# CHAPTER ONE

# INTRODUCTION

## 1.1 Overview:

The conductor system, by means of which electrical energy is conveyed from bulk power source (generating station or major substation supplied over transmission lines) to the consumers, is known as distribution system. The distribution system may be divided into two system known as high voltage (or primary) distribution and low voltage (or secondary) distribution.

Primary distribution system begins from generating station the electrical power is usually transmitted to various substations through extra high tension transmission lines at voltage from 33 to 110 kv. At these substations this voltage is stepped down to 11kv and power at this voltage is conveyed to different substation for distribution and to bulk supply consumers. The voltage employed for primary distribution system depended upon to the amount of power to be conveyed and the distance of the substation required to be fed.

In secondary distribution system the voltage is stepped down to 415 volts between phases and 240 volts between phase and neutral.

Distribution system may be classified in various ways, according to current classified as ac distribution and dc distribution system, according to character of service the distribution system may be classified as general light and power, industrial power, railway and street lighting. According to the type of construction distribution system is already classified to overhead line system and underground distribution system. According to the number of wires distribution system is classified to two wire system, three wire system and four wire system. Finally according to the scheme connection the distribution system may be classified as radial, parallel, ring and interconnected distribution system. [1]

Power generated in power stations pass through large and complex networks like transformers , overhead lines, cables and others equipment and reach at the end users.it is fact that the unit of electric energy generated by power stations dose not match with unit distributed to consumers. Some percentage of the units is lost in the distribution network. This difference in generated and distributed is known as transmission and distribution losses and these losses are not paid for by users. And there are two types' technical and nontechnical losses.

Technical losses are due to energy dissipated in the conductors, equipment used for transmission lines, sub transmission lines, transformers and distribution lines and magnetic losses and directly depend on network characteristics and mode of operation .the major amount of losses in a power system is in primary and secondary distribution lines .while transmission and sub transmission lines account for only about 30%of total losses.

There are two types of technical losses. Losses do not vary according to current called a fixed loss it's between ¼ and 1/3 of technical losses on distribution networks. And other varies with the amount of electricity distributed and is more precisely, proportional to the square of the current.

The main reasons for technical losses are length and size of distribution lines and feeders' cables, low power factor of primary and secondary distribution system, transformers size and selection, load factor, balancing three phase loads and over loading of lines [2].

## 1.2 Problem Statement:

- Transformer losses cause by low value of power factor
- Cables Losses cause by low value of power factor.

## 1.3 Objectives:

- Making a case study of (Alsahafa 28 compound) determining the cause of losses in the grid.
- Improving power factor for grid in case that had been studied as mentioned.
- A recommendation of suitable cross section area for cables and conductor has been proposed to Distribution Company.
- An optimization of grid transformer have been made and proposed as recommendation to Jabra Distribution Centre.

## 1.4 Methodology:

A side visit had been done to "Jabra distribution center", and distribution problems have been detected. And optimization of distribution system has been done by mathematical equations and practical measurements.

## 1.5 Project Outline:

- **Chapter one:** Include an introduction of distribution system, problem statement and the objectives of research.
- **Chapter two**: review the component of distribution system
- **Chapter three:** show the methodology measurements and calculation
- **Chapter four**: this chapter mainly to present the have calculation and measured
- **Chapter five**: include the conclusion

# CHTAPTER TWO

# Overview

## 1.1 Introduction:

The main consideration of distribution systems, as intermediate media between the subtransmission systems and the customer's premises, is to maximize the utilization of electric energy to supply the end users with energy in a secure and efficient manner. Several circuits feed customers at different locations, in comparison to the transmission and sub transmission systems, which have only a few circuits. Distribution systems have to cater to a large variety of customers with significantly different demand patterns[4]

Electric power distribution is the portion of the power delivery infrastructure that takes the electricity from the highly meshed, high-voltage transmission circuits and delivers it to customers. Primary distribution lines are "medium-voltage" circuits, normally thought of as 600 V to 35 kV. At a distribution substation, a substation transformer takes the incoming transmission-level voltage (35 to 230 kV) and steps it down to several distribution primary circuits, which fan out from the substation. Close to each end user, a distribution transformer takes the primary-distribution voltage and steps it down to a low-voltage secondary circuit (commonly 120/240 V; other utilization voltages are used as well). From the distribution transformer, the secondary distribution circuits connect to the end user where the connection is made at the service entrance. Figure 1.2 shows an overview of the power generation and delivery infrastructure and where distribution fits in. Functionally, distribution circuits are those that feed customers (this is how the term is used in this book, regardless of voltage or configuration). Some also think of distribution as anything that is radial or anything that is below 35 kV.

The distribution infrastructure is extensive; after all, electricity has to be delivered to customers concentrated in cities, customers in the suburbs, and customers in very remote regions; few places in the industrialized world do not have electricity from a distribution system readily available. Distribution circuits are found along most secondary roads and streets. Urban construction is mainly underground; rural construction is mainly overhead. Suburban structures are a mix, with a good deal of new construction going underground. [3]

Distribution planning is the study of future power delivery needs. Planning goals are to provide service at low cost and high reliability. Planning requires a mix of geographic, engineering, and economic analysis skills. New circuits (or other solutions) must be integrated into the existing distribution system within a variety of economic, political, environmental, electrical, and geographic constraints. The planner needs estimates of load growth, knowledge of when and where development is occurring, and local development regulations and procedures. While this book has some material that should help distribution planners, many of the tasks of a planner, like load forecasting, are not discussed.

Distribution systems represent an important parts in the electrical grids and for this reasons the electrical companies delicate approximately 40% of the capital investment for distribution systems, while the remaining amount is given to generation and transmission (40% generation & 20% transmission. The distribution system is particularly important for an electrical utility for two reasons; it is the close part to the customers and any failure in distribution system affect the customers directly. For example failures in transmission and generation sections may not cause customers service interruptions, its high investment cost

The main distribution components are sub transmission system, distribution substation, transformers and cables and conductors.

