

RANGIRA DIDIER

Student ID: UM74684SEL83855

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1. Introduction

The generated electrical power must be distributed or dispatched to the customers in order to facilitate works and give the light indoors and outdoors. Therefore to achieve that the electrical lines could be constructed, the electrical lines can be also called Grid as a technical term, for that reason of dispatching of electrical power in different areas or place where comes the Distribution term. The dispatched power energy is from generation plants according to the demand of users in the different places of the country, for qualitative services the substation must be in the system for stability and minimize disruption of the network which is served.

Related to the region where the distribution is intended to be implement, the transmission can be overhead lines or underground lines but the most used distribution is overhead which is friendly in the field of maintenance and demand less than underground lines.

This material will describe how electricity can be transported from one point to another and what technics should be used, specifications and selecting materials all these are going to be mentioned for clarifying the subject of the distribution of generated energy, the composition of electrical distribution such as poles, supports, substations and so on. The classification of voltage transported and why and what are benefits to the network and customers.

After completing the material the concern will be able to identify the comprises of the distribution system, voltages that can be transported for long distances in order to reduce losses and serve with qualitative and reliable energy for beloved customers.

2. Distribution System

Therefor the distribution system means that distribute or transfer power (energy) from one location to the other location where the energy is needed for use. In order to achieve this there are more things to do, constructing substations where the distribution and control will be done from. The poles or towers with purpose of handling the cables that are carrying the electricity, these cables are attached to the insulators which are used to prevents the leakages of electricity from the cables to the supports , in distribution different levels of voltages are used accordingly so that the transformers are else parts of the distribution.

2.1. Basic design

The facility that must be done before, is that to be aware of the demand of power to supply to the customers, which must be in maximum and qualitative to meet the requirements and also to specify all equipment and materials to be used so that the works will not fail before completion.

In this preparation, the qualified technicians and Engineers must be selected and trained to facilitate the works, Site visits, and more analysis for better progress incoming works.

Preliminary preparation of the documents such as drawing, financial and site maps are the keys of the whole project.

The criteria should be illustrated in order to minimize the faults, the specifications of works to be done and techniques to be used, in distribution or transmission to specify whether the overhead or underground line must be noted. All this depends on some criteria such as cost and the zone where the project is going to implement, the scalability of the network and the capacity to carry must also be considered. This is the way the attentions are needed in the preparation for the future and prevent to fall in an insufficient of energy, from that the statistics have to be conducted by the expert agents for the best plans of future. The transmission and distribution are mostly similar and has the main composition in common such as the foundation of the structure, insulators, support structures, and conductors; The only difference is that the transmission lines carry out the high voltages of 69KV or greater for long-distance and the distribution carry the low voltages of 12KV to 44KV just for the delivering electricity to the customers. All these parts will be described in this material for most details.

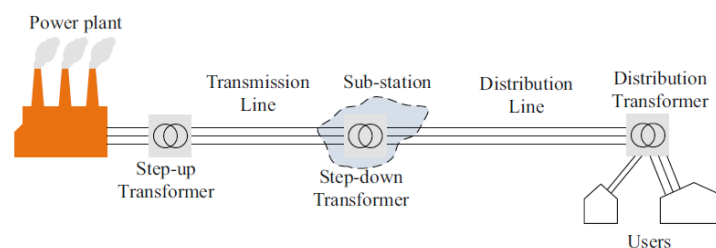


Figure 1: Traditional flow of power in a national grid

2.2. Network configuration

The technics to be used in transmission or distribution are reliability of time and scalability of the network in the objective of facilitating any addition to be adequate in the future, these technics are very useful even in the identification of types of line to be implemented, and these types are the overhead line and underground lines. In this material, we will only focus on three phases which is the best in power transportation with the advantage of reduced losses than single-phase line accordingly to the losses calculation as follows:

- ❖ The overhead network are the installed lines travel through the air where the conductors are hung on insulators and the insulators attached to the pole or tower (structure support) and then the poles are installed on the powerful foundation made of good concretes, the poles or towers are mounted related to the level of voltages to carry and the conductors to be handling and in addition the zone.

