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IMPACT OF THE EARTHING SYSTEM ON THE SHORT CIRCUIT CURRENT IN IRAQI POWER SYSTEM

Fadhaa Zaid AL-GBURI

Master's Thesis

Supervisor

Prof. Dr. Osman Nuri UÇAN

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The thesis titled IMPACT OF THE EARTHING SYSTEM ON THE SHORT CIRCUIT CURRENT IN IRAQI POWER SYSTEM prepared by FADHAA ZAID KHALAF AL-GBURI and submitted on 05/04/2023 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering

Prof. Dr. Osman Nuri UÇAN

Supervisor

Thesis Defense Committee Members:

Prof. Dr. Osman Nuri UÇAN	Department of Electrical and Electronic Engineering, Altınbaş University	_____
Asst. Prof. Dr. Sefer KURNAZ	Department of Electrical and Electronic Engineering, Altınbaş University	_____
Asst. Prof. Dr. Serdar KARGIN	Department of Electronics and Communication Engineering, Istanbul Arel University	_____

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Fadhaa Zaid Khalaf AL-GBURI

Signature

DEDICATION

To My Country "IRAQ"

To my mother and father … they were the first teachers in my life

To the most precious things in my life … My Wife and my children

To the secret of my happiness … My Brothers and Sisters.

ABSTRACT

IMPACT OF THE EARTHING SYSTEM ON THE SHORT CIRCUIT CURRENT IN IRAQI POWER SYSTEM

Al-Gburi, Fadhaa Zaid Khalaf

M.Sc., Electrical and Computer Engineering, Altınbaş University,

Supervisor: Prof. Dr. Osman Nuri UÇAN

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A grounding system must be utilized to provide a tiny amount of resistance channel to the earth in order to assure safety and prevent faults. When an unplanned or unanticipated above-normal potential current or voltage spike occurs while the system is working, the grounding system is crucial for completing an electrical path to the ground. Different grounding methods may be used in power systems. Since there is no fault current that may travel in the neutral channel in an unground system, the protection devices cannot detect the fault current when a defect occurs. Additionally, the healthy phases' voltages will be higher than the recommended value, which might harm equipment. However, in a system that is solidly grounded, the protection devices on the neutral point are able to detect the ground fault current, and the voltage of the healthy phase is equal to the pre-fault voltages. However, the fault current value will be high because there is no impedance in the neutral path. In this instance, the neutral grounding pathways must be given more resistance. In order to demonstrate how the ground fault current (single line to a ground fault) becomes larger than three-phase faults, the thesis will analyse the short circuit current of a case study for the Iraqi power system with the current grounding system. The investigation of the ground fault will then be performed in various ground system scenarios to increase system stability and dependability under various grounding scenarios. The simulation result show that when all

the power transformers are grounded, then the ratio of X0/X1 will be less than three and R0/X1 will be less than one. Thus mean the single line to ground fault will be higher than the three phase fault current and that will make the choosing of the circuit breaker rating not economically.

Keywords: Short Circuit Current, Neutral Grounding Point, Three Phase Fault, Single Line To Ground Fault, Earthing, Grounding, Effectively Grounding System.

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ABBREVIATIONS

PSS/E	:	Power System Simulation for Engineering
NESC	:	National Electrical Safety Code
IEEE	:	Institute of Electrical and Electronics Engineers
CB	:	Circuit Breaker
ABC	:	Three phase Voltage and /or Current
SCC	:	Short Circuit Capacity
MVA	:	Mega Volt Ampere
kV	:	Kilo Volt

1. INTRODUCTION

1.1 INTRODUCTION

An electric power system should operate in a healthy, balanced steady state. The electricity system's regular functioning state may be disturbed by faults. Any disruption that disrupts the regular flow of electricity and has an impact on the dependability, safety, and calibre of the power being supplied is referred to as a fault [1]. The voltages decrease and the currents strongly increase at the fault point when a failure occurs. As a result, the generator has issues with strong mechanical force and stability, customers lose power, the protective systems activate, and the primary devices may fail. As a result, fault analysis becomes a crucial role in power system analysis [2].

Power systems may suffer short circuits as a result of system over-voltage brought on by lightning strikes, load and generation switching surges, equipment insulating breakdown, or even insulator contamination. Short circuits can occasionally be caused by mechanical factors as well. Other well-known causes involve faults on overhead transmission lines that are line-to-ground, line-to-line, or line-to-ground. The circuit breaker must stop the short circuit that results after a few cycles [3].

To protect the electrical power grid from high short circuit currents of the ground faults (for example: line-to-ground, line-to-line-to-ground), power grids experts have created a number of efficient grounding techniques throughout the decades. In the past, there are only two options for system grounding: solid grounded and ungrounded [4]. Today, there are many other electrical system settings, including industrial, commercial, and others. With its benefit of causing protection devices to trip at high fault levels, solid grounding also has substantial drawbacks, such as the risks posed by arcs in dangerous regions. Additionally, the problem of important loads' continued service is directed away from this grounding technique. Ungrounded systems were strongly urged based on the belief that they maintain system reliability, at least during the initial ground failure [5]. To improve the system's reliability, security, and reduce the short circuit current, other grounding systems are developed such as resistance grounding systems, reactance grounding systems, voltage transformer grounding, Zig-Zag transformer, and effective grounding systems in addition to the solidly grounded and ungrounded systems, the features of each system will be discuss in the next chapters,

Figure (1.1) shows the different types of the neutral grounding system that can be used in power system.

The much more dangerous short circuits are frequently those that include three phases. Therefore, it is common to practice to limit phase-fault simulations to three while looking for the largest fault current values. But there are exceptions. Single line-to-ground short-circuit currents, for example, can be greater than three-phase short-circuit current rates when they happen electrically close to the following: the solidly grounded wye side of a three-phase core (three-leg) delta-wye transformers and/or autotransformers, a solidly grounded power generation unit. It is advised to run a single line-to-ground failure simulation for electrical systems when one or more of the aforementioned circumstances present [6].

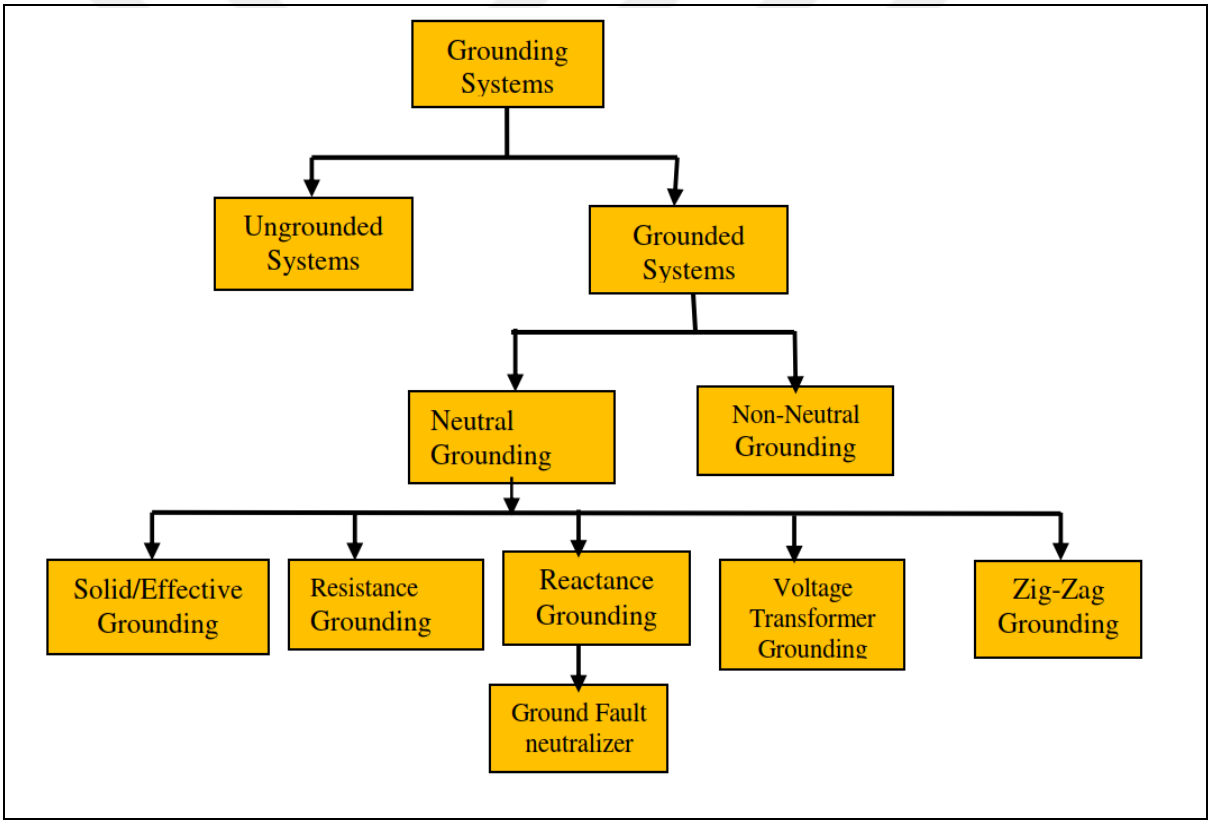

Figure 1.1: Different Types of Neutral Grounding Systems

In order to demonstrate how the ground fault current (single line to a ground fault) becomes larger than three-phase faults in the Iraqi power system, this thesis will analyse the short circuit current of a case study for a sector of The Iraqi power system to analyse the present grounding system. The evaluation of the ground fault current will be carried out in different ground system scenarios to identify the impact of the neutral grounding point to

explain how the system stability can be increased when the proper grounding points can be selected under various grounding scenarios.

The PSS/E Power System Simulation for Engineering program it will be used in this work to evaluated the grounding system of the Iraqi power grind and how the fault current can be affected by the types of the neutral ground point.

1.2 RELATIONSHIP BETWEEN GROUNDING AND FAULT CURRENT

The idea of linking anything to the soil is known as "grounding" or "Earthing" (or ground). The only notion in power grids that must not be ignored is grounding. For effective functioning and implementation of ground-fault relays, as well as for the revelation of single-phase voltage supply, and for the realization of reducing the fault current in case of resistance and reactance is used, and the drainage of harmonic voltages that skew system voltages, generators, reactors, and transformers must all be grounded at their star or neutral points. Every piece of equipment also has to have its metallic casing and non-conducting components earthed in order to safeguard users and staff from electrical risks. If this notion hadn't been used, it's impossible to estimate how many lives and how much property could have been lost due to electrical faults [7].

For a solidly grounded neutral point (transformers and generators) in the power system, a high amount of ground faults current can exceed the amount of the three phases fault current. The massive fault current destroys fault sites (equipment and operators), and increases ground voltage, which creates high step and contact voltages that are harmful to people and animals, destroys communication systems, and can be highly hazardous to users [8]. By adding resistance or reactance to the neutral grounding point of the injection feeding transformer and/or generators, the excessive fault currents may be decreased [9].

The significance and influence of neutral grounding resistance and/or reactance in a 33 kV or 11 kV system grids that used in Iraqi power system for distribution side [10], as well as its effect on identifying and restricting single-line-to-ground fault currents for a power system fed by a single or many sources, will be covered in this study. Also in the work, the evaluation and analysis will be present for the features of the neutral grounding resistance and/or reactance which are placed in 132/33 or 132/33/11 kV transformers. The neutral

grounding resistance needs to be increased in order to maintain the single-line-to-ground fault in lower levels for safe step and touch voltages.

1.3 IMPORTANCE OF THE SHORT CIRCUIT ANALYSIS

The main focus of network station investigations is on how to design and choose equipment as well as improve or forecast how a current or new power system will perform in the given circumstances. Short circuit analyses are more crucial than some other basic power system research when comparison to other significant power network subjects [11]. Due to acute energy shortages in developing nations, forced load shedding is used on the substation side. Instruments are gradually losing their strength as a result of this quick switching procedure. On the other hand, when the demand for power rises steadily, it is necessary to upgrade the substation's aging equipment rating [12].

The studying of the short circuit analysis is essential to ensure the proper selection of the various elements of the electrical network. For example, in the case of choosing a specific line to transmit electrical energy from one station to another, it can easily calculate the value of the current passing through this line by applying the load flow techniques. Therefore, it is possible to choose the cross-sectional area and all other parameters for this line that can withstand this current after choosing an additional safety factor, but this choice will remain incorrect until the insure of this line can also withstand the value of the expected short circuit current that passed in through this line as a result of faults.

Of course, this does not mean that this line should withstand this current permanently, but at least it bears it during the period needed by the electrical protection system on that line until it is disconnected. To ensure the system will work properly during faults conditions, calculations of the fault current should be used to predict the value of the short circuit current in the worst case, and therefore we make sure before choosing the line finally that it not only withstand the natural current permanently but also bear the fault current for a short period that is sufficient to separate it by means of protection devices. Circuit breaker ratings, current transformers, voltage transformers, etc. also need to be selected according to the fault current.

1.4 FAULTS IN POWER SYSTEM

Power systems typically function for the majority of their lives in a steady, sound, i.e. not faulty, working state. A power system fault is any failure that disrupts the regular flow of electric power. Power system faults are classified as either open circuits or short circuits [13][14].

Most power system fault research focuses majority of power system fault research is focused on the second category, short circuits. Short circuits (also known as shunt faults) are classified as symmetrical (involving three phases) or unsymmetrical (involving one or two of the three phases). According to system experience, 70% to 80% of line failures are single phase-to-ground faults (unsymmetrical), while three-phase symmetrical faults may account for roughly 5% of the system. Faults force the system to leave its normal condition, generating voltage and frequency variations until the fault is separated by protective mechanisms.

Throughout the first few cycles, the fault current waveform and behaviour change. Symmetrical components are well-known mathematical techniques for analysing unbalanced fault currents [15]. Figure (1.2) is a metaphorical example of asymmetrical power system faults. All short circuit faults in Figure (1.2) are considered to be solid on bolted faults, with zero fault path impedance, where (I_{fa}, I_{fb}, and I_{fc}) are the fault currents of phases (a, b, and c).

