PERFORMANCE ANALYSIS OF HARARI AND ADELLE HARAMAYA DISTRIBUTION SYSTEM WITH RING TOPOLOGY, AND INTEGRATION OF RENEWABLE ENERGY SOURCE

MSc. THESIS

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SEPTMEBER 2021

HARAMAYA UNIVERSITY, HARAMAYA

Performance Analysis of Harari and Adelle Haramaya Distribution System with Ring Topology, and Integration of Renewable Energy Source

A Thesis Submitted to the School of Electrical and Computer Engineering, School of Graduate Studies

HARAMAYA UNIVERSITY

In Partial Fulfillment of the Requirement for the Degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

(ELECTRICA POWER ENGINEERING)

Amanuel Kachiko

SEPTEMBER 2021

Haramaya University, Haramaya

HARAMAYA UNIVERSITY

SCHOOL OF GRADUTE STUDIES

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ACKNOWLEDGEMENTS

First and for most thanks to the mighty of God for allowing me to do this work. Next, I would like to express my deep and sincere gratitude to my advisor, Dr.V.Ramesh Kumar for his expert guidance, constructive comments, suggestions and encouragement without which this thesis work could have not been completed. Special thanks to my School Dean Mr.Wehib Abubeker for counseling and guidance on the subject matter. Thanks to those who helped in providing the data used in this thesis, mainly Mr.Endalew(DNO), Mr. Sultan(Chief maintenance), and Mr. Ibrahim(Chief technical) and other Adelle-Haramaya and Harar EEU staff for their cooperation for providing all the necessary data that are helpful to complete this thesis.

Last but not least, my gratitude is also to my lovely wife Astemamegn Moges and my beautiful son Elshadai Amanuel for their consistent encouragement and critical support while, I was doing this research.

ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
AENS	Average Energy Not Supplied
AMD	Advanced Micro Devices
ASAI	Average Service Availability Index
BCBV	Branch Current to Bus Voltage
BIBC	Bus Injection Branch Current
CAIDI	Customer Average Interruption Duration Index
CSO	Cat Swarm Optimization
DC	Direct Current
DFIG	Doubling –fed Induction Generator
DNO	Distribution Network Operator
DSTATCOM	Distribution Static Compensator
EELPA	Ethiopian Electric Light and Power Authority
EEP	Ethiopian Electric Power
EEPCO	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
ENS	Energy Not Supplied
E-TAP	Electrical Transient Analyzer Program
HDD	Hard Disk Drive
ICS	Interconnected System

ICSO	Improved Cat Swarm Optimization
IEEE	Institute of Electrical and Electronics Engineers
IG	Induction Generator
KCL	Kirchhoff's Current Law
KVL	Kirchhoff's Voltage Law
LSG	Linear Synchronous Generator
MATLAB	Matrix Laboratory
MPPT	Maximum Power Point Tracking
NPSO	Non-Domination Sorting Particle Swarm Optimization
ODGP	Optimal Distribution Generation Placement
PCC	Point of Common Coupling
PMSG	Permanent Magnetic Synchronous Generator
PSO	Particle Swarm Optimization
RAM	Random Access Memory
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCS	Self Contained System
SG	Synchronous Generator
STATCOM	Static Var Compensator
VSC	Voltage Source Converter
VSI	Voltage System Index

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ABSTRACT

High electrical power interruption is a major concern in Ethiopia. Most of the interruptions are caused in the power distribution system. Particularly the radial distribution system of Adelle-Haramaya and Harari, has higher power loss and poor voltage profile during heavy load conditions. In this thesis, performance analysis is done on existing systems, proposed Ring topology, and proposed Ring with Distributed Generation (DG) in the Adelle-Haramaya and Harari distribution system respectively. A Metaheuristic Particle Swarm Optimization (PSO) based is deployed for optimal Distributed Generation to significantly minimize the power loss and enhance the voltage profile of the system. The proposed method is tested by using MATLAB R2017a and ETAP16 software, and the objective function is evaluated by considering constraints. The simulation results of the Adelle-Haramaya and Harari distribution System show that 24.7Kw and 75.9Kw active power can be saved by applying the proposed method and also the entire buses voltage profile are minimum voltage 0.95760pu and maximum voltage 1.000pu and minimum voltage 0.78973pu and maximum 1.000pu are maintained within the IEEE acceptable range except for Harari distribution system minimum voltage (Ring with DG). In the end, reliability improvement of Adelle-Haramaya and Harari distribution system (from Radial to Ring with DG) of SAIFI (f/customer.yr), SAIDI (hr/customer.yr) and EEN (Mwhr/yr) are 16.3986, 399.4565 & 1151.021 to 11.3773, 287.6287 & 549.199 and 17.0493, 414.3857& 1031.956 to 11.05617, 270.1666 & 565.619 respectively. The cost- effectiveness and payback period are also assessed and the results obtained demonstrate that 77,114.9808 ETB and 476,302.22 ETB can be saved in each year after 32 years (Adelle-Haramaya) and 5 years (Harari) respectively. The proposed optimal results in term's voltage profile improvement, power loss reduction, and system index improvement of proposed Ring with DG system is better with respect to Radial and proposed Ring system. Future researches shall be done on the protection and control of the upstream and downstream sides of the system when DG is connected and installed.

Keywords: - Distribution System, Radial, Ring, Distribution Generation, PSO, MATLABR2018a, ETAP16

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Power system is the branch of Electrical Engineering studying for its design, operation, maintenance, and analysis. Generation stations, transmission lines, and the distribution system are the main component of the electric power system. Generation stations and a distribution system are connected through transmission lines, which also connect one power system (grid, area) to another. A distribution system connects all the loads in a particular area to the transmission lines. For economic and technological reasons, individual power systems are organized in the form of the electrically connected area or regional grids (also called power pools). Each area or regional grid operates technically and economically independently, but these are eventually interconnected a national grid (which may even form an international grid) so that each area is constructed tied to at the areas in respect to a certain generation and scheduling features.

Distribution systems have basic components such as distribution substation, feeder, distributer, distribution transformer, and service main. A feeder is a conductor connecting the substation to the area where power is to be distributed. The main consideration in the design of the feeder is the current-carrying capacity. A distributor is a conductor from which tapings are taken for supply to consumers. The current through is not constant because taping is taken at various places along its length. A service main is generally small cables that connect the distributor to the consumer terminal (V.Vita, 2016). There are various types of a distribution system based on the criteria of classification. According to its nature, a distribution system can be either DC distribution or AC distribution type whereas, based on its construction, there are overhead and underground types for distribution system.

The radial type system is the simplest, cheapest, and the most common form of the primary feeder. The main primary feeder branches into various primary laterals that in turn separate into several sub laterals to serve all the distribution transformers. Generally, the main feeder and sub feeders are three-phase or four-wire circuits, and laterals are three-phase or single-phase. The current magnitude is the greatest in the circuit conductors that leave the substation. The current magnitude continually lessens out toward the end of the feeder as lateral and sub-lateral are tapped off the feeders. Usually, as the current lessens the size of the feeder conductors is also reduced. However, the permissible voltage regulation may restrict any feeder size reduction which is based only on the thermal capability that is the current capacity of the feeder. The reliability of service continuity of the radial primary feeder is low. A fault occurrence at any location on the radial primary feeders causes a power outage for every consumer on the feeder unless the fault can be isolated from the source by a disconnecting device such as fuse, sectionalize, disconnect switch or reclose (Turan Gonen, 2008). Ring topology system is loop type primary feeders that loop through the feeder load area and return back to the bus. The loop system is used where a higher level of service reliability and continuity of supply is necessary. Two primary feeders for a closed-loop in order for all buses and loads to be supplied from one feeder or another in the event of a fault. One or more additional feeders along separate routes may be implemented for critical loads that can't tolerate extended interruptions.

At present, in many electric utilities, acceptable levels of service continuity are determined by comparing the actual interruption frequency and duration with arbitrary targets. Historically, the attention to the distribution reliability, planning was proportional to the operating voltage of utilities and the primary focus was on generation and transmission reliability studies (Valter Santos et al., 2014.). Nowadays, electric energy is considered an essential good, so it is extremely important to guarantee the service continuity and minimize all interruptions, the accidental as well as maintenance action (R.C.Dugan et al., 2012). It has, however, been reported in the technical literature that approximately 80% of the customer interruption occur due to the problem in the distribution system (Ali A. Chowdhury and Don O. Koval, 2009.). Detailed reliability evaluation of the distribution system has, therefore, become very important in the planning and operating stage of a power system. For economic reasons, minimization of the losses in the distribution system should also be considered in a distribution system reconfiguration process (B. Amanulla et al., 2012).

1.2. Statement of the Problem

In 2020, the total population of Ethiopia had been estimated to be 114,742,892 million, and it will be forecast to 129,749,455 million in 2025 (United Nations, 2020) . From the total population of the country only 45% are access to electricity, and the rest is living with no or little access to the modern forms of energy. Per capital energy consumption of the country is 69KWh which is one of the lowest in the world (Mekuriya Lema, 2014). To tackle this challenge, the government of Ethiopia is striving to expand distribution networks and boost standalone micro grids through different programs and schemes.

Preliminary analysis has revealed that the existing substations are acutely infected with precarious problems such as frequent power interruptions, low reliability, loading, and resource mismanagement. The main problems of existing performance of distributions systems are loading and poor quality of voltage profile. As a result, industries, most government and non-government organizations in this region are forced to buy and run diesel generators during these frequent power interruptions, expending the additional cost for purchasing, installation, maintenance, and fuel. The existing performance problems can be tackled by the transformation of existing radial topology into ring topology and optimal integration of renewable energy source (PV).

1.3. Objective of Research

1.3.1. General Objective

The primary objective of this research is to analyses the performance of Harari and Adelle-Haramaya distribution system with ring topology and integration of renewable energy source.

1.3.2. Specific Objective

To execute the primary objective of this research, the succeeding specific objectives are set:

- Literature review
- Primary and secondary data collection
- Determine reliability indices of the distribution systems
- Determine voltage profile and power loss improvement of the distribution systems
- Determine the loading of the radial topology of the distribution systems

- Simulate Ring topology of both distribution systems
- Study the economic aspects of the branch loss of network topology
- Determine optimal size and location of renewable energy source
- Simulate renewable energy source integration with Ring topology

1.4. Scope of the Study

The scope of this research is an analysis of performance and establishes mitigation of the distribution system. Hence, a preliminary study shows that most of the problems arise from the distribution and customer sides. With regards to the preliminary study, the distribution system was carefully analyzed with the assistance of the electrical software (ETAP16). The analysis carefully with reliability, voltage profile, and economical aspects of power loss. The research analysis the existing system against the standard, and mitigates the existing system to better performance. This task and mitigation technique is handled by ETAP16 and MATLAB R2017a Software.

1.5. Significance of Study

The results obtained from this research will benefit the Ethiopian Electric Utility (EEU) and its customers. Some of the significance is performances of the two distribution systems will be availed to the company, mitigation results will help EEU to understand the status of distribution of the system, power quality, availability, and predict the corresponding customer satisfaction and the research can serve as a springboard for similar future Analysis. Generally, the results of this research can be foundations for future operation, planning, and management of Harar and Adelle-Haramaya distribution systems. Hence, the results and recommendations from this research will benefit the Ethiopian Electric Utility company, the government and eventually the community we are working for.

CHAPTER TWO

2. LITERATURE REVIEW

Multi studies of affiliated research review based on the groundwork of the current study and the review blueprint based on the related research.

2.1. Global Overview

2.1.1. Analytical Methods

Effective, simple measures to improve electric power distribution power system service continuity are presented by (Valter Santos et al., 2014.). The ultimate goal is to evaluate the development and performance of distribution networks through the study of their characteristics and the analysis of the service quality indicator. The objective is achieved by computational software package DPlan. There was significant reduction of interruption due to the proposed measure and application to new technique by DNO performing maintained without interruption the supply electricity to customer. Power quality is the set of regulations of electrical properties that allows electrical systems to function without significant loss of performance or aging. (Marious Cornoiu et al., 2011) is to analyze the impact that different consumers acting on the open market, has on the power quality aspects. A real case study was analyzed based on the performed analysis with event detecting, power quality parameter computing, and serial communication. Only with the presence of several distortion of waveform is highlighted. A significant issue regarding the power quality aspects in the case of monitoring substation has not been point-out. (Xiao Kang et al., 2010) presents a probabilistic reliability method that models and simulates the outage of substation-related equipment, such as incoming or outgoing line or feeders, circuit breaker, disconnects switch, and bus sections. This method has been implemented in power a system analysis program that is widely used in the electric power industry. It can be used to simulate breaker and switching operations. In response to substation equipment failure and calculate indices that reflect the reliability assessment of different substations can also be input to the reliability assessment of the transmission grid. (Ganijo et al., 2014), a generalized quadratic model is developed for electric power distribution system contribution to the system reliability indices using Ikeja, port-Harcourt, Kduna, and Kano distribution system feeder's as case studies. The model developed can be used to find the static distribution of the reliability indices which will form a basis for system planning and maintains strategies. The paper explains the influences related to distribution and provide automation, construction on the power supply as well as a power system for existing systems.

2.1.2. Meta Heuristic Method

An algorithm for finding the minimal cut sets is utilized to find the minimal set of components appearing between the feeder and any particular load point stated by (B. Amanulla et al., 2012). a power distribution system reconfiguration methodology considering the reliability and the power loss is developed. Probabilistic reliability models are used in order to evaluate the reliability at the load points. The optimal status of the switch in order to maximize the reliability and minimize the real power loss is found by a Binary Particle Swarm Optimization-based search algorithm. The switches in the distribution system reconfiguration problem can remain only in two states: open or close. Assigning a value of 1 to the "close" state, and 0 to the "open" state, the switch status can be described by a binary vector. BPSO is an algorithm that searches for such binary vectors a solution of a problem.(Sabarinath.G and T.Gowri Manoha, 2018) presents to determine the suitable location, type, and size of the DG unit to minimize the power loss and to improve the voltage profile in the distribution network. In order to test and validate the performance IEEE-33- bus and IEEE-69 bus system have been considered. Combined loss sensitivity is used to identify the optimal location and whale optimization is used for optimal siting of DG. Therefore, type -2 DG unit performance is better in terms of power loss minimization and overall system voltage profile. (Neeraj Kanwar et al., 2015) addresses a new methodology for the simultaneous optimal allocation of DSTATCOM and DG in the radial distribution system to maximize power loss reduction while maintaining a better node voltage profile under a multi-level load profile. Therefore, an important (ICSO) technique is proposed to efficiently solve the problem. Where the seeking mode of CSO is modified to enhance its exploitation potential. The important property of CSO is that it provides local as well as global search capability simultaneously. The proposed ICSO has shown its potential to efficiently solve one of the large dimension problems of the power system. (Ramodoni Syahputra, 2015) Is targeting the network configuration optimization is based on an extended PSO algorithm in order to address low power loss, poor voltage profile, and loading among balance feeders. So, the system is tested in two models of IEEE 33 bus radial distribution network. Finally, the researcher concluded that the optimal configuration of the distribution network is able to reduce power loss and improve voltage profile. (K. Parakash et al., 2017) presents IEEE 13 bus radial distribution has been converted into a ring and mesh network to identify their reliability based on the reliability indices and factors. Finally, renewable energy source has been integrated into the ring and mesh network to determine the network performance. In the end, reliability factors and indices values are superior to the mesh network. (D. Haughton and G.T. Heydt, 2011) explores distribution system automation, automatic reconfiguration after a disturbance and the impact on reliability in a 'smart' power distribution system. The use of network incidence or connectivity matrices is shown and an example indicates the potential operational capabilities of a 'smart distribution system'. A discussion of the potential advantages of electronic switching in distribution engineering is also given.

2.1.3. Multi-Objective Function

(Soedibiye et al., 2014) proposes a strategy of power loss reduction of radial distribution network with (DG) integration based on a fuzzy multi-objective method in order to improve the distribution system efficiency. Multi-objective functions are considered for power loss reduction, minimization of bus voltage deviation, and maintaining the load balancing among feeders of the distribution network. Power loss reduction is achieved for the IEEE-33 radial distribution network system. (Subos R atana et al., 2016) State that a multi-objective method for optimal network reconfiguration as well as reactive power dispatch of DG has been proposed to improve network performance by using Non-domination sorting particle swarm optimization. The various network performances in terms of multi-objective function include minimization of system power loss, voltage deviation, and energy wastage from solar and wind generation systems. The method has been tested on the IEEE 33 bus radial distribution system for different combinations. The obtained result also compared and indicated that better network performance was achieved with network reconfiguration and reactive power output DG or its varying power factor. (Pavols Georgilakis and Nivos D Hatziargyriou, 2012) presents an overview of the state of art model and methods applied to the ODGP problem, analysis and classifying current and future research trends in the field. This paper achieves the optimal DG placement (ODGP) is to provide the best location and size of DG to optimizes electrical distribution network operator and plan into account DG capacity constraints. The distribution network operator has no control or influences about DG size and location below a certain limit is considered as a research gap. In the end, the paper points current and future trends to solve the ODGP problem. The most frequently used technique for the solution of the ODGP problem is the genetic algorithm and various practical heuristic algorithms. Future research areas include coordinating planning, dynamic ODGP, uncertainty, stochastic optimization, active network management, and islanded operation.

