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# Techno-Economic Analysis for Replacement of 11kV Overhead Koteshwor Feeder by Underground Distribution System

**by**

**Ganesh Kumar Sah**

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Techno-Economic Analysis for Replacement of 11kV Overhead Koteshwor Feeder by Underground Distribution System"** submitted by Ganesh Kumar Sah in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

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# ABSTRACT

Cost effective, Aesthetic and Reliable energy supply is the need of any mankind. In this study, technical and economic analysis for replacement of 11 kV overhead distribution feeder by 11kV underground cable is done with reference to Koteshwor Feeder under Baneshwor Distribution and Consumers Service. The cable rating and reliability indices of like SAIDI, SAIFI, ENS etc. of the feeder is performed by using DIgSILENT PowerFactory software. According to the connected load in each branches rating of cable is XLPE cable of size from 25 mm square to 400 mm square recommended and other related technical design is done by using available standards. Also, the reliability of overhead distribution system is evaluated by using real time system data system and similarly, historical IEEE standard data is used for underground distribution system. The reliability indices are compared for both distribution systems. Result shows that the SAIFI value is 49.99 per annum which is very high as compared to designed underground system which is 0.337 for designed underground distribution system. Also, the energy not supplied (ENS) value of existing system is almost five-time higher value as compared to designed underground distribution system. The replacement cost estimation is evaluated by using Nepal Electricity Authority unit rate and KEI industries quoted price for NEA underground project. The B/C ratio and Present Worth value for the 25-year period of useful life shows that the replacement of the existing overhead distribution system by underground distribution system is financially viable and can be payback in 6 to 7 year by saving revenue NRs. 3,424,993.00 obtained from the lower value of Energy Not Supply (ENS) of underground distribution system than overhead distribution system. In order to get the continuous of supply, aesthetic and public safety in electricity distribution field one may have to bear initially extra cost to use underground distribution systems which finally get payback. Thus, in case of densely populated city like Kathmandu, underground distribution system is reasonable requirement for continuous supply, aesthetic and public safety in electricity distribution filed.

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## LIST OF SYMBOLS

| **Symbol** | **Meaning** |
|---|---|
| V | Volt |
| $ | Dollar |
| / | Division |
| % | Percent |
| ° | Degree |
| & | And |
| λ | Failure Rate |
| μ | Repair Rate |
| = | Is Equal To |
| + | Addition |
| * | Multiplication |
| f | Cycle of frequency |
| m | Mean time to repair |
| R | Repair rate per hour |
| T | Cycle time |
| U | Annual outage time |
| L(i) | Average load connected at load point i |
| Ω | Ohm |

# LIST OF ABBREVIATIONS

| Abbreviation | Full-Form |
|---|---|
| AC | Alternating Current |
| NEA | Nepal Electricity Authority, Nepal |
| IEEE | Institute of Electrical and Electronics Engineers |
| AENS | Average Energy Not Supplied |
| ASAI | Average Service Availability Index |
| ASUI | Average Service Unavailability Index |
| CAID | Customer Average Interruption Duration Index |
| ENS | Energy Not Supplied |
| kV | Kilovolts |
| MAIFI | Momentary Average Interruption Frequency Index |
| MTBF | Mean Time Between Failure |
| MTTR | Mean Time to Repair |
| MW | Megawatts |
| SAIDI | System Average Interruption Duration Index |
| SAIFI | System Average Interruption Frequency Index |
| kW | Kilowatt |
| A | Ampere |
| UG | Underground |
| OH | Overhead |
| UGDS | Underground Distribution System |
| OHDS | Overhead Distribution System |
| GoN | Government of Nepal |
| DWSSM | Department of Water Supply and Sewerage Management |
| ADB | Asian Development Bank |
| EA | Executive Agency |
| Ph | Phase |
| XLPE | Cross Linked Poly Ethylene |
| GPS | Global Positioning System |
| B/C | Benefit Cost Ratio |
| PW | Present Worth |

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

For distribution system to be effective there should be less outage in the Feeder and if fault occur these faults should be cleared as soon as possible. Power outages are of two types a) planned and b) unplanned. Planned outages are due to demand being more than generation but unplanned sustained and temporary power outage is due to failure of the distribution system equipment.

There are two ways to distribute electric energy to customers: overhead (OH) lines and underground (UG) cables. Overhead lines and underground cables have different electrical characteristics. Cables have less resistance and inductance related to overhead lines. Also, overhead conductor has less capacitance than underground cables. So, regarding these characteristics of underground system low loss electrical distribution network can be designed with enhanced reliability. Although power system reliability analysis is a wide research filed, there is a rehabilitated attention in updating available network models and expressing improved reliability assessment measures.

All electrical, internet, telephone wires were suspended from poles and forming weird and jam-packed street. Unplanned city, roughly digging of road and dust pollution have disfigured attractiveness of Kathmandu. Kathmandu is in mess. Electric poles are hanging along the road side, creating problem in movement, creating high risk of accident. Such incidents happen in major towns of the city. Overhead electricity system presents many more dangers. First, it needs a lot of spaces in narrow city streets. Most of all, these wires, which hang right over heads, feel like death traps. Underground cabling should have been the highest priority of city authorities and Nepal electricity authority. The jumbled net of overhead cables all over the city has added to visual pollution.

Underground cables offer immense benefits. It helps in ensuring reliable power supply and it can supply power to densely populated areas where land is expensive or aesthetically sensitive. Which is applicable in the case of Kathmandu Valley. Underground distribution system also avoids any possible dangers in the event of accidents and dropping of poles. Simply placing the cable underground does not create efficient supply. The ultimate solution of the distribution system problem is underground distribution system (UGDS) which provoke in electricity operating utility of progressive cities. The efficient, economical and proper design must be required to get financially success of underground distribution system. The suggestions offered in this paper are based on many year experiences and are made with a sincere desire to aid those interested in this class of work, particularly in the design and installation of the first system in the smaller cities.

Safety is the top priority in electric utility. This work describes the complex electrical safety issues related to grounding underground distribution system and protecting electrical workers who are working in electrical vault and who are utilizing energy. There are lots of uncertain problems and challenges are associated with its practical implementation and it cannot be scoped for all the feeders. And fault clearing time period for this is another challenge for underground distribution. Although, high cost of underground distribution system this can be payback after a few years of installation by efficient and reliable operation of system.

### 1.2 Problem Statement

Electric power interruption is becoming a day to day phenomenon in the distribution system. Sustained power interruption occurs many times a day from few minutes to hours. Interruptions may be due to failure of substation equipment or failure of distribution network elements.

Reliability, safety and efficiency are the major challenges associated with the electric distribution lines for the metropolitan city. Further, aesthetic is also a part of it, which is desired by public dreaming of visually clean metropolitan city.

Many techniques and design methods were developed.  However, these designs are specific to location and environment. Accordingly, there's necessity to make clear conclusion and vision for the sustainable development in electricity distribution system of metropolitan city like Kathmandu. Major actions are needed to improve customer-based reliability indices, so that, frequency and duration of power interruption to its connected customer improves considering this fact, in this thesis work, a comprehensive analysis of Koteshwor Feeder problem will be improved from feeder side.

## 1.3 Scopes of Works

As per the result of analysis, design and performance improvement measures will be identified which can be used as proto-type to be implemented for other distribution system as well so that customer dissatisfaction related to frequent unscheduled power outages due to fault in feeder line will be minimized.

This thesis has a novel idea to analyze cost expenses that are required to replace overhead line with underground line and reliability of such system can be compared with the reliability of overhead distribution (OHDS) system.

## 1.4 Objectives

### 1.4.1 Main Objectives:

To evaluate the cost benefits  and benefits over replacement of overhead distribution system by designing underground distribution system.

### 1.4.2 Specific Objectives:

- To design the underground distribution line of saturated Koteshwor Feeder.
- To measure reliability indices of underground distribution line with respect to Koteshwor Feeder.
- To evaluate cost estimate and benefits over replacement of overhead conductor with underground cables.

## 1.5 Limitation of Research Work

The study assumes that the present existing Koteshwor feeder as a reference feeder for reliability evaluation of the feeder. Because of unavailability of recorded failure and repair duration distribution system equipment, for evaluating reliability induces of the feeder IEEE historical data which is may not suitable for selected distribution system. However, the consideration of this IEEE historical data it can be concluded that how much selected distribution system is unreliable with respect to IEEE standard distribution system.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Present Scenario of Underground Distribution System in Nepal

As the present scenario of Nepal distribution line all electrical, internet, and telephone wires are put off through the poles, making weird and crowded street. Unplanned and unmanaged city, roughly road excavation and dust pollution have spoiled beauty of Kathmandu. Kathmandu valley is in a mess. Electric masts sagging overhead or even lying along the main road and sub-road, hindering movement, posing higher risks of short circuits and accidents have made the matters inferior. The jumbled web of overhead conductors all over the Kathmandu valley has added to pictorial pollution. The electric, telephone wires and cables jumbled and dangling in a web like structure from the poles have contributed in disfiguring the city's beauty too.

With reference to the survey of many distribution centers of Nepal like Pokhara, Birgunj, Dharan, Hetauda, Itahari, Jankpur, Kalaiya, Simara, Patan, Simara, Bhaktpur, Maharajgunj, Ratnapark, Baneshwor, only a few meters(10 to 100 m) of line has been made underground whose propose is just to cross the road, buildings, etc., Where there is no any possibility of overhead line. There is only on dedicated underground feeder from Rajdurwar switching to Pradhan Mantri Nibas whose length is about 4 km.

In order to short out these associated problems The Nepal Electricity Authority planned to do underground major possible Hight Tension distribution line of city like Kathmandu valley, Biratnagar, Pokhara, Bharatpur, Jankpur etc. For the first phase in order to completion of this target NEA has been recently made contract with KEI Industries Limited, India to underground two Distribution and Consumer Service Center of Kathmandu valley that Ratnapark and Maharajganj Distribution and Consumer Service Center. In Second phase rest of the Distribution and Consumer Service Center of Kathmandu valley and another major city will be done.

The major limitations of first phase of implementation due to high cost of installation of Underground Network, only city core area is selected for Underground network, the digging and construction works in Heritage area is prohibited without the Approval of Environmental Impact Assessment, Social culture Impact Assessment and Historical Impact Assessment.

**Source of Fund and Stack Holders**

ADB = Asian Development Bank

GoN = Government of Nepal

NEA = Nepal Electricity Authority

EA = Executive Agency

DoR = Department of Road

DWSSM = Department of Water Supply and Sewerage Management

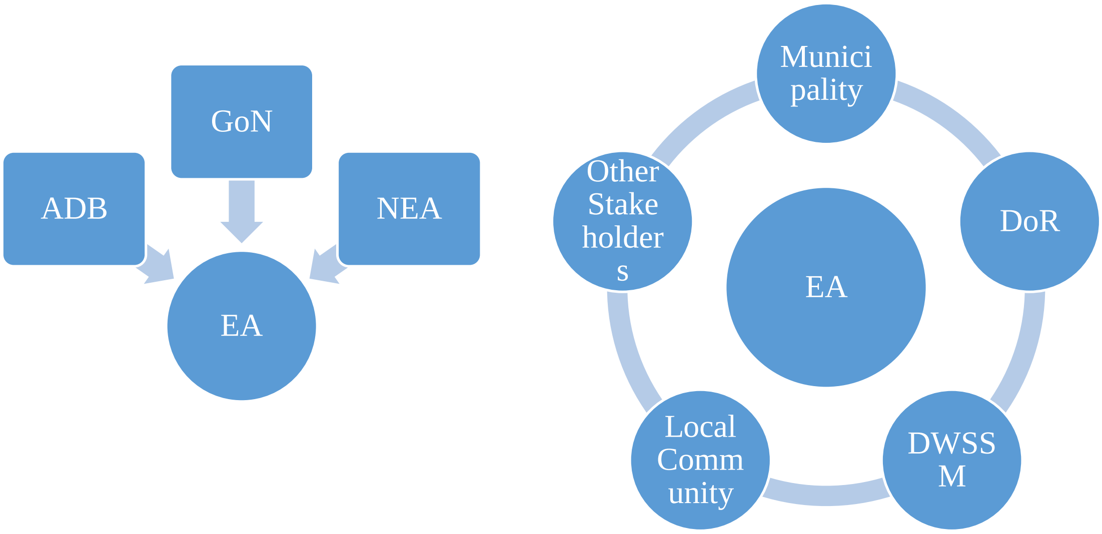



Figure 2.1 Source of Fund and Stack Holders

## 2.2 Distribution System

Distribution system "the part of the power system which distributes electrical power for local use is knows as distribution system." This system is the electrical system between the substation fed by transmission system and consumer meter. Distribution system generally consist of feeders, switching equipment, protection equipment, control equipment, one or more transformer etc. (Gesto, 2018). Some of the requirements of a good distribution system are: proper voltage, availability of power on demand and reliability (Mehta and Mehta, 2005).

Distribution system is a linkage of components that supplies power to consumers at their place of consumption in a ready to use form. Distribution system starts from distribution substation followed by distribution lines, distribution transformers, protection system, loads, etc. distribution lines (Feeder) is a network of conductor with different protection system feeding power to different localities from substation.The distribution system can be categorized into primary and secondary distribution. The distribution system elements are feeders, distributors and service mains.

**Feeders:** The conductors which connect the substations (in some cases generating stations) to the areas to be fed by those substations. Current is the major requirement for the designing of feeder.

**Distributor**: The conductors from which number of tapping is done for consumers is the Distributor. The voltage drop is the main criteria for designing the distribution (Gupta, 2011).

**Service main**: service main are the conductors, which connect the consumer's terminals to the distributor (Gupta, 2011).

According to type of construction, distribution system may be divided as (a) overhead system (b) underground system. The overhead system is generally hired for distribution as it is 5 to 10 times low cost than the underground system (Mehta and Mehta, 2005).

### 2.3 Overhead Distribution System

Followings are the major component for overhead distribution system : (Mehta and Mehta, 2005)

- **Conductors:** It carries power from the one end to the other end of the station.
- **Supports:** It used for hanging supports for conductors like poles or towers to maintain ground clearance of conductors.
- **Insulators:** It is used for support and insulate the conductor from ground.
- **Cross arms:** It provide support to the insulators.
- **Miscellaneous:** components such as danger plate, anticlimbing, lightning arrestors, etc.

### 2.4 Underground Distribution System

The principal causes of outages are the failures of following components:

- **Cable:** usually employing either a high molecular weight polyethylene (HMWPE) or cross-linked polyethylene (XLPE) insulation
- **Distribution Transformers:** either pad mounted or subsurface

- **Switches:** oil, vacuum or air break
- **Separable connectors (elbows)**: either load-break or no-load-break type
- **Splices:** molded rubber
- **Pole top terminators**
- **Load-break junctions (lateral taps)**

### 2.5 Comparison Between Overhead and Underground Distribution System

Comparison between overhead and underground system is: (Gupta, 2011).

- **Public safety**: UG is safer than OH system.
- **Initial cost**: Initially UG system is more expensive than OH system.
- **Flexibility**: Overhead system is more flexible than underground system.
- **Maintenance Cost**: Repair and maintenance cost of the UG system is low in with respect to OH system.
- **Frequency of Failure Rate**: In UG system less chances of failure in comparison to OH system.
- **Chances of Accident**: Less chance of accident in UG system than OH system.
- **Voltage Drop**: voltage drop in UG system is low as comparison to OH system because of the less value of inductance in UG system.
- **Appearance**: As in UG system cable laying below the ground so, it is visually clean.
- **Fault location and repair**: Although there are less chance of fault in UG system. But if occurs it is difficult to locate that fault and it is costly.
- **Jointing**: Jointing in the UG cable is complex so tapping for loads and service mains are not easily possible in UG system.
- **Damage Due to lightning and thunder storm**: There is no chance of interruption in service main from the thundering storm, lightning and objects in UG system.
- **Interference to communication circuits**: There is no any interference to communication system in UG system.

### 2.6 Cable

An underground cable basically consists of one or more conductors protected with suitable insulation and enclosed by a shielding cover. Although there are many types of cable, the type of cable to be used will depend upon the many factor like system voltage and service requirements. Generally, a cable should be fulfil the following compulsory requirements: (Mehta and Mehta, 2005)

- High conductivity type of conductor used like tinned stranded aluminum or copper.
- For the flexibility and carry more current stranding should be done.
- The size of the conductor should be able to bear rated load current without overheating and within limits of voltage drop.
- To get high degree of reliability and safety cable must have appropriate thickness of insulation at a designed voltage.
- Mechanical protection must be provided such that rough laying of cable will not be damaged.
- The complete physical and chemical stability in manufacturing of cable should have throughout the length of cable.

The insulating materials used in cables should have the following general characteristics: (Mehta and Mehta, 2005)

- To avoid leakage current, high insulating resistance of insulator is required.
- To avoid electrical breakdown of insulation, high dielectric strength is required.
- To withstand the mechanical stress while handling it, high mechanical strength is required.
- As moisture leads to decrease the insulation resistance so, it should be non-hygroscopic or for hygroscopic material it should have waterproof type covering.
- It should be non-inflammable.
- It should be cheaper.
- Should not be affected by acids and alkalies to prevent from chemical change.

### 2.6.1 XLPE Cable

XLPE cable constitutes the best cable for transmission and distribution lines because of its excellent electrical and physical properties. The excellent resistance to thermal deformation and the excellent aging property of XLPE cable permit it to carry large current under normal (90 $^{o}$C), emergency (130 $^{o}$C) or short circuit (250 $^{o}$C) conditions. XLPE cable withstands smaller radius bending and is lighter in weight, allowing for easy and reliable installation. Furthermore, the splicing and terminating methods for XLPE cable are simpler in comparison with other kinds of cables. XLPE cable can be installed anywhere without special consideration of the route profile (height limitations) since it does not contain oil and thus is free from failures due to oil migration in oil-filled cables. XLPE cable does not generally demand a metallic sheath. Thus, it is free from the failure's peculiar to metallic-sheathed cable, such as corrosion and fatigue.

### 2.6.2 Cable Joint

In a single protecting cover a complete insulated splice or group of splices is placed. Insulation material may be served for protective. Insulated end caps are considered joints in this context (IEEE Standard, 1977).

- **Straight joint**: A cable joint used for connecting two lengths of cable, each of which consist of one or more conductors.
- **Branch joint**: A cable joint used for connecting one or more cables to a main cable.
- **Insulating (isolating) joint**: Mechanically couples and electrically separates the sheath, shield, and armor through the lengths of cable is insulating joint.
- **Transition joint**: Two different types of cables is jointed in this type joint.

## 2.7 Load Flow Study

Power flow studies also usually named as load flow, are the major study of power system examination and design. It is required for operation, planning, economic scheduling and power flow in system. In addition, power flow analysis is necessary for transient stability analysis and contingency studies.

In a power system, reactive and active power flows from the generating station to the load via different grid network buses and branches. Basically, power flow is flow of active and reactive power in a grid network. The voltage of buses and their phase angle are affected by their power flows and voice-versa (Gupta, 2011).

A systematic mathematical approach can be obtained from load flow study for resolve of various bus voltages, their phase angle, reactive and active power flow of different branches, generators and loads under steady state conditions. Gause-Seidel method and Newton Raphson Methods are the two methods basically used for load flow study in power system. The load flow study is an extremely important and essential for power system planning, designing, expansion design and for providing a guide lines to control room operating engineers in the flowing activities (Gupta, 2011).

- Examining the effect of re-arranging the circuit on the power flows, bus voltage.
- Software for online operation, monitoring and control for the power system.
- Examining the effect of momentary loss of generating station or transmission lines on the power flow.
- Measurement of system losses for different power flow conditions.
- Under normal steady state operating performance of power system is evaluated.

### 2.8 Cable Selection Criteria or Design

In case of direct current system, the resistance is responsible for voltage drop alone. However, in AC. system, combined effects of resistance, inductance and capacitance is responsible for voltage drop. The cable should have its required insulating properties when subjected to its rated thermal limit (the combination of its maximum ambient temperature and its own generated heat) during the service life. Cable (or conductor) sizing is the process of selecting appropriate sizes for electrical power cable conductors. Proper sizing of an electrical (load bearing) cable ensures that the cable can: (IEEE Standard, 2008)

- Operate continuously under full load without being damaged
- The short circuit currents flowing through the cable should withstand
- Provide appropriate voltage to the load (and avoid excessive voltage drops)
- Guarantees operation of protective devices at the time of an earth fault

#### 2.8.1 Following Parameters should be Considered While Deciding the Size of the Cable.

- Voltage of the system
- Whether cable is used in earthed or unearthed system.
- Short circuit current of the system
- Ambient temperature
- Laying Methods – in air, duct or in ground

- Number of cables grouped together and their spacing
- Thermal resistivity of soil
- Depth at which cables is lying in ground

### 2.9 Need of Cable Design

As the feeder should carry whole current required by the consumers its losses, voltage drop limit, and thermal limit need to be within the acceptable value with respect to future growth load a proper technical and economical design is required. Also, in order to save initial installation cost and life of feeder with selected type of cable/conductor is playing vital role which make cable design essential.

### 2.10 Reliability Analysis

The ability of the power system to deliver an adequate supply of electrical energy is usually designated by the term reliability. Reliability assessment of electrical distribution system is a tool for the planning engineer to ensure a reasonable quality of service and to select between different system development plans that cost wise were analogous in view of system investment and cost of losses (Kjolle & Sand, 1992). Some of the frequently used terms and definitions used for the reliability analysis are

**Connected load**: Connected transformer or metered demand on the feeder or portion of feeder that is interrupted (IEEE Standard, 2012).

**Customer:** A metered electrical facility point for which tariff is established at a specific place (IEEE Standard, 2012).