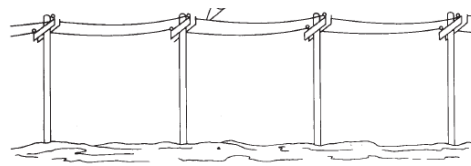


Figure 2: The overhead transmission line with towers as support Figure 3: The overhead line with poles as support

- ❖ The underground lines are the installed lines under the ground, the cables that carry the electricity are buried to the ground and transport to the destination, this method requires special materials to achieve the goal, which makes this option more expensive than overhead lines, and else this requires period maintenance



Figure 4: underground burial cables activities

Therefore in the distribution network there are two topologies mostly used, here there are and some explanations, this concerned with the way physical routing of the lines

- Hub-and-spoke : The single line is used from substation to a customer
- Trunk-and-branch: This line has one giant line where any customer must be connected like a branch, the trunk line with high capacity to carry enough energy and dispatch the energy to small branches (individual), according to the structure of the any topology the trunk-and-branch is less expensive compared to the hub-and-spoke.

2.3. Reliability consideration

System planning studies generally help in making decisions to build a transmission system. The basic consideration in system transmission and distribution are: Economics, Esthetic consideration, country policies, and practice, preferred materials and construction techniques, performance criteria, and line profile. There are also factors needed to be considered and established which are:

- Voltage level
- Conductor types and size
- Line regulation and voltage control
- Losses
- Proper load-flow and system stability
- System protection
- Grounding
- Insulation coordination
- Mechanical design
- Structural design

The two factors mechanical and structural design have the particularly consideration which are the followings:

- Mechanical design has the factors such as: sag and stress calculations, conductor composition, conductor spacing, and Insulator and conductor hardware selection.
- Structural design has the factors such as: Structure types and stress calculations

2.4. Load characteristics and types of customer

The term load in an electric field is mostly used and is referred to the consumption of electrical energy by the customers, if the appliances are connected to the electrical network the energy is been demanded from the generation system, and the flow of electricity starts through the network.

The load can be characterized into the following factors:

- Demand factor: this is the rate of maximum demand and the connected loads
- Load factor: this is the rate of average of the maximum demand during a given period of times
- Diversity factor: is the ratio of the individual maximum demands to the maximum of power generations
- Utilization factor: This is the ratio of maximum demand of the system to the rated capacity system
- Power factor: this is the power ratio sum of the customers to the generated power
- Loss factor: The rate of the average power losses over a specified period of time to the peak loss during the same period.

Types of load

The load can be classified into the following types:

- Domestic loads: For this type, the small appliances are mostly connected to the electrical network with small consumption of electrical energy.
- Commercial loads: This type is high to the domestic load where they use the appliances with more consumption energy capacity.
- Industrial loads: This type is the highest in energy consumption of energy than the others, into this type powerful machines are used with high capacity. Into this types, there are subdivided which are:
 - Small industrial load: This require power energy up to 25KW
 - Medium industrial load: This require power energy between 25KW to 100KW

- Heavy industrial load: This one is the last and high demand which require the power energy of 500KW and more.
- Municipal loads: These types of loads are for the public needs such as street lights which might use in the nights.

2.5. Equipment specification

In distribution and transmission, there have different equipment that are required the satisfaction of the customers, below are some equipment that are most important in the system.

❖ Transformer

The transformer is an electric device that can step up or step down voltage accordingly to the desired voltage. In a step-up transformer, the output voltage is increased and in a step-down transformer, the output voltage is decreased. This changes nothing about the distributed power only affect the voltage.

The ratio that describe the transformer is given with the following formula:

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f \Phi_m$$

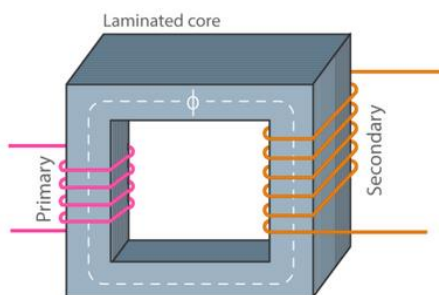


Figure 5: Coil Transformer



Figure 6: The transformer

N_1 : number of turns in primary.

N_2 : number of turns in secondary.

E_1 : Voltage on primary side

E_2 : Voltage on secondary side

Φ_m : Main Flux

F : Frequency

❖ Potential transformer

The potential transformer is commonly an instrument or equipment referred to as a step-down transformer that reduces a certain level voltage of a high voltage circuit to a lower voltage circuit. The reduced voltage can be measured by instruments like a voltmeter, wattmeter and watt-hour meters.