2.2. Local Overview

(Bikjs Alebachew Taye, 2018) identify, the main causes of interruption assess the duration and frequency of power interruption, indicate the power interruption influence on the economy of customers and utility, evaluate the reliability of the present distribution system and give recommendations based on performance evaluation of Debre Tabor electric power distribution system. To achieve the expected goal, the steps to be performed are secondary and primary data to be collected. Distribution reliability indices SAIFI, SAIDI, CAIDI, and ASAI analyzed for selected area values are 540 interruption/years, 1259.36 hours/customer. Year, 2.33 hours/interruption and 308.16 MW/year respectively. The total cost of energy which is lost by the utility is 2.033 million ETB /year. The calculated values compared to the benchmark are quite unreliable. The recommendation which is recommended by the researcher is to improve the system by installation of load break switch, auto re-closer and built new substation. (Solomon Derbie and Getachew Biru Worku, 2014) presents the assessment result of power distribution reliability for the city and the possibility of a smart re-closer for improving urgent and pressing power interruption problems. The smart re-closer is a key element for fault detection, isolation, and restoration. The simulation results designed model with 3 re-closer in each feeder and tie re-closer between connected nearby feeders. This indicates that the implementation of a smart re-closer improves the reliability of the distribution network by 75% in comparison with the reliability of the currently existing system. (Umar Abdi Geru, 2014) attempts, to analyze the reliability of the existing system identify the problem of a low-reliability system, and provide solution to minimize the interruptions and re-design of power distribution system to increase system reliability. To improve the reliability of the network, proper maintenance and redesign distribution network is suggested. Redesigning of existing system 15kV/2*25MVA of power distribution is replaced by 33kV/5*50MVA and reliability indices such as SAIFI, SAIDI and ASAI which is improved from 956.33, 923.3 and 89.46 %

to 2.75, 38.72, and 99.56 respectively by using E-TAP software. (Yishak Kifle et al., 2018) Attempt to identify the case of power interruption and customer dissatisfaction. Additionally, the authors discuss the design, maintenance, reliability, and operation of Hawassa distribution feeder number 10 Ethiopia. In order to achieve the targeted objective, the researchers present the study of the radial distribution system and illustrate the impact of placing DG (photovoltaic system, wind turbine, and battery storage). The reliability improvement measured by different indices that include SAIDI, CAIDI, EENS AND ASAI. The analyzed and calculated reliability indices value has been compared with the benchmark value. The largest improvement obtained (around 80% is obtained in feeder 10 reliability with the incorporation of renewable distribution generation.

Generally, analytical methods are easy to implement and fast to execute. However, their results are only indicative, since they make simplified assumptions including the consideration of only one power system loading snapshot. Meta heuristic methods are usually robust and provide near-optimal solutions for large, complex Optimal Dispersed Generation Placement problems. Generally, they require high computational effort. However, this limitation is not necessarily critical in DG placement applications.

In the end, the limitation (i) in the case Global overview is: some of the algorithms are limited to solve specific problems, simultaneous allocation algorithm to address for specific purpose, complexity, computational time, working memory, robustness, convergence and accuracy. (i) Local overview most of the works are limited to design and security strategy solution and most them were not addressed targeted problem with deployment of metaheurstic algorithm and adequacy solution (optimal size and site of DG integration)

Overall, Previews related work and other related work are in the area that helps to design methodology.

CHAPTER THREE

3. MATERIAL AND METHODS

3.1. Study Area

Harari is a city in eastern Ethiopia. It is the capital of East Hararghe and the capital of the Hareri Region of Ethiopia. The city is located on a hilltop in the eastern extension of the Oromia, about five hundred kilometers from the national capital Addis Ababa at an elevation of 1,885 meters and location coordinate $9^0\ 19'$ N$42^0 7'$E. Haramaya (Alemaya) is an east town in east-central Ethiopia, which is located in the East Hararge Zone in the Oromiya Region; the town has a latitude and longitude of $9^0\ 24'$N$42^0 01'$E with an elevation of 2047 meters above sea level. Haramaya city is the home to Haramaya University (formerly Alemaya University). Adelle is a village in the main road to Harar and Dire Dawa. The center along that road is connected to Haramaya.

3.2. Material

3.2.1. Software package

3.2.1.1. E-TAP 16

ETAP 16 is a fully graphical enterprises package that runs on Microsoft window 2008, 2012, 7.8, 8.1, and 10 operating systems. ETAP is the most comprehensive analysis tool for the design and testing of power system available using its standard offline simulation models, ETAP can utilize real-time simulation optimization energy management system, and high-speed intelligent load shedding.

- System Requirement
  - ➢ Operating system (64-bits)
  - ➢ Microsoft windows 7 and above
  - ➢ Microsoft server 2008 and above

3.2.1.2. MATLAB R2018a

- System Requirement

- For operating system Windows 8 and 10, processor (Intel or AMD), Disk Space (128GB of HDD/SDD space for MATLAB, 6GB for typical installation), RAM (8GB), Graphics (2GB).

3.3. Data Collection

3.3.1. Adelle-Haramaya Distribution System

Table 3. 1 Radial (Existing) Bus Loading and Line (Branch) Data

No. of Bus	P_{Load} (Kw)	Q_{Load} (Kvar)	No. of line	From Bus	To Bus	R(ohm)	X(ohm)
1	3086	318	1	1	2	9.85	128.08
2	3069	285	2	2	3	13.92	118.35
3	2637	166	3	3	4	17.60	34.71
4	425	25	4	4	5	733.88	266.12
5	404	15.8	5	5	6	366.94	133.06
6	1175	459	6	6	7	146.78	53.22
7	972	73.8	7	7	8	75.24	87.49
8	122	6.8	8	8	9	209.41	66.22
9	147	8.4	9	9	10	314.11	99.33
10	154	9.3	-	-	-	-	-

The 10-bus Radial Distribution System of Adelle-Haramaya is shown in Figure 4.1 in Chapter 4. It consists of 10 buses, 9 lines (branches), 6 loads, and 1 power grid. All buses have a voltage level of 66kV, 33kV, and 15kV respectively. Then the network is fed from the main substation through an overhead distribution line while it is loaded from 3.086 MW and 0.318. MVAR and additional data of one year existing load and interruption data are shown in Appendix A and Appendix B.

3.3.2. Harari Distribution System.

Table 3. 2 Radial (Existing) Bus Loading and Line (Branch) Data (Continued)

No. of Bus	P_{Load}(Kw)	Q_{Load}(Kvar)	No. of Line	From Bus	To Bus	R(ohm)	X(ohm)
1	2562	684	1.	1	2	5.34	69.38

2	2108	1256	2.	2	3	0.09	0.04
3	668	604	3.	3	4	0.03	-0.02
4	455	29.9	4.	4	5	1209.12	266.12
5	75.8	3.1	5.	5	6	314.99	122.44
6	49.3	1.8	6.	6	7	3606.21	130.38
7	95.8	3.3	7.	7	8	11636.05	420.68
8	176	14.4	8.	8	9	9661.13	1273.45
9	272	18	9.	9	10	1477.20	247.89
10	246	11	10.	10	11	4347.51	573.05
11	544	12.7	11.	11	12	7.54	14.69
12	776	52.8	12.	12	13	805.76	474.44

The 12-bus Radial Distribution System of Harar is shown in Figure 4.5 in Chapter 4. It consists of 12 buses, 12 lines (branches), 8 loads, and 1 power grid. All buses have a voltage level of 132kV, 66kV, 33kV, and 15kV respectively. Then the network is fed from the main substation through an overhead distribution line while it is loaded from 2.567 MW and 0.179MVAR. Additional data of one year existing load and interruption data are shown in Appendix C.

3.4. Methods

3.4.1. Load flow

Power system is assumed to be operating under balanced condition and can be represented by a single line diagram. The power system networks contain hundreds of buses and branches with impedance specified per unit on a common MVA buses. Power flow studies, commonly referred to as load flow, are also essential for power system analysis and design. Load flow studies are necessary for planning, economic operation, scheduling, and exchange of power between utilizing. Load flow study is also required many other analyses such as transient stability, dynamic stability, contingency, and state estimation (D.Das, 2006).

i. Voltage magnitude and it's angle

$$V_i = {}^{1}/_{Yij} \left[\frac{Pi - jQi}{Vi^*} - \sum_{\substack{k=1 \\ k \neq i}}^{n} YikVk \right] \quad i=1, 2, 3\ldots4 \text{ and } i \neq k \qquad \text{(Equaiton 1.)}$$

ii. Net Power

$$\frac{Pi-jQi}{Vi^*}=Y_{ij}V_i + \sum_{\substack{k=1\\k\neq i}}^{n} Y_{ik}V_k \qquad \text{(Equation 2.)}$$

iii. Real Power

$$P_i=\sum_{k=1}^{n}|V_i|\,|V_k||Y_{ik}|\cos(\theta_{ik}-\delta_i+\delta_k) \qquad \text{(Equation 3.)}$$

iv. Imaginary Power

$$Q_i= -\sum_{k=1}^{n}|V_i|\,|V_k||Y_{ik}|\sin(\theta_{ik}-\delta_i+\delta_k) \qquad \text{(Equation 4.)}$$

3.4.2. The Per-unit System

Power system quantities such as current, voltage, impedance, and power are often expressed in per-unit values. One major advantage of per-unit is that by properly specifying base quantities. The equivalent circuit of the transformer can be simplified. Another advantage of the per-unit system is that the comparison of the characteristics of the various electrical apparatus of different types and ratings is facilitated by expressing the impendence in per-unit based on their ratings.

Per-unit is a quantity is calculated as follows.

$$\text{Per-unit quantity} = \frac{\text{Actual quantity}}{\text{Base value of quantity}} \qquad \text{(Equation 5.)}$$

$$S_{pu}=\frac{S}{S_B}, \quad V_{pu}=\frac{V}{V_B}, \quad I_{pu}=\frac{I}{I_B}, \quad Z_{pu}=\frac{Z}{Z_B}$$

Where: S is apparent Power (D.Das, 2006).

3.4.3. Voltage Drop

The voltage drop is a quantity which defines the voltage relationship between any two points on a given network. Let the voltage of the two points on a given network be V_A and V_B. The voltage drop between these two points can be expressed using Equation 6 (M.Chakravorts and Das D., 2001).

$$V_{AB}=V_B-V_A \qquad \text{(Equation 6.)}$$

$$V_{AB}=-V_{BA} \qquad \text{(Equation 7.)}$$

In distribution network analysis, the source node voltage is usually considered as the reference rated voltage, from which other node voltage is estimated. This estimation is carryout using iterative technique. Therefore, the voltage drop (V_{Dk}) along the path linking the source and K^{th} node.

$$V_{DK} = V_{\text{rated}} - V_k \qquad \text{(Equation 8.)}$$

Where V_{Dk}:- Voltage drop at k^{th} node.

It's possible to express the Voltage Sensitive Index (VSI) as a function of voltage drop.

$$\text{VSI} = \sqrt{\frac{\sum_{k=1}^{n} V_{DK}^2}{n}} \qquad \text{(Equaiton 9.)}$$

3.4.4. Power Loss

The line loss in the distribution system can be in both primary and secondary feeders. Line loss is a function of the square of the current flowing through the resistance (R) and the reactance (X) of the line (G.Niazi and M. Ladwani, 2017).

$$P_{Loss} = \sum_{i,j=1,j\neq 1}^{N} i_{ij}^2 R_{ij} \qquad \text{(Equation 10.)}$$

Where: P_{Loss}= Total Active power loss

$$Q_{Loss} = \sum_{i,j=1,j\neq 1}^{N} i_{ij}^2 X_{ij} \qquad \text{(Equation 11.)}$$

Where: Q_{Loss}= Total Reactive power loss

i_{ij}= branch current flowing from bus i to bus j

R_{ij}=line resistance between bus i and bus j

X_{ij}= line reactance between bus i and bus j.

3.4.5. Forward Backward Sweep Load Flow (FBS)

Gauss –Siedel, Newton Raphson and Fast Decouple load flow analysis methods have been widely used in the last few decades for power system operation, control, and planning (H.R.Esmaeilian and R. Fadaeinedyad, 2015). However, these power flow techniques are inefficient for power flow analysis in the distribution system due to some peculiar characteristics of such network like radially in structure, high resistance-reactance ratio($^{r}/_{x}$), un-transposed line, and unbalanced load a long single-phase and three-phase laterals.

3.4.5.1. Algorithm for FBS Load Flow

To begin with, the application of the FBS power flow method on three phases balanced load flow (Paulo M. and DC Oliver-De Jesus, 2008). In this case, the calculation is conducted in terms of line voltage and current of single line diagram model in traditional power flow methods. The algorithm is developed based on two derived matrices, the bus injection to branch current matrix and the branch current to bus voltage matrix and equivalent current injection. For distribution networks, the equivalent current injection-based model is practical for the bus; the complex load (Si) is expressed by:

$$S_i = P_i + jQ_i \quad \text{where: i=1...N} \qquad \text{(Equation 12.)}$$

Step 1: Backward Sweep

For each iteration, the k branch current is aggregated from load to origin. But before finding the branch current we need to find the current injected at each bus and bus injection to the branch current. The current injection at the k^{th} iteration of the i^{th} bus is

$$I_i^k = \left(\frac{Si}{V_i^k}\right)^* = \left(\frac{Pi+jQi}{V_i^k}\right)^* \qquad \text{(Equation 13.)}$$

Where V_i^k and I_i^k are bus voltage and equivalent current injection of the i^{th} bus at the k^{th} iteration respectively. Matrix development for relating branch current and bus injected current at each bus.

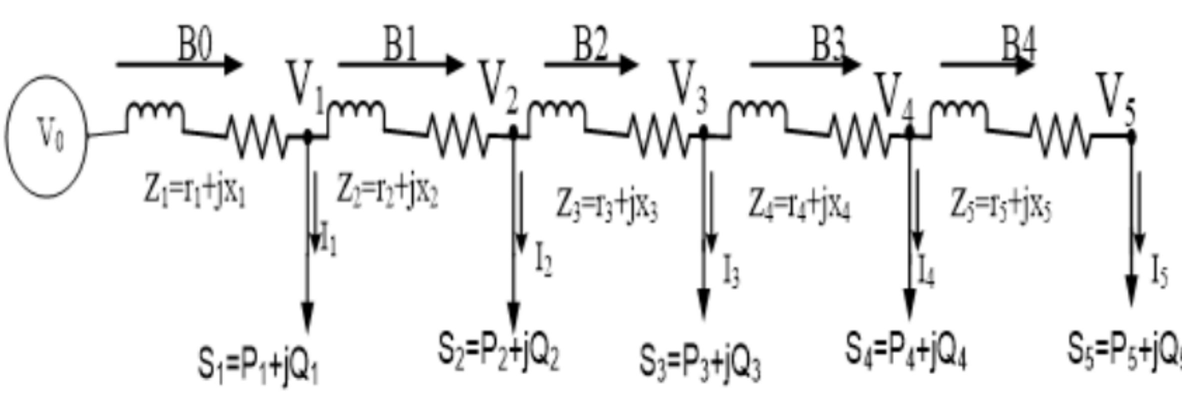

Figure 3. 1 Single line diagram of 5 nodes radial distribution feeder (Paulo M. and DC Oliver-De Jesus, 2008).

By applying Kirchhoff's Current Law (KCL) to the distribution network, the branch current is calculated as shown above using figure 3.1. Equivalent current injection at each bus.

B4=I5

B3=I4+B4=I4+I5

B2=I3+B3=I3+I4+I5

B1=I2+B2=I2+I3+I4+I5

B0=I1+B1=I1+I2+I3+I4+I5

The relationship between the bus current injection and branch currents can be expressed as

$$\begin{bmatrix} B0 \\ B1 \\ B2 \\ B3 \\ B4 \end{bmatrix} = \begin{bmatrix} 11111 \\ 01111 \\ 00111 \\ 00011 \\ 00001 \end{bmatrix} \begin{bmatrix} I1 \\ I2 \\ I3 \\ I4 \\ I5 \end{bmatrix} \qquad \text{(Equation 14.)}$$

Equation can be expressed

$$[B]=[BIBC][I] \qquad \text{(Equation 15.)}$$

Where, BIBC is the bus injection branch current for the given simple network.

Step 2. Forward Sweep (Paulo M. and DC Oliver-De Jesus, 2008)

Nodal voltage vector V is updated from the origin to loads according Kirchhoff's Voltage Laws (KVL), using previously calculated branch are currents vector B and branch current to bus voltage (BCBV). The relationship between branch current and bus voltage is shown in figure 3.1. is expressed as:-

$V1=V_0-B_0Z_{01}$

V2=V1-B1Z12=V0-B0Z01-B1Z12

V3==V2-N2Z23=V0-B0Z01-B1Z12-B2Z23

V4=V3-B3Z34=V0-B0Z01-B1Z12-B2Z23-B3Z34

V5=V4-B4Z45=V0-B0Z01-B1Z12-B2Z23-B3Z34-B4Z45

Where, Vi is the voltage at bus the i and Zij is the line impedance between bus i and bus j.

From the above equation, the bus voltage can be expressed as the function of branch currents, line parameter, and the substation voltage. Therefore, the relationship between branch current and bus voltage can be expressed as:

$$\begin{bmatrix} V1 \\ V2 \\ V3 \\ V4 \\ V5 \end{bmatrix} = \begin{bmatrix} V0 \\ V0 \\ V0 \\ V0 \\ V0 \end{bmatrix} - \begin{bmatrix} Z01 & 0 & 0 & 0 & 0 \\ Z01 & Z12 & 0 & 0 & 0 \\ Z01 & Z012 & Z23 & 0 & 0 \\ Z01 & Z12 & Z23 & Z34 & 0 \\ Z01 & Z12 & Z23 & Z34 & Z45 \end{bmatrix} \begin{bmatrix} B0 \\ B1 \\ B2 \\ B3 \\ B4 \end{bmatrix} \quad \text{(Equation 16.)}$$

The general form of the bus voltage at $(k+1)^{th}$ iteration can be expressed as

$$[V^{k+1}] = [V_0] - [BCBV] \quad \text{(Equation 17.)}$$

In general form, with i and k denoting the node and iteration number respectively.

$$I_{i-1,i}^{k} = I_i^k + I_{i,i+1}^k \quad \text{(Equation 18.)}$$

$$V_i^k = V_{i-1}^k - Z_{i-1,i} * I_{i-1,i}^{k-1} \quad \text{(Equation 19.)}$$

- **Procedure forming BIBC and BCBV matrix**

  Procedure 1: Forming BIBC (Paulo M. and DC Oliver-De Jesus, 2008)**.**

Step 1: For a distribution system with an m-branch section and n-bus, the dimension of the BIBC matrix is m x (n-1).

Step 2: If the line section (B_k) is located between bus i and bus j, copy the column of the i^{th} bus of the BIBC matrix to the column of the j^{th} bus and fill a 1 to the position of the k^{th} raw and the j^{th} bus column.

Step 3: Repeat step 2 until all line section are included in the BIBC matrix.

Procedure 2: Forming BCBV

Step 1: for a distribution system with an m-branch section and n-bus, the dimension of the BCBV matrix is (n-1) x m.

Step 2: if a line section is located between bus i and bus j, copy the row of the i^{th} bus of the BCBC matrix to the column of the j^{th} bus and fill the line impedance Z_{ij} to the position of the k^{th} column and j^{th} bus row.

Step 3: repeat step 2 until all line sections are included in the BCBV matrix.