**Customer count**: Number of customers which either interrupted served.

**Distribution system:** The part of a power system that sends electric energy from the transmission system to the customer via transformer and conductor. The distribution system is generally consists of all the components from the distribution substation fence to the customer meter (IEEE Standard, 2012).

**Interrupting device:** A device to stop the flow of power, usually in reaction to a fault. Operation of the device can be done by automatic, remotely, or manual methods (IEEE Standard, 2012). Examples include circuit breakers, line reclosures, line fuses, disconnect switches, sectionalizes, and/or others.

**Interruption:** The loss of electric power on one or more normally charged network to one or more customers associated to the distribution portion of the power system. Interruption category like sags, swells, impulses, harmonics, etc. are not included in any power quality issues.

**Interruption duration:** The time period from the commencement of an interruption until supply has been reestablished to customers (IEEE Standard, 2012).

**Momentary interruption:** The transitory loss of power to one or more customers due to the operation of an interrupting device.

**Outage**: The loss of a distribution component to deliver power is outage.

**Planned outage:** The intentional deactivating of a component's capability to deliver power, done at a pre scheduled time, usually for the purposes of construction, preventative maintenance, or repair (IEEE Standard, 2012).

**Total number of customers served:** The number of customers served during the selected period.

**Unplanned interruption:** The unintentional loss of electric power to customers.

A customer may experience loss of service (an outage) due to various reasons. We have divided these into the following categories:

(1) Failures of components
(2) External factors
(3) Loss of supply to the feeder

**Interruption causes category:** According to IEEE data collected should able to be placed into one of the ten categories recommended

**Equipment:** Any piece of the distribution system component that is defective or fails and causes an interruption to customers should be put in the equipment category (IEEE Standard, 2014). A few example of equipment types include controls, conductors, insulated transitions, interrupting devices, arresters, supports, switches, and transformers (IEEE Standard, 2014). Failure of any power system protection equipment can lead to major damage and financial losses to the utility. This will also lead to extend power outages for customers (Hewitso and L. G., 2006).

**Lightning:** Lightning category includes all interruptions caused by lightning which may be by direct stroke contacting the wires or another piece of equipment, or by a lightning-induced flashover of wires (IEEE Standard, 2014).

**Planned:** The planned category contains, but is not restricted to: Replacing equipment, road construction, repairs and maintenance, and house moves (IEEE Standard, 2014). Typically, planned interruptions are those interruptions that can be delayed by the utility personnel and achieved only after the proper or required customer notice (IEEE Standard, 2014). Often, regulatory commissions have specified rules describing planned interruptions.

**Power supply:** The power supply category includes interruptions caused by a failure in the transmission system including the transmission portion of a substation or the loss of a generating unit including those associated with distributed generation (IEEE Standard, 2014). It does not include outages due to the loss of equipment of distribution substation.

**Public:** Any interruptions resulting as an act of the public at large should be put into the public category (IEEE Standard, 2014). Examples include: customer worry, non-utility member or contractor dig-in, fire/police requests, external contact (such as crane boom, Mylar balloons, and aluminum ladder), traffic accidents, destruction, and fires and explosions not originating on or within utility-owned equipment (IEEE Standard, 2014).

**Vegetation:** The vegetation category includes interruptions caused by falling trees or limbs, growth of trees, vines, and roots. It should be emphasized that if a tree is involved, the cause category is vegetation. This is significant to note during wind storms. It may not be possible to regulate that a feeder may have a forestry problem if wind is recorded as the cause, when really a tree was involved.

**Weather:** The category of weather should include interruptions due directly to a weather phenomenon including: snow, wind, hail, ice, and rain where the weather itself caused the interruption and exceeded the system's design limits (IEEE Standard, 2014). Wind does not include slapping or galloping conductors, those would go under the equipment category (IEEE Standard, 2014). Overhead power lines are more likely to be affected by adverse weather conditions. Approximately 70% of all faults on overhead lines are transient faults.

**Wildlife:** This includes mammals, birds, reptiles, and insects, or any other non-human member of the animal kingdom (IEEE Standard, 2014). Animals can make interruptions directly via contacts mice, snakes, ants, raccoons, squirrels, or birds, etc.; or indirectly, like nests and bird excrement.

**Unknown:** The unknown group contains somewhat interruptions where a defined cause cannot be determined after examination (IEEE Standard, 2014).

**Other:** Any interruptions to customers that do not fall into any of the others cause categories should be assigned to the other category (IEEE Standard, 2014). Some examples include: errors in construction, maintenance, operating, or protecting, overload, and contamination.

**2.11 Equipment Failure or Deterioration** (IEEE Standard, 2014)

Benchmarking studies frequently examine equipment performance as well. This equipment is usually failed equipment that initiated the customer interruption. Typically, pieces of equipment are grouped into different categories. Data collected may be by number of interruption events, number of customers affected, or by duration of the interruption. Results from this data may reveal rates of failure for various types of equipment, if some utilities have a problem with a type of equipment as compared to other utilities, and how the use of equipment varies from one utility to another. The following is the recommended list of categories of equipment.

a) Cable
b) Wire
c) Connector
d) Control
e) Insulated transition
f) Interrupting device
g) Lightning/surge arrester
h) Other equipment
i) Structural support
j) Switch

k) Transformer

The cable category contains all the cable that are direct buried or placed in pipe or conduit. Wire is the overhead strung conductors and jumpers. Splices, connections, and another hardware are different than these two types. The connector type contains insulinks, connectors, splices, etc. The control type contains control equipment like covers relays, smart meters. Insulated transition is included of insulators, bushings, separable connectors, potheads, polymeric terminations, stress relief cones, etc. The interrupting device type contains of reclosures, circuit breakers, and fuse. The lightning/surge arrester and "other" categories are self-explanatory. Structural support category includes anchors, poles, towers, cross arms, braces, etc. The switch category contains disconnect, isolation, and load break switches, etc. The last category, transformer either power or distribution.

### 2.12 Need of Reliability Analysis

The reliability analysis is an essential study for the design, operation, maintenance and planning of the power system. With a specific reliability requirement, an optimal maintenance approach can be determined to minimize the running cost. Maintenance influences the deterioration process, failure rate, and reliability of the components and the system. Therefore, two basic aspects of system adequacy and system security is part of power system reliability assessment.

**Adequacy:** The ability of the distribution systems to provide the aggregate electrical power demand and energy requirements of their customers at all times, considering planned and reasonably unprepared outages of distribution system elements.

**Security:** It is the ability of the electric distribution systems to resist unexpected disturbances like electric short circuits or unexpected loss of system elements.

### 2.13 The Importance of Reliability in Distribution Systems

Distribution reliability mainly relates to distribution equipment outages and customer interruptions. Except standby in ordinary operating condition all equipment are energized and all customers are energized with planned and unplanned events disrupt typical operating condition and can lead to interruptions. The objectives of evaluating, planning and improving reliability in distribution systems are therefore to

- Maintain continuous supply of electricity to customers.
- Reduce the rate of recurrence and interval of interruptions.
- Minimize the severity of interruptions.

Determine the causes of interruptions in order to take remedial action to reduce interruptions in view of its enormous cost to customers. Ensure compliance with standards and analyze and improve system performance.

## 2.14 Reliability Evaluation Technique

In reliability evaluation, there are two basic approaches, namely, analytical techniques and simulations (Billinton and Wang, 1999). There is vast knowledge on analytical techniques as these techniques have been used for several decades and these techniques are also highly developed (Faulin and J., 2013). Simulations on the other hand are more specialized and flexible, but require large amounts of computing time. The Failure Modes and Effects Analysis (FMEA) technique are the One particular analytical technique and the technique for evaluating reliability indices and it is based on failure mode assessment (Allan and Billinton, 1993). In FMEA, for each component, all possible failure modes are systemically listed and their effects on the system are identified. The main disadvantage of the technique is that it can be difficult to directly evaluate the reliability of a complex system as the list of basic failure events becomes long and it has thousands of basic failure events. There are also software packages used in Power Engineering. The manufacturers of these software packages also attempt to make them as user-friendly as possible, especially those used in research and for educational purposes. The reason for this is to improve the analytical ability and computational efficiency (Bam and Jewell, 2005). NEPLAN and DIgSILENT Power Factory are two examples of these software packages.

## 2.15 Power System Reliability Indices

### SAIDI (System Average Interruption Duration Index)

The SAIDI of a network indicates the period of a sustained interruption the average customer would experience over a year. It is usually measured in customer hours of interruption or customer minutes. SAIDI can be expressed as

SAIDI = (customer interruptions duration p.a)/ (Total number of customers served) …. Equation 2.1

**CAIDI (Customer Average Interruption Duration Index)**

The CAIDI of a network shows the average duration of a sustained interruption that only the customers affected would experience annually. It is normally measured in customer minutes or customer hours of interruption. This index differs from SAIDI in that only the number of affected customers interrupted is used in the denominator and not the total number of customers served. CAIDI is also the ratio of SAIDI and SAIFI and can be mathematically expressed as

CAIDI = (customers interruption duration p.a)/ (Total number of customers interrupted) …. Equation 2.2

CAIDI is also the index used to measure the average customer restoration times. How long an average interruption lasts, and is used as a measure of utility response time to system contingencies is measure of CAIDI. It can be enhanced by decreasing the duration of interruptions, but can also be reduced by decreasing the number of quick interruptions. Consequently, a drop in CAIDI does not essentially reflect an improvement in reliability.

**CAIFI (Customer Average Interruption Frequency Index)**

The CAIFI of a network shows how often (frequency) on average only the customers affected by an interruption experience a sustained interruption per annum. The customer is counted only once in this calculation irrespective of the frequency of interrupted. This index differs from SAIFI in that only the number of customers interrupted is used in the denominator and not all the customers connected. Mathematically CAIFI can be expressed as

CAIFI = (Customer interruption duration p.a)/ (total number of customers interrupted) ……. Equation 2.3

**ASAI (Average Service Availability Index)**

ASAI represents the segment of time (often in percentage) that a customer has received power during the well-defined reporting time mathematically,

ASAI = (Customer hours service availability p.a)/ (Customer hours service demand …. Equation 2.4

ASUI = 1-ASAI = (Customer hours service unavailability)/ (customer hour service demand) ……. Equation 2.5

**ENS (Total energy not supplied)**

The ENS (Total energy not supplied) is the sum of each load times its outage duration.

ENS = $\sum$ La(i) $*$ Ui………. Equation 2.6

Where, La (i) is average load connected to load point i and Ui is annual outage time.

**Average Energy Not Supplied (AENS)**

It is the ratio of ENS and number of customers. Mathematically

AENS = (Total energy not supplied)/ (number of customers) ……… Equation 2.7

Mean Time between Failures (MTBF)

AENS = (Total energy not supplied)/ (number of customers) ……… Equation 2.8

Mean Time between Failures is the average or expected time between two consecutive failures of a component. It is a basic measure of a system's reliability and availability and is usually represented as units of hours (Rohani and Roosta, 2014).

Mean Time between Failures (MTBF) = (Total number of operating hour)/ (Number of failure) ……… Equation 2.9

**Mean Time to Repair (MTTR)**

Mean Time to Repair is the average time taken to repair a failed module.

MTTR represents the how much time required onsite to physically repair the failure section.(Rohani and Roosta, 2014). Just like MTBF, MTTR is usually stated in units of hours.

Mean Time to Repair (MTTR) = (Total duration of outage)/ (frequency of outage) ………. Equation 2.10

**2.16 Review of Related Research Works**

C.J. Soni, P.R. Gandhi and S.M. Takalkar presented the Design and analysis of 11 KV Distribution System using ETAP Software. Author designed and adopted Feeder bifurcation and re-conductoring methods for loss optimization of distribution system of urban power network. And found that Percentage loss reduction is 19.34% and 26.87% by Reconductoring and feeder bifurcation respectively. That is by feeder bifurcation we can reduce higher losses and it is economical. (Soni, C. J., 2015)

H. Khalidi and A.Kalam studied on the Enhancing Reliability of Power Transmission and Distribution Networks with underground cables made conclusion regarding potential benefits of underground cables and how they can enhance power network reliability. And found that Underground distribution cables have the ability to minimize outages, repair cost and losses in the best and most operative environment-friendly method possible Latest technology makes underground cables a more practical solution to prove grid network reliability. (Al-khalidi and Kalam,)

S. Ahmad and S. Sardar did simulation on Reliability Analysis of Distribution System using ETAP and the results depicted that higher the distance of the load point lower will be reliability, so most reliable location of the distribution system is place near to feeder. Thus, the Distribution system planning and designing may be done in such a way that customers get least affected, thus distribution system reliability is improved. (Ahmad, S., 2017)

Y. Jibril and K.R. Ekundayo studied outages on the 33kV feeders of the Kaduna Electricity distribution network for 16 months and concluded that Mogadishu feeder get maximum number of failures though it is not the least available that is most of the outage are due to temporary outage (transient fault) whose duration is short. Therefore, old or whose failure rate is high should be replaced by new component like wooden poles by concrete poles. (Jibril and Ekundayo, 2013)

According to O. Mokoka Simulation can be done in DIgSILENT Power Factory and NEPLAN which has the following features: load-flow, short-circuit calculations, reliability analysis, protection coordination, stability calculation etc. author, simulated sample feeder in both NEPLAN and DIgSILENT and Mokoka compared the result of both software and made a conclusion that results are similar. (Mokoka and Awodele, 2013)

According to A. Sumper System reliability is expressed by interruption indices. The variation of the interruption indices between countries and companies concludes that the factors influencing on these indices are inherited and inherent. Finally, decreasing fault rates, restoration time and number of affected customers will decrease interruption indices and increase distribution system reliability. (Samper, A., 2004)

A Ghods Studied 24 kV distribution network and suggested the method to improve system reliability by changing network topology. Author made a double circuit line for incoming feeder and changed the feeder route of some section. Significant improvement in ENS, SAIFI, CAIDI and ASAI is observed. (Ghods, A., 2009)

P.U. Okorieand A.I. Abdu studied Evaluation of Outages in Overhead and Underground Distribution Systems of Kaduna network. On utilities in Kaduna author evaluate outage of electric distribution system in this paper. The major reason of failures in system may be due to the variety of factors such as; weather conditions, contamination, vegetation, animals, human, excessive ambient temperature, moisture, excessive load, lack of maintenance, ageing, wear-out and design. These factors make the component failure rates vary with spell and place. The main conclusion is the environmental factors are mostly responsible for over 50% of the failure in system. (Okorie and Abdu, 2015)

C.I. Jones and M. McManus studied Life-cycle assessment of 11 kV electrical overhead lines and underground cables. Total of five options were analyzed, two underground cables and three overhead lines, which were compared based on their embodied impacts in production and total lifetime operational impacts. And key parameter for reducing the loss resistance of the conductor. In fact, lowest conductor resistance is used to be installed to decrease the environmental life cycle impact of distribution system. (Jones & McManus, 2010)

Peter H. Larsen studied method to estimate the costs and benefits of undergrounding electricity transmission and distribution lines. To estimate social cost and benefits of enhancing reliability of a distribution system comprehensive analysis framework is analyzed by author. And concluded that undergrounding electricity supply lines can be a cost-effective approach to enhance reliability, if certain criteria like large number of customers per line mile, less space for right of way etc. are met before the investment in underground system. (Larsen, 2016)

R. Benato studied the Overall Cost Comparison between Cable and Overhead Lines Including the Costs for Repair After Random Failures. Author presents a general method for the identification and calculation of deterministic and probabilistic components of the whole-of-life cost of overhead lines and of XLPE underground lines. He concluded that the overhead and underground supply system have been argued as competitors often without stating exact criteria. From an overall cost point of view and not from a mere investments cost point of view, the cost difference between underground cables and overhead lines is multiple times reduced due to underground cables energy loss savings and a less influence on region. (Benato, 2012)

S. Fenrick and L. Getachew studied the Cost and reliability comparisons of underground and overhead power lines. Author research that discloses the reliability and operation and maintenance impacts of electric underground lines comparative to overhead lines. 163 US electric utilities data set is used for comprehensive. Holding the impact of other important effective variables constant, their research shows that undergrounding reduces operation and maintenance cost and improve reliability by decreasing outage duration and provide regulators with a way to balance the net cost of undergrounding with the enhanced reliability. (Fenrick and Getachew, 2012)

## 2.17 Research Gap

Over Head distribution system is prevailing in Nepal. Almost all loads in Nepal are distributed through OH distribution lines. But there are certain difficulties for the lines to be distributed overhead, such as lack of place for the pole placement, improper hanging of power lines, less secure, subject to disturbances and fault, due to which reliability of power supply decreases. We can get rid of all these problems if we distribute the power using the underground cables. In, this research the design of underground cable is done for the comparison purpose with overhead lines.

# CHAPTER THREE: RESEACH METHODOLOGY

## 3.1 Data collection

In this dissertation work, methodology starts with literature review of various related literature followed by data collection from Baneshwor substation record file. Collected data are analyzed and categorized in momentary, planned and unplanned interruptions (sustained) according to IEEE guidelines. Frequency and duration of planned, unplanned and momentary interruption is noted since 2074 BS. Failure rate of existing overhead Koteshwor feeder is determined based on data from past 2075 BS. For designed underground Koteshwor Feeder standard failure rates and repair duration, various literatures are used. To determine customer number in feeder, data from different Distribution and consumer service (DCS) is collected and analyzed. DIgSILENT PowerFactory standard library is also used to determine some electrical parameters values. Also, the dismantle cost of overhead line is obtained from Nepal electricity authority. Per kilometer cost for new construction and installation of underground line is also obtained from Nepal electricity authority.

## 3.2 Introduction to DIgSILENT PowerFactory

DIgSILENT PowerFactory is an integrated power analysis tool that combines reliable and flexible system modelling capabilities with state-of-the-art solution algorithms and unique object-oriented database management. The Power Factory package has the following features: load-flow, short-circuit calculations, harmonic analysis, protection coordination, stability calculation, reliability analysis and modal analysis. The licensed thesis version of DIgSILENT PowerFactory version 15.1 is used for the analysis. This tool is validated by using the standard IEEE 33 bus radial distribution system for cable sizing and two bus RBTS system (created for educational purpose) for reliability evaluation.

Cable sizing tools is commonly used to choose the appropriate conductor size with respect to specified thermal limit, voltage drop limit from the provided load, conductor specification. This tool automatically recommends and upgrade the suitable conductor size with respect to loading condition.

Reliability assessment tools are commonly used to quantify the impact of power system equipment outages in economic terms. The results of a reliability assessment study may be used to justify investment in network upgrades such as new remote-control switches, new lines/transformers, bus bars etc.

For the cable sizing and reliability assessment first step is to draw a single line diagram of the network under study using the standard elements available at software library. For cable sizing a user defined library is created for the available conductors with their specifications. Every feeder to be studied should be defined clearly. Then the cable sizing tool recommend and upgrade the network with respect to specified thermal and voltage limits. Similarly, to calculate customer-based reliability indices, total number of customers connected in each feeder, load of feeder and reliability library should be defined. While configuration of switch, actuation time and power restoration option should be clearly specified. After running the reliability assessment tool various reliability indices of the system is obtained.

### 3.3 Summary of Overall Methodology

- Technical data is collected for selected Feeder. (Single line diagram, equipment specification, line length, type of conductors and cable, number of transformers, load, energy sales etc.)
- Validate the DIgSILENT PowerFactory load flow by using the standard IEEE 33 bus radial distribution system (Which is applicable for cable sizing).
- Simulate and run the cable sizing to obtain the recommended cable size with respect to load using Nepal electricity voltage drop limit and standard cable specification.
- Validate the DIgSILENT PowerFactory reliability assessment tool by using the standard IEEE RBTS 2- bus system (Which is created for educational purpose).
- Calculation of momentary and sustainable failure frequency and duration of interruption in existing overhead feeder for a time duration by following IEEE guidelines.
- Simulate and run reliability assessment of equivalent existing overhead single line diagram of feeder in DIgSILENT PowerFactory (Using real time system data).
- Calculate selected reliability indices like SAIFI, CAIFI, SAIDI, MTTF, MTBF, and ENS for the equivalent existing overhead feeder using DIgSILENT PowerFactory.

- Simulate and run reliability assessment of designed underground single line diagram of feeder in DIgSILENT PowerFactory (Using IEEE historical data).
- Calculate selected reliability indices like SAIFI, CAIFI, SAIDI, MTTF, MTBF, and ENS for the designed underground feeder using DIgSILENT PowerFactory.
- Simulate and run reliability assessment of designed overhead single line diagram of feeder in DIgSILENT PowerFactory (Using IEEE historical data).
- Calculate selected reliability indices like SAIFI, CAIFI, SAIDI, MTTF, MTBF, and ENS for the designed overhead feeder using DIgSILENT PowerFactory.
- Compare the reliability indices of existing overhead line, designed underground line and designed overhead line obtained from DIgSILENT PowerFactory results.
- Dismantle cost of overhead line, installation cost of designed underground cable and installation cost of designed overhead line is calculated. (By using NEA unit rate and KIE Industry Co. Ltd. unit rate)
- The economic benefit of the designed underground system is estimated and the replacement of the overhead line by underground cable is economically justified or not is evaluated/checked.

### 3.3.1 Methodology for Cable Design

In case of the distribution feeder there are lots of transformers connected through the feeder. If we consider each transformer as node then current at each branch is varies accordingly connected load and hence loss as well. Thus, voltage of all the node will be different and current of each branch too. Thus, load flow study of the feeder is required to find out the voltage of each node and branch current. After getting node voltage and branch current conductor and cable cab be designed by using the available conductor and cables.

**Following Steps is carried out for cable and conductor design**

- Validate the DIgSILENT PowerFactory load flow by using the standard IEEE 33 bus radial distribution system (Which is applicable for cable sizing).
- Single line diagram of the feeder is simulated in DIgSILENT PowerFactory with reference to GPS data of Koteshwor feeder.
- Branch length, load and Simulation conditions for overhead and underground is set Technical data is collected for selected Feeder.

