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Reliability Assessment and Optimal Placement of Switches in Electric Power Distribution System by Using PSO

Desta Tegegne Asradew

Department of Electrical and Computer Engineering, University of Debre Berhan, Debre Berhan, Ethiopia

Email address:
tegegn.desta439@dbu.edu.et

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Abstract: Reliable electric power supply is a pillar perquisite for technological, social, political and economic development of any nation. Modernization and developing in every aspect without reliable electric power supply is un predictable. Here in our country Ethiopian has a serious power interruption problem because of unwanted very high outage frequency and longtime system restoration. Due to this, utilities must strive and ensure that the customer's reliability requirements are met and the regulators requirements satisfied at the lowest possible cost. In this paper the reliability assessment is done on both 15kV Ankober electric power system to assess the performance of the existing system and also predictive reliability improvement for the future system considering distribution system reconfiguration (optimal coordination of switches) and by de. For predictive reliability and power quality improvement binary particle swarm optimization has been applied which delivers optimal number and optimal placement of switches on the selected The placement of switches in strategic places reduces the outage time in case of interruption, and improves the reliability of the network. There are many measures to assess the reliability of distribution network. The most common measures are expected outage cost (ECOST), system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), in this paper the focus of reliability measure is the impact of energy not supplied and its cost. To solve the problem of number of sectionalizes switches allocation a binary particle swarm optimization (BPSO) method has been selected. To illustrate the performance a proposed algorithm, an actual 15kV Ankober feeder of Debre Berhan distribution system was selected as the test system. As the result the optimal number and placement of sectionalizes switches changed from S8, S18, S22, and S26 to [S13, S19, S21, S26, S31, S33, S35, S39, S42] and the existing energy not supplied (EENS) can be improved 391.705 kW to 306.4322 kW.

Keywords: Distribution System Reliabity Assessment, Sectionalizer Switches, PSO

1. Introduction

Distribution system reliability evaluation is a measure of continuity and quality of power supply to the consumers, which mainly depends on interruption profile, based on system topology and component reliability data. To improve customer reliability problems of power distribution system different methods can be used. As different researchers agreed to perform distribution system reliability assessment different approaches and techniques can be used. Two approaches to reliability evaluation of distribution systems are normally used, namely, historical assessment and predictive assessment. Historical distribution reliability is described as measuring the past performance of a system, it generally summarizes discrete interruption events occurring at specific locations over specific time periods, whereas predictive assessment estimates the future behavior of systems by combining component failure rates and repair times with system configurations [1, 2]. The definition of reliability is very vast and covers all aspects of supplying reliable power to consumers. Major subdivisions of power system reliability are system adequacy and system security as shown in Figure 1, the term adequacy relates to the existence of sufficient facilities within the system to satisfy the consumers load demand and system operational constraints. This includes the facilities required to generate sufficient energy and the associated transmission and distribution facilities to supply energy to the consumers. Thus, adequacy majorly deals with static conditions and not the dynamic and transients of power system. Security is associated with system dynamics and disturbances in the system. Security is therefore related to the response of the system to perturbations it is subjected to. Reliability can be classified mainly into two aspects: adequacy and security as shown in figure 1, adequacy is the static evaluation of a system's ability to supply the load. Thus, adequacy majorly deals with static conditions and not the dynamic and transients of power system. Security is associated with system dynamics and disturbances in the system. Security is therefore related with how the system responds to disturbances it is subjected to. Power reliability is a very wide concept that encompasses all aspects of a system's capacity to meet customer demands.

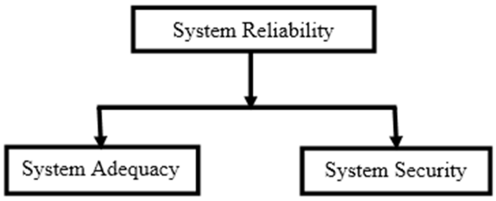

Figure 1. *System Reliability Subdivision.*

2. Statement of the Problem

Electricity networks are a critical part of our energy infrastructure and power utility company has the responsibility to ensure that they are developed consistently and in a manner that meets future demands of society and customers. The process of network development should be directed towards a long term vision aligned with the expectations of the present and future customers.

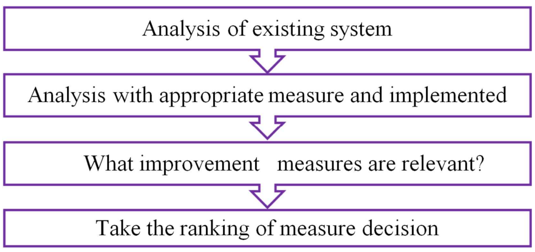

Figure 2. *Identification of problems and analysis of measures.*

The main problem facing by electric power utilities in developing countries today is that the power demand is increasingly rapidly where supply growth is constrained by scarce resources, environmental problems and other societal concerns [3, 1, 4]. This has resulted in a need for more extensive justifications of the new system facilities, and improvements in production and use of electricity. In the analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system, hence, improving distribution reliability is the key to improve customer reliability. Intelligent placement of protection devices, sectionalizer and switches in the distribution Feeders has significant impact in reliability improvement and this will be further assessed along with the outage mitigation techniques for the distribution system in Debre Berhan distribution substation. Therefore, in this paper, the distribution system of Debre –Berhan town has been considered, particularly focusing on Debre-Berhan district's distribution system. Figure 2 illustrates how the work is carried out during the study of this paper.

