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COLLEGE OF ENGINEERING AND TECHNOLOGY  
DEPARTMENT OF ELECTRICAL AND COMPUTER  
ENGINEERING (POWER STREAM)

BSc. Project on  
**RELIABILITY IMPROVEMENT FOR DISTRIBUTION SYSTEM WITH  
DISTRIBUTED GENERATION:**  
**(A CASE STUDY: WOLKITE SUBSTATIONS)**

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I

## ABSTRACT

The main mission of the utility companies, Ethiopian electric power (EEP) and Ethiopian electric utility (EEU) are to transmit, distribute and supply electricity in reliable and efficient manner. This project deals with power systems reliability including technical, economical, and decisional aspects. Knowing that almost 90% of failures occur in the distribution systems, great interest was dedicated to this part of the system, and the first work was oriented to reliability indices defined as objectives to attempt and as performance measures in the electricity market. There are many **causes of power** failures in an **electricity network**. Some of these **causes** include faults at **power** stations, damage to electric transmission lines, substations or other parts of the **distribution system**, a short circuit, cascading failure, fuse or circuit breaker operation. All of the above-mentioned causes affect the reliability of power system. Reliability is a key aspect of power system design and planning. In this project, we present a reliability improvement technique for power distribution system, normally operated (with respect to substation), electrical distribution systems. With recent advanced technology, utility expect to see increasing amount of distributed generation (DG) on the distribution system. Reliability improvement is very important in power system. Having a DG ensures reliability improvement and may be used to increase the reliability worth. This project presents the study of radial distribution system and the impact of placing DG in order to increase reliability. The reliability of power distribution system can be analyzed using reliability indices. The aim of the project is to perform and assessment of how and where a DG have to be placed. In addition, the impact of adding one DG to each feeder of the system, as well as the impact of placing DG at various distance plus the amount of DG installed is presented. It also pretends to recall the importance of understanding of power system reliability from an investment view for the supplier in order to enhance the DG installation to costumer. The study is performed using DIG silent software and ETAP software's.

**KEY WORDS:** Distribution system, Indices, Interruptions, Reliability, DIGSILENT and ETAP soft ware.

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# CHAPTER ONE

## INTRODUCTION

### Background

The electrical energy is an important factor in the economic and social growth of any country in maintaining and developing a modern economy and society. Economic, social and environmental sustainability are the most important variables in the energy scenario of the 21<sup>st</sup> century. Ethiopia electric power system is at risk to system abnormalities such as control failures, protection or communication system failures, transmission line failures, poor maintenances and disturbances, such as lightning, grounding, system overload and human operational errors, growing demand for high-quality supply and rising customer expectations. As a result maintaining a reliable power supply to the customer service is a very important issue for power systems design and operation of the utility company.

Power reliability can be defined as the degree to which the performance of the elements in a bulk system results in electricity being delivered to customers within accepted standards and in the desired amount. Or it is defined as the ability of the system to provide an adequate supply of electrical energy. The concept of power system reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There is a reasonable subdivision of “system reliability”.

- 1) System adequacy and
- 2) System security.

Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points.

Security relates to the ability of the system to respond to disturbances arising within that system. Security is therefore associated with the response of the system to perturbations or disturbances. The reliability improvement technique presented in this project is in the domain of system

adequacy assessment. With recent advances in technology, the use of distributed generation (DG) in the radial distribution system is increasing. Incorporating DG into the radial distribution system possess numerous challenges in terms of interconnection, protection coordination, system losses and voltage regulation. Increased in reliability and reduced cost of interruption are the primary advantages of adding DG to an existing distribution network. Distributed generations (DG) generally refer to small scale electric power generators near to customers or are connected to an electric distribution system. Distributed generators ( Distributed Resources) come in many forms including synchronous generators, wind powered induction generators, fuel cells with inverter circuitry, and other. Among these types of DGs, Solar Photovoltaic (PV) power generation type of distributed generator is used in this project. Some advantages of using DG in power distribution systems are improving system integrity, increasing overall energy efficiency and reducing fuel Costs, enhancing system reliability, reducing emissions of pollutants and health care costs, and improving power quality. In order to achieve the mentioned goals, proper location and size of distributed generation resources known as optimal DG placement is of great importance to obtain their maximum Potential benefits.

Radial distribution system is a system whereby power is received at the utility supply voltage level by a single, incoming substation. Through a series of step downs and splits, the power is converted for individual end-use equipment. The case study of radial distribution system investigation and simulation is carried out on WOLKITE substation system which consists of 230 kV, 66 Kv, 33 kV and 15 kV outgoing feeder network. The reliability assessment and load flow analysis through 66/15 kV, 6.3 MVA transformer is done on two 15 kV feeders such as wolkite university (feeder 1) and beer industry (feeder 2) system to assess the performance of the present system and also introduce DG allocation, and size to reliability analysis for the existing system considering load and system configurations. The alternative which gives low value of SAIFI, CAIDI, EENS SAIDI, and Interruption costs are being assessed and considered. The reliability of 15 kV systems could be further improved by installation of Distributed generation.

## **1.2 Statement of the problem**

Problems of electricity mainly caused by main parts of power system components, which are generation site, transmission and distribution systems. Concerns had been given to generation and transmission system dealing with problems of electric reliability. But the major reliability problems occurring in customers utility are problems created by distribution system.

With the existing distribution system, the customer interruptions exist and most of the interruption has been caused due to the failure in the distribution systems especially as a result of change of weather conditions. Hence it is necessary to improve the reliability of the system in order to improve the utilities performance and to keep our valued customers satisfied. So in this project, power distribution system reliability problems are considered.

## **1.3 Objective**

### **1.3.1 General objective**

To provide power distribution system reliability improvement concerning reliability problems and making it a general guide line as solution set to avoid reliability problem.

### **1.3.2 Specific objective**

- Analysis Reliability improvement of distribution system using distributed generation in the system.
- Asses the existing distribution network.
- Study the electrical power reliability assessment of distribution system.
- Collect the interruption duration, occurrences, causes, number of customers etc.
- Identify the causes of interruptions.
- Provide a better reliability improving method.
- Calculating reliability index and comparison base case with the modified system Index.

## **1.4. Contribution of the Project**

This work provides a general guideline scenario to inject DGs in a distribution system. Our major contribution in this work is introducing this method for analyzing optimal location of DGs in the system. Thus, our contribution can be mentioned as a new approach in improving distribution system reliability by injecting distributed generation (DG).

## **1.5. Scope of the project**

In this project, our intention is urged to provide reliability improvement method for a specific power distribution system. As a result of short period we have, the specific place we focus is the power distribution system that comes from wolkite substation to wolkite city, and our installed DG is PV cell based.

## **1.6. Methods**

The study is started by reviewing literatures related to the investigation of reliability problems of power systems. Recent and unpublished important information and data have been collected from wolkite substation and distribution transformers. Interviews with respective to professionals at substations (utility) have been considered.

Generally the following method is used in doing the project:

- ❖ Technical data collection from wolkite substation and utility.
- ❖ Collecting interruption duration, occurrences of existing system.
- ❖ Identifying the causes of interruptions.
- ❖ Modeling the existing system with DG
- ❖ Calculating reliability index and compare base case with the modified system index.

## CHAPTER TWO

### Literature Review

#### 2. Power System

The power system is a network which consists of generation, transmission and distribution system. It uses the form of energy (like coal and diesel) and converts it into electrical energy. The power system includes the devices connected to the system like the synchronous generator, motor, transformer, circuit breaker, conductor, etc. The transmission line transfers the power to the various substations. Through substation, the power is transferred to the distribution transformer which step-down the power to the appropriate value which is suitable for the consumers.

#### 2.1 Structure of Power System

The power system is the complex enterprise that may be subdivided into the following sub-systems. The subsystems of the power system are explained below in details.

##### 2.1.1 Generating Substation

In generating station the fuel (coal, water, nuclear energy, etc.) is converted into electrical energy. The electrical power is generated in the range of 11kV to 25kV, which is step-up for long distance transmission. Generator and transformer are the main components of the generating station. The generator converts the mechanical energy into electrical energy. The transformer transfers the power with very high efficiency from one level to another. The step-up transformer will reduce losses in the line which makes the transmission of power over long distances.

##### 2.1.2 Transmission Substation

The transmission substation carries the overhead lines which transfer the generated electrical energy from generation to the distribution substations. It only supplies the large bulk of power to bulk power substations or very big consumers. The transmission lines mainly perform the two functions: It transports the energy from generating stations to bulk receiving stations and It interconnects the two or more generating stations. The transmission voltage is operating at more than 66kv and is standardized at 69kv, 115KV, 138KV, 161KV, 230KV, 345KV, 500KV, and 765KV, line-to-line. The transmission line above 230KV is usually referred to as extra high voltage (EHV).