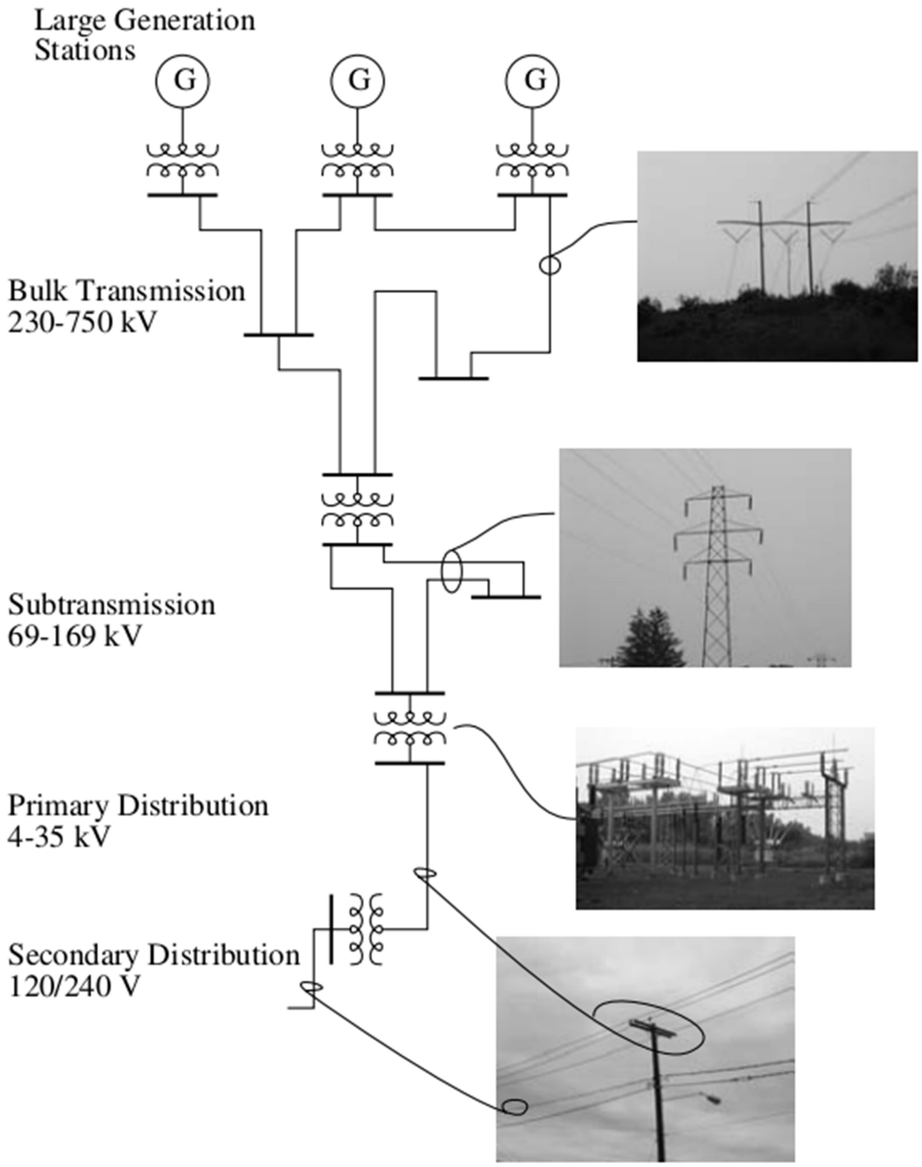


**Figure (2.1): Overview of the electricity infrastructure**

## 1.2 Sub transmission system:

Sub transmission systems are those circuits that supply distribution substations. Several different sub transmission systems can supply distribution substations. Common sub transmission voltages include 34.5, 69, 115, and 138 kV. Higher voltage sub transmission lines can carry more power with fewer losses over greater distances. Distribution circuits are occasionally supplied by high-voltage transmission lines such as 230 kV; such high voltages make for expensive high-side equipment in a substation. sub transmission circuits are normally supplied by bulk transmission lines at sub transmission substations. For some utilities, one transmission system serves as both the sub transmission function (feeding distribution substations) and the transmission function (distributing power from bulk generators). There is much crossover in functionality and voltage. One utility may have a 23-kV sub transmission system supplying 4-kV distribution substations. Another utility right next door may have a 34.5-kV distribution system fed by a 138kV sub transmission system. And within utilities, one can find a variety of different voltage combinations. Of all of the sub transmission circuit arrangements, a radial configuration is the simplest and least expensive (see Figure 2.2). But radial circuits provide the most unreliable supply; a fault on the sub transmission circuit provide the most unreliable supply; a fault on the sub transmission circuit. [3]

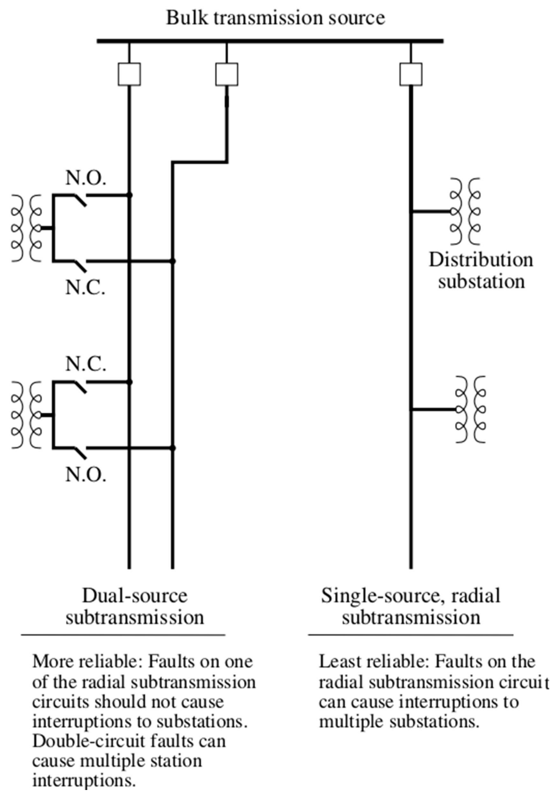


**Figure (2.2): Shows Radial sub transmission systems**

can force an interruption of several distribution substations and service to many customers. A variety of redundant sub transmission circuits are available, including dual circuits and looped or meshed circuits (see Figure 1.16). The design (and evolution) of sub transmission configurations depends on how the circuit developed, where the load is needed now and in the future, what the distribution circuit voltages are, where bulk transmission is available, where rights-of-way are available, and, of course, economic factors. Most sub transmission circuit's is overhead. Many are built right along roads and streets just like distribution lines. Some — especially higher voltage sub transmission circuits — use a private right-of-way such as bulk transmission lines use. Some new sub transmission lines are put underground, as development of solid-insulation cables has made costs more reasonable.