- A user define library for conductor rating and cable rating is created in DIgSILENT PowerFactory for both overhead conductor and underground cable.
- Set the initial type and rating of conductor and cable from the library for all the branches.
- Run the cable sizing to obtain the recommended conductor and cable size with respect to load using Nepal electricity voltage drop limit and standard cable specification.
- Run the load flow assessment to check the voltage drop limit of each branch and node.
- The recommended conductors and cable obtained from result of in DIgSILENT PowerFactory are summarized.

**Route of Koteshwor Feeder Obtained from GPS Map**

Mahadevsthan Marg, Alok Nagar Chowk, Subidh Marg, Samudaik, Koteshwror-Santi Chowk Via Madan Bhandari Road, Munibhaairah Marg, Ratha Marg, Sarswati Marg, Setiopi Marg, Aishwaray Marg, Sanjnani Marg, Phulbari Nagar Marg, Koteshwor To Balkumari Vai Ring Road,Gananayak Marg, Kotdevi Marg, Koteshwor To Jadibuti Chowk Via Arniko Highway.

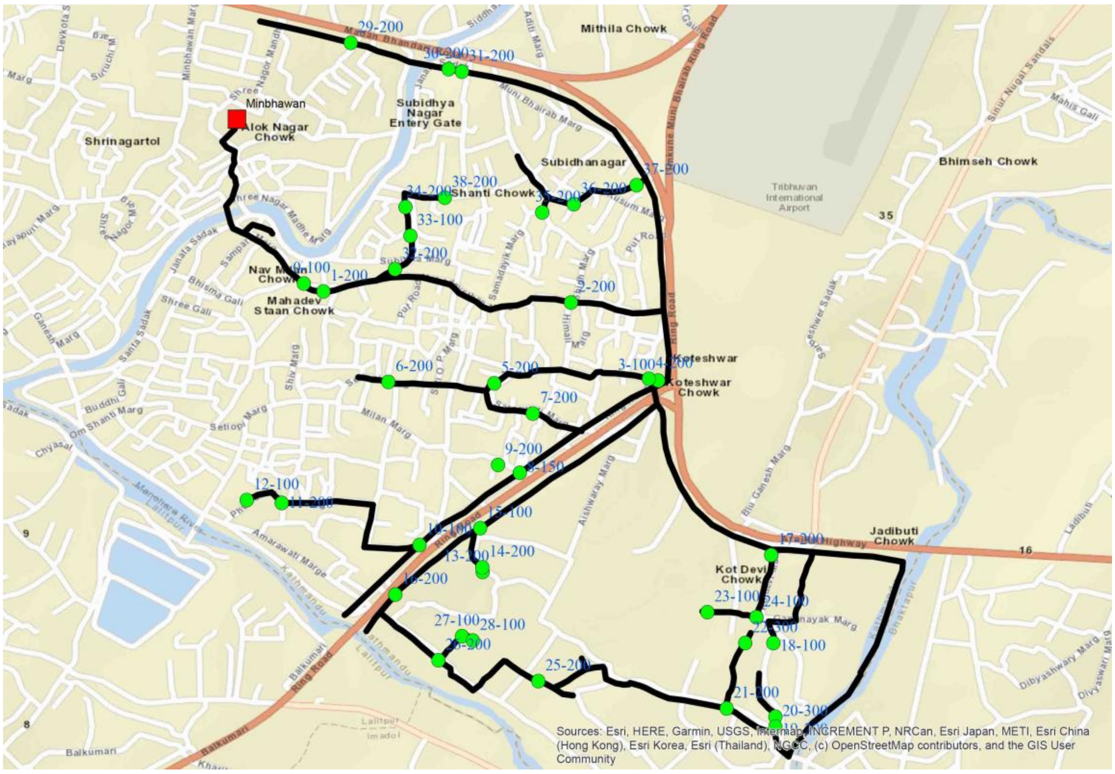


Figure 3.1 GPS Map of Koteshwor Feeder

**Meteorological data:**

- Altitude above sea level: 1420 m
- Ambient Air Temperature: -5 ºC (minimum) to 40 ºC (maximum)
- Average Humidity (in %): 100 (maximum), 40 (minimum)

**3.3.2 Selection of Cables Size**

Simulation conditions for underground distribution system:

- Designed temperature = 90º C
- Ambient temperature of soil = 20º C
- Derating factor = 0.9
- Voltage drop limit = 5%
- Fault Level = 11 kV 25kA for 3 Sec
- Number of Cores = 3
- Rated Voltage = 11 kV
- Maximum System voltage = 12 kV
- Rated Voltage between conductor and screen = 6.35 kV
- Rated Voltage between two conductors = 11 kV
- Conductor Material = Aluminum
- Class of Stranding = Class 2
- Thickness of Conductor Screen = 0.6 mm
- Thickness of XLPE insulation mm 3.6
- Thickness of Insulation Screen = 0.7 mm
- Thickness of Copper Screen = 0.12 mm
- Nominal Thickness of PVC Inner sheath = 1.3 mm
- Nominal Thickness of PVC Outer Sheath = 3.5 mm
- Thermal loading limit = 100%
- Spacing of conductor = 300 mm
- Conductor type = 3 Core, XLPE Aluminum
- Nominal frequency = 50 + 2.5%
- Initial selected conductor = Magpie ACSR, 12.7 square mm
- Laying = Ground at the depth 0.8 m
- Soil Type = Normal
- Conduit type = HDPE pipe
- Rated Insulation levels
- Full wave impulse withstand voltage (1.2/50 microsec.) = 75 kVp
- One-minute power frequency dry and wet withstand voltage (rms) = 28 kV

- Minimum creepage distance (25mm/kV) = 300mm
- Minimum Clearances

i. Phase to phase 120 mm

ii. Phase to earth 120 m

**Cable Construction Details**

The XLPE insulated cables should be of IEC 60502-2 for construction and IEC 60840 for other. The terminating accessories should be of IEC 60840/ IEC 62067. The cables and its accessories should be well-matched with each other. The cable should be of three core, armored, stranded, compacted conductor Aluminum, core screening by a layer of semiconducting XLPE, treeing resistant XLPE insulation, insulation screening by a layer of semiconducting XLPE. The core screening, insulation and insulation screening to be triple extruded and dry cured. Helically wound copper wire screening with equalizing tape, should be provided on each conductor. Each core should have a Polyethylene sheath. Allowable tolerance on the overall diameter of the cables should be + 2 mm.

**Conductor:** All conductors should be stranded, circular and compacted and comply with IEC 60228.

**Conductor Screen:** The conductor screen should consist of extruded semi-conducting XLPE with separator tapes applied between conductor and the extruded semi-conductor XLPE. The conductor screen (non-metallic semi-conductive) should be extruded in a single one-time process to ensure homogeneity and absence of voids. The conductor should be screened with an extruded layer of semi-conducting material of 0.5mm thickness for the cables.

**Conductor:** The conductor should be made from Electrolytic H4 Grade, high conductivity, stranded aluminum to form compacted and circular /shaped conductor with resistance within permissible value. Uniform in quality, solid, smooth and free from scale, sharp edges and circular cross section type conductor should be used.

**Insulation**: The insulating material should be cross linked Poly Ethylene (XLPE), The major property of the insulating material is to have excellent electrical properties, dielectric constant and loss factor and should have high tensile strength and resistance. This should not weaken at raised temperatures or when immersed in water. The insulation should be fire resistant and chemical resistant. And it should be stable under thermal conditions temperature of 90°C rising continuous and momentarily to 250°C under short circuit conditions. The thickness of insulation should be determined by taking the average of the number of measurements and should be not less than the values of IEC - 60502.

**Core identification:** Individual core of three-core cables should be color coded and/or numbered for proper identification. All cores insulation should be black colored.

Red line should represent - R ph. Blue line should represent - B ph.
Yellow line should represent - Y ph.

**Inner Sheath:** The inner sheath should be extruded FRLS PVC, Type ST2, compatible with thermal rating of insulation. The laid-up cores should be used with inner sheath applied by extrusion method. the negative tolerance should not be used.

**Armoring:** The armour of cables should consist of either galvanized round steel wires or galvanized steel strips. The armoring should be applied so that the less area of coverage should be 90% and the clearance between any two armour strips/ wire should not be more than the width of strip/ diameter of armour wire. the negative side tolerance should not be used.

**Insulation Screen:** The insulation screen should consist of extruded semi-conducting XLPE. Suitable bedding tapes should be applied over the extruded semi-conducting XLPE in combination with 1 non-magnetic metallic shield.

**Longitudinal Water Barrier:** The longitudinal water barrier should be applied over insulation screen by a layer of nonwoven synthetic tape with appropriate water swellable absorbent.

**Metallic Screen:** The metallic screen should be of plain copper wires, helically over the radial wetness barrier. Over the copper wire screen, a binder tape of annealed plain copper should be used in the form of open helix. The combination of the metallic sheath (lead sheath) in combination with wire screen should be used.

**Outer Sheath:** The outer sheath should contain of extruded black colored HDPE. The outer sheath should be appropriately designed by the adding of chemicals in the outer sheath for protection against termite and rodent attack. The outer sheath should have adequate strength and thickness to withstand the test voltage and mechanical tests and be suitable for ambient conditions at site. The outer sheath material should be capable of withstanding the maximum temperature achieved with the cable at its rated current without damage or deformation at site ambient conditions.

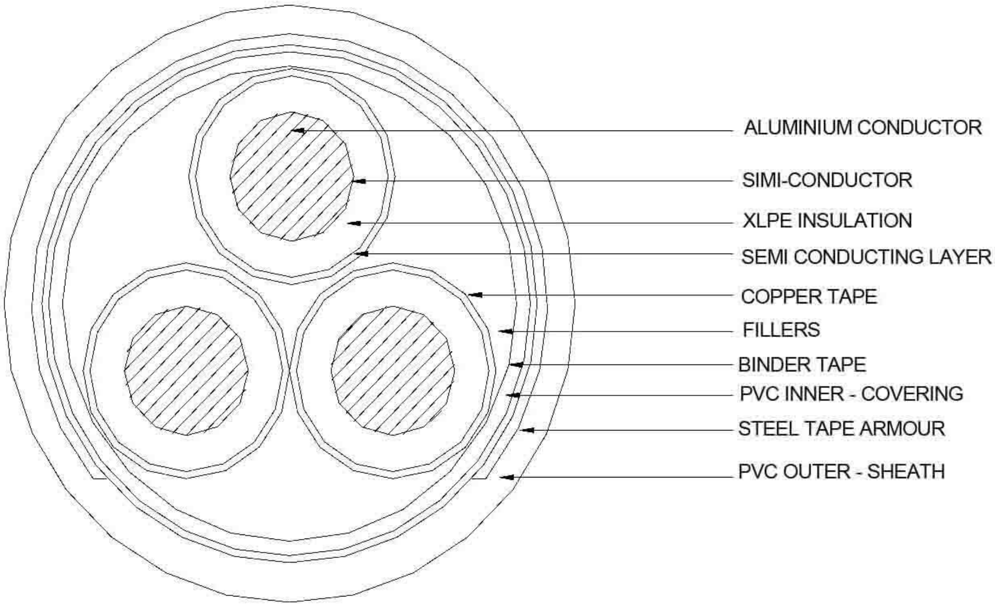



Figure 3.2 XLPE Cable Construction Detail.

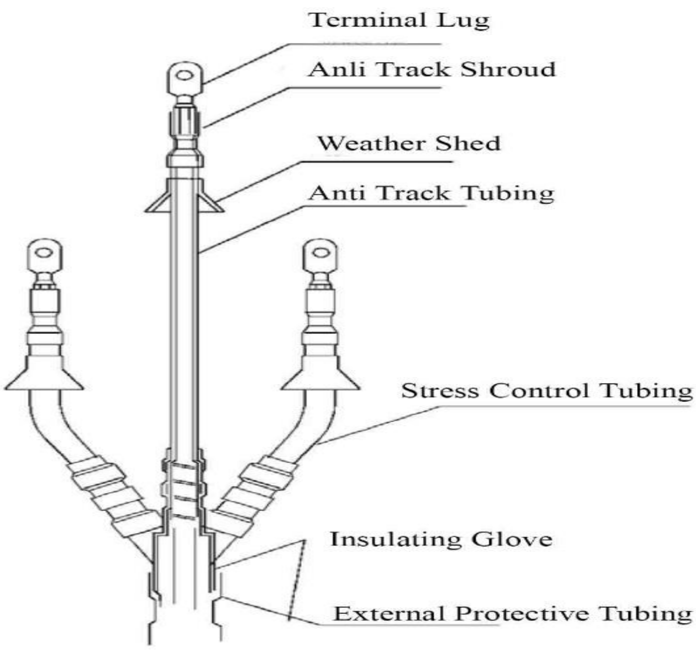



Figure 3.3: Cable termination

**Cable Jointing Accessories:** The cable jointing accessories should include all the straight through joints. Straight joints should be heat shrink type with compression ferrules. The cable end terminations should be of anti-fog type and should be of Polymeric type suitable for withstanding the climatic conditions with required Creepage distance. The terminations should also be capable to withstand mechanical forces during normal and short circuit operations. The entire termination and joint kit should be environmentally sealed and capable of preventing the ingress of external moisture and contamination.

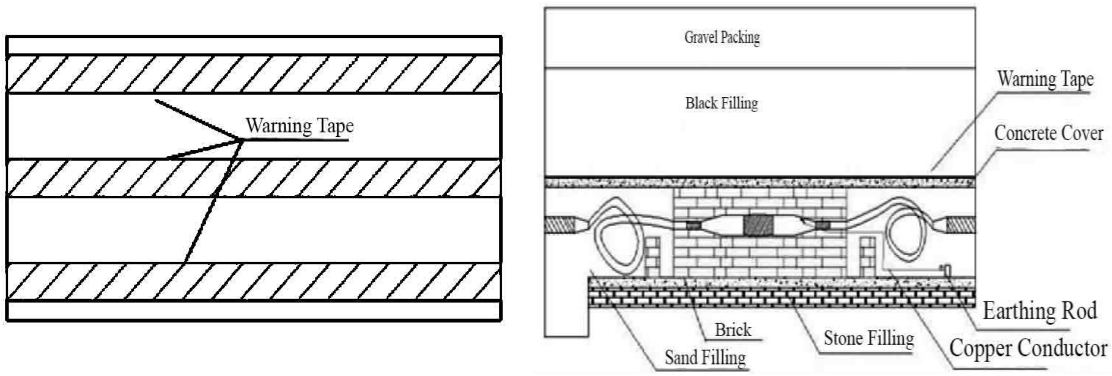



Figure 3.4 Cable tape and cable joint

**HDPE Pipe:** The 160 mm and 125mm (outer diameter) Flexible HDPE Pipe used for XLPE power cable in underground 11kV distribution system. The HDPE pipes are black and should suitable for inserting cable. The flexible conduit pipe should be corrugated hard polyethylene pipe should be used for installation of XLPE power cable. The flexible pipe should be buried before the cable installation and, then the cables should be pulled in. The HDPE pipe material should be Fire Retardant or non-Flammable. The HDPE pipes should be fabricated and tested in accordance with BS: 3412, Class N. The minimum tensile strength of the pipe should be 240 kg/cm2. The HDPE pipe should be suitable for 6 kgf/cm2 pressures with thickness not less than 6.5 mm and weight of the HDPE pipe should not be less than 2.5 kg per meter. The HDPE pipe should have a minimum tensile strength of 3200 kg/mm2. The HDPE pipes should have design at 27 deg. C for a stress of over 50 kg/cm2 with safety factor of 1.3. The flexible conduit pipe should be withstand the density force from heavy trucks when it is buried in depth of more than 80 cm below the ground level and temperature rise up to 80 degree Celsius.

Table 3.1 HDPE Pipe of 160mm and 125 mm Diameter

| **No.** | **Item Description** | **Unit** | **Requirement** | |
|---|---|---|---|---|
| | | | **160 mm Diameter** | **125 mm Diameter** |
| 1 | M.F.R. (190°C,5kg load) | gm/10 mins | 0.20 to 1.10 | 0.20 to 1.10 |
| 2 | Specified base density | kg/m3 | 940 to 958 | 940 to 958 |
| 3 | Material Grade | | PE-63 | PE-80 |
| 4 | Wall Thickness | Mm | 7.7 - 8.7 | 4 .9 - 5.6 |
| 5 | Carbon Black | % | 2.5 ± 0.5 | 2.5 ± 0.5 |
| 6 | Ant1ox 1dant | % by | <0.3% by mass | <0.3% by mass |
| 7 | Overall Migration | Mg/dm2 | 10 Max | 10 Max |
| 8 | Reversion | % | <=3% | <=3% |
| 9 | Hydraulic Characteristics | | No sign of restricted swelling, leakage or weeping (at 80°C for 48 & 165 hrs.) | No sign of restricted swelling, leakage or weeping (at 80°C for 48 |
| 10 | Continuous Temperature withstand capacity | | 120 deg. C | 110 deg. C |

**Lying of Underground Cable:** The laying of cables should normally be done direct in ground through trenchless boring using HDPE pipes (if not possible then, by manual digging). Cable laying at road crossings should preferably be made by trenchless (Horizontal drilling technology) method. However, in exceptional circumstances the cables may have to be laid in covered trenches or in racks fixed to the walls. Adequate strength of HDPE pipe should be laid where cable crossing the road, residential house gates.

For the crossing the National highways, and Canals etc. trenchless digging should be used. The various methods of trenchless digging such as hand/ manual auguring (up to 15m), impact moling (from 16m to about 40-50m), HDD (above 40-50m) may be used according to on the soil/site conditions and the requirement. At least 100 m at one go should be drilled by equipment for HDD. Manholes should be made at every proposed joint location for jointing. Any overstress due to over-bending, excess pulling must be avoided. The minimum bending radius of XLPE insulated cables should be 20XD where "D" means the Outer diameter of the cable.

**Restoration of Road:** The laying of the power cables and other works may require digging alongside/ across the roads/streets/pavements/or any other public/private area. The road has to restore the dugout area by back filling and suitable compacting. The top layer has to be restored in the same fashion and condition to give it the original look as per the norms and standards of Department of Road, GoN.

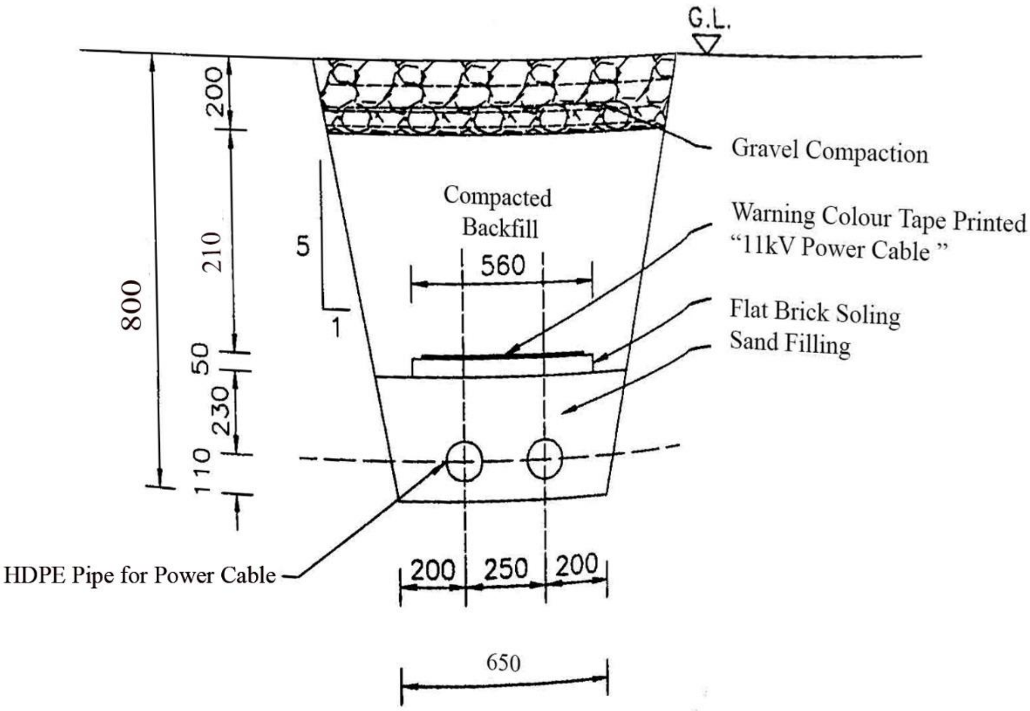



Figure 3.6 Trench for HDPE Pipe

### 3.3.3 Followings Steps is Carried Out for Reliability Evaluation

- Validate the DIgSILENT PowerFactory reliability assessment tool by using the standard IEEE RBTS 2- bus system (Which is created for educational purpose).
- Single line diagram of the feeder is simulated in DIgSILENT PowerFactory with reference to GPS data of Koteshwor feeder.
- Branch length, load and Simulation conditions for overhead and underground is set Technical data is collected of selected Feeder.

- A user define library for reliability evaluation is created in DIgSILENT PowerFactory for both overhead conductor and underground cable by using IEEE Historical data.
- Run the reliability assessment to obtain the value of reliability indices with respect to IEEE historical data.
- The obtained result of reliability assessment for both the overhead distribution system and underground distribution system is summarized

### 3.3.4 Finding the Number of Customers of Koteshwor Feeder

Since number of customers per feeder is unknown, to determine the number of customers, monthly sales report of Kuleshwor, Ratnapark, Naxal distribution center and Koteshwor feeder outgoing average energy per month is collected. After analyzing the sales report, it is known that out of total customer about 96% are domestic and 4% of customers are others (industrial, commercial, irrigation, water supply, non-domestic and street light etc.) and of the total energy consumed domestic customers consume only 58% of total energy. The number of customers of Koteshwor feeder is calculated in table 3.2. Hence, number of customers of Koteshwor feeder is 7855 approximate.