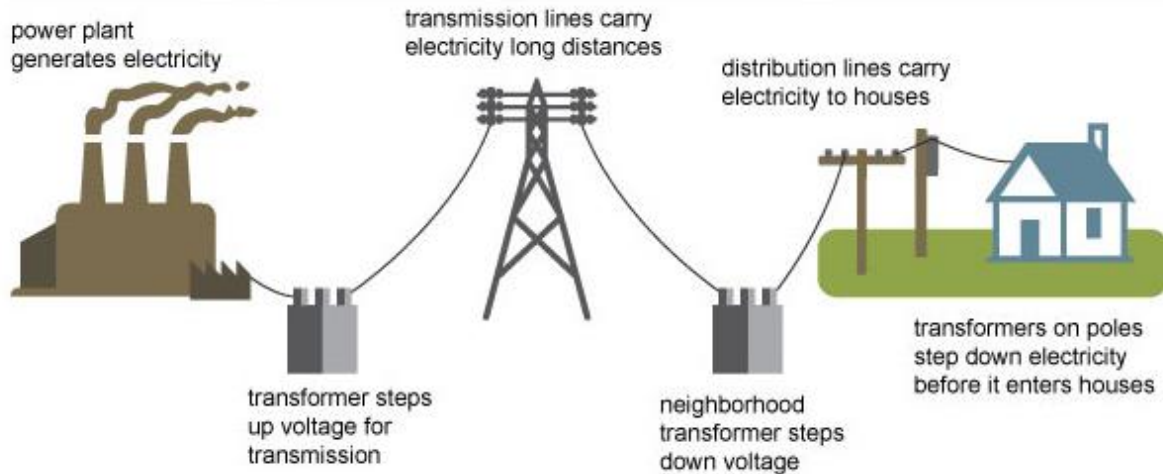
### **2.1.3 Sub-transmission Substation**

The portion of the transmission system that connects the high voltage substations through the step-down transformer to the distribution substations is called the sub-transmission system. The sub-transmission voltage level ranges from 90 to 138KV. The sub-transmission system directly serves some large industries. The capacitor and reactor are located in the substations for maintaining the transmission line voltage. The operation of the sub-transmission system is similar to that of a distribution system. It differs from a distribution system in the following manner.

1. A sub-transmission system has a higher voltage level than a distribution system.
2. It supplies only bigger loads.
3. It supplies only a few substations as compared to a distribution system which supplies some loads.

### **2.1.4 Distribution Substation**

Distribution Substation have step-down power transformers, a few incoming high voltage sub-transmission lines and several outgoing medium voltage overhead lines or underground cables. Step down power transformers in the substation step down sub-transmission voltage levels to primary distribution levels. First, the distribution substations step down the voltage from 66 kV to 15 kV. Then, the primary distribution system transfers the electric power from the substation to the distribution transformers. Some industrial customers are served directly from the primary distributions. The distribution transformers step down the voltage again to utilization levels, namely: 120/230 V for single phase, 400 V for three phases.



*Figure 1 General block diagram of power system*

## 2.2 Power System Reliability Evaluation

The concept of power system reliability was first proposed in 1978. Starting from that time many efforts have been applied to develop different kinds of reliability assessment approaches.

Marlin and Bak have first proposed a feeder reconfiguration technique for loss minimization in distribution system. In this method all the network switches are closed to form a closed system, and then the switches are opened successively, to restore to the radial configuration, thus minimizing the losses. However, this method involves approximations.[1]

[2] Morton has proposed a method based on an exhaustive search algorithm for obtaining a minimum loss of a radial distribution system.[3] M.W. Siti has proposed a technique at the low-voltage and medium-voltage levels of a distribution network with reconfiguration at both levels.

[4] K. Viswanadha Raju has proposed a new, two stages, and heuristic method for determining a minimum loss configuration of a distribution network, based on real power loss sensitivities with respect to the impedances of the candidate branches.[5] Javad Olamaei et al have proposed distribution feeder reconfiguration for loss minimization using modified honey bee mating optimization algorithm[6] The reliability assessment method uses a probabilistic model that balanced demand for lower customer rates with improved reliability for a distribution system with DG. The objective is to determine the DG equivalence to a distribution facility with comparable reliability and load requirements. Accordingly, DG installation in the distribution was a better solution since the capital cost for the additional feeder could be avoided, the independent power

producers would receive distribution capacity deferral credit and adding DG to the area would also provide voltage control for the network [7].

From the above literature it can be concluded that distribution losses account for a major portion of the technical losses. Most of the methods available for this purpose may not be economical and they may not give an immediate solution. So there is a need to adopt an economical method like relocation/optimal placement of distribution generator which gives an immediate solution.

## **2.3 Distributed Generation**

DG can be defined as “electric power generation within distribution networks or on the customer side of the network” or the process of generating electricity through systems that are located on the distribution network or at the customer side [17]. From an environmental prospective, use of renewable energy reduces emissions as well as help in avoidance of construction of new transmission lines and large power plants. DG units can also have a beneficial impact on power quality and reliability such as improved voltage profile, reduced power losses and network congestion [18]. DGs also have the potential to increase competition in generation which will lead to better service and low energy price. Another incentive for the penetration of renewable energy based DG sources is feed-in- Tariffs (FIT) paid by regulators to achieve their goals of meeting electricity demand with clean or

The second classification is based upon unit technologies which are renewable, modular or combined heat and power (CHP). DG units based on renewable energy resources can be readily replenished and are viewed as ‘environmentally friendly’. Modular DG units refers to that can be built and placed within a short time span and can be operated together (as distinct units) to meet larger output requirements.

According to IEEE defines DG as “the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system [22, 23].” IEEE compared the size of the DG to that of a conventional generating plant. A more precise definition is provided by the International Council on Large Electric Systems (CIGRE) and The International Conference on Electricity Distribution (CIRED) [24, 25], which DG based on size, location, and type. CIGRE defines distributed generation as “all generation units with a maximum capacity of 50 MW to 100

MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched.” The distributed generation as “the relatively small generation units of 30MW or less that are located to near customer sites to meet specific customer needs, to support economic operation of the distribution grid, or both [26]”. Dondi, et al., [27] defines distributed generation as “a small source of electric power generation that is not a part of a large central power system and is located close to the load center.” Ackermann [17] defines a distributed generation as “an electric power generation connected directly to the distribution network or on the customer side of the meter.” This is most generic one, because there is no limit on the DG size, capacity, and location of the DG.

One aspect investigated here is the effect of Distributed Generators on power system reliability. Standards for connecting DGs into distribution systems are just being developed. An investigation of power utilities and industry interconnection standards was performed to identify the key requirements for a DG connection. The results of this investigation led to the development of a unified approach for determining interconnection requirements [28]. The requirement considers many aspects of DGs in distribution systems, including protection, harmonics, transients, and voltage and frequency control [29].

## **2.4 Distributed Generation Technologies**

Distributed generation technologies can be categorized into conventional and renewable DG technologies. The conventional technologies such as fossil-fuel based generators have been widely deployed in distribution system as back-up generation or cogeneration without having significant interaction with distribution networks. In recent years, the development of technology in different fossil-fuel based DG technologies and distribution system automation have made as one of the attractive options for distribution system reinforcement. On the other hand, the renewable DG technologies such as wind turbine generator, solar, hydropower and geothermal are also seen to be increasingly employed in distribution networks due to environmental concerns. Fossil fuel based DG technologies, capable of power output control; the power generation by renewable DG technologies is non-controllable. The power output of renewable DG impacted by the availability of energy sources, such as water, wind and solar radiation, is an important factor of selecting potential sites for DG at required plans.

### 2.4.1 Fossil-fuel Based DG

The application of fossil-fuel based DG units, such as diesel, micro-turbine and gas turbine generator, and combined heat and power (CHP) has been well important to power industry. Traditionally, the diesel and gas generator units are installed at the load center sites to ensure reliability of sensitive loads, especially in case of system emergencies, whereas CHP units are employed to generate power while providing auxiliary services such as heat to increase the overall efficiency associated with the generation system. Although the name “diesel” is always associated with light fuel, these generators can actually be tuned to use a wide variety of liquid and gaseous fuels, including natural gas, propane, and residual fuel oil.

These technologies are installed as back-up generator, the innovations and improvements in their designs significantly increase their efficiency and make them capable of exporting power to distribution systems for effective system support. The advantages and disadvantages associated with fossil-fuel based DG units are summarized in Table 2.2.

*Table 1: Advantages and disadvantages of fossil-fuel based DG*

Advantages	Disadvantages
<ul style="list-style-type: none"><li>➤ Readily reliable with continuous production</li><li>➤ Easy to access fuels</li><li>➤ Controllable and dispatchable</li><li>➤ Relatively low capital investment</li><li>➤ Utilization of waste heat (CHP)</li><li>➤ Possible export of reactive power for network support</li></ul>	<ul style="list-style-type: none"><li>➤ High operation and maintenance cost</li><li>➤ High fuel cost</li><li>➤ High noise pollution</li><li>➤ High emission</li></ul>

### 2.4.2 Wind Power Generation Based DG

In the last few decades, increasing number of wind turbine generators are getting interconnected in transmission networks. Recently, the wind turbine generators are also being installed in distribution systems due to significant technological development and reduced cost associated with their construction and integration. The wind power generator often is

installed in areas of high wind speed that area has the well developed infrastructure of the distribution system, leading to a requirement for careful consideration of the integration of wind to relative weak electrical part of the distribution system.

A wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity. The power generated by a wind turbine is proportional to the swept area of the rotor disc and to the cube of wind speed that pass through the mentioned disc. Also the air density and a power coefficient that express the average of extracted energy from the wind by the turbine rotor are implicated [30]. Among these factors, the most important factor is the wind speed, since its impact is cubic.