Flow chart for Forward Backward Sweep method

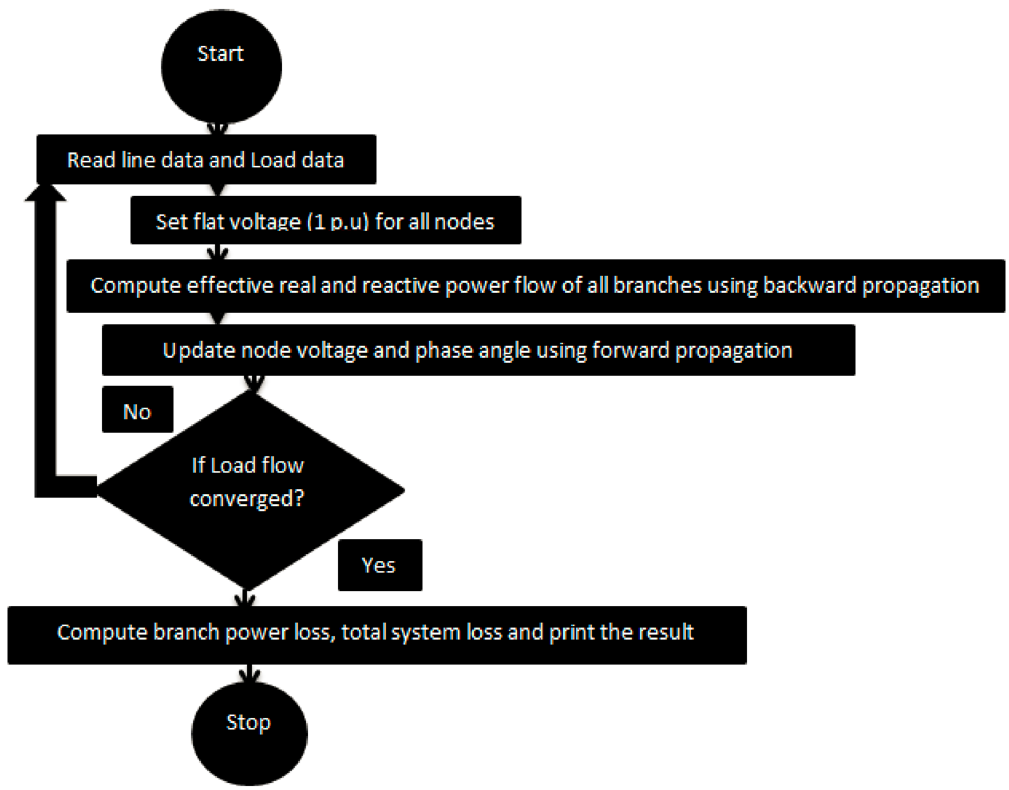

Figure 3. 2 Flow chart for FBS Load flow analysis.

3.4.6. Reliability Indices

Distribution reliability primarily relates to equipment outages and customer interruption. In normal operating conditions, all equipment (except stand-by) is energized schedule and unscheduled events disrupt normal operating conditions and can lead to outage and interruptions (Richard E. Brown, 2002). Distribution system reliability assessment deals with the availability and quality of power supply at each customer service entrance. Improving customers' service reliability is always the major object. The customer's annual power supply duration, outage duration, failure rate, and degree of outage affection have all affected the distribution system reliability (Lin W, 2000). The distribution network is also the most important factor to influence the reliability of the distribution system (Ali A. Chowdhury and Don O. Koval, 2009.). The reliability of the power supply is assessed using known reliability indices. The system indices for distribution system analysis include customer-oriented indices and load or energy-oriented indices as defined in IEEE standard 1366 (C.R Bayliss and B.J. Hardy, 2007) (Valeire, E.Zelents, 1999) (Richard E. Brown, 2002).

3.4.6.1. Customer Oriented Reliability Indices

The most widely used reliability indices are average that weights each customer equally. Customer-based indices are popular with regulating authority. Since a small residential customer has just as much as important as a large customer. They have limitations, but are generally considered a good aggregate measure of reliability and are often used as reliability benchmark. And improved targets (Richard E. Brown, 2002).

- System Average Interruption Frequency Index

$$\text{SAIFI} = \frac{\text{Total Number of Customer Interruption}}{\text{Total Number of Customer Served}} \quad Intr./_{yr.cust.} \qquad \text{(Equation 20.)}$$

- System Average Interruption Duration Index

$$\text{SAIDI} = \frac{\sum \text{Customer Interruption Duration}}{\text{Total Number of Customer Served}} \quad hr/_{yr.cust.} \qquad \text{(Equation 21.)}$$

- Customer Average Interruption Duration Index

$$\text{CAIDI} = \frac{\sum \text{Customer Interruption Durations}}{\text{Total Number of Customers Interruption}} \quad hr./_{yr.cust.} \qquad \text{(Equation 22.)}$$

SAIFI is a measure of how many sustained interruptions an average customer will experience over the course of the year. SAIDI is a measure of how many interruptions haves an average customer will experience over the course of the year. CAIDI is a measure of how long an average interruption lasts and is used as a measure of utility response to the system contingencies. ASAI the customer weighted availability of the system and provides the same information as SAIDI.

3.4.6.2. Load- Based Reliability Indices

Two of the oldest distribution reliability indices weight customers based on connected KVA instead of weighting each customer equally.

- Average Energy is Not Supplied (AENS)

$$\text{AENS}=\frac{\sum Piri}{ri}\, kwhr/yr.cust. \qquad \text{Equation 23.}$$

Where Pi= power express in KW

3.5. Optimal Placement and Size of DG (Distribution Generation) in Distribution Network's

3.5.1. DG Size Limits

To have a considerable impact on DG on the system and to avoid voltage rise problems, constraints are imposed on DG size. Active power generated by DG is limited as:-

$$DG_{pmin} \leq DG_{p1} \leq DG_{pmax} \qquad \text{(Equation 24.)}$$

DG at any bus is assumed to generate the active the power within limit above. DG_{Pmin} is the minimum active power of DG and is set as the 25% of the total active power load on the system. DG_{pmax} is the max active power of DG and is set as the 80% of the total active power load on the system. Reactive power is generated by DG is limited within the following limits:-

$$DG_{Qmin} \leq DG_{Qi} \leq DG_{Qmax} \qquad \text{(Equaiton 25.)}$$

DG_{Qmin} is the minimum reactive power of DG and is set as the 25% of the total reactive power load on the system. DG_{Qmax} is the maximum reaction power of DG and is set as the 80% of the total reactive power load on the system (Andersson G et al., 2010).

3.5.2. Best Sizing of DG

The total power loss against injected power is a parabolic function and at minimum losses, the rate of change losses with respect to injected power loss becomes zero (Mahat P et al., 2012).

$$\frac{\partial PL}{\partial Pi}=2\alpha_{ii}P_i + 2\sum_{\substack{j=1 \\ j\neq i}}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)=0 \qquad \text{(Equation 26.)}$$

It follows that $P_i=\frac{1}{\alpha_{ii}}\left[\sum_{\substack{j=1 \\ j\neq i}}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right]$

Where, P_i is the real power injection of node I, which is the difference between real power generation and real power demand at the node: P_i=$(P_{DGi} - P_{Di})$ where P_{DGi} is real power injection from DG placed at a node I, and P_{Di} is the load demand at node i by a combination the above, we get:-

$$P_{DGi} = P_{Di} - \frac{1}{\alpha_{ij}} \left[\sum_{\substack{j=1 \\ j \neq i}}^{N} \left(\alpha_{ij} P_j - \beta_{ij} Q_j \right) \right] \quad \text{(Equation 27.)}$$

Equation 29. Gives the best size of DG for each bus i, for the loss to be minimized. Any size of DG other than P_{DGi} place at bus i, will lead to higher loss.

3.5.3. Best Location of DG

After finding the optimal size of DG at each bus, the next step is to find the best location of DG, which will give the lowest possible total losses. The bus having less power loss will be the optimal location for the placement of DG (Cheng H. and Wang C. Zhang J, 2009)

3.5.4. Particle Swarm Optimization (PSO)

Particle Swarm Optimization is one of the most popular nature inspired metaheuristic optimization algorithm developed by James Kennedy and Russel Elberhart in 1995 (J. Kennedy, R.Elberhart, 1995). It's inspired by the social behavior of bird flocking or fish schooling. By definition Particle Swarm is an approach to problems whose solution can be represent as a point in an n-dimensional solution space (Jamdi S., Rezaei L. and Gudakahriz S., 2013). During every iteration the particle observer the ''fitness'' of themselves and their neighbors and ''emulate'' successful neighbors (those whose current position represents a better solution to the problem than theirs) (Srivatsa Sarat Kumar Sarvelpalli, 2019).Particle velocities on each dimension are limited to a maximum velocity Vmax. If the sum of the velocity of all the particles exceeded Vmax, then thier velocities are limited to Vmax (Srivatsa Sarat Kumar Sarvelpalli, 2019).

There are many ways to define a ''Neighbored'' (J. Kennedy, R.Elberhart, 1995) but we can distinguish them into two classes: (i)'' Physical'' Neighbored, which takes distance into account. (ii) ''Social'' Neighbored, which just take the relationship into account. A PSO algorithm is in general subjected to four common topologies or neighbors.

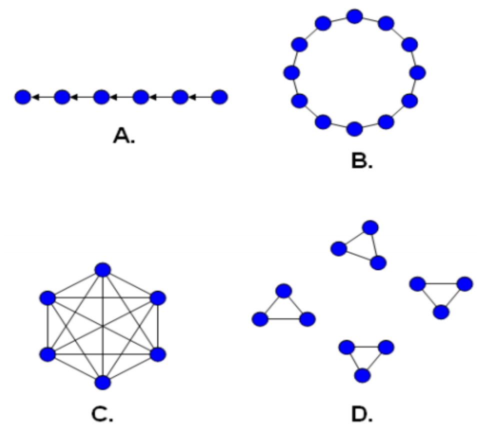

Figure 3. 3 Common Topologies of PSO

A. Single –Sighted Topology: - individual particle compare themselves to the next best.
B. Ring Topology:- each individual only compares to those left and right
C. A fully Connected Topology: - is where every individual compare to one another.
D. Isolated Topology: - where the individual only compare with those within specific groups (Mnemstudio.org, 2015).

3.5.4.1. Efficiency, Accuracy, and Robustness

A robust algorithm can operate despite the abnormalities in the inputs and the calculating. In order for an algorithm to gain maximum efficiency, it must minimize the usage of its resources. The common resources are time and space (i.e. the total time it takes for an algorithm to complete and also the amount of working memory required for it to get the desired output). Working memory includes the memory needed for the code as well as for the data used for testing (Srivatsa Sarat Kumar Sarvelpalli, 2019).

- A basic PSO algorithm has the following features (Srivatsa Sarat Kumar Sarvelpalli, 2019):-

➢ Ease of Implementation: - PSO can be implemented with just a few lines of code.

➢ Flexibility:- often when adopting the PSO to a new problem, no major adjustment has to be made

➢ Robustness: - the solution of the PSO is almost independent of initialization of swam.

➢ Parallelism: - the PSO is inherently well suited for parallel computing. The swarm population can be divided between many processors to reduce computation time.

There are also two versions of PSO: - (1) Global Version is faster but might converge to local optimum for some problems. (2) Local Version is a little bit slower but not easy to be trapped into local optimum. Global version to get quick results and local version to refine the search (Srivatsa Sarat Kumar Sarvelpalli, 2019).

3.5.4.2. Particle Swarm Optimization: Algorithm

Particle Swarm Optimization is inspired by social and cooperative behavior displayed by various species to fill their needs in the search spaces. The algorithm is guided by personal experiences(P_{best}), overall experiences (G_{best}) and the present movement of the particle to decided their next position in search spaces. Experiences are accelerated by two factors C_1 and C_2 and two random numbers generated between[0,1], whereas present movement is multiplied by an inertia factor ω varying between$[\omega_{min}, \omega_{max}]$. The initial population (swarm) of size N and dimension D is denoted as X=$[X_1, X_2 \ldots . X_N]^T$, where ''T'' denote the transpose operator. Each individual (particle) $X_i(i = 1,2 \ldots . N)$ is given as X_i=$\left[X_{i,1}, X_{i,2} \ldots . . X_{i,D}\right]$. Initial velocity of the population is denoted as v=$[v_1, v_2 \ldots . . v_N]^T$. The velocity of each particle $X_i(i = 1,2 \ldots N)$ is given as v_i=$\left[v_{i,1}, v_{i,2} \ldots v_{i,D}\right]$. The index i vary from 1 to N. whereas the index j varies from 1 to D. (M.N. Alam, B.Das, V.Pant, 2015)

$$v_{i,j}^{k+1}=\omega \text{x} v_{i,j}^{k}+C_1 \text{x} r_1 \text{x}\left(Pbest_{i,j}^{k} - X_{i,j}^{k}\right)+C_2 \text{x} r_2 \text{x}\left(Gbest_{j}^{k} - X_{i,j}^{k}\right) \qquad \text{(Equation 28.)}$$

$$X_{i,j}^{k+1}=X_{i,j}^{k} + v_{i,j}^{(k+1)} \qquad \text{(Equation 29.)}$$

$Pbest_{i,j}^{k}$ Represent present best j^{th} component of i^{th} individual, where as $Gbest_{j}^{k}$ represent j^{th} component of best individual of population up to iteration k.

- The difference steps of PSO are as follows (M.N. Alam, B.Das, V.Pant, 2015).
  1. Set parameters ω_{min},ω_{max},C_1 and C_2 of PSO
  2. Initialize population of particle having position X and velocity V.
  3. Set iteration k=1
  4. Calculate of fitness of particle F_i^k =f(Xi^k), ∇_i and find the index of best particle
  5. Select $Pbest_i^k$=X_i^k,∇_i and $Gbest_i^k$=X_b^K
  6. ω=ω_{max}-Kx$(\omega_{max} - \omega_{min})/maxite$

7. Update velocity and position particle.

   $v_{i,j}^{k+1}$=ωx$v_{i,j}^{k}$+ C_1x rand () x $\left(Pbest_{i,j}^{k} - X_{i,j}^{k}\right)$ + C_2x rand () x $\left(Gbest_{i,j}^{k} - X_{i,j}^{k}\right)$; ∇_j and ∇_i

   $X_{i,j}^{k+1}$=$X_{i,j}^{k}$ + $v_{i,j}^{k+1}$; ∇_i and ∇_j

8. Evaluate fitness F_i^{k+1}=$f\left(X_i^{k+1}\right), \nabla_i$ and find the index of the best particle.

9. Update P_{best} of population ∇_i if $F_i^{k+1} < F_i^k$ then $Pbest_i^{k+1}$=X_i^{k+1} else $Pbest_i^{k+1}$=$Pbest_i^k$

10. Update G_{best} of population

    If $F_{b1}^{k+1} < F_b^k$ then, G_{best}^{k+1} =$Pbest_{bi}^{k+1}$ and set b=b_1 else G_{best}^{k+1}=$G_{\ best}^{\ k}$

11. If k<maxite then k=k+1 and go to step 6 else go to step 12

12. Print optimum solution G_{best}^{k}

- The most common used parameter of PSO algorithm are considered as follows: (Mohamad Nabab Alam, 2016)

➢ Inertial weight (ω): 0.9 to 0.4

➢ Acceleration factor s (C_1 and C_2) : 2 to 2.5

➢ Population sizes : 10 to 100

➢ Maximum iteration (maxite): 500 to 10,000

➢ Initial velocity : 10% of position

- Detail flow of PSO considering the above steps

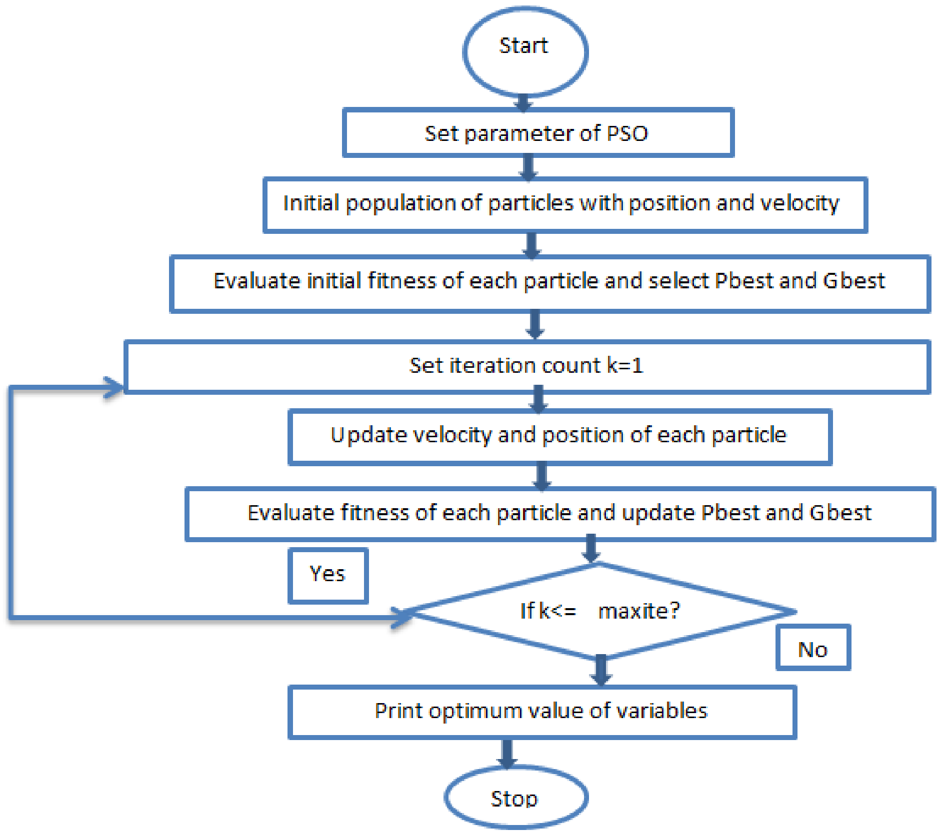

Figure 3. 4 Flow chart of PSO.

3.5.5. Integration or interfacing with DG (Distribution Generation)

The connection point of an energy source to the grid is usually referred to as the point of common coupling (PCC). Its definition depends on the ownership and utility interconnect requirements (Math Bollen and Fainan Hassan, 2011). Two different possible definitions are shown in Figure 3.5, where typically the interconnection relay (protection) is installed at the PCC. It will be assumed here that the PCC is the connection point before the interconnection.