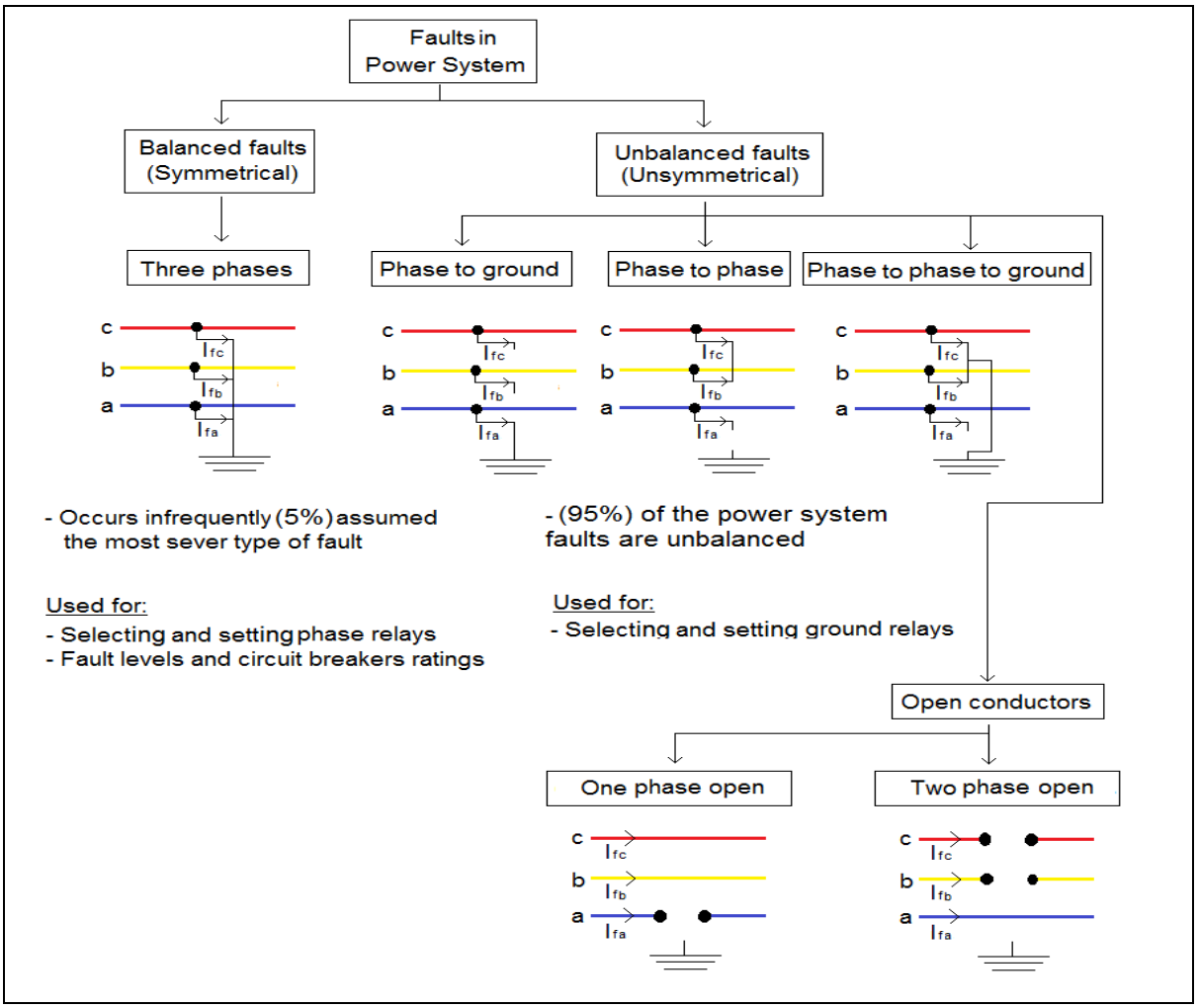

Figure 1.2: Faults in Power System

1.5 PROBLEM STATEMENTS

It is necessary to employ a grounding system to create a little value of resistance channel to the earth in order to assure safety and avoid breakdowns. When there are non-designed or unplanned above-normal potential current or voltage spikes while running, the grounding system is crucial to completing an electrical path to the ground.

Different types of grounding systems can be used in power systems. The ungrounded system has no fault current that can flow in the neutral path, then the protection devices cannot sense the fault current during fault conditions, in addition, the voltages of the healthy phases will be higher than the rated value and may damage the equipment. On the other hand, in the solidly grounded system, the protection devices on the neutral point can sense the ground fault current and the voltage of the healthy phase is equal to the pre-fault voltages but the

value of the fault current will be high because there is no impedance if the neutral path. For this case, the impedance needs to be added in the neutral grounding paths, such as resistance and/or reactance.

The goal of the thesis involves studying the short circuit current of a case study for the Iraqi power system with the present grounding system, and explaining how the ground fault current (single line to a ground fault) becomes higher than three-phase faults. Then the evaluation of the ground fault will be present in different cases of the grounded system to improve the system stability and reliability during different grounding types.

1.6 THESIS OBJECTIVE

a. To study and analyse different types of neutral grounding points on the power system.

b. To study the short circuit analysis for the main types symmetrical and asymmetrical.

c. To evaluate the short circuit current of a sector of the Iraqi power system as a case study.

d. To evaluate the main reasons for the high values of the short circuit current in the Iraqi power system.

e. To describe the impact of the neutral grounded point on the ground faults.

f. Use PSS/E program to implement the case study.

g. Give recommendations to improve the stability of the power system and reduce the short circuit current.

h. To control the healthy phases voltage during ground faults during different types of grounding systems.

1.7 THESIS ORGANIZATION

This thesis will contain five chapters, Chapter One will include the introduction with brief description of the relation between the ground fault current and neutral grounding types in addition to the importance of the fault current. While the chapters from two to five will be describe as follows:

Chapter Two in this chapter describe the theoretical background of the neutral grounding system and the calculation of the short circuit current (symmetrical and asymmetrical faults) with all required equations and drawings.

Chapter Three in this chapter the system modelling by using PSS/E program will be present; the case study will discuss the relation between the fault current and the grounding system for the selected case study.

Chapter Four this chapter will include the simulation and results of the short circuit cases for the proposed system will be explained here.

Chapter Five Conclusion and future works will be present in this chapter.

2. THEORETICAL BACKGROUND

2.1 INTRODUCTION

If a ground fault happens to an overhead transmission line or an underground cable, the technique of grounding becomes significant and useful. Throughout normal operation conditions of system functioning, it has little effect. Detailed analysis is necessary while choosing the system grounding approach [16]. Numerous computations and models of the system throughout a fault may be used to determine the proper grounding solution. A power system fault is an abnormal circumstance that raises the possibility of equipment failure. Typically, failures fall into one of two categories. The first causes a short circuit defect due to a breakdown in the insulation. The second failure causes the current flow to be interrupted [17]. According to this analysis, the manner of neutral point grounding that used in the Iraqi power system determines the features of ground-fault current as will show in this thesis.

2.2 TYPES OF GROUNDING SYSTEM

The technique of connecting a three-phase system's neutral point to the earth, or soil, either directly or through a circuit component (such as resistance, reactance, etc.), is known as neutral grounding [18]. Safety for people and equipment is provided by neutral grounding. This is so that the damaged conductor may be separated from the remainder of the system using protection equipment like fuses, which function when an earth fault occurs and completes the current route via the earthed neutral [19]. Using a star-connected system with neutral earthing as an example, let's say a single line-to-ground occurs in line A at point F. This will help to highlight the significance of the grounding system. The result will be the current flowing via the ground route as seen in Figure (2.1). Observe how current travels from A-phase to earth, then to neutral point N, and returns to A-phase. An enormous current flow via this channel since the impedance is low. This substantial current will rupture the A-phase fuse and isolate the faulty line A. This will safeguard the system against the negative consequences of the malfunction, such as damage to equipment, electric shock to workers, etc. The voltage differential between both the live wire and the ground will almost always remain constant and won't rise over the phase voltage of the system, which is a key characteristic of grounded neutral [20][21].

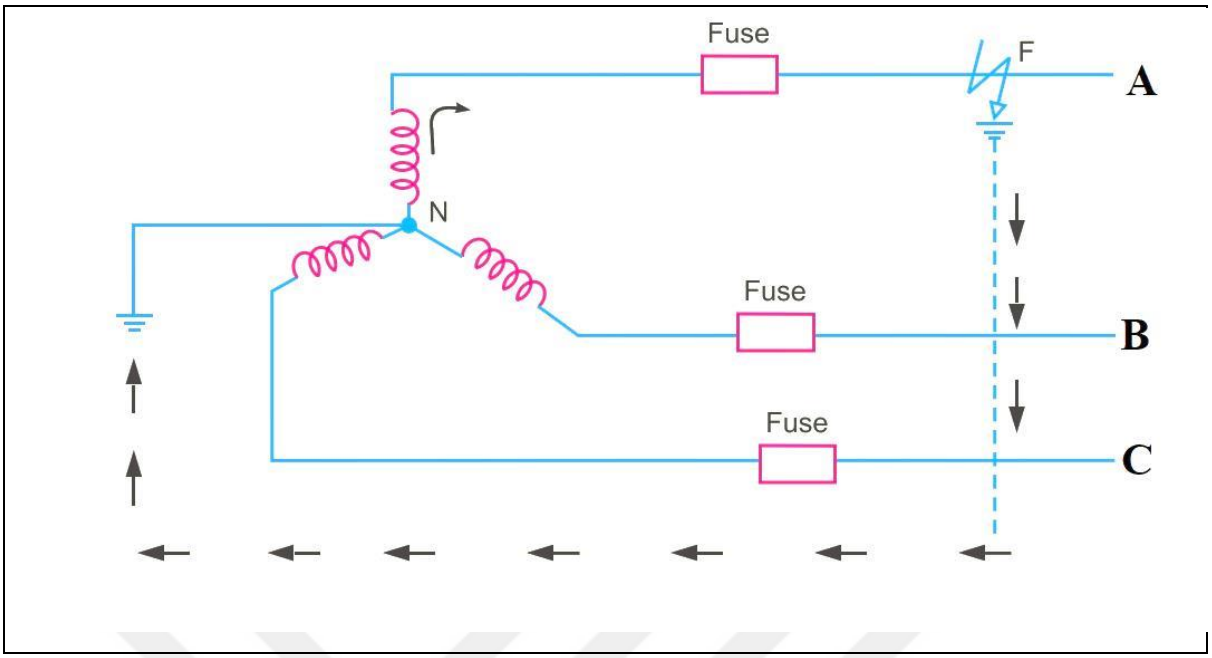

Figure 2.1: Fault Current Flow in Grounding System

The benefits of neutral grounding are as below [22]:

a. The voltages of the healthy phases are essentially constant and do not reach line-to-ground voltages.

b. Electrical discharge grounds' high voltages are removed.

c. Earth fault protection can be offered using protective relays. The protective relay will activate in the event of a ground faults on any line to isolate the damaged line.

d. Lightning-related overvoltage's are dumped to the ground.

e. It increases the safety of the workers and the machinery.

f. It offers enhanced service dependability.

g. Operating and upkeep costs are decreased.

2.2.1 Solidly Grounding System

It is referred to as solid grounding when the neutral point of a three-phase system is directly linked to the ground through a wire without resistance or reactance. The neutral point of the solidly grounding system is depicted in Figure (2.2) [23]. The neutral point is maintained at

earth potential under all circumstances since it is wired directly to the earth. As a result, during grid faults, the voltage of any wire to earth won't be higher than the system's typical phase voltage. The main advantage of the solid grounding system is the potential voltages during fault don’t exceed the system voltage, and the very simple system that can be used for protection purposes [24]. The drawbacks of using this system can be listed as:

a. Since phase-to-ground faults make up the majority of an overhead system's faults, the system must withstand a lot of extremely damaging shocks. The system becomes unstable as a result of this.

b. Strong ground fault currents are caused by solid grounding. High-ground faults currents may result in the burning of circuit breaker connections since the fault must be removed by the circuit breakers.

c. Because of the higher ground faults current, nearby communication links are more likely to experience interference.

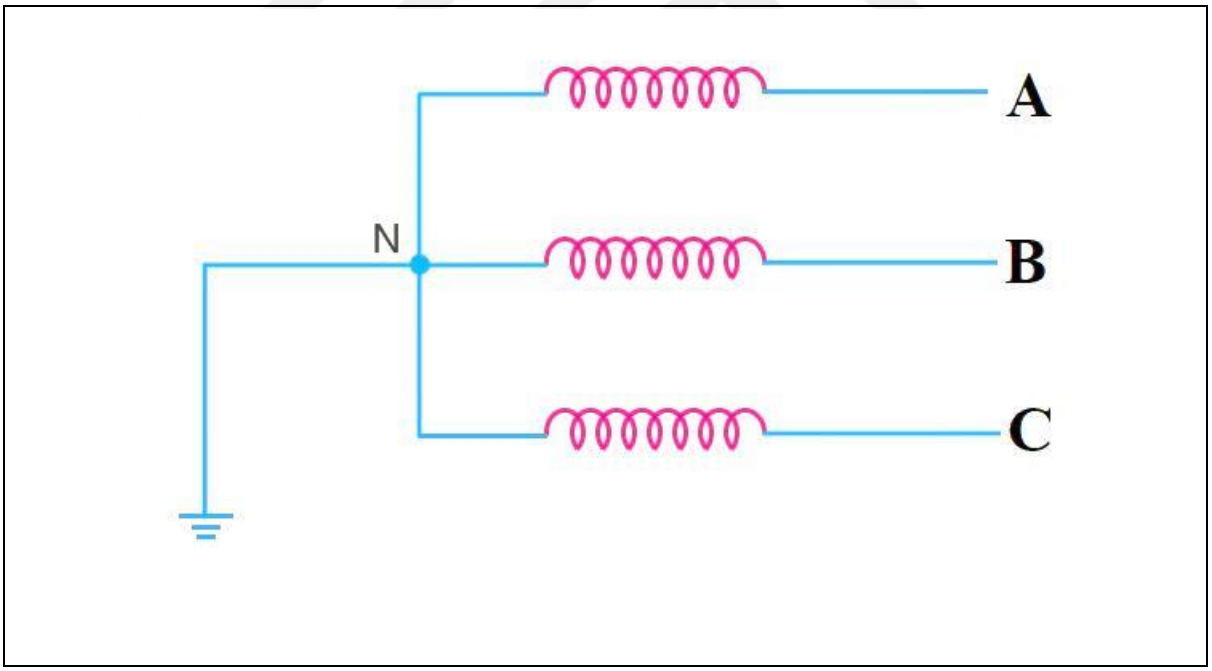

Figure 2.2: Solidly Grounding System

2.2.2 Resistive Grounding System

The neutral point of a three-phase system is often connected to the earth through a resistor to reduce the size of the earth's fault current. A resistor R is used to ground the neutral point,

as shown in Figure (2.3) [25]. When the earthing resistance R is very low, the system resembles a solid grounding system because the earth fault current is high. However, if the earthing resistance R is extremely large, the system characteristics resemble those of an unground neutral system, so the proper selection of the resistance value depends on how the fault current needs to be reduced throughout the proper operation of the protection devices. The main drawbacks are the high expensive and the voltage of the healthy phase may be exceed the voltage system, and when the resistance grounding is high, the protection system may be an accurate [26].

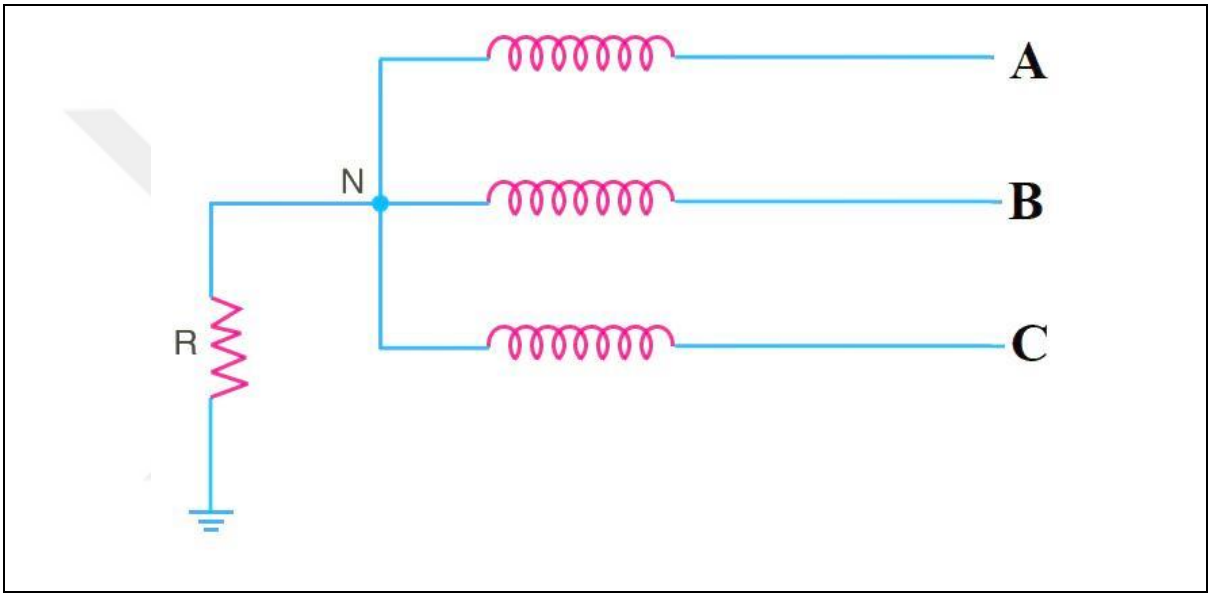

Figure 2.3: Resistive Grounding System

2.2.3 Reactance Grounding System

As seen in Figure (2.4), a reactance is added in this system between the neutral and ground. Reactance serves to restrict the fault current on the ground. The earth fault current can be altered to create conditions akin to solid grounding by altering the earthing reactance [27]. The main drawbacks prevent this strategy from being employed today:

a. For the identical fault conditions in this system, the fault current needed to activate the protective device is larger than it would be for resistance grounding.

b. Relative high voltages manifest themselves when there is a problem.