### **2.4.3 Photovoltaic Power Generation Based DG**

Photovoltaic (**PV**) generation, directly converting sunlight into electricity, is a well established technology for supplying power to sites at a way the distribution substation [31]. It is currently being considered for integration into distribution system for large scale, medium scale and small scale DG. The power generated by PV based DG units are inherently intermittent; it is less variable and is much easier to predict. The modular design of PV based DG systems allows them to be easily incorporated into various places such as buildings and rooftops. However, the power quality problems arising from integration of large amount of PV based DG units and high cost associated with PV cells and ancillary equipment are the two main factors limiting the widespread implementation of this technology.

The PV energy is produced when the solar cells are exposed to direct sunlight, each cell generates less than one watt of DC power, with the lowest voltage around 0.5 V. A solar cell is basically a semiconductor diode in which the photons of sunlight fall on the cell and generate electron-hole pairs separated on the diode junction, thus forming the junction potential or voltage. The generated voltage potential is limited by the forward potential drop across the semiconductor p-n junction. The current produced is proportional to the surface area and to the density of the solar power radiation [32, 41].

#### 2.4.4 Micro Turbine

Micro turbine generator systems are considered as distributed energy resources which are interfaced with the electric power distribution system. They are most suitable for small to medium-sized commercial and industrial loads. The micro turbine provides input mechanical energy for the generator system, which is converted by the generator to electrical energy. The generator nominal frequency is usually in the range of 1.4-4 kHz. This frequency is converted to the supply frequency of 50 Hz by a converter.

There are two types of micro turbine: Recuperated MT and UN recuperated MT. Recuperated micro turbines, which recover the heat from the exhaust gas to boost the temperature of combustion and increase the efficiency. UN recuperated micro turbines, which have lower efficiencies, but also lower capital costs.

Mechanically the MTG is a single shaft, gas turbine with compressor, power turbine and permanent magnet generator being mounted on the same shaft. MTG 's have a high speed gas turbine engine driving an integral electrical generator that produces 20-100 KW power while operating at a high speed generally in the range of 50,000-120,000 rpm. Electric power is produced in the range of 10 kHz converted to high voltage dc and then inverted back to 50 Hz, 400 V ac by an inverter.

## CHAPTER THREE

### RELIABILITY EVALUATION METHOD

The evaluated and identified reliability problems of power distribution system which are expected to occur and already exist from researches conducted locally and internationally are set in to mind, then by correlating the international standard indices and locally exhibited problems, reliability improvement techniques are forwarded.

#### 3.1 Power System Reliability Evaluation

The power system reliability evaluation strategy has three functional zones i.e generation, transmission and distribution facilities. The three functional zones are:



*Figure :2 Reliability analyses of three functional zones*

#### **Reliability assessment of functional zone A**

- Concerned only with the generation facilities and their ability to satisfy the system demand.
- The total system generation is examined to determine its adequacy to meet the total system load requirement considering random failures, and corrective and protective maintenance of the generation units.
- The transmission and distribution system and the ability to move the generated power to the consumer load points are not included in this analysis.

#### **Reliability assessment of functional zone B**

- Includes generation and transmission facilities and the ability to deliver energy to the bulk power points.

- Used to assess the adequacy of an existing system including the impact of various reinforcement alternatives at both the generation and transmission levels on bulk load point and overall system indices.

### **Reliability assessment of functional zone C**

- Refers to the complete system assessment includes all three functional zones and starts at the generating point and terminates at the satisfaction of the individual customers in the distribution systems.
- Studies are not usually done directly. The analysis is usually performed only in the distribution facilities zone and the functional zone B load point indices are used as input values to the zone. The common reliability indices in this level (SAIFI), (SAIDI), (CAIDI), (EENS), and (EIC).

An overall system reliability evaluation is normally not conducted as a result of the enormity of the problem. Instead, reliability evaluations of individual system components are conducted. So that in this project distribution system reliability improvement is conducted since 80% of power interruption is caused by distribution system failure (such as burnt of fuse, operational problems, change of weather conditions, etc) while the rest 20% of power interruption occurred in both generation and transmission systems.

## **3.2 Distribution System Reliability**

Distribution System is part of power system which distributes electrical power for local use. And also it is the electrical system between substations fed by the transmission system and consumer meter. Generally, distribution lines consist of feeder, distributors and service mains.

- Feeders are the power lines through which electricity is transmitted in power systems. It transmits power from Generating station or substation to the distribution points. The feeder which serves the community around wolkite and university has a capacity of 15Kv with 23,242 total number of customers.
- A distributor is a conductor from which tapings are taken from pole mounted transformer to the consumer.
- Service mains are generally a small cable which connects the distributor to the consumer's meter.

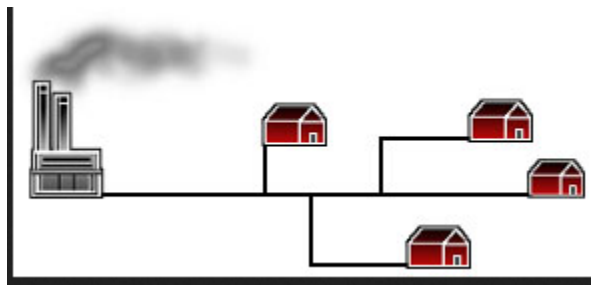
There are three basic **types of distribution system** design or configuration. These are:

- Radial
- Loop and
- Network types of configurations

The majority of distribution systems are designed to operate with a radial topology.

❖ The Radial distribution system is:

- The cheapest to build, and is widely used in sparsely populated areas
- Has only one power source for a group of customers  
(a power failure, short-circuit, or a downed power line would interrupt power in the entire line which must be fixed before power can be restored)
- Have a set of series components between a substation and a load point, including breakers, lines, cables, transformers, switches, fuses and other equipment.
- A failure of any component in the series path results in the outage of a load point. Sectionalizing devices provide a means of isolating a faulted section. In some systems there is an alternative supply source for sections that become disconnected from their original source after the failure is isolated.

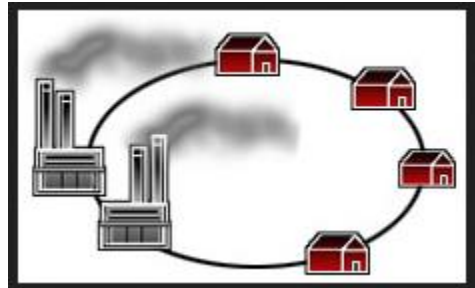


*Figure 3; Radial distribution system*

❖ **A loop system**

- Loops (circulates) through the service area and returns to the original point.
- is usually tied into an alternate power source. By placing switches in strategic locations, the utility can supply power to the customer from either direction.
- If one source of power fails, switches are thrown (automatically or manually), and power can be fed to customers from the other source.

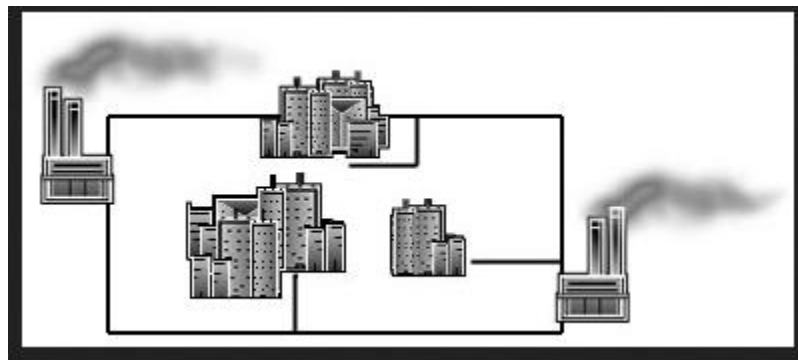
- Provides better continuity of service than the radial system, with only short interruptions for switching. In the event of power failures due to faults on the line, the utility has only to find the fault and switch around it to restore service. The fault itself can then be repaired with a minimum of customer interruptions.
- Is more expensive than the radial because more switches and conductors are required, but the resultant improved system reliability is often worth the price.



*Figure 4; Loop distribution system*

❖ **Network systems**

- Are the most complicated and are interlocking loop systems.
- A given customer can be supplied from two, three, four, or more different power supplies.
- Obviously, the big advantage of such a system is added reliability.
- However, it is also the most expensive. For this reason it is usually used only in congested, high load density municipal or downtown areas.



*Figure 5; Network distribution system*

Reliability assessment is of primary importance in designing and planning distribution systems that operate in an economical manner with minimal interruption of customer loads. Distributed generation (DG) is expected to play an increasing role in emerging power systems because they use different type of resources and technologies to serve energy to power systems. DG is expected to improve the system reliability as its backup generation. Since DG units are subject to failures as all other generation units, the random behavior of these units must be taken into account in the analysis. The Impacts of DG units, their location, number of DG units in each location and their availability, on distribution system reliability are investigated.

The majority of distribution systems are designed to operate with a radial topology. Radial distribution systems have a set of series components between a substation and a load point, including breakers, lines, cables, transformers, switches, fuses and other equipment. A failure of any component in the series path results in the outage of a load point. Sectionalizing devices provide a means of isolating a faulted section. In some systems there is an alternative supply source for sections that become disconnected from their original source after the failure is isolated.

