptual cases. In Tables 11 and Table 12, Case-1, Case-2 and Case-3 represent the designed distribution system for two, three and four part segmented-feeders. The result clearly shows that the reliability of the system has been improved from 50% to 66.67% and then 75% respectively, by increasing the number of sections from two to three and then to four respectively.

Table 11: Summary system customer-oriented reliability indices

		Customer-Oriented Reliability Indices					
		SAIFI	SAIDI	CAIFI	CAIDI	ASAI	ASUI
Existing Grid		141	177	0.04	1.251	0.9798	0.02
Smart Grid	Case-1	70.7	88.4	0.02	1.251	0.9899	0.01
	Case-2	47.1	58.9	0.01	1.251	0.9933	0.007
	Case-3	35.3	44.2	0.01	1.251	0.995	0.005

Table 12: Summary of system energy-oriented reliability indices

		Energy-Oriented Reliability Indices			
		ENS (kWh)	**AENS**	**ALIFI**	**ALIDI**
Existing Grid		14,498,100	809.59	118	145
Smart Grid	Case-1	7,571,592	422.81	74.34	73.5
	Case-2	5,262,158.70	293.84	50.67	49.6
	Case-3	4,108,663.80	229.43	38.85	37.6

The simulation result shows clearly the significant improvement of power reliability with an increase of the number of feeder segments. However, for proper coordination of series smart reclosers, the maximum number of smart reclosers in a loop network should not exceed eight [4].

CONCLUSION

The average frequency of interruption and average duration of interruption of the city grid have been estimated to be 141 interruptions per customer per year and 177 hours per customer per year respectively. This indicates that there is a high unavailability of electric power in the distribution network. The average unsupplied energy is 14,498,100 kWh per year. This resulted in a revenue loss of about 350,000 USD per year. The revenue loss of commercial and industrial customers as a consequence of power interruption is also huge. For instance, the average revenue loss of small food complex factory is estimated and amounts to 367,000 USD per year.

A distribution system automation using smart-reclosers has been evaluated for implementation on the distribution system. The result of this study shows that significant reliability improvement of 50%, 66% and 75% using three different arrangements of the smart-reclosers.

A cost estimate for upgrading the protection system of the distribution system with a total of 15 reclosers for achieving 50% reliability improvement shows significant cost effectiveness of the proposed solution. The investment cost which includes the cost of the smart reclosers, communication devices and software amounts to 360,500 USD. The average saved revenue by the utility because of 50% reliability improvement is estimated to be 167,500 USD per year. Hence, the payback period is estimated to be about 2 years which clearly indicates the economic viability of the idea.

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