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Analysis of smart grid technology application for power distribution system reliability enhancement: A case study on Bahir Dar power distribution

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ABSTRACT

Reliability improvement of power distribution systems is a pre-request for economic and social development of any country. Currently, there is a rapid growth of industrial, commercial, residential and other service supplying institutions. All of these institutions need reliable power supply. Due to this, utilities must work hard and ensure that the customers are getting a reliable power supply. However, higher power interruption frequency and longer interruption duration are the most serious problem facing Ethiopian power distribution systems and this problem affects the daily activity of customers. In this paper, smart grid technology applications using optimal placement of switching/automating devices, network reconfiguration and rapid power restoration is performed to improve the reliability problem of Bahir Dar power distribution system. Optimal placement of switching/automating devices and network reconfiguration is determined by the Genetic Algorithm optimization technique using mat lab software. The rapid power restoration is carried out by Prim's Algorithm used for constructing the Minimum Spanning Tree in mat lab software. The study is tested at Bata the 34 bus feeder of Bahir Dar distribution system. The existing network is assessed and the reliability indices such as SAIFI, SAIDI, ASAI, CAIDI and EENS are evaluated using ETAP 12.6.0 software.

Introduction

Electric power distribution systems are responsible for supplying electricity from the bulk power systems to the end users, even though, currently most customers are not satisfied because of unreliable electric power supply. Radial distribution systems, aging of distribution infrastructures, operation practices and high exposure to environmental conditions (lightning) are the main problems facing the electric power distribution systems reliability. About 90% of the reliability problems experienced by customers are originated from the electric power distribution systems [1,2]. Such statistics forces to do research on reliability enhancement of the electric power distribution systems.

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In Bahir Dar city, enhancing power distribution reliability is a challenging issue due to many problems in the distribution network: Radial distribution system is exposed to faults, occurrences of supply and demand imbalance, aging of distribution system devices and time taking fault location techniques. Unexpected and un-programmed power outage and long outage duration are affecting electricity supply to customers. So, the reliability problem is still the basic challenge for power utility to meet the customers need.

Power distribution system reliability

Power system reliability has different definitions at different levels. The definition with relation to customers, and widely accepted definition, describes the reliability as uninterrupted power supply at demand [3]. The concept of reliability can be subdivided into the two main aspects of system adequacy and system security [4]. System adequacy relates the ability of the power system to provide aggregate electricity services to their customers at all times within the system operating constraints and System security relates the ability of the power system to withstand the sudden disturbances and respond to dynamic changes in the network.

Smart grid technology

The term smart grid, is referred to a conventional electric power system that has been equipped with advanced technologies for purposes such as reliability improvement, high power quality and stability, ease of control and management, integrating of distributed generators and electricity market operations. Even though, many literatures define it in different ways, the ideas agree with, how the smart it is stable, reliable and efficient system. Momoh and Momoh [6] and Aljahani [11] defines the smart grid as: "The smart grid is an advanced digital two way power flow power system capable of self-healing, and adaptive, resilient, and sustainable, with foresight for prediction under different uncertainties."

Literature review

There are many researches which describes the benefit that can arise from the application of the smart grid technology into the enhancement of the reliability of the power system distribution grids. Many researches have done to improve the reliability of the distribution system by using different methods.

P.V.N.Prasad [2] describes the concept and characteristics of smart grid distribution systems, basic difference between conventional and smart grid distribution systems, functional management and reliability evaluation of smart grid distribution systems. In the paper, the reliability indices of a radial distribution system for (i) conventional (non-automated), (ii) automated and (iii) smart grid configurations are calculated and the results are compared.

Masoud AMOHADI, et al. [7] suggests a new method to determine the optimal number and locations of autorecloser and sectionalizer switches in distribution networks. The costs of AR/S investment, switch maintenance, and undistributed energy as well as reliability coefficients are considered in the objective function. Reliability parameters such as SAIFI, SADI, MAIFI, and ENS are evaluated in the case study system. As a new method, the weights of the reliability parameters are obtained by decision-makers using the Analytical Hierarchy Process (AHP). The optimal size, type, and location of automatic switches are determined by minimizing the objective function using the Particle Swarm Optimization (PSO) algorithm. The paper did not describe about power restoration. Therefore, by including power restoration mechanisms reliability can be improved more and more.