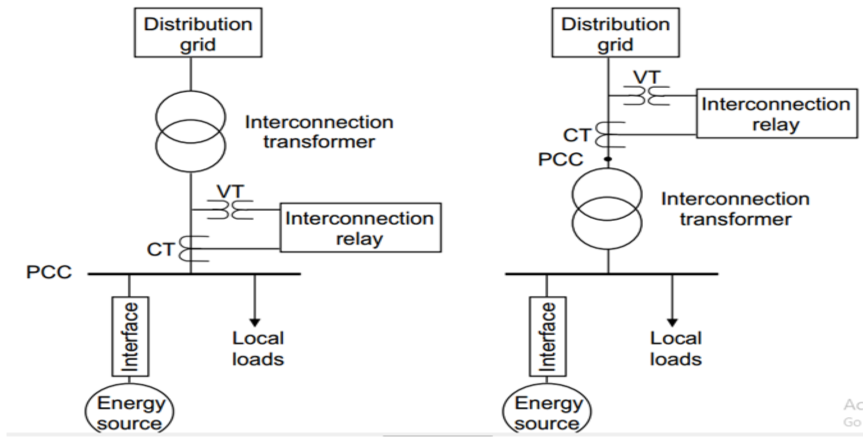

Figure 3. 5 Two possible definitions of the point-of-common coupling (PCC)

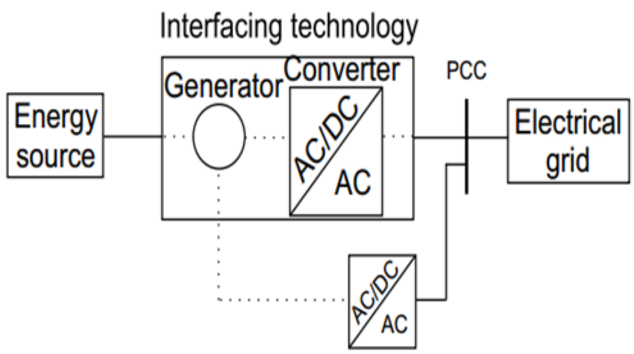

Figure 3. 6 Interfacing of energy source with grid

Transformer (the left-hand schematic of the figure). The technology that connects an energy source to the PCC, which is referred to as the interfacing technology, may comprise another transformer. There are different interfacing technologies used; in common is the use of generators and power electronics converters, as shown in Figure 3.6. The main goal of the interfacing technology is to accommodate the energy produced to the grid requirements. Depending on the nature of their produced power, different energy sources use different technologies to interface/couple with the grid, as reported in Table 3.1.

The interfacing technologies are classified here into four categories: direct machine coupling, full power electronics coupling, partial power electronics coupling, and modular or distributed power electronics coupling (Math Bollen and Fainan Hassan, 2011). The different grid couplings are explained below in more detail:-

A. Direct Machine Coupling with the Grid

In general, the sources that could be directly coupled to the grid are those that originally produce mechanical power, such as wind power, small hydropower, and some others. It is then more efficient to transfer the mechanical power into electrical power through direct machine coupling to the grid without any intermediate stage.

Table 3. 3 Interfacing Technologies for Different Energy Sources

Energy Source	Source of Energy	Electrical Generator	Power Electronics
Wind Power	Wind	SG,PMSG,IG,DFIG	Optional, AC/AC
Hydropower	Water	SG	N/A
Fuel cell (CHP)	Hydrogen	N/A	DC/AC
Biomass	Biomass	SG,IG	Optional, AC/AC
Micro Turbine (CHP)	Diesel/Gas	SG,IG	Optional, AC/AC
Photovoltaic (Solar Power)	Sun	IG	AC/AC
Wave Power	Ocean	LSG	AC/AC
Flow of river (small hydro)	River	PMSG	AC/AC

Where, SG, Synchronous Generator; PMSG, Permanent Magnet Synchronous Generator; IG, Induction Generator; DFIG, Double-fed Induction Generator; N/A, Not Applicable; LSG, Linear Synchronous Generator.

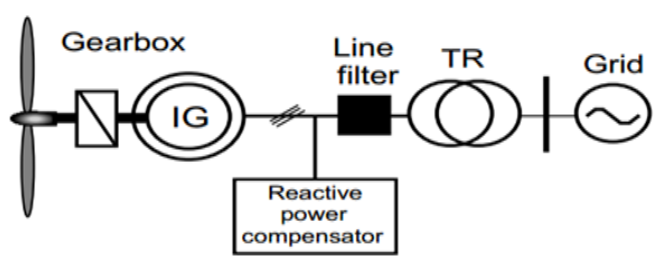

Figure 3. 7 Direct induction of generator coupling for wind turbine.

The choice of the type of the machine depends on the nature of the mechanical power supplied. For a constant mechanical power, resulting in constant rotating shaft speed, the synchronous machine is a proper candidate, whereas for strongly variable power, the induction machine is more suitable.

B. Full Power Electronics Coupling with the Grid

The main task of the power electronics interface is to condition the energy supplied by the DG to match the grid requirements and to improve the performance of the energy source. Power electronics equipment has the capability to convert power from one form to another by using controlled electronic switches and hence called power electronics converters (or converters in short). For instance, they are used to convert the direct current (DC) power to alternating current (AC) power that matches the grid requirements. Such converters are referred to as DC/AC converters.

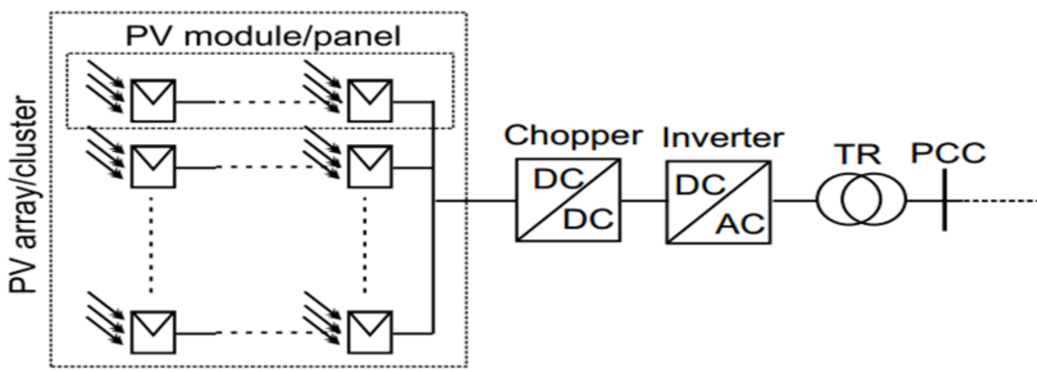

Figure 3. 8 Conventional photovoltaic array interface to the grid through central conversion.

C. Partial Power Electronics Coupling to the Grid

Other arrangements of power electronics coupling to the grid may implement smaller sizes of the converter, where the converter is rated for a certain percentage of the DG apparent power hence, referred to as partial power electronics coupling. Two such systems are shown in Figure 3.9 and 3.10.

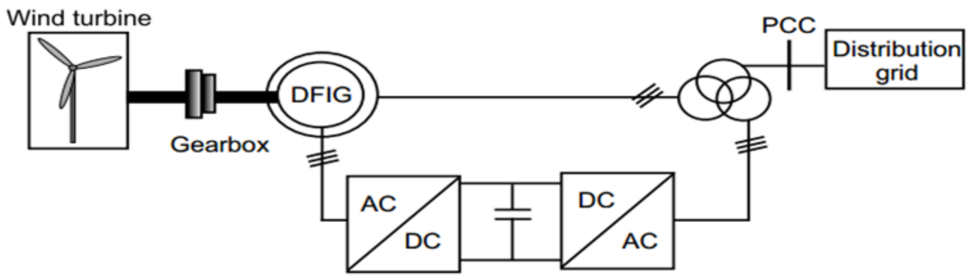

Figure 3. 9 Double-fed induction generator connection of a wind turbine.

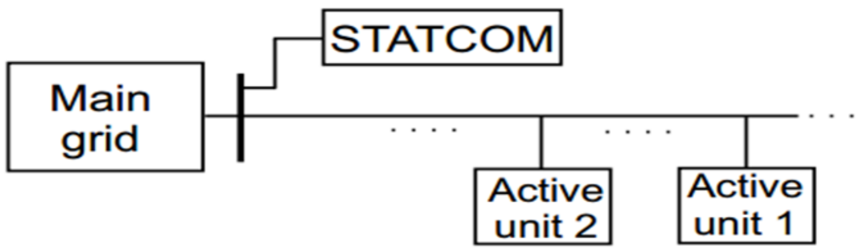

Figure 3. 10 Centralized power electronics connection

In a variable speed wind turbine with a double-fed induction generator, the converter feeds the rotor winding, while the stator winding is connected directly to the grid. This converter setup, through decoupling mechanical and electrical frequency and making variable speed operation possible can vary the electrical rotor frequency.

A partially rated power electronics converter at the connection point of a wind farm (or any other aggregate of sources) is usually needed to mainly provide a voltage dip ride-through capability, which is a required feature regarding different grid codes, and possible reactive power support. Usually a STATCOM (static var compensator), which is mainly a voltage source converter (VSC), is used for this purpose as shown in Figure 3.10. The voltage source converter is the main enabling technology to interface energy sources at the front end of the grid for either full or partial power electronics interfaces.

D. Distributed Power Electronics Interface

Distributed power electronics interfaces refer in this context to a number of distributed generations that are connected to the same local grid through power electronics converters. If such units belong to the same owner, their operation can be coordinated in a way to achieve certain benefits such as regulating the local voltage.

The module-integrated photovoltaic system, shown in Figure 3.11, is also a type of distributed active interface structure that has been basically developed in order to increase the efficiency and reliability of the solar power cells. This is possible since different solar cells in an array or a cluster are exposed to different irradiation. Hence, operating each integrated converter at a different point that is related to the MPP results in better reliability compared to using a central conversion. It has been found that using this structure increases the power efficiency to about 96% in addition to providing a better power quality.

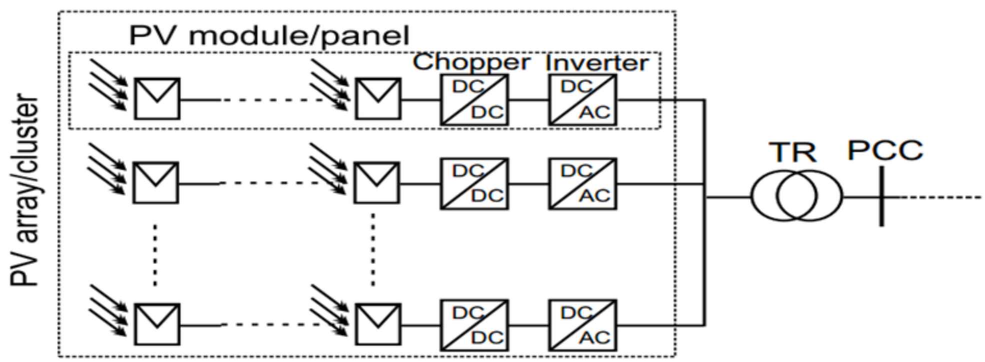

Figure 3. 11 Photovoltaic array interface through modular conversion.

- The interfacing technology of distributed generation to the grid determines its impact on the distribution system operation and also the impact of different upstream contingencies on the energy sources (Math Bollen and Fainan Hassan, 2011). The interfacing technology impacts the system in different ways:
- It determines the quality of the power supplied by the energy source. Usually, the grid operator (DNO) sets certain requirements over the power quality injected by the DG. It is the DG owner's responsibility to ensure that the DG technology meets the DNO requirements.
- It determines the impact of different power quality on the energy source. Different interfaces have different sensitivities to different power quality events at the grid.

- It determines the efficiency of the energy source. For example, using modular power electronics for solar power interfacing results in more efficient systems compared to central full power electronics interfacing.
- It determines the availability of the energy source. This is again determined by the sensitivity of different interfaces to the different power quality phenomena that originated from the upstream network.
- It impacts the cost of the DG installation.
- It determines the complexity of the DG application.
- It determines the controllability of the energy source. For instance, full power electronics interfaces introduce the most controllability of all interfacing technologies since they provide independent control overactive and reactive powers injected into the grid.

Table 3. 4 General Comparison of Interfacing (Math Bollen and Fainan Hassan, 2011)

Interfacing technology	Controllability	Robustness	Efficiency	Cost
Induction generator	Less	Less	High	Less
Synchronous generator	High	High	Very High	High
Partial power electronics	Very high	Less	High	Very high
Full -power electronics	Advanced high	Less	Less	Advanced high
Modular/distributed power electronics	Extreme high	High	Advanced high	Very high

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Introduction

Active and reactive power loss minimization and voltage profile improvement are conducted on Adelle-Haramaya and Harari distribution system which has 10 and 12 buses as shown in Figure 4.1 and Figure 4.5 respectively. The power losses and voltage profile of the existing system are determined based on the collected data which are presented in Table 3.1 and Table in chapter 3 using backward/forward load flow algorithm. In order to carry out the research ETAP16 and MATLABR2018a are deployed. Based on the flow chart a MATLAB code is developed for existing or radial, ring, and ring with DG. The proposed algorithm was executed for the minimization of power losses, voltage profile and reliability system indices improvement for all three scenarios.

4.2. Adelle-Harmaya Distribution System

- We can classify the result's in the three scenarios:-

I. Radial (Existing system)

II. Ring system

III. DG connected with the Ring system

4.2.1. Radial or existing system

The distribution system of Adelle-Haramaya was simulated with the help of ETAP 16 software and its diagram is presented in Figure 4.1. A load flow analysis using a backward/forward algorithm has been performed without connecting any DG in order to calculate voltage profiles at each bus and both real and reactive power losses in each line by using the bus load and line data in Table 3.1 in chapter 3. The radial voltage profiles and power loss of the system are presented in Table 4.1 and Table 4.2 respectively.

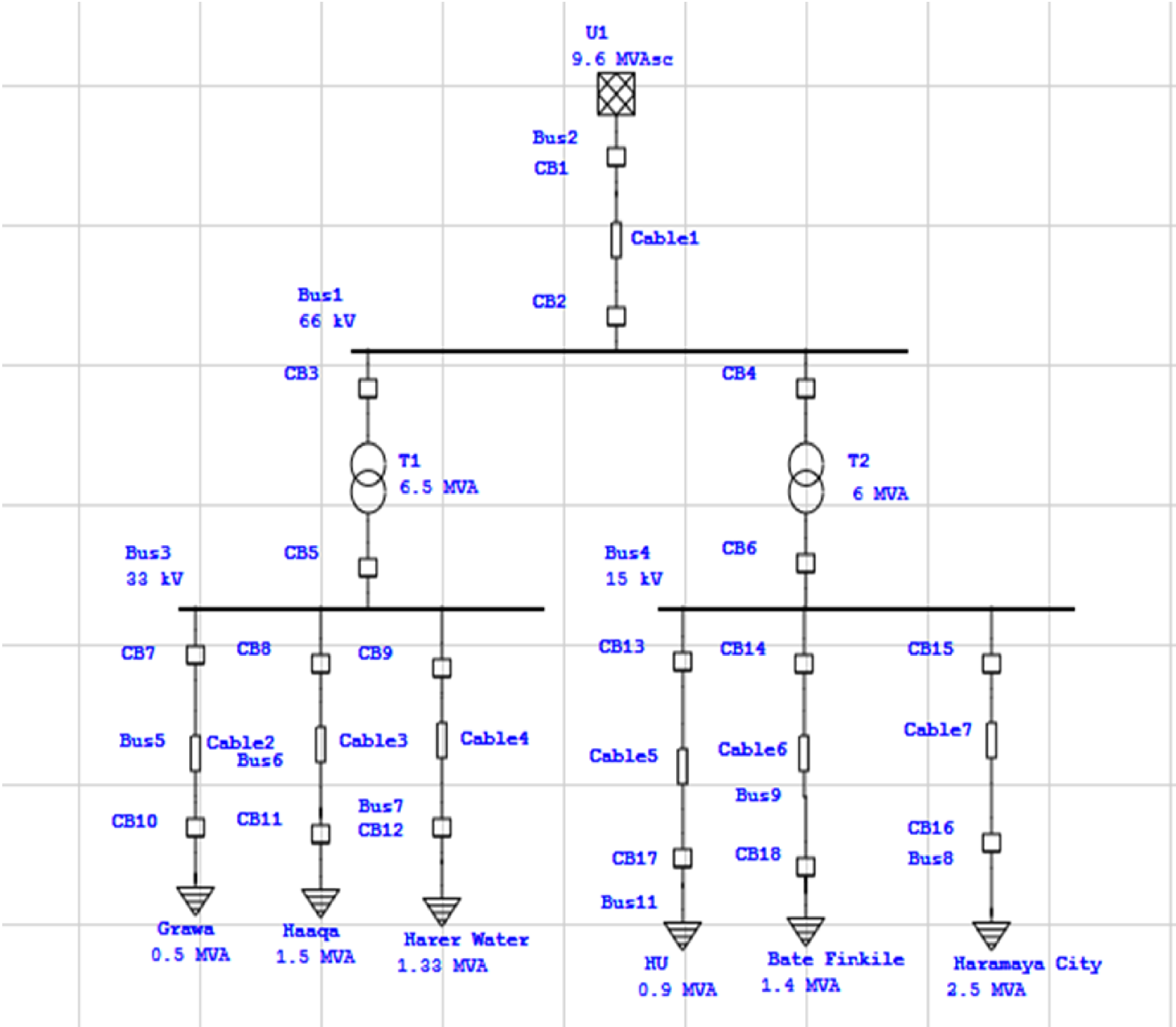

Figure 4. 1. Radial System of Adelle-Haramaya

- For the radial system we can determine power loss, voltage profile, and system index by using bus data and line data as input Table 3.1 from chapter 3 and Appendix A and B.
- By using the above Forward and Backward Sweep (FBS) (Appendix G) we can determine voltage profile and Power loss at the line.
- According to the IEEE standard voltage magnitude should be maintained between 0.95 to 1.05 Pu.

A. Voltage Profile and Power Losses result of Radial system

Table 4.1. Voltage Profile

Bus Name	Voltage (pu)
Bus 1	1.0000
Bus 2	0.6257
Bus 3	0.4735
Bus 4	0.4622
Bus 5	0.6429
Bus 6	0.7522
Bus 7	0.7736
Bus 8	0.7757
Bus 9	0.7823
Bus10	0.7875

In Table 4.1. As it can be observed the radial voltage profile of all buses except bus 1 are below the minimum threshold value (0.95pu). Bus 4 presents the lowest voltage profile among other buses.

