WOLKITE UNIVERSITY

COLLEGE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING (*Power stream)*

Title: Study on Voltage drop minimization at Wolkite University

This project which entitled Study on voltage drop minimization at Wolkite University is submitted to Wolkite University's Electrical and Computer Engineering Department for the fulfillment of Degree of Bachler Science.

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June14/2011E.C,

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DECLARATION

We declare that all the work presented in this Study is our own work. All the work that is not our own has been acknowledged and referenced accordingly herein. This Study is being submitted for the degree of Bachler of Science in Electrical and Computer Engineering in Wolkite University. It had not been submitted before for any degree or examination at any other university.

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Approval

This is to certify that the project entitled study of voltage drop minimization at Wolkite University has not submitted for the partial fulfilment of the requirement for the award of Bachelor of Science at Electrical Engineering in our University or any other Universities. It is developed and submitted by students listed above.

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ABSTRACT

The main aim of this project is to give reliable electric access to Wolkite University by minimizing the voltage drop and electric power interruption from the selected distribution network. All most all of the institution's offices, cafe's, lounges, library or lecture class and dorms use electronic equipment's which needs to electrify for their efficient operations and also the institutes water source is electric power based. But due to some technical problems of the existing distribution network, they are exposed to a voltage drop. Even though there is high voltage drop and power interruption face the institute at different time, there was no any solution is found for the problem rather than using diesel generator.

This work can solve such problems by using well designed installation and loss reduction method. The cause of voltage drop can be improper installation like: under conductor size, poor power factor, unbalanced circuit, distance from the distribution transformer, over loading or over load current on the selected power source, lack of load sharing system etc. So, this type of problem including power interruption can be minimized using the above two methods. In these two methods every important points and methods are identified well. For the success of this project and to analyses we have used commercial and popular w\power system software DigSILENT power factory 15.1

Key Words: voltage drop, well designed installation, load current, power loss, loss reduction.

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ACHRONYMS

AC	alternative current
ACC	all copper conductor
DB	distribution board
EEPCO	Ethiopian electric power corporation
EEU	Ethiopian electric utility
EDN	electric distribution network
HV	high voltage
IEE	international electrical engineering
KVA	kilovolt ampere
LV	low voltage
LTC	load tap changers
MVA	megavolt ampere
RC	reinforced concrete
VA	volt ampere
WKU	Wolkite University

CHAPTER- ONE

INTRODUCTION

1.1. Background

Electric-power transmission is the bulk transfer of electrical energy, from generating power plants to electrical substations located near demand centers. This is distinct from the local wiring between high-voltage substations and customers, which is typically referred to as electric power distribution. Transmission lines, when interconnected with each other, become transmission networks.

Nowadays power systems are complicated networks. They have hundreds of generating stations and load centers that are interconnected through power transmission lines. Electricity is generated and supplied to consumers via transmission and distribution networks and contributes a major share in the consumer markets of the world. Power systems of the modern time are more reliable and serve customer load with minimum voltage drop in utility equipment. Generation facilities should have the capacity to produce required power to meet the customer demand. Bulk power generated must be transported through transmission systems over a long distance without overheating or jeopardizing system stability. It is responsibility of the distribution system to deliver electricity to each customer's service entrance with less drop voltage. Voltage drop is caused by improper installation, less cross sectional area of the conductor, distance from the distribution transformer to the customer and such likes. Additionally, in this project we tried to mention all the causes of this voltage drop and how can we minimize it by using different methodologies.

1.2. Statement of problem

Electricity is a core utility for the development of one country. Electric power providers have a duty to ensure that customers are supplied with the required voltage level at all times. Surprisingly, the causes and effects of voltage drops on transmission and distribution systems have not been extensively looked as much. This voltage drops causes burning of equipment and insufficient working, WKU still complaining since there is a high voltage drop and power interruption within the distribution network in the institution. Therefore, this work will minimize such problems by proposing necessary techniques after identifying the main causes for the voltage drop.

1.3. Objective of the project

1.3.1. General objective

The main objective of this study is to minimize the voltage drop in Wolkite University by using well-designed installation and loss reduction method in order to get reliable energy in the institution.

1.3.2. Specific objectives

- To show and solve for the main causes and consequences of voltage drop
- To show the exact location where the problem occurs and understand how can solve the problem.
- Improving reliability and safety of the distribution networks.
- By showing the relationship between distances of the customer from the distribution transformer, operating voltage and its resistance; reducing voltage drop.
- To minimize loss by using reactive power compensation

1.4. Research Questions

- What is voltage drop and how it occurs?
- What are the consequences of voltage drop in an electrical system?
- How can minimize a voltage drop in a power system?
- Is Wolkite University faces a problem of voltage drop?
- Are power interruption and voltage drop inter related?

1.5. Scope of the study

The project will conduct in Wolkite University. And it will focus on determining the magnitude of voltage drop and minimizing its value to a standard value and reducing power interruption by using well-designed installation and reactive power compensation method using a popular software known as DigSilent power factory software. Although this study is focus on Wolkite University electric power utility and distributions in the institution, anyone can use this study to solve loss problems in the area specified by taking permission from the study's owner.

1.6. Significance of the Study

This study used to achieve goal of socio economic development through proper management of electricity at the Institute of Wolkite University. Without electric power it is difficult to accelerate any satisfied work since most of the institute offices, cafe's internal equipment(like computers, copy and printing machines, motors) are electronic, students can't use any choice of light to read or work as they want without electric power. Thus, it is mandatory to look at possible approaches which will help to minimize voltage drop in the distribution. Generally, this work will provide good and suitable electric accesses, improve productivity of individuals, the governmental institutes assure comfort with safety of pedestrian and create job opportunity for skilled and unskilled persons.

1.7. Organisation of the study

The study is organized based on the following flow chart to achieve the objective of the project.

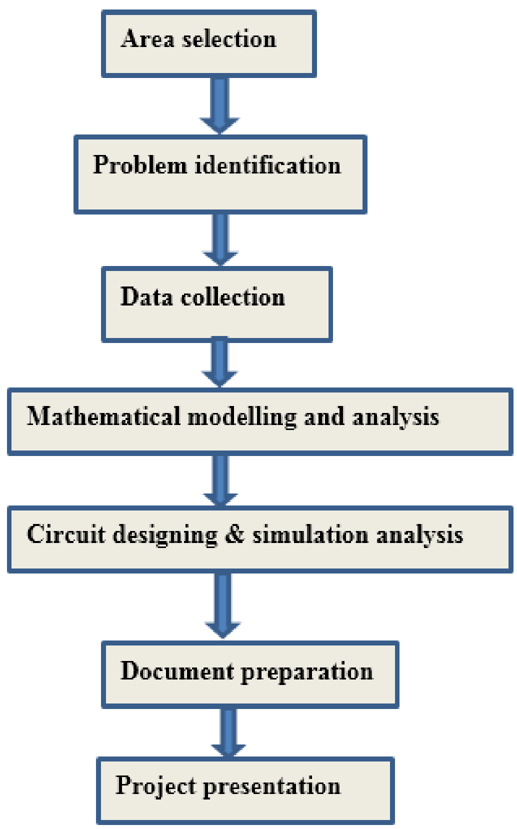


Chart1. Structure of the study

CHAPTER TWO

LITERATURE REVIEW

2.1. Electric power system

The electricity network develops from time to time with localized street lighting systems and have evolved to become today interconnected national transmission and distribution network. An electric power system consists of three principal divisions; the generating station, the transmission lines, and the distribution systems. These have their own function as described below.

"*Generation station:* Electrical energy is generated at power generation stations which are located far from customers. There are different power plants that generate power in our country like geothermal, wind, biomass and hydropower plant but hydropower plant is the major.

Transmission system: Transmission network used to transfer the electric power from the generating unit to the distribution system. The transmission line can be categorized into high voltage (>100kv), medium voltage (20kv-100kv) and low voltage(<20kv) transmission line. All the transmissions will be terminated at the substation.

Distribution system: it consists of step-down transformers of different voltage levels and bus bars. High voltage levels from transmission line will be stepped down to low and medium voltage at the substations. This will then be connected to the bus bars. The distribution voltages are132kv, 66kv, 33kV, 15kV, and 380-400/220-240 V. In power distribution system, one of the main purposes of system operation is to keep the voltage supplied to the customers stable and reliable. Magnitude and frequency at the terminals of all equipment should be within the allowed operating range. Consumer must receive voltage that suitable with their demand. So the customers shall get voltage at the determined voltage level" [1].

2.2. Voltage drop

"Voltage drop is defined as the reduction of voltage in an electrical circuit between the source and load. In the power distribution system, the main concern for distribution utilities about power stability is voltage drop. Energy is transferred from the bulk supply substations towards the ends of distribution networks. Also Voltage drop is the amount of voltage loss that occurs through all or part of a circuit due to impedance. Excessive voltage drop may result in unsatisfactory operation of electrical equipment's and damage to, electrical and electronic equipment" [2].

2.2.1. Causes of voltage drop and location of occurrence

"Voltage drop is caused by different ways; such as improper wiring, distance of the customer from the distribution transformer, falling of tree on the transmission line, cross sectional area of the conductor and resistance. The resistance of a conductor increases as the length increases and/or the cross sectional area (c.s.a.) decreases. Associated with an increased resistance is a drop in voltage, which means that a load at the end of a long thin cable will not have the full supply voltage available" [3].

"Voltage drop can be tolerated as long as compensation means are provided by voltage regulation equipment that adjusts the voltage drop on the circuit. Usually load tap changer (LTC) or bus regulator at the substation regulates the voltage at the source" [4]. Voltage drops may occur in

- Primary distribution line,
- Distribution transformer, and
- Secondary distribution line.

Voltage drop in the distribution circuit during peak loads and voltage rise during low loads is the main problem, in addition to the problem of overloading of distribution transformers and secondary feeders. Therefore, in order to maintain voltage, one cannot ignore consumers connected at the starting point as well as at the terminating point of the distribution network. At the end of line, voltage level is usually dependent on the transformer loading as well as length of secondary distribution line. However, the voltage drop allocation for the secondary line also relies on utility's design practice. The total voltage drop in the secondary circuit of distribution system is highest at the remote end voltage.

2.2.2. Consequences and acceptable value of voltage drop

"Low voltage can cause lights to dim, some television pictures to "shrink," motors to run hot, electric heaters to not produce their rated heat output, appliances to not operate properly, poor efficiency, wasted energy as well as it may be causes of power interruption." [3].

The maximum permitted voltage drop varies from one country to another. But national and local electrical codes may set guidelines for the maximum voltage drop allowed in electrical wiring, to ensure efficiency of distribution and proper operation of electrical equipment. The national electrical code accepted by EEPCO states that "a voltage drops of 5% at the furthest end customer in a branch wiring circuit is acceptable for normal efficiency" [5].

2.2.3. Limiting the voltage drop

Voltage-drop limit refer to normal steady-state operating conditions and do not apply at times of motor starting, simultaneous switching of several loads, etc. When voltage drops exceed the values of the acceptable voltage larger cables must be used to correct the condition. Voltage drop limits the design and operation of distribution networks with long feeders. The maximum allowable voltage variation on the HV and LV networks is a major and often primary constraint in the planning and design of the distribution feeders, which cannot be considered in isolation from each other [6]. Assumed or assigned volt drop limits affect the capital and lifetime costs of the networks.

2.3. Transformer

"A transformer can accept energy at one voltage and deliver it at another voltage. This permits electrical energy to be generated at relatively low voltages and transmitted at high voltages and low currents, thus reducing line losses and voltage drop. Transformers consist of two or more coils that are electrically insulated, but magnetically linked. The primary coil is connected to the power source and the secondary coil connects to the load.

The turn's ratio is the ratio: $\boldsymbol{\alpha} = \frac{\mathbf{N1}}{\mathbf{N2}} = \frac{\mathbf{V1}}{\mathbf{V2}} = \frac{\mathbf{I2}}{\mathbf{I1}}$

Where N_1 and N_2, V_1 and V_2, I_1 and I_2 are primary and secondary turns, voltage and current of the transformer respectively; α is turns ratio of the transformer. Similarly, voltage regulation of a transformer is given by;

$V_R = \frac{Vnl - Vfl}{Vnl}$ x 100%" [8]; where; V_{nl} voltage at no load

V_{fl} voltage at full load and V_R voltage regulation.