M. Sedighizadeh, et al. [8] propose a multi-objective framework for optimal network reconfiguration with objective functions of minimization of power losses, System Average Interruption Frequency Index(SAIFI), System Average Interruption Duration Index (SAIDI), Average Energy Not Supplied (AENS), and Average Service Unavailability Index (ASUI). The optimization problem is solved by the Imperialist Competitive Algorithm (ICA) as one of the most modern heuristic tools. Since objective functions have different scales, a fuzzy membership is utilized to transform objective functions into a same scale and then to determine the satisfaction level of the afforded solution using the fuzzy fitness. The efficiency of the proposed method is confirmed by testing it on 32-bus and 69-bus distribution test systems. Simulation results demonstrate that the proposed method not only presents intensified exploration ability but also has a better converge rate compared with previous methods.

Based on the above literatures reviewed, smart grid technology application on reliability improvement of distribution systems through optimal network reconfiguration and rapid power restoration by optimal placement of switching/automating devices is presented in this paper. This study clearly shows that, smart grid technology using optimal network reconfiguration and optimal placement of switching device for rapid power restoration is the advanced method in improving the severe power distribution reliability problem facing in Ethiopia, rather than using separate systems such as, optimal placement of switching devices or optimal network reconfiguration studied by many researchers.

Smart grid technology for distribution reliability enhancement

The smart grid uses smart technologies such as, Integrated Electronic Devices (IED) which have great performance in advanced communication and control center. These devices are used to automatically and remotely control the operation of distribution system. In addition to IEDs there are other devices which are used to increase the availability of electric power in distribution systems by minimizing the duration of interruptions. The following are some of the major switching/automating devices used in smart grid technologies for power distribution systems reliability improving.

Sectionalizer Switches: Sectionalizers are automatic switches that are controlled by a built-in logic system [9]. They are manually or remotely controllable load break switches which are installed on a feeder.

Auto reclosers: are smart devices which are used to open circuits during overcurrent conditions. They are also used to isolate loads in a feeder under normal conditions. Like automatic sectionalizer, they are remotely operable with the help of Intelligent Electronic Devices [12,13].

Distribution system reliability indices

Reliability indices are simply statistical aggregations of reliability data of well-defined loads, equipment and power users. The electrical distribution system is basically analyzed based on its reliability and reliability can be evaluated using reliability indices [5]. In distribution systems the reliability indices can be categorized as customer based indices and energy based indices as defined in IEEE Standard 1366 [1,14]. System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI) and Average Service Availability Index (ASAI) are customer based indices whereas; Expected Energy Not Supplied Index (EENS) is energy based index used in this study.

$$\mathrm{SAIFI} = \frac{\text{Total number of customers interrupted}}{\text{Total number of customers served}} = \frac{\sum_{i}^{n} \lambda \mathrm{iNi}}{\mathrm{N}} \tag{3.1}$$

Where, n=total number of load points, λi= average failure rate of each segment i. Ni=number of customers interrupted at i^{th} node and N= total number of customers supplied.

$$\mathrm{SAIDI} = \frac{\text{Total interruption durations}}{\text{Total number of customers served}} = \frac{\sum_{i=1}^{n} \mathrm{Ui\ Ni}}{\mathrm{N}} \tag{3.2}$$

Where, Ui= average annual outage rate of component i.

$$\mathrm{CAIDI} = \frac{\text{Sum of all customers interruption durations}}{\text{Total number of customer interruptions}} = \frac{\mathrm{SAIDI}}{\mathrm{SAIFI}} \tag{3.3}$$

$$ASAI = \frac{\sum_{i=1}^{N} (Ni * 8760) - \sum_{i=1}^{N} (UiNi)}{\sum_{i=1}^{N} (Ni * 8760)} = \frac{8760 - SADI}{8760} \tag{3.4}$$

Distribution reliability improvement methods

In this study, optimal placement of switching devices and optimal network reconfiguration is performed using genetic algorithm optimization technique. In addition rapid power restoration for a fault in certain distribution line segment is done using Prim's algorithm.