Table 3.2 Determination of Number of Customers of Koteshwor Feeder

<table>
<tr><th rowspan="2">Name of DCS</th><th colspan="2">Domestic</th><th colspan="2">Others</th><th colspan="2">Total</th><th colspan="2">Unit Consumption Per Customer</th></tr>
<tr><th>Customers (1)</th><th>Unit Consumed (2)</th><th>Customer (3)</th><th>Unit Consumed (4)</th><th>Customers (5) = (1) +(3)</th><th>Unit Consumed (6) = (2) +(4)</th><th>Others (7) = (4)/ (3)</th><th>Domestic (8) = (2)/ (1)</th></tr>
<tr><td>Kuleshwor</td><td>47330</td><td>7234996</td><td>1951</td><td>4359143</td><td>49280</td><td>11594139</td><td>2235</td><td>153</td></tr>
<tr><td>Ratnapark</td><td>39466</td><td>8871083</td><td>3606</td><td>13587904</td><td>43072</td><td>22458986</td><td>3768</td><td>225</td></tr>
<tr><td>Naxal</td><td>6329</td><td>1614669</td><td>453</td><td>605927</td><td>6782</td><td>2220595</td><td>1338</td><td>255</td></tr>
<tr><td colspan="7" rowspan="2">Average consumption Per</td><td>2447</td><td>211</td></tr>
<tr><td>Other Customer (9)</td><td>Domestic Customer (10)</td></tr>
</table>

<table>
<tr><th rowspan="3">Name of DCS</th><th colspan="2">Percentage of Total Customer</th><th colspan="2">Percentage of Total Unit Consumed</th></tr>
<tr><th>Domestic</th><th>Others</th><th>Domestic</th><th>Others</th></tr>
<tr><th>(11) = (1) *100/ (5)</th><th>(12) = (3) *100/ (5)</th><th>(13) = (2) *100/ (6)</th><th>(14) = (4) *100/ (6)</th></tr>
<tr><td>Kuleshwor</td><td>96</td><td>4</td><td>62</td><td>38</td></tr>
<tr><td>Ratnapark</td><td>92</td><td>8</td><td>39</td><td>61</td></tr>
<tr><td>Naxal</td><td>93</td><td>7</td><td>73</td><td>27</td></tr>
<tr><td></td><td>94</td><td>6</td><td>58</td><td>42</td></tr>
</table>

| **Average Percentage of Total** | **Domestic Consumers (15)** | **Other Customer (16)** | **Domestic Unit Consumed (17)** | **Other Unit Consumed (18)** |
|---|---|---|---|---|

| | | **Unit Consumed** | | **Customer Number** | | |
|---|---|---|---|---|---|---|
| **Feeder** | **Average Unit Consumption Per Month (19)** | **Domestic (20) = (19) *(15)/100** | **Other (21) = (19) *(16)/100** | **Domestic (22) = (20)/ (10)** | **Others (23) = (21)/ (9)** | **Total (24)** |
| Koteshwor | 1758625 | 1647189 | 111436 | 7809 | 46 | **7855** |

### 3.3.5 Following Steps is Carried Out for Financial Analysis

- Total cost estimation of the designed overhead distribution system is calculated by using NEA unit rate for required amount of material and labor.
- Total cost estimation of the designed underground distribution system is calculated by using unit rate of KIE Industries Co. Ltd. Quoted price for NEA underground project for required material and installation.
- The useful material cost saved from dismantle of existing overhead distribution system is calculated by subtracting labor cost required for dismantle.
- The net cost required to replace the existing overhead distribution system by underground distribution system is calculated.
- Per year revenue saved from replacing existing overhead distribution system by underground is calculated by using product of flat unit rate tariff and difference of ENS of existing overhead distribution system and underground distribution system.
- Investment decision is made by calculating B/C ratio and Present Worth value for 25-year useful life.
- Finally, payback period is calculated.

## CHAPTER FOUR: RESULTS AND DISCUSSION

### 4.1 Load Flow of Standard IEEE 33 Node Distribution System

As the voltage level along the feeder get change from one point to other, so, load flow is required to do cable sizing for the feeder. Hence, while doing cable sizing the validation of load flow analysis is to be done in DIgSILENT PowerFactory. The standard IEEE 33 node distribution system is used for this purpose.

Table 4.1 Data Used in Paper for IEEE 33 Node (Rajaram, R., 2015)

| Branch No | Sending End Bus | Receiving End Bus | Branch Resistance (Ω) | Branch Reactance (Ω) | P(kW) | Q(kVar) |
|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 0.092041459 | 0.046919182 | 0 | 0 |
| 2 | 2 | 3 | 0.492152267 | 0.250668224 | 100 | 60 |
| 3 | 3 | 4 | 0.36537065 | 0.186079478 | 90 | 40 |
| 4 | 4 | 5 | 0.380444685 | 0.193766238 | 120 | 80 |
| 5 | 5 | 6 | 0.817591698 | 0.705784286 | 60 | 30 |
| 6 | 6 | 7 | 0.186878102 | 0.61773595 | 60 | 20 |
| 7 | 7 | 8 | 0.71017672 | 0.234695736 | 200 | 100 |
| 8 | 8 | 9 | 1.028228875 | 0.738727542 | 200 | 100 |
| 9 | 9 | 10 | 1.042204802 | 0.738727542 | 60 | 20 |
| 10 | 10 | 11 | 0.196261939 | 0.06488823 | 60 | 20 |
| 11 | 11 | 12 | 0.373756205 | 0.123587122 | 40 | 30 |
| 12 | 12 | 13 | 1.465475718 | 1.153013933 | 60 | 40 |
| 13 | 13 | 14 | 0.540668698 | 0.711674141 | 60 | 40 |
| 14 | 14 | 15 | 0.589983754 | 0.525095523 | 120 | 80 |
| 15 | 15 | 16 | 0.745016709 | 0.544062851 | 60 | 10 |
| 16 | 16 | 17 | 1.286783515 | 1.718040675 | 60 | 20 |
| 17 | 17 | 18 | 0.730741298 | 0.573012986 | 60 | 20 |
| 18 | 18 | 19 | 0.163717995 | 0.156230893 | 90 | 40 |

| Branch No | Sending End Bus | Receiving End Bus | Branch Resistance (Ω) | Branch Reactance (Ω) | P(kW) | Q(kVar) |
|---|---|---|---|---|---|---|
| 19 | 19 | 20 | 1.50161347 | 1.353069338 | 90 | 40 |
| 20 | 20 | 21 | 0.40879585 | 0.477577373 | 90 | 40 |
| 21 | 21 | 22 | 0.707681019 | 0.935688277 | 90 | 40 |
| 22 | 22 | 23 | 0.450424144 | 0.307769867 | 90 | 40 |
| 23 | 23 | 24 | 0.896455854 | 0.707880675 | 90 | 40 |
| 24 | 24 | 25 | 0.894459294 | 0.699894432 | 420 | 200 |
| 25 | 25 | 26 | 0.202650934 | 0.1032222 | 420 | 200 |
| 26 | 26 | 27 | 0.283711307 | 0.144451182 | 60 | 30 |
| 27 | 27 | 28 | 1.05717901 | 0.932094467 | 60 | 30 |
| 28 | 28 | 29 | 0.802817147 | 0.699395291 | 60 | 20 |
| 29 | 29 | 30 | 0.506627334 | 0.258055499 | 120 | 70 |
| 30 | 30 | 31 | 0.972724482 | 0.961344085 | 200 | 600 |
| 31 | 31 | 32 | 0.309966083 | 0.361277699 | 150 | 70 |
| 32 | 32 | 33 | 0.340413637 | 0.529288301 | 210 | 100 |
|  |  |  |  |  | 60 | 40 |

Figure 4.1 Shows the Simulation of IEEE 33 node distribution system in DIgSILENT PowerFactory

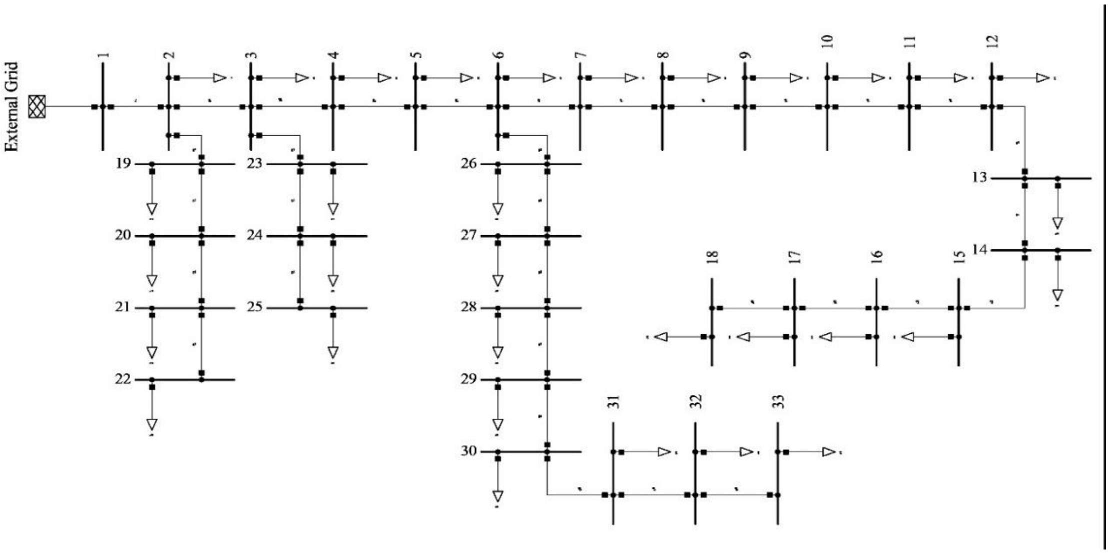



Figure 4.1 Single Line Diagram of Feeder on DIgSILENT PowerFactory

Figure 4.2 shows the bus voltage deviation of standard IEEE 33 node distribution system from simulation in DIgSILENT PowerFactory.

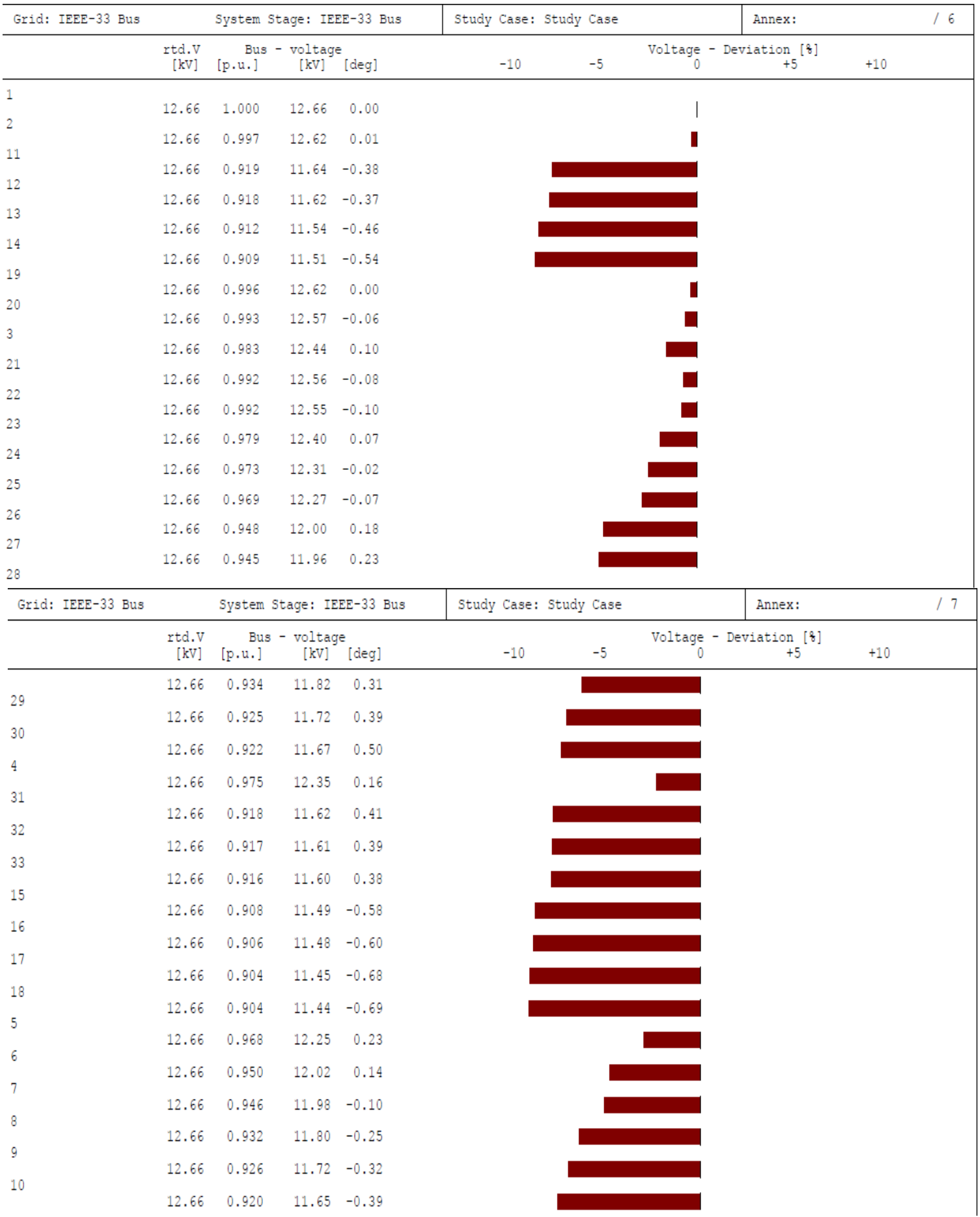



Figure 4.2 Output for Node Voltage Deviation of IEEE 33 Node

Table 4.2 shows the comparison of bus voltage obtained from simulation in DIgSILENT PowerFactory and standard IEEE 33 node distribution system results. Here, IEEE values are considered as standard and percentage deviation in results with respect to standard values is calculated. The highest deviation is obtained in the

Bus number 20 which is 3.021%. As the obtained maximum deviation is within acceptable limit (<5%), the paper results of load flow are compiled to the DIgSILENT PowerFactory results.

Table 4.2 Comparison of Paper Result and Simulation Result for IEEE 33 Node

| Bus Number | Bus Voltage (P.U.) | | Deviation | Deviation % |
|---|---|---|---|---|
| | Paper Result | Simulation Result | | |
| 1 | 1.000 | 1.000 | 0.000 | 0.000 |
| 2 | 0.997 | 0.997 | 0.000 | -0.010 |
| 3 | 0.983 | 0.984 | -0.001 | -0.051 |
| 4 | 0.975 | 0.976 | -0.001 | -0.133 |
| 5 | 0.968 | 0.969 | -0.001 | -0.134 |
| 6 | 0.950 | 0.951 | -0.001 | -0.084 |
| 7 | 0.946 | 0.947 | -0.001 | -0.137 |
| 8 | 0.932 | 0.934 | -0.002 | -0.182 |
| 9 | 0.926 | 0.927 | -0.001 | -0.151 |
| 10 | 0.920 | 0.922 | -0.001 | -0.163 |
| 11 | 0.919 | 0.921 | -0.002 | -0.174 |
| 12 | 0.918 | 0.919 | -0.001 | -0.120 |
| 13 | 0.912 | 0.908 | 0.004 | 0.395 |
| 14 | 0.909 | 0.907 | 0.002 | 0.253 |
| 15 | 0.908 | 0.919 | -0.011 | -1.244 |
| 16 | 0.906 | 0.918 | -0.012 | -1.313 |
| 17 | 0.904 | 0.917 | -0.013 | -1.416 |
| 18 | 0.904 | 0.905 | -0.001 | -0.133 |
| 19 | 0.996 | 0.967 | 0.029 | 2.952 |
| **20** | **0.993** | **0.963** | **0.030** | **3.021** |
| 21 | 0.992 | 0.962 | 0.030 | 2.994 |
| 22 | 0.992 | 0.992 | 0.000 | 0.030 |
| 23 | 0.979 | 0.980 | -0.001 | -0.092 |

| Bus Number | Bus Voltage (P.U.) | | Deviation | Deviation % |
|---|---|---|---|---|
| | Paper Result | Simulation Result | | |
| 24 | 0.973 | 0.973 | 0.000 | -0.021 |
| 25 | 0.969 | 0.970 | -0.001 | -0.093 |
| 26 | 0.948 | 0.949 | -0.001 | -0.095 |
| 27 | 0.945 | 0.946 | -0.001 | -0.148 |
| 28 | 0.934 | 0.935 | -0.001 | -0.096 |
| 29 | 0.925 | 0.927 | -0.002 | -0.184 |
| 30 | 0.922 | 0.923 | -0.001 | -0.130 |
| 31 | 0.918 | 0.919 | -0.001 | -0.109 |
| 32 | 0.917 | 0.918 | -0.001 | -0.120 |
| 33 | 0.916 | 0.918 | -0.002 | -0.197 |
| Total Real Power Load | 3.71 | 3.715 | -0.005 | -0.135 |
| Total Reactive Power Load | 2.3 | 2.3 | 0.000 | 0.000 |
| Initial Power Loss | 0.21 | 0.20987 | 0.000 | 0.062 |
| **Maximum Deviation** | | | **0.030** | **3.021** |

### 4.2 Cable Rating Calculation

Koteshwor Feeder of Baneshwor substation under Baneshwor DCS is located central location of Kathmandu valley. As the peak load demand of this feeder is 380 A, 320A, 300 A and 310 A in fiscal year 2072/73, 2073/74, 2074/75 and 2075/75 respectively, this means feeder is considered as almost saturated feeder. The Koteshwor feeder is selected for the study purpose because it is one of loaded feeder having length about 9451 m. And also, it contains 34 distribution transformers having rating of 100KVA, 150 kVA, 200 kVA, 300 kVA, 400 KVA, 500 kVA with total rating capacity of 6850 KVA. Therefore, maximum current of the feeder is 359.54 ampere. This feeder consists of ACSR DOG conductor having cross-sectional area 100 square mm. and current rating in air 291 Ampere. This means at present situation Koteshwor feeder is running in overload at peak time.

Table 4.3 shows the length and connected load of each branch is measured from GPS map of Koteshwor feeder.

Table 4.3 Branch Length and Connected Load of Koteshwor Feeder

| **Branch** | | **Length, m** | **Load, KVA** | **Total Load, KVA** |
|---|---|---|---|---|
| **From** | **To** | | | |
| Busbar | 0 | 508 | 100 | 100 |
| 0 | 1 | 52 | 200 | 200 |
| 0 | 1(1) | 124 | | 0 |
| 1(1) | 32 | 52 | 200 | 200 |
| 32 | 33 | 103 | 100 | 100 |
| 33 | 34 | 73 | 200 | 200 |
| 34 | 38 | 128 | 200 | 200 |
| 1(1) | 2 | 481 | 200 | 200 |
| 2 | 2(2) | 215 | | 0 |
| 2(2) | 37 | 364 | 200 | 200 |
| 37 | 36 | 160 | 200 | 200 |
| 36 | 35 | 102 | 200 | 200 |
| 37 | 30,31 | 527 | 200,200 | 400 |
| 30,31 | 29 | 267 | 200 | 200 |
| 2(2) | 3,4 | 198 | 100,200 | 300 |
| 3,4 | 5 | 400 | 200 | 200 |
| 5 | 6 | 254 | 200 | 200 |
| 3,4 | 3,4(1) | 232 | | 0 |
| 3,4(1) | 7 | 120 | 200 | 200 |
| 3,4(1) | 8 | 176 | 150 | 150 |
| 8 | 9 | 55 | 200 | 200 |
| 8 | 10 | 295 | 100 | 100 |
| 10 | 11 | 450 | 200 | 200 |

| Branch | | Length, m | Load, KVA | Total Load, KVA |
|---|---|---|---|---|
| **From** | **To** | | | |
| 11 | 12 | 97 | 100 | 100 |
| 3,4 | 15 | 593 | 100 | 100 |
| 15 | 13,14 | 113 | 200,200 | 400 |
| 15 | 16 | 258 | 200 | 200 |
| 3,4 | 17 | 576 | 200 | 200 |
| 17 | 24 | 162 | 100 | 100 |
| 24 | 23 | 116 | 100 | 100 |
| 17 | 18 | 100 | 100 | 100 |
| 18 | 19,20 | 890 | 200,300 | 500 |
| 19,20 | 21 | 127 | 200 | 200 |
| 21 | 22 | 174 | 300 | 300 |
| 21 | 25 | 486 | 200 | 200 |
| 25 | 26 | 311 | 200 | 200 |
| 26 | 27,28 | 112 | 100,100 | 200 |
| **Total** | | **9,451** | | **6,850** |

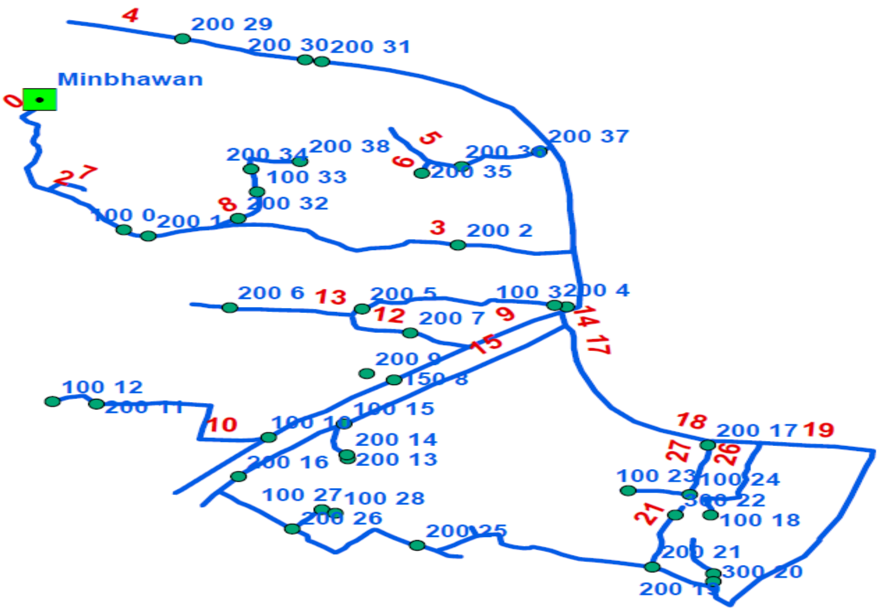



Figure 4.3 Location of Transformer in Koteshwor feeder

### 4.3 Overhead Conductor Design

Simulation conditions for overhead distribution system:

| | |
|---|---|
| Designed temperature = 90º C | Spacing of conductor = 300 mm |
| Ambient temperature = 25º C | Conductor type = ACSR |
| Derating factor = 1 | Nominal frequency = 50 Hz |
| Voltage drop limit = 5% | Nominal system voltage = 11 kV |
| Thermal loading limit = 100% | Initial selected conductor = Magpie ACSR, 12.7 square mm |

By using NEA voltage drop criteria that is 5% in distribution line and 100% thermal load cable sizing is run.