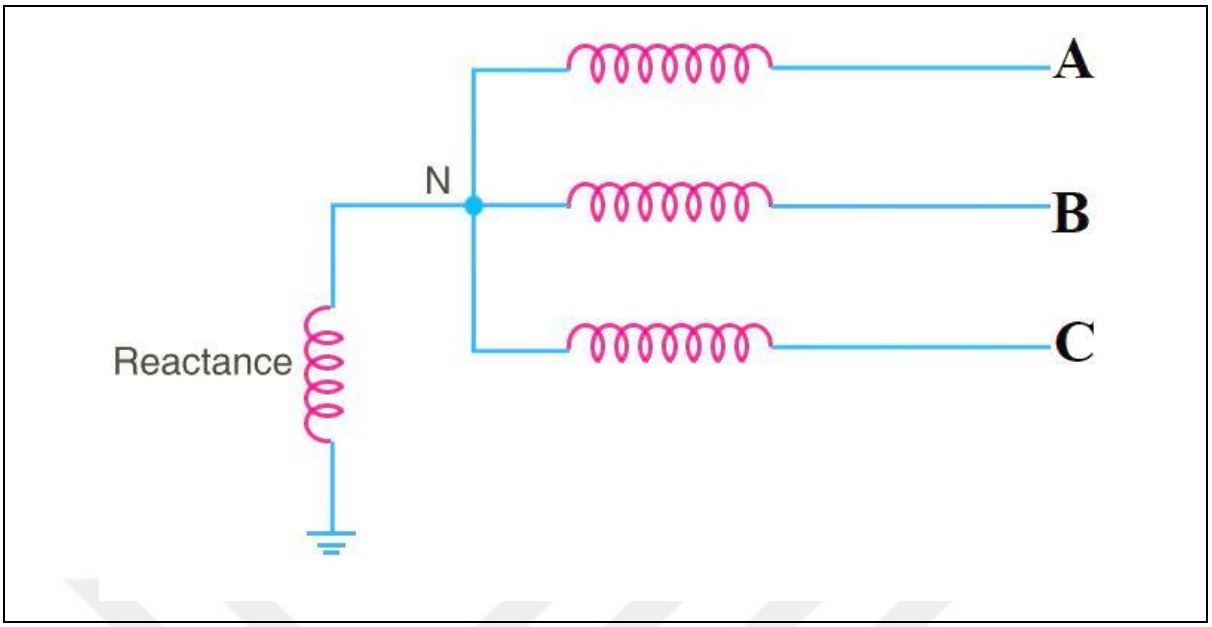

Figure 2.4: Reactance Grounding System

2.2.4 Ungrounding System

The term "ungrounded neutral system" refers to a neutral system where neutral and grounds are isolated from one another, meaning there is neither wire among the neutral point and the earth. In light of this, the ungrounded neutral system is sometimes referred to as an isolated neutral system, a free neutral system, or an insulated neutral system [28]. Figure (2.5) shows the ungrounded system. Ungrounded neutral has the following consequences on a system's performance:

a. Arcing discharge to grounds—a phenomenon that frequently occurs in ungrounded systems as a result of earth faults—can cause the insulation to fail.

b. The insulating of all power equipment connected to the system would be put under a great deal of stress when an earth fault develops in an unground system, increasing the voltage of the healthy phases above the earth by around three times the typical amount.

c. The ungrounded system cannot be adequately protected since it is difficult to detect the earth's fault in this system. Since the fault current won't be enough to start the protective relay operating, this system's earth fault relay is therefore more complex

d. In an unground system, the malfunctioning phase's capacitive current will increase to three times the per-phase average value.

e. In an unground system, overvoltage’s caused by lightning surges and generated static charges won't be discharged to the earth and instead stay inside the system, potentially damaging the system's hardware.

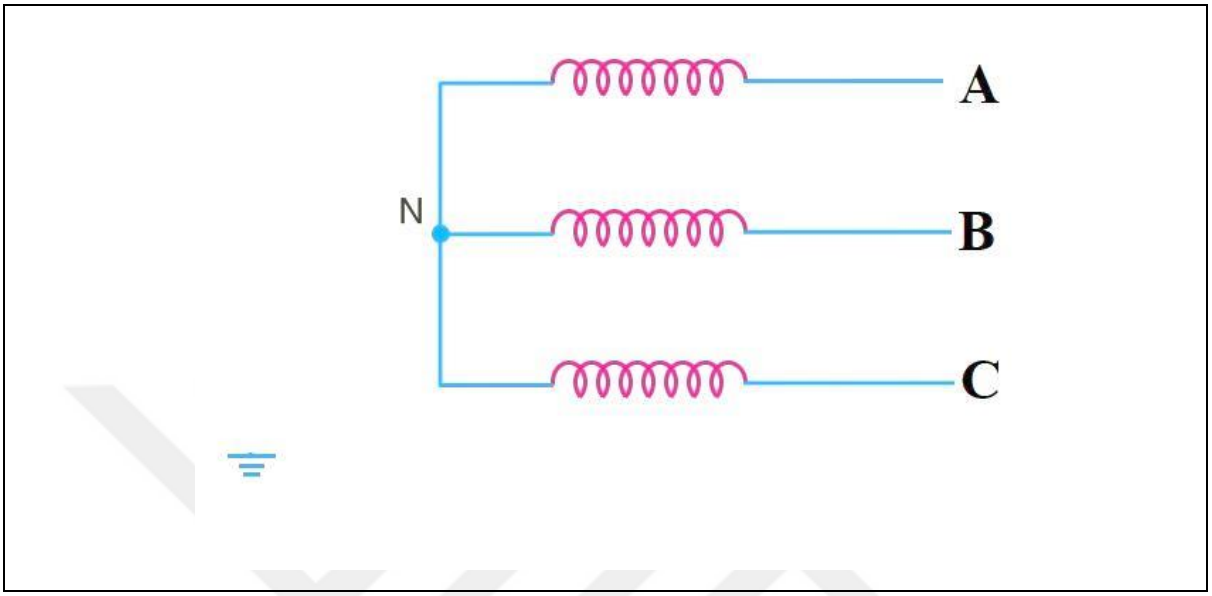

Figure 2.5: Ungrounded System

2.2.5 Arc Suppression Coil Grounding System

As seen in Figure (2.6), an iron-cored coil linked between the neutral and ground is an arc suppression coil, often known as a Peterson coil (i). The reactor has tapings that may be used to modify the coil's inductance. Resonant grounding can be obtained by altering the tapings on the coil such that it is tuned to the capacitance of the system. The following benefits of Peterson coil grounding [29][30]:

a. The Peterson coil is 100% efficient in shielding against arcing ground damage.

b. The Peterson coil benefits from an unground neutral system.

The following drawbacks of the Peterson coil grounding [31]:

a. The network's capacitance varies periodically due to changing system performance. As a result, the Peterson coil's inductance L needs to be revised.

b. The overhead transmission line needs to be transposed.

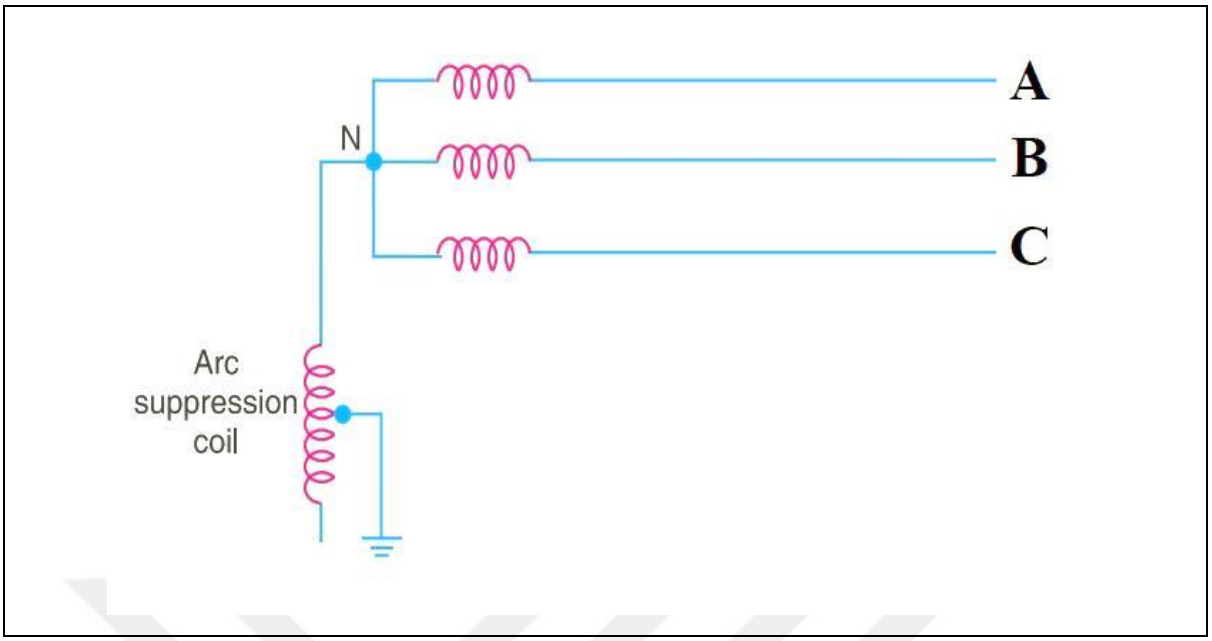

Figure 2.6: Arc Suppression Coil Grounding System

2.2.6 Voltage Transformer Grounding System

According to Figure (2.7), the main of a single-phase voltage transformer is linked among the neutral and the ground in this way of neutral grounding. A relay and a low resistor are linked in series and placed throughout the secondary voltage transformer. Because of its high reactance in the neutral grounding system, the voltage transformer functions essentially as an unground neutral system [32]. A voltage is created across the relay by ground faults on any phase. The protection device is triggered by this to operate.

The benefits of earthing voltage transformers include the following [33]:

a. Switching and arcing grounds decrease the system's transient overvoltage's.

b. This is due to the voltage transformer's high earth path reactance.

c. An ungrounded neutral system has all the benefits of this sort of earth.

d. Arcing grounds are removed.

The below are drawbacks of earthing voltage transformers:

a. The line voltage is visible across the line to earth capacitances when an earth fault occurs on any phase. Overstressing of the system insulation will occur.

b. The grounding neutral serves as a point of reflection for waves moving through the machine's winding. High voltage build-up can be the outcome of this.

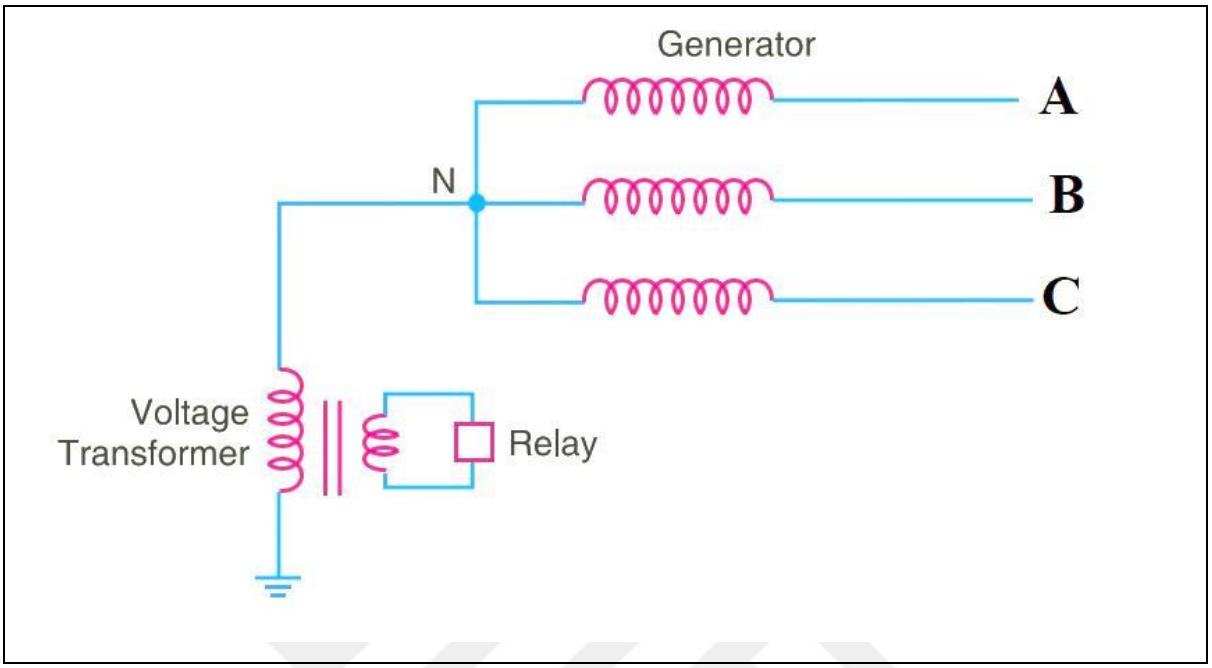

Figure 2.7: Voltage Transformers Grounding System

2.2.7 Effectively Grounding System

Providing a low-impedance conduit for current to drain into the earth at the site of fault with the shortest clearing time is the goal of any power system grounding. Nevertheless, there can be circumstances in which getting a low-impedance route is not a cost-effective solution. It will be valuable to contrast the next two definitions [34]:

The National Electrical Safety Code (NESC) defines an effectively grounded system as one that is purposefully linked to the earth via a ground connection that is sufficiently low in impedance and capable of carrying enough current to prevent excessive voltage build-up that could endanger people or compatible devices.

The Green Book (IEEE Standard 142) states - effective grounding is achieved when:

$$3X_1 > X_o \quad (2.1)$$

$$Ro/X_1 > 1 \quad (2.2)$$

The neutral is connected directly to the soil in a system that is solidly grounded without any deliberate resistance or reactance. The transient overvoltages are held to a minimum when the system is effectively grounded. The effectively grounding system can be made up by close or open the solidly neutral point to ground.

2.3 TRANSFORMERS IN IRAQI POWER SYSTEM

The listed below explain the main types of the transformers and their grounded system that used in Iraqi power system.

2.3.1 Autotransformers

Which are used to connect the ultra-high voltage system (400 kV) star connected with high voltage system (132kV) also star connected, this type of transformers has tertiary winding (11 kV) system delta connection, the neutral grounding of the high and ultra-high voltage systems is solidly grounded, the connections of the autotransformers that used in the Iraqi power system is shown in Figure (2.8).