Rapid power restoration: During fault clearance or after fault area in a distribution system is isolated; a rapid power restoration is a technique to restore to the rest of distribution network.

Rapid power restoration problem formation: The objective function used to find the minimum spanning tree for rapid power restoration should maximize the power supplied. Thus, the following requirements should be fulfilled.

I Maximize the power supplied to the target point.

$$Maximize\ y = \sum_{i}^{n} L_i X_i \tag{3.5}$$

Where, n = total number of nodes in the feeder. Li = the load at node point i. Xi= binary decision variable for the switch in the line (determines open/close state of the tie and sectionalizer switches).

$$X_i = \begin{cases} 1 & \text{if switch i is closed/on and} \\ 0 & \text{if switch i is open/off} \end{cases}$$

Numbers of switches determine network reconfiguration options. For example, if a power distribution network has two switches, switching vector **X** can have $\mathbf{2^2} = 4$ switching options of **X= [0 0], X= [1 0] X= [0 1] or X= [1 1]**. One of the switches can be closed, both can be closed or both can be open. The network can be configured for various combinations of the switches. For network with 'n' number of switches, the switching options for the network are 2^n. Thus, the values of the vector **X** will be a decision vector with status of switches. Values in the decision vector show states of switches in sequential order of their representation. Index order of decision vector stands for switches from one up to the number of existing switches. The decision vector has the form: **X=[X1 × 2 × 3….. Xn].**

I New power restoration path should not contain loops. The supply method should to be radial.

II Feeder capacity and load point capacity must be within constraint limits. Node points must not be forced to supply above the transformer capacity at that node.
III Restoration problem shall reconnect as maximum number of customer as possible.

Distribution network reconfiguration

Network reconfiguration is the process of operating switches to change the circuit topology so that operating costs and power losses are minimized while satisfying the specified constraints. Genetic algorithm optimization technique is used to determine the optimal network reconfiguration in this study. The reconfiguration is carried out using two basic design methods called customer based and energy serve based. Genetic algorithm optimization technique: is an Artificial Intelligent optimization technique based on natural selection of Darwin‘s theory of evolution. It uses the principle of natural evolution and population genetics to search and arrive at a high quality near optimal solution. Genetic algorithm uses initial population of best fitness and generates new individuals by using genetic operators (reproduction, crossover and mutation) [8,10].

Reproduction: Reproduction is a probabilistic process for selecting two parent strings from the population of strings on different basis. This ensures that the probability of a string to be selected is proportional to its fitness relative to the rest of the population.

Crossover: Crossover is the process of selecting a random posit ion in the parents' strings and swapping the characters either left or right of this point with each other. This random position is called the crossover point. Mostly, characters of two parent chromosomes to the right of a crossover point are swapped each other to carryout crossover operation.

Mutation: Mutation is the process of random modification of a string position by changing "0" to “1” or vice versa, with a small probability. It prevents complete loss of genetic through reproduction and crossover by ensuring that the probability of searching any region in the problem space is never zero [15,16].

Theory of connectivity of distribution network matrix is used to design the optimization problem. The connectivity matrix of feeder is formed from the number of nodes in the feeder. If a feeder has K number of nodes, then connectivity matrix of that feeder will be a K $\times$ K matrix [1]. The digital numbers in the elements of the matrix, represent the nature of connection among the nodes of the feeder. If a node is connected to particular node, value one is set and is a node is not connected with other node the value will be zero. The whole matrix is formulated by looking into the interconnection among the node points in the feeder. The existence of more zeros in the matrix shows more connectivity options for lateral path selection. Connecting these zero valued parts in the matrix, lateral networks that can reconnect large number of customers are chosen as optimal network lines for reconfiguration during outages.

$$B_{ij} = \begin{cases} 1; & \text{i = j connection of a node with itself} \\ 1; & \text{i is connected to j} \\ 0; & \text{I is not connected to j} \end{cases}$$

Where, i and j are nodes in the feeder. i, j=1,2,3……n. n is total number of nodes in the feeder. The connectivity matrix, Bij, is used as initial population for Genetic Algorithm optimization.