Figure 7: The Potential Transformer

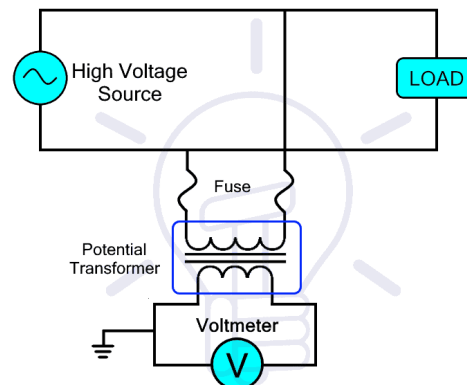


Figure 8: Potential transformer diagram

❖ Current transformer

The current transformer is the electromagnetic device used to produce an alternating current on the secondary, proportional to the AC on the primary. This procedure has been used when the current or voltage is too high to measure directly. The induced current on secondary is suitable for measuring instruments or processing in electronic equipment, which typically needs to be isolated between the primary and secondary circuits.

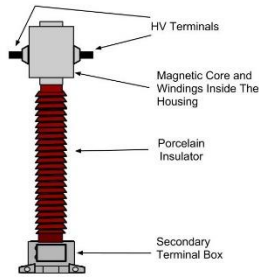


Figure 9: Current Transformer

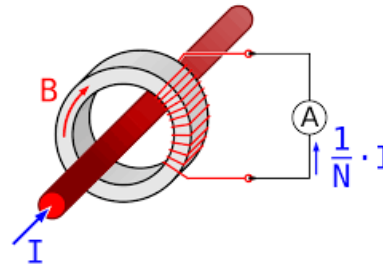


Figure 10: Current transformer diagram

❖ Lightning arrester

The lightning arrester is a device used in electrical circuits as protection from lightning and overvoltage switching, in a manner for increases the stability and reliability of the electrical network. This device diverts the abnormal high voltage to the ground not affecting the supply.



Figure 11: Surge protector

❖ Poles or Towers

Poles

The poles are preselected and treated woods, metals, or concrete support used to handle the electric components and conductors that transfer energy, they must be examined for the force to carry out and level of medium, and low voltage in order to satisfy the customers, they are

mounted on a well-designed structure to ensure the stability, their selection related to the voltage level to transfer and the zone to be installed.

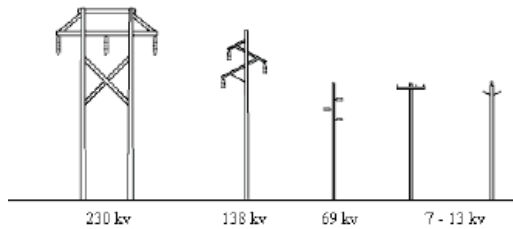


Figure 12: Different types of pole

Towers

This is the high voltage support in transmission and carries out the conductors with big sections to facilitate the huge amount of energy to be transferred.

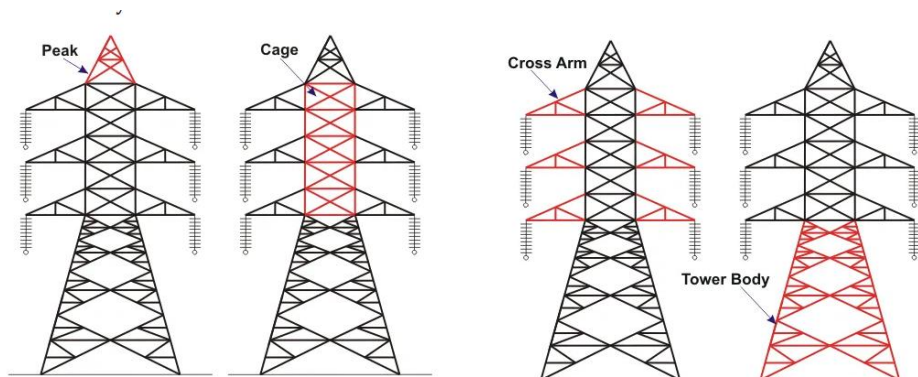


Figure 13: Different parts of tower

❖ Insulators

Insulators are devices or substances that block the flow of electrons, the insulators are very important on overhead line in electrical insulation, they can also be used as support of wire and prevent the electricity travel to the ground. Most of the insulators are made in porcelain, glasses and other chemical substance that are no conductive, these insulators have roles of protecting line against any leakage of electricity and support the wire for overhead lines.