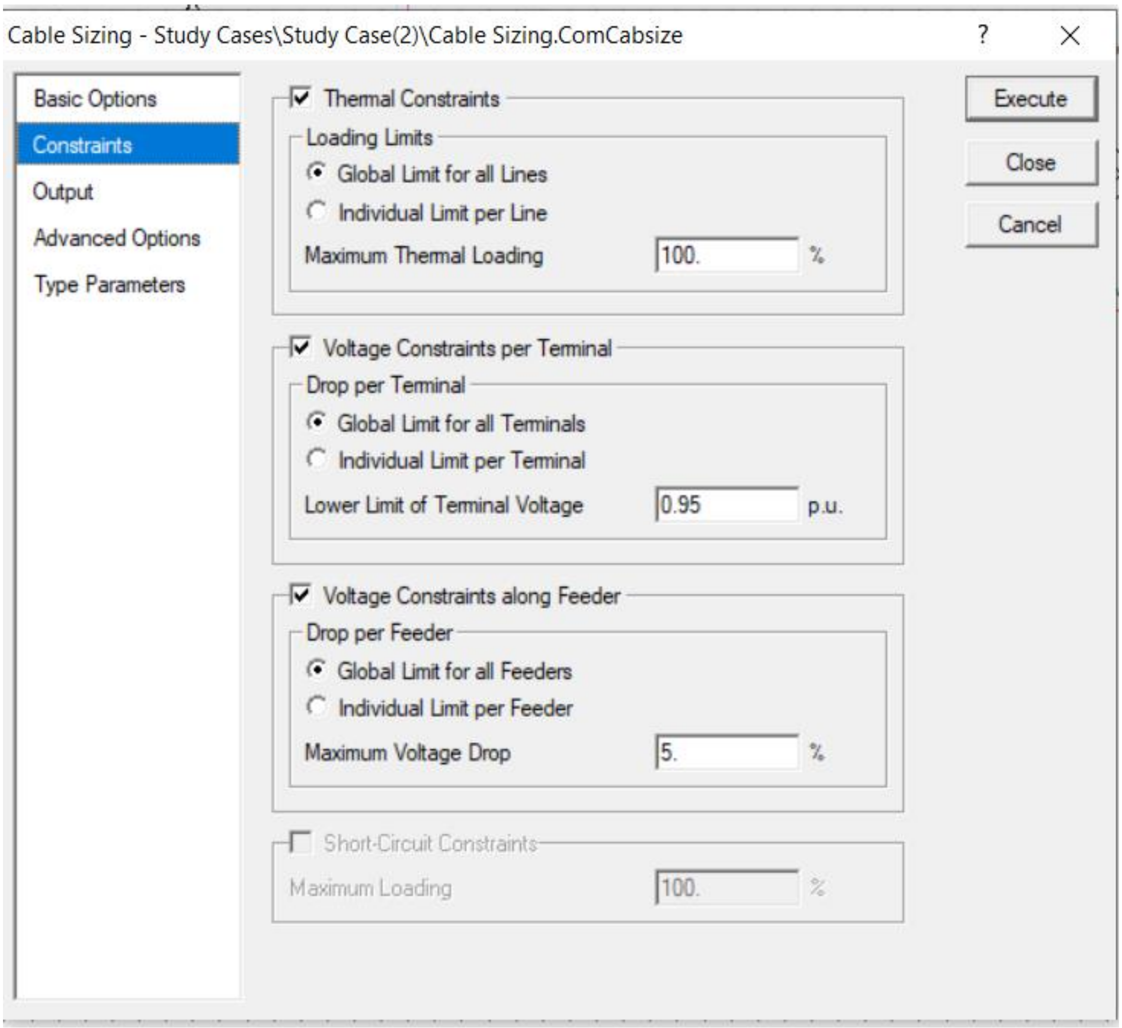



Figure 4.4 Cable Sizing Constraints Used in DIgSILENT PowerFactory Simulation

After running the load flow of the design overhead distribution system, the voltage drops at different node (Acceptable limit: less than 5%) in designed overhead distribution system is as shown in Figure 4.5.

| | | DIgSILENT PowerFactory 15.1.7 | Project: |
|---|---|---|---|
| | | | Date: 9/8/2019 |

Load Flow Calculation Complete System Report: Substations, Voltage Profiles, Grid Interchange, Zone Interchange, Area Interchan

| | | | |
|---|---|---|---|
| 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(2) | Annex: / 6

| | rtd.V [kV] | Bus - voltage [p.u.] | [kV] | [deg] | Voltage - Deviation [%] -10 -5 0 +5 +10 |
|---|---|---|---|---|---|
| Bus Bar | 11.00 | 1.000 | 11.00 | 0.00 | |
| 0 | 11.00 | 0.994 | 10.93 | -0.22 | |
| 1 | 11.00 | 0.993 | 10.92 | -0.24 | |
| 37 | 11.00 | 0.979 | 10.77 | -0.41 | |
| 36 | 11.00 | 0.978 | 10.76 | -0.37 | |
| 35 | 11.00 | 0.978 | 10.76 | -0.36 | |
| 30/31 | 11.00 | 0.974 | 10.71 | -0.23 | |
| 29 | 11.00 | 0.973 | 10.70 | -0.20 | |
| 3/4(1) | 11.00 | 0.978 | 10.76 | -0.46 | |
| 8 | 11.00 | 0.976 | 10.73 | -0.38 | |
| 10 | 11.00 | 0.974 | 10.71 | -0.32 | |
| 11 | 11.00 | 0.972 | 10.69 | -0.24 | |
| 1(1) | 11.00 | 0.992 | 10.91 | -0.29 | |
| 17 | 11.00 | 0.976 | 10.74 | -0.54 | |
| 18 | 11.00 | 0.975 | 10.73 | -0.53 | |
| 19/20 | 11.00 | 0.966 | 10.63 | -0.39 | |
| 21 | | | | | |

Grid: Grid | System Stage: Grid | Study Case: Study Case(2) | Annex: / 7

| | rtd.V [kV] | Bus - voltage [p.u.] | [kV] | [deg] | Voltage - Deviation [%] -10 -5 0 +5 +10 |
|---|---|---|---|---|---|
| | 11.00 | 0.965 | 10.61 | -0.35 | |
| 25 | 11.00 | 0.960 | 10.56 | -0.18 | |
| 26 | 11.00 | 0.957 | 10.53 | -0.11 | |
| 27/28 | 11.00 | 0.957 | 10.53 | -0.10 | |
| 24 | 11.00 | 0.976 | 10.73 | -0.53 | |
| 32 | 11.00 | 0.991 | 10.90 | -0.27 | |
| 15 | 11.00 | 0.975 | 10.72 | -0.35 | |
| 16 | 11.00 | 0.974 | 10.71 | -0.32 | |
| 12 | 11.00 | 0.971 | 10.69 | -0.23 | |
| 5 | 11.00 | 0.979 | 10.77 | -0.49 | |
| 6 | 11.00 | 0.978 | 10.76 | -0.46 | |
| 22 | 11.00 | 0.964 | 10.60 | -0.32 | |
| 33 | 11.00 | 0.990 | 10.89 | -0.24 | |
| 34 | 11.00 | 0.990 | 10.89 | -0.23 | |
| 38 | 11.00 | 0.989 | 10.88 | -0.21 | |
| 2 | 11.00 | 0.986 | 10.85 | -0.46 | |
| 2(1) | 11.00 | 0.984 | 10.83 | -0.54 | |
| 3/4 | 11.00 | 0.982 | 10.80 | -0.58 | |

Figure 4.5 Node Voltage Deviation in Designed OHDS

By choosing Magpie ACSR, 12.7 square mm conductor as initial conductor with the

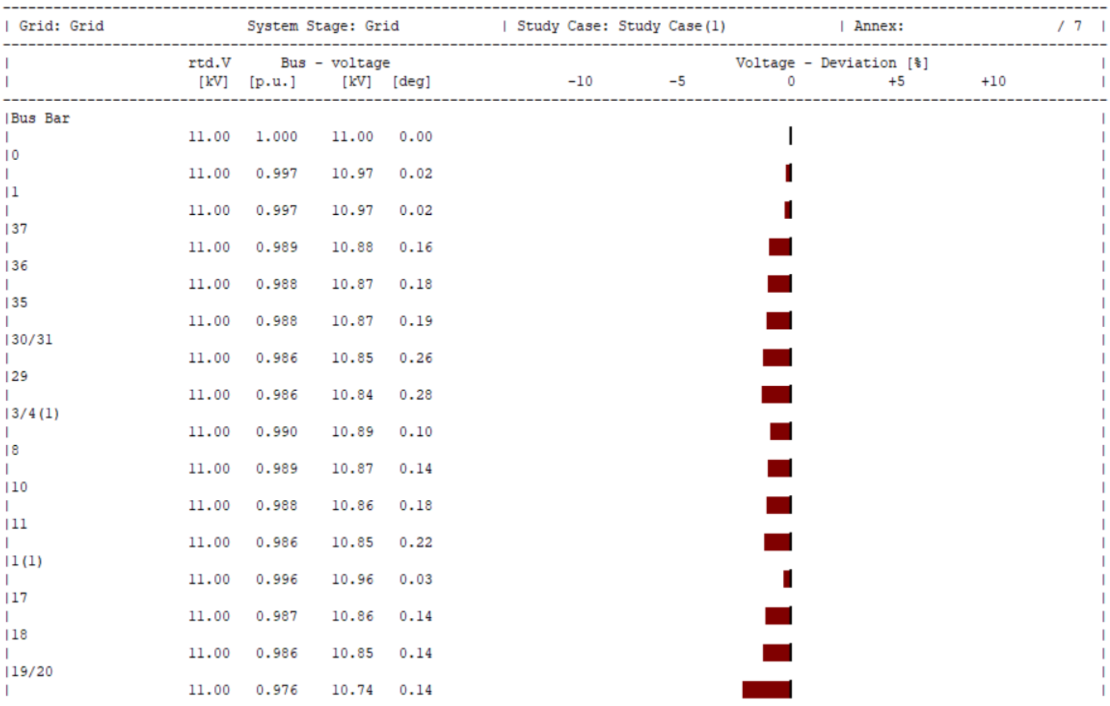
Figure 4.5 constraints. The recommended conductor for the overhead distribution obtained from the cable sizing run in DIgSILENT PowerFactory is shown in Table 4.4. The available conductor table is attached in ANNEXURE A.

Table 4.4 Recommendation of conductor by DIgSILENT PowerFactory for OHDS

| Name of Conductor | Area, square mm | Required Length, m |
|---|---|---|
| **Magpie** | 12.8 | 5888 |
| **Quirrell** | 20.7 | 364 |
| **Ferret** | 41.8 | 990 |
| **Mink** | 62.2 | 576 |
| **Wolf** | 155 | 198 |
| **Goat** | 317 | 1328 |
| **Zebra** | 420 | 52 |
| **Pawpaw** | 584 | 55 |
| **Total Length** | | **9451** |

### 4.4 Underground Cable Design

After Running the load flow of the design underground distribution system, the voltage


Grid: Grid System Stage: Grid | Study Case: Study Case(1) | Annex: / 7

| | rtd.V [kV] | Bus - voltage [p.u.] | [kV] | [deg] |
|---|---|---|---|---|
| Bus Bar | 11.00 | 1.000 | 11.00 | 0.00 |
| 0 | 11.00 | 0.997 | 10.97 | 0.02 |
| 1 | 11.00 | 0.997 | 10.97 | 0.02 |
| 37 | 11.00 | 0.989 | 10.88 | 0.16 |
| 36 | 11.00 | 0.988 | 10.87 | 0.18 |
| 35 | 11.00 | 0.988 | 10.87 | 0.19 |
| 30/31 | 11.00 | 0.986 | 10.85 | 0.26 |
| 29 | 11.00 | 0.986 | 10.84 | 0.28 |
| 3/4(1) | 11.00 | 0.990 | 10.89 | 0.10 |
| 8 | 11.00 | 0.989 | 10.87 | 0.14 |
| 10 | 11.00 | 0.988 | 10.86 | 0.18 |
| 11 | 11.00 | 0.986 | 10.85 | 0.22 |
| 1(1) | 11.00 | 0.996 | 10.96 | 0.03 |
| 17 | 11.00 | 0.987 | 10.86 | 0.14 |
| 18 | 11.00 | 0.986 | 10.85 | 0.14 |
| 19/20 | 11.00 | 0.976 | 10.74 | 0.14 |

drops (Acceptable limit: less than 5%) at different node of the system is as shown in Figure 4.6.

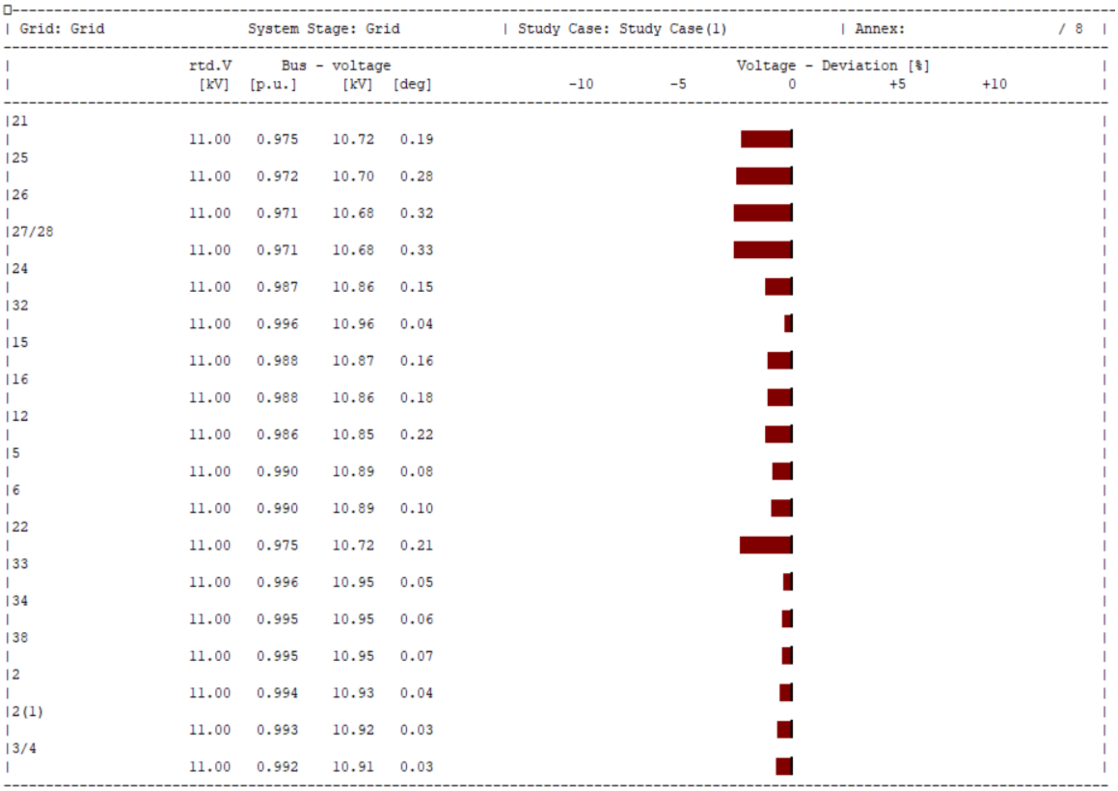



Figure 4.6 Node Voltage Deviation in Designed Underground Distribution System

By choosing three core XLPE cable, 25 square mm conductor as initial conductor with the figure 4.6 Constraints. The recommended cable for the underground distribution obtained from the cable sizing run in DIgSILENT PowerFactory is shown in table 4.5.

Table 4.5 Recommendation of cable by DIgSILENT PowerFactory for UGDS

| Name of Conductor | Area, Square mm | Required Length, m |
|---|---|---|
| **3 C-XLPE** | 25 | 6307 |
| **3 C-XLPE** | 50 | 990 |
| **3 C-XLPE** | 70 | 576 |

| Name of Conductor | Area, Square mm | Required Length, m |
|---|---|---|
| **3 C-XLPE** | 185 | 1165 |
| **3 C-XLPE** | 240 | 198 |
| **3 C-XLPE** | 400 | 215 |
| **Total Length** | | **9451** |

### 4.5 Reliability Evaluation of RBTS 2 Bus Network

The IEEE Application of Probability Methods (APM) Subcommittee published a Reliability Test System (RTS) in 1979(Albrecht, et al., 1979). This has proved to be a appreciated and consistent reference source for comparing alternative methods and computer programs. It has been used widely in reliability calculation of generation by the universities, consultants and utilities (Allan, et al., 1991). RBTS Bus 2 and Bus 4 are used as test systems because they were created for educational purposes and all reliability data of components are informed. This case study is used to verify the correctness of reliability assessment tool(Suthapanun, 2015).

Table 4.6 shows the standard RBTS 2 bus system data used in simulation for the validation of DIgSILENT PowerFactory.

Table 4.6 Standard RBTS 2 Bus System Data(Allan, and R. N., 1991)

| Load points RBTS | Average (MW) Load (Mw) | Peak Load (MW) (Mw) | Customer (N) |
|---|---|---|---|
| 1,2,3,10,11 | 0.535 | 0.8668 | 210 |
| 12,17,18,19 | 0.45 | 0.7291 | 200 |
| 8 | 1 | 1.6279 | 1 |
| 9 | 1.15 | 1.8721 | 1 |
| 4,5,13,14,20,21 | 0.566 | 0.9167 | 1 |
| 6,7,15,16,22 | 0.454 | 0.75 | 10 |

| Length of the feeder Section | |
|---|---|
| Length (km) | Feeder Section |
| 0.6 | 2,6,10,14,17,21,25,28,30,34 |
| 0.75 | 1,4,7,9,12,16,19,22,24,27,29,32,35 |
| 0.8 | 3,5,8,11,13,15,18,20,23,26,31,33,36 |

| **Failure Rate Component of RBTS 2- Bus System** | | | |
|---|---|---|---|
| **RBTS Equipment** | **Failure rates (1/a)** | **Replacement time (Hour)** | **Repair time (Hour)** |
| Transformer (33/11) kV | 0.15 | 15 | |
| Transformer (11/0.415) kV | 0.15 | 10 | 200 |
| Busbar (33 kV) | 0.001 | 2 | |
| Busbar (11 kV) | 0.001 | 2 | |
| Cable | 0.04 | | 30 |
| Circuit breakers (33 kV) | 0.002 | 4 | |
| Circuit breakers (11kV) | 0.006 | 4 | |

Figure 4.7 shows the Simulation of RBTS 2 bus system in DIgSILENT PowerFactory, the results have been discussed in the succeeding sections of this report.

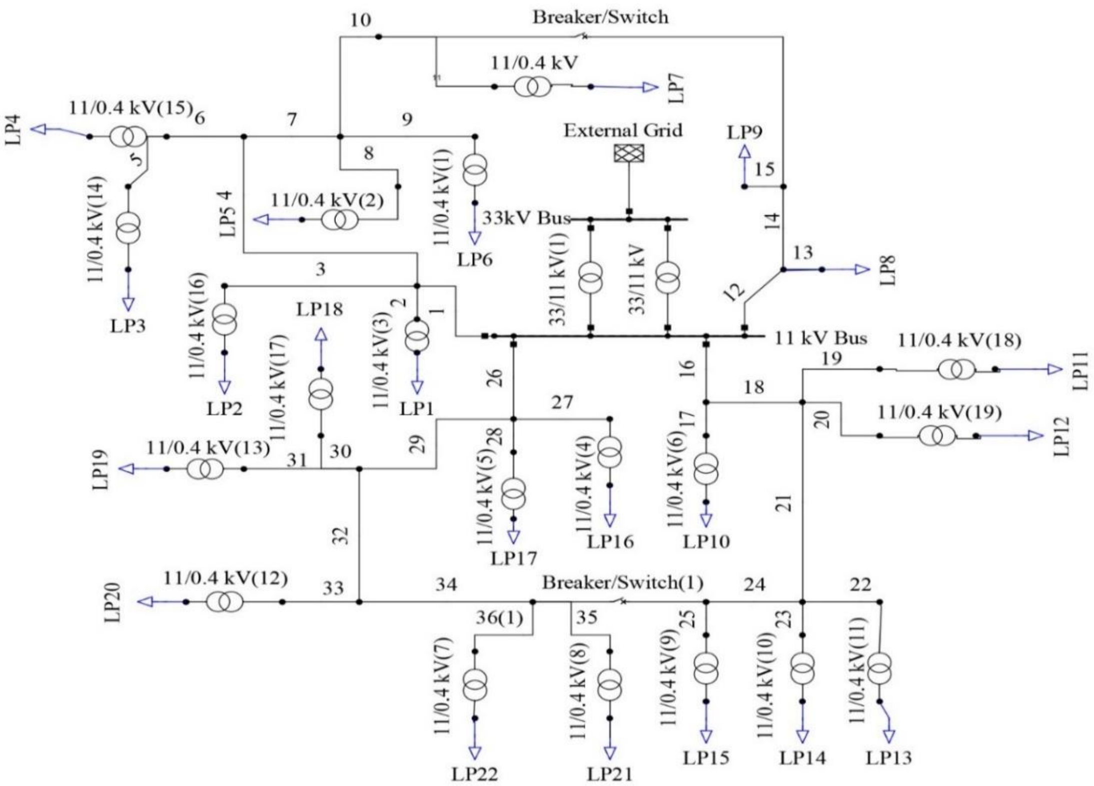



Figure 4.7 Simulation of RBTS 2 Bus System in DIgSILENT PowerFactory

Table 4.7 shows the comparison of reliability indices obtained from simulation in DIgSILENT PowerFactory and standard IEEE results. Here, IEEE values are considered as standard and percentage deviation in results with respect to standard values is calculated. The highest deviation is seen in the value of SAIDI which is -0.516%. As the obtained maximum deviation is within acceptable limit (<5%), the paper results of reliability indices are compiled to the DIgSILENT PowerFactory results.