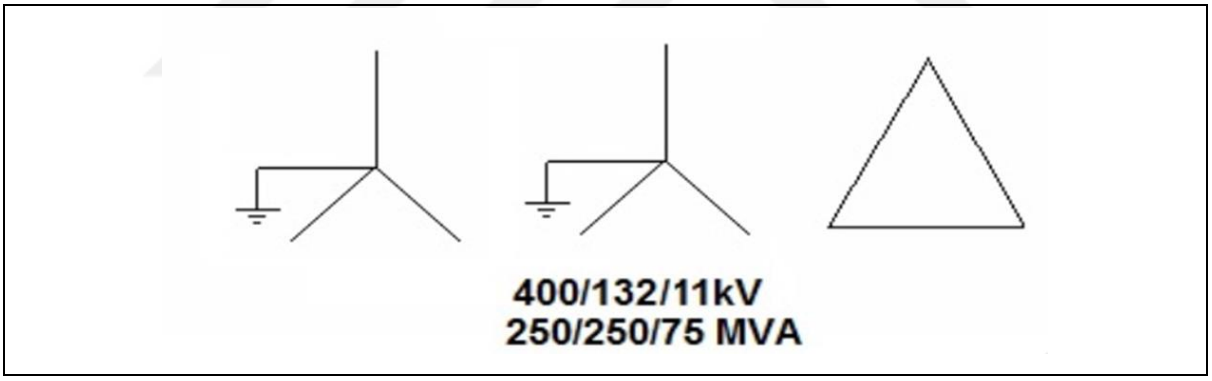

Figure 2.8: Autotransformers Neutral Grounding Connection

2.3.2 Three Winding Transformers

In Iraqi power system, the connection the high voltage system (132 kV) is star connected (solidly grounded with switch) while for the distribution voltage system (33 and 11 kV) the connection will be via resistance or Zig-Zag earthing transformers. Figure (2.9) shows the two types of the three winding transformers that are used in Iraqi power system, Figure (2.9/a) star-star-delta used all Iraqi governorates except Baghdad city, while Figure (2.9/b) star-delta-star used in Baghdad. The resistance that used in the 33 kV systems is about 19 Ω

while the resistance on the 11 kV systems is about 22 Ω. Zig-Zag transformers are used to grounding the delta side of the transformers, Figure (2.9).

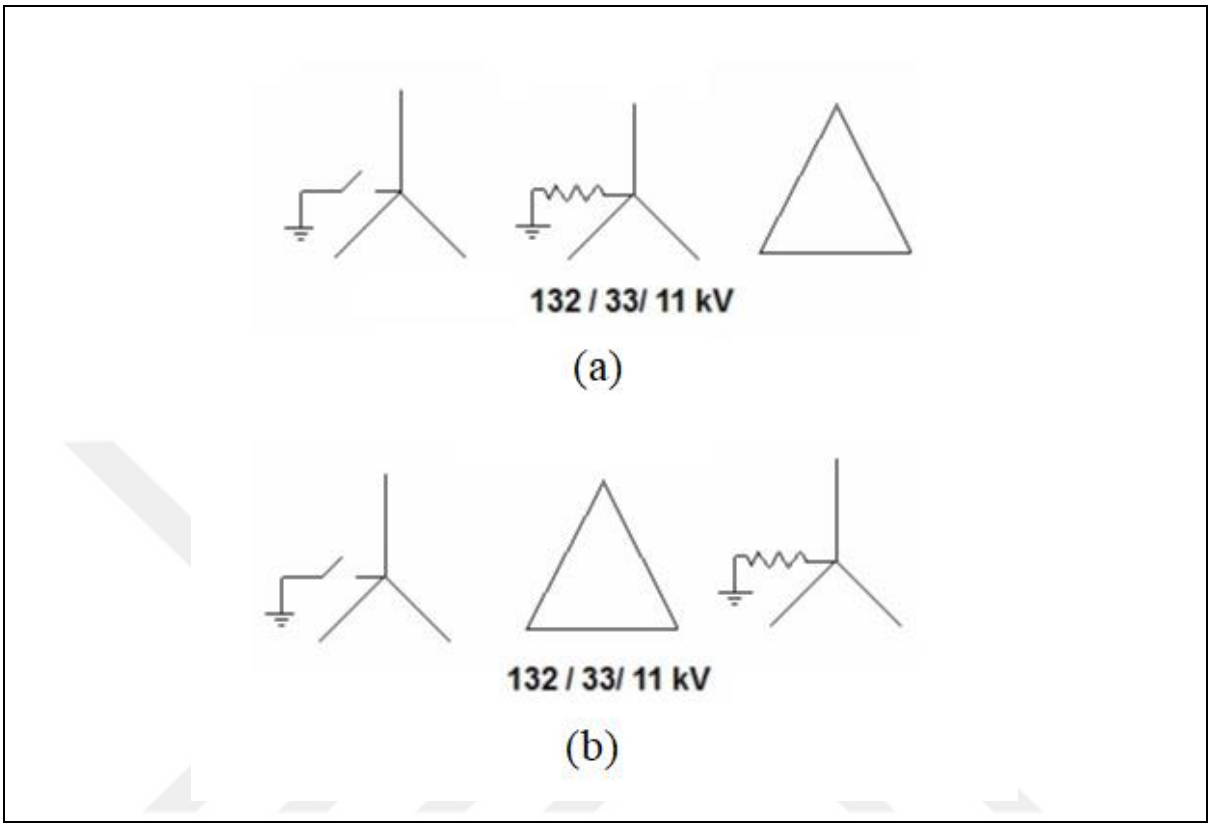

Figure 2.9: Three Winding Transformers 132/33/11 Kv Neutral Grounding Connection (A) Used in Other Cities of Iraq Except Baghdad, (B) Used in Baghdad City

2.3.3 Two Winding Transformers

The two winding transformers are used to connect the high voltage system (132 kV) star connected (solidly grounded with switch) with distribution voltage system (33 kV). Figure (2.10) shows the two types of the two winding transformers that are used in Iraqi power system in both Baghdad and in the other governorates.

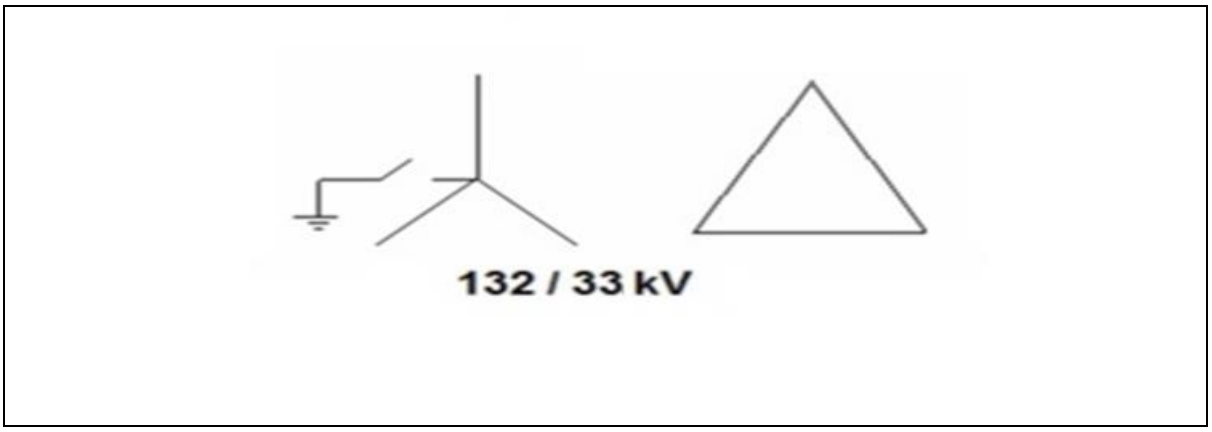

Figure 2.10: Two Winding Transformers 132/33 Or 132/11 Kv Neutral Grounding Connection That Used in Baghdad City And in The Other Cities

2.3.4 Zig-Zag Transformers

The transformer's zig-zag windings are where the term "zig-zag" first appeared. Inside a transformer of this type, the secondary winding is absent. Its only function is to ground systems with extremely high voltages more than 33 kV. The fact that this type of grounding transformer offers a split route for fault current to travel is its most significant advantage [16]. Each three conductors receive an equal share of the fault current, which limits the high fault currents (see Figure (2.11)). The various grounding transformer designs that were stated before might be employed with circuit breakers. Transformers and breakers should only be installed with caution. The breaker's rating shouldn't be higher than the rating of the transformer.

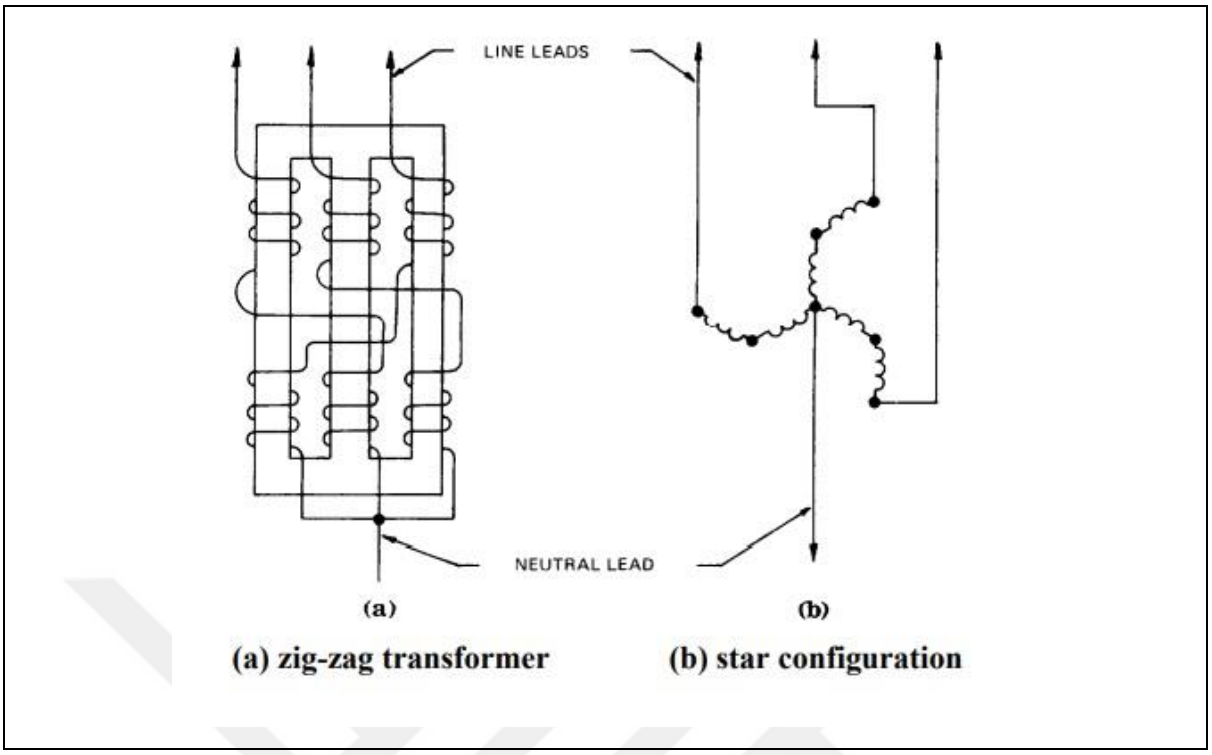

Figure 2.11: Zig-Zag Transformer Connection

2.4 SHORT CIRCUIT ANALYSIS

Power system evaluation must include fault studies. Unbalanced faults, which include single line-to-ground faults, line-to-line faults, and double line-to-ground faults, can be broadly categorized as three-phase balanced faults and unbalanced faults. The network system and the impedance of the network's components into which the short circuit current flows heavily influence the short circuit current's properties [35]. Figure (2.12) illustrates the characteristics of the short circuit current, which is mostly produced by synchronous generators in a standard power system. Synchronous generators' short circuit impedance varies over time when they are exposed to short circuit situations. The equivalent short circuit current is often divided into the sub-transient period (the first few cycles), transient period (the following few cycles), and steady-state period for the purposes of fault research [36].

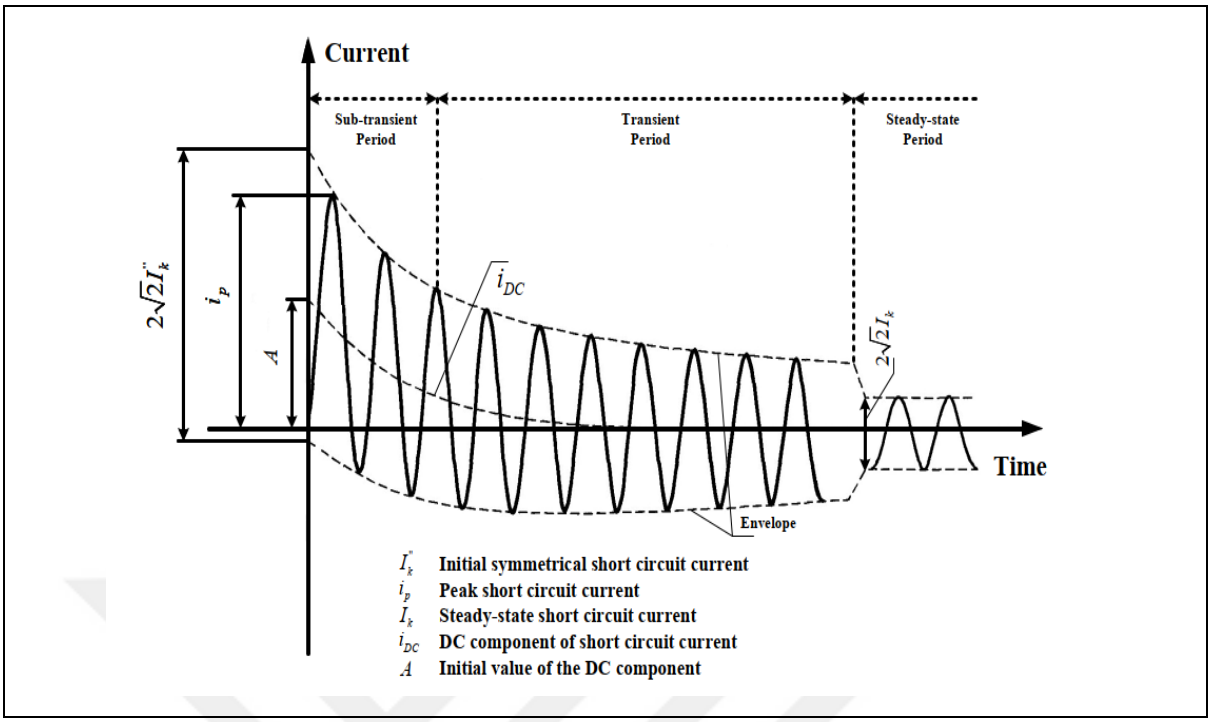

Figure 2.12: The Fault Current Behaviour During Short Circuit Condition

The maximum momentary short-circuit magnitude, or peak short-circuit current, is utilized to find the rating of a circuit breaker (CB). Only the maximum short-circuit current allows for the calculation of the peak short-circuit current [37]. Equation (2.3) is utilized to compute the contribution of the peak short-circuit current from one branch for a three-phase balanced fault scenario, and the results are displayed in Figure (2.13).

$$I_p = k \,.\sqrt{2}\,.I_k'' \tag{2.3}$$

"k" is a function of the "R/X" ratio and can be calculated with formula (2.4).