Data collection, analysis and methodology

Bahir Dar city electrical loads are supplied from two substations called substation-I with one 66/45/15kV substation and substation-II with one 230/66/15kV and 230/132/15kVsubstation. Bahid Dar town power distribution network has six feeders (Bata, Ghion, Papyrus, Airforce, Sematate and Industry). In this thesis, Bata feeder which has higher annual interruption duration and interruption frequency is selected for study. The single line diagram of Bata feeder distribution network is shown in figure 1 below. The distribution network is radial configuration as shown in the figure and it has a total of thirty-four buses. From the total buses node-1 is taken as a slack bus (reference bus),the other twenty -nine buses/nodes are connected to loads through step-down distribution transformers and the remaining four buses/nodes are used as common coupling nodes. The nodes of the distribution line, that is from 1 to 34 are represented by numbers with red color and the sectionalize lines of the feeder, that is from 1 to 33 are represented by numbers with black color as shown in the single line diagram of Bata feeder. Figure SM3 and SM4 shows frequency and duration of interruptions with faults types of Bata feeder in 2017-2018 G.C. Similarly, Figure SM5 and SM6 shows frequency and duration of interruptions in 2018-2019 G.C. as we can see from the figures operational interruption is maximum and should be improved.

The distribution system of Bata feeder is modeled and the reliability indices of the system are calculated using Electrical Transient Analysis Program (ETAP) software. Figure SM7 shows the complete existing single line diagram and table SM1 shows the existing reliability indices values of the feeder evaluated using ETAP.

Simulation results and discussion

In this paper, network reconfiguration and optimal placement of switching devices are performed using genetic algorithm optimization technique. Rapid power restoration is simulated using Prim's algorithm in matlab software.

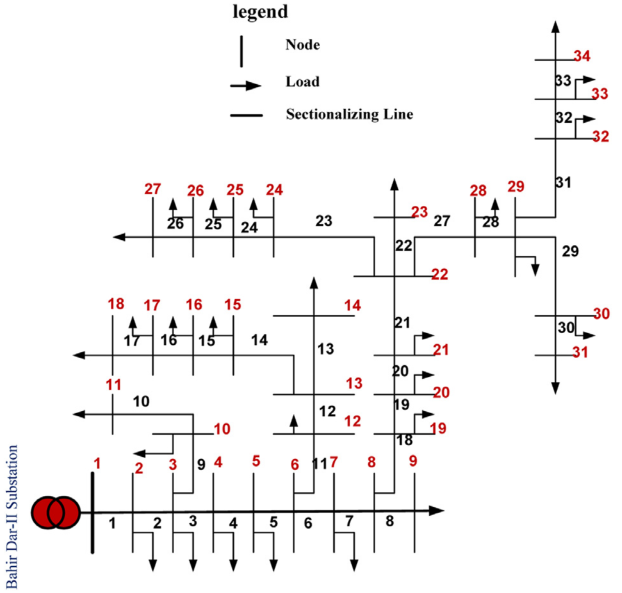

Figure 1. Bata Feeder Single Line Diagram

Power distribution network reconfiguration

In Bahir Dar power distribution, some transformers with higher KVA capacity are supplying few customers and transformers with lower KVA capacity are supplying many numbers of customers. Transformers connected with many customers are working in overload condition and this leads the transformers to become overheated and lastly it may cause failure of the device. As a result, customers connected with the failed transformers will be forced to last in outage. Thus, network reconfiguration design for sharing some loads from overloaded transformers to under loaded transformers is implemented using Genetic Algorithm (GA) optimization technique. Two basic scenarios called maximizing number of customers reconnected and maximizing served energy are designed for improving the existing distribution network reliability. Figure SM2 shows Genetic Algorithm flow chart.