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipment (except standby) are energized and all customers are energized. Scheduled and unscheduled events disrupt normal operating conditions and can lead to outages and interruptions. A reliability assessment model quantifies reliability characteristics based on system topology and component reliability data. Areas of inherently good or poor reliability can be identified. The model also identifies overloaded and undersized equipment that degrades system reliability. Other useful results include the expected number of switch and protective device operations and the sensitivity of results to component reliability parameters. The reliability of a distribution system may be increased by modifying failure rate and repair time of each section of the network. Such modifications may require additional investments which in the presence of DG may be mitigated. This will result in annual savings. On the other hand cost per unit energy obtained from DG may be high. Further the traditional reliability indices covered sustained interruption durations.

The time necessary to start up the DG should be taken in to account for the reliability evaluation of distribution system. If this time is sufficiently short the customers suffer a momentary interruption, while, if not, they suffer a sustained interruption. Distributed generation (DG) is

expected to play an increasing role in emerging power systems. Studies have predicted that DG will be a significant percentage of all new generation going online. Different resources can be used in DG. Its impact on distribution systems may be either positive or negative depending on the system's operating condition, DGs characteristics and location.

Potential positive impacts include:

- Improved system reliability
- loss reduction and
- Improved power quality.

Potential Negative impacts include:

- It takes high amount of capital to install DG.
- Its is not efficient on summer season, that's why there is no more sun shine during summer.

### **3.3 Distributed Generation**

Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power. The distributed generation as “the relatively small generation units of 30MW or less that are located to near customer sites to meet specific customer needs, to support economic operation of the distribution grid”. Dondi and et al. defines distributed generation as “a small source of electric power generation that is not a part of a large central power system and is located close to the load center.” Ackermann defines a distributed generation as “an electric power generation connected directly to the distribution network or on the customer side of the meter.” This is most generic one, because there is no limit on the DG size, capacity, and location of the DG.

DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits such as lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators. DG technologies yield power in capacities that range from a fraction of a kilowatt [kW] to about 100 megawatts [MW]. Some Examples of Distributed Generation Technologies are: Wind turbines, geothermal energy production, solar systems (photovoltaic), and some hydro-thermal plants. In this project, PV system is used.

There are two main classifications of DGs based on unity capacity and unity technology.

### **Based on unit capacity**

- Micro DG: 1 W - 5 kW
- Small DG: 5 kW - 5 MW
- Medium DG: 5 MW - 50 MW
- Large DG: 50 MW - 300 MW

### **Based on unit technologies**

- Renewable
- Modular
- Combined heat and power (CHP).

#### **3.3.1 Solar systems (photovoltaic power generation) based DG**

A photovoltaic system, (PV system/solar power system) is a power system designed to supply usable solar power by means of photovoltaic. It generates electricity directly from solar energy radiation. The solar energy generation of a PV system is mostly weather dependent, since the total amount of solar radiation gathered by the module varies with weather conditions. Solar radiation is made up of two components: direct and diffuse. Direct radiation comes directly from the sun, while diffuse radiation is scattered in the atmosphere and approaches the module from all parts of the sky. Energy can be generated during less than half of the day, and total generation varies over the year. On a clear day direct radiation may account for 80-90% of the total radiation collected, but on a cloudy day this can drop to zero, leaving a small diffuse component providing 10-20% of the radiation collected on a typical clear day.

It is currently being considered for integration into distribution system for large scale, medium scale and small scale DG. The power generated by PV based DG units are inherently intermittent; it is less variable and is much easier to predict. The modular design of PV based DG systems allows them to be easily incorporated into various places such as buildings and rooftops. However, the power quality problems arising from integration of large amount of PV based DG units and high cost associated with PV cells and ancillary equipment are the two main factors limiting the widespread implementation of this technology.

Positive effects of these types of power plants are far more significant than the negative ones. In PV electricity generation, there are no CO<sub>2</sub> and greenhouse gas emissions. During power plant operation, there is neither emission of particles that cause respiratory problems in humans and animals nor emission of heavy metals such as lead (Pb) nor noise. It consists of an arrangement of several components, including:

- Solar panels: to absorb and convert sunlight (radiation) into electricity
- Solar inverter: to change the electric current from DC to AC
- Mounting, cabling, and other electrical accessories to set up a working system.
- A solar tracking system to improve the system's overall performance and include an integrated battery solution, as prices for storage devices are expected to decline.

### *3.3.1.1 Advantage and Disadvantages of PV based DG*

#### *Advantages*

- Electricity produced by solar cells is clean and silent. Because they do not use fuel other than sunshine, PV systems do not release any harmful air or water pollution into the environment, deplete natural resources, or endanger animal or human health.
- Photovoltaic systems are quiet and visually unobtrusive.
- Small-scale solar plants can take advantage of unused space on rooftops of existing buildings.
- PV cells were originally developed for use in space, where repair is extremely expensive, if not impossible. PV still powers nearly every satellite circling the earth because it operates reliably for long periods of time with virtually no maintenance.
- Solar energy is a locally available renewable resource. It does not need to be imported from other regions of the country or across the world. This reduces environmental impacts associated with transportation and also reduces our dependence on imported oil. And, unlike fuels that are mined and harvested, when we use solar energy to produce electricity we do not deplete or alter the resource.
- A PV system can be constructed to any size based on energy requirements. Furthermore, the owner of a PV system can enlarge or move it if his or her energy needs change. For instance, homeowners can add modules every few years as their energy usage and financial resources

grow. Ranchers can use mobile trailer-mounted pumping systems to water cattle as the cattle are rotated to different fields.

### *Disadvantages*

- Some toxic chemicals, like cadmium and arsenic, are used in the PV production process. These environmental impacts are minor and can be easily controlled through recycling and proper disposal.
- Solar energy is somewhat more expensive to produce than conventional sources of energy due in part to the cost of manufacturing PV devices and in part to the conversion efficiencies of the equipment. As the conversion efficiencies continue to increase and the manufacturing costs continue to come down, PV will become increasingly cost competitive with conventional fuels.
- Solar power is a variable energy source, with energy production dependent on the sun. Solar facilities may produce no power at all some of the time, which could lead to an energy shortage if too much of a region's power comes from solar power.

### **3.4 Impact of DG on The Power System**

Interconnecting a DG to the power system can have significant effects on the system such as power flow, voltage regulation, reliability enhancement, and power loss etc. DG changes traditional characteristics of the distribution system. Most of the distribution systems are that the power flows in one direction. When the DG power is more than the downstream load, it sends power upstream reversing the direction of power flow and at some point between the DG and substation; the real power flow is zero due to back flow of power from DG.

The central power plants are located at specific remote sites and are connected to an extended transmission system which transfers bulk electrical power to the distribution system. This way of power system operation is often called a vertically-operated power system. While the decentralized power generation sources are small in size and mainly connected to the distribution system. Because of the implementation of DG in the distribution system the power is generated closer to the load which will affect the local power flow.