2.3.1. Types of Transformers

Transformers are classified into two categories:

I. Power transformers

Power transformers are used in transmission network of higher voltages, deployed for step up and step down transformer application (400 kV, 200 kV, 110 kV, 66 kV, 33kV).

II. Distribution transformers

Distribution transformers are providing the final voltage transformation in the electric power distribution system, stepping down the voltage used in the distribution lines to the level used by the customer. Because of weight restrictions transformers for pole mounting are only built for primary voltages less than 30 kV. So that it is used for lower voltage distribution networks as a means to end user connectivity (15kV, 220V, 380V, 440V, 230V).

2.3.2. Rating of Transformer

Rating of the transformer is calculated based on the connected load and applying the diversity factor on the connected load, applicable to the particular industry and arrive at the kVA rating of the transformer. KVA is the output with the transformer conductive at rated Voltage and frequency under usual service conditions without exceeding the standard limits of temperature rise. The standard ratings of distribution transformers are 50KVA, 100KVA, 200KVA, 315KVA, 400KVA, 630KVA, 800KVA [9].

2.3.3. Location of Transformer

Location of the transformer is very important as far as distribution loss is concerned. Transformer receives HT voltage from the grid and steps it down to the required voltage. Transformers should be placed close to the load centre, considering other features like optimization needs for centralized control, operational flexibility etc. This will bring down the distribution loss in cables.

2.3.4. Transformer Losses and Efficiency

The efficiency of the transformer depends on the design and on the effective operating load. Transformer losses consist of two parts:

No-load loss (core loss)

Is the power consumed to sustain the magnetic field in the transformer's steel core. It occurs whenever the transformer is energized and does not vary with load and caused by two factors:

I. ***Hysteresis loss***: Is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction

II. Eddy current loss: Is a result of induced currents circulating in the core.

Load loss (copper loss)

• Is associated with full-load current flow in the transformer windings.

• Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings; it can be calculated as $P = I^2R$; where P is power, I is current passing through the winding and R is winding resistance

2.4. How voltage drop is produced in case of distribution transformer?

If a wood is used to carry a distribution transformer in an area, it can't serve for several years. Because the wood is decay after few years: as a result, the falling of the distribution transformer causes the disorder of the internal and external parts of the transformer which leads to increase loss and as well as power interruption is occur. The following figures show a transformer out of function due to falling from its pole. This problem can be avoiding by using RC pole to carry the transformer or it is better to use indoor distribution system.

Figure 2.1. using wooden pole causes fall of transformer

By using the above information this study going to be solve the problem proposed in the problem statement to achieve the main and specific objective of the project. Since, voltage drop and power interrupption is a series problem in our institution, by applying this project directly in to action the problem can be easily solve. All the information discussed above are used in the next methodolgy section to minimize the voltage drop to the standard value.

CHAPTER THREE

METHODOLOGY

In order to achieve the objective of this study, well-designed installation method and loss reduction methods are used. As the methods are two so the voltage drop minimization system is in two ways. The first method is well-designed installation method; thus, it identifies the different loss reduction method proper installation system. The second system is loss reduction method; it shows how voltage drop as well as power loss is minimized by using reactive power compensation. Finally, by applying the information listed in the two methods, the result can be seen in a DigSILENT power factory 15.1 software. Now, it is better to go the detail part.

3.1. Well-designed installation method

Voltage drop can be reduced easily by well-designed installation methods. Well-designed installation means designing and building or electrical installation at standard way and installing it based on the proper electrical design by well-educated and experienced person. It includes proper installation system, load sharing and load current or simply load reducing system in the power supply. Let see them one by one.

3.1.1. proper installation system

Electrical installation refers to the actual laying out of conduits, cables, drawing wires, interconnecting associated switchgears, protective devices and accessories in the consumer building. Proper electrical installation is a system of electrical installation and it is performed by well-experienced personnel. Proper installation identifies and take care of the following power system characteristics.

A. **“Electricity hazards:** The principal hazards envisaged by the statutory regulations relate both to electrical machines and other current-using equipment and to the fixed installation. It includes

- shock currents
- excessive temperatures likely to cause burns, fires and other injurious effects;
- ignition of potentially explosive atmosphere;

- under voltages, overvoltage's and electromagnetic influences likely to cause or result in injury or damage

B. **Electrical law:** it implies the law that an electrician must follows; this includes:

i. *Electricity Safety, Quality and Continuity Regulations:* The regulations are intended to prevent danger to persons, livestock or domestic animals. The hazards envisaged are burns, electric shock, injury from mechanical movement, fire and explosion, attendant upon the generation, transformation, transmission, distribution or use of electricity. The regulations cover, for example, such matters as definitions, voltage ranges and limits, neutral continuity and earthing, underground cables, overhead lines, safety and reliability, maximum voltages, limits on supply voltages, protective measures, inspection, enclosed spaces and consumers' installations.

ii. *The Electricity at Work Regulations:* made under the umbrella of the Health and Safety at Work etc. So, any person who is at electrical work he/she must be licensed and shall have full experience permission from the electrical company.

C. **Standards and codes of practice**: it includes the IEE Wiring Regulations, Electric signs and high-voltage luminous-discharge-tube Installations, Emergency lighting, Electrical equipment for use in the presence of combustible dust, Electrical installations in opencast mines and quarries, Equipment, Lightning protection" [10].

In general, Voltage drop can be minimizing in the following ways.

- Re-conduct ring of existing poor distribution networks with a larger size to keep voltage drops at acceptable international standards.
- Replacing damaged poles and adding new poles.
- Establishing load management database for the distribution transformers so as to manage the peak load of each transformer.
- Increasing power factor
- Conversion of single-phase sections to three-phase sections
- Reducing overload
- Reducing length of the conductor
- Replacing the damaged transformer by new transformer.

Balance circuits and Conversion of single-phase sections to three-phase sections

- *Reducing* of the over load means reducing the number of customers that feeds by one transformer. So to eradicate the voltage drop problem we have to share the power to every end user equally. Since three-phase supply is more power full than single phase; this conversion leads to minimize the problem and mostly used for a three phase supplier equipment.

Using underground cable rather than using overhead distribution line

- Since, overhead distribution lines are affected by different factors. Such as: falling trees on the line, improperly planted pole; which can fall easily by wind, un correctly tied cable can be open/separate by wind or any other contact. Therefore, using underground cable is safety than overhead distribution line. It is not only for the success of power distribution to the customer, but also used to prevent electric hazards.
- The underground cables have several advantages such as less liable to damage through storms or lightning, low maintenance cost, less chances of faults, smaller voltage drop and better general appearance. [11]

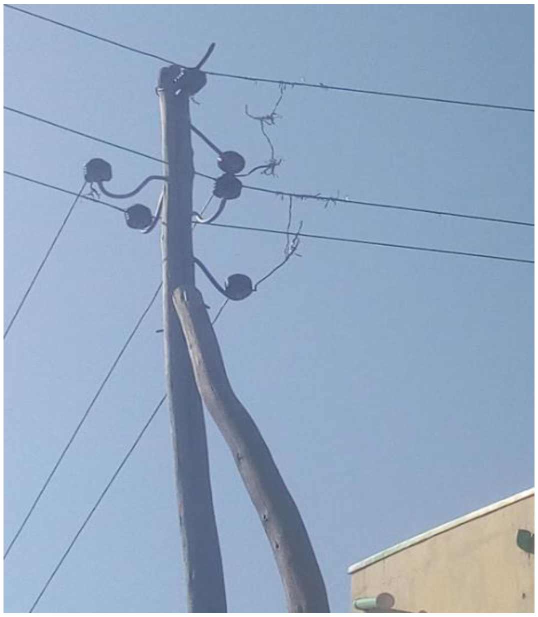


Figure3.1 incorrect cable splicing/twisting.

Reducing length of the conductor: If the distance of the customer from distribution transformer is higher; the voltage drop is proportionally increase. So we have to decrease the length of the conductor. Generally, we can conclude the above information by its mathematical modelling below.

By protecting distribution board

- If distribution board is not protected which means if the DB is installed everywhere that seems appropriate by the installer understanding and not looks what will be happen in the DB. So, such types of installing distribution board as the installer wants without considering the future hazards suffer to voltage drop as well as power interruption due to unprotected environmental conditions. Look the figure 3.2 given below.
- Many of Wolkite University's DB are not protected as well as installed properly. DB board shall design in standard and install at unconfused way.

Using standard color coding

- "Color identification of the conductor shall be specified" [12] in a given electrical installation. This is why? Because, using standard color coding of cable avoids confusion for any electricians and also used to install the system without fault as well as used to reduce loss by connecting the cable at the correct position.

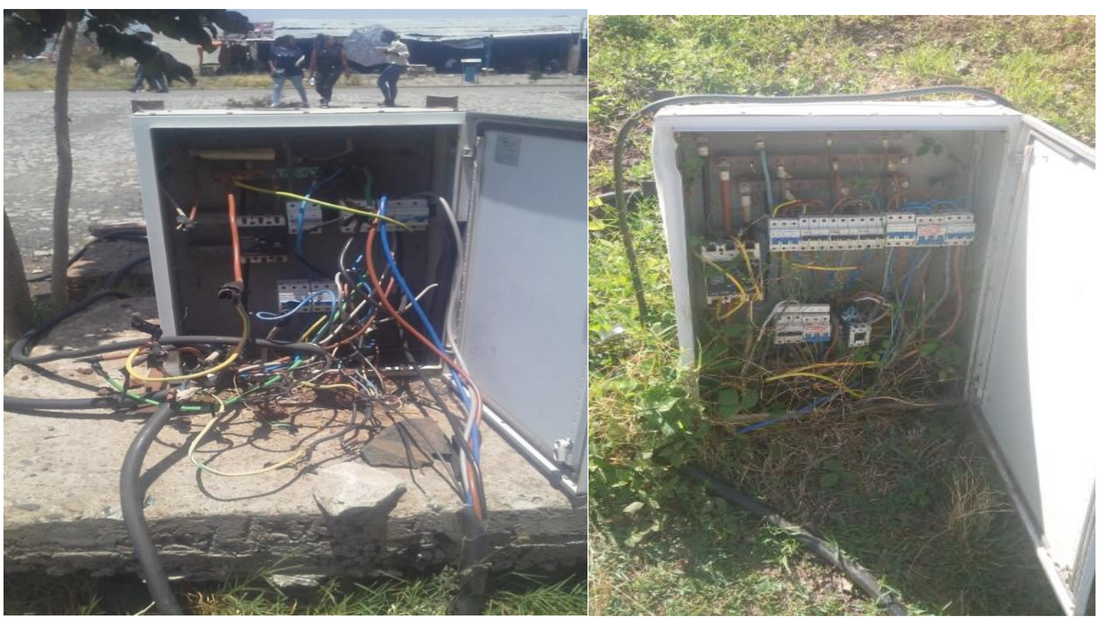


Figure3.2 unprotected and improper installed DB.