The insulators have the following types which are Pin insulators, Suspension insulators, Strain insulators, Shackle insulators and pole line hardware such as suspension strings, tension strings and spindles.



Figure 14: Strain insulators

Figure 15: Pin Insulators

Figure 16: Suspension Insulators

Figure 17: Shackle Insulators

❖ Conductors and cables

Conductors

The conductors are special materials made in aluminum, copper and laminated steel to reduce the losses in electrical transportation, their size varies accordingly to the level of voltages to carry. The conductors are used in electrical transmission and distribution by transporting energy over different places, the most used conductors are those made in aluminum for reduction of cost and losses.



Figure 18: Conductor covered with insulator



Figure 19: Overhead conductor

Cables

The electric cables are used to transport electrical energy from one place to another, but the insulated cables are buried underground for cables protection, they are mostly used in densely populated such as urban areas and industrial areas.

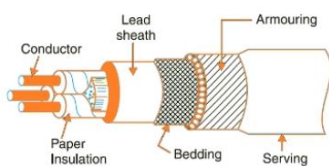


Figure 20: Cable with its all parts



Figure 21: Underground cable

❖ Disconnectors

These devices are used just to make sure that the electrical power is de-energised the line for maintenance or any services that are progressing in line. When is closed it does not be open with energy flowing in it, it is absolutely opened with zero voltages.

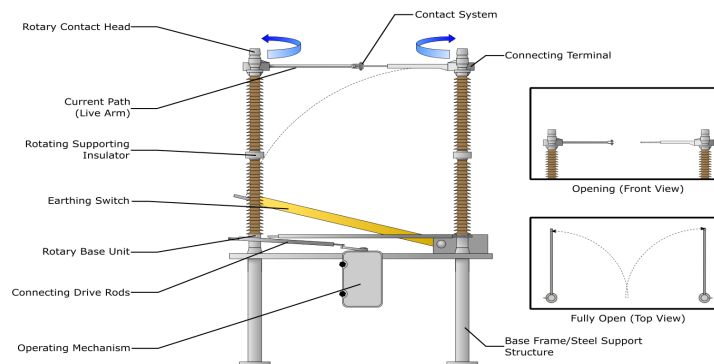


Figure 22: Disconnector with its all parts

❖ Circuit breakers

For transmission and distribution lines protection we need some efficiency devices such as circuit breaker is the best one in transportation protection associated with relays to improve the security of lines, the circuit breaker is device that allow the operation maneuvers in network. The circuit

break cans open or close the flow of electricity even if the load is on peak without any issue, it is designed for that. The circuit breaker is used to take action once the fault arise and allows the maintenance. In selection of circuit breaker some criteria must be focused such as rate insulation rate, rate normal current, rate voltage and rate frequency or more. Actually the main purpose of circuit breaker is to interrupt the fault current once it is happening and separate the part in fault to the network.



Figure 23: High voltage Circuit Breaker



Figure 24: The medium circuit breaker

❖ Spark gap

The spark gap is a device with the responsibility to protect the line and network's apparatus against overvoltage, they are acting like traps while the overvoltage is acquired and direct the current to the ground. The spark gap is made with two conducting electrodes that are separated with specified space according to the normal voltage.

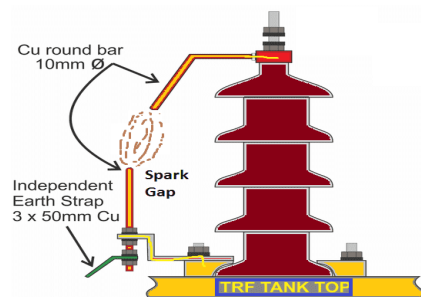


Figure 25: The spark gap

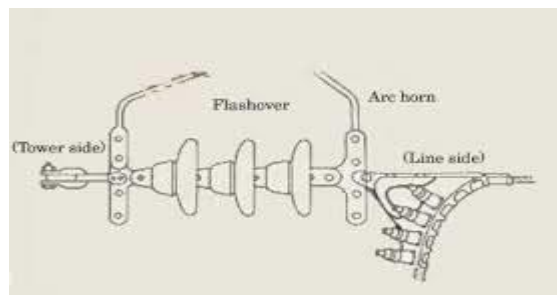


Figure 26: Flashover spark gap

3. Distribution grids

3.1. Distribution system types

There are two topologies of distribution which are hub – and – spoke and trunk – and – branches all of both topologies share the same types which are following:

1. Single-phase two wires distribution
2. Two phases three-wires distribution
3. Three phases three or four wires distribution.