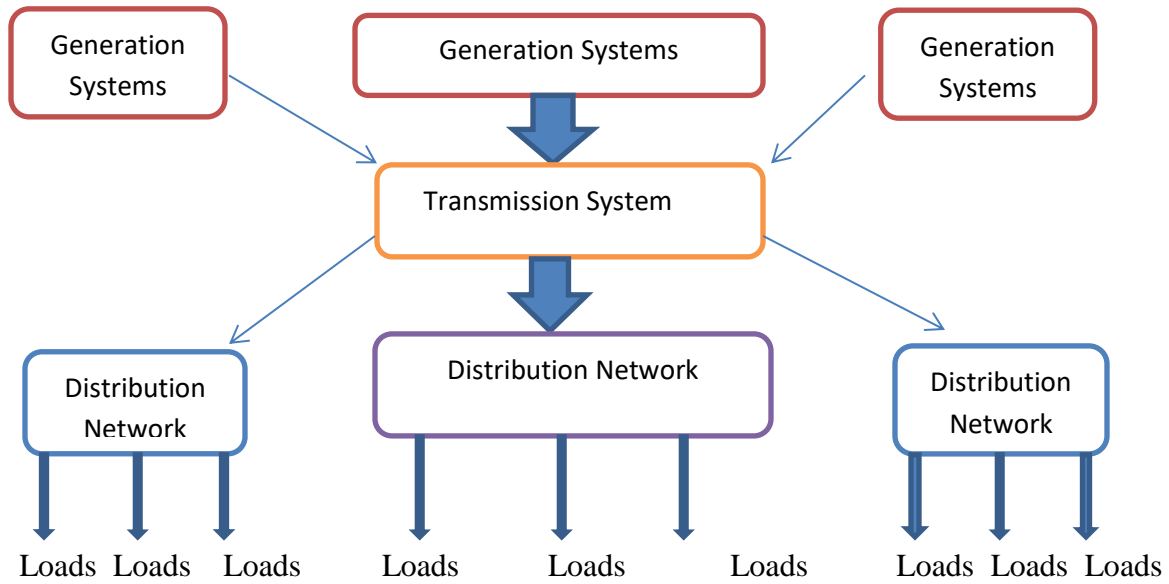
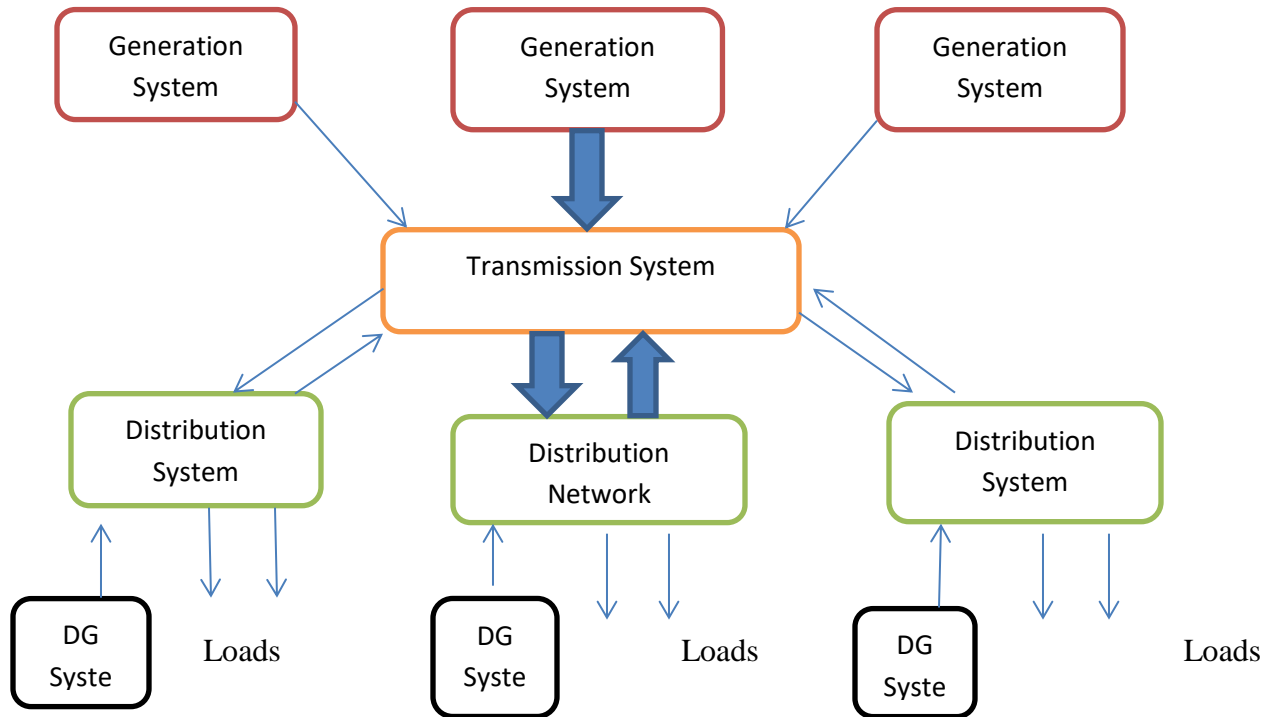


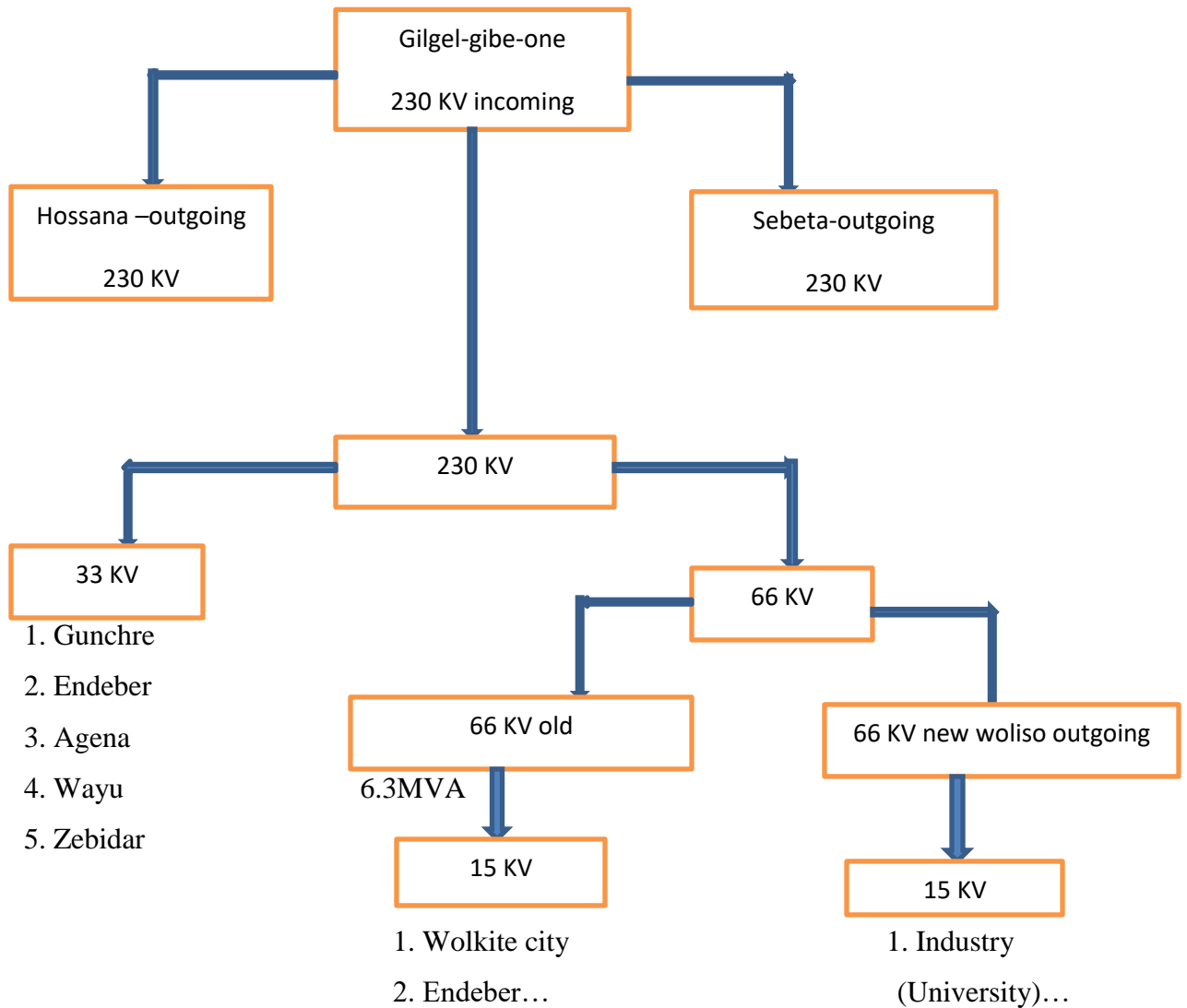
Figure 6; The current existing power flow



(b) Proposed power flow

Figure 7; Transition from vertically to a horizontally operating power system

The general block diagram of the power flow for incoming power from generation to distribution system looks like as shown in the figure below.



*Figure 8; General Power flow*

As shown from the above figure, the 15kv feeder is supplied for 23242 customers. Among these customers 365 customers are supplied with three phase power (3 $\phi$ ) and the rest are supplied with single phase. Even though power interruptions on these customers are caused due to short circuit, burnt of fuse and circuit breaker, operational problems, change of weather conditions etc,

### 3.4 Power system reliability indices

Assessment of reliability indices typically consider the following aspects

- The number of customers
- The connected load are four.
- The duration of the interruption measured in seconds, minutes, hours, or days
- The amount of power (kVA) interrupted.
- The frequency of interruptions

According to the data collected from the utility, the total number of customers around wolkite served by 15 KV is 23242

There are many indices for measuring reliability of power distribution system. Some of the indices are: SAIDI, CAIDI, SAIFI, ASAI, ASUI, EENS, and AENS.

Name	Description
SAIDI	System average interruption duration index is the average interruption duration per customer served. It is determined by dividing the sum of all customer interruption durations during a year by the number of customers served (hrs /customer year).
SAIFI	System average interruption frequency index indicates the frequency of a sustained interruption experienced by the average customer served in a distribution system during a predefined period of time. It is determined by dividing Total Number of Customers Interruption by Total Number of Customers Served (interruption /Customer. yr).
CAIDI	Customer average interruption duration index is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the total number of customer's interruption (hours/customer interruption).
ASAI	Average service availability index indicates the percentage of time in the defined reporting time horizon that the power has been provided to customer. It is

determined by dividing Customer hours of available Service by Customers hours service Demands (%)

**EENS** Expected energy not supplied is the expected amount of energy not supplied due to capacity deficiency in the period of observation. It is the sum of each load times its outage duration (kWh/yr).

**AENS** Average energy not supplied is the total Energy not supplied in system divided by total number of customers served (kWh/yr. customer)

**EIC** Expected Interruption Cost Index is the cost of not supplied energy at that load point (\$/yr)

Two sets of reliability indices, customer load point indices and system indices have been established to assess the reliability performance of distribution systems. Load point indices measure the expected number of outages and their duration for individual customers. System indices such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) measure the overall reliability of the system . These indices can be used to compare the effects of various design and maintenance strategies on system reliability.