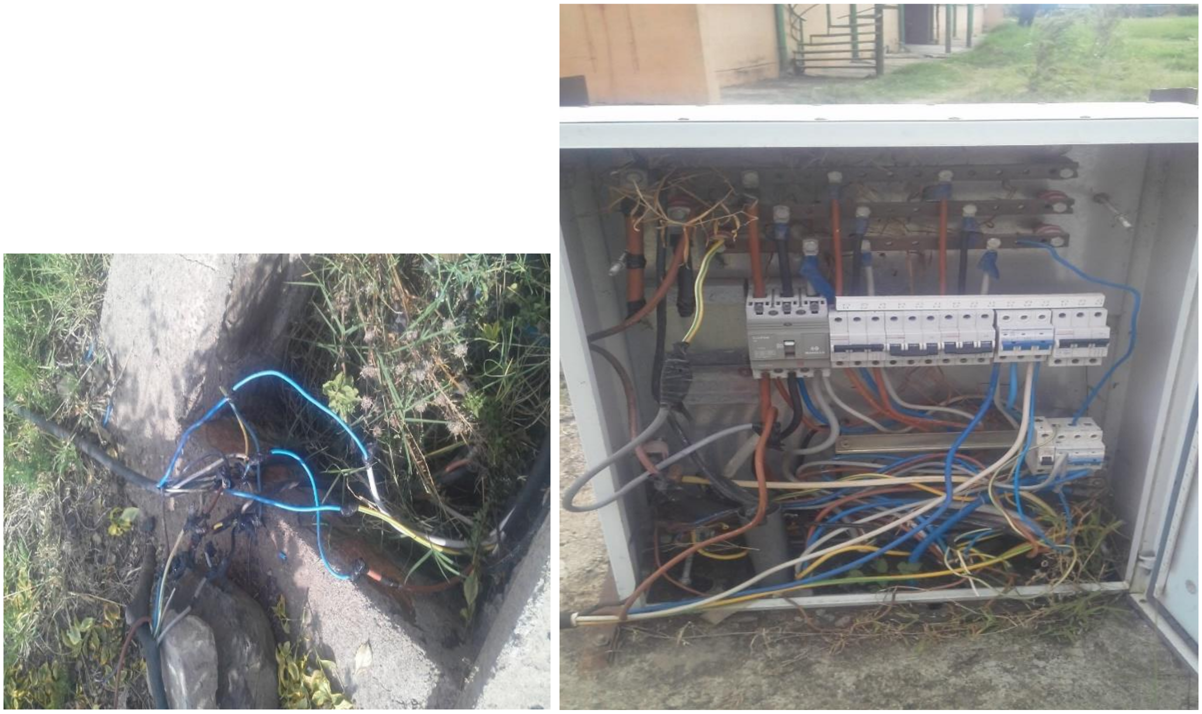


Figure3.3 incorrect use of cable’s color and connection

3.1.2. Mathematical expressions of voltage drop

The problem of voltage drop along a feeder is evident from the figure drawn below

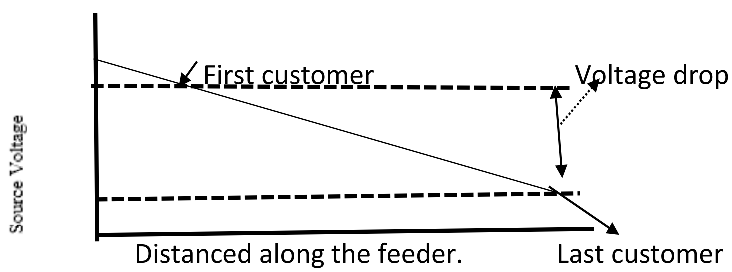


Fig3.4. Voltage drop along a distribution feeder

As line impedance is constant hence large load requires more power. This leads to higher current drawn by the load and higher voltage drop. This figure shows the effect of feeder length on the voltage and hence tolerance limit. Therefore, voltage regulation measures have to be adopted to maintain permissible voltage level along the whole length of a feeder.

As voltage at the end of feeder changes with load variation hence voltage compensation is required at different times. The voltage drops in an alternating current, AC circuit is the product of the current, I and the impedance, Z of the circuit.

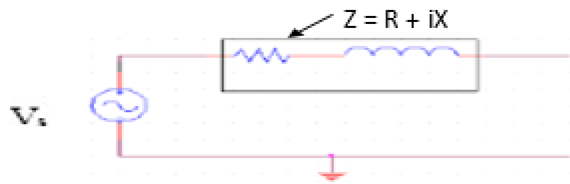


Figure3.5. voltage drop in AC circuit.

From the above circuit

$Vd = Vs - Z\,I$ and $Z = R + jX$ and $I = Ir + Ix$ …(3.1)

Where V_d – feeder voltage drops in V.

V_s – Source voltage in V.

Z – Impedance of the AC circuit in Ω.

I – line current in A.

R – Resistance Ω.

X – Reactance of the ac circuit Ω.

Since the increasing of the conductor size leads to reducing the value of resistor's. i.e

$R = \frac{\rho L}{A} \rightarrow R \propto 1/A$ and $R \propto L$, $X = X_L - X_C = 2\pi f L - \frac{1}{2\pi f c}$ ……………………………(3.2)

Where ρ is resistivity of the conductor, L is length of the conductor, X_L and X_C are inductor and capacitor reactance respectively, *f* frequency, L - inductor and C is capacitor.

So $Z = \frac{\rho L}{A} + j(X_L - X_C) = \frac{\rho L}{A} + j\,(2\pi f L - 1/2\pi f C)$…………………………………....(3.3)

From this $Vd = Vs - ZI = Vs - [\rho L/A + j\,(2\pi f L - 1/2\pi f C)]$ but also $A = \pi r^2$; where r is the radius of the conductor and A is cross sectional area of the conductor.

Therefore, the magnitude of the voltage drop will be

$|V\ d| = |Vs| - |Vr| = |Vs| - |IR * R + Ix * X|$ $= |Vs| - I \times \sqrt{[(\rho L/A)2 + (2\pi fL - 1/2\pi fC)2]}$ …………………………………………………………………... (3.4)

Thus, considering the reactive loss negligible; equation 3.4 is reduced to

$|Vd| = |Vs| - \rho LI/A.$ ……………………………………………………………… (3.5)

For instance; A circuit (Fig. 3.3) comprises two heating elements each of 28.8 Ω resistance. These are connected in series across a 230 V supply. If the supply cable has a resistance of 2.4Ω calculate:

(a) the cable voltage drop

(b) the voltage available across each heater.

Solution: Total resistance:

$R = R_c + R_e + R_e$

= 2.4 + 28.8 + 28.8 = 60Ω

Total current:

I = V/R = 230/60 = 3.833 A

(a) Thus, the Cable voltage drop is:

$V_c = I \times R_c = 3.833 \times 2.4 = 9.2V$

(b) Voltage across each element:

$V_E = I\ x\ R_E = 3.833 \times 28.8 = 110.4V$

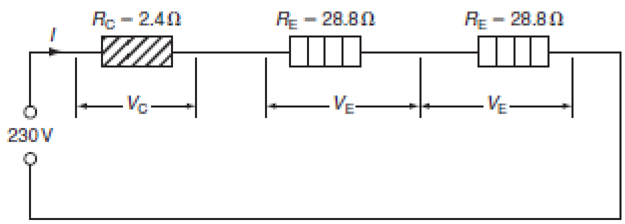


Figure3.6. voltage drop through a source cable

Voltage drop and resistance value increase with distance.

Table3.1. Voltage drop at some WKU's building

BDG No.	Distance from the DT(m)	Conductor type	Conductor size	V_s(V)	V_R(V)	V_d(V)	V_d(%)	remarks
B223	25	ACC	3*16mm^2	220	214	6	2.73	acceptable
B221	105	ACC	3*16mm^2	220	206	14	6.36	Not acceptable
B218	116	ACC	3*16mm^2	220	200.3	19.7	8.955	Not acceptable
B121	309	ACC	3*16mm^2	220	172	48	21.82	Not acceptable
TLaugn	400	ACC	5*16mm^2	380	348	32	8.42	Not acceptable

From the table: BDG refers to building and B223 refers to building number or block

Remember: The allowable voltage drops according to IEE is 5%; thus, the table is calculated and remarked based on that concept.

V_S – Source voltage

V_R – Received voltage

V_d – Voltage drop

$V_d(\%) = \frac{V_d}{V_s}\, x\ 100\%$ and $V_d = V_S - V_R$

Now calculate the resistance of the conductor based on the table at the resistivity of $1.68x10^{-8}\Omega$-m of ACC conductor with respect to distance (L) in meter; from the table we have taken B223, B218 and B121 to show the relationship between resistance and distance.

$$R_{25m} = \frac{\rho L_1}{A} = \frac{1.68*10^{-8}*25m}{16mm^2} = 0.0263\Omega$$

$$R_{116m} = \frac{\rho L_2}{A} = \frac{1.68*10^{-8}*116m}{16mm^2} = 0.122\Omega$$

$$R_{309m} = \frac{\rho L_3}{A} = \frac{1.68*10^{-8}*309m}{16mm^2} = 0.325\Omega$$

As we have seen earlier distance and resistance have direct relation which means when the resistance is increase as distance increase. But voltage drop has inverse relation with distance and resistance, similarly power loss has direct relationship with voltage drop.

3.1.2. load current reducing method

"Limiting the amount of equipment that can be connected to a single circuit will limit the load current on the circuit. Limit the number of receptacles on each branch circuit to three to six.

For residential applications, install outdoor receptacles not to be exceed 50 linear feet between receptacles, with a minimum one outdoor receptacle on each side of the house and with individual branch circuits with a minimum of 12 AWG to each receptacle" [13].

Even the smallest installation needs to be divided into number of circuits; because failure in one circuit should not cause shutdown of the circuit and also Sufficient socket outlets should be provided to avoid extension usage as it will load the circuit. Reducing over load or minimize the number of receptacles in a given circuit also used to improve power quality. Power quality is simply the interaction of electrical power with electrical equipment. If electrical equipment operates correctly and reliably without being damaged or stressed, we would say that the electrical power is of good quality.

Figure3.7 overloaded circuit (general socket outlet).

3.2. Loss reducing Method.

As we have discussed in the literature review section; the modern power system has three major sections, namely generation, transmission and distribution. For economic reasons, the power is generated in bulk and then transmitted over a long distance. Finally, the distribution system provides electric power to the end consumers. Among the three sections, the distribution system has more loss and this loss leads to poor voltage regulation at the end buses. The function of a distribution system is to deliver electrical power from the transmission network to end users. The distribution systems are usually unbalanced and have a high R/X ratio compared to transmission systems, which results with the effect of high voltage drops and power losses in the distribution feeders. The vital tasks in the distribution system are reduction of power losses and improvement of the system voltage profile.

Reconfiguring the network means altering its topology by changing the status of normally opened and normally closed switches.

Feeder reconfiguration is a very important tool to operate the distribution system at minimum cost and improve the system reliability and security.

3.2.1. Power factor compensation

The power factor of an AC electric power system is defined as the measurement of the degree to which a given load matches that of a pure résistance. It is a ratio of average power of any given load to average power of a resistive load for same voltage and current magnitude and its value is also between 0 and 1. Active power is the actual amount of the power being used, or dissipated, in a circuit is called active power (P), and it is measured in watts. Active power is the product of the sinusoidal voltage and current wave form. Reactive power is the power consumed in the ac circuit because of the inductive and capacitive field. The unit used for measuring reactive power is KVAR. Apparent power is the combination of the active power and reactive power. It is the product of a circuit voltage and current without reference to phase angle. Apparent power(S) is measured in the unit of volt-amps (VA).

A poor power factor can be the result of a significant phase between the applied voltage and the current at the load terminals or it can be due to a high harmonic content or distorted (discontinuous current wave form). The poor load current phase angle can be generally the result of inductive loads such as induction motor, power transformers and lighting ballasts.

Reactive power compensation has been increasing, mainly because of the way in which energy supplier charge a customer for reactive power. In addition to the above explanation, the energy price is growing, what force the industry plants and individual customers to minimize energy consumption, including reactive power. Generally, there are solutions that allow handle the problem of reactive power compensation. The first one is reactive power compensator using power factor capacitors.

Power triangle

The cosine of the angle blow is also equal to KW per KVA so you can think of the power factor as the ratio of real power to what you measure with a volt and amp meter (apparent power). If they are equal, then the power factor is one. The power triangle is used to show the mathematical expression and relation of apparent power, active power, reactive power and also the angle between them.

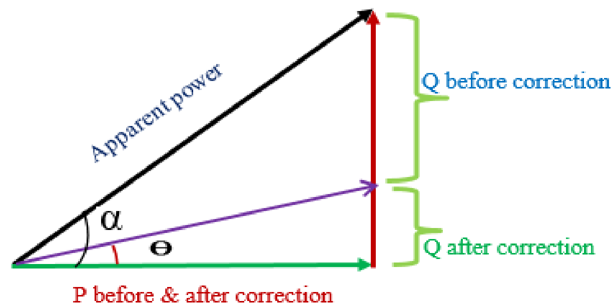


Figure 3.8 power triangle.

Mathematical expression for correcting power factor

Our aim is to increase power factor of Wolkite University above 0.9 to avoid paying power factor penalties that are being charged by the electrical utility and to increase efficiency of the power system. So, calculating how much reactive power compensation / power factor correction they need to install to raise the power factor to the desired value is very important.

$$S = P + jQ$$

$$S = P/pf$$

$$S = \sqrt{(P^2 + Q^2)}$$

$$Pf = P/S$$

Where S is apparent power, P is active power, Q is reactive power and pf is the power factor. To get the appropriate capacitor size for the reactive power compensation which means to improve the power factor to reducing loss in the electric power system we have following the next calculation systems. This is done based on the new desired power factor which is 0.9 for a given active power of 3MW. data gathered given as follow in the table below.