2.1. Reliability Cost/Worth

The other main relevant issue for the analysis of quality of power supply is the fact that the level of system reliability is interrelated with the economic aspects. Reliability costs are used for rave reviews and request for rate increase. The economic analysis of system reliability can be a very useful planning tool in determining the capital expenditures required to improve the real value of additional (and incremental) investment in to the system. It is necessary to combine the reliability criteria with certain cost considerations. Reliability worth is the benefit derived by the utility, consumer and society because of higher reliability due to more investment in system.

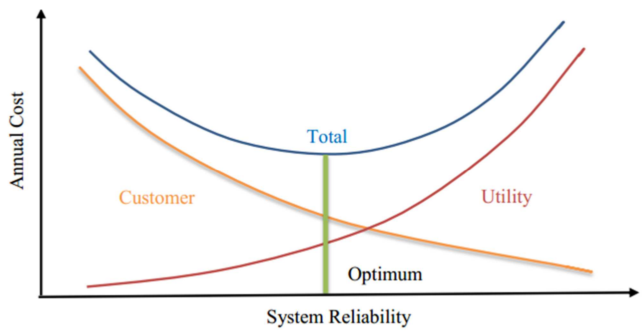

Figure 3. *Costs as a Function of System Reliability.*

Reliability cost/worth assessment provides the opportunity to incorporate cost analysis and quantitative reliability assessment into a common structured framework. Reliability cost refers to the investment needed to achieve a certain level of adequacy [3, 4]. Reliability worth is the benefit derived by the utility, consumer and society because of higher reliability due to more investment in system. As shown in Figure 3, the utility cost, i.e. investment cost, maintenance cost and operating cost, increases while the socio-economic customer interruption cost decreases with increase in the level of service reliability. The total cost is the sum of the two curves. The optimum level of reliability occurs at the point of lowest total cost. In a reliability cost/worth analysis, the annual expected customer interruption costs are added to the predicted annual capital and operating costs to obtain a total cost evaluation. Possible alternative configurations are examined to minimize the total cost and to identify the most appropriate configuration. The reliability cost/worth concept can be illustrated using Figure 3. This figure also shows that the system cost will generally increase with higher investment cost in equipment and facilities which provide higher reliability [4, 5]. According to figure 3, when the level of service reliability rises, the utility costs i.e., the costs associated with investments, maintenance and operations, increases while the cost associated with socio-economic consumer interruptions decreases. The sum of the two curves represents the overall cost. The optimum level of reliability occurs at the point of lowest total cost. In a reliability cost/worth study, the annual anticipated costs associated with customer interruption are added to the anticipated annual capital and operational costs to get a total cost assessment.

2.2. Component Reliability

Based on experience and failure data for a certain component, its characteristics in terms of reliability can be modelled [6, 7]. To describe the reliability of a component, there are a number of mathematical functions that can be used. The most important are defined as: The *distribution function* for the continuous one-dimensional random variable is defined by:

$$F_X(x) = P(X<x), -\infty<x<\infty \quad (1)$$

The distribution function is evaluated by integration as follows:

$$F_X = \int_{-\infty}^{X} FX(t).dt \quad (2)$$

If the function $F_X(x)$ exists and applies to the function, then *X* is a continuous random variable of the distribution. The function $F_X(x)$ is then called the density function of *X*.

The simultaneous optimization of both protection device and DGs' location may be performed in the planning stage of the feeder design [2, 3].

$$\text{SAIFI} = \frac{\text{Total Number of Customer Interruption}}{\text{Total Number of Customers Served}} = \frac{\Sigma\,(\lambda_i\,N_i)}{\Sigma\,N_i} \quad (3)$$

$$\text{SAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customers}} \quad (4)$$

$$\text{CAIDI} = \frac{\text{Sumof Customer Interruption Durations}}{\text{Total Number of Customers Interruptions}} = \frac{\text{SAIDI}}{\text{SAIFI}} \quad (5)$$

$$\text{EENS} = \sum L_i * U_i \quad (6)$$

3. System Design and Analysis

Reliability indices are a statistical aggregation of reliability data for a well-designed set of loads, components [5, 6]. The overall system design is presented as shown in Figure 4. The first step in reliability study of distribution system is the reliability assessment of the existing system which is known as historical reliability assessment. The predictive reliability is then followed to predict the changes in reliability measures after a change in system configuration or any improvement strategy is planned to be implemented as shown in figure 4 below.