In order to find the values of the above reliability indices, some analytical calculations take place as follows:

### **Customer based indices**

1. **(SAIDI)** System average interruption duration index: a measure of how many interruption hours on average customer will experience over the course of a year. For a fixed number of customers, SAIDI can be improved by decreasing the number of interruptions or by decreasing the duration of these interruptions. Since both of these reflect reliability improvements, a reduction in SAIDI means an improvement in reliability.

$$\text{SAIDI} = \frac{\text{Sum of customer interruptions durations}}{\text{Total number of customer served}} = \frac{\sum r_i N_i}{N_T}$$

Where,  $N_T$  = Total number of customers served = 23242

$N_i$  = Number of interruption = 101 (due to feeder fault)

$r_i$  = duration of customer interruption = (30-40)minutes = avg = 35minutes

2. **(SAIFI)** System Average Interruption Frequency Index: is a measure of how many sustained interruptions on average customer will experience over the course of a year. For a fixed number of customers, the only way to improve SAIFI is reduce the number of sustained interruption experienced by customers.

$$\text{SAIFI} = \frac{\text{Total Number of Customers Interrupted}}{\text{Total number of customers served}} = \frac{\sum \lambda_i N_i}{N_T}$$

Where,  $N_T$  = Total number of customers served = 23242

$N_i$  = Number of interruption = 101

**(CAIDI)** Customer average interruption duration index: is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system incidents. CAIDI can be improved by decreasing the length of interruptions, but can also be decreased by increasing the number of short interruptions. As a result, a decrease in CAIDI does not necessarily mean an improvement in reliability.

$$\text{CAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total number of customers interrupted}} = \frac{\sum r_i N_i}{\sum \lambda_i N_i}$$

3. **(ASAI)** Average Service Availability Index: is the fraction of time (percentage) that a customer has received power during the reporting period. Customer hours demanded are determined as the twelve-month average number of customers served timed 8760 hours. This is sometimes known as the "Service Reliability Index" Higher ASAI values means higher level of system reliability, with most us utilities having ASAI greater than 0.999.

$$\text{ASAI} = \frac{\text{Customer hours of available service}}{\text{Customer's hour demand}} * 100 \%$$

Customer's hour demand

4. (EENS) Expected energy not supplied: is the expected amount of energy not supplied due to capacity deficiency in the period of observation. It is the sum of each load times its outage duration (kWh/yr).
5. (AENS) Average energy not supplied: is the total Energy not supplied in system divided by total number of customers served (kWh/yr. customer)

$$\text{AENS} = \frac{\text{Total energy not supplied}}{\text{Total number of customers served}}$$

Total number of customers served

*Table 2 calculated data from substation*

Substation Feeders	Outage duration (hrs)	Interruption occurrences	Failure rate $\lambda$ (Failures/year)	Average outage U (hrs/yr)
Wolkite	58.97	101	0.05543	1.464849

## Design of Distributed Generation (DG) size

We have four load points on customer side

*Table 3 load points and number of customer*

Feeder name	Load point	Number of customers	load (MW)
WOLKITE	1	8000	5.2
	2	4700	3.1
	3	5612	3.7
	4	4900	3.4

Energy total= Total Load power \*total outage

Energy total =P\*t(hr)

$$= 15.4\text{MW} * 58.97\text{hr}$$

$$= 908.138\text{MWhr}$$

To know the size of DG ;

P = Energy total /sunshine hour

$$= 908.138\text{MWhr}/49.6\text{hr}$$

$$= 18.31\text{MW}$$

Since 18.31 MW is the total load of the DG for the design purpose we take the average value of it. That is;

The size of DG will be;

$$18.31\text{MW}/4 = 4.57\text{MW}$$

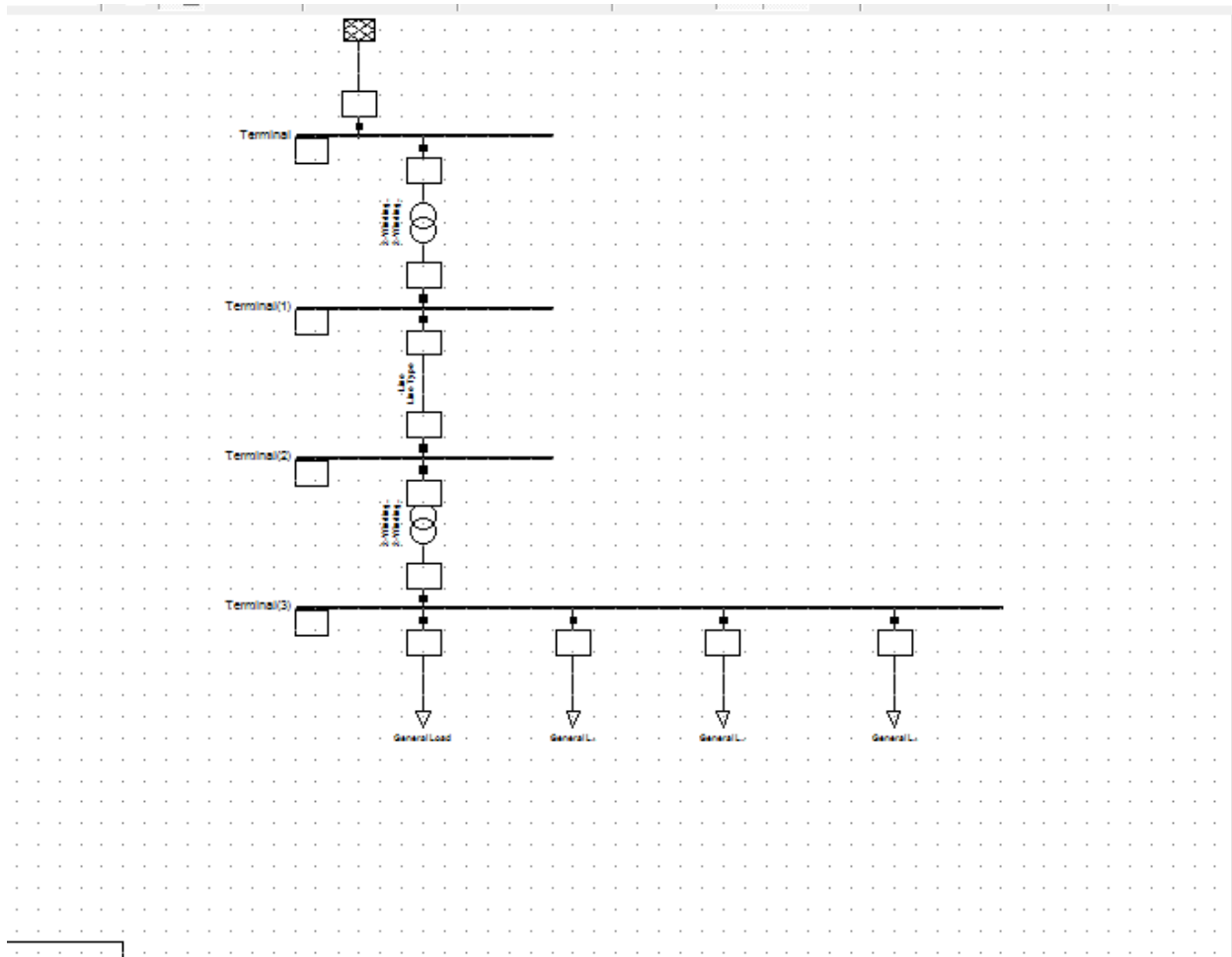
## CHAPTER FOUR

### SIMULATION RESULTS AND DISCUSSION

#### 5.1 Modeling of distribution system with out DG

This chapter discusses the overall simulation results obtained from DIgSILENT PowerFactory and ETAP on the distribution system of wolkite substation 15/0.4 KV distribution substation. The Wolkite 15/0.4 KV substation distribution system (**Wolkite city**) simulation modeling is represented in the DIgSILENT PowerFactory as shown in figure below(simulation modeling before DG installed ) and figure 2 (simulation modeling after DG installed).

The single line diagram of the distribution substation network is shown in Fig. 5.1. The network is formed by ONE radial feeder and four load points for our project.



*Figure 9 Simulation modeling before DG installed.*

Automatic Contingency Definition			
Selection	Whole System		
Busbars / terminals	Yes	Common mode	No
Lines / cables	Yes	Independent second failures	No
Transformers	Yes	Double earth faults	Yes
		Protection/switching failures	No
-----			
Study Case: Study Case			Annex:
-----			
System Summary			
-----			
System Average Interruption Frequency Index	: SAIFI =	2.245050	1/Ca
Customer Average Interruption Frequency Index	: CAIFI =	2.245050	1/Ca
System Average Interruption Duration Index	: SAIDI =	264.669	h/Ca
Customer Average Interruption Duration Index	: CAIDI =	117.890	h
Average Service Availability Index	: ASAI =	0.9697866506	
Average Service Unavailability Index	: ASUI =	0.0302133494	
Energy Not Supplied	: ENS =	1376.261	MWh/a
Average Energy Not Supplied	: AENS =	0.059	MWh/Ca
Average Customer Curtailment Index	: ACCI =	0.066	MWh/Ca
Expected Interruption Cost	: EIC =	0.000	M\$/a
Interrupted Energy Assessment Rate	: IEAR =	0.000	\$/kWh
System energy shed	: SES =	0.000	MWh/a
Average System Interruption Frequency Index	: ASIFI =	2.245021	1/a
Average System Interruption Duration Index	: ASIDI =	264.665582	h/a
Momentary Average Interruption Frequency Index	: MAIFI =	0.000000	1/Ca

†

*Figure 10 Simulation out put before DG installed.*

## 2. Modeling of distribution system with installed DG.

In this model distributed generation is installed on the customer side of 0.4 kv.