Scenario-One: Network Reconfiguration for Maximizing Supplied Energy: considers maximizing the energy supplied to customers. 34 nodes of the existing feeder are selected for forming 34 × 34 connectivity matrices as initial population. By equation 5.1 as objective function and after performing different genetic operations such as crossover, mutation 8700KVA is obtained with 0.9302 selecting probability, determined by selection function in equation 5.2 from the new five chromosomes reconfiguration shown in table SM2.

$$\text{Maximize } Y = \sum_{i=1}^{n} S_i \tag{5.1}$$

Where, Y= Sum of KVA values in a chromosome (Y≤ installed capacity of the feeder (9.353MVA)). S_i=KVA value of i^{th} node. i= Nodes of the feeder, i=1, 2, 3…..n=34

$$\text{Probability of Selection} = \frac{F_i}{\sum_{i=1}^{n} F_i} \tag{5.2}$$

Where, Fi= fitness value of an individual in row i. n= number of populations=34.

The following individual representation shows node to node connection of the best chromosome determined through generations. The string shows the connection of nodes to other load points.

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1 1 1 1 1 1

In the string representation 1 means the node is connected with the consecutive load point and 0 means the node point is not connected with other node. Figure 2 shows the new network reconfiguration after determining optimal reconfiguration to maximize served energy and improve the reliability of the feeder. Figure SM8 and SM9 shows fitness score of all chromosomes and fitness score of best individuals for maximizing supplied energy respectively.

Scenario-Two: Network Reconfiguration for Maximizing Number of Customers Connected: uses 34 × 34 connectivity matrix and 34 × 3 feeder data matrix as input for mat lab programing. The feeder data matrix contains KVA of each load point in the first column, number of customers connected in each node in second column and line segment length in the

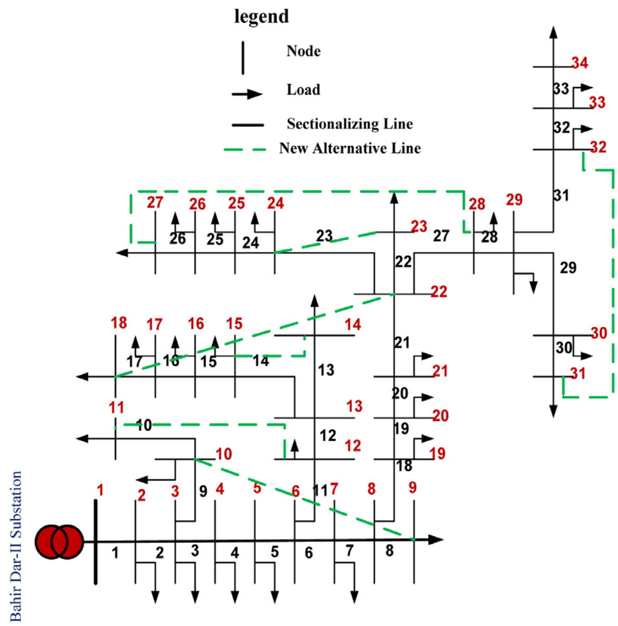

Figure 2. New Network Reconfiguration of Bata Feeder for Maximizing Supplied Energy

third column. Equation 5.3 is the objective function of this network reconfiguration.

$$\text{Maximize } C = \sum_{i=1}^{n} C_i \tag{5.3}$$

Where, C_i=number of customers connected in node i. i= node in feeder

The optimization problem reaches to maximum value with a selection probability of **0.9159** and during new network reconfiguration **5470** customers can be connected to the network as shown in table SM3. Figure SM10 and SM11 shows fitness score of all chromosomes and fitness score of best individuals for maximizing number of customers connected respectively.

The following string representation shows node to node connection of the best chromosome determined through generations for maximizing number of customers connected. By using this chromosome the existing network is reconfigured.