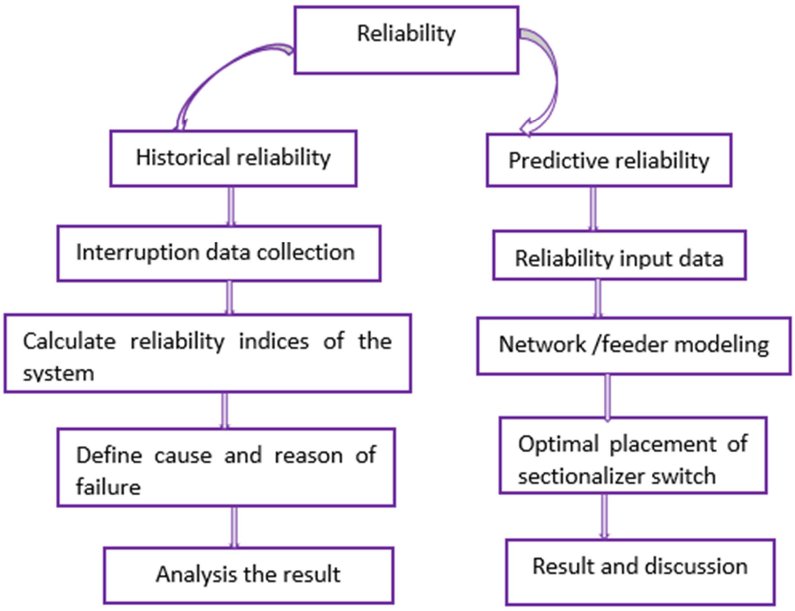

Figure 4. *Overall System Design.*

4. Overview of Debre-Berhan Town Distribution Substation

The town of Debre Berhan is located at 09041'N latitude and 39031'E longitude, 130 km from Addis Ababa on the main road Addis Ababa- Dessie -Mekele road in the Amhara region, north shoa administrative zone, and district of Debre Berhan Zuria. Debre Berhan is situated on a plateau in the central Ethiopia highland system about 15km west of the great rift escarpment at an average elevation of between 2800 and 2845m at sea level.

The Debre-Berhan town Distribution system has started electrifying since 1969 in G.C from mini hydropower of Abogedam which is found at the north of river versa and from diesel source. Currently in Debre Berhan town distribution systems there are 15,266 customers from these 161 of them are higher industry customers (which use active and reactive-meters), 1940 of them are commercial customers and 13,165 customers are residential. These loads mainly supplied from a single substation. This substation has seven (7) radially configured feeders are engaged to distribute primary voltage level power to the distribution transformer and industrial loads as shown in figure 5. The feeders in the town are configured radially with voltage level of 33 kV and 15 kV primary feeders. 33 kV feeders have three outgoing lines, these are: Sheno, Enwary and Aliu Amba and 15 kV feeders have four outgoing lines such as blanket factory, Ankober, Mendida and Sheno. These feeders are connected to a total of more than 200 distribution transformers; most of them are pole mounted, for further step down to 380 V three-phase and 220 V single-phase for secondary distribution purpose.

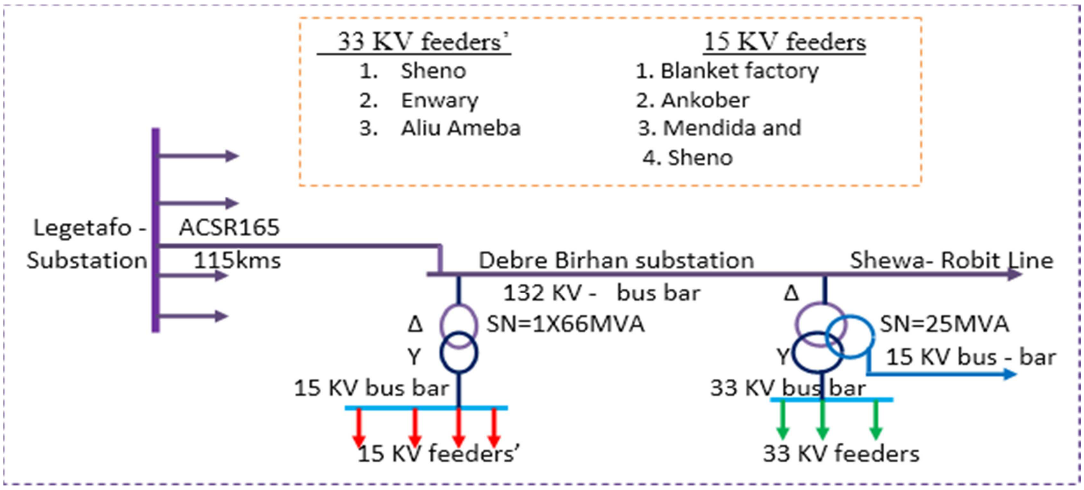

Figure 5. *Single line diagram of Debre –Berhan substation with two distribution transformers.*

5. Modeling of Debre Berhan Distribution System with ETAP Software

Modeling: ETAP software is a powerful electrical engineering analysis and management tools established at a world leader in power system design analysis and monitoring. The Electrical Transient Analyzer Program (ETAP) is used as the analytical tool [7, 8]. To model the system with ETAP software Ankober (15kV) feeder is selected for modeling. To calculate the failure rate of each component in the feeder for active failure rate and passive failure rate the fault rate data and its cause is required. In order to model the feeder, the cumulative load, sample feeder line, for each type of transformer one sample and other component and devices are modeled. The reliability analysis and assessment using ETAP software for radial and looped systems is a very efficient analytical algorithm [9, 10].

6. Methodology

Binary Particle Swarm Optimization (BPSO)

Kennedy and Eberhart proposed a discrete binary version of PSO for binary problems [4]. In their model a particle will decide on "yes" or " no", "true" or "false", "include" or "not to include" etc. also this binary values can be a representation of a real value in binary search space. In the binary PSO, the particle's personal best and global best is updated as in real-valued version. The major difference between binary PSO with real-valued version is that velocities of the particles are rather defined in terms of probabilities that a bit will change to one [5, 6]. Using this definition a velocity must be restricted within the range [4, 11]. So a map is introduced to map all real valued numbers of velocity to the range as shown in the figure 3. The normalization function used here is a sigmoid function as:

$$vij(t) = sigvij(t) = \frac{1}{1+e^{-vij(t)}} \tag{7}$$

It is assumed that our search space is d-dimensional and the ith particle of swarm can be represented by a d-dimensional position vector Xi = (Xi1, Xi2,… Xid). The velocity of the particle is denoted by Vi = (Vi1, Vi2,…Vid). Also consider best visited position for the particle is Pi,best = (Pi1, Pi2,… Pid) also the best position explored so far is Pg, best= (Pg1, Pg2,… Pgd). Therefore, the position of particle and its velocity is being updated as follows:

$$Vi(t+1)=wVi(t) +c1r1 (Pl,best-X1) +c2r2 (Pg,best-X1 \tag{8}$$

$$Xi (t+1) = Xi (t) + Vi(t) \tag{9}$$

Where c1 and c2 are positive acceleration constant, r1 and r2 are random variables with uniform distribution between 0 and. This equation is the inertia weight which shows the effect of the previous velocity vector on the new vector [12, 13]. An upper bound is placed on the velocity in all dimensions. This limitation prevents the particle from moving to rapidly from one region in search space to another [2, 14].