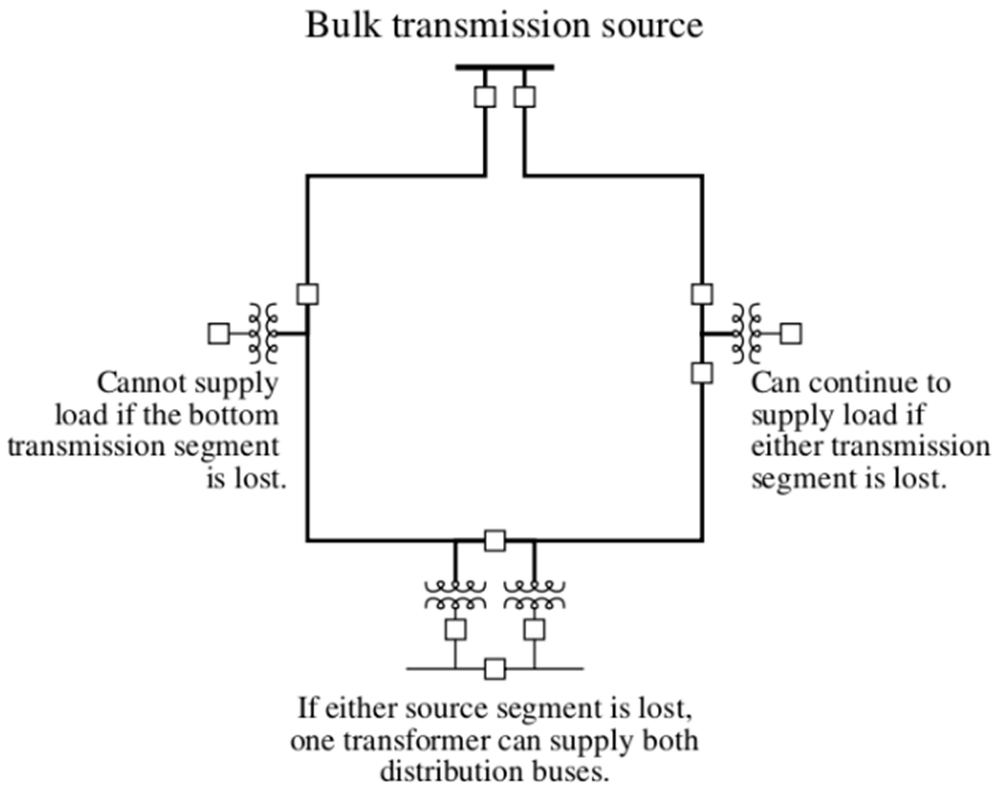


**Figure (2.3): Shows looped Sub transmission systems**

Lower voltage sub transmission lines (69, 34.5, and 23 kV) tend to be designed and operated as are distribution lines, with radial or simple loop arrangements, using wood-pole construction along roads, with recloses and regulators, often without a shield wire, and with time-overcurrent protection. Higher voltage transmission lines (115, 138, and 230 kV) tend to be designed and operated like bulk transmission lines, with loop or mesh arrangements, tower configurations on a private right-of-way, a shield wire or wires for lightning protection, and directional or pilot-wire relaying from two ends. Generators may or may not interface at the sub transmission level (which can affect protection practices).[3]

## 1.3 Distribution substations:

Distribution substations come in many sizes and configurations. A small rural substation may have a nominal rating of 5 MVA while an urban station may be over 200 MVA. Figure (2.4) through Figure (2.5) show examples of small, medium, and large substations. As much as possible, many utilities have standardized substation layouts, transformer sizes, relaying systems, and automation and SCADA (supervisory control and data acquisition) facilities. Most distribution substation bus configurations are simple with limited redundancy. Transformers smaller than 10 MVA are normally protected with fuses, but fuses are also used for transformers to 20 or 30 MVA. Fuses are inexpensive and simple; they don't need control power and take up little space. Fuses are not particularly sensitive, especially for evolving internal faults. Larger transformers normally have relay protection that operates a circuit switcher

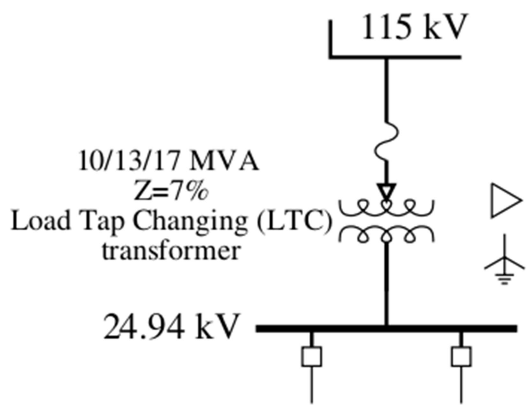


**Figure (2.4):Rural  distribution substation**

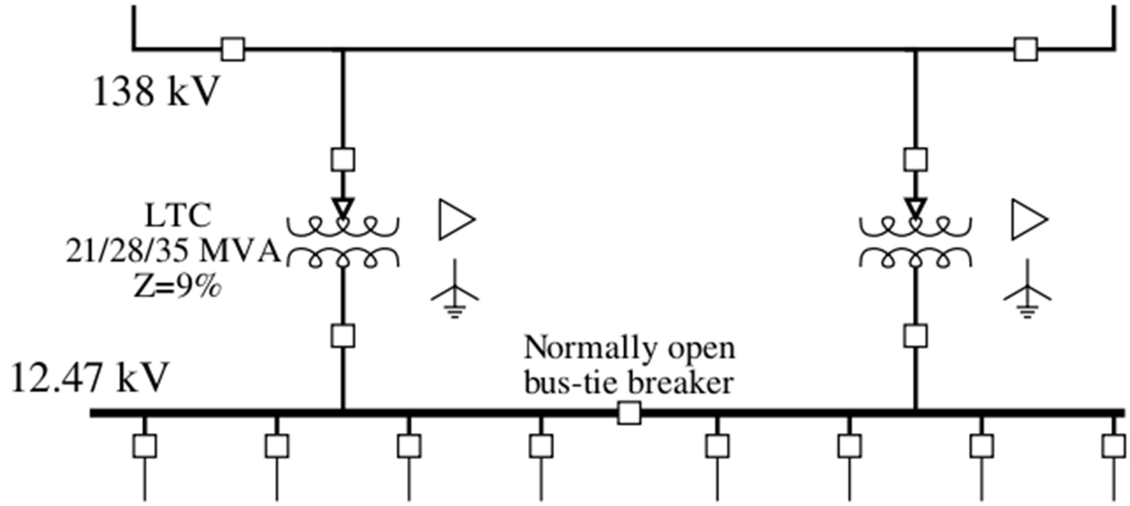


**Figure (2.5): shows suburban distribution substation**

or a circuit breaker. Relays often include differential protection, suddenpressure relays, and overcurrent relays. Both the differential protection and the sudden-pressure relays are sensitive enough to detect internal failures and clear the circuit to limit additional damage to the transformer. Occasionally, relays operate a high-side grounding switch instead of an interrupter. When the grounding switch engages, it creates a bolted fault that is cleared by an upstream device or devices. The feeder interrupting devices are normally relayed circuit breakers, either free-standing units or metal-enclosed switchgear. Many utilities also use recloses instead of breakers, especially at smaller substations. Station transformers are normally protected by differential relays which trip if the current into the transformer is not very close to the current out of the transformer. Relaying may also include pressure sensors. The highside protective device is often a circuit switcher but may also be fuses or a circuit breaker. Two-bank stations are very common (Figure 1.13); these are the standard design for many utilities. Normally, utilities size the transformers so that if either transformer fails, the remaining unit can carry the entire substation's load. Utility practices vary on how much safety margin is built into this calculation, and load growth can eat into the redundancy