Table3.2 Data obtained from the University from energy meter 1090390.

Month	Power	Pervious reading	Present reading	Consumption(Kwh/KVA)
October	Active	14789	16224	287000
	Reactive	13690	15390	
November	Active	7409	7569	32000
	reactive	6196	6265	
December	active	7569	7569	48109.37
	reactive	6107	6129	
January	active	16412	16412	62541.42
	reactive	13201	14201	
February	active	4395	4395	22191.01
	reactive	3519	3521	

S_{old} = P/pf = $\sqrt{P^2 + Q^2}$

$P_{ave.}$ = P_{total}/5 = 50,574/5 = 10,114.8KW.

$Q_{ave.}$ = Q_{total}/5 = 42,713/5 = 8,542.6KVar.

$S_{old} = \sqrt{10{,}114.8^2 + 8{,}542.6^2}$

= 13,239.53KVA from this we can calculate the power factor.

$Pf_{old} = P/S_{old} = \frac{10{,}114.8}{13{,}239.53} = 0.764$

$S_{new} = P/pf_{new} = \frac{10{,}114.8}{0.94} = 10{,}760.43KVA$

- ⇨ $Q_{new} = \sqrt{S_{new}^2 - P^2} = \sqrt{(10{,}760.43)^2 - (10{,}114.8)^2}$
- ⇨ Q_{new} = 3671.2KVar.
- ⇨ $Q_{required} = Q_{old} - Q_{new} = 8{,}542.6KVar. - 3671.2KVar.$
- ⇨ $Q_{required}$ = 4871.4KVar.

Also S can be calculated as follows

S = VI. This used to calculate the reactive current before and after compensation.

- ⇨ $I_{old} = \frac{13{,}239.53KVA}{380V}$ = 34.841KA; $\alpha = \cos^{-1}(0.764) = 40.182^o$
- ⇨ $I_{active} = I*\cos\alpha$ = 26.618KA.
- ⇨ $I_{reactive} = I\sin\alpha$ = KA

⇨ I_L = Isinα = 22.48KA

Where cosα is the power factor before correction.

$I_{new} = S_{new}/V = \frac{10{,}760.43KVA}{380V} = 28.32KA$

⇨ $I_{newreactive} = I_{new}sine(cos^{-1} 0.94)$

⇨ $I_{newreactive} = I_{new}sine(19.95^o)$

⇨ $I_{newreactive}$ = 28.32KAsine(19.95^o) = 9.66KA

Therefore, to connect the capacitor bank in star connection the capacitor line current is calculated from the difference of corrected reactive current from uncorrected reactive current.

$I_c = Ioldreactive - Inewreactive$

$I_c = 22.48KA - 9.66KA$

I_c = 12.82KA

and $I_{cp} = V_p/Xc = 2\pi fCV$; V = 380V.

=> $C = I_{cp}/2\pi fV_p = \frac{12.82KA}{2\pi * 50 * \sqrt{3} * 380} = 0.062F$

Rating of capacitor connected

Before connecting capacitors to a specified circuit determining its rating is very essential. To do this we have to use the former pf and the desired power factor at assumed efficiency of 100%.

$Pf_{old} = 0.764 = 40.182^o$

$Pf_{new} = 0.94 = 19.95^o$

$\mathbf{C_{MVAR1}} = P_1(\tan\alpha_1 - \tan\alpha_2)$ or C_{MVAR} at S = 1250KVA Transformer

= 1MW (tan (40.182)-tan (23.0734)) = 1MW (0.483)

= 0.482MVAR (capacitor rating of the higher transformer)

$\mathbf{C_{MVAR2}} = P_2(0.482)$ or C_{MVAR} at S = 500KVA Transformer

= 400KW (0.482)

= 192.8KVAR = 0.193MVAR

$\mathbf{C_{MVAR3}} = P_3(0.482)$ or C_{MVAR} at S = 315KVA Transformer

= 252KVAR = 0.252MVAR

3.2.2. Formulation

In this paper, the objective is to minimize the system power loss under a certain load pattern through network optimization while electrical and operational constraints are met, that is the process of altering the topological structures of distribution network by changing the open/closed status of switches so as to minimize total system real power loss. The objective function of the problem is,

$$\text{Minimiz } P_{loss} = \sum_{i=1}^{nl} R_j \frac{P_j^2+Q_j^2}{V_j^2}$$

The branch's capacity and voltage magnitude at each branch and each bus must be maintained within limits. These constraints are expressed as follows:

For any branch: $s_j \le s_{j,max}$

For any bus: $|Vi, min| \le |Vi| \le |Vi, max|$

The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in Figure below.

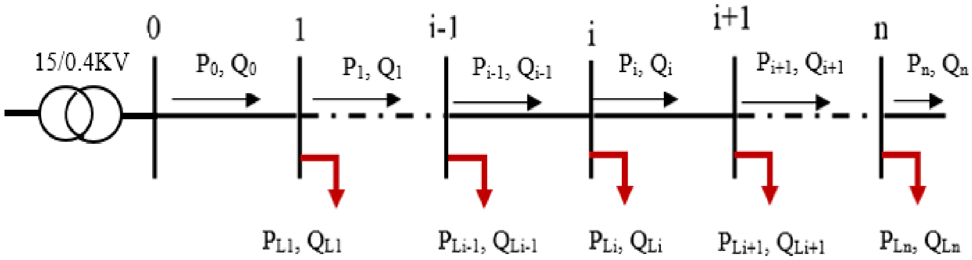


Figure3.9 Single line diagram of main feeder.

$$P_{i+1} = P_i - P_{Li+1} - R_{ij+1}\frac{P_i^2+Q_i^2}{|Vi|^2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1}\frac{P_i^2+Q_i^2}{|Vi|^2}$$

$$|V_i|^2 = |V_i|^2 - 2(R_{ij+1} P_i + X_{ij} + Q_i) + (R^2{}_{ij+1} + X^2{}_{ij+1}) \times \frac{P_i^2+Q_i^2}{|V|i^2}$$

Where P_i and Q_i are the real and reactive powers flowing out of bus i, and P_{Li} and Q_{Li} are the real and reactive load powers at bus i. The resistance and reactance of the line section between buses i and i+1 are denoted by $R_{i,\,i+1}$ and $X_{i,\,i+1}$ respectively. The power loss of the line section connecting buses i and $_{i+1}$ may be computed as

$$P_{Loss\,(i,\,i+1)} = R_{i,\,i+1}\frac{P_i^2+Q_i^2}{|Vi|^2}$$

The total power loss of the feeder, P_{TLOSS} may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{TLOSS} = \sum_{i=0}^{n-1} P_{loss\,(i,i+1)}$$

3.3. Wolkite University's power distribution.

Wolkite University accepts 3.6MW, 15KV from Wolkite sub-station. Wolkite University is found at 12km far from Wolkite Town. From this we can understand that the electric transmission line length from Wolkite Sub-station to WKU is 12km. when distance increase loss is increase as we have seen in the above section. The block diagram of WKU university's electric power distribution is given in the figure below. The institution has 8 transformers having different ratings. Each has 25KVA, 315KVA, 500KVA and 1.25MVA. The former design of electric distribution has many problems. For instance, distance, using overhead line rather than using underground cable, cable twisting problem which means the cables are not twisted correctly one another, using wooden poles which are incorrectly planted, have no capacitor bank for loss reduction, most of the DB are unprotected, incorrect use of colour coding and such likes.

The new design of electric power distribution in the institution solves all the above problems which are listed in the former design. Solution is that the revers of all listed problems in the above and also all are discussed in the above sections and additional one is decreasing the number of Transformer.

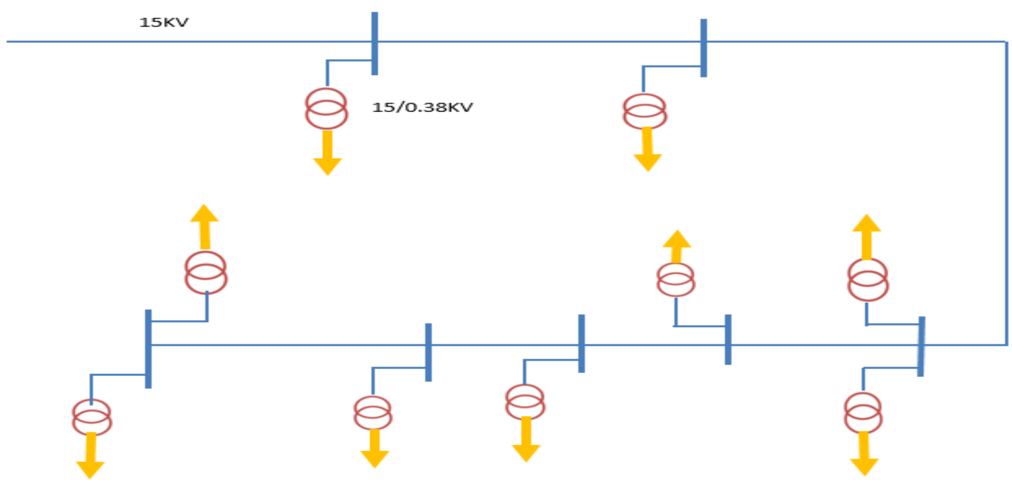


Figure3.10 the former electric power distribution of WKU.

Line parameters

Line resistance at 20°C $R_{20} = \frac{\rho L_m}{A}$

$R_{80} = R_{20}(1+\alpha(T_2-T_1))$ where T_2 and T_1 are temperature at 80°C and at 20°C respectively, α is temperature coefficient at 20°C

Pf = Z/R => Z = R*pf; where pf = 0.94

Where Z = R + jX

Z = is the impedance, measured in ohms

R = is the resistance, measured in ohms

X = is the reactance, measured in ohms.

R = $\frac{\rho L_m}{A} = \frac{2.83 \; x \; 10^2 \; x \; 12000m}{50mm^2}$ = 6.792Ω = 0.566/km

Z = R * pf. = 0.566 * 0.94 = 0.532Ω/km

X = Z – R = 0.532 – 0.566 = -0.034/km

⇨ Z = (0.566Ω –j0.034)/km at 20^{o}C

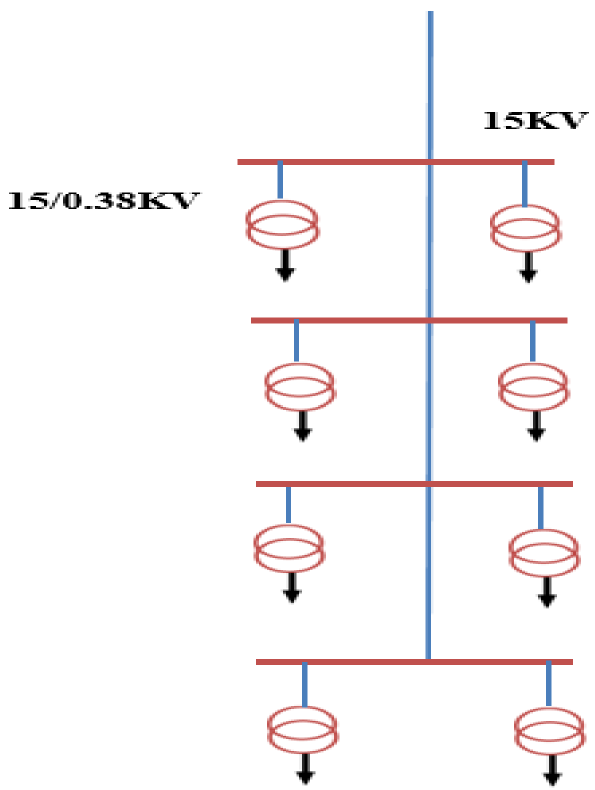


Figure3.11 the new design of electric power distribution of WKU.

CHAPTER FOUR

RESULT AND DESCUSSION

4.1. Result

After completing the analysis, data collection and necessary information, the relationship between the voltages received by the customer that is the operating voltage of the customer's appliance versus the distance of the customer from the distribution transformer is drawn as in the figures below; in addition to this from the standard values, the relation between resistance and the voltage drop; the resistance versus the distance, the power loss with distance, voltage drop, resistance and distance as in the chart drawn below.

- As the distance of the customer from the distribution transformer increases the received voltage decreases and vice versa.