Table 4.2. Power loss

No. of Line	P_{Loss}(Active Power in Kw)	Q_{Loss} (Reactive Power in Kvar)
1	16.9	33.4
2	7.0	91.6
3	0.3	2.2
4	13.1	4.8
5	57.3	20.8
6	14.7	5.3
7	0.1	0.1
8	0.5	0.1
9	0.8	0.2
Total	110.7	158.6

Table 4.2. Describes power loss of branches in terms of active power and reactive power of proposed existing system. The result's show's existing system has high power loss and going to improve with proposed Ring system and Ring with DG system

B. Reliability (System Index and Load Point Report (Appendix H.))

Table .4. 3. System Index

SAIFI	16.7693 f/customar.yr
SAIDI	408.8273 hr/customer.yr
EENS	1177.862 MWhr/yr
AENS	196.3104Mwhr/customer.yr

Table 4.3. Describes system index of Adelle-Haramaya Distribution System for proposed existing System. The result's show's existing system has low reliability and going to improve with proposed Ring system and Ring with DG system.

4.2.2. Proposed Ring System

For Adelle Haramaya distribution system 10 bus radial network, six additional lines have been connected. Line 14 between bus 3 and 12, line 15 between bus 12 and 13, line 16 between bus 14 and 15, line 17 between bus 15 and 4 to form a loop. Both the lines are 50m and follow ICEA rubber line configurations as shown. The rating of buses such as 3, 12, and 13 are 15kV and the rest of the buses are rated 33kV. To synchronize the voltage rating of every bus, a transformer is used between bus 13 and 14 to step up the bus voltage from 15kV to 33kV.

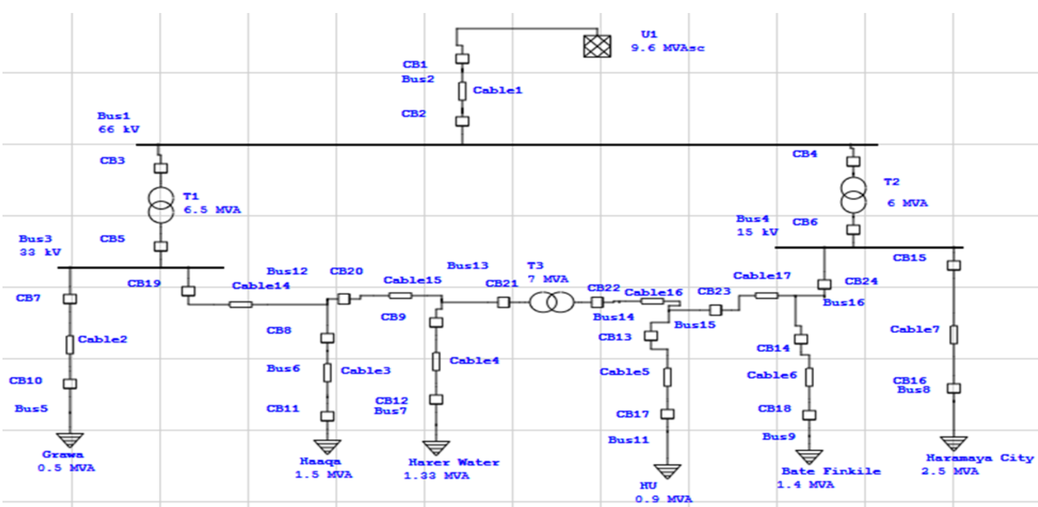

Figure 4. 2. Ring System of Adelle-Haramaya

Table 4. 4. Proposed Ring Bus Loading and Line (Branch) Data (Continued)

No. of Bus	P Load (Kw)	Q Load (Kvar)	No of Line	From Bus	To Bus	R(ohm)	X(ohm)
1	2939	268	1	1	2	9.85	128.08
2	2954	299	2	2	3	13.92	118.35
3	1769	158	3	3	4	9.15	118.35
4	1165	52.1	4	4	5	17.60	34.71
5	388	21.4	5	5	6	629.92	251.06
6	935	99.2	6	6	7	344.96	125.53
7	1124	38.4	7	7	8	157.48	62.76
8	154	9.3	8	8	9	470.07	72.89
9	171	9.6	9	9	10	470.89	72.89
10	97.1	5.6	10	10	11	235.04	36.44
11	1371	136	11	11	12	0.22	0.07
12	1145	47.8	12	12	13	0.22	0.07
13	740	27.3	12	13	14	4.93	0.32
14	838	32.9	13	14	15	4.93	0.32
15	1010	42.7	14	15	16	-	-

Table 4.4. Describes the 15-bus Ring the Distribution System of Adelle-Haramaya is consists of 15 buses, 14 lines (branches), 6 loads and 1 power grid. All buses have a voltage level of 66kV, 33kV, and 15kV respectively. Then the network is fed from the main substation through an overhead distribution line while it is loaded from 2.954 MW and 0.299MVAR.

- By using the bus data, line data from table 3.2 in chapter 3, and Forward and Backward Sweep (FBS) from Appendix G we can determine voltage profile and power loss at the line.

C. Voltage Profile and Power Losses result of proposed Ring system

Table 4.5. Voltage Profile

Bus Name	Voltage (pu)
Bus 1	1.0000
Bus 2	0.7050
Bus 3	0.5786
Bus 4	0.5023
Bus 5	0.4883
Bus 6	0.5281
Bus 7	0.5889

Bus 8	0.6144
Bus 9	0.7062
Bus 10	0.7993
Bus 11	0.8461
Bus 12	0.8461
Bus 13	0.8461
Bus 14	0.8465
Bus 15	0.8467

In Table 4.5. As it can be observed the Ring voltage profile of all buses except bus 1 are below the minimum threshold value (0.95pu). Bus 5 presents the lowest voltage profile among other buses. But it shows remarkable improvement to achieve the target.

Table. 4.6. Power Loss (Continued)

No. of Line	P_{Loss} (Active Power in Kw)	Q_{Loss} (Reactive Power in Kvar)
1	15.5	30.6
2	3.2	41.2
3	1.9	16.4
4	10.2	4.1
5	0.0	-2.8
6	0.6	0.1
7	30.4	12.1
8	21.1	8.4
9	1.4	0.2
10	0.5	0.1
11	0.0	-2.8
12	0.5	6.6
13	0.3	0.0
14	0.4	0.0
Total	86.0	114.3

Table 4.6. Describes power loss of branches in terms of active power and reactive power of proposed Ring system. The results show that power loss is minimized for proposed Ring system compared existing system.

D. Reliability (System Index and Load Point Report (Appendix I.))

Table 4.7. System Index

SAIFI	14.9391 f/customer.yr
SAIDI	360.0402 hr/customer.yr
EENS	771.467 MWhr/yr
AENS	128.5778 MWhr/customer.yr

Table 4.7. Describes system index of Adelle-Haramay Distribution System for proposed Ring System. The result's show's proposed Ring system has remarkable solution when it's compare to existing system.

4.2.3. Proposed Ring with DG

- So, the bus having less power loss will be the optimal location for the placement of DG and by using DG placement and size of PSO code we can determine their size.
- The power injections from renewable DG unit located close to the load center provide an opportunity for the system voltage support reduction in energy loss and emission and reliability improvement (Mahat P et al., 2012).
- By using the above PSO code (Appendix J) we can determine the size and location of DG respectively.

Table 4. 8. Optimal Location and Size

No.	**Optimal location**	**Optimal size**		
1	8	Per unit (pu)	Power (Kw)	Power (MW)
		0.2893	28.93 kw	0.02893
2	9	0.7668	76.68 kw	0.07668

Table. 4.8. Describes the optimal location and optimal size Dispersed Generation for proposed Ring with DG System. The optimal size can be described in per unit, kilowatt and megawatt. After optimal placement and size the voltage profile and power loss as follows:

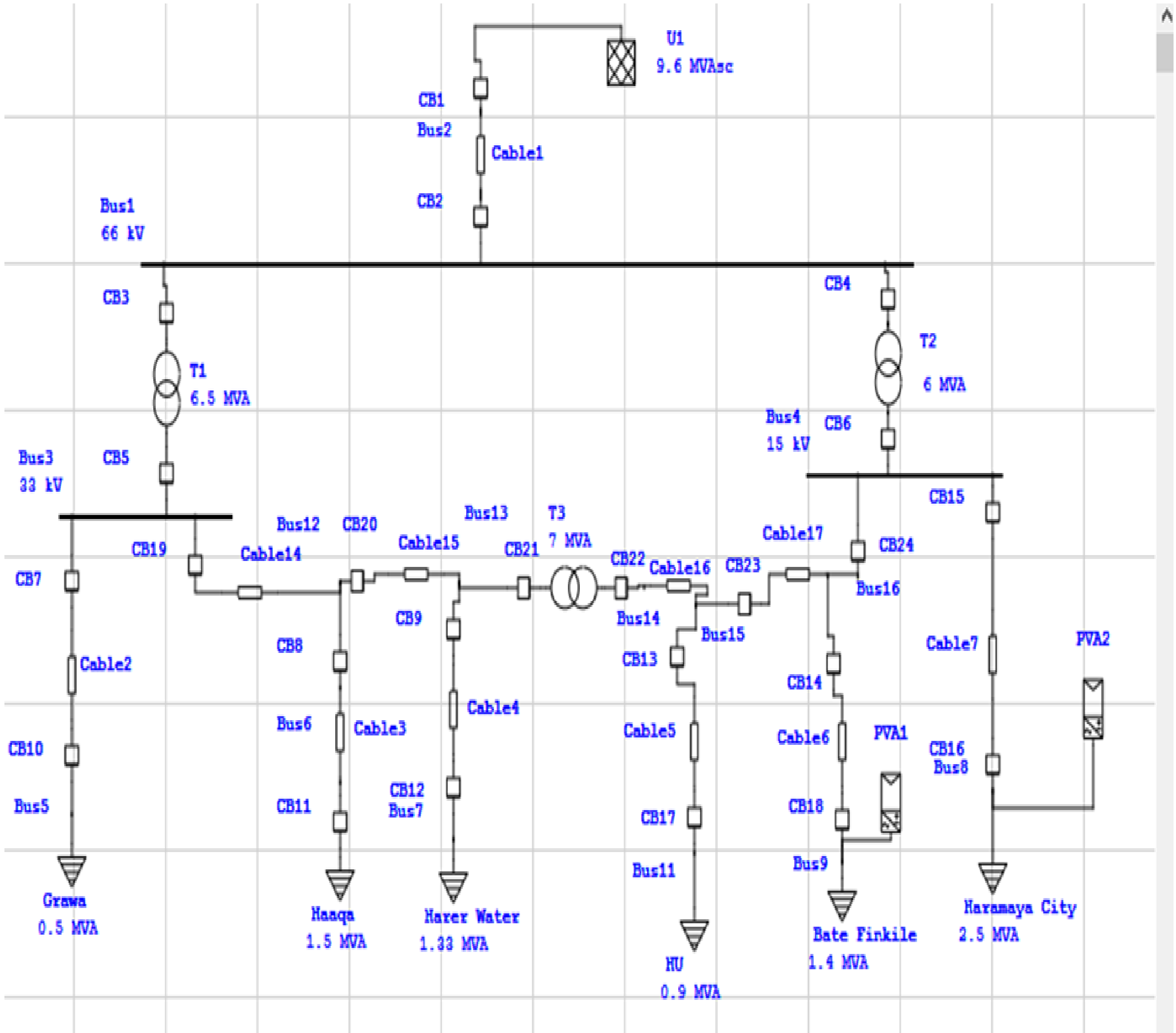

Figure 4. 3. Ring with Dg system

- By using the bus data, line data (From table 3.3. in chapter 3) and Forward and Backward Sweep (FBS, appendix G) we can determine voltage profile and Power loss at the line.

E. Voltage Profile and Power Losses result of proposed Ring with DG system

Table 4.9. Voltage Profile (Continued)

No. of Bus	Voltage (pu.)
1	0.99381
2	1.0000

3	0.98974
4	0.99146
5	0.96381
6	0.95760
7	0.97120
8	0.98776
9	0.98322
10	0.98637
11	0.98971
12	0.98970
13	0.99067
14	0.99104

As it can be observed that Ring with DG voltage profile of all buses are above the minimum threshold value (0.95pu). Bus 6 presents the lowest voltage profile among other buses. But it shows remarkable improvement has achieved the target.

Table 4. 10 Power Loss

No. of Line	**P_{Loss}(Active Power in Kw)**	**Q_{Loss}(Reactive Power in Kvar)**
1	15.52	30.6
2	10.22	4.07
3	30.38	12.11
4	21.11	8.41
5	0.457	0.0709
6	1.42	0.22
7	0.573	0.0888
8	0.0419	-2.76
9	0.0036	-2.77
10	0.275	0.0177
11	0.353	0.0227
12	3.17	41.24

13	1.93	16.36
14	0.511	6.64
Total	85.9645	113.3201

Table 4.10. Describes power loss of branches in terms of active power and reactive power of proposed Ring with DG system. The results show that power loss is minimized for proposed Ring with DG system compared to proposed Ring system and existing system.

F. Reliability (System Index and Load Report (Appendix K)) for proposed Rind with DG

Table 4. 11 System Index

SAIFI	11.3773 f/customer.yr
SAIDI	287.0287 hr/customer.yr
EENS	549.199 MWhr/yr
AENS	91.5332Mw hr/customer.yr

Table 4.11. Describes system index of Adelle-Haramaya Distribution System for proposed Ring with DG. The result's show's proposed Ring with DG has remarkable solution when it's compare to proposed Ring system and existing system.

4.2.4. Summary Result on Adelle-Haramaya Distribution system

1. System Index

Table 4.12. System index

System index	Radial	Ring	Ring with DG
SAIFI f/customer.yr)	16.3986	14.9391	11.3773
SAIDI (hr/customer.yr)	399.4565	360.0402	287.0287
EENS (MWhr/yr)	1151.021	771.467	549.199
AENS (Mw hr/customer.yr)	191.8369	128.5778	91.5332

Table 4.12. Reveals the summery of reliability system index for Adelle Haramaya Distribution system. In fact, reliability system index is a quantity that used to determine reliability performance of distribution system. Based on the results proposed Ring with DG has better reliability index compare with proposed Ring system and existing system.

2. Voltage Profile

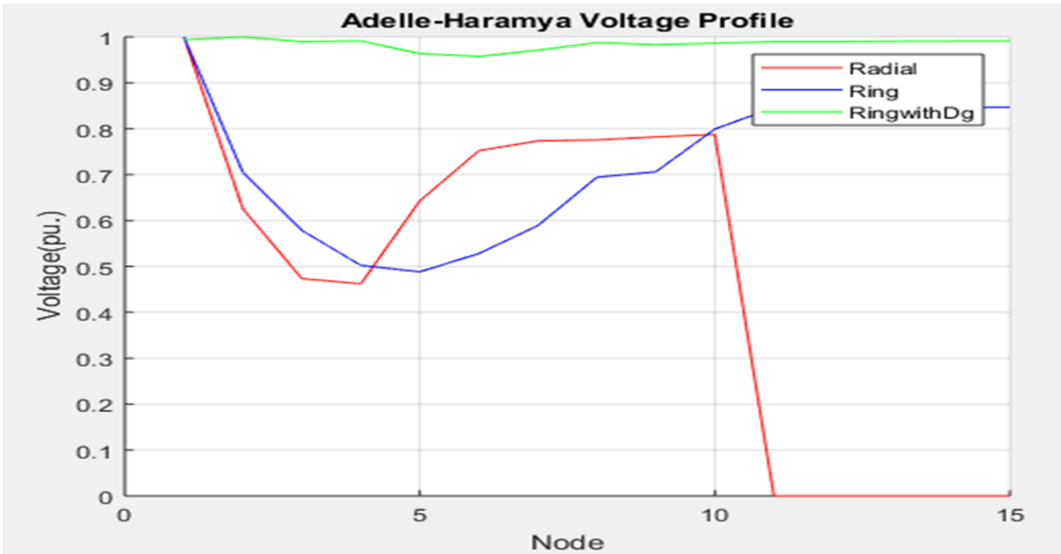

Figure 4. 4. Summary of Voltage profile of Adelle-Haramaya Distribution System

The simulation results reveal that the voltage profile of the system is significantly improved after the ring with DG is connected as shown in figure 4.7 above. The minimum voltage before the system connected with DG was 0.4622pu, and it is improved to 0.95760 pu after the system connected to the ring with DG by using PSO optimization. The ring with DG diagram is presented in figure 4.5 the voltage profile of all buses is still above the minimum threshold value.

Table 4.13. Adelle-Haramaya Distribution System Summary in all Scenarios (Continued)

Scenarios	Performance analysis	
Radial (Scenario 1)	Active power loss (Kw)	110.7
	Reactive power loss(Kvar)	158.6
	Minimum voltage (pu)	0.4622 (Bus 4)
	Maximum voltage (pu)	1.000 (Bus 1)
	SAIFI (f/customer.yr)	16.3986
	SAIDI (hr/customer.yr)	399.4565
	EENS (MWhr/yr)	1151.021
	AENS (MW hr/customer.yr)	191.8369

Ring (Scenario 2)	Active power loss (Kw)	86.0
	Reactive power loss(Kvar)	114.3
	Minimum voltage (pu)	0.4883 (Bus5)
	Maximum voltage (pu)	1.000 (Bus 1)
	SAIFI (f/customer.yr)	14.9391
	SAIDI (hr/customer.yr)	360.0402
	EENS (MWhr/yr)	771.467
	AENS (MW hr/customer.yr)	128.5778
Ring with DG(Scenario 3)	DG size in (Kw)	28.93 and 76.68
	DG location	8 and 10
	Active power loss (Kw)	85.0
	Reactive power loss(Kvar)	113.3
	Minimum voltage (pu)	0.95760 (Bus 6)
	Maximum voltage (pu)	1.000 (Bus 1)
	SAIFI (f/customer.yr)	11.3773
	SAIDI (hr/customer.yr)	287.0287
	EENS (MWhr/yr)	549.199
	AENS (MW hr/customer.yr)	91.5332

Table 4.13. Describes summery performance analysis Adelle-Haramaya Distribution System in three scenarios such as Radial system, proposed Ring system and Ring with DG system. Based on the simulation results proposed Ring with DG system shows remarkable improvement with respect to proposed Ring system and existing system.

3. Cost of Energy analysis

- The economical attributes of energy loss of P and Q power of DG considered based on Energy loss on annual basis is given by:
- Energy loss= $(Total real power loss)*(Ec*T) (Equation 4.1)
  Where, Ethiopian electric billing tariff, cost of energy is given below
  Cost of Energy=0.03318$/Kwh and T=8760hr/yr.
- Based on the Ethiopian electric billing tariff cost of energy, loss of distribution system is calculated by using equation 4.1.