$$\mathrm{k} = 1.02 + 0.98\, e^{\frac{-3R}{X}} \tag{2.4}$$

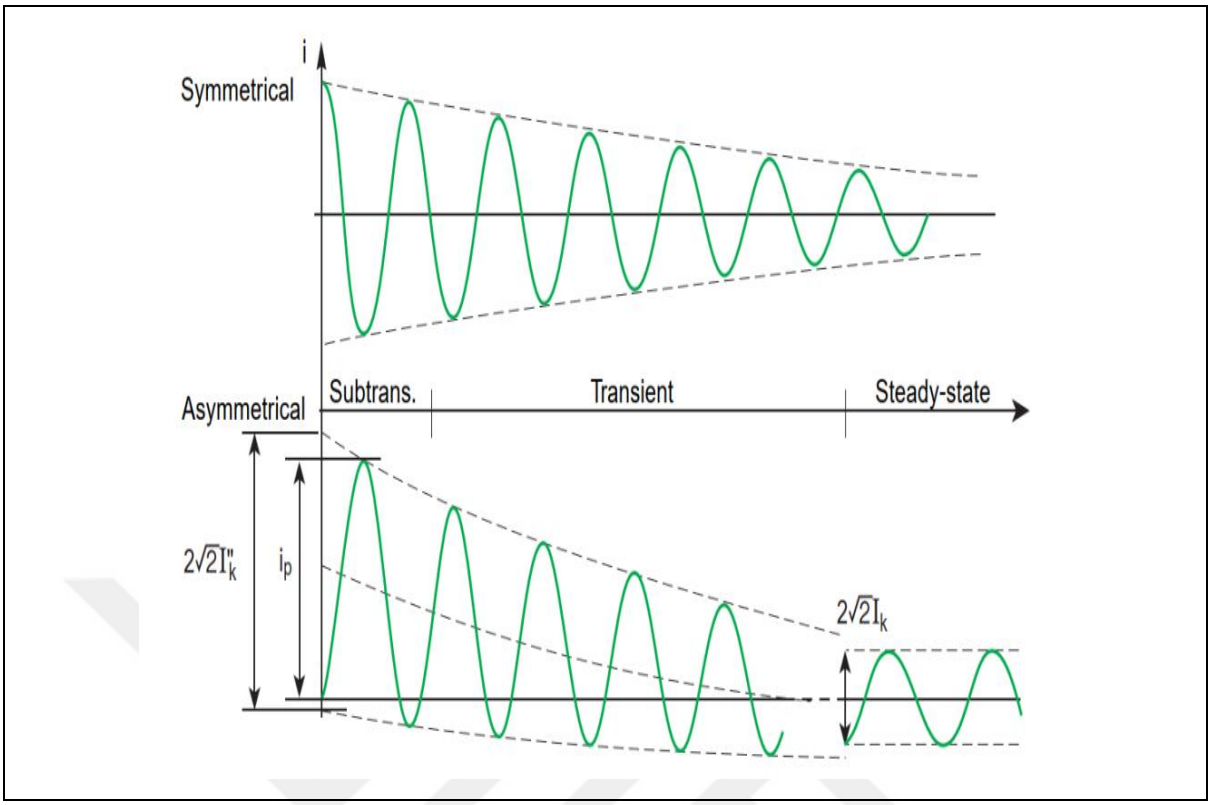

Figure 2.13: The Peak Short Circuit Current

At a fault location point F, the total amount of Peak short-circuit current Ip is the sum of the absolute value of all the partial short-circuit currents, Figure (2.14) shows the relationship between k and X/R ratio.

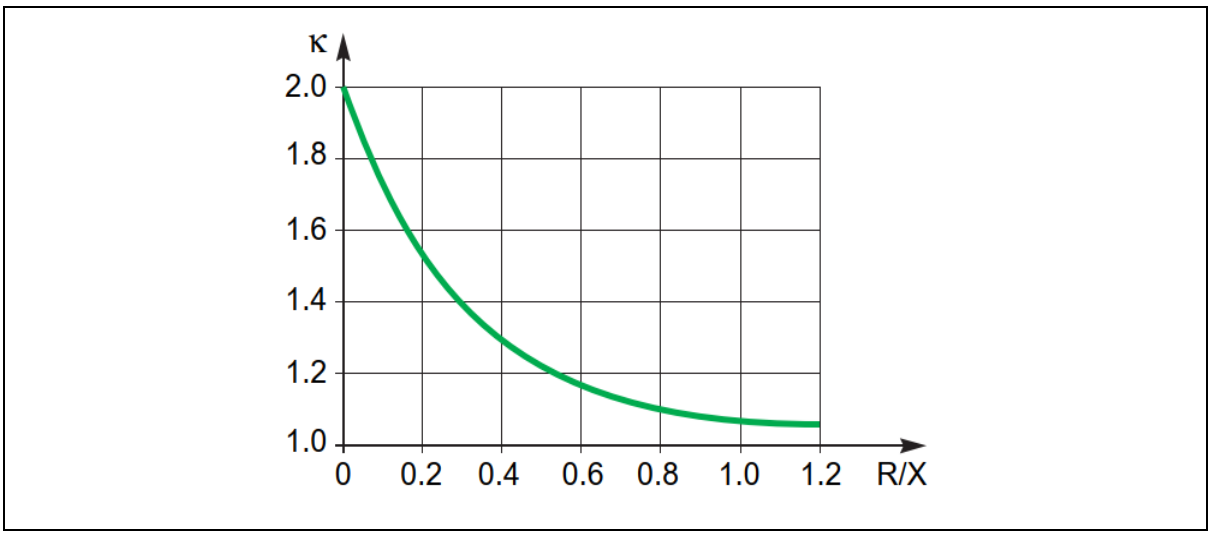

Figure 2.14: Variation of Coefficient K Depending On R / X Or R / L

Table 2.1 provides a summary of the basic equations and circumstances used in the various fault investigations [38][39].

Table 2.1: Fault Equations and Conditions

Type of fault	Current and voltage	Conditions
Three phases	$I_F = I_1 = \frac{V_f}{Z_1}$	$V_0 = V_1 = V_2 = 0$ $I_0 = I_2 = 0$
Single phase-to-ground	$I_F = 3I_0 = \frac{V_f}{Z_1 + Z_2 + Z_0}$ $V_0 = Z_0 I_0$ $V_1 = V_f - Z_1 I_1$ $V_2 = -Z_2 I_2$	$I_0 = I_1 = I_2$
Phase-to-phase	$I_1 = \frac{V_f}{Z_1 + Z_2}$ $V_2 = -Z_2 I_2$	$I_0 = 0$ $I_1 = -I_2$ $V_2 = V_1$ $V_0 = 0$
Phase-to-phase-to-ground	$I_1 = \frac{V_f}{Z_1 + \left(\frac{Z_0 Z_1}{Z_0 + Z_1}\right)}$ $I_0 = \frac{Z_2}{Z_0 + Z_2} I_1$ $I_2 = \frac{Z_0}{Z_0 + Z_2} I_1$	$V_0 = V_1 = V_2 = Z_0 I_0$

The symmetrical components methods are:

a. V_f: before voltage fault.

b. Z_1, Z_2, Z_0: are the positive, negative and zero sequence impedances.

c. V_1, V_2, V_0: are the positive, negative and zero sequence voltages.

d. I_1, I_2, I_0: are the positive, negative and zero sequence currents

Figure (2.15) shows the general three phase connection with the sequence networks arrangement during single-line-to-ground fault condition.

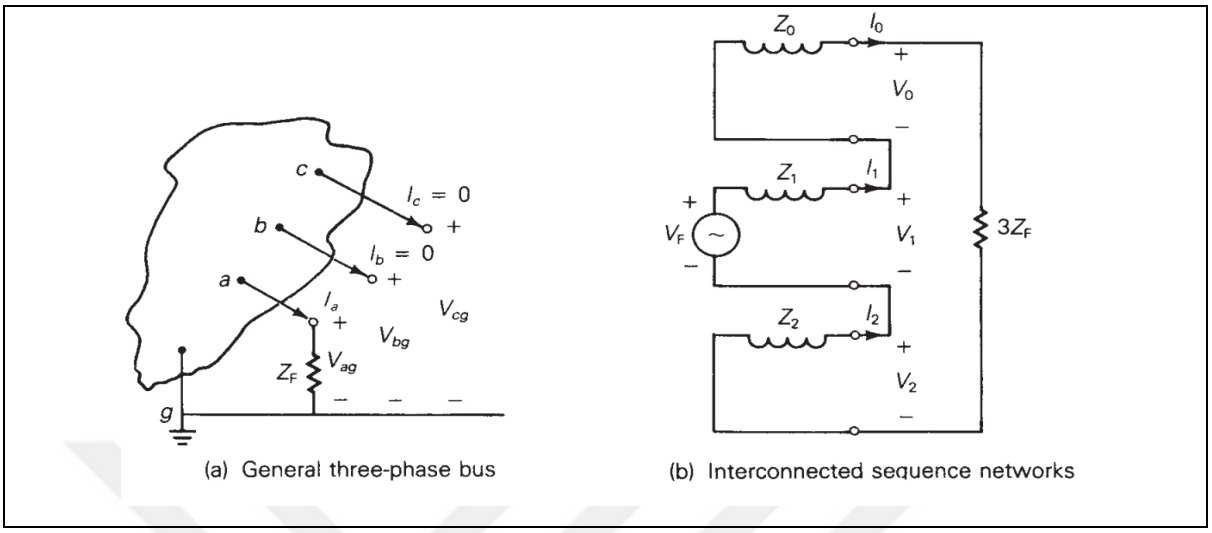

Figure 2.15: Voltages and Currents With Sequence Networks Arrangement During Single Line to Ground Fault Condition

Figure (2.16) shows the general three phase connection with the sequence networks arrangement during line-line fault condition.

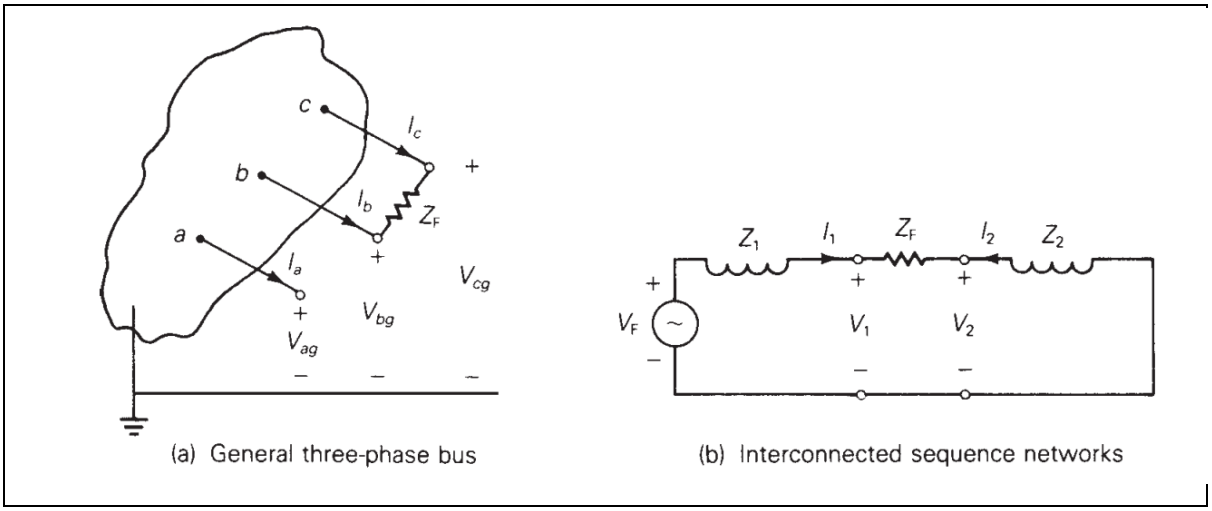

Figure 2.16: Voltages and Currents With Sequence Networks Arrangement During Line-Line Fault Condition

Figure (2.17) shows the general three phase connection with the sequence networks arrangement during line-line-to-ground fault condition.

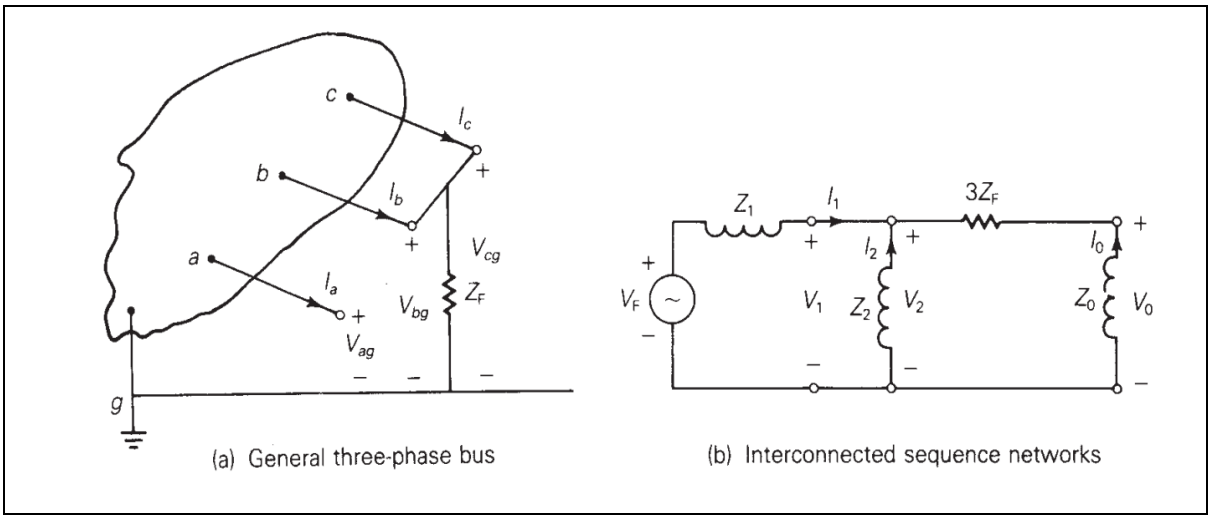

Figure 2.17: Voltages and currents with sequence networks arrangement during line-line fault Condition

The sources positive, negative and zero sequence impedances can be explained as:

a. Positive sequence impedance Z_1 :

The real value of the practical impedance in the electrical power equipment (measured under normal condition).

b. Negative sequence impedance Z_2 :

Is unreal value of the impedance that appears in the rotating machine (measured under abnormal condition by testing) for static equipment the Negative Sequence impedance equal to Positive Sequence Impedance (ABC) - (ACB).

c. Zero sequence impedance Z_0 :

The real value of the practical impedance in ground path and depend on Earth properties (measured under normal condition (off state)).

The positive sequence components follow the same order as the initial phases, are of similar size, and are separated from one another by 120^o (electrical degree). The positive sequence currents and voltages mimic the original source's cycle order. The Figure (2.18) shows the positive sequence phasor for a common counter clockwise rotation electrical system. The positive current phasors are in the same situation. The sign "+" or "1" is typically used to indicate this sequence, which is also known as the "abc" sequence [40].

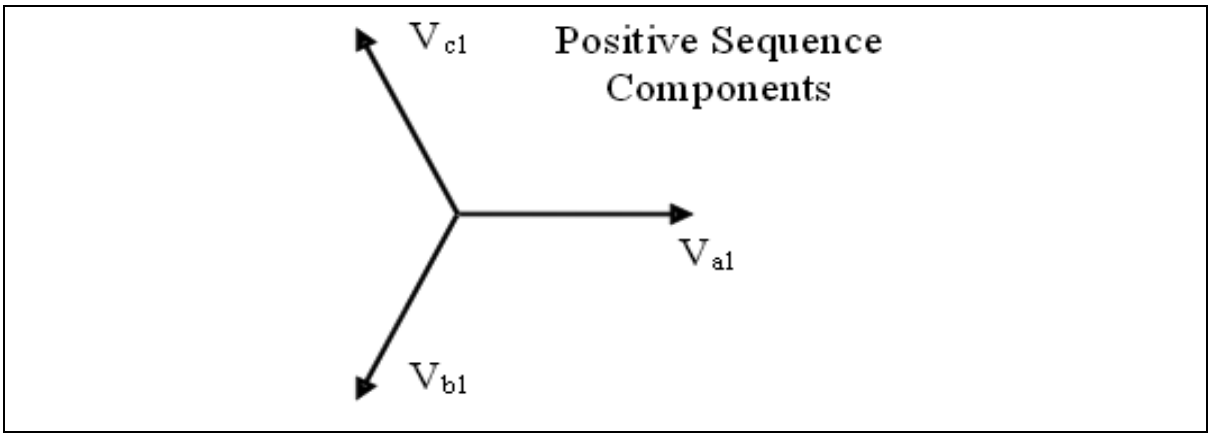

Figure 2.18: Positive Sequence Components

Similar to the positive sequence components, the negative sequence components likewise have components that are identical in magnitude and separated from one another by 120^{o} (electrical degree). The phase order is different from the original method, though. The "acb" sequence is known as the negative sequence, and it is typically indicated by the sign "-" or "2." Figure (2.19) illustrates the sequence's phasors, which spin counter clockwise. Only when an unsymmetrical fault happens in spite of the positive sequence components can this sequence arise.