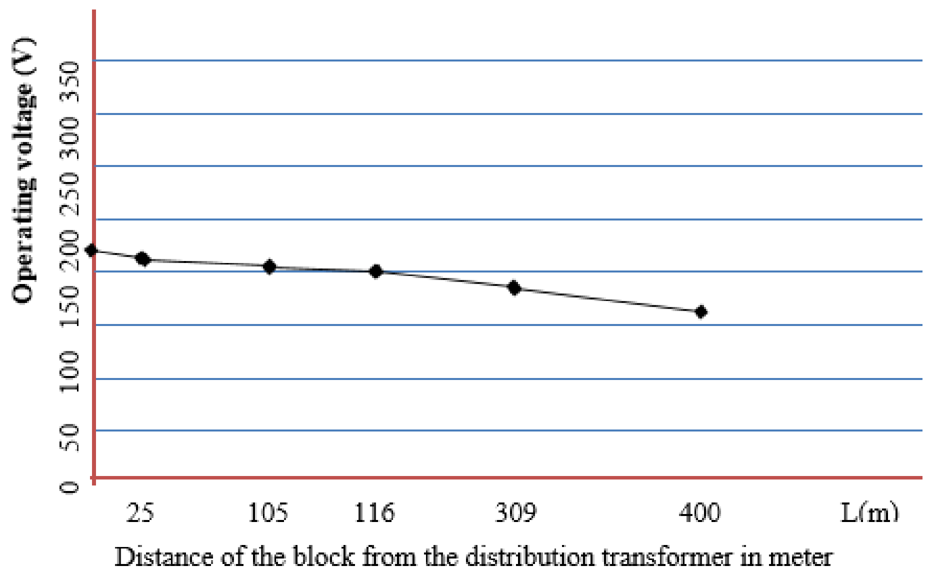


Figure 4.1. Distance from the distribution transformer versus received voltage

Relationship between power loss, voltage drop, resistance and distance

The power loss is inversely proportional to the resistance and distance but directly proportional to the voltage drop as shown below in figur4.2. in this figure we understand that voltage drops, resistance and power loss are strongly affected by distance from the distribution transformer. This can be expressed as voltage drops, power loss and resistance has direct relation with distance.

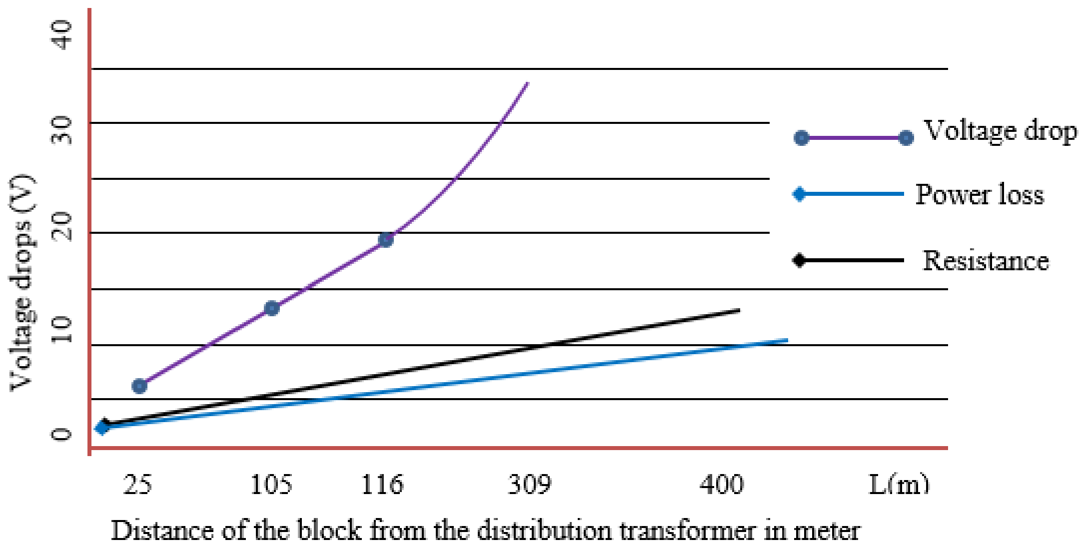


Figure4.2. Relationship of power loss, voltage drop, resistance & distance

Result from load distribution of power flow (at DigSilent power factory software)

As discuss earlier as the user is far away from the distribution network the voltage drop is increase and also the power loss. Similarly, if there is more power loss due to distance, improper installation, and another cause as previously discussed power interruption is created. These are shown in the DigSilent power factory software in the fig4.3

Figure 4.3 below shows the former EDN of WKU at DigSILENT power factory 15.1; in this diagram anyone can understand that distance and incorrect design of EDN can also be causes of voltage drop and power losses in a given a distribution network. In this network the power factor is less than the allowed value 0.8 and also the voltage drop in percentage is greater than the allowed value “5%” [ebc-10] which is approximately 0.764. These are given in the data sheet below. So, all these are corrected in our design: i.e. the power factor is improved to 0.94 then the voltage drop is minimized to allowable value.

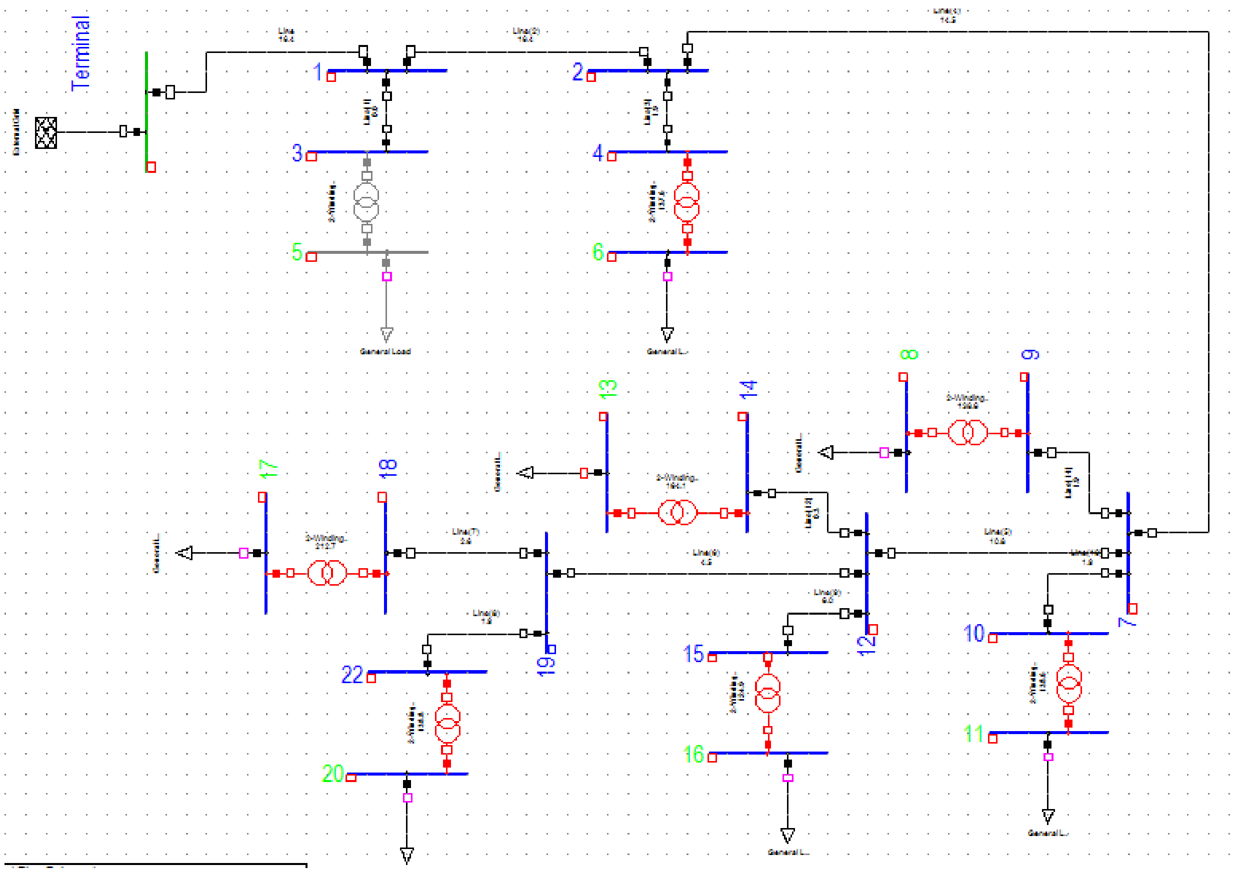


Figure 4.3. the former EDN of WKU

From table 4.1 we got the voltage drop as follows.

$V_d = V_s - V_R$ and $V_d\% = \frac{V_S - V_R}{V_S}$ x 100

V_{d1}= 15KV – 12.32KV = 2.68KV = 17.86%...........not acceptable; pf = 0.79

V_{d12} = 15kv – 12.18kv = 2.82kv = 18.8%........not acceptable; pf = 0.77

V_{d18} = 15kv – 12.17kv = 2.83kv = 18.9%.......not acceptable; pf = 0.76

Table 4.1 Voltage profile of the former EDN of WKU.

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
Terminal	15.00	1.000	15.00	0.00
1	15.00	0.821	12.32	-1.35
2	15.00	0.818	12.28	-1.38
4	15.00	0.818	12.27	-1.38
3	15.00	0.821	12.32	-1.35
5	0.38	0.000	0.00	0.00
6	0.38	0.795	0.30	-3.80
7	15.00	0.813	12.19	-1.43
9	15.00	0.813	12.19	-1.43
8	0.38	0.789	0.30	-3.88
10	15.00	0.813	12.19	-1.43
11	0.38	0.789	0.30	-3.88
12	15.00	0.812	12.18	-1.44

Voltage - Deviation [%]: -10 -5 0 +5

Table4.2 power flow analysis before compensation

Grid: Grid System Stage: Grid | Study Case: Study Ca

		rated Voltage [kV]	Bus-voltage [p.u.]	[kV]	[deg]	Active Power [MW]	Reactive Power [Mvar]	Power Factor [-]	Current [kA]	Loading [%]
Terminal		15.00	1.00	15.00	0.00					
Cub_2	/Xnet	External Grid				3.82	3.10	0.78	0.19	
Cub_1	/Lne	Line				3.82	3.10	0.78	0.19	18.94
1		15.00	0.79	11.90	-1.56					
Cub_1	/Lne	Line				-3.10	-2.38	-0.79	0.19	18.94
Cub_2	/Lne	Line(1)				0.32	0.23	0.81	0.02	1.91
Cub_3	/Lne	Line(2)				2.78	2.14	0.79	0.17	17.02
2		15.00	0.79	11.86	-1.59					
Cub_1	/Lne	Line(2)				-2.77	-2.13	-0.79	0.17	17.02
Cub_2	/Lne	Line(3)				0.32	0.23	0.81	0.02	1.92
Cub_3	/Lne	Line(4)				2.45	1.90	0.79	0.15	15.10
18		15.00	0.78	11.75	-1.65					
Cub_1	/Lne	Line(7)				-0.42	-0.36	-0.76	0.03	2.72
Cub_2	/Tr2	2-Winding Transfor				0.42	0.36	0.76	0.03	221.21

As discussed previously well-design installation method and reactive power compensation can improve voltage or minimize voltage drop, power interruption and power loss that caused by different factors.