- Cost of energy loss per year=Power loss(Kw)*Time (hr/yr)*tariff (ETB/Kwhr) (Equation 4.2)
- Selecting electric price tariff (from appendix D) for the radial system is 0.4993 ETB/Kwhr.

- **For Radial cost of Energy loss is 110.7 Kwhr/yr**
  - 110.7 Kwhr/yr * 8760hr/yr*0.4993ETB/Kwhr= 484,187.188ETB/yr.
- **For Ring with Dg cost of Energy loss is= 86 Kwhr/yr**
  - Selecting electric price (from appendix D) tariff for the ring with DG system is 0.3564 ETB/Kwhr
  - 86 Kwhr/yr* 8760hr/yr*0.3564 ETB/Kwhr= 268,497.504 ETB/yr
  - Saved Energy interim's of Kwhr and ETB as follows
  - Saved power loss interim's of Kwhr = Radial power loss – Ring with DG power loss. = 110.7 Kwhr/yr - 86Kwhr/yr= 24.7Kwhr/yr.
  - Saved cost of Energy loss is= Radial cost of Energy loss – Ring with DG cost of Energy loss.
    = 484,187.188ETB/yr. − 268,497.504 ETB/yr = 77,114.9808 ETB/yr is saved.

Payback period: - the cost of effectiveness of DG integration on the existing network is determined from the saving cost which is different of losses in birr before and after applying the proposed technique.

$$\text{Payback period} = \frac{\text{Captial Cost (ETB)}}{\text{Saving Cost (ETB/yr)}} \qquad \text{(Equation 4.3.)}$$

- Saving cost is 77,114.9808 ETB/yr
- Capital cost is the summation of cost of solar panels, inverters, battery, installation the cost, and maintenance cost. Since my DG is PV.
- The required material for 1MW/125Kw solar power plant such as panel, inverter, battery, mounting structure for the panel, fencing material, isolator taken from current market assessment like HagBes P.L.C, Pulse Business, RacRoB business and Adavis shirt fit.

Table 4. 14 Initial Capital Cost of solar plant according current market assessment:

Type of Equipment	Price in Birr(ETB) for 1MW	Price in Birr(ETB) for 125Kw
Solar panel	10.0711 million	1.25888 million
Inverter	3.486 million	0.43575 million
Batteries	2.124 million	0.2655 million
Mounting structure and fencing material cost with accessories	2.425 million	0.303125 million
Installation and maintenance cost (10% of Total cost)	1.8106 million	0.22635 million

- Then total capital cost is 19.9167 million ETB/2.491355million ETB.
- Payback=$\frac{2.49135 \text{ million ETB}}{77{,}114.9808 \text{ ETB/yr}}$=32.3069 yr.
- This means the cost of DG can be paid from 32.306 years of revenue loss from the distribution system.

4.3. Harari Distribution System

4.3.1. Radial or Existing System

For the radial system we can determine power loss, voltage profile and system index by using bus data and line data as input from table 3.3 in chapter three.

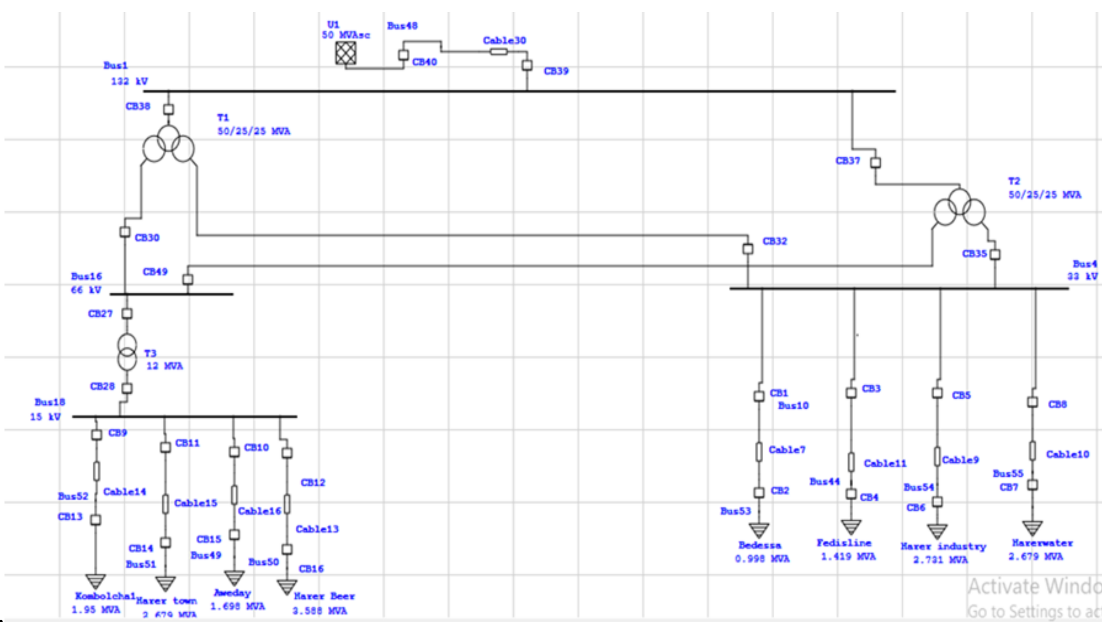

Figure 4.5. Radial system of Harari Distribution.

- By using the bus data, line data and Forward and Backward Sweep (FBS) (from appendix G) we can determine voltage profile at the bus and Power loss at the line.

G. Voltage Profile and Power Losses result of Radial system

Table 4. 15 Voltage profile (Continued)

No. of Bus	Voltage (pu.)
1	1.0000
2	0.5758
3	0.5759
4	0.5760
5	0.7833
6	0.8443
7	1.7407
8	2.0011
9	3.8748
10	4.1147
11	4.6982
12	4.6989

In Table 4.15. As it can be observed the radial voltage profile of all buses except bus 1 are below the minimum threshold value (0.95pu) and Bus 6,7,8,9,10,11,12 are above the maximum threshold value (1.05pu). Bus 2 presents the lowest voltage profile among other buses.

Table 4.16. Power Loss

No. of lines	P_{Loss} (Active Power in Kw)	Q_{Loss} (Reactive Power in Kvar)
1	5.0	9.7
2	9.7	2.1
3	201.3	7.3
4	56.7	33.4
5	141.6	-2933.0

6	0.1	1.4
7	3.2	0.1
8	50.2	6.6
9	1.4	0.2
10	2.7	0.4
11	0.00	0.00
12	0.00	0.00
Total	332.3	62.0

Table 4.16. Describes power loss of branches in terms of active power and reactive power of proposed existing system. The result's show's existing system has high power loss and going to improve with proposed Ring system and Ring with DG system.

H. Reliability (System Index and Load Report (Appendix L))

Table .4.17. System Index

SAIFI	17.0493 f/customer.yr
SAIDI	414.3857 hr/customer.yr
EENS	1031.956 Mw hr/yr
AENS	128.9945 Mwhr/customer.yr

Table 4.17. Describes system index of Harari Distribution System for proposed existing System. The result's show's existing system has low reliability and going to improve with proposed Ring system and Ring with DG system.

4.3.2. Proposed Ring system

For Harar distribution system 12 bus radial network, six additional lines have been connected. Line 29 between bus 29 and 36, line 30 between bus 36 and 37, line 31 between bus 37 and 38, line 32 between bus 39 and 40, line 33 between bus 40 and 41, line 34 between bus 41 and 5 to form a loop. Both the lines are 50m and follow ICEA rubber line configurations as shown. The rating of buses such as 29kV, 36kV, 37kV and 38kV are 15kV and the rest of the buses are rated 33kV. To synchronize the voltage rating of every bus, a transformer is used between bus 38 and 39 to step up the bus voltage from 15kV to 33kV.

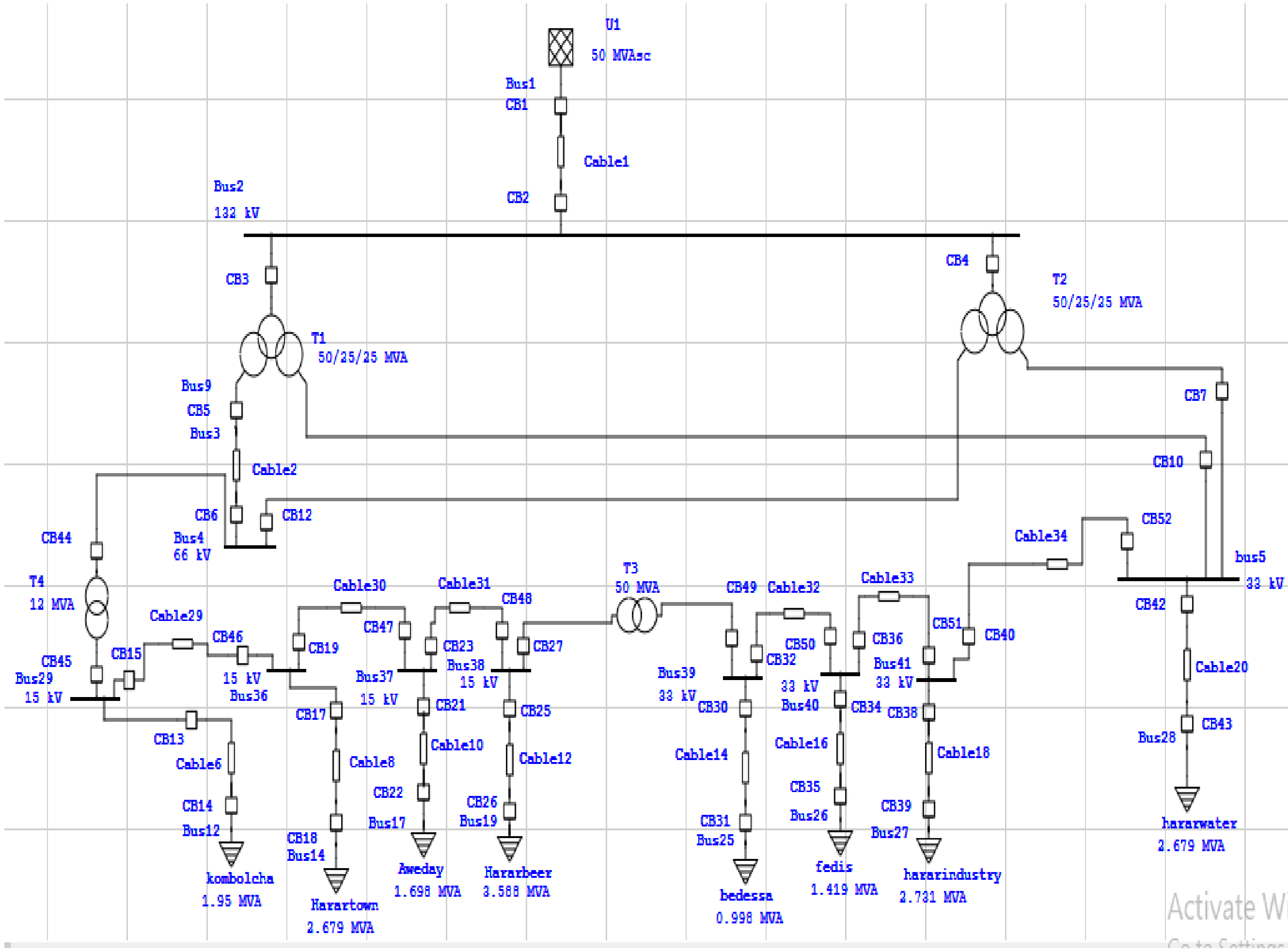

Figure. 4.6. Ring of Harar Distribution System

Table 4. 18. Proposed Ring Bus Loading and Line (Branch) Data (Continued)

Bus	P_{Load} (Kw)	Q_{Load}(Kvar)	Branch	Sending	Receiving	R(ohm)	X(ohm)
Bus 2	1791	370	T3	Bus20	Bus 22	1.28	16.65
Bus 4	192	111	T4	Bus 4	Bus 29	5.34	69.38
Bus 6	1917	459	T 1	Bus 2	Bus 9	0.09	0.04
Bus 9	126	111	T 2	Bus 2	Bus 4	0.03	-0.02
Bus 9	61	2.7	Cable 1	Bus 1	Bus 2	340.82	6.76
Bus 12	94.4	3.3	Cable 2	Bus 9	Bus 4	1.00	0.04
Bus 14	121	4.2	Cable 6	Bus 29	Bus 12	1939.341	701.13
Bus 25	207	5.3	Cable 7	Bus 29	Bus 13	5818.02	2103.4
Bus 26	352	8.1	Cable 8	Bus 13	Bus 14	5818.02	2103.4
Bus 27	406	10.4	Cable 9	Bus 13	Bus 16	4006.90	1893.0
Bus 28	269	8.8	Cable 11	Bus 18	Bus 16	2804.83	1014.0
Bus 29	72.5	20.5	Cable 12	Bus 18	Bus 19	1001.73	473.2
Bus 36	107	17.4	Cable 13	Bus 18	Bus 20	2404.14	869.2

Bus 37	107	13.9	Cable 14	Bus 22	Bus 25	4.93	0.33
Bus 38	239	13.9	Cable 15	Bus 22	Bus 23	4.93	0.33
Bus 39	471	9.2	Cable 16	Bus 23	Bus 26	4.93	0.33
Bus 40	875	9.9	Cable 17	Bus 18	Bus 20	1.00	0.04
Bus 41	1309	13.6	T3	Bus20	Bus 22	1.28	16.65

The 17-bus Ring the Distribution System of Harar is consists of 17 buses, 16 lines (branches), 8 loads and 1 power grid. All buses have a voltage level of 132kV, 66kV, 33 kV, and 15kV respectively. Then the network is fed from the main substation through an overhead distribution line while it is loaded from 1.766 MW and 0.0479MVAR.

By using the bus data, line data and Forward and Backward Sweep (FBS) (from Appendix G) we can determine voltage profile at the bus and Power loss at the line.

I. Voltage Profile and Power Losses result of Ring system

Table .4.19. Voltage profile (Continued)

No. of Bus	Voltage (pu.)
1	1.0000
2	0.8747
3	0.4963
4	0.4963
5	0.4963
6	0.9568
7	0.9584
8	1.2261
9	1.3156
10	1.3971
11	1.4469
12	1.4790
13	1.4892
14	1.5134
15	1.5185
16	1.5232
17	1.5270

In Table 4.19. As it can be observed the ring voltage profile of buses 2,3,4,5 are below the minimum threshold value (0.95pu) and Bus 8,9,10,11,12,13,14,15 are above maximum threshold value (1.05pu). Bus 3, 4, 5 presents the lowest voltage profile among other buses. But its show that remarkable improvement to achieve the target.

Table. 4. 20 Power Loss (Continued)

No. of lines	P_{Loss} (Active Power in Kw)	Q_{Loss} (Reactive Power in Kvar)
1.	106.4	2.1
2	0.0	0.0
3	0.0	0.0
4	23.3	0.8
5	0.0	-2.5
6	11.6	0.4
7	24.4	1.2
8	51.7	1.9
9	20.6	1.0
10	0.0	0.00
11	0.0	0.00
12	0.0	0.00
13	0.0	0.1
14	0.0	-0.2
15	0.0	-0.2
16	0.0	0.0
Total	256.4	5.2

Table 4.20. Describes power loss of branches in terms of active power and reactive power of proposed Ring system. The results show that power loss is minimized for proposed Ring system compared existing system.

J. Reliability (System Index and Load Report (Appendix K)) for Proposed Ring System

Table 4. 21. System Index

SAIFI	15.9380 f/customer.yr
SAIDI	385.1297 hr/customer.yr
EENS	784.376 Mwhr/yr
AENS	112.0537 MWhr/customer.yr

Table 4.21. Describes system index of Harari Distribution System for proposed Ring System. The result's show's proposed Ring system has remarkable solution when it's compare to existing system.

4.3.3. Proposed DG connected with the Ring system

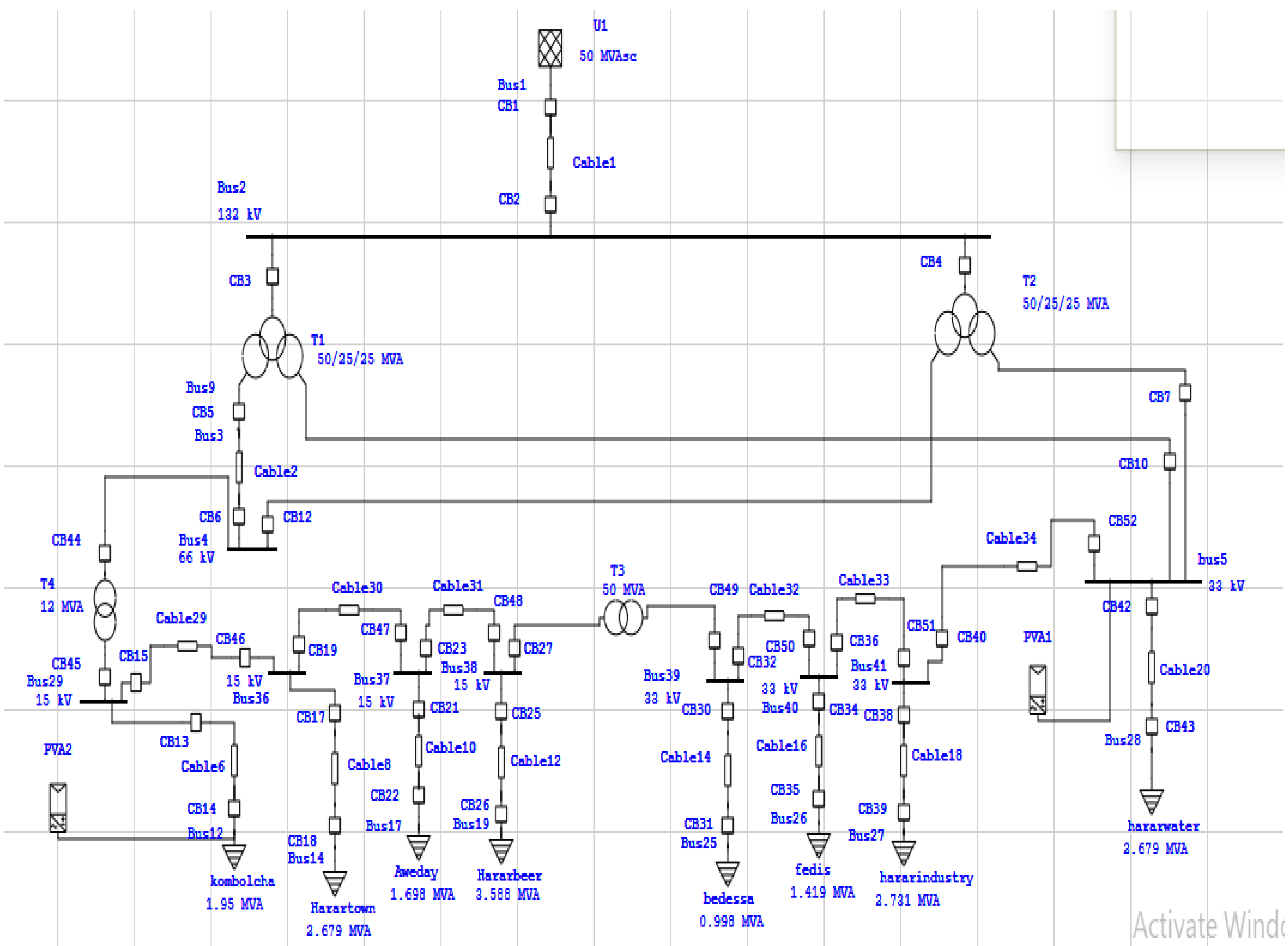

Figure 4.7. Ring with Dg Distribution System

By using the PSO code (appendix J) we can determine size and location of DG respectively.