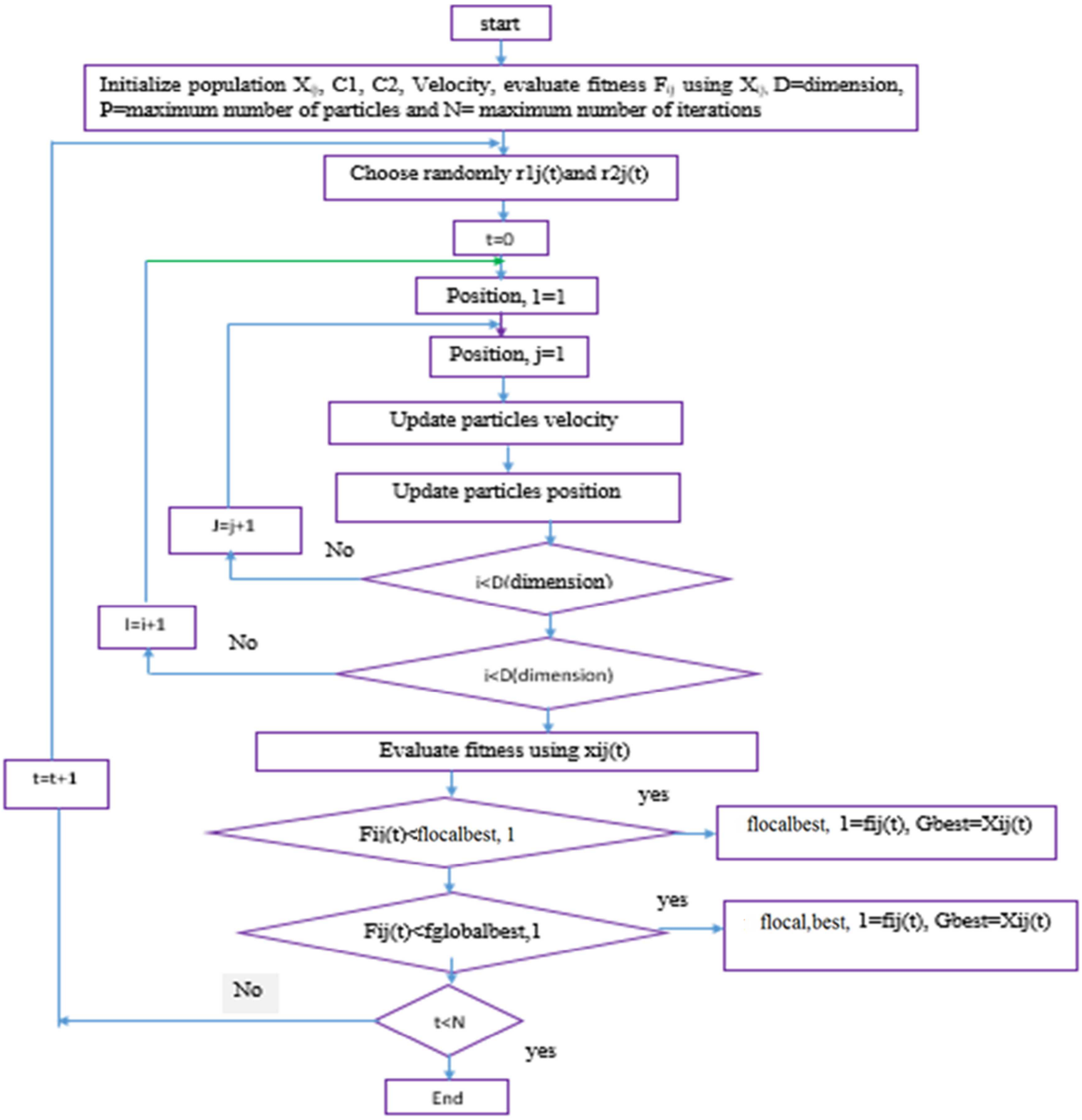

Figure 6. *The Framework of PSO Algorithm.*

Given the data for a specific electric power distribution system, the program calculates the load point indices and system indices as shown in Figure 7, it shows the function of the program which givens the relation between the components, the reliability data for the components, customer and power data the results are presented. It is clearly illustrated that the simulation result was simulated as it has already shown in this figure for all reliability indices of the Ankober feeder of Debre Berhan power distribution system.