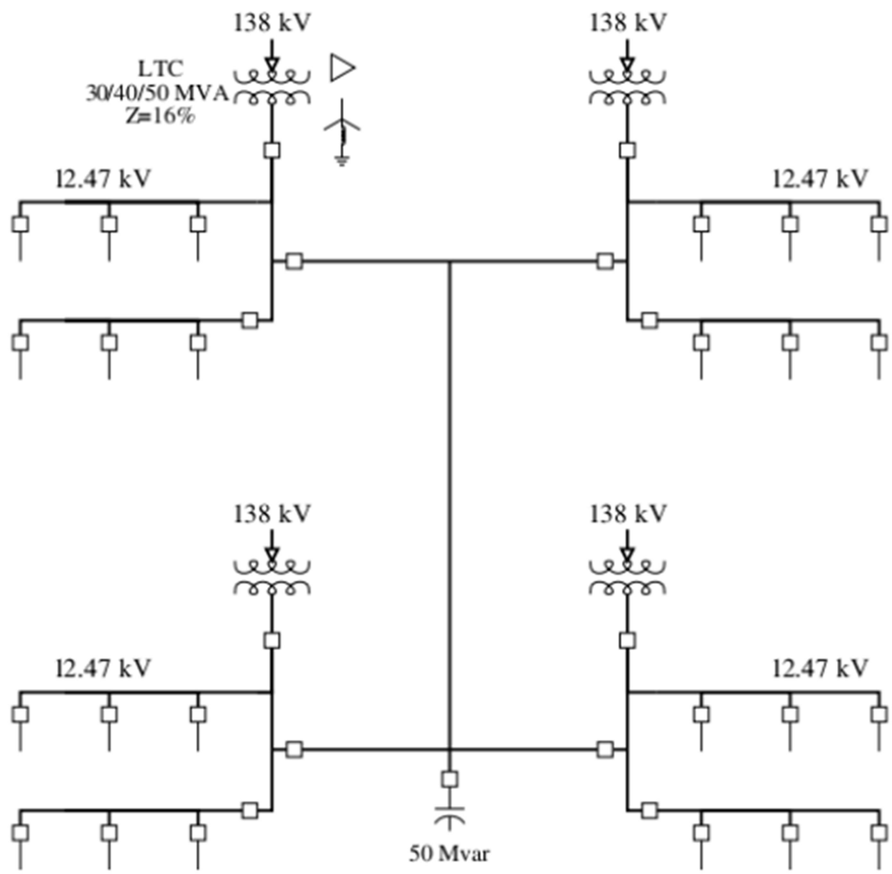


**Figure (2.6): Urban distribution substation**

Most utilities normally use a split bus: a bus tie between the two buses is normally left open in distribution substations. The advantages of a split bus are:

- Lower fault current — this is the main reason that bus ties are open. For a two-bank station with equal transformers, opening the bus tie cuts fault current in half.
- Circulating current — with a split bus, current cannot circulate through both transformers.
- Bus regulation — Bus voltage regulation is also simpler with a split bus. With the tie closed, control of paralleled tap changers is more difficult.

Having the bus tie closed has some advantages, and many utilities use closed ties under some circumstances. A closed bus tie is better for

- Secondary networks — when feeders from each bus supply either spot or grid secondary networks, closed bus ties help prevent circulating current through the secondary networks.
- Unequal loading — a closed bus tie helps balance the loading on the transformers. If the set of feeders on one bus has significantly different loading patterns (either seasonal or daily), then a closed bus tie helps even out the loading (and aging) of the two transformers.

Whether the bus tie is open or closed has little impact on reliability. In the uncommon event that one transformer fails, both designs allow the station to be reconfigured so that one transformer supplies both bus feeders. The closed-tie scenario is somewhat better in that an automated system can reconfigure the ties without total loss of voltage to customers (customers do see a very large voltage sag). In general, both designs perform about the same for voltage sags. Urban substations are more likely to have more complicated bus arrangements. These could include ring buses or breaker-and-a-half schemes. Figure 1.14 shows an example of a large urban substation with feeders supplying secondary networks. If feeders are supplying secondary networks, it is not critical to maintain continuity to each feeder, but it is important to prevent loss of any one bus section or piece of equipment from shutting down the network (an N-1 design). For more information on distribution substations, see (RUS 1724E-300, 2001; Westinghouse Electric Corporation, 1965).[3]

## 1.4 Distribution Transformers:

Determines the customer's voltages and grounding configuration. Distribution transformers are from a few kVA to a few MVA, distribution transformers convert primary voltage to low voltage that customers can use. In North America, 40 million distribution transformers are in service, and another one million are installed each year (Alexander Publications, 2001). The transformer connection available in several standardized sizes as shown in Table 4.2. Most installations are single phase.

## Table (2.1):

**Standard distribution transformers size**

| **Distribution transformer standard ratings, kvA** | |
|---|---|
| **Single phase** | 5, 10, 15, 25, 37.5, 50, 75, 100,167, 250, 333, 500 |
| **Three phase** | 30, 45, 75, 112.5, 150, 225,300,500 |

## Table (2.2)

**Insulation Levels for Distribution Transformers**

| Low frequency Test Levels KVrms | Basic Lightning Impulse Insulation Levels KV Crest | Chopper Wave Impulse Levels: Minimum voltage KV Crest | Chopper Wave Impulse Levels: Minimum Time to Flashovers |
|---|---|---|---|
| 10 | 30 | 36 | 1.0 |
| 15 | 45 | 54 | 1.5 |
| 19 | 60 | 69 | 1.5 |
| 26 | 75 | 88 | 1.6 |
| 34 | 95 | 110 | 1.8 |
| 40 | 125 | 145 | 2.25 |
| 50 | 150 | 175 | 3.0 |
| 70 | 200 | 230 | |