Table 4.7 Result comparisons of RBTS Bus 2 and DIgSILENT PowerFactory

| **Reliability Indices** | **Paper Result** | **Simulation Result** | **% Deviation from Standard** |
|---|---|---|---|
| SAIFI (1/ca) | 0.409 | 0.41111 | **-0.516** |
| SAIDI (h/ca) | 29.26 | 29.264 | -0.014 |
| CAIDI (h) | 71.52 | 71.183 | 0.471 |
| ASAI | 0.99666 | 0.996659368 | 0.000 |

| Reliability Indices | Paper Result | Simulation Result | % Deviation from Standard |
|---|---|---|---|
| ASUI | 0.00334 | 0.003340632 | -0.019 |
| ENS (MWh/a) | 305626 | 305675 | -0.016 |
| AENS (MWh/ca) | 160.2 | 160 | 0.125 |
| **Maximum Deviation %** | | | **-0.516** |

### 4.6 Reliability Evaluation of Existing Koteshwor Feeder

Figure 4.8: Equivalent Single line diagram for existing overhead feeder simulated in DIgSILENT PowerFactory

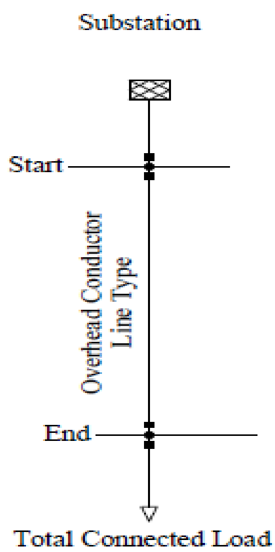



Figure 4.8 Simulation of Equivalent OH Feeder in DIgSILENT PowerFactory

Customer based reliability indices how often each customer connected to the system faces sustained power interruption and duration of each interruption. The calculations considering sustained outage only. In all the calculations mentioned below interruptions caused to the customers due to grid failure is not included. SAIFI SAIDI and CAIDI are the most important reliability indices in distribution system.

Interruptions that last not more than 5 minutes are called momentary interruption. Since these interruptions are not sustained, they are not considered to evaluate reliability indices like SAIFI, SAIDI, and CAIDI etc. Momentary interruption is only used to calculate MAIFI.

By using failure rate of Koteshwor feeder as shown in table 4.8 and After running the reliability assessment of existing overhead line following results were obtained from DIgSILENT PowerFactory as shown in table 4.9.

Table 4.8 Real Time Failure Rate and Repair Duration of Koteshwor Feeder

| | **Total Number of Fault** | **Total Repair Time** |
|---|---|---|
| 2075 B.S. (1) | 52 | 48:12 |
| 2074 B.S. (2) | 48 | 48:09 |
| **Average (3) = ((1) +(2))/2** | 50 | 48:10 |
| Average failure per annum (4) | | 50 |
| Average Fault Clearing Time in Hour per annum (5) | | 48:10 |
| Length of the Feeder in km (6) | | 9.452 |
| **Failure Rate Per Year Per km Per Annum (6) = (4)/ (6)** | | 5.29 |
| **Repair Duration Per Failure (7) = (5)/ (4)** | | 0.963 |

The Detailed failure rate sheet is attached in ANNEXURE B

Table 4.9 Reliability Indices of Existing Overhead Line

| Reliability Indices | Index | Value | Unit |
|---|---|---|---|
| System Average Interruption Frequency Index | SAIFI | **49.99** | 1/Ca |
| System Average Interruption Duration Index | SAIDI | **48.156** | h/Ca |
| Customer Average Interruption Duration Index | CAIDI | 0.963 | h/Ca |
| Average Service Availability Index | ASAI | 0.9945 | |
| Average Service Unavailability Index | ASUI | 0.005497 | |
| Energy Not Supplied | ENS | **329.38** | MWh/a |
| Average Energy Not Supplied | AENS | 0.042 | MWh/Ca |
| Average Customer Curtailment Index | ACCI | 0.042 | MWh/Ca |
| Average System Interruption Frequency Index | ASIFI | 49.99 | 1/a |
| Average System Interruption Duration Index | ASIDI | 48.155 | h/a |

In the year 2074, discussing Koteshwor feeder, each customer connected to Koteshwor feeder suffered 49.99 per annum outages for the total duration of 48.156 hour per annum and average interruption duration per outage was 0.963 hours per annum. And energy not supplied is 329.38 MWh per annum.

The result shows that energy not served due to failure of Feeder is 329.38 MWh/a. which means in one year 329380 unit is not supplied from feeder to the one customer in one year.

## 4.7 Reliability Evaluation of Designed Underground Feeder

By using IEEE historical data shown in table 4.10, the simulation of underground distribution system was done.

Table 4.10 IEEE Historical Data for Distribution System

| Equipment/Rate | Failure Rate | Repair Time/Replacement Time (Hour) |
|---|---|---|
| Transformer (Per Year) | 0.0041 | 73.4 |
| Cable (Per km Per Year) | 0.0291617 | 27.2 |
| Cable Joint/Terminator (Per Year) | 0.000307 | 30.2 |
| Conductor (Per km Per Year) | 0.062008 | 4.6 |
| Conductor Joint/Terminator (Per Year) | 0.001848 | 15.3 |

Figure 4.9 shows Single line diagram of Koteshwor feeder simulated in DIgSILENT PowerFactory.

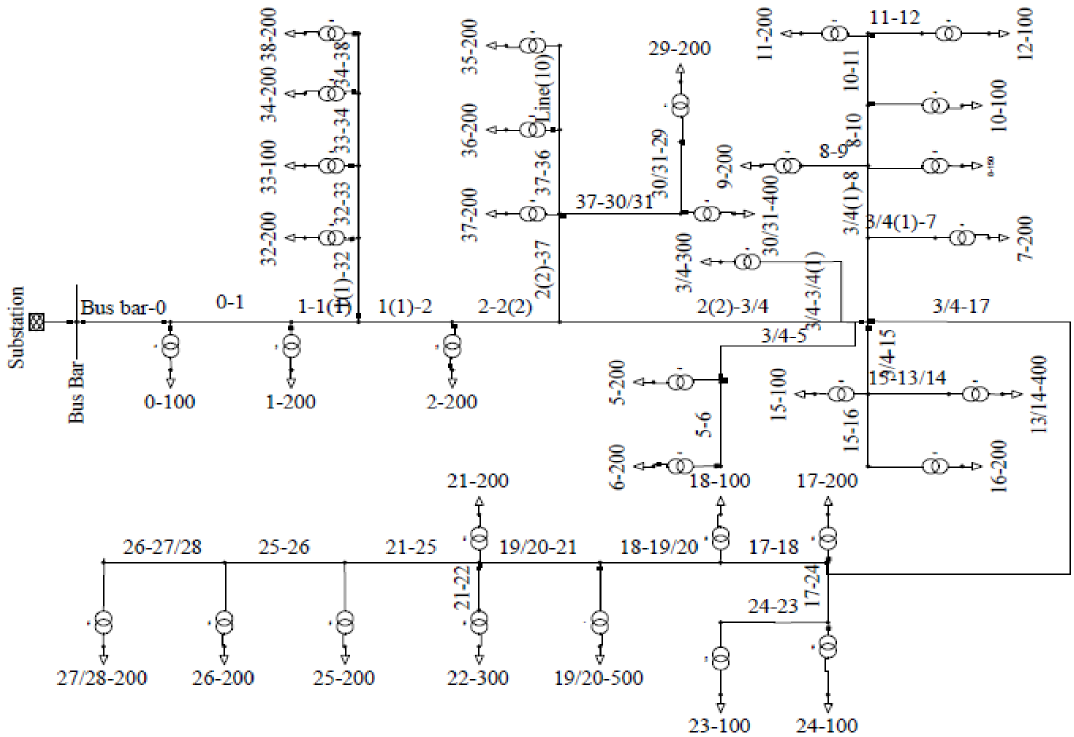



Figure 4.9 Simulation of Koteshwor feeder in DIgSILENT PowerFactory

After running the reliability assessment of underground line following results were obtained from DIgSILENT PowerFactory as shown in table 4.11.

Table 4.11 Reliability Indices of Designed UGDS

| **Reliability Indices** | **Index** | **Value** | **Unit** |
|---|---|---|---|
| System Average Interruption Frequency Index | SAIFI | **0.337** | 1/Ca |
| System Average Interruption Duration Index | SAIDI | **11.98** | h/Ca |
| Customer Average Interruption Duration Index | CAIDI | 35.554 | h/Ca |
| Average Service Availability Index | ASAI | 0.988632 | |
| Average Service Unavailability Index | ASUI | 0.00136793 | |
| Energy Not Supplied | ENS | **65.919** | MWh/a |
| Average Energy Not Supplied | AENS | 0.009 | MWh/Ca |
| Average Customer Curtailment Index | ACCI | 0.026 | MWh/Ca |
| Average System Interruption Frequency Index | ASIFI | 0.337035 | 1/a |
| Average System Interruption Duration Index | ASIDI | 11.9852 | h/a |

The result shows that energy not served due to failure of feeder is 65.919 MWh/a., which means in one year 65919 unit is not supplied from feeder to the one customer in one year. After running the reliability assessment of overhead line following results were obtained from DIgSILENT PowerFactory as shown in table 4.12

Table 4.12 Reliability indices of designed OHDS

| Reliability Indices | Index | Value | Unit |
|---|---|---|---|
| System Average Interruption Frequency Index | SAIFI | **0.674055** | 1/Ca |
| System Average Interruption Duration Index | SAIDI | **7.846** | h/Ca |
| Customer Average Interruption Duration Index | CAIDI | 11.64 | h/Ca |
| Average Service Availability Index | ASAI | 0.9991043 | |
| Average Service Unavailability Index | ASUI | 0.0009856 | |
| Energy Not Supplied | ENS | **43.16** | MWh/a |
| Average Energy Not Supplied | AENS | 0.006 | MWh/Ca |
| Average Customer Curtailment Index | ACCI | 0.009 | MWh/Ca |
| Average System Interruption Frequency Index | ASIFI | 0.673986 | 1/a |
| Average System Interruption Duration Index | ASIDI | 7.848761 | h/a |

The result shows that energy not served due to failure of substation equipment is 43.16 MWh/a., which means in one year 43160 unit is not supplied from feeder to the one customer in one year.

### 4.8 Comparison of Reliability Indices

The SAIFI value of overhead distribution system is higher than the underground distribution system as shown in table 4.13. This indicates that the reliability of the underground distribution system is quite higher but due to high repair duration of the underground system SAIDI is higher for the underground distribution system. Similarly, the energy not supplied to the costumer is higher for underground distribution system as repair duration is higher for the underground distribution system.

As we see the reliability indices of the existing overhead line, there is very high value of SAIFI, SAIDI ENS as compared to designed distributions system. This indicate that how much unreliable that poor quality of energy is supplied by the Koteshwor feeder to the customers.

Table 4.13 Comparison of Reliability Indices of OH, UG and Existing OHDS

| **Reliability Indices** | **Index** | **Unit** | **Designed OH** | **Designed UG** | **Existing OH** |
|---|---|---|---|---|---|
| System Average Interruption Frequency Index | SAIFI | 1/Ca | **0.674055** | **0.337** | **49.99** |
| System Average Interruption Duration Index | SAIDI | h/Ca | **7.846** | **11.98** | **48.156** |
| Customer Average Interruption Duration Index | CAIDI | h/Ca | 11.64 | 35.554 | 0.963 |
| Average Service Availability Index | ASAI | | 0.9991043 | 0.988632 | 0.9945 |
| Average Service Unavailability Index | ASUI | | 0.0009856 | 0.00136793 | 0.005497 |
| Energy Not Supplied | ENS | MWh/a | **43.16** | **65.919** | **329.38** |
| Average Energy Not Supplied | AENS | MWh/Ca | 0.006 | 0.009 | 0.042 |
| Average Customer Curtailment Index | ACCI | MWh/Ca | 0.009 | 0.026 | 0.042 |
| Average System Interruption Frequency Index | ASIFI | 1/a | 0.673986 | 0.337035 | 49.99 |
| Average System Interruption Duration Index | ASIDI | h/a | 7.848761 | 11.9852 | 48.155 |

### 4.9 Financial Analysis

#### 4.9.1 Cost Estimate of Overhead Distribution System

All the unit costs has been taken from NEA for reference. The material cost estimation for designed overhead distribution system is as shown in table 4.14.

Table 4.14 Material Cost of the Designed OHDS

| **Materials Cost Estimate of Designed OHDS Koteshwor Feeder** | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Description** | **Unit** | **Qty** | **Rate NRs.** | **Amount NRs.** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| **1** | **Supply of pole complete set with accessories** | | | | | |
| 1.1 | 11 m. Steel Tubular Poles with fittings and accessories complete (single arm structure) | Nos. | 113 | 23,324.83 | 2,635,705.79 | NEA |
| 1.2 | 11 m steel tubular pole intermediate support structure complete (Double Dead-End Structure) | Nos. | 22 | 33,521.66 | 737,476.52 | |
| 1.3 | 11 m. Steel Tubular Pole (H structure) complete | Nos. | 45 | 64,674.98 | 2,910,374.21 | |
| **2** | **Supply of conductor complete set with accessories** | | | | | |
| 2.1 | All Required ACSR Type Conductor with all accessories complete (for 11 kV) | Lot | 1.00 | 630,588.89 | 630,588.89 | NEA |
| **3** | **Supply of Stay Set Complete with Accessories** | | | | | |
| 3.1 | Single Stay set with all accessories complete for HT Steel Tubular Pole - Type A | Set | 72 | 2,241.50 | 161,388.00 | NEA |
| **Total Material Cost** | | | | | **7,075,533.41** | |

The labor cost estimation for designed overhead distribution system is as shown in table 4.15.

Table 4.15 Labor Cost of the Designed OHDS

| **Labor Cost Estimate of Designed OHDS Koteshwor Feeder** | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Description** | **Unit** | **Qty** | **Rate NRs.** | **Amount NRs.** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| **2** | **Erection of pole with accessories** | | | | | |
| 2.1 | 11 m. Steel Tubular Pole with fittings and accessories complete (single arm structure) | Nos. | 113 | 5,516.84 | 623,402.64 | NEA |
| 2.2 | 11 m steel tubular pole intermediate support structure complete (Double Dead-End Structure) | Nos. | 22 | 5,516.84 | 121,370.43 | |
| 2.3 | 11 m. Steel Tubular Pole (H structure) complete as per drawing and specifications | Nos. | 45 | 1,033.68 | 96,515.38 | |
| **3** | **Stringing of ACSR conductor with accessories** | | | | | |
| 3.1 | ACSR Conductor with all accessories complete as per drawing and specifications (for 11 kV) | km | 9.40 | 67,704.34 | 636,420.81 | NEA |
| **4** | **Installation of stay set with accessories** | | | | | |
| 4.1 | Single Stay set with all accessories complete as per drawing and specifications for HT Steel Tubular Pole - Type A | Set | 72 | 2,305.28 | 165,980.05 | NEA |
| **Total** | | | | | **2,043,689.29** | |

The total cost estimation with 5% contingency and 13% VAT for designed overhead distribution system is as shown in table 4.16.

Table 4.16 Total Cost Estimate of the Designed OHDS

| **Total of Cost Estimate of Designed OHDS Koteshwor Feeder** | | |
|---|---|---|
| **Cost Estimate NRs.** | | |
| Materials Cost | (1) | 7,075,533.00 |
| Labor Cost | (2) | 2,043,689.00 |
| Total Cost Estimate | (3) = (1) +(2) | 9,119,223.00 |
| Contingency 5 % | (4) = 5% of (3) | 455,961.00 |
| Total with Contingency | (5) = (3) + (4) | 9,575,183.84 |
| VAT @ 13 % | (6) = 13% of (5) | 1,244,773.90 |
| **Grand Total Cost Save** | **(7) = (5) + (6)** | **10,819,957.74** |

### 4.9.2 Cost Estimate of Underground Distribution System

The all the unit rate is taken from KEI industries Co. Ltd. quoted for the NEA underground project. The material cost estimate for designed underground system is shown table 4.17

Table 4.17 Material cost of the designed UHDS

| **Material Cost of Designed UHDS Koteshwor Feeder** | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Item description** | **Estimated** | | **Unit Rate** | **Amount** | **Source** |
| | | **Unit** | **Quantity** | | | |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| 1 | HT Cables along with Straight Jointing Kit, O/D & I/D Termination Kit and other accessories | | | | | Average Unit Rate of KEI Industries Co. |
| | 3/C 25 mm2 11 kV XLPE Armored cable | km | 6.31 | 267100.86 | 1684605.14 | |

| Material Cost of Designed UHDS Koteshwor Feeder | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Item description** | **Estimated** | | **Unit Rate** | **Amount** | **Source** |
| | | **Unit** | **Quantity** | | | |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| | 3/C 50 mm2 11 kV XLPE Armoured cable | km | 0.99 | 534201.72 | 528859.71 | |
| | 3/C 70 mm2 11 kV XLPE Armoured cable | km | 0.58 | 747882.41 | 430780.27 | |
| | 3/C 185 mm2 11 kV XLPE Armoured cable | km | 1.17 | 1976546.38 | 2302676.53 | |
| | 3/C 240 mm2 11 kV XLPE Armoured cable | km | 0.20 | 2564168.27 | 507705.32 | |
| | 3/C 400 mm2 11 kV XLPE Armoured cable | km | 0.22 | 4273613.79 | 918826.96 | |
| 2 | HDPE Pipe | | | | | |
| | 90 mm Diameter | km | 6.31 | 453301.11 | 2858970.12 | |
| | 90 mm Diameter | km | 0.99 | 453301.11 | 448768.10 | |
| | 110 mm Diameter | km | 0.58 | 554034.69 | 319123.98 | |
| | 125 mm Diameter | km | 1.17 | 629584.88 | 733466.38 | |
| | 140 mm Diameter | km | 0.20 | 705135.07 | 139616.74 | |
| | 160 mm Diameter | km | 0.22 | 807732.22 | 173662.43 | |
| 3 | Joint | | | | | |
| | HT Cable RCC Route Marker and | Lump Sum | 1 | 5987.85 | 5987.85 | |

| Material Cost of Designed UHDS Koteshwor Feeder | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Item description** | **Estimated** | | **Unit Rate** | **Amount** | **Source** |
| | | **Unit** | **Quantity** | | | |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| | Straight Joint marker | | | | | |
| **Total** | | | | | **11053050** | |

The installation cost estimate for designed underground system is shown table 4.18.