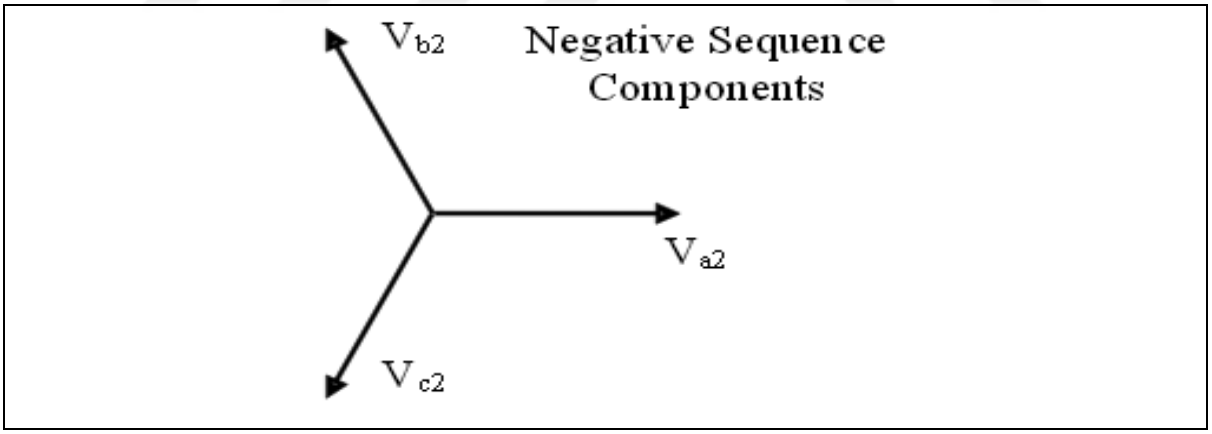

Figure 2.19: Negative Sequence Components

Three phasors with the same magnitude as previously but zero displacements make up zero sequence components. The phasor parts are in synchronization with one another. The Figure (2.20) demonstrates this sequence, which represents the residual electricity in the system through an asymmetrical fault state in terms of voltages and currents where a ground or fourth wire is present. It occurs when any electrical system grounding point allows ground

currents to return to the power system. Both the positive and the negative elements are present in this category of defects. The sign "0" is used to identify this sequence.

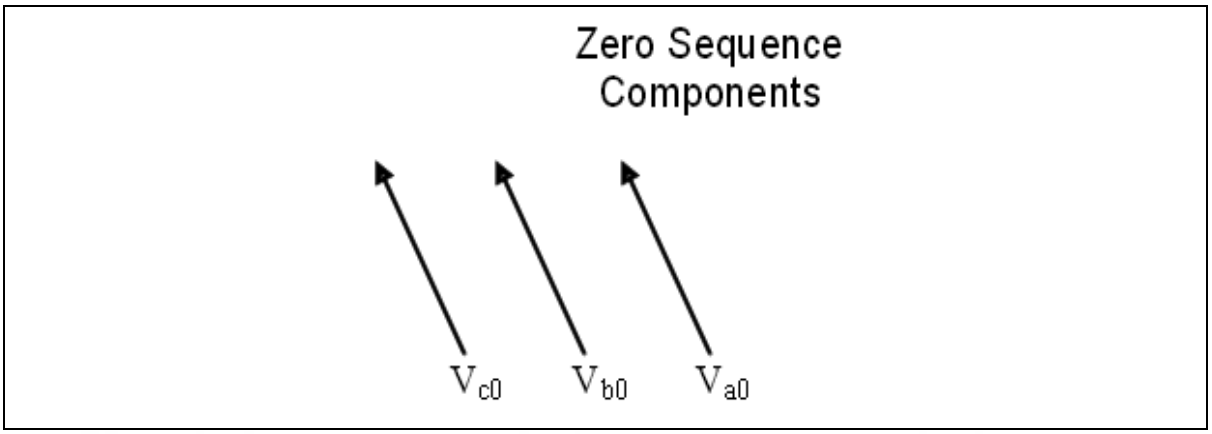

Figure 2.20: Zero Sequence Components

The equations of the phase current used in voltage phasor decomposition will give as [41]:

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} . \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} \quad (2.5)$$

Therefore, the positive sequence, negative sequence and zero sequence from the phasor can as well be obtained as shown;

$$\begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix} = \frac{1}{3} . \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (2.6)$$

Where (a) is $1 \angle 120$

2.5 RELATION BETWEEN SHORT CIRCUIT CURRENT AND GROUNDING SYSTEM

The relationship between the short circuit current (during line to ground fault and the grounding system can be considering with following points) [42]:

a. The single-line-to- ground fault current is about (0 to 3) of the three-phase fault current neutral grounding method.

b. The voltage of the healthy phases is about (0.6 to 2) of the phase system voltage and also depend on the neural grounding method.

c. When $X_0 / X_1 < 3$ and $R_0 / X_1 > 1$ then the system can be called as effectively grounded system.

d. When $X_0 / X_1 > 40$ then the system can be called as ungrounded system.

e. When $3 > X_0 / X_1 > 40$ then the system can be called as resistance or reactance or other types of the grounding system.

f. When $X_0 / X_1 < 1$ then the system can be called as solidly grounded system.

The relationship between the fault current (three phase and single phase) and voltages (before and after) faults for different X_0 / X_1 can be consider as:

a. When $X_0 / X_1 = 1$

Then the three-phase fault current = single-line-to-ground fault current.

Healthy phases voltage before fault = Voltage after the fault

b. When $X_0 / X_1 > 1$

Then the three-phase fault current > single-line-to-ground fault current.

Healthy phases voltage before fault > Voltage after the fault

c. When $X_0 / X_1 < 1$

Then the three-phase fault current < single-line-to-ground fault current.

Healthy phases voltage before fault < Voltage after the fault

Figure (2.21) shows how the increasing of the X_0 / X_1 will decrease the single-line-to-ground fault current, on the other hand, the negative to positive reactance ratio X_2 / X_1 is also can effect on the value of the single-line-to-ground fault current. Figure (2.21/a) shows the relation between the single-line-to-ground fault current and the X_0 / X_1 when $X2 / X_1$ is 0.5. Figure (2.21/b) shows the relation between the single-line-to-ground fault current and the X_0 / X_1 when $X2 / X_1$ is 1, Figure (2.21/c) shows the relation between the single-line-to-ground

fault current and the X_0 / X_1 when $X2 / X_1$ is 1.5. The relation between the voltages of the healthy phases and the X_0 / X_1 is shown in Figure (2.22).

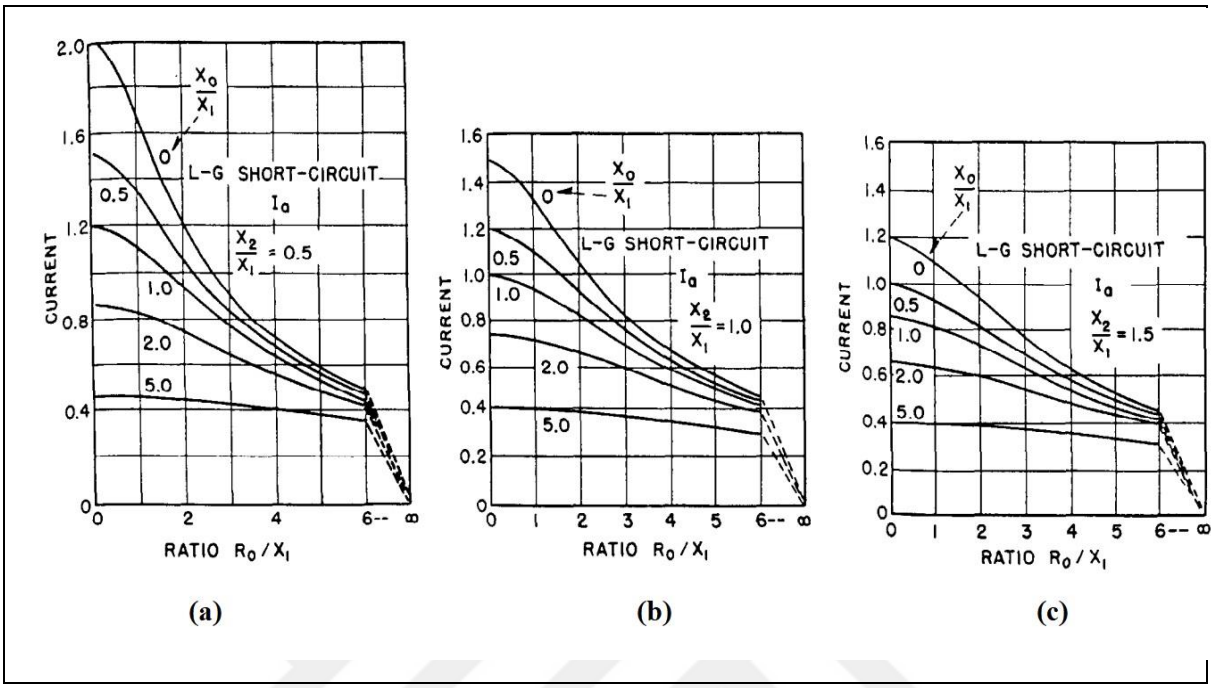

Figure 2.21: The Relation Between The Single-Line-to-Ground Fault Current and The Ratio of X_0 / X_1 When (A) X_2 / X_1 Is 0.5; (B) X_2 / X_1 Is 1, (C) X_2 / X_1 Is 1.5

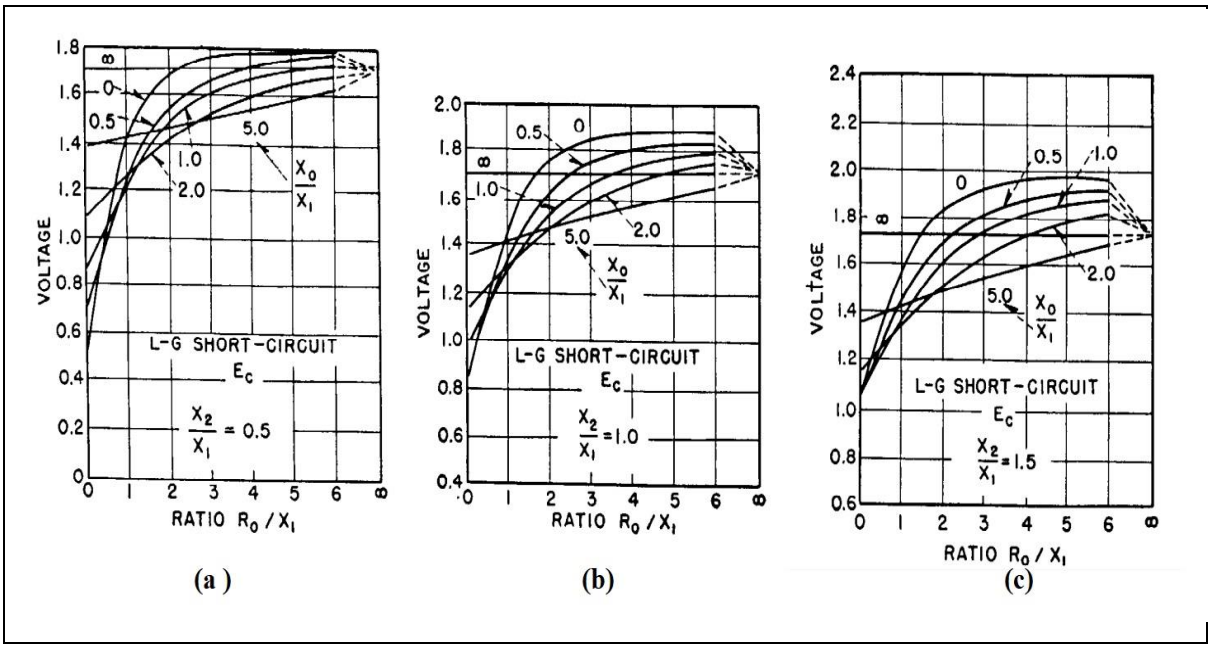

Figure 2.22: The Relation Between The Voltages of The Healthy Phases and The Ratio of X_0 / X_1 When (A) X_2 / X_1 Is 0.5; (B) X_2 / X_1 Is 1, (C) X_2 / X_1 Is 1.5,

2.6 SHORT CIRCUIT LEVEL AND FAULT ANALYSIS

Short circuit level, short circuit MVA, short circuit capacity (SCC), fault level and fault MVA, are all synonyms of the same electrical quantity in MVA. This quantity at a bus is a measure of bus strength, the higher is that approaching to an infinite bus, i.e., ideal voltage source. Equation wise, the short circuit capacity is given as:

$$\mathrm{SCC} = \sqrt{3} * (\text{nominal kV}) * \mathrm{I_F} * 10^{-3} \quad \text{MVA} \tag{2.7}$$

A station with a high fault level will be more resistant to the effects of fault consequences. Fault levels are required in deciding the specification of substation plant equipment.

Power system fault studies include the following:

a. Computation the values of three-phase short circuit currents and fault level (MVA).

b. Computation of unsymmetrical fault current; single phase-to- ground, phase-to-phase, phase-to-phase to ground.

c. Evaluate of the circuit breakers capacity.

d. Choice of protective devices and settings.

e. Computation of voltage magnitudes at bus bars during fault

2.7 THE PSS/E SOFTWARE

Power System Simulation for Engineering (PSS/E) is a collection of tools that may be used to study both the dynamic and steady-state of the power system transmission networks and generating capabilities. For a number of system investigations, computations are made easier with the PSS/E. These consist of switching studies, equivalence, fault analysis, optimal power flow, load flow, and optimal power flow. PSS/E offers the user a wide selection of auxiliary programs for installation, data input, output processing, and preparation in addition to steady state and dynamic analysis. Another fundamental tenet of PSS/E is that the engineer may profit from computational tools by maintaining control over how they are used. The entirety of state analysis capabilities is provided through PSS/E's graphical user interface. Among the top computer packages used globally in the electric power business is the PSS/E.

This is because of its adaptability in handling various data files, the abundance of features included, and the variety of presentation options for study findings [43].

For modelling and analytical studies of the Iraqi power system, the PSS/E software is employed. For carrying out both long-term it is accessible at the Planning and Studies Office (P&SO) / Ministry of Electricity.

3. SIMULATION OF THE PROPOSED SYSTEM

3.1 BACKGROUND OF IRAQI POWER SYSTEM

The power system is divided into three industries: generation, transmission, and distribution. The voltages in the generating sector of the Iraqi electricity system do not take more than 20 kV. In the transmission industry, step-up transformers are utilized to boost voltage levels to 132 kV and 400 kV. Autotransformers link the 132kV high voltage transmission with the 400kV extra high voltage transmission. Step-down transformers are employed in the distribution sector to reduce voltage levels to 33kV and/or 11kV [10]. The rating of the three-winding transformer for 132/33/11 kV is 63/50/25 MVA and in some region 50/50/25 MVA is used, for two winding transformer 132/33 kV is 63 MVA. In the distribution sector the rating of the 33/11 kV is 31.5 MVA. On the other hand, the rating of the autotransformer 400/132/11 kV is 250/250/75 MVA [44].