Table 4. 22 Optimal location and optimal size

No.	Optimal Placement	Optimal size		
1	Bus 5	Per unit (pu)	Power (Kw)	Power (MW)
		0.5736	57.36	0.05736
2	Bus 12	0.8308	83.08	0.08308

Table 4.22. Describes the optimal location and optimal size Dispersed Generation for proposed Ring System. The optimal size can be described in per unit, kilowatt and megawatt. After optimal placement and size the voltage profile and power loss as follows:

K. Voltage Profile and Power Losses result of Ring with DG system

Table 4. 23 Voltage Profile

No. of Bus	Voltage (p.u)
1 (bus 1)	1.0000
2(bus 2)	0.93976
3 (bus 4)	0.93976
4 (bus 6)	0.93976
5(bus 9)	0.93975
6 (bus 12)	0.78973
7 (bus 14)	0.87692
8 (bus 19)	0.85782
9 (bus 20)	0.84072
10 (bus 25)	0.81919
11 (bus 26)	0.89421
12 (bus 27)	0.86489
13 (bus 28)	0.93968

As it can be observed the ring voltage profile of all buses except bus 1 are below the minimum threshold value (0.95pu). Bus 6 presents the lowest voltage profile among other buses. But it shows that remarkable improvement to achieve the target.

Table 4. 24 Power Loss (Continued)

No. of lines	P_{Loss}(Active Power in Kw)	Q_{Loss} (Reactive Power in Kvar)
1.	106.4	2.1
2.	0.0	0.0
3.	0.0	0.0
4.	23.3	0.8
5.	0.0	-2.5
6.	11.6	0.4
7.	6.8	0.2
8.	11.5	0.4
9.	24.4	1.2
10.	51.7	1.9
11.	20.6	1.0
12.	0.00	0.00
13.	0.00	0.00
14	0.00	0.00
15	0.00	0.1
16	0.00	-0.2
17	0.00	-0.2
Total	256.4	5.2

Table 4.24. Describes power loss of branches in terms of active power and reactive power of proposed Ring with DG system. The results show that power loss is minimized for proposed Ring with DG system compared to proposed Ring system and existing system.

L. Reliability (System Index and Load Report (Appendix L)) for Ring with DG

Table 4. 25 System Index

SAIFI	11.05617 f/customer.yr
SAIDI	270.1666 hr/customer.yr
EENS	565.619 Mw hr/yr
AENS	80.8027 hr/customer interruption

Table 4.25. Describes system index of Harari Distribution System for proposed Ring with DG. The result's show's proposed Ring with DG has remarkable solution when it's compare to proposed Ring system and existing system.

4.3.4. Summary report on Harari Distribution system

1. Reliability of System Index

Table 4. 26 Summary of System Index

System index	Radial	Ring	Ring with DG
SAIFI (f/customer.yr)	17.0493	15.9380	11.05617
SAIDI (hr/customer.yr)	414.3857	385.1297	270.1666
EENS (Mwh/hr.yr)	1031.956	784.376	565.619
AENS (Mwhr/customer.yr)	128.9945	112.0537	80.8027

Table 4.26. Reveals the summery of reliability system index for Hareri Distribution system. In fact, reliability system index is a quantity that used to determine reliability performance of distribution system. Based on the results proposed Ring with DG has better reliability index compare with proposed Ring system and existing system.

2. **Voltage Profile**

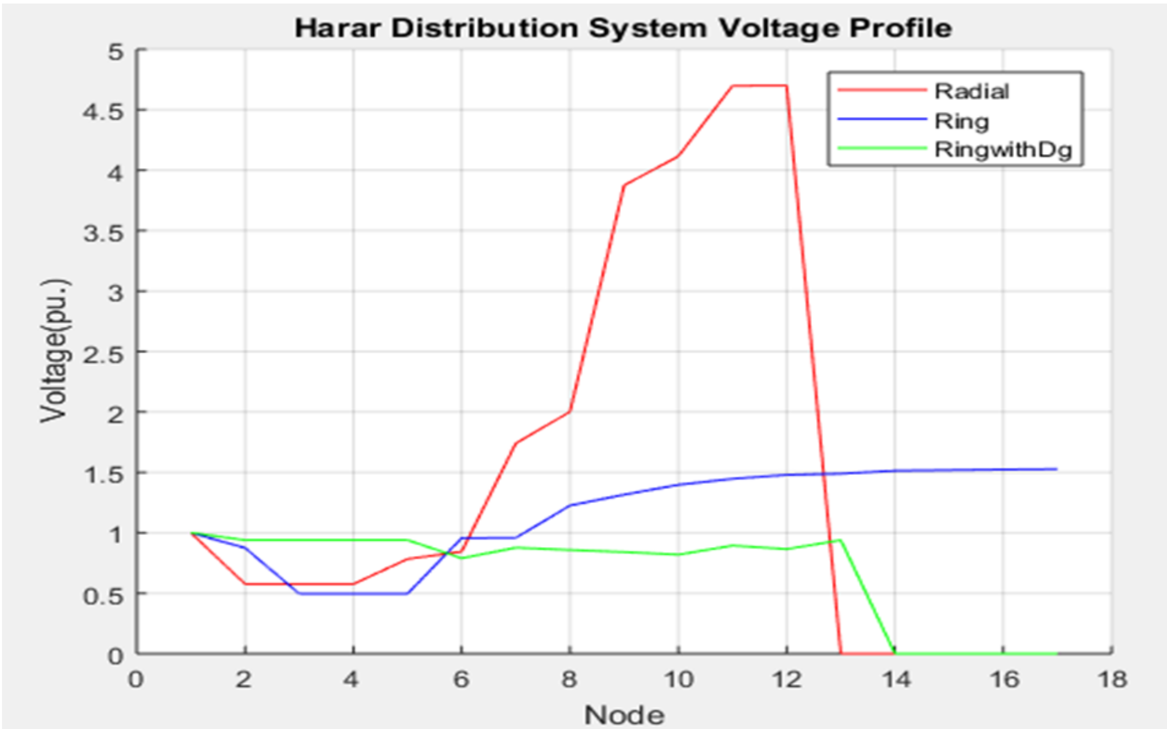

Figure 4.8. Voltage Summery of Harar Distribution System

The simulation results reveal that the voltage profile of the system is significantly improved after the ring with DG is connected as shown in figure 2.7 above. The minimum voltage before the system connected with DG was 0.5758pu, and it is improved to 0.78973 pu after the system connected to the ring with DG by using PSO optimization. The ring with DG diagram is presented in figure 1.5 the voltage profile of all buses is improved.

Table 4. 27 Harari Distribution System Summary in all cases (Continued)

Scenarios	**Performance analysis in all Scenarios**	
Radial (scenarios 1)	Active power loss (Kw)	332.3
	Reactive power loss(Kvar)	62.0
	Minimum voltage (pu)	0.5758 (Bus 2)
	Maximum voltage (pu)	4.6989 (Bus 12)
	SAIFI f/customer.yr)	17.0493
	SAIDI (hr/customer.yr)	414.3857

	EENS (MWhr/yr)	1031.956
	AENS (MW hr/customer.yr)	128.9945
Ring (scenarios 2	Active power loss (Kw)	256.4
	Reactive power loss(Kvar)	5.2
	Minimum voltage (pu)	0.4963 (Bus 3,4 & 5)
	Maximum voltage (pu)	1.5270 (Bus 17)
	SAIFI f/customer.yr)	15.9380
	SAIDI (hr/customer.yr)	385.1297
	EENS (MWhr/yr)	784.376
	AENS (MW hr/customer.yr)	112.0537
Ring with DG (scenarios 3)	DG size in (Kw)	57.36 and 83.08
	DG location	5 and 12
	Active power loss (Kw)	245.6
	Reactive power loss(Kvar)	1.2
	Minimum voltage (pu)	0.78973 (Bus 6)
	Maximum voltage (pu)	1.000 (Bus 1)
	SAIFI f/customer.yr)	11.05617
	SAIDI (hr/customer.yr)	270.1666
	EENS (MWhr/yr)	565.619
	AENS (MW hr/customer.yr)	80.8027

Table 4.27. Describes summery performance analysis Hareri Distribution System in three scenarios such as Radial system, proposed Ring system and Ring with DG system. Based on the simulation results proposed Ring with DG system shows remarkable improvement with respect to proposed Ring system and existing system.

3. Cost of Energy loss on Harari distribution system

Based on Ethiopia electric bill tariff cost of energy (Appendix D), loss of the distribution system is calculation using:-

Cost of energy loss per year from equation 4.2

- Radial system

- Energy loss=332.3 Kwhr/yr and the tariff based on range is 0.5880 ETB/Kwhr
- Cost of energy loss per year for radial =1,711,637.42 ETB/yr

- Ring with DG

- Energy loss per year=256.4Kwhr/yr and the tariff based on range is 0.5500ETB/Kwhr.
- Cost of energy loss per year for ring with DG =1,235,335.2 ETB/yr.
- By using payback equation 4.3, since saving cost and energy are 476,302.22 ETB/yr and 75.9 Kwhr/yr respectively.
- The capital cost and connected PV is close to 1MW/125 Kw.
- The capital cost from table 4.5, according to market assessment price including PV accessories and installation cost for 1MW is 19.9167 million ETB /2.491355million ETB.
- Payback period = (2.491355 million ETB) / (476,302.22 ETB/yr)= 5.23 years.
- The cost of DG can be paid from the 5.23 yearly revenue losses from distribution system.

4.4. Interface with Grid

For my research work, I choose from different types of interfacing technology (which is described clearly in chapter 3) the Distributed (Modular) Power Electronics Interface with Grid is essential for my research work. Since, the DG is PV, because PV is injecting active power to the grid. The selected interfacing technology is, Distributed Power Electronics Interface with Grid is refer in this context to a number of distributed generations that are connected to the same local grid through power electronics converters. If such units belong to the same owner, their operation can be coordinated in a way to achieve certain benefits such as regulating the local voltage. The module-integrated photovoltaic system, shown in Figure 4.16, is also a type of distributed active interface structure that has been basically developed in order to increase the efficiency and reliability of the solar power cells. This is possible since different solar cells in an array or a cluster are exposed to different irradiation. Hence, operating each integrated converter at a different point that is related to the MPP (Maximum Power Point of Tracking) results in better reliability compared to using a central conversion. It has been found that using this structure increases the power efficiency to about 96% in addition to providing a better power quality.

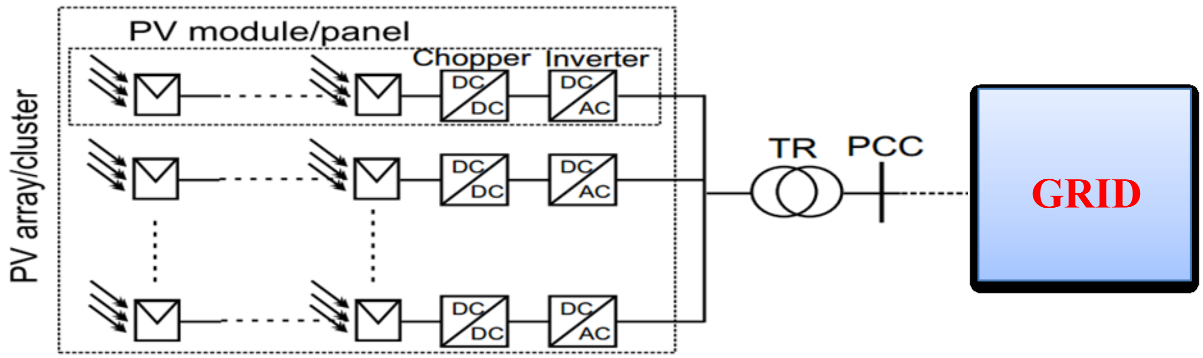

Figure 4.9. Photovoltaic array interface through modular conversion

In the end, the selection for my research, the Distributed (Modular) Power Electronics Interface with Grid is better when it compare with other interface technology based on controllability, robustness, efficiency, and cost (from chapter 3 in Table 3.2). Regarding controllability, it's extremely high, robustness is high, efficiency is advanced high, and the cost is high.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this research work, an efficient method has been implemented during DG integration and installs DG units simultaneously in distribution systems. In addition, different loss reduction methods (radial, ring, and ring with DG) are also simulated to establish the superiority of the proposed method. A Metaheuristic PSO is used in the optimization process for DG integration. The proposed method is tested Adelle-Haramaya and Harari Distribution System. The results show that 24.7Kw and 75.9Kw active power and 77,114.9808 ETB/year and 476,302.22 ETB/year can be saved by applying the proposed method and also the entire buses voltage profile are minimum voltage 0.95760pu and maximum voltage 1.000pu and minimum voltage 0.78973pu and maximum 1.000pu are maintained within the IEEE acceptable range except for Harar distribution system minimum voltage (ring with DG). The minimum voltage profile is 0.9500pu and 0.78973pu which confirms DG installation method is more effective in reducing power losses and improving the voltage profile compared to other methods. In the end, reliability improvement of Adelle-Haramaya and Harar Distribution system (from radial to ring with DG) of SAIFI (f/customer.yr), SAIDI (hr/customer.yr) and EEN (Mwhr/yr) are 16.3986, 399.4565 & 1151.021 to 11.3773, 287.6287 & 549.199 and 17.0493, 414.3857& 1031.956 to 11.05617, 270.1666 & 565.619 respectively.

The cost-effectiveness and payback period are also assessed and the results obtained demonstrate that 77,114.9808 ETB and 476,302.22 ETB can be saved each year after 32 and 5 years from when the DG unit is integrated into the system.

5.2. Recommendation

First of all, I strongly recommend that further researches shall be done on the protection and controlling of the upstream and downstream side of the system when DG is connected and installed. However, DG integration to the existing system can bring have an impact on the system such as poor system instability; reverse current flow, higher fault current, harmonics and complexity of the network.

Finally, I highly recommend to Ethiopian Electric Utility (EEU) to apply DG integrated system with PV for Adelle-Haramaya and Harar distribution system in order to improve existing system (voltage profile, power loss and reliability) data recording method and existing data it should be documented in advanced manner.

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7. APPENDIXCES

Table 1. Detail one year (2018-2019) load flow data and Interruption data of 33 KV Basbar Adelle- Haramaya Substation.

Name of feeder	Max Load (A) /MW	Min Load (A)/MW	MWh	MVAR	Time	TSC	PSC	TEF	PEF
Feeder (33KV	157.57/3.909	46.219/1.165	2131.07	561.857					
Haaqa (L1)	47.3571/0.798	17/0.272	361.5714	41.5714	F=7.14 T= 7.751	F=0.78 T=0.007	F=2.48 T=14	F= 0.85 T=0.013	F=3.785 T=24.77
Grawa (L2)	49/1.238	17.148/0.421	703.7142	248.785	F=9.5 T=7.102	F=3.642 T=0.054	F=4.571 T=22.62	F=1.35 T=0.014	F=3.214 T=20.02
Harer water (L4)	75.785/1.867	22.5/0.496	754.785	178.78857	F=1.714 T=1.784	F=0.928 T=0.010	F=1.214 T=19.67	F=1 T= 0.012	F=1.142 T=34.97

Where: - TSC, PSC, TEF, and PEF: - Temporary Short Circuitry, Permanent Short Circuitry, Temporary Earth Fault, and Permanent Earth Fault respectively.