The hub – and – spoke is the topology of distribution that transfer energy from generation to different customers, this type is also called radial topology where each line to the user is directly from the powerhouse, the generation is considered as a single point where all of the clients are connected as the following images.

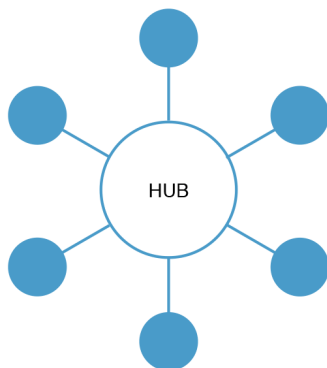


Figure 27: Hub topology

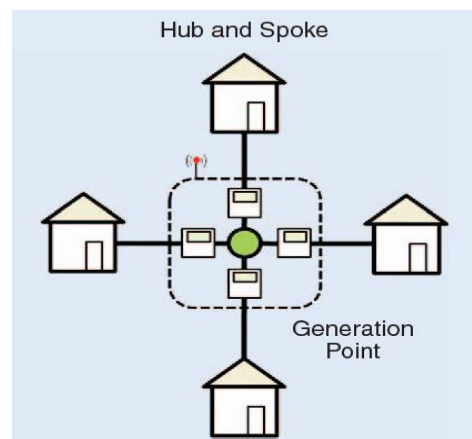
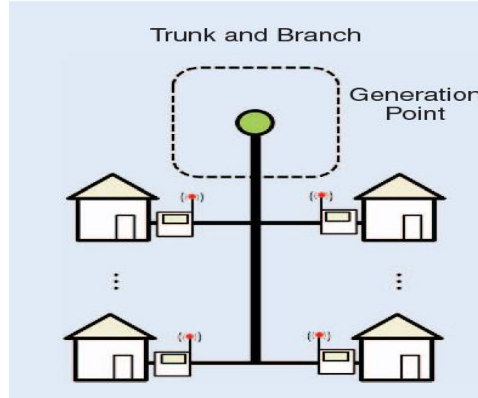


Figure 28: Hub and spoke topology

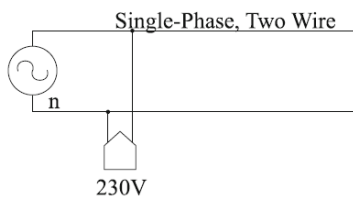
The trunk – and – branch topology is big line with high ampacity lines that can be connect to it for serving individual or small customers groups, this topology is used to serve the customers who are far away from the generation system.



As described the both hub – and – spoke, and trunk – and – branch can be adopted in the mentioned types of distribution. The next step going to explain in little details each type of distribution.

1. The single phase with two wires

A single-phase line is a transportation medium of electrical energy from one place to another via two wires as conductor, one wire is carrying phase which is called else alive wire and other wire carry the neutral, in this configuration the voltage is in range of low voltage.



With this configuration, the losses are greater compared to others and are more expensive, in order to make a calculation each wire is modelled as impedance $Z_w = R_w + jX_w$. Both wires are identical and therefore to calculate the voltage drop is given by the voltage on the source side minus the voltage on the customer side.

$$V_a - V_b = V_c$$

Where V_a is the voltage on supply, V_b is the voltage on the clients side and the V_c is voltage drop, from this formula it is possible to get the impedance of line

$$Z_l = \frac{V_c}{I}$$

Where the Z_l is Total impedance of the line, I is the total current of line.

There is also the way to calculate the impedance of the line which measured in Ohm

$$R(\Omega) = \rho \frac{l}{A}$$

Where

ρ is the resistivity of the conductor in $\Omega.m$

l is the Length of the conductor in m

A is the effective cross sectional area used in m

We see that the voltage drop increases in proportion to the number of households served as well the current supplied to each household. Half of the voltage drop is caused by the phase wire and half by the neutral wire. Equivalently, the total voltage drop is twice that along with the phase or neutral wire. There is also power loss along each wire. The total power loss is

$$Pl = RI_s^2$$

Where Pl is power loss, R is impedance of conductor and I_s is current of the line

2. The two phases three-wires or split phase

This configuration is three – wires line which is more efficient than single phase, it has also a lower voltage drop, normal the split phase configuration one wire is for neutral and the other two are for phases which are out of phase on an angle of 180 degrees.