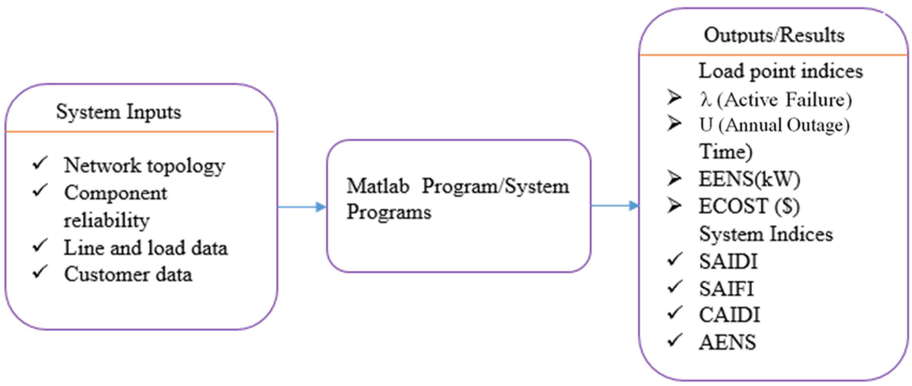

Figure 7. *System Structure for Simulation.*

7. Modeling of the Ankober Feeder of Debre Berhan Distribution System with ETAP Software

The distribution system reliability analysis employs a new analytical algorithm to assess the reliability indices of mixed radial and meshed distribution systems [8, 11].

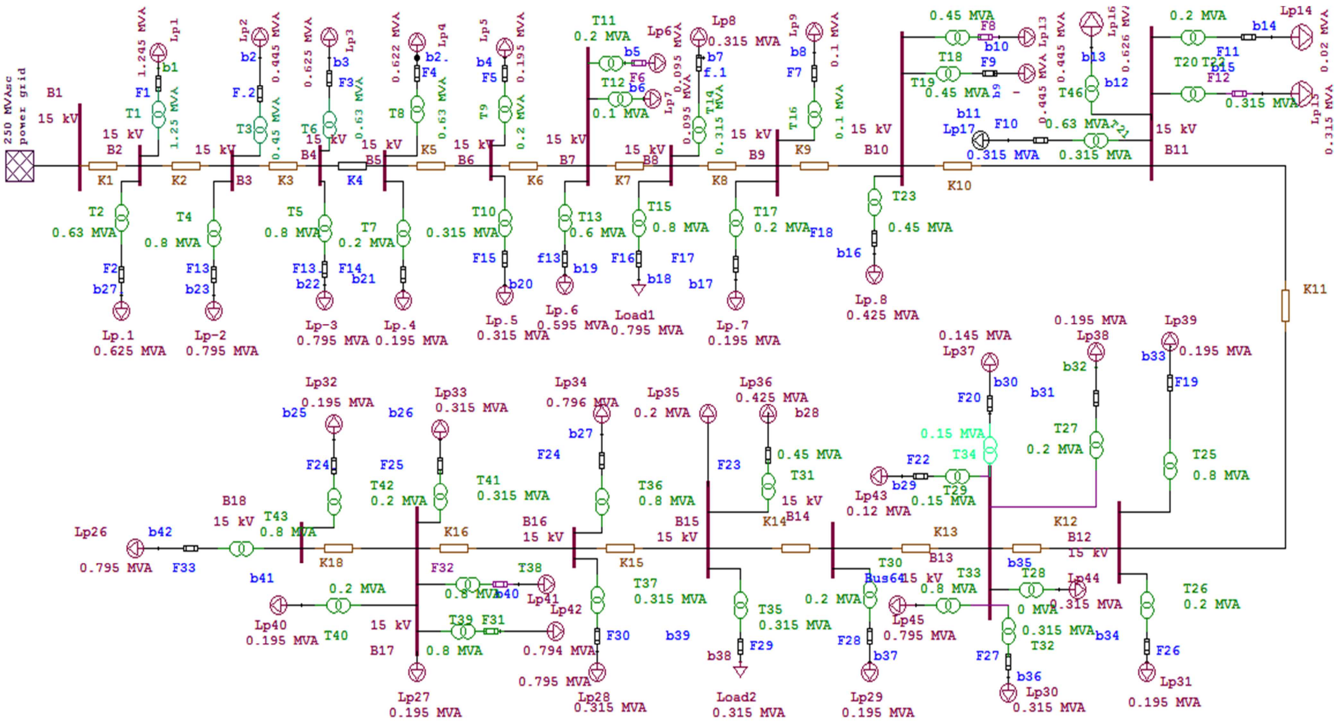

Figure 8. *Ankober Feeder Model using ETAP Software.*

8. Simulation Results

8.1. ETAP Software Result

Figure 9, illustrated that the simulation result of exciting system of Ankober feeder which was modeling using electrical transient analyzer program (ETAP) software with only four sectionalizers switches. This feeder must be further studied to place the sectionalizer switches on optimal placement and optimal number of switches using binary particle optimization particles (BPSO).