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1 1 1

Fig. 3 shows the new Bata feeder reconfiguration after obtaining optimal value for maximizing customer connection. Figure SM12 shows new configuration with tie switches.

Optimal placement of switching devices

Cost of installation of devices shown in equation 5.4 is the objective function for the problem of improving reliability of distribution systems using reclosing, sectionalizing and automating devices. Figure SM1 shows Genetic Algorithm flow chart to determine optimal placement of switching devices. Thirty four chromosomes are used for representing the line segments for device placement. The line segments are represented by nine binary digits. From these binary digits the first 6 digits are used to represent the line segment number and the last 3 represents the type of device installed in the line. Therefore, 34 × 9 chromosomes represent Bata feeder line segment and the population is stored in mat lab script as M-file. Thus, one chromosome of the population can be represented as:

B1B2B3B4B5B6B7B8B9

Where, B1, B2, B3....B9 binary digit representation.

From the above representation B1-B6 represents line segment of the feeder. B7 shows the whether switching device is installed in the line or not. If B7 is 1 it indicates that new device is installed in the line segment and if it is 0 there is no device installed in the line. B8 represents the whether the installed device is switch or recloser. That is if B8=1 the device installed in the line is recloser and if it is 0 the device is switch. B9 determines if the installed switch has automating device or not. If B9=1 the switch has automating device. For B7=1, if B8=1, it represents new recloser is installed. B9 not required if the installed device is recloser because automating equipment is required to enable remote-control capability of sectionalizing switches. Therefore, in this case, the value of B9 doesn't represent anything. B7=1, B8=0, B9=1 represent the new device placed as sectionalizing switch because automating equipment connected with it. If there is previously an existing switch, only automating equipment is required. B7 =0 shows the status of B8 and B9 has no effect in the process.

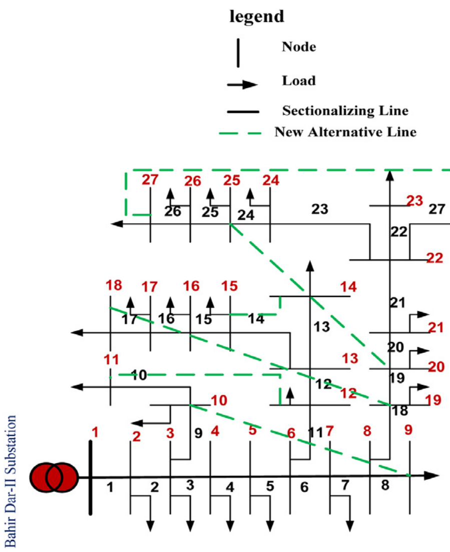

Figure 3. New Network Reconfiguration of Bata Feeder for Maximizing Number of Customer Connected

It means no device is installed. However, if an existing switch is there no matter the value of B7, the value of B8=0, B9=1 implies the existing switch is automated. For getting alternative point of installing switching devices in the distribution line a one point crossover recombination is used.

Parent-1: 0 0 1 0 0 0 1 0 1
Parent-2: 1 0 1 0 0 1 1 0 0
Child-1: 0 0 1 0 0 0 1 0 0
Child-2: 1 0 1 0 0 1 1 0 1

In this way all 34 chromosomes make crossover recombination using a user defined mat lab function.

$$\text{Minimize } Y = 1000 \times Ns + 15000 \times Nr + 5000 \times Na \tag{5.4}$$

Subjected to

SAIFI$\leq$ 0.15 Int./cust./yr.
SAIDI$\leq$ 0.25 hr./cust./yr.

Where, Ns = new switch installed, Nr = new recloser installed, Na = new automating equipment installed, cust. = customer, yr. = year

Nodes/load points that are affected by failure of line segment are grouped into three sections. The first section is from substation to the line segment 6 where first existing switch is installed.