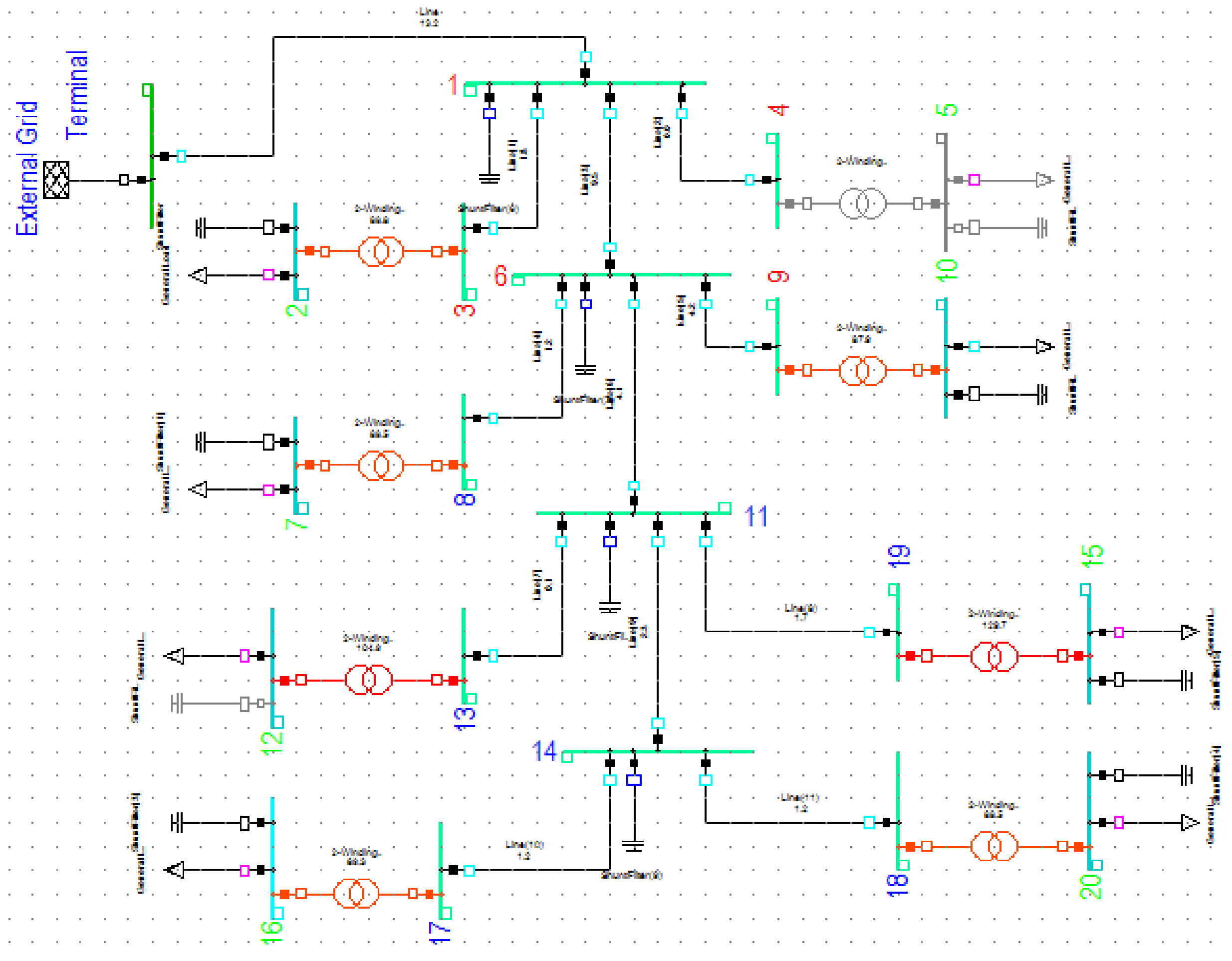
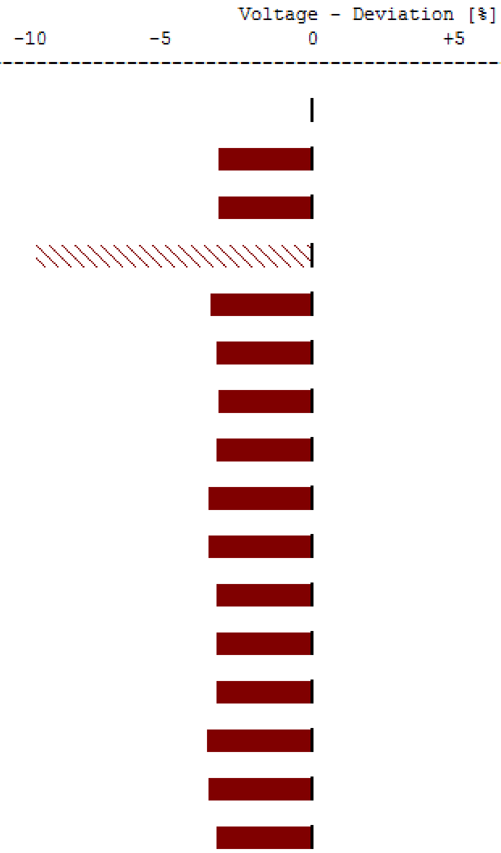


Figure 4.4 New design of EDN of WKU

Figure 4.4 shows the optimized or minimized voltage drop design of Wolkite University which is the new design. Its voltage profile is given in the table 4.3 below.

Table 4.3 Voltage profile of new EDN at 0.94pf

Terminal	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
Terminal	15.00	1.000	15.00	0.00
1	15.00	0.965	14.48	-8.17
4	15.00	0.965	14.48	-8.17
5	0.38	0.000	0.00	0.00
10	0.38	0.962	0.37	-8.69
9	15.00	0.965	14.47	-8.19
3	15.00	0.965	14.48	-8.18
6	15.00	0.965	14.47	-8.19
2	0.38	0.962	0.37	-8.67
7	0.38	0.962	0.37	-8.69
8	15.00	0.965	14.47	-8.19
11	15.00	0.965	14.47	-8.20
19	15.00	0.965	14.47	-8.20
15	0.38	0.961	0.37	-8.95
20	0.38	0.962	0.37	-8.69
18	15.00	0.965	14.47	-8.20



From table 4.3 the voltage drop can be calculated as follws.

V_{d1}= 15KV – 14.48KV = 0.52KV = 3.47%.............accepted. pf = 0.94

Similarly, V_{d3} = V_{d9} = V_{d19} = 0.53KV = 3.53% at power factor of 0.94

Look the following voltage profile which is calculated from DigSILENT power factory 15.1 at power factor of 0.94

Table 4.4. power flow analysis after compensation

Grid: Grid			System Stage: Grid				Study Case: Study Ca				
		rated Voltage [kV]	Bus-voltage [p.u.]	[kV]	[deg]	Active Power [MW]	Reactive Power [Mvar]	Power Factor [-]	Current [kA]	Loading [%]
Terminal										
		15.00	1.00	15.00	0.00					
Cub_2	/Xnet	External Grid				3.34	-1.03	0.96	0.13	
Cub_1	/Lne	Line				3.34	-1.03	0.96	0.13	13.47
1										
		15.00	0.94	14.10	-7.99					
Cub_5	/Shnt	Shunt/Filter(6)				-0.00	-1.26	-0.00	0.05	
Cub_1	/Lne	Line				-2.98	1.40	-0.90	0.13	13.47
Cub_2	/Lne	Line(1)				0.42	0.18	0.92	0.02	1.86
Cub_3	/Lne	Line(2)				0.28	0.12	0.92	0.01	1.24
Cub_4	/Lne	Line(3)				2.28	-0.43	0.98	0.09	9.49
9										
		15.00	0.94	14.10	-8.01					
Cub_1	/Lne	Line(5)				-1.00	-0.39	-0.93	0.04	4.39
Cub_2	/Tr2	2-Winding Transfor				1.00	0.39	0.93	0.04	91.28
3										
		15.00	0.94	14.10	-7.99					
Cub_1	/Lne	Line(1)				-0.42	-0.18	-0.92	0.02	1.86
Cub_2	/Tr2	2-Winding Transfor				0.42	0.18	0.92	0.02	92.28

4.2. Discussion

Generally, to solve this problem applied the following considerations:

- The small sized conductor should be changed by larger cable.
- Reducing the number of loads in a given transformer
- Reduce the number of receptacles at a single circuit and design or install addition socket/circuit to reduce work inefficiency.
- Making good splicing
- Making free of contact with external equipment like tree, hook, building and others for overhead transmission or the most suitable way is using *underground cable*.
- Using concrete pole or steel pole for transmission line or carrying transformer rather than using wooden pole.
- If copper wire is costly/ expensive it can be change by larger and appropriate AAC.
- Use capacitor banks to reduce losses at a given distribution networks.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion:

From this study we conclude that the voltage drop as well as power interruption of Wolkite University is dependent on:

- ✓ The length of the secondary distribution system.
- ✓ The load connected to the given transformer.
- ✓ The cross sectional area of the conductor.
- ✓ Improper wiring of conductor cables.
- ✓ Lack of load sharing system from one distribution transformer to another.
- ✓ Incorrect placement and lack of protection of distribution board.
- ✓ Using overhead transmission line rather than using underground cable.
- ✓ On the activities of the user itself.
- ✓ Types of load of the user he/she use.

We also see that reducing the value of resistance of a conductor increases the operating voltage. Small reduction in voltage will produce high reduction in load magnitude. In addition to this we also concluded that if we use the materials properly as the customer wants there will be

- Good voltage to the equipment being powered, causing proper, consistent, or operates properly and doesn't damage to the equipment.
- High efficiency and no wastage of energy.
- The operating voltage shall be 220V for single phase user and 380-400V for three phase equipment user.
- Satisfying the customers need in terms of electrical power.
- Using loss reduction system for distribution network improves work efficiency.
- Since power factor highly affects and forced a customer to pay penalty due to low value of power factor increases power loss; so using reactive power compensation is an important method.

5.2. Recommendation

We want to recommend that the link between the distribution system, the HV and LV network that carries different types and sizes should be considered. That is all of the distribution network must be responsible for the system protection.

5.2.1. Recommendation for the University

We recommended that WKU shall ask wolkite substation to change all the overhead transmission lines inside the institution by underground cables. Also the DB must be protect.

WKU shall have well trained and educated electricians. When the institute pay electric utility cost it must accept Electric bill which has full information about the monthly electric consumption. This can help to change the use of Electricity system in the institution.

5.2.2. Recommendation for Wolite Substation or EEU.

The EEPCO/EEU also has to insure that the total numbers of customers connected to one transformer should be based on loads that the customers used. In the expansion of new residential, commercial and industrial areas instead of giving power to these from the existed network it is better to construct other new network with its new planted transformer. Since the customers are daily raised their complaints to the office of the distribution system it must rehabilitate any failure network as fast as possible before the customer comes to the office.

The organization/EEU shall employ well trained, experienced and educated electrical technicians for different types of installation and design. Also the organization shall use modern and standard method of installation system.

We also recommend for the customer to check the splicing of the conductors, to check good installation and to have the specified voltage since it causes a voltage drop. We want also to recommend that the distribution system must taker of in using the materials with their specified standards to realize the efficiencies of the customer’s appliances

Reference

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***[11].** principles of power system. pdf. pp264*