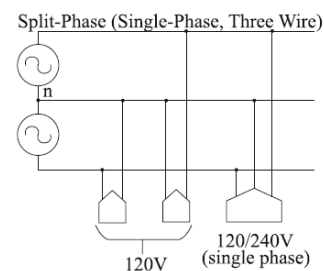


Figure 29: Split-phase

3. The three phases three or four wires distribution

The three – phase configuration is commonly used in transport of energy worldwide and carry capacity of energy and else has less losses compare to others configurations, this configuration can be configured as wye or delta, this configuration eventually has four wires or three wires accordingly to the configuration. The wye or star configuration which comprise with four wires is

the configuration used the appliances with reduced voltages and the delta has the three wires with only one range of voltage.

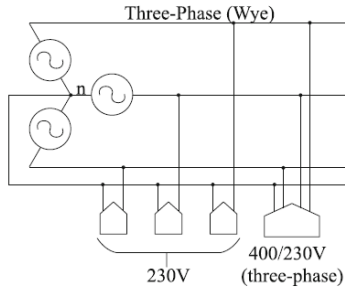


Figure 30: Three phases Wye Diagram

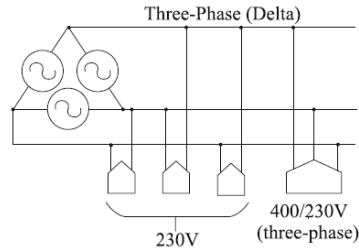


Figure 31: Three phases Delta diagram

3.2. Transmission lines and Distribution lines

The nominal voltage of a distribution line refers to the root mean square (RMS) magnitude of the line – to – line voltage V_{LL} . The relationship between the magnitude of the line – to – line and the magnitude of the line – to – neutral voltage of a balanced system is given by the following formula.

$$V_{\phi} = \frac{V_{LL}}{\sqrt{3}}$$

Where V_{ϕ} is the nominal line – to – neutral voltage, to get the voltage of line – to – line the RMS will help us in these calculations which are accurate to the values given by a multi - meter.

$$V_{LL} = V_{\phi}\sqrt{3}$$

Due to the losses both real and reactive along the line, there are different of power to the source and the receiver of the power (Customers), the different of these powers resulting from the loss of power. In distribution we got the three types of power which are the real power (P), imaginary power or reactive power (Q) and apparent power (S), these are expressed by the W as watt, VAR as volt-ampere reactive and VA as volt-ampere this is resulted by the sum of the real power and imaginary power.

There are other possible ways to get the real power from the apparent power associated with the power factor (Pf) which is related to the load.

$$P_s = S_s * P_f$$

$$P_r = S_r * P_f$$

Where the P_s stand for Power on the source side and P_r power for the receiver side, the reasonable power factor is 0.85 lagging.

The conductor in line is modeled as a resistance R_{line} in series with inductive reactance X_{line} where the capacitive affects are ignored in single line once the line is less than 50km and if the length is more than 50km then the capacitive affects become increasingly important then the impedance is given by

$$Z_{line} = R_{line} + jX_{line}$$

Here is the equivalent of the single line

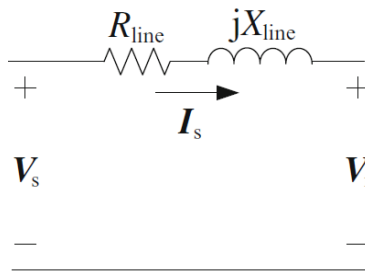


Figure 32: The equivalent single line diagram

The line resistance of each conductor in distribution is given by the length, cross – sectional, frequency and material used.

$$R(\Omega) = \rho \frac{l}{A}$$

Where

ρ is the resistivity of the conductor in ohmmeters.

l is the Length of the conductor in meters.

A is the effective cross sectional area used in m squared.

The resistivity is the property of the conductor material, it can be Aluminum or Aluminum alloy.