The most common overhead transformer is the 25-kVA unit; pad mounted transformers tend to be slightly larger where the 50-kVA unit is the most common. Distribution transformer impedances are rather low. Units under 50 kVA have impedances less than 2%. Three-phase underground transformers in the range of 750 to 2500 kVA normally have 5.75% impedance as specified in (ANSI/IEEE C57.12.24-1988). Lower impedance transformers provide better voltage regulation and less voltage flicker for motor starting or other fluctuating loads. But lower impedance transformers increase fault currents on the secondary and secondary faults impact the primary side more (deeper voltage sags and more fault current on the primary). Standards specify the insulation capabilities of distribution transformer windings (see Table 4.3). The low-frequency test is a power-frequency (60 Hz) test applied for one minute. The basic lightning impulse insulation level (BIL) is a fast impulse transient. The front-of-wave impulse levels are even shorter-duration impulses. The through-fault capability of distribution transformers is also given in IEEE C57.12.00-2000 (see Table 4.4). The duration in seconds of the short-circuit capability is [3]:

$$t = \frac{1250}{I^2}$$

Anything on the ground or in the ground, Pad mounted transformers tend to corrode where I is the symmetrical current in multiples of the normal base current from Table 4.4. Overhead and pad mounted transformer tanks are normally made of mild carbon steel. Corrosion is one of the main concerns, especially for

**Table (2.3)**

Thought Fault Capability of Distribution Transformers

| Single_Phas Rating KVA | Three Phase Rating KVA | Withstand Capability in per Unit of Base Current (Symmetrical) |
|---|---|---|
| 5_25 | 15-75 | 40 |
| 37.5_110 | 112.5-300 | 35 |
| 167_500 | 500 | 25 |

Source: IEEE Std.C57.1200-2000, IEEE Standard General Requirement for Liquid-Immersed Distribution, Power, and Regulating Transformers.

Near the base (where moisture and dirt and other debris may collect). Submersible units, being highly susceptible to corrosion, are often stainless steel. Distribution transformers are "self-cooled"; they do not have extra cooling capability like power transformers. They only have one kVA rating. Because they are small and because customer peak loadings are relatively short duration, overhead and pad mounted distribution transformers have significant overload capability. Utilities regularly size them to have peak loads exceeding 150% of the nameplate rating. Transformers in underground vaults are often used in cities, especially for network transformers (feeding secondary grid networks). In this application, heat can be effectively dissipated (but not as well as with an overhead or padmounted transformer). Subsurface transformers are installed in an enclosure just big enough to house the transformer with a grate covering the top. A "submersible" transformer is normally used, one which can be submerged in water for an extended period (ANSI/IEEE C57.12.80-1978). Heat is dissipated through the grate at the top. Dirt and debris in the enclosure can accelerate corrosion. Debris blocking the grates or vents can overheat the transformer. Direct-buried transformers have been attempted over the years. The main problems have been overheating and corrosion. In soils with high electrical and thermal resistivity, overheating is the main concern. In soils with low electrical and thermal resistivity, overheating is not as much of a concern, but corrosion becomes a problem. Thermal conductivity in a direct-buried transformer depends on the thermal conductivity of the soil. The buried transformer generates enough heat to dry out the surrounding soil; the dried soil shrinks and creates air gaps. These air gaps act as insulating layers that further trap heat in the transformer.

### 2.4.1 Transformer Losses:

Transformer losses are an important purchase criterion and make up an appreciable portion of a utility's overall losses. The Oak Ridge National Laboratory estimates that distribution transformers account for 26% of transmission and distribution losses and 41% of distribution and sub transmission losses (ORNL-6804/R1, 1995). At one utility, Grainger and Kendrew (1989) estimated that distribution transformers were 55% of distribution losses and 2.14% of electricity sales; of the two main contributors to losses, 86% were no-load losses, and 14% were load losses. Load losses are also called copper or wire or winding losses. Load losses are from current through the transformer's windings generating heat through the winding resistance as I2R. No-load losses are the continuous losses of a transformer, regardless of load. No-load losses for modern silicon-steel-core transformers average about 0.2% of the transformer rating (a typical 50-kVA transformer has no-load losses of 100 W), but designs vary from 0.15 to 0.4% depending on the needs of the utility. No-load losses are also called iron or core losses because they are mainly a function of the core materials. The two main components of no-load losses are eddy currents and hysteresis. Hysteresis describes the memory of a magnetic material. More force is necessary to demagnetize magnetic material than it takes to magnetize it; the magnetic domains in the material resist realignment. Eddy current losses are small circulating currents in the core material. The steel core is a conductor that carries an alternating magnetic field, which induces circulating currents in the core. These currents through the resistive conductor generate heat and losses. Cores are typically made from cold-rolled, grain-oriented silicon steel laminations. Manufacturers limit eddy currents by laminating the steel core in 9- to 14-mil thick layers, each insulated from the other. Core losses increase with steady-state voltage. Hysteresis losses are a function of the volume of the core, the frequency, and the maximum flux density (Sankaran, 2000):

$$P_k = V_e \, f \, B^{1.6} \qquad (2.1)$$

Where

Ve = volume of the core

f = frequency

B = maximum flux density

The eddy-current losses are a function of core volume, frequency, flux density, lamination thicknesses, and resistivity of the core material (Sankaran, 2000):[3]

$$P_e = V_e = B^2 f^2 \frac{t^2}{r} \qquad (2.2)$$

Where

t: thickness of the lamination

r : resistivity of the core material

## 2.5 Overhead Lines:

Along streets, alleys, through woods, and in backyards, many of the distribution lines that feed customers are overhead structures. Because overhead lines are exposed to trees and animals, to wind and lightning, and to cars and kites, they are a critical component in the reliability of distribution circuits. This chapter discusses many of the key electrical considerations of overhead lines: conductor characteristics, impedances, capacity, and other issues.

Overhead constructions come in a variety of configurations (see Figure( 2.7). Normally one primary circuit is used per pole, but utilities sometimes run more than one circuit per structure. For a three-phase circuit, the most common structure is a horizontal layout with an 8- or 10-ft wood cross arm on a pole. Armless constructions are also widely found where fiberglass insulator standoffs or post insulators are used in a tighter configuration. Utilities normally use 30- to 45-ft poles, set 6 to 8 ft deep. Vertical construction is also occasionally used. Span lengths vary from 100 to 150 ft. In suburban areas to as much as 300 or 400 ft. in rural areas. A distribution circuit normally has an underbuilt neutral — the neutral acts as a safety ground for equipment and provides a return path for unbalanced loads and for line-to-ground faults. The neutral is 3 to 5 ft. below the phase conductors. Utilities in very high lightning areas may run the neutral wire above the phase conductors to act as a shield wire. Some utilities also run the neutral on the cross arm. Secondary circuits are often run under the primary. The primary and the secondary may share the neutral, or they may each have their own neutral. Many electric utilities share their space with other utilities; telephone or cable television cables may run under the electric secondary.