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Appendixes

The former design's DigSilent power factor results of WKU EDN

```
DIgSI/info - Element ' External Grid' is local reference in separated area of ' Terminal'
DIgSI/wrng -    1 area(s) are unsupplied.
DIgSI/info - Grid split into 2 isolated areas
DIgSI/info - Calculating load flow...
DIgSI/info - --------------------------------------------------------------------------------
DIgSI/info - Start Newton-Raphson Algorithm...
DIgSI/info - load flow iteration: 1
DIgSI/info - load flow iteration: 2
DIgSI/info - load flow iteration: 3
DIgSI/info - Newton-Raphson converged with 3 iterations.
DIgSI/info - Load flow calculation successful.
DIgSI/info - --------------------------------------------------------------------------------
DIgSI/info -      Report of Control Condition for Relevant Controllers
DIgSI/info - --------------------------------------------------------------------------------
DIgSI/info - Control conditions for all controllers of interest are fulfilled.
```

```
----------------------------------------------------------------------------------------------------------
| Grid: Grid          System Stage: Grid        | Study Case: Study Case          | Annex:           / 4 |
----------------------------------------------------------------------------------------------------------
|                      rated. V    Bus - voltage                   Voltage - Deviation [%]               |
|                       [kV]   [p.u.]   [kV]   [deg]        -10     -5      0      +5     +10             |
----------------------------------------------------------------------------------------------------------
|Terminal              15.00   1.000   15.00   0.00                        |                            |
|1                     15.00   0.821   12.32  -1.35         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|2                     15.00   0.818   12.28  -1.38         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|4                     15.00   0.818   12.27  -1.38         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|3                     15.00   0.821   12.32  -1.35         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|5                      0.38   0.000    0.00   0.00         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|6                      0.38   0.795    0.30  -3.80         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|7                     15.00   0.813   12.19  -1.43         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|9                     15.00   0.813   12.19  -1.43         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|8                      0.38   0.789    0.30  -3.88         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|10                    15.00   0.813   12.19  -1.43         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|11                     0.38   0.789    0.30  -3.88         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|12                    15.00   0.812   12.18  -1.44         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|15                    15.00   0.812   12.18  -1.44         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|16                     0.38   0.789    0.30  -3.59         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|14                    15.00   0.812   12.18  -1.44         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|13                     0.38   0.780    0.30  -4.15         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|19                    15.00   0.811   12.17  -1.44         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|22                    15.00   0.811   12.17  -1.44         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|20                     0.38   0.788    0.30  -3.90         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|18                    15.00   0.811   12.17  -1.44         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
|17                     0.38   0.771    0.29  -5.05         <\\\\\\\\\\\\\\\\\\\\\\\|                            |
```

```
| Load Flow Calculation                    Complete System Report: Substations, Voltage Profiles, Grid Interchange |
-----------------------------------------------------------------------------------------------------------
|   AC Load Flow, balanced, positive sequence          |  Automatic Model Adaptation for Convergence        No              |
|   Automatic Tap Adjust of Transformers          No   |  Max. Acceptable Load Flow Error for                               |
|   Consider Reactive Power Limits                No   |    Nodes                                                1.00 kVA  |
|                                                      |    Model Equations                                      0.10 %    |
--------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid                   System Stage: Grid              | Study Case: Study Case                   | Annex:         / 1  |
-----------------------------------------------------------------------------------------------------------------------
|                         rated                               Active Reactive Power                  |                           |
|                          Voltage    Bus-voltage       Power   Power  Factor Current Loading|          Additional Data          |
|                       [kV]   [p.u.]    [kV]   [deg]    [MW]   [Mvar]   [-]     [kA]     [%]    |
---------------------------------------------------------------------------------------------------------------------------------------------
|Terminal          15.00   1.00    15.00     0.00                                      |                                  |
|  Cub_2  /Xnet     External Grid                   3.32       2.67      0.78       0.16          |Sk": 10000.00 MVA          |
|  Cub_1  /Lne      Line              3.32     2.67   0.78     0.16   16.39 |Pv:    541.73 kW      cLod: -0.00 Mvar L:   12.00 km     |
|1                  15.00    0.82   12.32   -1.35                                       |                                 |
|  Cub_1  /Lne      Line                      -2.78    -2.13  -0.79     0.16    16.39     |Pv:    541.73 kW   cLod: -0.00 Mvar L:   12.00 km|
|  Cub_2  /Lne      Line(1)                        0.00     0.00   1.00     0.00     0.00 |Pv:      0.00 kW   cLod:  0.00 Mvar L:    0.20 km|
|  Cub_3  /Lne      Line(2)                        2.78     2.13   0.79     0.16    16.39 |Pv:      9.21 kW   cLod:  0.00 Mvar L:    0.45 km|
|2                 15.00    0.82   12.28   -1.38                              |                                            |
|  Cub_1  /Lne      Line(2)                     -2.77    -2.12  -0.79     0.16    16.39 |Pv:      9.21 kW   cLod:  0.00 Mvar L:    0.45 km|
|  Cub_2  /Lne      Line(3)                        0.32     0.23   0.81     0.02     1.85 |Pv:      0.03 kW   cLod:  0.00 Mvar L:    0.22 km|
|  Cub_3  /Lne      Line(4)                        2.45     1.89   0.79     0.15    14.54 |Pv:     15.17 kW   cLod:  0.00 Mvar L:    0.65 km|
|4                 15.00    0.82   12.27   -1.38                              |                                              |
|  Cub_1  /Lne      Line(3)                       -0.32    -0.23  -0.81     0.02     1.85 |Pv:      0.03 kW   cLod:  0.00 Mvar L:    0.22  km|
|  Cub_2  /Tr2     2-Winding Transfor           0.32     0.23   0.81     0.02  137.57 |Tap:     0.00      Min:      0      Max:            0   |
|3                  15.00    0.82   12.32   -1.35                               |                                            |
|  Cub_1  /Lne      Line(1)                       -0.00    -0.00  -1.00     0.00     0.00 |Pv:      0.00 kW   cLod:  0.00 Mvar L:    0.20 km|
|  Cub_2  /Tr2     2-Winding Transfor                                         |Tap:       0      Min:      0         Max:            0   |
|5                  0.38     0.00     0.00     0.00                             |                                            |
|  Cub_2  /Lod      General Load                   0.00     0.00    1.00     0.00        |Pl0:    0.32 MW   Ql0:   0.21 Mvar                   |
```

The new design's DigSilent power factor results of WKU EDN

```
DIgSI/info - Element ' External Grid' is local reference in separated area of ' Terminal'
DIgSI/wrng -    1 area(s) are unsupplied.
DIgSI/info - Grid split into 2 isolated areas
DIgSI/info - Calculating load flow...
DIgSI/info - ----------------------------------------------------------------------------
DIgSI/info - Start Newton-Raphson Algorithm...
DIgSI/info - load flow iteration: 1
DIgSI/info - load flow iteration: 2
DIgSI/info - load flow iteration: 3
DIgSI/info - Newton-Raphson converged with 3 iterations.
DIgSI/info - Load flow calculation successful.
DIgSI/info - ----------------------------------------------------------------------------
DIgSI/info -      Report of Control Condition for Relevant Controllers
DIgSI/info - ----------------------------------------------------------------------------
DIgSI/info - Control conditions for all controllers of interest are fulfilled.
```

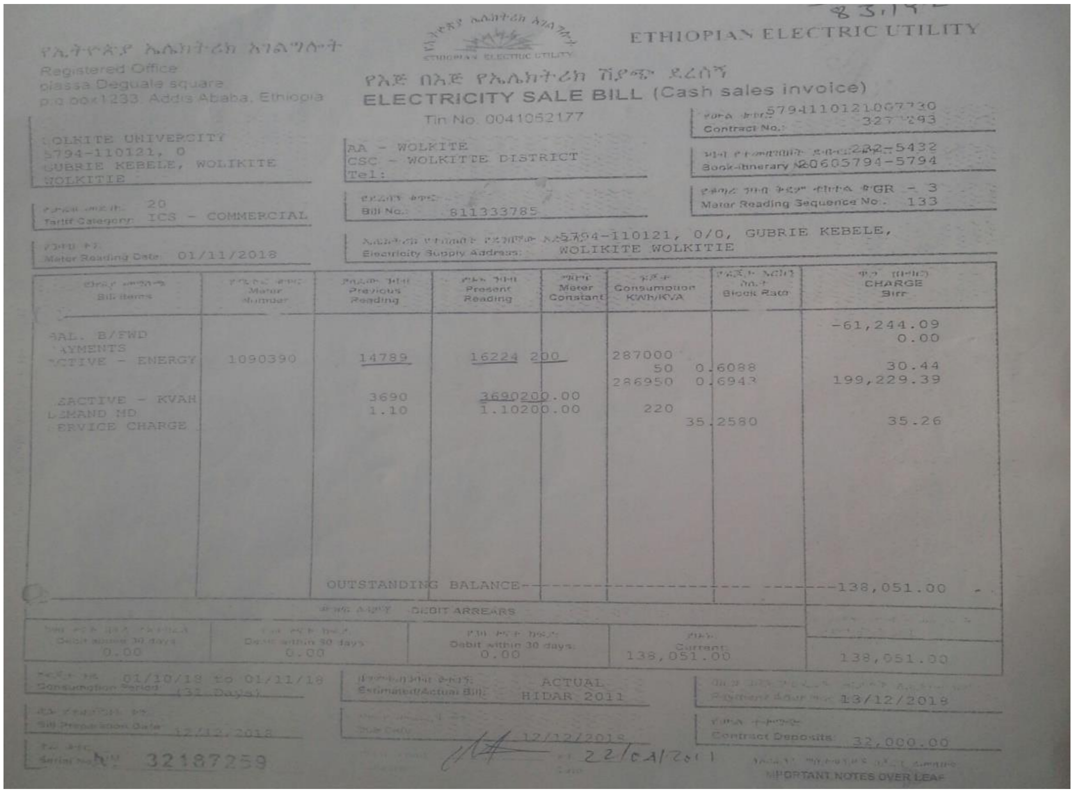
```
---------------------------------------------------------------------------------------------------------
| Grid: Grid          System Stage: Grid       | Study Case: Study Case          | Annex:          / 5  |
---------------------------------------------------------------------------------------------------------
|            rtd.V   Bus - voltage                     Voltage - Deviation [%]                |
|             [kV]  [p.u.]   [kV]   [deg]        -10      -5       0       +5      +10        |
---------------------------------------------------------------------------------------------------------
|Terminal    15.00  1.000   15.00   0.00                         |                            |
|1           15.00  0.965   14.48  -8.17              <<<<<<<<|                               |
|4           15.00  0.965   14.48  -8.17              <<<<<<<<|                               |
|5            0.38  0.000    0.00   0.00        <\\\\\\\\\\\\\\\\\\\\\\\\|
|10           0.38  0.962    0.37  -8.69             <<<<<<<<<|                               |
|9           15.00  0.965   14.47  -8.19              <<<<<<<<|                               |
|3           15.00  0.965   14.48  -8.18              <<<<<<<<|                               |
|6           15.00  0.965   14.47  -8.19              <<<<<<<<|                               |
|2            0.38  0.962    0.37  -8.67             <<<<<<<<<|                               |
|7            0.38  0.962    0.37  -8.69             <<<<<<<<<|                               |
|8           15.00  0.965   14.47  -8.19              <<<<<<<<|                               |
|11          15.00  0.965   14.47  -8.20              <<<<<<<<|                               |
|19          15.00  0.965   14.47  -8.20              <<<<<<<<|                               |
|15           0.38  0.961    0.37  -8.95             <<<<<<<<<|                               |
|20           0.38  0.962    0.37  -8.69             <<<<<<<<<|                               |
|18          15.00  0.965   14.47  -8.20              <<<<<<<<|                               |
|14          15.00  0.965   14.47  -8.20              <<<<<<<<|                               |
|13          15.00  0.965   14.47  -8.20              <<<<<<<<|                               |
|12           0.38  0.959    0.36  -8.69            <<<<<<<<<<|                               |
|17          15.00  0.965   14.47  -8.20              <<<<<<<<|                               |
|16           0.38  0.955    0.36  -9.69          <<<<<<<<<<<|                               |

---------------------------------------------------------------------------------------------------------
| Load Flow Calculation           Complete System Report: Substations, Voltage Profiles, Grid Interchange |
---------------------------------------------------------------------------------------------------------
```

```
|   AC Load Flow, balanced, positive sequence            |  Automatic Model Adaptation for Convergence        No     |
|   Automatic Tap Adjust of Transformers         No   |  Max. Acceptable Load Flow Error for                          |
|   Consider Reactive Power Limits               No   |     Nodes                                         1.00 kVA  |
|                                                       |     Model Equations                               0.10 %   |
-------------------------------------------------------------------------------------------------------------------------------------------
| Grid: Grid          System Stage: Grid        | Study Case: Study Case          | Annex:            / 1  |
------------------------------------------------------------------------------------------------------------------------
|                  rated                         Active   Reactive Power                |                               |
|                  Voltage    Bus-voltage        Power   Power   Factor Current Loading|          Additional Data
|                   [kV]  [p.u.]    [kV]   [deg]  [MW]   [Mvar]   [-]      [kA]        [%] |                            |
------------------------------------------------------------------------------------------------------------------------
|Terminal          15.00   1.00   15.00   0.00                                          |                             |
|  Cub_2  /Xnet    External Grid              3.05    -1.55      0.89     0.13           |Sk": 10000.00 MVA           |
|  Cub_1  /Lne     Line                       3.05    -1.55   0.89    0.13   13.15 |Pv: 348.73 kW,cLod:-0.00 Mvar L:12.00 km|
|1                 15.00    0.97   14.48   -8.17                                        |                             |
|  Cub_5  /Shnt    Shunt/Filter(6)           -0.00     -1.33   -0.00        0.05          |                             |
|  Cub_1  /Lne     Line                  -2.70     1.90  -0.82    0.13   13.15 |Pv:    348.73 kW   cLod: -0.00 Mvar L:   12.00 km|
|  Cub_2  /Lne     Line(1)                    0.42     0.16   0.93    0.02    1.79 |Pv:     0.00 kW   cLod:  0.00 Mvar L:    0.05 km|
|  Cub_3  /Lne     Line(2)                    0.00     0.00   1.00    0.00    0.00 |Pv:     0.00 kW   cLod:  0.00 Mvar L:    0.05 km|
|  Cub_4  /Lne     Line(3)                    2.28    -0.73   0.95    0.10    9.54 |Pv:     0.62 kW   cLod:  0.00 Mvar L:    0.20 km|
|4                 15.00    0.97   14.48   -8.17                                        |                             |
|  Cub_1  /Lne     Line(2)                   -0.00    -0.00  -1.00    0.00    0.00 |Pv:     0.00 kW   cLod:  0.00 Mvar L:    0.05 km|
|  Cub_2  /Tr2     2-Winding Transfor                                          |Tap:      0     Min:     0     Max:     0  |
|5                 0.38    0.00    0.00    0.00                                         |                             |
|  Cub_2  /Lod     General Load(1)             0.00     0.00   1.00    0.00       |Pl0:    0.28 MW   Ql0:   0.21 Mvar          |
|  Cub_3  /Shnt    Shunt/Filter(16)             0.00     0.00   1.00    0.00                 |                              |
|  Cub_1  /Tr2     2-Winding Transfor                                          |Tap:      0     Min:     0     Max:     0  |
|10                0.38    0.96    0.37   -8.69                                          |                              |
|  Cub_2  /Lod     General Load(2)             1.00     0.72   0.81    1.95       |Pl0:    1.00 MW   Ql0:   0.72 Mvar          |
|  Cub_3  /Shnt    Shunt/Filter(15)             0.00    -0.39   0.00    0.61                 |                              |
|  Cub_1  /Tr2     2-Winding Transfor          -1.00    -0.33  -0.95    1.66   87.90 |Tap:    0.00     Min:     0     Max:     0  |
|9                 15.00    0.96   14.47   -8.19                                         |                              |
|  Cub_1  /Lne     Line(5)                   -1.00    -0.35  -0.94    0.04    4.23 |Pv:     0.00 kW   cLod:  0.00 Mvar L:    0.01 km|
|  Cub_2  /Tr2     2-Winding Transfor      1.00     0.35   0.94    0.04   87.90 |Tap:    0.00     Min:     0     Max:     0  |
|3                 15.00    0.97   14.48   -8.18                                         |                              |
|  Cub_1  /Lne     Line(1)                   -0.42    -0.16  -0.93    0.02    1.79 |Pv:     0.00 kW   cLod:  0.00 Mvar L:    0.05 km|
|  Cub_2  /Tr2     2-Winding Transfor      0.42     0.16   0.93    0.02   88.78 |Tap:    0.00     Min:     0     Max:     0  |
|6                 15.00    0.96   14.47   -8.19                                         |                              |
|  Cub_5  /Shnt    Shunt/Filter(7)            0.00    -0.89   0.00    0.04                   |                              |
|  Cub_1  /Lne     Line(3)                   -2.28     0.73  -0.95    0.10    9.54 |Pv:     0.62 kW   cLod:  0.00 Mvar L:    0.20 km|
|  Cub_2  /Lne     Line(4)                    0.28     0.10   0.94    0.01    1.19 |Pv:     0.00 kW   cLod:  0.00 Mvar L:    0.10 km|
```

```
| Cub_3 /Lne    Line(5)                1.00   0.35  0.94   0.04   4.23 |Pv:    0.00 kW  cLod: 0.00 Mvar L:   0.01 km|
| Cub_4 /Lne    Line(6)                1.00  -0.30  0.96   0.04   4.15 |Pv:    0.07 kW  cLod: 0.00 Mvar L:   0.15 km|
|2              0.38  0.96  0.37  -8.67                                        |                              |
| Cub_2 /Lod    General Load           0.42   0.31  0.80   0.83       |Pl0:   0.42 MW  Ql0:  0.31 Mvar          |
| Cub_3 /Shnt   Shunt/Filter          -0.00  -0.16 -0.00   0.26                |                              |
| Cub_1 /Tr2    2-Winding Transfor    -0.42  -0.15 -0.94   0.71  88.78 |Tap:   0.00    Min:    0    Max:   0  |
|7              0.38  0.96  0.37  -8.69                                        |                              |
| Cub_2 /Lod    General Load(3)        0.28   0.21  0.80   0.55       |Pl0:   0.28 MW  Ql0:  0.21 Mvar          |
| Cub_3 /Shnt   Shunt/Filter(1)        0.00  -0.11  0.00   0.18       |                              |
| Cub_1 /Tr2    2-Winding Transfor    -0.28  -0.10 -0.94   0.47  88.54 |Tap:   0.00    Min:    0    Max:   0  |
|8              15.00  0.96  14.47  -8.19                     |                              |
| Cub_1 /Lne    Line(4)               -0.28  -0.10 -0.94   0.01   1.19 |Pv:    0.00 kW  cLod: 0.00 Mvar L:   0.10 km|
| Cub_2 /Tr2    2-Winding Transfor     0.28   0.10  0.94   0.01  88.54 |Tap:   0.00    Min:    0    Max:   0  |
|11             15.00  0.96  14.47  -8.20                     |                              |
| Cub_6 /Shnt   Shunt/Filter(10)       0.00  -0.26  0.00   0.01       |                              |
| Cub_1 /Lne    Line(6)               -1.00   0.30 -0.96   0.04   4.15 |Pv:    0.07 kW  cLod: 0.00 Mvar L:   0.15 km|
| Cub_2 /Lne    Line(7)                0.02   0.01  0.79   0.00   0.08 |Pv:    0.00 kW  cLod: 0.00 Mvar L:   0.04 km|
| Cub_3 /Lne    Line(8)                0.42   0.12  0.96   0.02   1.75 |Pv:    0.06 kW  cLod: 0.00 Mvar L:   0.35 km|
| Cub_4 /Lne    Line(9)                0.56  -0.17  0.95   0.02   2.34 |Pv:    0.01 kW  cLod: 0.00 Mvar L:   0.10 km|
---------------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------------
```