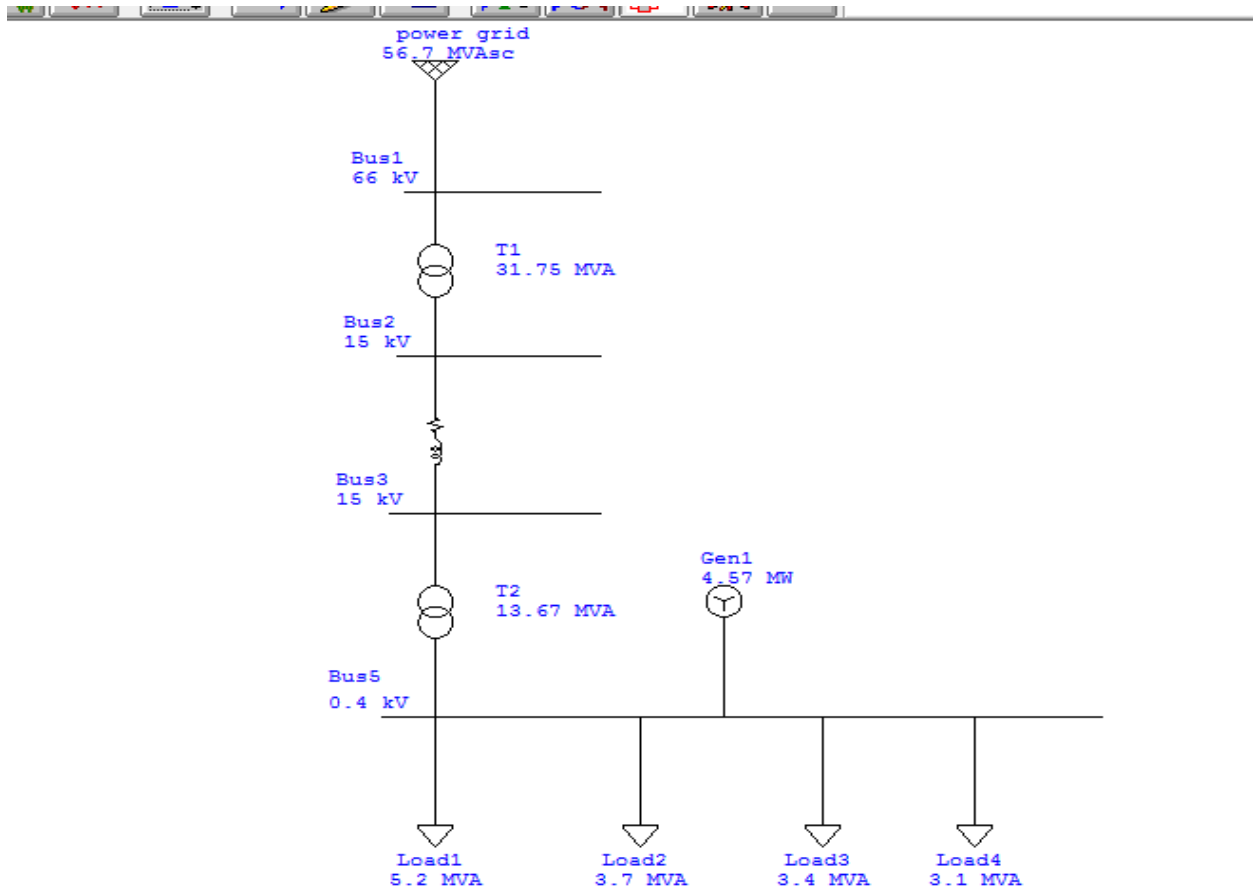


Figure 11 Simulation modeling after DG installed.

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## SUMMARY

### System Indexes

SAIFI	0.9627 f / customer.yr
SAIDI	7.7455 hr / customer.yr
CAIDI	8.045 hr / customer interruption
ASAI	0.9991 pu
ASUI	0.00088 pu
EENS	95.424 MW hr / yr
ECOST	0.00 \$ / yr
AENS	23.8560 MW hr / customer.yr
IEAR	0.000 \$ / kW hr

SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
CAIDI	Customer Average Interruption Duration Index
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
EENS	Expected Energy Not Supplied
ECOST	Expected Interruption Cost
AENS	Average Energy Not Supplied
IEAR	Interruption Energy Assessment Rate

*Figure 12 Simulation out put after 4.57MW DG installed.*

*Table 4 System indices for before and after DG is installed*

Indices	Base case (No DG)	(4.57 MW) DG at 0.4 kV bus
SAIFI	2.245	0.9627
SAIDI	264.669	7.7455
CAIDI	117.89	8.045
ASAI (%)	96.978	99.91
ASUI (%)	3.02	0.088
EENS (MWh/yr)	1376.261	95.424

## CHAPTER FIVE

### CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

#### 6.1 Conclusion

This thesis investigates the size for reliability assessments of wolkite substation distribution system, based on reliability improvement. The reliability assessment processes, using analytical conducted with radial distribution system of 15 kV one feeder (WOLKITE). The integration of DG units into the distribution system significantly affects system operation including voltage deviation, loss reduction, reliability improvement. These impacts were analyzed to determine the contribution of each unit to the improvement of the distribution systems.

The basic objective of the research is to perform reliability assessment of distribution substation system with DG units, by applying analytical approach using DIG Silent/ETAP soft ware. The objective is described in detail in system failures are related outages that can propagate to other parts of a system and cause severe damages.

In the base case study it is seen that there is a higher outage as the load point is further from the supply point, therefore there a higher vulnerability in term of reliability worth; EENS (1376.261 MWh/yr are higher at the base case study. And also overall system reliability indices are high.

The proposed solution is chosen for this research as and the option for improving the system reliability indices. From 15 kV main feeder it is seen that 0.4 kV buses of is taken into the reliability improvements with higher distribution indices.

From the case study analysis the installations of DG unit at supply point will barley improve system reliability than DG at near to the load centers. As far the location is from the substation there reliability system indices increase. The case study location for the placement of the DG is at 0.4 kV bus in terms of reliability improvement. In the base case Expected Energy not supplied of the system is 1376.261 MWh/yr , while it is EENS of proposed case study is decreased to 95.424 MWh/yr for the case of appropriate DG size installed at 0.4 kV bus.

In the case study scenarios are found for reliability improvement is placing a DG at 0.4 kV bus. There is a high profitability for the case study scenario the EENS is reduced from 1376.261MWh/yr to 95.424 MWh/yr .

Finally the expected, produces the worst set of indices because this system is the most basic and least capital intensive. All the other studies provide facilities for improving system reliability.

It is shown that by adding DG units at places and size the system reliability increases more and more the best condition is when the system includes all of the components together.

So that the reduction of SAIDI and SAIFI indicates an improvement in system reliability.

## 6.2 Recommendations and Future Works

While many aspects of reliability assessment of the distribution system with DG have been covered by this thesis, several other issues are interesting for future investigation. Some of the issues that are believed interesting are listed as follows:

- ✓ This research work only conducted the 15 kV line feeders, future work use the same analysis to improve reliability of the 33 kV and 45 kV line feeders of the substations.
- ✓ When considering installation of DG near to the individual load point, it improves more system reliability indices.
- ✓ Solutions overcoming the issues with a significant presence of DG were briefly described. These solutions could be implemented in DIgSILENT to analyze if the problems found in this thesis persist with the employment of another kind of system's mitigation mechanisms.
- ✓ The modeling of the distribution system is done by treating the system as a radial network. Other forms of distribution systems such as meshed networks may be considered for reliability evaluation in the future.
- ✓ Distributed generation may cause noticeable voltage flicker and introduce harmonics into the system. Further research could also focus on the impacts of DG on the short circuit levels of the system and the harmonic distortion of the systems.