Table 2. Detail one year (2018-2019) load flow data and Interruption of 15 KV BusBar Adelle- Haramaya Substation

Name of feeder	Max. Load (A/MW)	Min. Load (A/MW)	MWh	MVAR	Time	TSC	PSC	TEF	PEF
Feeder (15KV)	55.21/2.87	11.57/0.545	-	-					
HU (L2)	33.21/1.626	7.857/0.387	-	-	F=10.28 T=6.102	F=4.925 T=0.062	F=6.857 T=26.39	F= 0.85 T=0.008	F=1.857 T=11.71
Bate(L1)	8.071/0.3667	7.857/0.387	-	-	F=2.357 T=1.314	F=7.928 T=00.07	F=4.071 T=6.137	F=0.928 T=0.012	F=0.5714 T=0.32
Haramaya city (L4)	28.8571/-	4.07/0.211	-	-	F=18.42 T=11.20	F=2.785 T=0.042	F=4.5 T=16.35	F=3.5 T=0.057	F=3.428 T=15.98

Table 3. Harar Distribution Feeder Load

Feeder Load	Active Power (MW)	Reactive (MVAR)
fedis line 7	1.41421	0.12197
Kombolcha line 1	1.8375	0.6529
harar town line 2	1.6838	0.22059
Harer water	2.679	0.0068
Aweday line 3	1.82	0.126
Harer Beer	3.5877	0.0068
Harer Industry	3	0.3439

Table 4. Ethiopian Electric Billing System

	Active energy rate (Kwhr)	Price rate(ETB/Kwhr)
Residential	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	401-500	0.5880
	>500	0.6088
	0-500	0.6088
	>500	0.6943
Low voltage time of day industry @15Kv		
Peak		0.7426
Off peak		0.5354
High voltage Industry 132kV		
Peak		0.4736
Off peak		0.3664

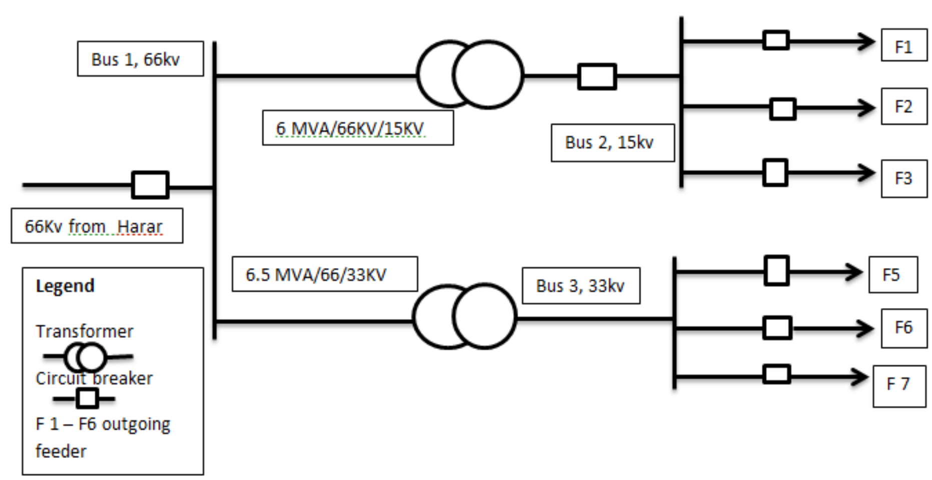

Figure 1. Single Line Diagram of Adelle-Haramaya Distribution system

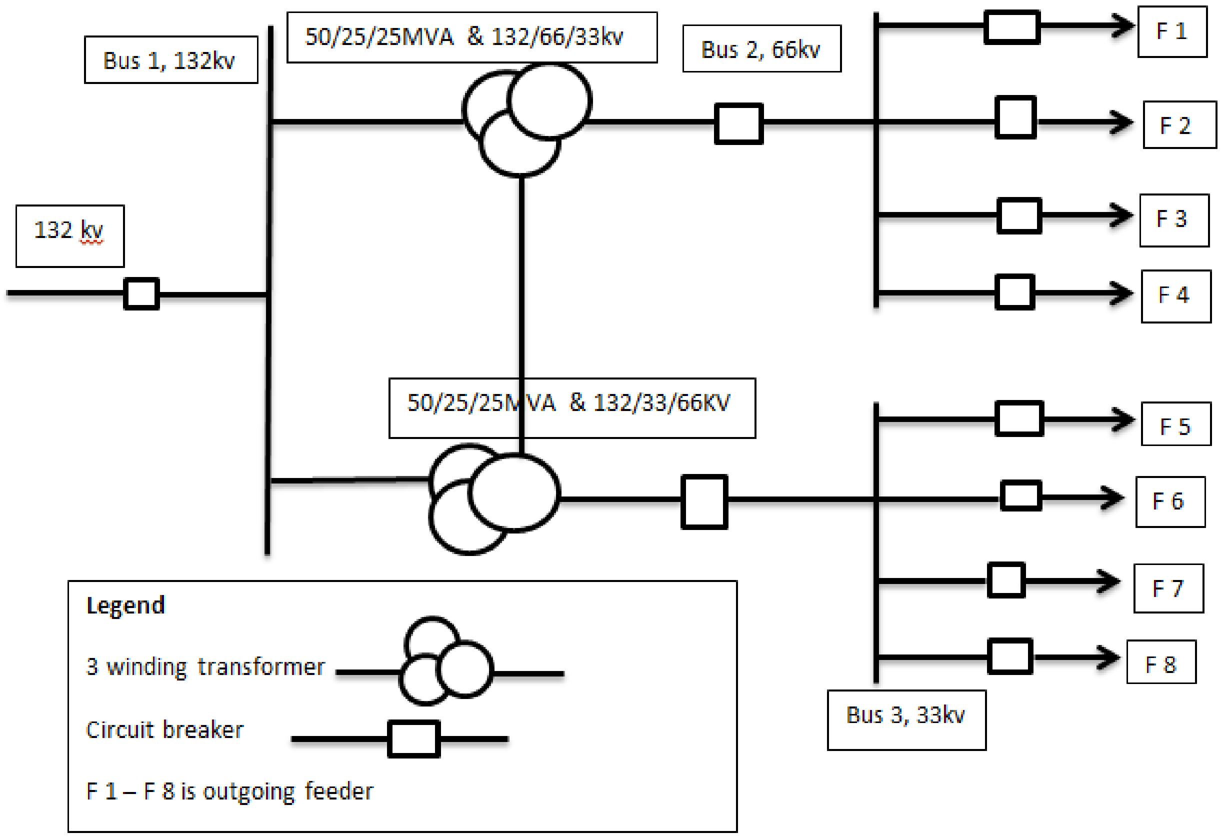

Figure 2. Single line Diagram of Harar Distribution System

1. Backward Forward Sweep Algorithm

```
clc
clear all
close all
LD=load('linedata7bus.m'); %loaded line data(LD)from another script
BD=load('Busdata7bus.m'); %loaded Bus data(BD)from another script
Sbase=100;%Base Power in MVA
Vbase=15;%Base Voltage in KV
Zbase=(Vbase^2)/Sbase;
LD(:,4:5)=LD(:,4:5)/Zbase;%Pu conversation of LD of 4 and 5 Coulumun
BD(:,2:3)=BD(:,2:3)/Sbase;%Pu conversation of BD of 2 and 3 coulumun
N=max(max(BD(:,2:3)));%Maximum number of bus system
Sload=complex(BD(:,2),BD(:,3));%Sload of each bus
V=ones(size(BD,1),1); %Initial Voltage
```

```
Z=complex(LD(:,4),LD(:,5));%Impedance of the line
Iline=zeros(size(LD,1),1); %Current in the line
Iter=2000;
%The main Algorithim
%BackWard Sweep
for i=1:Iter
   Iload=conj(Sload./V);
   for j=size(LD,1):-1:1 %Starting from end of the feeder
      c=[];
      e=[];
      [c,e]=find(LD(:,2:3)==LD(j,3));
      if size(c,1)==1%if has c one value then j is begining or end
        Iline(LD(j,1))=Iload(LD(j,3));
      else
  Iline(LD(j,1))=Iload(LD(j,3))+sum(Iline(LD(c,1)))-Iline(LD(j,1));
      end
   end
%Forward Sweep
for j=1:size(LD,1)
   V(LD(j,3))=V(LD(j,2))-Iline(LD(j,1))*Z(j); %KVL
end
end
%Voltage Magnitude
Voltage=abs(V);
Vangle=angle(V);
%Losses of the line
P=real(Z.*(Iline.^2));
loc1=find (~(isnan(P)));
Q=imag(Z.*(Iline.^2));
loc2=find(~(isnan(Q)));
real_power_loss=sum(P(loc1));
```

```
reactive_power_loss=sum (Q(loc2));
f1=real_power_loss;
f2= reactive_power_loss;
%% vsf calculation
for kk=1:length(BD(:,2))
for ki=1:length(LD(:,4))
vsfval (kk) =Voltage (kk)./0.95;
end
end
cvd=sum((1-abs(Voltage(:,1))).^2);
```

Table 5. Load Point Report of Existing Adelle-Haramaya System (Continued)

Load	**Average interruption rate (f/yr)**	**Average Outage duration (hr)**	**Annual Outage Duration (hr/yr)**	**EENS (Mwhr/yr)**
Bus 1	2.0540	17.92	36.8130	0.000
Bus 2	3.4660	20.87	72.3400	0.000
Bus 3	3.5030	21.81	76.3920	0.000
Bus 4	3.5030	21.81	76.3920	0.000
Bus 5	23.5360	24.56	577.9941	255.4067
Bus 6	11.5360	24.10	277.9940	368.5239
Bus 7	15.1360	24.31	367.9940	377.9016
Bus 8	18.3360	24.43	447.9940	55.7275
Bus 9	15.9360	24.35	387.9940	58.3165
Bus 10	16.1360	24.36	392.9940	61.9860
Grawa	35.5360	24.71	877.9941	387.9721
Haaqa	15.5360	24.33	377.9940	501.0892
Harer water	25.1360	24.59	617.9941	634.6324
HU	32.3360	24.68	797.9941	99.2653
Bate finkile	27.9360	24.63	687.9941	103.4074

Haramaya city	28.1360	24.63	692.9941	109.3044

Table 6. Load Point Report for Ring System of Adelle-Haramya

Load	**Average interruption rate (f/yr)**	**Average Outage duration (Hr)**	**Annual outage duration (Hr/yr)**	**EENS (Mwhr/yr)**
Bus 1	3.4660	20.87	72.3400	0.000
Bus 2	2.0545	17.92	36.8130	0.000
Bus 3	3.4760	20.94	72.7920	0.000
Bus 4	3.4760	20.94	72.7920	0.00
Bus 5	23.5090	24.43	574.3941	258.8801
Bus 6	13.4855	23.97	323.1940	373.0147
Bus 7	11.5100	23.84	274.4190	326.9066
Bus 8	18.3090	24.27	444.3940	60.6243
Bus 9	14.7100	24.09	354.4190	62.5847
Bus 11	16.7110	24.20	404.4210	57.3742
Bus 12	3.4770	20.94	72.8170	0.000
Bus 13	3.4770	20.94	72.8190	0.000
Bus 14	3.4780	20.94	72.8190	0.000
Bus 15	3.4780	20.94	72.8190	0.000
Bus 16	3.4770	20.94	72.8170	0.000
Grawa	42.7090	24.69	1054.3940	439.9339
Haaqa	33.1100	24.60	814.4191	830.6691
Harar water	12.3100	23.92	294.4190	350.7320
HU	39.9110	24.67	984.4211	98.2513
Bate finkile	23.9100	24.44	584.4191	103.1990

2. DG placement and size of PSO code.

```
tic;
 for ii = 1:10
  x(ii) = ii+1;
 end
 y = toc;
i=1;
S1=0.2777*ones(40,1)+(0.8329-0.2777)*rand(40,1);%sizing
S2=0.2777*ones(40,1)+(0.8329-0.2777)*rand(40,1);%sizing
L1=35*ones(40,1);%location
L2=25*ones(40,1);%location
X=[S1 S2 L1 L2];
d=4;
pop=40;
wmax=0.9;
wmin=0.4;
imax=200;
c1=2;
c2=2;
Vi=rand(pop,d);
pb=X;
worsts = zeros(40, 1);
bests = zeros(40, 1);
meanfits = zeros(40, 1);
pb1=P;
pb2=Voltage;
M=P;
N=Voltage;
[p_g, I]=min(M);
gb1=X(I,:);
gb2=X(I,:);
```

```
for i=1:imax
w=wmax-((wmax-wmin)/imax)*i;
for h=1:2
for j=1:pop
Vi(j,h)=w.* Vi(j,h)+c1*rand*(pb(j,h)-X(j,h))+c2*rand*(gb1(1,h)-X(j,h));
X(j,h)=X(j,h)+Vi(j,h);
Vi(j,h)=w.* Vi(j,h)+c1*rand*(pb(j,h)-X(j,h))+c2*rand*(gb2(1,h)-X(j,h));
X(j,h)=X(j,h)+Vi(j,h);
end
end
M1=P;
N1=Voltage;
[p_g1 ,I1]=min(M1);
if (M1<M) & (0.95<= N1) & (N1<=1.05)
pb=X;
end
if p_g1<=p_g
p_g=p_g1;
gb1=X(I1,:);
end
worsts(i) = max(M1);
bests(i) = p_g;
meanfits(i) = mean(M1);
end
gb1;
toc
```

Table 7. Load Point Report of Ring with DG (Adelle Haramaya)

Load	Average interruption (f/yr)	Average outage duration (hr)	Annual outage duration (hr/yr)	EENS (Mwhr/yr.)
Bus 1	0.0100	45.20	0.4520	0.000
Bus 2	1.4070	25.09	35.3020	0.00
Bus 3	0.0100	45.20	0.4520	0.000
Bus 4	0.0100	45.20	0.4520	0.000
Bus 5	21.2430	25.05	532.0541	221.9935
Bus 6	1.6195	25.23	40.8540	41.6691
Bus 7	4.8440	25.20	122.0790	145.4289
Bus 8	12.0560	25.51	307.5520	48.5095
Bus 9	10.0560	25.61	257.5520	45.4795
Bus 11	18.4450	25.05	462.0810	46.1186
Bus 12	0.0110	43.36	0.47770	0.000
Bus 13	0.0110	43.36	0.47770	0.000
Bus 14	0.0120	39.92	0.4790	0.000
Bus 15	0.0120	39.92	0.4790	0.0000
Bus 16	0.0110	43.36	0.47770	0.000
Grawa	39.2430	25.02	982.0541	409.7509
Haaqa	29.6440	25.03	742.0790	756.8856
Harar water	8.8440	25.11	222.0790	264.5557
HU	36.4450	25.03	912.0811	91.0314
Bate finkile	20.0560	25.31	507.5520	89.6255
Haramaya city	24.0560	25.26	607.5520	95.8278
Dg 1	12.0560	25.51	307.5520	0.000
Dg 2	10.0560	25.61	257.5520	0.000

Table 8. Load Point Report of Radial Harar Distribution System

Load	Average Interruption rate (f/yr)	Average outage Duration (hr.)	Annual outage duration (hr/yr)	EENS (MWhr/yr)
Bus1	5.4660	22.38	122.3400	0.000
Bus 4	5.4850	22.47	123.2420	0.000
Bus 16	5.4760	22.42	122.7920	0.000
Bus 18	5.5160	23.02	126.9940	0.000
Bus 44	8.2935	23.35	193.6189	239.7990
Bus 48	3.0545	20.24	61.8130	0.000
Bus 49	21.1490	24.52	518.5962	42.3682
Bus 50	25.9490	24.61	638.5962	35.96666
Bus 51	17.1490	24.41	418.5959	41.5181
Bus 52	13.5245	24.21	327.3709	95.8681
Bus 54	25.5180	24.49	624.8442	183.1588
Bus 55	7.4935	23.17	173.6189	43.6524
Kombolcha	19.5490	24.48	478.5959	140.5131
Harer Town	27.1490	24.63	668.5962	66.3142
Aweday	33.1490	24.69	818.5962	66.3142
Harer Beer	43.9490	24.77	1088.5960	61.3112
Fedis line	17.5180	24.25	424.8440	383.4635
Harer water	15.1180	24.13	364.8440	374.2622
Harer industry	43.5180	24.70	1074.8440	270.2243
Bedessa	37.5180	24.65	924.8440	271.0970
U1	0.6460	2.22	1.4360	0.000

Table 9. Load Point Report of Rind Harar Distribution system

Load	Average interruption rate (f/yr)	Average outage duration (hr)	Annual outage duration (hr/yr)	EENS (Mwhr/yr)
Bus 1	2.6545	19.52	51.8130	0.000
Bus 2	4.6660	21.93	102.3400	0.000
Bus 4	4.6760	21.98	102.7920	0.000
Bus 6	4.6790	22.00	102.9420	0.000
Bus 9	4.6750	21.97	102.6920	0.000
Bus 12	18.7090	24.29	454.3940	44.4175
Bus 13	13.9090	24.04	334.3940	41.0788
Bus 14	11.9090	23.88	284.3940	46.5915
Bus 16	20.7090	24.36	504.3940	147.9871
Bus 18	13.5090	24.01	324.3940	170.0362
Bus 19	13.7090	24.03	329.3940	167.1861
Bus 22	19.1120	24.31	464.5440	167.0790
Bus 23	4.6760	21.98	102.6420	0.000
Bus 24	4.6760	21.98	102.6420	0.000
Bus 25	4.6730	21.96	102.6420	0.000
Bus 26	4.6760	21.98	102.6420	0.000
Bus 27	4.6760	21.98	102.6420	0.000
Bus 28	4.6760	21.98	102.6420	0.000
Bus 29	4.6760	21.98	102.6420	0.000
Kombolcha	28.7090	24.54	704.3941	68.8552
Harer Town	21.9090	24.39	534.3941	65.6479
Aweday	21.9090	23.27	179.3940	234.8260
Harer Beer	17.9090	24.26	434.3940	248.6611
Fedis line	19.5090	24.32	474.3940	248.6975
Harer water	31.1120	24.57	764.5441	274.9777
Harer industry	32.7090	24.59	804.3941	236.0058

Table 10. Load Point Report of Ring with DG Harar Distribution System (Continued)

Load	Average interruption rate (f/yr)	Average outage duration (hr)	Annual outage duration (hr/yr)	EENS (Mwhr/yr)
Bus 1	2.0070	25.06	50.3020	0.000
Bus 2	0.0100	45.20	0.4520	0.000
Bus 4	0.0100	45.20	0.4520	0.000
Bus 6	1.2670	5.42	6.8720	0.000
Bus 9	0.0090	39.11	0.3520	0.000
Bus 12	11.2780	22.83	257.4220	164.8538
Bus 13	9.2430	25.11	232.0540	028.5068
Bus 14	7.2430	25.14	182.0540	29.8254
Bus 16	16.0430	25.06	402.0540	117.9610
Bus 18	8.8430	25.11	222.0540	116.3931
Bus 19	9.0430	25.11	227.0540	115.2428
Bus 20	15.7000	23.47	368.4740	132.5262
Bus 22	0.0100	45.20	0.4520	0.000
Bus 23	0.0100	45.20	0.4520	0.000
Bus 24	0.0070	45.20	0.4520	0.000
Bus 25	0.0100	45.20	0.4520	0.000
Bus 26	0.0100	45.20	0.4520	0.000
Bus 27	0.0100	45.20	0.4520	0.000
Bus 28	0.0100	45.20	0.4520	0.000
Bus 29	0.0100	45.20	0.4520	0.000
Kombolcha	21.2780	23.85	507.4220	49.6010
Harer Town	17.2430	25.06	432.0540	53.0759
Aweday	13.2430	25.07	332.0540	54.3995
Harer Beer	13.0430	25.07	332.0540	195.0179
Fedis line	14.8430	25.53	332.0540	195.0179
Harer water	27.7000	24.13	668.4741	240.4249

Harer industry	17.0430	25.06	427.0540	216.7541
Bedessa	28.0430	25.03	702.0541	205.9797
U1	0.6460	2.22	1.4360	0.000
Inv1	1.2670	5.42	6.8720	0.0000