The supply reliability is among the most significant considerations in power system operation and planning. As a result, the power provider utility is required to offer high-quality electricity under a variety of operating and load-growth scenarios, definitely not forgetting the economic impact. The study of the impact of the earthing system of the power transformer on the short circuit is important for the Ministry on Electricity (M.O.E) of Iraq.

Until the mid-sixties of the last century, the Iraqi power grid was made of three unconnected power areas, Namely, North, Middle and South areas. The high voltage transmission at 132 kV level, then introduced to mesh the three mentioned areas to form the Iraqi high voltage grid. Two decades later the extra high voltage transmission at 400 kV was used in order to upgrade the transmission to handle higher power capabilities. One extra power area was introduced later namely Middle Euphrates which covering some of the midland governorates [45].

3.2 STATISTICAL INFORMATION OF IRAQI POWER SYSTEM

The statistical of the Iraqi power system can be divided into: Generation and Load Demand, Transmission Sector, Distribution Sector.

3.2.1 Generation and Load Demand

The installed capacity and the available generation in MW are shown in Table (3.1). While the average available imports power to the Iraqi power system it can be given in the following Table (3.2) [10].

Table 3.1: Installed and Available Generation of Iraqi Power System /2022

Type of generation units	Installed capacity MW	Available capacity MW
Thermal generation units	8565	4453
Gas generation units	24185	13301
Hydro generation units	1864	745
Diesel generation units	1955	685
Mobile generation unit	308	123
Combined Cycle unit	4212	1895
Total MW	41089	21204

Table 3.2: The Import Power to Iraqi Power System

Type of Import	Average available MW
Import power from Iran and Turkey	750
Import power from Kurdistan	150
Import power from Investment projects	5500
Total import MW	6400

The available generation and the load demand can be given in Table (3.3) and Figure (3.1) shows the gap between them from 2003 to 2022.

Table 3.3: Load Demand and Actual Generation From 2003 Till 2022 [10]

Year	Actual Generation MW	Load Demand MW
2003	3400	6721
2004	5496	7372
2005	5389	8845
2006	5283	9339
2007	5028	9628
2008	5630	10490
2009	6830	11142
2010	6775	14013
2011	7065	15201
2012	8750	15370
2013	12075	17454
2014	12320	18653
2015	13400	21221
2016	14355	24020
2017	15625	25581
2018	16465	26341
2019	19170	27346
2020	19365	29000
2021	21145	31859
2022	24000	34060

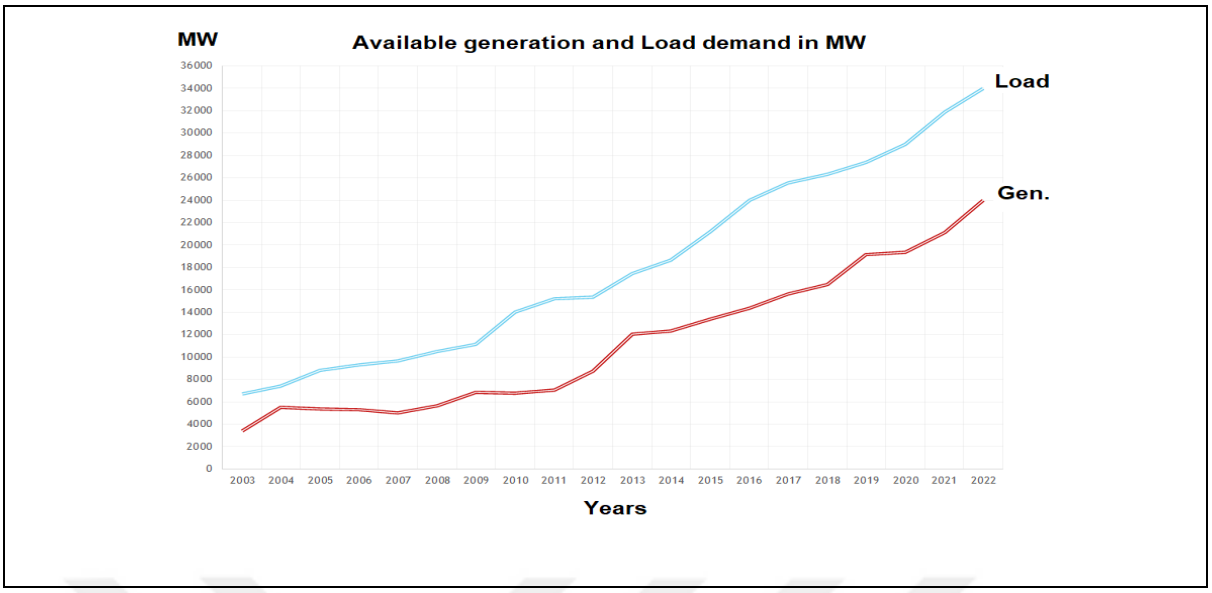

Figure 3.1: The Available Generation and Load Demand From 2003 To 2022

Table (3-3) shows the annual load demand with actual generation in MW for the period from 2003 to 2022, it can be clear to see there is a gap between the load demand and the generation and the load shedding strategy is applied in Iraqi power system to control the frequency. This gap it present from 1990 after the first gulf war, in future the Ministry of electricity have master plan to remove this gap at 2030 [44]. The reasons for electric power industry crumbling in Iraq can be given as follow:

a. Uncertain environment.

b. A long-term economic blockade on Iraq.

c. Terrorist attacks.

d. Issues in supplying suitable fuel to the manufacturing plants (amount and kind).

e. The emphasis has been on generational expansion without an expansion plan for the transmission sector.

f. The rapid increase in electrical demand (residential, governmental, and commercial) as a result of income growth after 2003.

g. The challenges of implementing an effective power rate structure.

h. Water resource scarcity and its impact on hydropower generating

i. Maintenance and refurbishment of old power plants.

j. There are no electrical regulating provisions in the Iraqi legal system.

3.2.2 Transmission Sector

Table (3.4) shows a summing review of the two voltage levels, the substations, number and type of transformers and ratings [45].

Table 3.4: Transmission Substations: Grid Summary (2022)

Year	No. of 132kV Substation	No. of 400kV Substation	No. of Mobile Substation	Capacity of 132kV substations in MVA	Capacity of 400kV substations in MVA	Capacity of Mobile substation in MVA
2003	169	21	-	22208	14000	-
2022	303	59	323	50042	42850	9793

In the 132 kV transmissions, overhead lines and underground cables are used with MVA rating regarding from 74 MVA to 330 MVA. Overhead lines are used in the 400 kV transmissions with capacity of 970 MVA to 1000 MVA. Table (3.5) shows a summary of the two voltage levels line numbers and lengths. The details of the line conductor types and rating are given in Table (3.6).

Table 3.5: Grid Lines Summary Length in Km

Year	Length of 132 kV Transmission Lines in Km	Length of 400 kV Transmission Lines in Km
2003	11299	3680
2022	17075	6048

Table 3.6: Transmission Line Conductors and Parameters, Where (R_0, X_0, R_1 And X_1) (Are Zero and Positive Resistance and Reactance) In ($\Omega*10^{-3}$/Km), And (B) (Shunt-Susceptance) In (Ʊ $*10^{-3}$/Km)

Type	Symbol	Voltage kV	R_0	X_0	R_1	X_1	B	Rated MVA
Lark	L	132	2.1483	6.9894	0.8316	2.4255	0.4554	97
Teal	T		1.8612	6.9201	0.5445	2.3562	0.4554	123
Oriel	OR		2.3067	7.0191	0.9801	2.4552	0.4455	86
Redwing	R		1.782	6.8805	0.4653	2.3265	0.4752	147
Partridge	P		2.5542	7.0785	1.2375	2.5146	0.4356	74
Cupper 120	CU2		2.1879	7.1379	0.8613	2.574	0.4257	79
Cupper 150	CU5		2.0097	7.1082	0.6831	2.5443	0.4257	91
Twin lark	T.L		1.7424	6.2964	0.4158	1.7325	0.6336	189
Twin teal	T.T		1.5939	6.2964	0.2673	1.7028	0.6435	236
Almalak	AL		1.7028	6.7419	0.594	2.1978	0.4653	116
Pigeon	PI		4.3263	7.3953	1.5444	2.6334	0.4554	50
Zebra	Z		0.8811	3.96	0.2277	1.7919	0.3465	156
TAA 132	TAA		1.7028	5.544	0.1881	1.782	0.6039	180
Cable	C		1.4157	1.1286	0.1188	0.3267	19.503	120
Double cable	DC		0.7128	0.5544	0.0594	0.1584	39.006	228
Double partridge	DB		1.2771	3.5343	0.6138	1.2573	8.8704	150
Twin Aluminum Alloy, All Aluminum Alloy Conductor	TAA, AAAC	400	0.18	0.61	0.02	0.19	5.83	1000
Aluminum Conductor Steel re-forced	ACSR	400	0.09	0.47	0.02	0.18	5.78	970

3.2.3 Distribution Sector

The Table (3.7) shows the total number of the distribution substation 33/11 kV for the period 2003 to 2022 and there capacity, it's worth mentioned here, mobile substations are added to the distribution sector after the second gulf war 2003 [10].

Table 3.7: Number of the Distribution Substation (With Mobile Substations) and There Capacity For The Period (2003 To 2022)

Year	No. of the Substations	No. of the mobile Substations	Total Capacity in MVA
2003	412	-	13637
2022	418	208	47987.5

3.3 CASE STUDY SYSTEM

The proposed system of this study is a sector of Iraqi power grid 132 kV side which is located in the north of Iraq (Mosul Gov.), the system consists from six 132 kV station, in addition to the one 400 kV substation which named Gayara 400 kV substations. Figure (3.2) shows the single line diagram of the proposed system. Auto-transformer is connected to the Gayara 400 kV substation to transform the power to the 132 kV side (Gayara 132 kV substation) as shown in Figure below, while the number, names and the rated voltage of the proposed system bus bars are given in the Table (3.8)

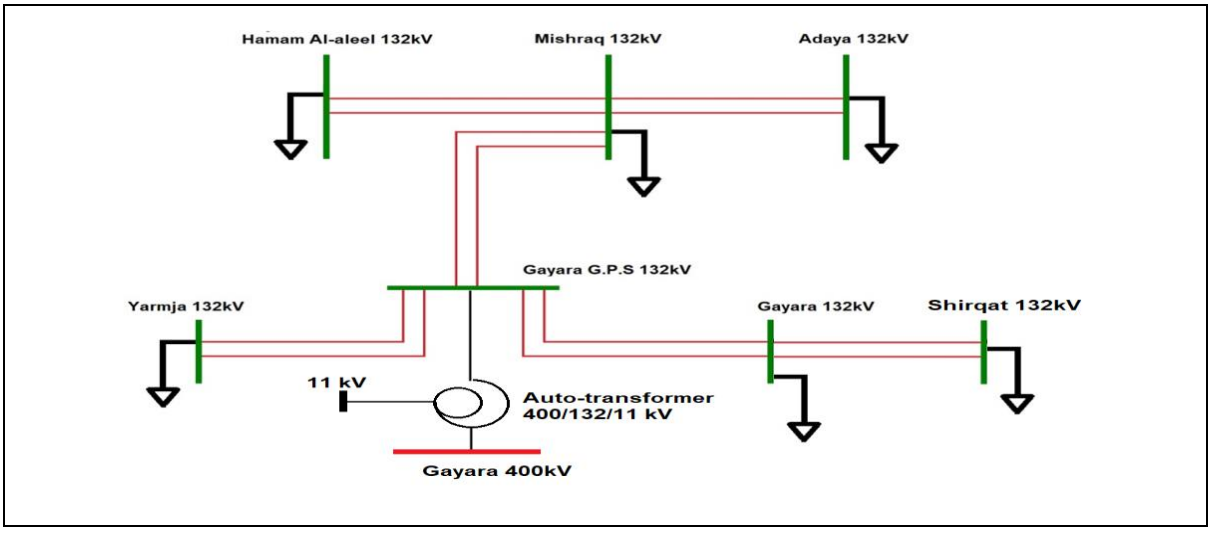

Figure 3.2: The Single Line Diagram of The Proposed System

Table 3.8: Numbers, Names, and Rated Voltage of The Bus Bars of The Proposed System

No. Bus	Name of Bus	Voltage of Bus kV
1010	QAYARA11	11
1011	YARMJA11	11
1012	QAYARA OLD11	11
1030	QAYARA132	132
1031	YARMJA	132
1032	QAYARA OLD	132
1033	SHIRQAT	132
1034	MISHRAQ	132
1035	ADAYA	132
1036	HAMAM	132
1040	QAYARA400	400
1051	YARMJA33	33
1052	QAYARA OLD33	33
1053	SHIRQAT33	33
1054	MISHRAQ33	33
1055	ADAYA33	33
1056	HAMAM33	33

The parameters of the transmission lines of the proposed system it can be given in Table (3.9), Table (3.9) shows the name of the transmission lines (form – to), resistance (R), reactance (XL), and shunt-susceptance (B) according to the length of the transmission line. The zero resistance and reactance are also given in this table; the zero impedance are so important for short circuit calculation that will be used in the next chapter.

Table 3.9: Transmission Line Parameters of The Proposed System

From Bus Name	To Bus Name	ID	Resistance in P.U	Reactance in P.U	shunt-susceptance in P.U	Rating in MVA	Length	Zero Resistance in P.U	Zero Reactance in P.U
QAYARA132	YARMJA	1	0.022041	0.136038	0.052037	236	79	0.12719	0.502993
QAYARA132	YARMJA	2	0.022041	0.136038	0.052037	236	79	0.12719	0.502993
QAYARA132	QAYARA OLD	1	0.002616	0.009242	0.002345	236	4.3	0.008323	0.029121
QAYARA132	QAYARA OLD	2	0.002616	0.009242	0.002345	236	4.3	0.008323	0.029121
QAYARA132	MISHRAQ	1	0.007087	0.043739	0.016731	236	25.4	0.040894	0.161722
QAYARA132	MISHRAQ	2	0.007087	0.043739	0.016731	236	25.4	0.040894	0.161722
QAYARA OLD	SHIRQAT	1	0.032133	0.093366	0.017617	97	38	0.08246	0.268432
QAYARA OLD	SHIRQAT	2	0.032133	0.093366	0.017617	97	38	0.08246	0.268432
MISHRAQ	ADAYA	1	0.036361	0.105651	0.019935	97	43	0.09331	0.303752
MISHRAQ	ADAYA	2	0.036361	0.105651	0.019935	97	43	0.09331	0.303752
MISHRAQ	HAMAM	1	0.024522	0.071253	0.013444	97	29	0.06293	0.204856
MISHRAQ	HAMAM	2	0.024522	0.071253	0.013444	97	29	0.06293	0.204856

The Tables (3.10) and (3.11) shows the buses names and numbers that used to connect the two and three winding transformers of the proposed system respectively according to the PSS/E program file. Five (two winding transformers) and five (three winding transformers) are used in the proposed system and distributed according to the Tables that mentioned above.