**Figure (2.7): overhead distribution structures**

A wire is metal drawn or rolled to long lengths, normally understood to be a solid wire. Wires may or may not be insulated. A conductor is one or more wires suitable for carrying electric current. Often the term wire is used to mean conductor. Table 2.1 shows some characteristics of common conductor metals. Most conductors are either aluminum or copper. Utilities use aluminum for almost all new overhead installations. Aluminum is lighter and less expensive for a given current-carrying capability. Copper was installed more in the past, so significant lengths of copper are still in service on overhead circuits. Aluminum for power conductors is alloy 1350, which is 99.5% pure and has a minimum conductivity of 61.0% IACS [for more complete characteristics, see the Aluminum Electrical Conductor Handbook (Aluminum Association, 1989)]. Pure aluminum melts at 660∞C. Aluminum starts to anneal1.5.5 Conductors Data:

**Table (2.4):**

Nominal or Minimum Properties of Conductor Wire Materials

| Property | International Annealed Copper Standard | Commercial Hard-Drawn Copper Wire | Standard 1350-H19 Aluminum Wire | Standard 6201-T81 Aluminum Wire | Galvanized Steel Core Wire | Aluminum Clad Steel |
|---|---|---|---|---|---|---|
| Conductivity,% IACS at 20°C | 100.0 | 97.0 | 61.2 | 52.5 | 8.0 | 20.3 |
| Resistivity at 20°C, Ω·in.²/1000 ft | 0.008145 | 0.008397 | 0.013310 | 0.015515 | 0.101819 | 0.04007 |
| Ratio of weight for equal dc resistance and length | 1.00 | 1.03 | 0.50 | 0.58 | 9.1 | 3.65 |
| Temp. coefficient of resistance, per °C at 20°C | 0.00393 | 0.00381 | 0.00404 | 0.00347 | 0.00327 | 0.00360 |
| Density at 20°C, lb/in.³ | 0.3212 | 0.3212 | 0.0977 | 0.0972 | 0.2811 | 0.2381 |
| Coefficient of linear expansion, $10^{-6}$ per °C | 16.9 | 16.9 | 23.0 | 23.0 | 11.5 | 13.0 |
| Modulus of elasticity, $10^6$ psi | 17 | 17 | 10 | 10 | 29 | 23.5 |
| Specific heat at 20°C, cal/gm-°C | 0.0921 | 0.0921 | 0.214 | 0.214 | 0.107 | 0.112 |
| Tensile strength, $10^3$ psi | 62.0 | 62.0 | 24.0 | 46.0 | 185 | 175 |
| Minimum elongation,% | 1.1 | 1.1 | 1.5 | 3.0 | 3.5 | 1.5 |

*Source:* Southwire Company, *Overhead Conductor Manual*, 1994.

## 2.6 Cables:

At the center of a cable is the phase conductor, then comes a semiconducting conductor shield, the insulation, a semiconducting insulation shield, the neutral or shield, and finally a covering jacket. Most distribution cables are single conductor. Two main types of cable are available: concentric-neutral cable and power cable. Concentric-neutral cable normally has an aluminum conductor, an extruded insulation, and a concentric neutral (Figure 3.2 shows a typical construction). A concentric neutral is made from several copper wires wound concentrically around the insulation; the concentric neutral is a true neutral, meaning it can carry return current on a grounded system. Underground residential distribution normally has concentric-neutral cables; concentric-neutral cables are also used for three-phase mainline applications and three-phase power delivery to commercial and industrial customers. Because of their widespread use in URD, concentric-neutral cables are often called URD cables. Power cable has a copper or aluminum phase

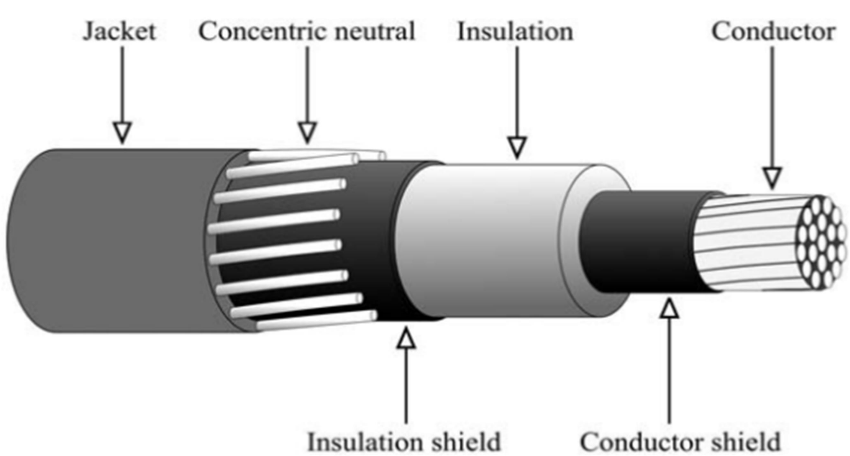


**Figure (2.8): Shows underground cable structure**

Conductor, an extruded insulation, and normally a thin copper tape shield. On utility distribution circuits, power cables are typically used for mainline feeder applications, network feeders, and other high current, three-phase applications. Many other types of medium-voltage cable are available. These are sometimes appropriate for distribution circuit application: three-conductor power cables, armored cables, aerial cables, fire-resistant cables, extra flexible cables, and submarine cables.

## 2.7 power factor correction

A high power factor is generally desirable in a transmission system to reduce transmission losses and improve voltage regulation at the load. It is often desirable to adjust the power factor of a system to near 1.0. When reactive elements supply or absorb reactive power near the load, the apparent power is reduced. Power factor correction may be applied by an electric power transmission utility to improve the stability and efficiency of the transmission network. Individual electrical customers who are charged by their utility for low power factor may install correction equipment to reduce those costs. In many industrial applications, the problems associated with thermistor based systems like huge space requirement; bulkiness, lower power factor and lower efficiency have largely been eliminated with the advent of switched mode power supply technologies. The SMPS technology has many added advantages like higher efficiency, reduced harmonics and improved ripple noise.

An electrical system with Power Factor Correction circuit gives reduced harmonics and distortion. It gives improvement in power factor of the electrical system but the efficiency increases with increase in load current. The circuit without PFC is prone to harmonics, distortion and current peaks but gives better efficiency at higher load currents unlike circuits with PFC.[6]

# CHABTER THREE

# METHODOLOGY

## 3.1 Introduction:

At this chapter a study of particular grid by visiting “Alsahafa 28 compound ”, at this visit loss of the grid have been detected and other optimizations of transformer, cables and power factor improvement device will be proposed to reduce the losses. All this optimization have been done by mathematical equations

## 3.2 Site visit

A visit to “Jabra Distribution Centre” to collect data about transformer losses, conductors and cables size.