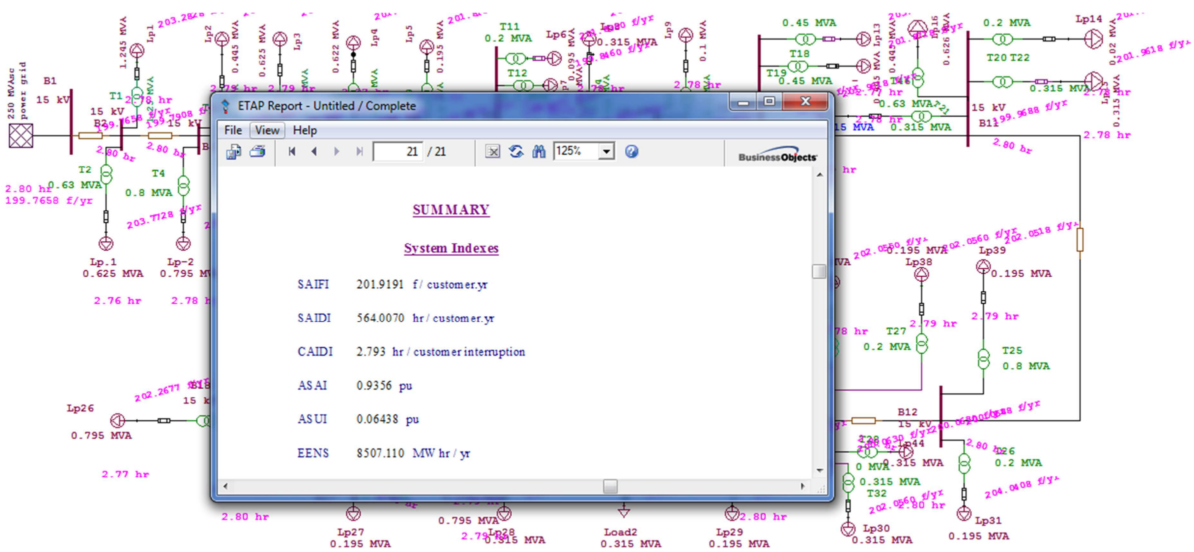

Figure 9. *Simulation Result of Ankober Feeder Using ETAP Software.*

ETAP software generated as indicated in figure 10, the plot that indicated the ranking order of the components contributing to different outages. As shown in Figure 12 above the components are shown their ranking order power grid, F15, F14, K14, and CB1etc indicated that the ranking of order of components which are contributing to the total expected energy not supplied. This ranking order of the component is used to take the measure of actions (EENS). Figure 12 shows SW2, T26, line 7, SW1 and CB1 are components which were contributing for EENS due to an expected frequent power interruption.

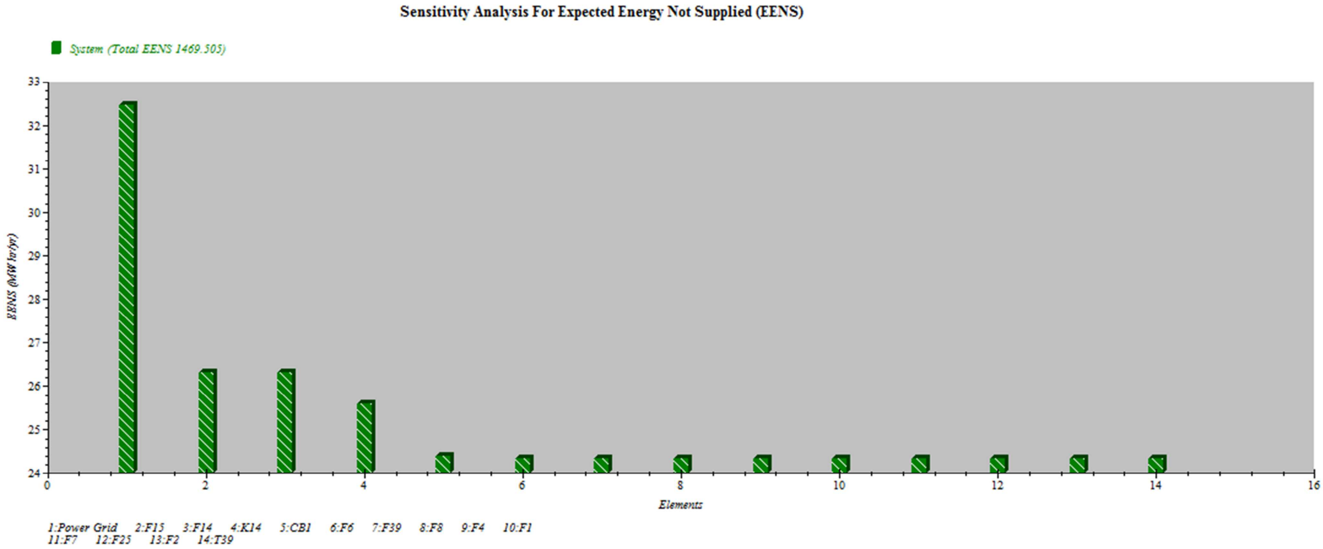

Figure 10. *EENS ranking order of the component of Ankober feeder.*

8.2. System Simulation with Matlab

The effectiveness of the proposed methodology is tested on a 45- bus radial distribution system. The possible location of switches is shown in Figure-7. Each switch can either open or close. The optimal status (open or close) of the switches is determined by using computing techniques of BPSO. For simplified analysis, it is assumed that the reconfigured system should be radial, since the radially of the system is taken as a necessary constraint.

The practical distribution system used to test the optimal placement of sectionalize switches algorithm is Ankober feeder, this is shown in Figure -8. It consists of a feeder with 88 transmission line sections, 41 load points and 47 possible switch locations (S1-S47). The proposed method (PSO) is implemented using MATLAB 8.1.0 (R2016a). By running this program, the optimal solution (optimal number and position) is obtained. The MATLAB program for the proposed algorithm incorporates two main subprograms. The first is used to solve the total cost of the system, and reliability indices. The total cost and reliability indices program consists of:

A file (Rinptdata.m) defines the system failure rate, repair/switching time data, A file (Tinptdata.m) defines the topology data, A file (equifeder.m) defines the equivalent failure rate and repair/switching time of sub feeders.