X1= [1 2 3 4 5 6 10 11 12 13 14 15 16 17 18
1 2 3 4 5 9 10 11 12 13 14 15 16 17 0]

The first raw of X1 is the load point of Bata feeder and the second raw is the line segments where any fault happened on the segment affects the load connected to the nodes. As shown in figure 4 switch installed in line segment 6 sectionalizes any fault happened downstream of it. The second sections are when fault happens upstream of L6 and L28 and between these lines. That is when any fault exists between and upstream of these lines, the downstream sections of loads are sectionalized and power supply will continue for up streams.

X2= [7 8 9 19 20 21 22 23 24 25 26 27 28 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28]

First raw of X2 indicates load connected between the two switches and the second raw is the line - segment where fault happens.

The last section is effect of fault on loads connected to downstream of line 28. Loads connected to downstream of this line are affected when fault happen any section of the feeder.

X3= [29 30 31 32 33 34]

Table SM4 shows the line number and the type of switching device placed in the line. Figure SM13 shows Bata feeder single line diagram after placement of new switching devices and SM14 shows fitness score of switching device placement. The reliability improvement of the existing reliability indices values of the feeder after installation of automatic switching device, reclosers and sectionalizing switches is shown in table SM5, SM6 and SM7 respectively.

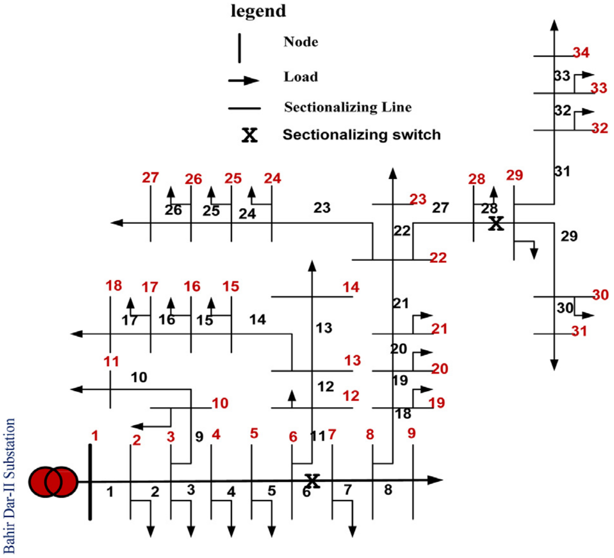

Figure 4. Bata Feeder Single Line Diagram before Installing New Devices

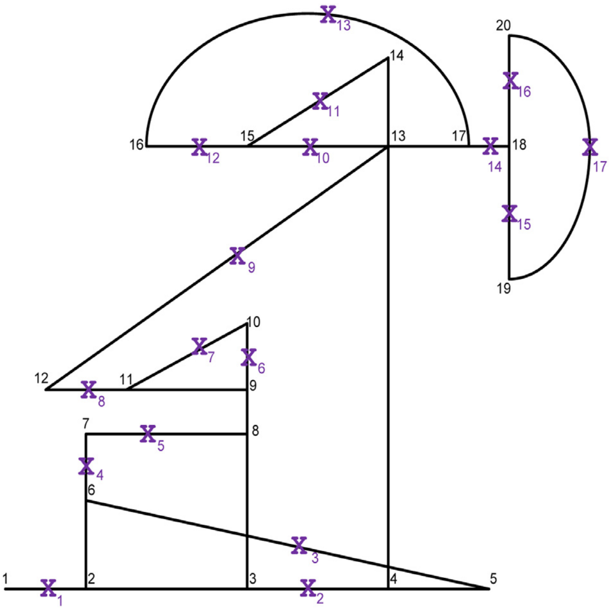

Figure 5. Bata Feeder Undirected Connected Graph with New Installed Switches

Rapid power restoration

For a fault happened in a certain line the prim's algorithm sectionalizes the faulted line and it searches alternative path to continue supplying the remaining healthy loads. Figure 5 shows Bata feeder undirected connected graph with installed switching devices. Equation 3.5 shown is used to maximize the restored power after isolating the faulted line. The decision vector 'X' used in the equation is used to determine the status of switches located in the shortest path built by the algorithm. In this study there are a total of 17 switches and 2^{17}=131072 switching probabilities. Therefore, the decision vector X will have 17 digital strings. That is X=[$x_{1,}$ $x_{2,}$ $x_{3.....}$ x_{17}]. After minimum spanning tree is obtained the switching status (on/off) is set by the operator. From the graph shown below [X_1, X_{16}] are reclosers, X_{10} is automating switch, [X_2, X_4, X_6, X_8, X_{12}, X_{14}, X_{15}] are sectionalizing switches and [X_3, X_5, X_7, X_9, X_{11}, X_{13}, X_{17}] are tie switches. Bata feeder smart grid distribution after optimal placement of switching devices and optimal network reconfiguration is shown in figure SM15 and the undirected connected graph shown in figure 5 is developed from figure SM15.

Table 1
Reliability Improvement of the Feeder by New Distribution Network Reconfiguration

Faulted line	Reliability indices values after restoration with new configuration			
	SAIFI	SAIDI	CAIDI	ASAI
1	–	–	–	–
2	18.2948	34.2939	1.875	0.9961