Table 4.18 Installation Cost of the Designed UHDS

| Installation Cost of Designed UHDS Koteshwor Feeder | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Item Description** | **Unit** | **Quantity** | **Unit Rate** | **Total Charges** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| 1 | HT Cables along with Straight Jointing Kit, O/D & I/D Termination Kit and other accessories | | | | | |
| | 3/C 25 mm2 11 kV XLPE Armoured cable | km | 6.31 | 16011.03 | 100981.57 | Average Unit Rate from KEI |
| | 3/C 50 mm2 11 kV XLPE Armoured cable | km | 0.99 | 32022.06 | 31701.84 | |
| | 3/C 70 mm2 11 kV XLPE Armoured cable | km | 0.58 | 44830.88 | 25822.59 | |
| | 3/C 185 mm2 11 kV XLPE Armoured cable | km | 1.17 | 118481.63 | 138031.10 | |

| Installation Cost of Designed UHDS Koteshwor Feeder | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Item Description** | **Unit** | **Quantity** | **Unit Rate** | **Total Charges** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| | 3/C 240 mm2 11 kV XLPE Armoured cable | km | 0.20 | 153705.89 | 30433.77 | Average Unit Rate from KEI |
| | 3/C 400 mm2 11 kV XLPE Armoured cable | km | 0.22 | 256176.49 | 55077.95 | |
| 2 | HDPE Pipe | | | | | |
| | 90 mm Diameter | km | 6.31 | 34209.39 | 215758.66 | |
| | 90 mm Diameter | km | 0.99 | 34209.39 | 33867.30 | |
| | 110 mm Diameter | km | 0.58 | 41811.48 | 24083.41 | |
| | 125 mm Diameter | km | 1.165 | 47513.05 | 55352.70 | |
| | 140 mm Diameter | km | 0.20 | 53214.61 | 10536.49 | |
| | 160 mm Diameter | km | 0.22 | 60816.70 | 13075.59 | |
| 3 | Excavation in all types of soil and rock including backfilling disposal etc. for all leads and lifts | Cubic Meter | 1516.05 | 363.09 | 550464.90 | |
| 4 | Black topping as per TS of Road Department and/or Kathmandu Municipality | Cubic Meter | 2738.02 | 1270.80 | 3479486.20 | Average Unit Rate from KEI |
| 5 | Miscellaneous Structural edge protection angles for cable trenches | Metric Tone | 0.13 | 125264.26 | 15878.57 | |

| Installation Cost of Designed UHDS Koteshwor Feeder | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Item Description** | **Unit** | **Quantity** | **Unit Rate** | **Total Charges** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| 6 | Local Sand filling around and under Foundation and for backfilling of cable and pit as applicable. | Cubic Meter | 456.33 | 2677.74 | 1221954.59 | Average Unit Rate from KEI |
| 7 | Trenchless laying of Cable using HDD method with HDPE pipe | | | | | |
| | 90 mm Diameter | km | 6.307 | 442781.91 | 2792625.53 | |
| | 90 mm Diameter | km | 0.99 | 442781.91 | 438354.09 | |
| | 110 mm Diameter | km | 0.576 | 541177.89 | 311718.47 | |
| | 125 mm Diameter | km | 1.165 | 614974.88 | 716445.74 | |
| | 140 mm Diameter | km | 0.198 | 688771.86 | 136376.83 | |
| | 160 mm Diameter | km | 0.215 | 787167.84 | 169241.09 | |
| **Total** | | | | | **10591352** | |

The Total cost estimate for designed underground system is shown table 4.19

Table 4.19 Total Cost Estimation of the Designed UHDS

| Total of Cost Estimate of Designed UHDS Koteshwor Feeder | | |
|---|---|---|
| **Cost Estimate NRs.** | | |
| Materials Cost | (1) | 11,053,050.00 |
| Installation Cost | (2) | 10,591,352.00 |
| Total Cost Estimate | (3) = (1) +(2) | 21,644,402.00 |
| Contingency 5 % | (4) = 5% of (3) | 1,082,220.00 |
| Total with Contingency | (5) = (3) + (4) | 22,726,622.00 |
| VAT @ 13 % | (6) = 13% of (5) | 2,954,461.00 |
| **Grand Total Cost Save (NRs)** | **(7) = (5) + (6)** | **25,681,083.00** |

### 4.9.3 Dismantling Cost Estimate

After dismantling of existing overhead distribution system conductor, poles, insulator etc. can be saved by taking tentative depreciation value on it. The useful material obtained from the dismantling of existing distribution is listed and cost save from the dismantling is obtained by using NEA unit rate. The material cost saves after dismantling of existing overhead distribution system is as shown in table 4.20.

Table 4.20 Material Cost Save from Dismantle of Existing OHDS

| **Materials Cost Save from Dismantle of Koteshwor Feeder** | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Description** | **Unit** | **Qty** | **Rate NRs.** | **Amount NRs.** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| **1** | **Pole complete set with accessories** | | | | | NEA |
| 1.1 | 11 m. Steel Tubular Poles with fittings and accessories complete (single arm structure) | Nos. | 113 | 54,494.72 | 6,157,903.13 | |
| 1.2 | 11 m steel tubular pole intermediate support structure complete (Double Dead-End Structure) | Nos. | 22 | 15,851.20 | 348,726.31 | |
| 1.3 | 11 m. Steel Tubular Pole (H structure) complete | Nos. | 15 | 37,810.19 | 567,152.84 | |
| **2** | **Conductor complete set with accessories** | | | | | |
| 2.1 | ACSR Conductor with all accessories complete | km | 9.40 | 227,389.91 | 2,137,465.15 | |
| **3** | **Stay Set Complete with Accessories** | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3.1 | Single Stay set with all accessories complete and HT Steel Tubular Pole | Set | 60 | 1,699.50 | 101,970.00 | |
| **Total Material Cost** | | | | | **9,313,217.44** | |

The labor cost investment required for dismantling of existing overhead distribution system is as shown in table 4.21.

Table 4.21 Labor Cost Expenditure in Dismantle of Existing OHDS

| **Labor Cost Expenditure for Dismantle of Koteshwor Feeder** | | | | | | |
|---|---|---|---|---|---|---|
| **S. No.** | **Description** | **Unit** | **Quantity** | **Rate NRs.** | **Amount NRs.** | **Source** |
| **(1)** | **(2)** | **(3)** | **(4)** | **(5)** | **(6) = (4) *(5)** | **(7)** |
| **1** | **Pole with accessories** | | | | | |
| 1.1 | 11 m. Steel Tubular Pole with fittings and accessories complete (single arm structure) | Nos. | 113 | 1,518.58 | 171,598.98 | NEA |
| 1.2 | 11 m steel tubular pole intermediate support structure complete (Double Dead-End Structure) | Nos. | 22 | 1,518.58 | 33,408.65 | |
| 1.3 | 11 m. Steel Tubular Pole (H structure) complete | Nos. | 15 | 3,037.15 | 45,557.25 | |
| **2** | **ACSR conductor with accessories** | | | | | |
| 2.1 | ACSR Conductor with all accessories complete (for 11 kV) | km | 9.40 | 17,092.36 | 160,668.17 | |
| **Total** | | | | | **411,233.04** | |

The total cost save from dismantling of existing overhead distribution system is as shown in table 4.22.

Table 4.22 Total Cost Save from Dismantle of Existing OHDS

| **Total of Cost Save from Dismantle of Koteshwor Feeder** | | |
|---|---|---|
| **Cost Estimate NRs.** | | |
| Materials Cost Save | (1) | 9,313,217.00 |
| Labor Cost Expenditure | (2) | 411,233.00 |
| Total Cost Save | (3) = (1) - (2) | 8,901,984.00 |
| Contingency 5 % | (4) = 5% of (3) | 445,099.00 |
| Total with Contingency | (5) = (3) - (4) | 8,456,885.18 |
| VAT @ 13 % | (6) = 13% of (5) | 1,099,395.07 |
| **Grand Total Cost Save** | **(7) = (5) + (6)** | **9,556,280.25** |

### 4.9.4 Investment Decision

After the calculation of total cost required for replacement of existing overhead distribution system by underground distribution system, the investment decision is checked by Energy Not Served (ENS) value of underground and existing overhead distribution system as shown in table 4.23.

Table 4.23 Energy save cost and cost required for replacement

| **Cost Save From Reliability Analysis** | | | |
|---|---|---|---|
| ENS of the UGDS | (1) | 65.919 | MWh/a |
| ENS of Existing OHDG | (2) | 329.38 | MWh/a |
| Save Due to ENS per Annum | (3) = (2)-(1) | 263.461 | MWh/a |
| At NRs 13 Per Unit Flat Tariff Rate, Revenue Saved | (4) = (3) *13*1000 | **3424993** | Source: NEA |
| **Cost Required from Technical Design Analysis** | | | |
| Cost of the UGDS | (5) | 25681082.89 | NRs |
| Dismantle Cost Save from Existing OHDS | (6) | 9,556,280.25 | NRs |
| Extra Cost Required for Replacement | (7) = (5)-(6) | **16,124,802.63** | NRs |

By taking 25-year useful life of the underground distribution system and at 10 % MARR rate B/C ratio is calculated as shown in table 4.24

Table 4.24 B/C Ratio for Investment

| **Taking life of 25 years** | |
|---|---|
| Initial investment, NRs | 16124802.63 |
| Useful life (year) | 25 |
| MARR 10% | 0.1 |
| Annual revenue saved, NRs | 3424993 |
| (PW) Benefit NRs | 31088798.52 |
| B/C ratio | **1.93** |
| PW (10%), of cash flow, NRs | 14963995.89 |

As B/C ratio is greater than one, the investment is accepted (For replacement of existing overhead distribution system feeders). Also, present wroth of cash flow is positive, the investment cab be done.

The returned of the investment is calculated as shown in table 4.25

Table 4.25 Payback Periods of Investment

| **Discounted Payback Period** | | | |
|---|---|---|---|
| **Year** | **Cash Flow** | **PW of Net Cash Flow** | **Cumulative Cash Flow (NRs)** |
| 0 | -16124803 | -16124803 | -16124803 |
| 1 | 3424993 | 3113630 | -13011173 |
| 2 | 3424993 | 2830573 | -10180600 |
| 3 | 3424993 | 2573248 | -7607352 |
| 4 | 3424993 | 2339316 | -5268036 |
| 5 | 3424993 | 2126651 | -3141384 |
| **6** | **3424993** | **1933319** | **-1208065** |
| **7** | **3424993** | **1757563** | **549498** |

| Discounted Payback Period | | | |
|---|---|---|---|
| **Year** | **Cash Flow** | **PW of Net Cash Flow** | **Cumulative Cash Flow (NRs)** |
| 8 | 3424993 | 1597785 | 2147282 |
| 9 | 3424993 | 1452531 | 3599814 |
| 10 | 3424993 | 1320483 | 4920297 |

The cumulative cash flow is positive between 6$^{th}$ and 7$^{th}$ year. Hence, the payback period lies between 6$^{th}$ and 7$^{th}$ year. That is after 7$^{th}$ year of replacement of the existing overhead feeder of Koteshwor by underground distribution system investment cab be payback.

Further, the cost of the designed underground distribution system is 2.37 times higher than designed overhead distribution system.

# CHAPTER FIVE: CONCLUSIONS

In the existing Koteshwor feeder all conductor used in ACSR Dog conductor having cross-section area 100 mm square. But after designing of overhead feeder, it shows there are many branches where Magpie conductor of cross section area 12.8 mm square to Pawpaw conductor having cross-section 584 mm square is required if 5% voltage drop and 100% thermal limit is considered. Similarly, In the underground distribution system design required cable is from three core XLPE cable of 25 mm square to 400 mm square is required.

After evaluation of the reliability indices of the existing overhead system shows that SAIFI value is 49.99 per annum which is very high as compared to designed distribution system which is 0.674 for designed overhead distribution system and 0.337 for designed underground distribution system. Also, the energy not supplied (ENS) value of existing system is almost four-time higher value as compared to designed overhead distribution system. And three times as compared to designed underground distribution system. Thus, revenue is saved from underground distribution system. The value SAIF is lower for the underground distribution system but higher value of SAIDI and CAID indicates that the interruption duration in underground distribution system is higher this is because the fault clearing time required in underground distribution system is more than overhead distribution system.

The Cost of the underground distribution system is almost 2.37 time higher than overhead distribution system. By investing NRs. 411,233.04 in the labor expenditure total NRs. 9,556,280.25 useful material is saved from dismantling of existing overhead distribution system. Also, NRs. 3,424,993.00 revenue per annum is saved because of lower ENS value of designed underground system. Thus, considering these cost B/C ratio, Present Worth calculation implies to invest in replacement of existing overhead distribution system by underground distribution system and finally which is pay backed after 6 to 7 year of replacement.

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## ANNEXURE A: ACSR CONDUCTOR

| Code Name | Equivalent Aluminum Cross Sectional Area (mm2) | Calculated DC Resistance at 20⁰C (Ohm/km) | Reactance at 50Hz with 300 mm Spacing (Ohm/km) | Current Rating Still Air (Amps) |
|---|---|---|---|---|
| **Magpie** | 12.7 | 2.23 | 0.349 | 59 |
| **Squirrel** | 20.7 | 1.37 | 0.322 | 75 |
| **Gopher** | 26 | 1.09 | 0.315 | 86 |
| **Ferret** | 41.8 | 0.677 | 0.299 | 117 |
| **Mink** | 62.2 | 0.455 | 0.287 | 152 |
| **Raccoon** | 77.7 | 0.364 | 0.28 | 175 |
| **Dog** | 103 | 0.274 | 0.271 | 210 |
| **Dingo** | 155 | 0.182 | 0.257 | 274 |
| **Wolf** | 155 | 0.183 | 0.252 | 280 |
| **Jaguar** | 207 | 0.137 | 0.248 | 336 |
| **Goat** | 317 | 0.0893 | 0.229 | 462 |
| **Zebra** | 420 | 0.0674 | 0.222 | 544 |
| **Cardinal** | 474 | 0.0597 | 0.219 | 590 |
| **Moose** | 517 | 0.0547 | 0.216 | 626 |
| **Pawpaw** | 584 | 0.0485 | 0.212 | 678 |

## ANNEXURE B: FAILURE DATA OF EXISTING KOTESHWOR FEEDER

| 2074 B.S. | | | | |
|---|---|---|---|---|
| **Month** | **Start Time** | **End Time** | **Reason** | **Sustain Time** |
| **Baishakh** | 18:52 | 19:17 | Line Repair | 0:25 |
| | 20:20 | 20:37 | Jumper | 0:17 |
| | 7:48 | 8:16 | Jumper | 0:28 |
| | 17:05 | 17:48 | Line Repair | 0:43 |
| | 17:29 | 18:20 | Transformer fire | 0:51 |
| | 17:10 | 17:35 | Jumper | 0:25 |
| | 8:12 | 8:47 | Jumper | 0:35 |
| **Jesth** | 13:35 | 14:51 | Line Check | 1:16 |
| **Ashar** | 4:30 | 5:25 | Transformer fire | 0:55 |
| | 14:40 | 15:25 | Transformer | 0:45 |
| | 5:40 | 9:41 | Transformer FIre | 4:01 |
| | 14:47 | 15:07 | Transformer Repair | 0:20 |
| | 17:02 | 17:37 | Cable Repair | 0:35 |
| **Shrawan** | 11:03 | 14:32 | Line Check | 3:29 |
| | 10:52 | 13:15 | Transformer | 2:23 |
| | 8:15 | 8:36 | Jumper | 0:21 |
| | 20:30 | 21:55 | Jumper | 1:25 |
| **Bhadra** | 10:15 | 10:30 | DO Change | 0:15 |
| | 13:10 | 13:58 | Line Repair | 0:48 |
| | 17:10 | 17:42 | Line Repair | 0:32 |
| | 12:08 | 14:08 | Jumper | 2:00 |
| **Ashoj** | 13:50 | 16:02 | Transformer Repair | 2:12 |
| | 16:05 | 17:22 | Big Jurk and Trip | 1:17 |
| | 10:34 | 12:35 | Line Repair | 2:01 |
| | 11:53 | 12:20 | Jumper | 0:27 |
| | 16:06 | 16:32 | DO Change | 0:26 |
| **Kartik** | 20:05 | 21:24 | Transformer | 1:19 |
| | 15:12 | 15:30 | Jumper | 0:18 |

| 2074 B.S. | | | | |
|---|---|---|---|---|
| **Month** | **Start Time** | **End Time** | **Reason** | **Sustain Time** |
| | 15:23 | 16:26 | Line | 1:03 |
| | 12:44 | 12:52 | Fuse | 0:08 |
| **Mansir** | 14:10 | 14:50 | Transformer pole | 0:40 |
| | 16:58 | 17:28 | Wire check | 0:30 |
| | 11:22 | 15:40 | Line | 4:18 |
| | 14:06 | 15:03 | Line | 0:57 |
| **Paush** | 7:56 | 10:16 | Line Repair | 2:20 |
| | 10:51 | 11:03 | Jumper | 0:12 |
| | 15:18 | 15:44 | Jumper | 0:26 |
| | 15:45 | 16:10 | Jumper | 0:25 |
| | 15:43 | 16:25 | Jumper | 0:42 |
| **Magh** | 17:11 | 17:40 | Transformer Fire | 0:29 |
| | 11:35 | 11:57 | Fuse | 0:22 |
| | 15:15 | 15:36 | Line Repair | 0:21 |
| **Falgun** | 13:55 | 14:37 | Jumper | 0:42 |
| **Chaitra** | 18:10 | 18:25 | Transformer pole | 0:15 |
| | 15:58 | 16:20 | Line Repair | 0:22 |
| | 19:24 | 20:45 | Line Check | 1:21 |
| | 11:15 | 11:40 | Line | 0:25 |
| | 17:50 | 19:12 | Fire | 1:22 |
| **Total Number of Fault** | | **48** | **Total Repair Time** | **48:09** |

| 2075 B.S. | | | | |
|---|---|---|---|---|
| **Month** | **Start Time** | **End Time** | **Reason** | **Sustain Time** |
| **Baishakh** | 9:45 | 11:20 | Line | 1:35 |
| **Jesth** | 14:10 | 15:30 | DO Fuse | 1:20 |
| | 14:10 | 14:40 | Jumper | 0:30 |
| **Ashar** | 8:10 | 9:57 | Jumper | 1:47 |
| | 12:10 | 12:52 | Jumper | 0:42 |
| | 10:50 | 11:13 | Jumper | 0:23 |
| | 13:46 | 13:59 | DO Fuse | 0:13 |
| | 9:46 | 11:07 | Fire | 1:21 |
| **Shawan** | 11:15 | 11:35 | Line | 0:20 |
| | 12:15 | 12:32 | Line | 0:17 |
| | 16:50 | 17:15 | Line | 0:25 |
| | 18:04 | 18:25 | Jumper | 0:21 |
| | 18:09 | 18:15 | Fire | 0:06 |
| | 4:25 | 6:10 | Line Check | 1:45 |
| | 8:00 | 8:35 | Jumper | 0:35 |
| | 17:38 | 18:35 | Bird | 0:57 |
| **Bhadra** | 20:55 | 22:02 | Transformer Spark | 1:07 |
| | 15:25 | 16:43 | Pole Repair | 1:18 |
| | 13:45 | 14:45 | Transformer Repair | 1:00 |
| | 13:00 | 16:56 | Transformer Fire | 3:56 |
| | 21:44 | 22:32 | Jumper | 0:48 |
| | 17:25 | 17:55 | Pole Repair | 0:30 |
| | 10:25 | 12:10 | Transformer | 1:45 |
| | 19:55 | 20:25 | Line | 0:30 |
| | 15:20 | 17:14 | Transformer | 1:54 |
| | 8:23 | 9:46 | Line | 1:23 |
| | 11:47 | 12:33 | Fire | 0:46 |
| **Ashoj** | 7:50 | 9:10 | Jumper | 1:20 |
| | 15:38 | 17:12 | DO Fuse | 1:34 |

| | | | | |
|---|---|---|---|---|
| | 18:16 | 18:53 | Jumper | 0:37 |
| **kartik** | 9:17 | 11:30 | Pole Repair | 2:13 |
| | 16:07 | 16:32 | Jumper | 0:25 |
| | 13:53 | 15:18 | Line Repair | 1:25 |
| **Mansir** | 10:37 | 11:20 | Jumper | 0:43 |
| | 15:40 | 16:05 | Jumper | 0:25 |
| | 14:55 | 15:10 | Jumper | 0:15 |
| | 10:58 | 12:40 | Line | 1:42 |
| | 7:15 | 8:46 | Line Repair | 1:31 |
| **Paush** | 19:45 | 20:40 | Fire | 0:55 |
| | 16:10 | 16:30 | Jumper | 0:20 |
| | 16:50 | 17:07 | Jumper | 0:17 |
| **Magh** | 8:12 | 8:34 | Jumper | 0:22 |
| | 11:58 | 12:50 | Jumper | 0:52 |
| | 8:27 | 9:10 | Pole Repair | 0:43 |
| | 9:55 | 10:40 | Pole Repair | 0:45 |
| | 20:15 | 20:30 | Jumper | 0:15 |
| | 11:47 | 12:20 | Cable Check | 0:33 |
| | 13:05 | 13:20 | Kit thread in Line | 0:15 |
| **Falgun** | 14:15 | 14:35 | Jumper | 0:20 |
| | 21:05 | 21:45 | Jumper | 0:40 |
| **Chaitra** | 11:32 | 12:43 | DO Fuse | 1:11 |
| | 7:55 | 8:55 | Jumper | 1:00 |
| **Total Number of Fault** | | **52** | **Total Repair Time** | **48:12** |

## ANNEXURE C: PEAK LOAD OF KOTESHWOR FEEDER

| **Month/Year** | **Peak Current (A)** | | | |
|---|---|---|---|---|
| | **2072/73** | **20073/74** | **2074/75** | **2075/76** |
| Baishakh | 345 | 220 | 220 | 185 |
| Jesth | 320 | 175 | 230 | |
| Asar | 320 | 230 | 210 | |
| Shrawan | 290 | 320 | 200 | 225 |
| Bhadra | 280 | 295 | 200 | 250 |
| Aswim | 280 | 270 | 170 | 270 |
| Kartik | 280 | 305 | 195 | 300 |
| Mansir | 300 | 230 | 175 | 280 |
| Paush | 300 | 240 | 300 | 310 |
| Magh | 380 | 240 | 280 | 305 |
| Falgun | 350 | 275 | 240 | 250 |
| Chaitra | 335 | 225 | 216 | |
| **Maximum** | **380** | **320** | **300** | **310** |