## 3.3 Transformer losses:

Transformer losses are produced by the electrical current flowing in the coil and the magnetic field alternating in the core. The losses associated with the coil are called the load losses, while the loss produced in the core are called no load losses

### 3.3.1 No load loss:

Losses are caused by the magnetizing current needed to energize the core of the transformer, and do not vary according to the loading on the transformer and its constant. And this loss consist from hysteresis loss, eddy current loss and dielectric loss. These losses calculated by no load test

#### 3.3.1.1 Hysteresis losses:

The hysteresis losses can be calculated by this equation

$$W_h = K_h \, B_{max}^{1.6} \, f \, v \qquad (3.1)$$

$W_h$ : Hysteresis losses, W

$K_h$ : Constant depended on magnetic material

$B_{max}$: maximum value of flux density in the core, Tesla

f: frequency, Hz

v: operating rms voltage, V

Hysteresis losses cause by fraction between material molecules and change in polarity at each magnetic field cycle. This losses can be reduce by using patter magnetize material

### 3.3.1.2 Eddy current loss:

When the magnetic flux cross iron core an eddy current is produced at iron core and cause losses called eddy current losses. These losses equal 50% of core losses

$$W_e = K_e B_{max}^2 f^2 \qquad (3.2)$$

$W_e$: eddy current losses

$B_{max}$: maximum magnetic flux, Tesla

F: applied frequency, Hz

$K_e$: Constant depends on sheet thickness.

### 3.3.1.3 Dielectric loss:

Materials which are used to insulated the conductors produced stray capacitors, which different from ideal capacitors and it's have resistance effect distribution factor

$$P_d = 2\pi\, f v^2 c \;\; tand \qquad (3.3)$$

$P_d$: dielectric losses, W

f: applied frequency, Hz

c: capacitance, F

v: operating voltage rms, V

Tanβ: dissipation factor

### 3.3.2 Load losses:

Load losses are caused by the winding impedance and vary according to the loading on the transformer. And it's divided into two parts, losses

### 3.3.3 Copper losses:

Load losses vary according to the loading on the transformer. They include heat loss and eddy currents in the primary and secondary conductors of the transformer.

A heat loss calculate from this equation

$$P = I^2\, R \qquad (3.4)$$

P: copper loss

I: current

R: resistance

This loss reduced by use conductors with low resistance

## 3.4 Power factor correction:

Power factor improvement has to be done by adding power factor correction capacitors to the plant distribution system. When apparent power (KVA) is greater than working power (Kw), the utility must supply the excess reactive current.

$$Q_c = P(tan\emptyset_1 - tan\emptyset_2) \qquad (3.5)$$

Where

$Q_c$: compensator power (KVA)

P: Active power (Kw)

$\Phi_1$ and $\Phi_2$: Phase angle after and before improvement

$$C = \frac{Q_c}{2\pi f v^2} \qquad (3.6)$$

Where

C: capacity, μF

f: frequency, Hz

v: operating voltage, V

## 3.5 Cables loss:

This loss occurs when current flowing through cable and its depended on length and material cable.

This loss calculated from equation (3.4)

$$P = RI^2$$

Where

P: loss power in cable, Kw

R: cable resistance, Ω

I: current, A

$$R = \frac{\rho l}{A} \qquad (3.7)$$

Where

R: Resistance for cable, Ω

$\rho$ : Resistivity, Ω/m

L: length of cable, m

A: area of cable, $m^2$

# CHAPER FOUR

# JEBRA DISTURBUTION CENTER

## 4.1 Introduction:

In order to get the result in table (3), no load and short circuit test have been done to transformer in chapter five in figure (5.1), and to calculate the result in table (1) and table (2) we use the current value in table (3) with equation (3.4)

## 4.2 Case study:

In Jabra distribution center we detect problems in power factor correction and underground cable for transformer and to solve this problem we proposed the flowing solution.

## 4.3 Power Factor Correction Calculation:

To calculate the capacity this used to improve the power factor e use equation (3.5) and table (4.3)

For line one

From table (4.3)

P1 =157.96 Kw, $\emptyset_1$ =42.26 degree $\emptyset_2$= 16.260 degree

V1=419.5 V, f = 50.042 Hz, Pf= 0.74

Qc= P1 (tan$\emptyset_1$ - tan$\emptyset_2$)

Qc = 157.96(tan42.27-tan16.260) = 97.5 KVAR

From equation (3.6)

$C_1 = \frac{Q_c}{2\pi f v^2}$

$C_1 = 97.5*1000/2\pi*50.0428*419.5^2 = 1762.05\mu F$

For line two

$P_2 = 166.24$ Kw,   Pf= 0.74, $\emptyset_1 = 42.26$ degree   $\emptyset_2 = 16.260$ degree

$V_1 = 416.89$ V, f = 50.042

From equation (3.5)

Qc = 166.24(tan (42.26) - tan (16.260)) =102.62 KVAR

Used equation (3.6)

$C_2 = \frac{Q_c}{2\pi f v^2}$

$C_2 = 102.62*1000/2\pi*50.042*416.89^2 = 1877.9\ \mu F$

For line three

$P_3 = 168.78$ Kw, Pf = 0.79,  $\emptyset_1 = 37.81$ degree,   $\emptyset_2 = 16.260$ degree

$V_3 = 416.54$ V, f = 50.042 Hz

From equation (3.5)

Qc =168.78 (tan (37.81) - tan (16.260)) =81.74 KVAR

Used equation (3.6)

$C_3 = \frac{Q_c}{2\pi f v^2}$

$C_3 = 81.74*1000/2\pi*50.042*416.54^2 = 1498.327\ \mu F$

## 4.3 Cable loss calculations:

By using equation (3.5) and table (1)

The resistance of cable is

R= $\frac{1.77*10^{-8}*15}{95*10^{-6}}$ = 0 .002795 Ω

By using equation (3.4) and table (2) the losses in cables for three lines:

Before correction (Pf = .76)

For $L_1$

$P_1$= $852.1^2 * .002795$ = 2.029 Kw

For $L_2$

$P_2$ =$897.7^2 * .002795$ = 2.2524 Kw

For $L_3$

$P_3$ = $858.6^2 * .002795$ = 2.06 Kw

For neutral

$P_n$ = $162.6^2 * .002795$ = 0.074 Kw

After correction ( pf = .96)