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# Appendix

## Detail Interruption report

15 kV Feeder to wolkite city

NO	FEEDER/BAY	DATE	TYPE OF FAULT RELAY ACTED	CAUSE OF FAULT	INTERRUPTION TIME (HRS)	RECONNECTION TIME ( HRS )	DIFFERENCE (HRS)	LION LOAD(KW)	UN SOLDE ENERGY (KWH)
1	WOLKITE	23/01/09	TIE>>> R	MENTENASE	10:38	10:42		100 A	
2	WOLKITE	24/01/09		MENTENASE	8:55	9:14		102 A	
3	WOLKITE	26/01/09	TIE >>>RS		15:47	15:52		100 A	
4	WOLKITE	27/01/09	IR >>> RAETH		12:50	13:21		85 A	
5	WOLKITE	27/01/09		MENTENASE	15:56	16:28		56 A	
	WOLKITE	27/01/09	IE >>> EARTH		18:56	20:03		139 A	
	WOLKITE	28/01/09	TIE >>> T		17:08	17:16		105 A	
	WOLKITE	29/01/09		MENTENASE	9:25	9:34		97 A	
	WOLKITE	29/01/09		MENTENASE	14:00	14:05		106 A	
	WOLKITE	1/2/2009	I >>> RT		15:12	15:52		97 A	
	WOLKITE	2/2/2009	TIE >>>RS		14:55	15:55		96 A	
	WOLKITE	3/2/2009	IE >>> EARTH		22:20	23:34		145 A	
	WOLKITE	4/2/2009	I >>> RS		16:12	16:35		94 A	
	WOLKITE	5/2/2009	TIE >>>RS		17:42	18:29		85 A	
	WOLKITE	9/2/2009	TIE >>>RS		14:55	15:55		96 A	
	WOLKITE	10/2/2009	IE >>> EARTH		22:20	23:34		145 A	
	WOLKITE	12/2/2009	TIE >>> T		17:08	17:16		105 A	
	WOLKITE	13/02/09		MENTENASE	9:25	9:34		97 A	
	WOLKITE	13/02/09		MENTENASE	14:00	14:05		106 A	
	WOLKITE	14/02/09	TIE >>>RS		15:47	15:52		100 A	
	WOLKITE	16/02/09	IR >>> RAETH		12:50	13:21		85 A	
	WOLKITE	16/02/09		MENTENASE	15:56	16:28		56 A	
	WOLKITE	17/02/09	IE >>> EARTH		18:56	20:03		139 A	
	WOLKITE	20/02/09	TIE >>>RS		14:55	15:55		96 A	
	WOLKITE	21/02/09	IE >>> EARTH		22:20	23:34		145 A	
	WOLKITE	23/02/09	TIE >>>RS		14:55	15:55		96 A	
	WOLKITE	23/02/09	TIE>>> R		10:38	10:42		100 A	
	WOLKITE	24/02/09		MENTENASE	8:55	9:14		102 A	
	WOLKITE	26/02/09	TIE >>>RS		15:47	15:52		100 A	

WOLKITE	27/02/09	IR >>> RAETH		12:50	13:21		85 A	
WOLKITE	27/02/09		MENTENASE	15:56	16:28		56 A	
WOLKITE	27/02/09	IE >>> EARTH		18:56	20:03		139 A	
WOLKITE	29/02/09	TIE >>> T		17:08	17:16		105 A	
WOLKITE	30/02/09		MENTENASE	9:25	9:34		97 A	
WOLKITE	30/02/09		MENTENASE	14:00	14:05		106 A	
WOLKITE	1/3/2009	I >>> RT		15:12	15:52		97 A	
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WOLKITE	3/3/2009	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	4/3/2009	I >>> RS		16:12	16:35		94 A	
WOLKITE	5/3/2009	TIE >>>RS		17:42	18:29		85 A	
WOLKITE	8/3/2009	TIE>>> R		10:38	10:42		100 A	
WOLKITE	9/3/2009		MENTENASE	8:55	9:14		102 A	
WOLKITE	12/3/2009	I >>> RT		15:12	15:52		97 A	
WOLKITE	13/03/09	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	14/03/09	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	15/03/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	16/03/09	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	17/03/09	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	19/03/09	TIE>>> R		10:38	10:42		100 A	
WOLKITE	21/03/09	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	21/03/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	22/03/09	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	23/03/09	TIE>>> R		10:38	10:42		100 A	
WOLKITE	24/03/09		MENTENASE	8:55	9:14		102 A	
WOLKITE	27/03/09	TIE >>>RS		15:47	15:52		100 A	
WOLKITE	28/03/09	IR >>> RAETH		12:50	13:21		85 A	
WOLKITE	28/03/09		MENTENASE	15:56	16:28		56 A	
WOLKITE	1/4/2009	TIE>>> R		10:38	10:42		100 A	
WOLKITE	3/4/2009	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	3/4/2009	I >>> RT		15:12	15:52		97 A	
WOLKITE	5/4/2009	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	6/4/2009	I >>> RT		15:12	15:52		97 A	
WOLKITE	7/4/2009	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	10/4/2009	IE >>> EARTH		22:20	23:34		145 A	

WOLKITE	12/4/2009	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	14/04/09	TIE >>>RS		17:42	18:29		85 A	
WOLKITE	17/04/09	TIE >>> T		17:08	17:16		105 A	
WOLKITE	18/04/09		MENTENASE	9:25	9:34		97 A	
WOLKITE	18/04/09		MENTENASE	14:00	14:05		106 A	
WOLKITE	20/04/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	21/04/09	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	22/04/09	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	23/04/09	TIE>>> R		10:38	10:42		100 A	
WOLKITE	27/04/09	IR >>> RAETH		12:50	13:21		85 A	
WOLKITE	27/04/09		MENTENASE	15:56	16:28		56 A	
WOLKITE	27/04/09	IE >>> EARTH		18:56	20:03		139 A	
WOLKITE	30/04/09		MENTENASE	9:25	9:34		97 A	
WOLKITE	30/04/09		MENTENASE	14:00	14:05		106 A	
WOLKITE	2/5/2009	I >>> RT		15:12	15:52		97 A	
WOLKITE	3/5/2009	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	4/5/2009	I >>> RT		15:12	15:52		97 A	
WOLKITE	5/5/2009	TIE>>> R		10:38	10:42		100 A	
WOLKITE	9/5/2009		MENTENASE	8:55	9:14		102 A	
WOLKITE	12/5/2009	I >>> RT		15:12	15:52		97 A	
WOLKITE	13/05/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	17/05/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	19/05/09	TIE>>> R		10:38	10:42		100 A	
WOLKITE	21/05/09	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	21/05/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	22/05/09	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	24/05/09	TIE>>> R		10:38	10:42		100 A	
WOLKITE	25/05/09		MENTENASE	8:55	9:14		102 A	
WOLKITE	28/05/09	TIE >>>RS		15:47	15:52		100 A	
WOLKITE	29/05/09	IR >>> RAETH		12:50	13:21		85 A	
WOLKITE	30/05/09		MENTENASE	8:56	10:28		56 A	
WOLKITE	30/05/09	IE >>> EARTH		18:56	20:03		139 A	
WOLKITE	3/6/2009	TIE >>> T		17:08	17:16		105 A	
WOLKITE	4/6/2009		MENTENASE	9:25	9:34		97 A	
WOLKITE	6/6/2009	I >>> RT		15:12	15:52		97 A	

WOLKITE	8/6/2009	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	9/6/2009	IE >>> EARTH		22:20	23:34		145 A	
WOLKITE	12/6/2009	I >>> RS		16:12	16:35		94 A	
WOLKITE	13/06/09	TIE >>>RS		17:42	18:29		85 A	
WOLKITE	16/06/09	TIE>>> R		10:38	10:42		100 A	
WOLKITE	17/06/09		MENTENASE	8:55	9:14		102 A	
WOLKITE	20/06/09	I >>> RT		15:12	15:52		97 A	
WOLKITE	21/06/09	TIE >>>RS		14:55	15:55		96 A	
WOLKITE	23/06/09	IE >>> EARTH		22:20	23:34		145 A	

### Annual sun shine duration data obtained from metrology agency

S5

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	NAME	YEAR	LONG	LANT	ELEMENT	YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2	wolkite	2082	37.936	8.1183	SUNHRS	2006													7.4
3	wolkite	2082	37.936	8.1183	SUNHRS	2007		7.7		8.4	6.1	5.8							
4	wolkite	2082	37.936	8.1183	SUNHRS	2008			8.7	8.5	6	5.4	3.6	2.7	2.8	4.5	6.7	7.7	8.5
5	wolkite	2082	37.936	8.1183	SUNHRS	2009		6.8	7.2	7	6.6	7.4	5.2	3.2	3.6	4.2	6.9	7.8	5.8
6	wolkite	2082	37.936	8.1183	SUNHRS	2010		7.7	5.1	6.2	5	4.3	4.9	2.5			5.4	6.4	
7	wolkite	2082	37.936	8.1183	SUNHRS	2011						5.5	4			3		7.2	9.3
8	wolkite	2082	37.936	8.1183	SUNHRS	2012					5.8	6.3	3.4	2.1	2.7	3.3			
9	wolkite	2082	37.936	8.1183	SUNHRS	2013						4.4	2.2	2.5	2.8	5.5	6.3	8.2	
10	wolkite	2082	37.936	8.1183	SUNHRS	2014			6.5	5.6		5.2	4.2		3.6				
11	wolkite	2082	37.936	8.1183	SUNHRS	2015		8.4	8.6	7.6	7.7	5.6	3.6	5.1	5.1	5.6	7.7		
12	wolkite	2082	37.936	8.1183	SUNHRS	2016		7.8	9.2	7	6.6	7.4	5.2	3.2	3.6	6.2	8.9	9.7	7.8
13	wolkite	2082	37.936	8.1183	SUNHRS	2017		9.1	6.9	6.5	7.2	5.5	4.6	2.5			7.1		
14	wolkite	2082	37.936	8.1183	SUNHRS	2018		8.2	7.3			6		3.3					7.9
15																			
16																			