1) A file (fcost.m) evaluates the total cost for a given set of switches. The second subprogram, which is coded in this thesis, is dedicated for applying the proposed optimization algorithm in selecting the optimal number and position of the sectionalize switches in the distribution network. The developed optimization program consists of: 2) a file (obf.m) to call the cost subprogram (fcost.m) to determine the objective function, 3) a file (BPSO.m) to find the optimal number and position of the switches to evaluate the total cost of the system the equations described in network equivalent method, The PSO parameters used during the simulation study for the optimal placement of sectionalize switches of the distribution network are summarized in Tables 1&2.

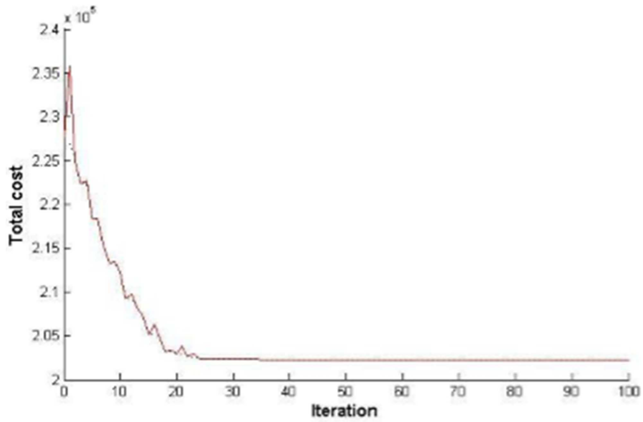

Figure 11. *Convergence Characteristics Result of PSO.*

The convergence characteristic of PSO algorithm is shown in Figure 11. From the figure it can be observed that the PSO algorithm has good convergence characteristic.

Table 1. *System Cost and Sectionalizers Switch Location Result Using PSO Optimization.*

Number of sectionalizer Switches	Cost of EENS [Birr]	Switch Cost [Birr]	Total Cost [Birr]	Switch locations
0	317,500	0	317,500	no switch
4 (Existing)	227,190	10,876	238,066	S8 S18 S22 S26
47	164,320	127,800	292,120	S1 to S47
9 (Optimal)	177,730	24,472	202,202	S13 S19 S21 S26 S31 S33 S35 S39 S42

The number of switches and the locations were determined using the PSO optimization technique and the results are presented below. The algorithms were applied in the test system considering four case studies as shown in Table 1:

Case 1: When no sectionalizer switches are allocated.

Case 2: Allocation of 47 sectionalizer switches in the distribution network, Case 3: Original system with 4 sectionalizer switches (base case).

Case 4: Allocation of 9 (optimal) sectionalizer switches in the distribution network, without considering the switches in the original system as shown in the above table.

Figure 10 and Figure 11 illustrated the topology of the Ankober feeder at the initial and optimal configuration respectively. The number of sectionalize switches for Ankober feeder before optimization (in the initial configuration) were four switches with position set of (8 18 22 26) of the line segments. After optimization (in the optimal configuration) the number of sectionalize switches are changed from four switches to nine switches with position set of (13 19 21 31 33 35 39 42) of the line segments. From Table 2, it is clear that switch cost increases as the number of switch increases but cost of EENS decreases as the number of switch increases. Compared with the original switch set the cost of EENS decreases by 27.67% from 227,190 Birr/yr to 177,730 Birr/y. The switch investment cost increases by 55.56% from 10,876 Birr/yr to 24,472 Birr/yr. The total system cost decreases by 15.1% from 238,066 Ethiopian Birr/yr. to 202,202 Ethiopian Birr/yr. Thus shows that more switches are required in Ankober Feeder as shown in figure 12 and table 2.

From Table 2, it is clear that switch cost increases as the number of switch increases but cost of EENS decreases as the number of switch increases. Compared with the original switch set the cost of EENS decreases by 27.67% from 227,190 Birr/yr to 177,730 Birr/y. The switch investment cost increases by 55.56% from 10,876 Birr/yr to 24,472 Birr/yr.

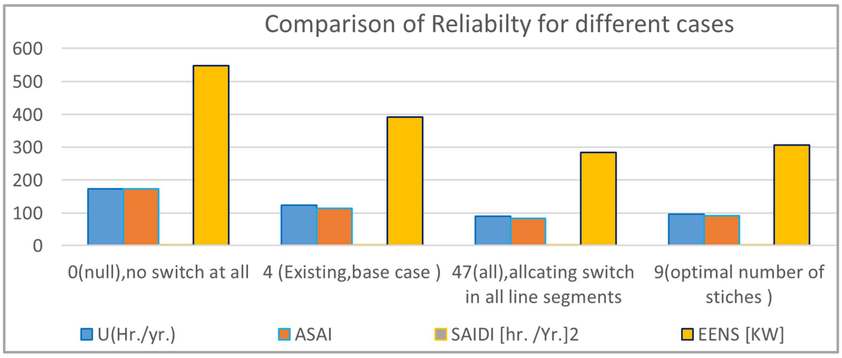

Figure 12. *Shows the simulation result of the Ankober feeder at the no sectionalizer case, initial configuration case, optimal configuration case and all section sectionalizer switches configuration cases.*