3	14.0588	26.3535	1.875	0.9970
4	14.5834	27.3368	1.875	0.9969
6	23.6455	44.3240	1.875	0.9949
8	14.3866	26.9681	1.875	0.9969
9	14.8457	27.8285	1.875	0.9968
11	26.8192	50.2732	1.875	0.9943
13	15.8161	29.6477	1.875	0.9966
15	22.3078	41.8165	1.875	0.9952
17	16.0128	30.0164	1.875	0.9966
18	23.4488	43.9553	1.875	0.9950
20	13.3244	24.9768	1.875	0.9971
23	21.5210	40.3415	1.875	0.9954

The prim's algorithm uses one node as reference point and searches appropriate shortest path to supply load points with maximum power restoration after clearing fault point. Table SM8 shows the summary of power restored, number of customers reconnected and the percentage improvement by considering different fault points in the undirected connected graph shown in figure 5. Figure SM16 shows the feeder undirected connected graph and minimum spanning tree for rapid power restoration.

The reliability indices improvement of the feeder due to fault on different line segments is calculated and tabulated in table 1. As we can see from the table the value of CAIDI is not change throughout different faults. This is because of CAIDI is the ratio of SAIDI to SAIFI and this two reliability indices are improved with the same percent.

Conclusion

In this paper, an improvement of the reliability of power distribution systems using smart grid technology applications is performed. Mostly, smart grid applications have been considered and used in generation and transmission systems till recent years. Even if the technology of smart grid is a very broad concept, three applications of smart grid technology are used to improve the reliability of the distribution system in this study. These technologies are optimal placement of switching devices, optimal network reconfiguration and rapid power restoration. Rapid power restoration using optimal placement of switching devices and optimal network reconfiguration minimizes the annual frequency and duration of interruptions of customers. Therefore, using smart grid technology is the better method for enhancing the reliability of Ethiopian power distribution systems.

In this study, a Bata feeder with 34 bus of Bahir Dar power distribution system is considered as case study area for the purpose of analyzing and testing smart grid technology applications. From 2017-2019, interruption data in duration and frequency are collected from EEU and analyzed. Based on the interruption data analyzed, the Bata feeder faces 604 average interruption frequencies per year and 712.425h average interruption per year. The existing distribution network reliability indices (SAIFI, SAIDI, CAIDI and ASAI) are analyzed using ETAP software. From the software analysis, the reliability indices values of SAIFI, SAIDI, CAIDI and ASAI are 131.1454 int/yr, 245.8348 h/yr, 1.875 h/cust.int and 0.9719 pu respectively.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sciaf.2021.e00840.

CRediT authorship contribution statement

Getaye Yeshaneh Sinishaw: Conceptualization, Methodology, Software, Validation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing, Data curation. **Belachew Bantyirga:** Supervision, Resources, Project administration. **Kirubel Abebe:** Resources.

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