Loss in $L_1$

$P_1$= $661.6^2 * .002795$ = 1.223 Kw

For $L_2$

$P_2$ = $68105^2 * .002795$ = 1.298 Kw

For $L_3$

$P_3$ = $746.7^2 * 0.002795$ =1.558 Kw

For neutral

$P_n = 144.1^2 * 0.002795 = 0.05804$

**Table (4.1):** shows the cable loss before power factor correction

| No.line | $P_{loss}$ (Kw) |
|---|---|
| L1 | 2.029 |
| L2 | 2.252 |
| L3 | 2.060 |
| Ln | 0.074 |

**Table (4.2):** shows the cable loss after power factor correction

| No.line | $P_{loss}$ (Kw) |
|---|---|
| L1 | 1.223 |
| L2 | 1.298 |
| L3 | 1.558 |
| Ln | 0.058 |

**Table (4.3)** Transformer Short Circuit and No Load Test Data

| Without compensator | | | | | With compensator | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Voltage | | L1 | L2 | L3 | Voltage | | L1 | L2 | L3 |
| (rms) | | 419.5 | 416.89 | 416.54 | (rms) | | 429.27 | 430.05 | 426.81 |
| Amps | L1 | L2 | L3 | N | Amps | L1 | L2 | L3 | N |
| | 852.1 | 897.7 | 858.6 | 162.6 | | 661.5 | 581.5 | 746.7 | 144.1 |
| TOTAL(KW) | | L1 | L2 | L3 | TOTAL(KW) | | L1 | L2 | L3 |
| 482.670 | | 157.960 | 166.240 | 168.780 | 497.820 | | 158.780 | 163.850 | 175.20 |
| TOTAL(KVAR) | | L1 | L2 | L3 | TOTAL(KVAR) | | L1 | L2 | L3 |
| 394.440 | | 134.460 | 140.060 | 121.940 | 130.020 | | 41.520 | 39.180 | 54.750 |
| TOTAL(KVA) | | L1 | L2 | L3 | TOTAL(KVA) | | L1 | L2 | L3 |
| 614.040 | | 205.870 | 216.00 | 205.510 | 515.190 | | 162.620 | 168.510 | 183.310 |
| P.F | | L1 | L2 | L3 | P.F | | L1 | L2 | L3 |
| 0.76 | | 0.74 | 0.74 | 0.79 | 0.96 | | 0.96 | 0.96 | 0.96 |
| THD% | | L1 | L2 | L3 | THD% | | L1 | L2 | L3 |
| (voltage) | | 1.28 | 1.31 | 1.35 | (voltage) | | 1.92 | 1.96 | 2.09 |
| THD% | | L1 | L2 | L3 | THD% | | L1 | L2 | L3 |
| (Current) | | 3.66 | 5.38 | 5.09 | (Current) | | 9.59 | 12.67 | 11.65 |
| Frequency (Hz) | | 50.042 | | | Frequency (Hz) | | 50.031 | | |

## 4.4 Result discussion:

A result shown in table (4.1) and table (4.2) we found the power factor improved we note that the losses in table (4.2) after power factor corrected to 0.96 less than the losses in table (4.1) and the no load losses and load losses with compensator less than no load losses and load losses without compensator.

# CHAPTER FIVE

# CUNCLUSION AND RECOMMENDATION

## 5.1 Conclusion:

Sudanese national grid suffers from main problem, this problem is electrical power losses, and it's referred to the difference between the magnitude of power generated and power consumed. The need for reducing electrical power losses either in transmission or distribution is came from the high cost that the utility incurs.

## 5.2 Recommendation:

Some recommendations for transformer design are mentioned below:

Use power factor improvement device to reduce no-load and load losses for transformer and also reduce line current in secondary side as a result the loss in cable and conductor reduced and Select the suitable location for the transformer to avoid long cable length and conductor.

To improve the factor in lines we need to connect capacitor with capacity ($C_1$ =1762.05μF) for line one, and ($C_2$ =1877.9 μF) for line two and ($C_3$ = 1498.327 μF) connect in parallel with lines.

# References:

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[7] المرجع في محولات القوى الكهربائية \ أ.د محمود جيلاني

# Appendix:

**Table (5.1):** Cable Data

| Length (m) | Area($mm^2$) | $\rho_{cu}$ Ω/m |
|---|---|---|
| 15 | 95 | 1.77 $*10^{-8}$ |

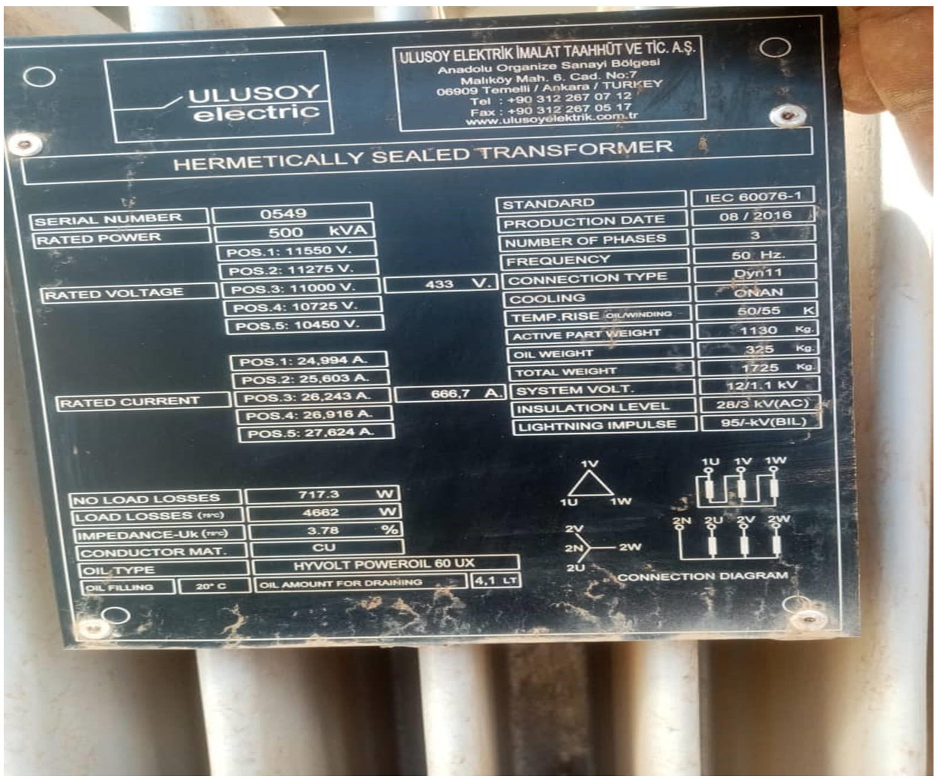


**Figure (5.1): Transformer's case study preamble**