The inductive reactance is also the effect of significant inductive of distribution line. The inductive L in the distribution line of one conductor depends on:

- The length of line,
- Physical distance separating the phases,
- Effective radius of the conductors.

From that the inductive reactance is given by

$$X_{line} = \omega L$$

Where ω is the frequency of the system in radius per second, in a distribution there are two technics to consider for technical limitation

- The voltage drop is restricted for the radius of the conductor and its length.
- The thermal limit of line, this restrict the amount of the current that can flows through the conductor.

A conductor with a large cross – sectional area minimize the voltage drop and it increases the capacity of the current flow through it. The voltage drop gives the low voltage at the side of customers, this can lead to a destruction of appliances and equipment connected to the line. It cans also make them malfunction.

$$V_{drop} = |V_s| - |V_r| = |I_s| * |Z_{line}|$$

The voltage drop can also be expressed in percentage %

$$V_{drop, \%} = \frac{V_{drop}}{|V_s|} * 100$$

The voltage drop and power loss are related by not the same. The limit of flow of current is normally associated by heat of conductor, this process is considered as power loss.

$$P_{loss, \emptyset} = |I_s|^2 * R_{line}$$

$$P_{loss, Total} = 3 * P_{loss\emptyset}$$

Where the \emptyset is refer as phase.

There is a certain acceptable level of heat that a conductor can be generated and produce the power loss but this situation can not cause t anneal and mechanical fail of conductor.

3.3. Sub transmission lines

The sub – transmission line are parts of transmission line where they are mostly used to carry the medium level voltage that are stepped down by the electrical cabinet with the objective of supplying electrical energy for medium industries, that are near the main high voltage transmission.



Figure 33: The sub transmission line chuted from main transmission

3.4. LV network

The low voltage networks are the line sides of transformer to the customers with low level voltage which supported by low voltage appliances, the low voltage customers such as home or business are also referred as the service connection or service drop.

The low voltage has two common topologies:

- ❖ The Europeans topology: This topology uses the three phases distribution transformers
- ❖ The Americans topology: Each phase of the distribution line is connected to another conductor which is known as a lateral or split – phase.

3.5. Primary and secondary distribution system

For the distribution system with purpose of transporting electrical energy from generation to the consumers there must be the two types of distribution: the primary distribution and secondary distribution which are going to be explained briefly.

3.5.1. Primary distribution

This distribution system distributes the energy between substation and customers with high level voltage, normal for potential customers with high demand of electrical energy.

The primary distribution has classified into three types:

3.5.1.1. Radial network

In this topology, only one path is used to distribute the electrical energy to the customers this path line is also called the trunk or mainline. The electrical power flows exclusively away from the substation to the customers along a single path, this can be the disadvantage of this topology if the interruption arise in the network the most whole network fails, besides that is the most used topology around worldwide.

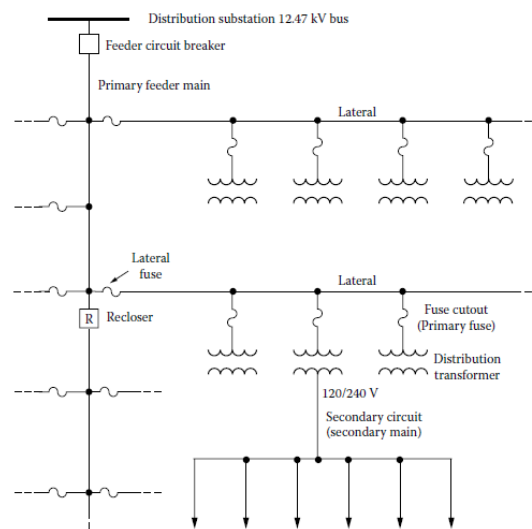


Figure 34: The network with primary distribution single line

3.5.1.2. Loop topology

This type of topology has two pathway to supply the electrical energy to the customers, this guaranty reliable services to the customers, it is also resulting the complication in voltage drop, sizing and protection engineering than radial systems, but the loop system is more reliable than the radial system, the interruption will not affect the majority of the system only the segment with the issues will be out of service.

3.5.2. Secondary distribution

The topology which is normally getting the power energy from the secondary side of transformer distribution and is connected directly to the end of the primary distribution topology, the stepped-down voltage is supplied to the various customers via service line, it is the final subsystem of the power system.