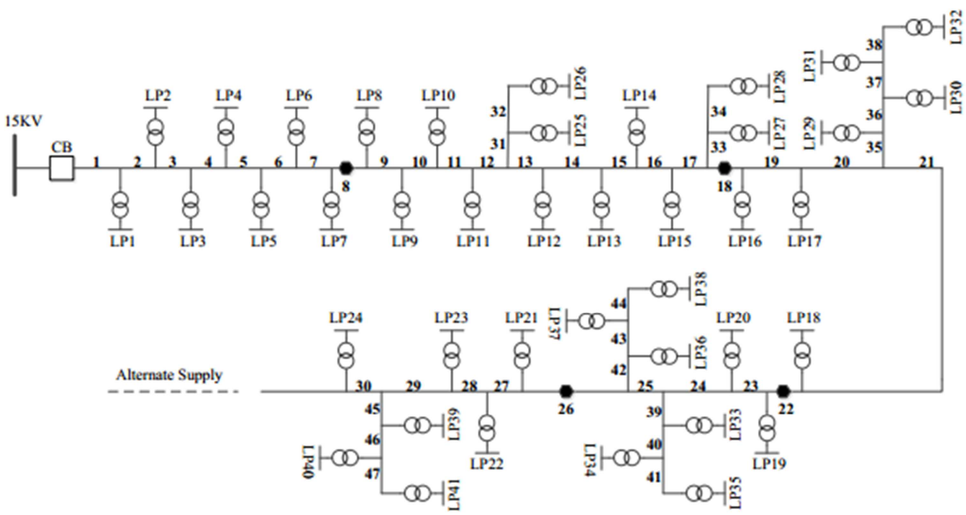

Figure 13. *Reliability model of Ankober 15kV feeder before optimization.*

Table 2. *Difference in Value of Reliability Indices.*

Reliability Indices	**Number of Switches**			
	0 (null), if there is no switch at all	**4 (Existing), base case with only 4 switches**	**47 (all), install if from all line segment**	**9 (optimal placement of sectionalizer switches)**
SAIDI [hr. /Yr.]	173.338	124.011	89.69	97.02
U [hr. /yr.]	173.288	114.845	83.347	92.033
ASAI	0.9802	0.9858	0.9898	0.9889
EENS [KW]	547.42	391.705	283.30	306.4322
TCOST [Birr]	317,500	238066	292120	202,202

Figure 13, show that the initial configuration of Ankober feeder in Debre Berhan distribution substation which is drawn using Visio and the optimal configuration also indicated on figure 14 below.

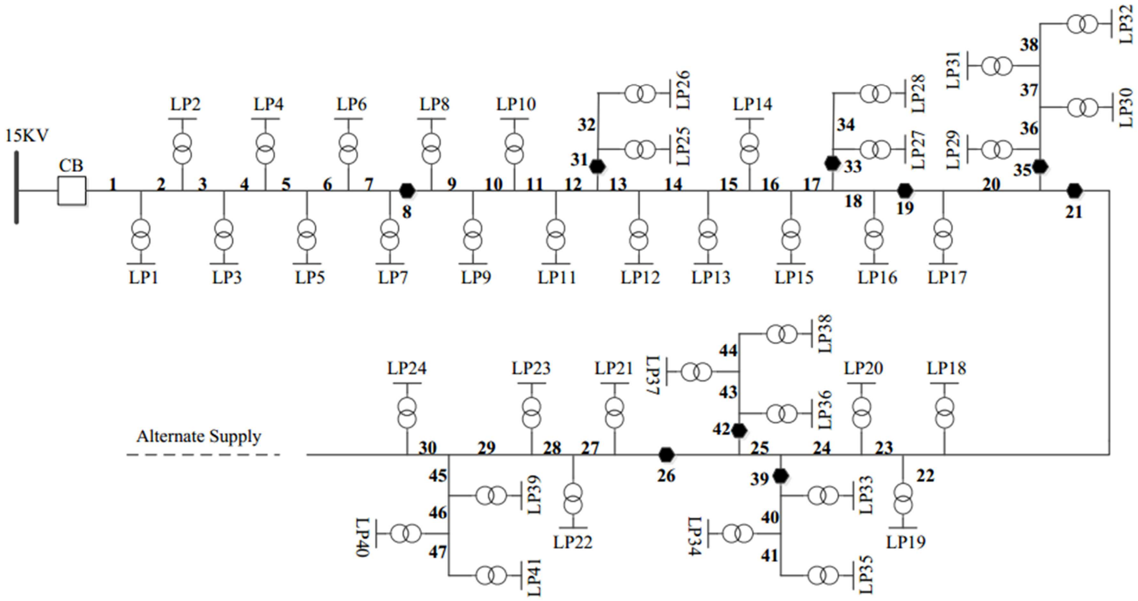

Figure 14. *Reliability model of Ankober 15kV feeder after optimization.*

From Table 2, it can be seen that all the values of reliability indices (SAIDI, U, ASAI, and EENS) except total cost (TCOST) are reduced as the number of switches increased which shows the improvement in reliability of the feeder. Since the total cost depends on both the switch cost and cost of EENS, it is minimal when the number of switches is optimal (9 switches). As also shown in figure 10 & figure 11.

9. Conclusions

This study presented mainly focused on decreasing the system reliability of 47 bus Ankober feeder of Debre Berhan distribution system. The reliability and quality of distribution system can be improved by using different improvement techniques. To select the appropriate and relevant improvement method for a particular system the first step was making reliability and power quality assessment for existing system; through the assessment process using different approaches and reliability indices that shows the performance of the system was evaluated. For identifying the improvement techniques which are relevant to the system predictive reliability alternatives are suggested. Moreover, the major causes for power interruptions are identified and the cost incurred by customers and utility are evaluated.

In this paper both the historical and predictive reliability analysis of sebeta town distribution system were carried out. The most common reliability indices, which include SAIDI, SAIFI, EENS, and ASAI, etc. are used to measure the performance of the distribution system.

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