## ANNEXURE D: OVERHEAD CONDUCTOR OUT PUT FROM DIGSILENT POWERFACTORY

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | |
| From | To | Conductor Type | Area, sq mm | Number of Parallel Path | Length, m | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Conductor Type | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 1(1) | 32 | Magpie | 12.7 | 1 | 52 | 0.059 | 0.117 | 8.894 | 0.115 | 0.018 | Magpie | 12.7 | 0.059 | 0.117 | 8.894 | 0.115 | 0.018 |
| 10 | 11 | Magpie | 12.7 | 1 | 450 | 0.059 | 1.015 | 8.894 | 1.003 | 0.157 | Magpie | 12.7 | 0.059 | 1.015 | 8.894 | 1.003 | 0.157 |
| 12 | 11 | Magpie | 12.7 | 1 | 97 | 0.059 | 0.218 | 8.894 | 0.216 | 0.033 | Magpie | 12.7 | 0.059 | 0.218 | 8.894 | 0.216 | 0.033 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | | |
| **From** | **To** | **Conductor Type** | **Area, sq mm** | **Number of Parallel Path** | **Length, m** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Conductor Type** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 15 | 13/14 | Magpie | 12.7 | 1 | 113 | 0.059 | 0.255 | 8.894 | 0.251 | 0.039 | Magpie | 12.7 | 0.059 | 0.255 | 8.894 | 0.251 | 0.039 |
| 16 | 15 | Magpie | 12.7 | 1 | 258 | 0.059 | 0.582 | 8.894 | 0.575 | 0.090 | Magpie | 12.7 | 0.059 | 0.582 | 8.894 | 0.575 | 0.090 |
| 17 | 24 | Magpie | 12.7 | 1 | 162 | 0.059 | 0.365 | 8.894 | 0.361 | 0.056 | Magpie | 12.7 | 0.059 | 0.365 | 8.894 | 0.361 | 0.056 |
| 22 | 21 | Magpie | 12.7 | 1 | 174 | 0.059 | 0.392 | 8.894 | 0.388 | 0.060 | Magpie | 12.7 | 0.059 | 0.392 | 8.894 | 0.388 | 0.060 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | |
| From | To | Conductor Type | Area, sq mm | Number of Parallel Path | Length, m | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Conductor Type | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 21 | 25 | Magpie | 12.7 | 1 | 486 | 0.059 | 1.096 | 8.894 | 1.083 | 0.169 | Magpie | 12.7 | 0.059 | 1.096 | 8.894 | 1.083 | 0.169 |
| 23 | 24 | Magpie | 12.7 | 1 | 116 | 0.059 | 0.261 | 8.894 | 0.258 | 0.040 | Magpie | 12.7 | 0.059 | 0.261 | 8.894 | 0.258 | 0.040 |
| 26 | 25 | Magpie | 12.7 | 1 | 311 | 0.059 | 0.701 | 8.894 | 0.693 | 0.108 | Magpie | 12.7 | 0.059 | 0.701 | 8.894 | 0.693 | 0.108 |
| 27/28 | 26 | Magpie | 12.7 | 1 | 112 | 0.059 | 0.252 | 8.894 | 0.249 | 0.039 | Magpie | 12.7 | 0.059 | 0.252 | 8.894 | 0.249 | 0.039 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | |
| From | To | Conductor Type | Area, sq mm | Number of Parallel Path | Length, m | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Conductor Type | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 3/4(1) | 7 | Magpie | 12.7 | 1 | 120 | 0.059 | 0.270 | 8.894 | 0.267 | 0.041 | Magpie | 12.7 | 0.059 | 0.270 | 8.894 | 0.267 | 0.041 |
| 3/4(1) | 8 | Magpie | 12.7 | 1 | 176 | 0.059 | 0.397 | 8.894 | 0.392 | 0.061 | Magpie | 12.7 | 0.059 | 0.397 | 8.894 | 0.392 | 0.061 |
| 15 | 3/4 | Magpie | 12.7 | 1 | 593 | 0.059 | 1.338 | 8.894 | 1.322 | 0.206 | Magpie | 12.7 | 0.059 | 1.338 | 8.894 | 1.322 | 0.206 |
| 3/4 | 3/4(1) | Magpie | 12.7 | 1 | 232 | 0.059 | 0.523 | 8.894 | 0.517 | 0.080 | Magpie | 12.7 | 0.059 | 0.523 | 8.894 | 0.517 | 0.080 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | |
| From | To | Conductor Type | Area, sq mm | Number of Parallel Path | Length, m | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Conductor Type | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 5 | 3/4 | Magpie | 12.7 | 1 | 400 | 0.059 | 0.902 | 8.894 | 0.892 | 0.139 | Magpie | 12.7 | 0.059 | 0.902 | 8.894 | 0.892 | 0.139 |
| 30/31 | 29 | Magpie | 12.7 | 1 | 267 | 0.059 | 0.602 | 8.894 | 0.595 | 0.093 | Magpie | 12.7 | 0.059 | 0.602 | 8.894 | 0.595 | 0.093 |
| 33 | 32 | Magpie | 12.7 | 1 | 103 | 0.059 | 0.232 | 8.894 | 0.229 | 0.035 | Magpie | 12.7 | 0.059 | 0.232 | 8.894 | 0.229 | 0.035 |
| 34 | 33 | Magpie | 12.7 | 1 | 73 | 0.059 | 0.164 | 8.894 | 0.162 | 0.025 | Magpie | 12.7 | 0.059 | 0.164772 | 8.894767 | 0.16 | 0.025 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | |
| From | To | Conductor Type | Area, sq mm | Number of Parallel Path | Length, m | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Conductor Type | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 34 | 38 | Magpie | 12.7 | 1 | 128 | 0.059 | 0.288 | 8.894 | 0.285 | 0.044 | Magpie | 12.7 | 0.059 | 0.288 | 8.894 | 0.285 | 0.044 |
| 30/31 | 37 | Magpie | 12.7 | 1 | 527 | 0.059 | 1.189 | 8.894 | 1.175 | 0.183 | Magpie | 12.7 | 0.059 | 1.189 | 8.894 | 1.175 | 0.183 |
| 37 | 36 | Magpie | 12.7 | 1 | 160 | 0.059 | 0.361 | 8.894 | 0.356 | 0.055 | Magpie | 12.7 | 0.059 | 0.361 | 8.894 | 0.356 | 0.055 |
| 6 | 5 | Magpie | 12.7 | 1 | 254 | 0.059 | 0.573 | 8.894 | 0.566 | 0.088 | Magpie | 12.7 | 0.059 | 0.573 | 8.894 | 0.566 | 0.088 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Conductors | | | | | | | | | | | Recommended Conductors | | | | | | |
| From | To | Conductor Type | Area, sq mm | Number of Parallel Path | Length, m | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Conductor Type | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 8 | 10 | Magpie | 12.7 | 1 | 295 | 0.059 | 0.665 | 8.894 | 0.657 | 0.102 | Magpie | 12.7 | 0.059 | 0.665 | 8.894 | 0.657 | 0.102 |
| 36 | 35 | Magpie | 12.7 | 1 | 102 | 0.059 | 0.230 | 8.894 | 0.227 | 0.035 | Magpie | 12.7 | 0.059 | 0.230 | 8.894 | 0.227 | 0.035 |
| 21 | 19/20 | Magpie | 12.7 | 1 | 127 | 0.059 | 0.286 | 8.894 | 0.283 | 0.044 | Magpie | 12.8 | 0.059 | 0.178 | 13.226 | 0.173 | 0.040 |
| **Total Length, m** | | | | | **5888** | | | | | | **Magpie** | | | | | | |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Conductors** | | | | | | | | | | | **Recommended Conductors** | | | | | | |
| **From** | **To** | **Conductor Type** | **Area, sq mm** | **Number of Parallel Path** | **Length, m** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Conductor Type** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 2(1) | 37 | Magpie | 12.7 | 1 | 364 | 0.059 | 0.821 | 8.894 | 0.811 | 0.127 | Quirrell | 20.7 | 0.075 | 0.512 | 13.226 | 0.498 | 0.117 |
| **Total Length, m** | | | | | **364** | | | | | | **Quarrel** | | | | | | |
| 17 | 18 | Magpie | 12.7 | 1 | 100 | 0.059 | 0.225 | 8.894 | 0.223 | 0.034 | Ferret | 41.8 | 0.117 | 0.074 | 23.828 | 0.067 | 0.029 |
| 18 | 19/20 | Magpie | 12.7 | 1 | 890 | 0.059 | 2.008 | 8.894 | 1.984 | 0.310 | Ferret | 41.8 | 0.117 | 0.658 | 23.828 | 0.602 | 0.266 |
| **Total Length, m** | | | | | **990** | | | | | | **Ferret** | | | | | | |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Conductors** | | | | | | | | | | | **Recommended Conductors** | | | | | | |
| **From** | **To** | **Conductor Type** | **Area, sq mm** | **Number of Parallel Path** | **Length, m** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Conductor Type** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 17 | 3/4 | Magpie | 12.7 | 1 | 576 | 0.059 | 1.300 | 8.894 | 1.284 | 0.201 | Mink | 62.2 | 0.152 | 0.309 | 32.24 | 0.262 | 0.165 |
| **Total Length, m** | | | | | **576** | | | | | | **Mink** | | | | | | |
| 3/4 | 2(1) | Magpie | 12.7 | 1 | 198 | 0.059 | 0.446 | 8.894 | 0.441 | 0.069 | Wolf | 155 | 0.28 | 0.061 | 54.01 | 0.036 | 0.049 |
| **Total Length, m** | | | | | **198** | | | | | | **Wolf** | | | | | | |
| 1(1) | 2 | Magpie | 12.7 | 1 | 481 | 0.059 | 1.085 | 8.894 | 1.072 | 0.167 | Goat | 317 | 0.462 | 0.118 | 68.69 | 0.042 | 0.110 |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Conductors** | | | | | | | | | | | **Recommended Conductors** | | | | | | |
| **From** | **To** | **Conductor Type** | **Area, sq mm** | **Number of Parallel Path** | **Length, m** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Conductor Type** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 1(1) | 1 | Magpie | 12.7 | 1 | 124 | 0.059 | 0.279 | 8.894 | 0.276 | 0.043 | Goat | 317 | 0.462 | 0.030 | 68.69 | 0.011 | 0.028 |
| 2 | 2(1) | Magpie | 12.7 | 1 | 215 | 0.059 | 0.485 | 8.894 | 0.479 | 0.075 | Goat | 317 | 0.462 | 0.052 | 68.69 | 0.019 | 0.049 |
| 0 | Bus Bar | Magpie | 12.7 | 1 | 508 | 0.059 | 1.146 | 8.894 | 1.132 | 0.177 | Goat | 317 | 0.462 | 0.124 | 68.69 | 0.045 | 0.116 |
| **Total Length, m** | | | | | **132 8** | | | | | | **Goat** | | | | | | |

| Overhead Conductor Design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Conductors** | | | | | | | | | | | **Recommended Conductors** | | | | | | |
| **From** | **To** | **Conductor Type** | **Area, sq mm** | **Number of Parallel Path** | **Length, m** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Conductor Type** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 0 | 1 | Magpie | 12.7 | 1 | 52 | 0.059 | 0.117 | 8.894 | 0.115 | 0.018 | Zebra | 420 | 0.544 | 0.012 | 73.11 | 0.003 | 0.011 |
| **Total Length, m** | | | | | **52** | | | | | | **Zebra** | | | | | | |
| 9 | 8 | Magpie | 12.7 | 1 | 55 | 0.059 | 0.124 | 8.894 | 0.122 | 0.019 | Pawpaw | 584 | 0.678 | 0.011 | 77.11 | 0.002 | 0.011 |
| **Total Length, m** | | | | | **55** | | | | | | **Pawpaw** | | | | | | |
| **Total, m** | | | | | **945 1** | | | | | | | | | | | | |

## ANNEXURE E: UNDERGROUND CABLE OUT PUT FROM DIGSILENT POWERFACTORY

| Underground Cable design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Cable | | | | | | | | | | | | Recommended Cable | | | | | |
| From | To | Cable Type | Area, sq mm | Number of Parallel | Length, m | Derating Factor | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 1(1) | 32 | 3C-XLPE | 25 | 1 | 52 | 0.9 | 0.074 | 0.063 | 6.324 | 0.062 | 0.007 | 25 | 0.074 | 0.063 | 6.324 | 0.062 | 0.00 |
| 10 | 11 | | | 1 | 450 | 0.9 | 0.074 | 0.543 | 6.324 | 0.540 | 0.060 | 25 | 0.074 | 0.543 | 6.324 | 0.540 | 0.06 |
| 12 | 11 | | | 1 | 97 | 0.9 | 0.074 | 0.117 | 6.324 | 0.116 | 0.013 | 25 | 0.074 | 0.117 | 6.324 | 0.116 | 0.01 |
| 15 | 13/14 | | | 1 | 113 | 0.9 | 0.074 | 0.136 | 6.324 | 0.136 | 0.015 | 25 | 0.074 | 0.136 | 6.324 | 0.136 | 0.01 |
| 16 | 15 | | | 1 | 258 | 0.9 | 0.074 | 0.311 | 6.324 | 0.310 | 0.034 | 25 | 0.074 | 0.311 | 6.324 | 0.310 | 0.03 |
| 17 | 24 | | | 1 | 162 | 0.9 | 0.074 | 0.196 | 6.324 | 0.194 | 0.022 | 25 | 0.074 | 0.196 | 6.324 | 0.194 | 0.02 |
| 21 | 19/20 | | | 1 | 127 | 0.9 | 0.074 | 0.153 | 6.324 | 0.152 | 0.017 | 25 | 0.074 | 0.153 | 6.324 | 0.152 | 0.02 |
| 2(1) | 37 | 3C- | 25 | 1 | 364 | 0.9 | 0.074 | 0.439 | 6.324 | 0.437 | 0.048 | 25 | 0.074 | 0.439 | 6.324 | 0.437 | 0.04 |

| Underground Cable design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Cable | | | | | | | | | | | | Recommended Cable | | | | | |
| From | To | Cable Type | Area, sq mm | Number of Parallel | Length, m | Derating Factor | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 22 | 21 | | 25 | 1 | 174 | 0.9 | 0.074 | 0.210 | 6.324 | 0.209 | 0.023 | 25 | 0.074 | 0.210 | 6.324 | 0.209 | 0.02 |
| 21 | 25 | | 25 | 1 | 486 | 0.9 | 0.074 | 0.587 | 6.324 | 0.583 | 0.065 | 25 | 0.074 | 0.587 | 6.324 | 0.583 | 0.06 |
| 23 | 24 | | 25 | 1 | 116 | 0.9 | 0.074 | 0.140 | 6.324 | 0.139 | 0.015 | 25 | 0.074 | 0.140 | 6.324 | 0.139 | 0.01 |
| 26 | 25 | | 25 | 1 | 311 | 0.9 | 0.074 | 0.375 | 6.324 | 0.373 | 0.041 | 25 | 0.074 | 0.375 | 6.324 | 0.373 | 0.04 |
| 27/28 | 26 | | 25 | 1 | 112 | 0.9 | 0.074 | 0.135 | 6.324 | 0.134 | 0.015 | 25 | 0.074 | 0.135 | 6.324 | 0.134 | 0.01 |
| 3/4(1) | 7 | | 25 | 1 | 120 | 0.9 | 0.074 | 0.145 | 6.324 | 0.144 | 0.016 | 25 | 0.074 | 0.145 | 6.324 | 0.144 | 0.01 |
| 3/4(1) | 8 | | 25 | 1 | 176 | 0.9 | 0.074 | 0.212 | 6.324 | 0.211 | 0.023 | 25 | 0.074 | 0.212 | 6.324 | 0.211 | 0.02 |
| 15 | 3/4 | | 25 | 1 | 593 | 0.9 | 0.074 | 0.716 | 6.324 | 0.712 | 0.079 | 25 | 0.074 | 0.716 | 6.324 | 0.712 | 0.07 |
| 3/4 | 3/4(1) | | 25 | 1 | 232 | 0.9 | 0.074 | 0.280 | 6.324 | 0.278 | 0.031 | 25 | 0.074 | 0.280 | 6.324 | 0.278 | 0.03 |

| Underground Cable design | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Cable** | | | | | | | | | | | | | **Recommended Cable** | | | | | |
| **From** | **To** | **Cable Type** | **Area, sq mm** | **Number of Parallel** | **Length, m** | **Derating Factor** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 5 | 3/4 | | 25 | 1 | 400 | 0.9 | 0.074 | 0.483 | 6.324 | 0.480 | 0.053 | 25 | 0.074 | 0.483 | 6.324 | 0.480 | 0.05 |
| 30/31 | 29 | | 25 | 1 | 267 | 0.9 | 0.074 | 0.322 | 6.324 | 0.320 | 0.036 | 25 | 0.074 | 0.322 | 6.324 | 0.320 | 0.03 |
| 33 | 32 | | 25 | 1 | 103 | 0.9 | 0.074 | 0.124 | 6.324 | 0.124 | 0.014 | 25 | 0.074 | 0.124 | 6.324 | 0.124 | 0.01 |
| 34 | 33 | | 25 | 1 | 73 | 0.9 | 0.074 | 0.088 | 6.324 | 0.088 | 0.010 | 25 | 0.074 | 0.088 | 6.324 | 0.088 | 0.01 |
| 34 | 38 | | 25 | 1 | 128 | 0.9 | 0.074 | 0.155 | 6.324 | 0.154 | 0.017 | 25 | 0.074 | 0.155 | 6.324 | 0.154 | 0.02 |
| 30/31 | 37 | | 25 | 1 | 527 | 0.9 | 0.074 | 0.636 | 6.324 | 0.632 | 0.070 | 25 | 0.074 | 0.636 | 6.324 | 0.632 | 0.07 |
| 37 | 36 | 3C-XLPE | 25 | 1 | 160 | 0.9 | 0.074 | 0.193 | 6.324 | 0.192 | 0.021 | 25 | 0.074 | 0.193 | 6.324 | 0.192 | 0.02 |
| 6 | 5 | | 25 | 1 | 254 | 0.9 | 0.074 | 0.307 | 6.324 | 0.305 | 0.034 | 25 | 0.074 | 0.307 | 6.324 | 0.305 | 0.03 |
| 8 | 10 | | 25 | 1 | 295 | 0.9 | 0.074 | 0.356 | 6.324 | 0.354 | 0.039 | 25 | 0.074 | 0.356 | 6.324 | 0.354 | 0.04 |

| Underground Cable design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Initial Cable** | | | | | | | | | | | | **Recommended Cable** | | | | | |
| **From** | **To** | **Cable Type** | **Area, sq mm** | **Number of Parallel** | **Length, m** | **Derating Factor** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** | **Area, sq mm** | **I Rated, kA** | **Z, Ω** | **Phase, Degree** | **R1, Ω** | **X1, Ω** |
| 9 | 8 | | 25 | 1 | 55 | 0.9 | 0.074 | 0.066 | 6.324 | 0.066 | 0.007 | 25 | 0.074 | 0.066 | 6.324 | 0.066 | 0.01 |
| 36 | 35 | | 25 | 1 | 102 | 0.9 | 0.074 | 0.123 | 6.324 | 0.122 | 0.014 | 25 | 0.074 | 0.123 | 6.324 | 0.122 | 0.01 |
| **Total Length, m** | | | | | **630 7** | | | | | | | **25** | | | | | |
| 17 | 18 | 3C-XLPE | 25 | 1 | 100 | 0.9 | 0.074 | 0.121 | 6.324 | 0.120 | 0.013 | 50 | 0.104 | 0.081 | 37.676 | 0.064 | 0.05 |
| 18 | 19/20 | | 25 | 1 | 890 | 0.9 | 0.074 | 1.075 | 6.324 | 1.068 | 0.118 | 50 | 0.104 | 0.721 | 37.676 | 0.570 | 0.44 |
| **Total Length, m** | | | | | **990** | | | | | | | **50** | | | | | |
| 17 | 3/4 | 3C-XLPE | 25 | 1 | 576 | 0.9 | 0.074 | 0.695 | 6.324 | 0.691 | 0.077 | 70 | 0.126 | 0.263 | 14.737 | 0.254 | 0.07 |
| **Total Length, m** | | | | | **576** | | | | | | | **70** | | | | | |
| 0 | 1 | 3C- | 25 | 2 | 52 | 0.9 | 0.148 | 0.031 | 6.324 | 0.031 | 0.003 | 185 | 0.24 | 0.005 | 30.603 | 0.004 | 0.00 3 |

| Underground Cable design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Cable | | | | | | | | | | | | Recommended Cable | | | | | |
| From | To | Cable Type | Area, sq mm | Number of Parallel | Length, m | Derating Factor | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| 1(1) | 2 | | 25 | 2 | 481 | 0.9 | 0.148 | 0.290 | 6.324 | 0.289 | 0.032 | 185 | 0.24 | 0.046 | 30.603 | 0.039 | 0.02 |
| 1(1) | 1 | | 25 | 2 | 124 | 0.9 | 0.148 | 0.075 | 6.324 | 0.074 | 0.008 | 185 | 0.24 | 0.012 | 30.603 | 0.010 | 0.01 |
| 0 | Bus Bar | | 25 | 2 | 508 | 0.9 | 0.297 | 0.086 | 18.489 | 0.081 | 0.027 | 185 | 0.24 | 0.048 | 30.603 | 0.042 | 0.03 |
| **Total Length, m** | | | | | **1165** | | | | | | | **185** | | | | | |
| 3/4 | 2(1) | 3C-XLPE | 25 | 1 | 198 | 0.9 | 0.074 | 0.239 | 6.324 | 0.238 | 0.026 | 240 | 0.275 | 0.030 | 33.901 | 0.025 | 0.02 |
| **Total Length, m** | | | | | **198** | | | | | | | **240** | | | | | |
| 2 | 2(1) | 3C-XLPE | 25 | 1 | 215 | 0.9 | 0.074 | 0.260 | 6.324 | 0.258 | 0.029 | 400 | 0.350 | 0.025 | 48.841 | 0.017 | 0.02 |

| Underground Cable design | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Initial Cable | | | | | | | | | | | | | Recommended Cable | | | | |
| From | To | Cable Type | Area, sq mm | Number of Parallel | Length, m | Derating Factor | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω | Area, sq mm | I Rated, kA | Z, Ω | Phase, Degree | R1, Ω | X1, Ω |
| Total Length, m | | | | | 215 | | | | | | | 400 | | | | | |
| Total, m | | | | | 9451 | | | | | | | | | | | | |