The secondary distribution uses the radial topology in daily life

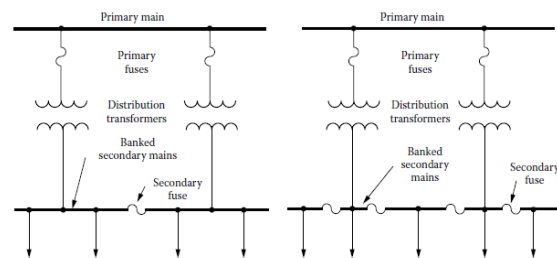


Figure 35: The single diagram of Secondary distribution

Secondary distribution has mainly the two types of network which are:

3.5.2.1. Grid network

Where the network is used for suburban commercial loads over the large zone.

3.5.2.2. Spot network

Where the network is used to serve the concentrated zone of the customers or essential customers such as hospital and commercial buildings.

4. Substation

A substation is a very well occupied house with specific devices, its purpose is to take electrical energy at high-level voltage and transform it in low-level voltage and vice versa into different zone accordingly to the use of the consumers, it is also performing operational and contingency switching, and protection of the lines both of transmission and distribution.

The substations classified into two classifications according to the service and design.

4.1.Types of substation

The substation that classified according to the service are:

- Transmission substation
 - Primary substation
 - Secondary substation
 - Distribution substation
- Industrial substation
- Switching substation
- Synchronous substation
- Frequency change substation
- Converting substation

The substation according to design are:

- Indoor substation
- Outdoor substation
 - Pole mounted substation
 - Foundation mounted substation

All these types of substations have the same purpose of receiving the electrical energy from the primary substation through primary transmission at the high-level voltage and stepping down the voltage for desired voltage required to the customers.

4.2.Mobile Substation

The mobile substation is a portable trailer substation that is well equipped with very high technology power system equipment, that can supply the electrical energy in particular places where the possibility of electrical distribution is limited, and where the space is too small to build the outdoor substation, the mobile substation can be used to quickly restore of electrical energy during an outage caused by disasters.

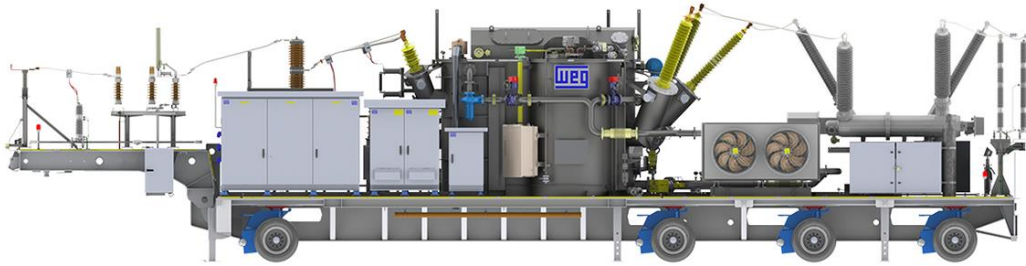


Figure 36: Mobile substation

The mobile substation has the following parts:

- Transformer
- Cooling system
- High voltage switchgear and low voltage
- Metering
- Protection relaying device
- AC/DC Auxiliary
- Surge protector
- Cables connection arrangement

The mobile substation normally used for emergency, new service, and temporary service.

4.3.Metering

Metering is a system used to measure energy consumption in order to provide accurate bills to customers. These devices used to measure are technically called the meters such as Wattmeter, Ampmeter, Voltmeter, and var meter.

- Wattmeter is device used to measure the power consumed by the customers.
- Amp meter is device that used to measure the amperes that are flowing in line.
- Voltmeter is device used to measure the line – to – line voltage and line – to – neutral voltage
- Var meter is device used to measure the reactive power consumed by the customers.

All these devices can be combined in a single device to perform the mentioned purpose at once.

5. Conclusion

The transportation of electrical energy is one of the major parts of the electrical system, this part requires potential engineers in electrical and construction, the more attention on infrastructure for guaranteed results.

The transmission and distribution used the more expensive materials but they are last longer in service, the periodical maintenance is required just for the reliability of the service. This part of the system requires a much more economical budget compared to the other parts of the electrical system and it has a positive impact on development worldwide.

If not disasters on the implemented transmission and distribution they guarantee a long period of service.

In this material, the covered by are the most important in the field of technical and application.

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