Electricity sales bill



ETHIOPIAN ELECTRIC UTILITY

Registered Office
piassa Deguale square
p.o.box1233 Addis Ababa, Ethiopia

ELECTRICITY SALE BILL (Cash sales invoice)

Tin No. 0041052177

WOLKITE UNIVERSITY
5794-110121, 0
GUBRIE KEBELE, WOLKITE
WOLKITIE

AA - WOLKITE
CSC - WOLKITTE DISTRICT
Tel:

Contract No.: 57941101210077730 327293

Book-Itinerary No.: 232-5432 20605794-5794

Meter Reading Sequence No.: GR - 3 133

Tariff Category: 20 ICS - COMMERCIAL

Bill No.: 811333785

Meter Reading Date: 01/11/2018

Electricity Supply Address: 5794-110121, 0/0, GUBRIE KEBELE, WOLKITE WOLKITIE

Bill Items	Meter Number	Previous Reading	Present Reading	Meter Constant	Consumption KWh/KVA	Block Rate	CHARGE Birr
BAL. B/FWD							-61,244.09
PAYMENTS							0.00
ACTIVE - ENERGY	1090390	14789	16224	200	287000		
					50	0.6088	30.44
					286950	0.6943	199,229.39
REACTIVE - KVAH		3690	3690	200.00			
DEMAND MD		1.10	1.10	200.00	220		
SERVICE CHARGE						35.2580	35.26
OUTSTANDING BALANCE							138,051.00

DEBIT ARREARS

Debit above 90 days	Debit within 60 days	Debit within 30 days	Current	
0.00	0.00	0.00	138,051.00	138,051.00

Consumption Period: 01/10/18 to 01/11/18 (31 Days)

Estimated/Actual Bill: ACTUAL HIDAR 2011

Payment After: 13/12/2018

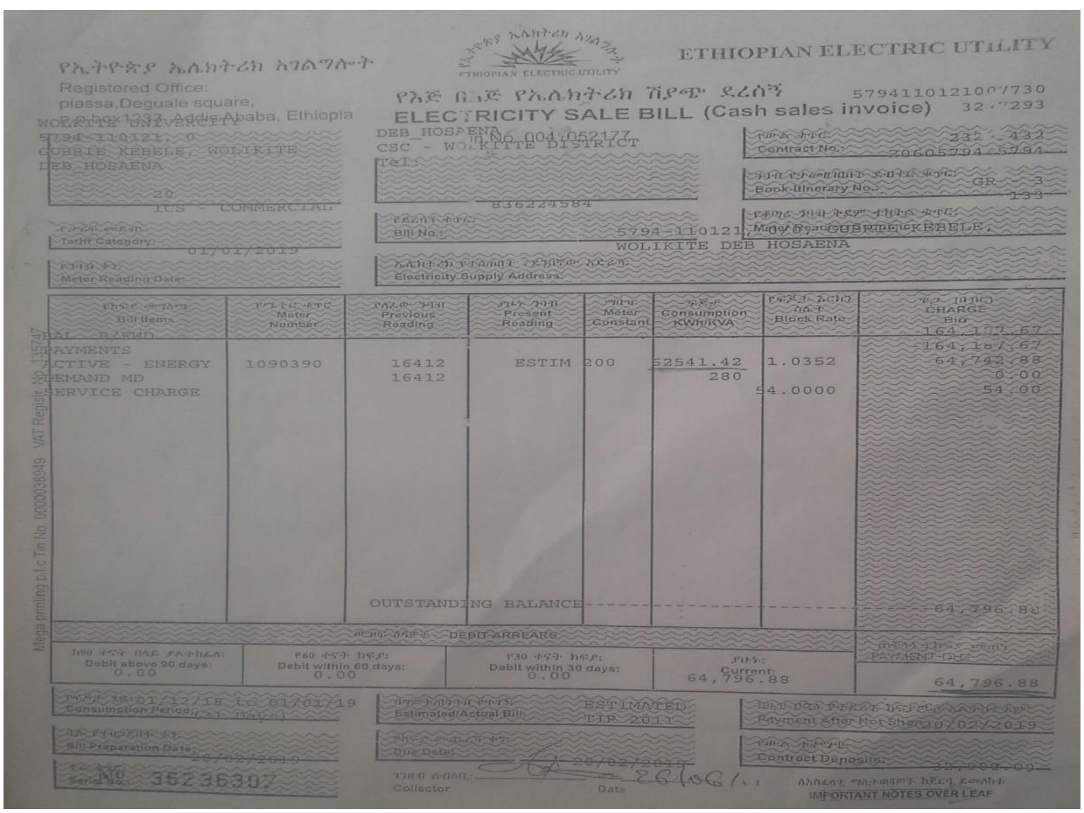
Bill Preparation Date: 12/12/2018

Contract Deposits: 32,000.00

Serial No. 32187259

12/12/2018

IMPORTANT NOTES OVER LEAF



ETHIOPIAN ELECTRIC UTILITY

Registered Office:
piassa,Deguale square,
p.o.box1233 Addis Ababa, Ethiopia

ELECTRICITY SALE BILL (Cash sales invoice)

57941101210077730 327293

WOLKITE UNIVERSITY
5794-110121, 0
GUBRIE KEBELE, WOLKITE
DEB HOSAENA

DEB HOSAENA
CSC - WOLKITTE DISTRICT
Tel:

Tin No. 0041052177

Contract No.: 232-5432 20605794-5794

Book-Itinerary No.: GR - 3 133

Tariff Category: 20 ICS - COMMERCIAL

Bill No.: 836224584

Meter Reading Date: 01/01/2019

Electricity Supply Address: 5794-110121, GUBRIE KEBELE, WOLKITE DEB HOSAENA

Bill Items	Meter Number	Previous Reading	Present Reading	Meter Constant	Consumption KWh/KVA	Block Rate	CHARGE Birr
BAL. B/FWD							164,167.67
PAYMENTS							164,167.67
ACTIVE - ENERGY	1090390	16412	ESTIM	200	62541.42	1.0352	64,742.88
DEMAND MD		16412			280		0.00
SERVICE CHARGE						54.0000	54.00
OUTSTANDING BALANCE							64,796.88

DEBIT ARREARS

Debit above 90 days	Debit within 60 days	Debit within 30 days	Current	PAYMENT DUE
0.00	0.00	0.00	64,796.88	64,796.88

Consumption Period: 01/12/18 to 01/01/19 (31 Days)

Estimated/Actual Bill: ESTIMATED TIR 2011

Payment After Not Shown: 10/02/2019

Bill Preparation Date: 20/02/2019

Contract Deposits: 32,000.00

Serial No. 35236307

Collector 20/02/2019 Date

IMPORTANT NOTES OVER LEAF