Table 3.10: Two Winding Transformers of The Proposed System Form The PSS/E File

	From Bus Number	From Bus Name		To Bus Number	To Bus Name		Id
	1035	ADAYA	132.00	1055	ADAYA33	33.000	1
▶	1036	HAMAM	132.00	1056	HAMAM33	33.000	1
	1034	MISHRAQ	132.00	1054	MISHRAQ33	33.000	1
	1033	SHIRQAT	132.00	1053	SHIRQAT33	33.000	1
	1033	SHIRQAT	132.00	1053	SHIRQAT33	33.000	2
*							

Table 3.11: Three Winding Transformers of The Proposed System From The PSS/E File

	From Bus Number	From Bus Name		To Bus Number	To Bus Name		Last Bus Number	Last Bus Name		Id
	1031	YARMJA	132.00	1051	YARMJA33	33.000	1011	YARMJA11	11.000	1
	1031	YARMJA	132.00	1051	YARMJA33	33.000	1011	YARMJA11	11.000	2
	1032	QAYARA OLD	132.00	1052	QAYARA OLD3	333.000	1012	QAYARA OLD1	111.000	1
	1032	QAYARA OLD	132.00	1052	QAYARA OLD3	333.000	1012	QAYARA OLD1	111.000	2
	1040	QAYARA400	400.00	1030	QAYARA132	132.00	1010	QAYARA11	11.000	1
*										

The auto-transformers connection (vector group) is YNYnd1, and the PSS/E implementation for the 400/132/11 kV sides can be given in Figure (3.3). While the vector group of the 132/33/11 kV transformers base on PSS/E program is shown in Figure (3.4).

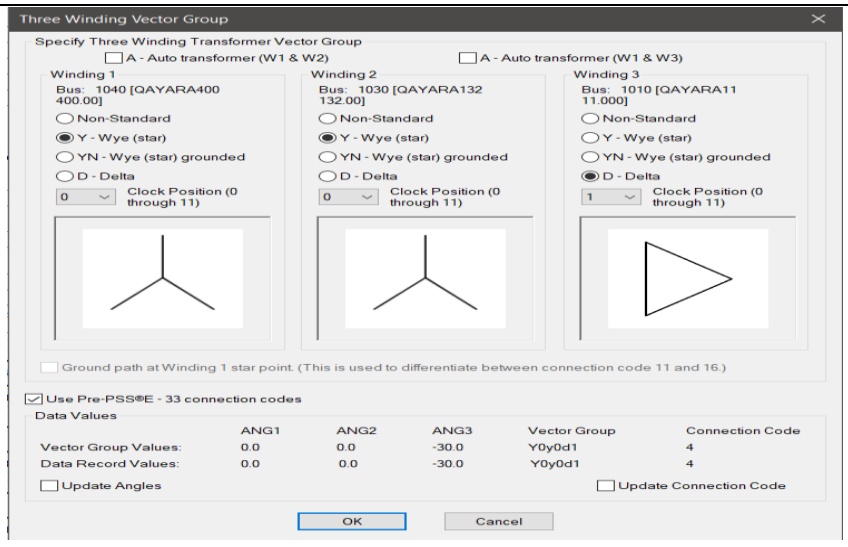

Figure 3.3: Auto-Transformer 400/132/11 Kv Connections by PSS/E Program

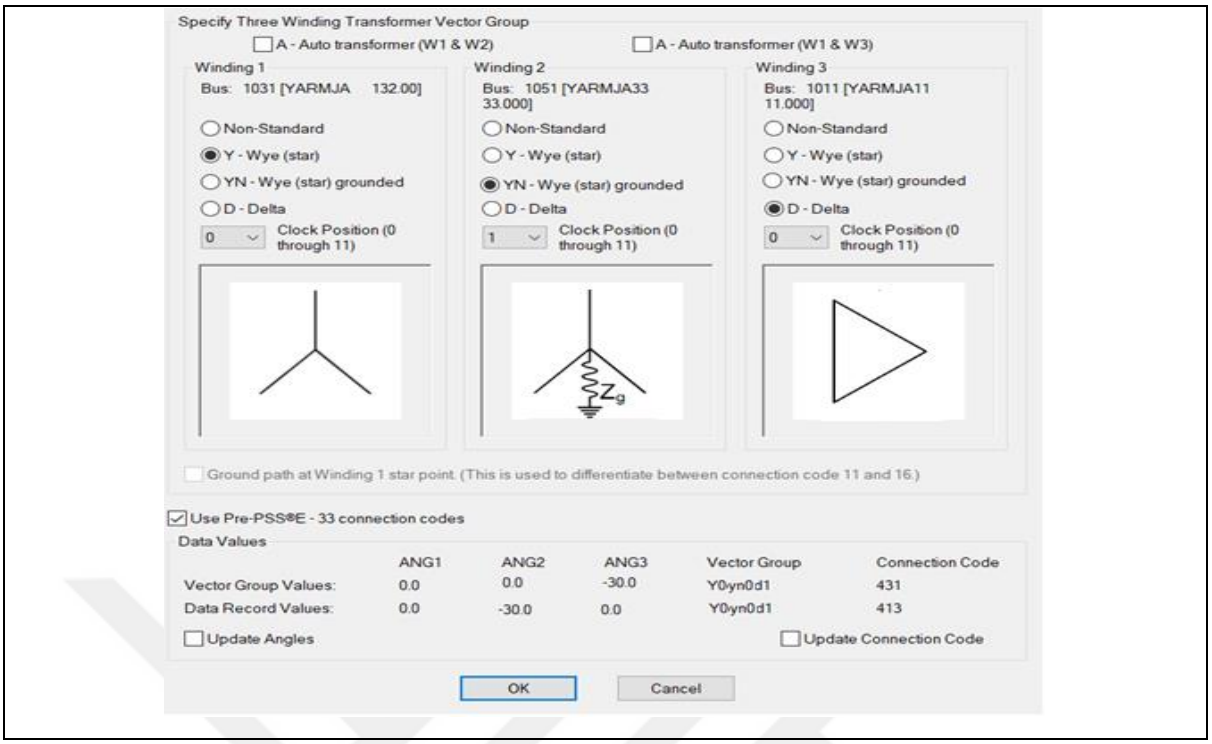

Figure 3.4: The 132/33/11 Kv Connections By PSS/E Program

The vector group of the 132/33 kV transformers base on PSS/E program is shown in Figure (3.5).

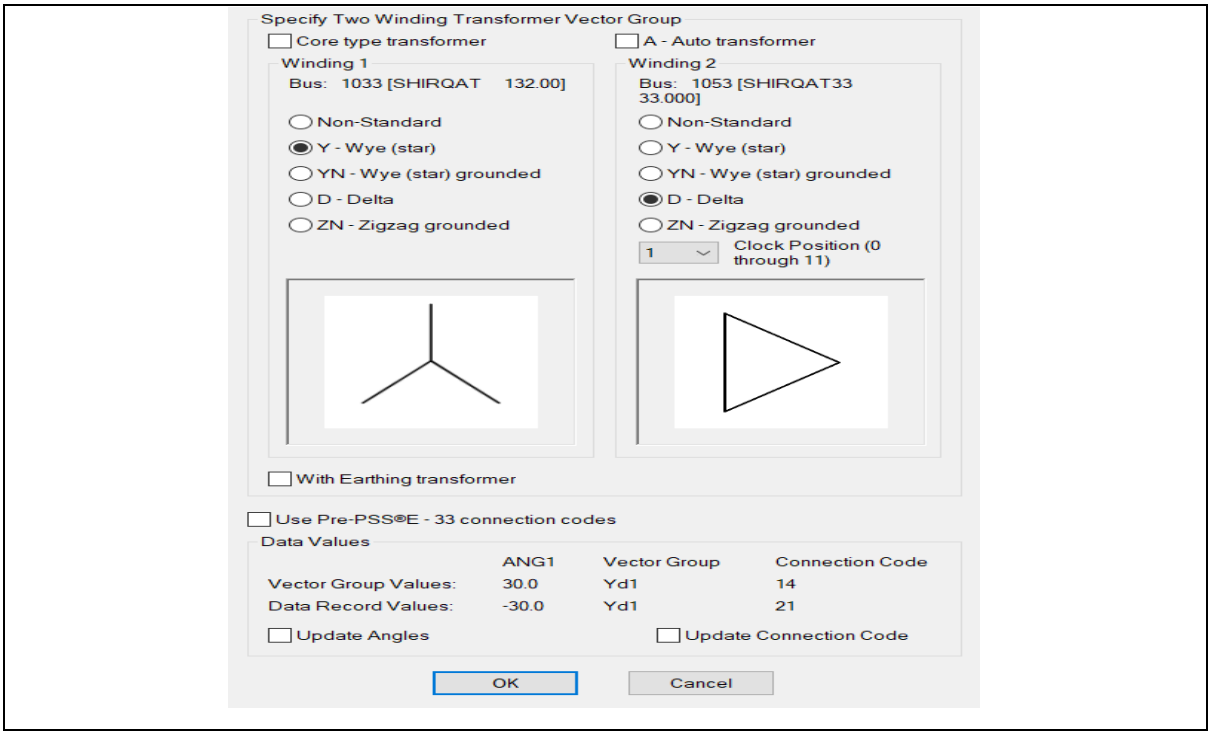

Figure 3.5: The 132/33 Kv Connections by PSS/E Program

3.4 PSS/E SIMULATION OF THE CASE STUDY SYSTEM

The PSS/E simplifies computations for a variety of system inquiries. These include fault analysis, switching studies, equivalency, optimal power flow, load flow, and optimal power flow. In addition to steady state and dynamic analysis, PSS/E provides the user with a vast array of auxiliary programs for setup, data input, output processing, and preparation [46]. The engineer can benefit from computational tools by keeping control over how they are utilized, according to another core principle of PSS/E. The graphical user interface of PSS/E provides all of the state analysis features. The PSS/E is one of the most popular computer programs used internationally in the electric power industry [47]. This is due to the program's flexibility in processing different data files, the wealth of features it offers, and the range of display possibilities for research results.

The implementation of the proposed system by using PSS/E program can be shown in Figure (3.6).

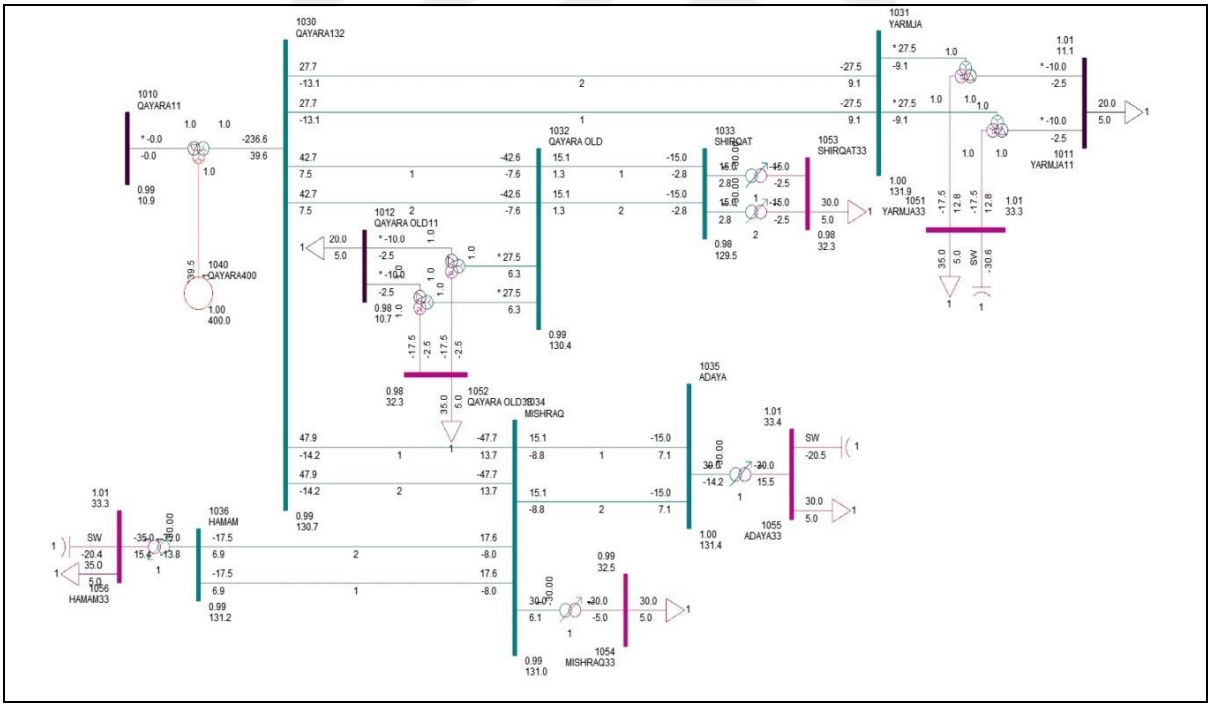

Figure 3.6: The Implementation of the Proposed System by Using PSS/E Program

The Gayara 132 kV substation is connected to the Gayara 400 kV substation via auto-transformer 400/132/11 kV. The single line diagram of the Gayara 132 kV (bus bar no. 1030) and there transmission line by using PSS/E program is shown in Figure (3.7), while the

Figure (3.8) shows the Yarmja substation implementation with two three winding transformer.

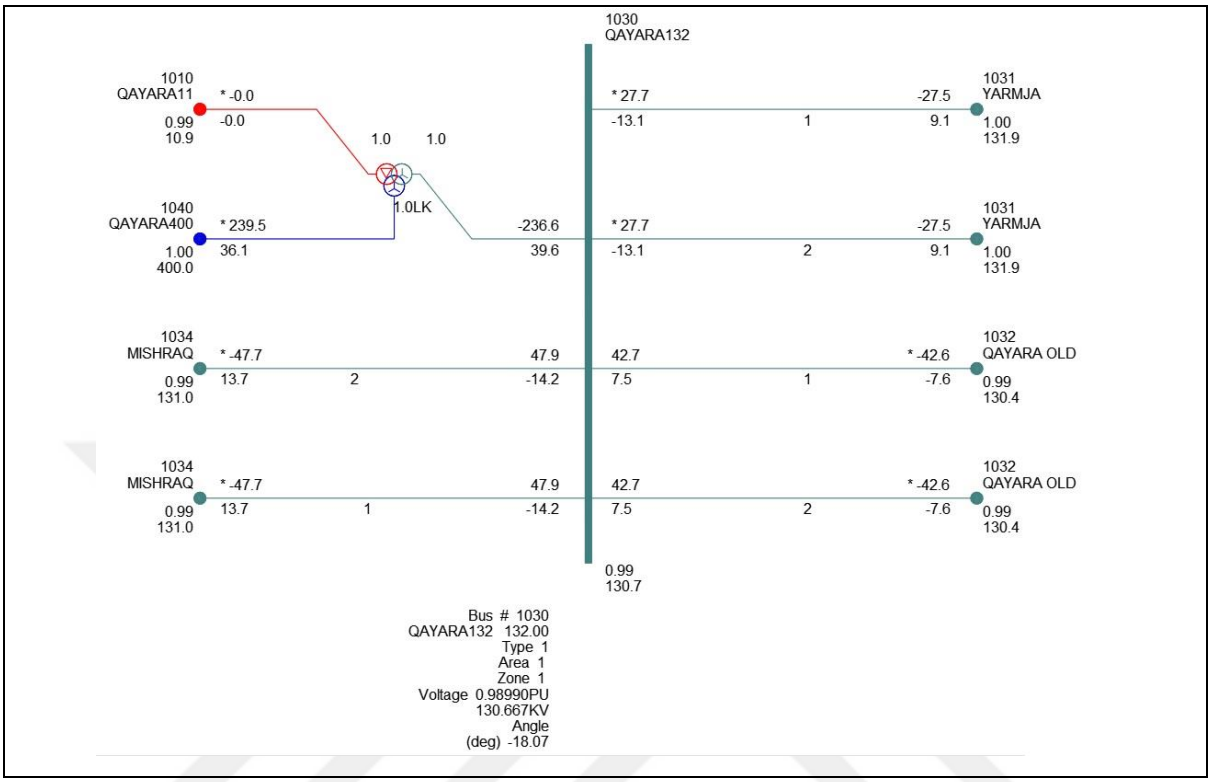

Figure 3.7: Gayara 132 Kv Substation by Using PSS/E Program

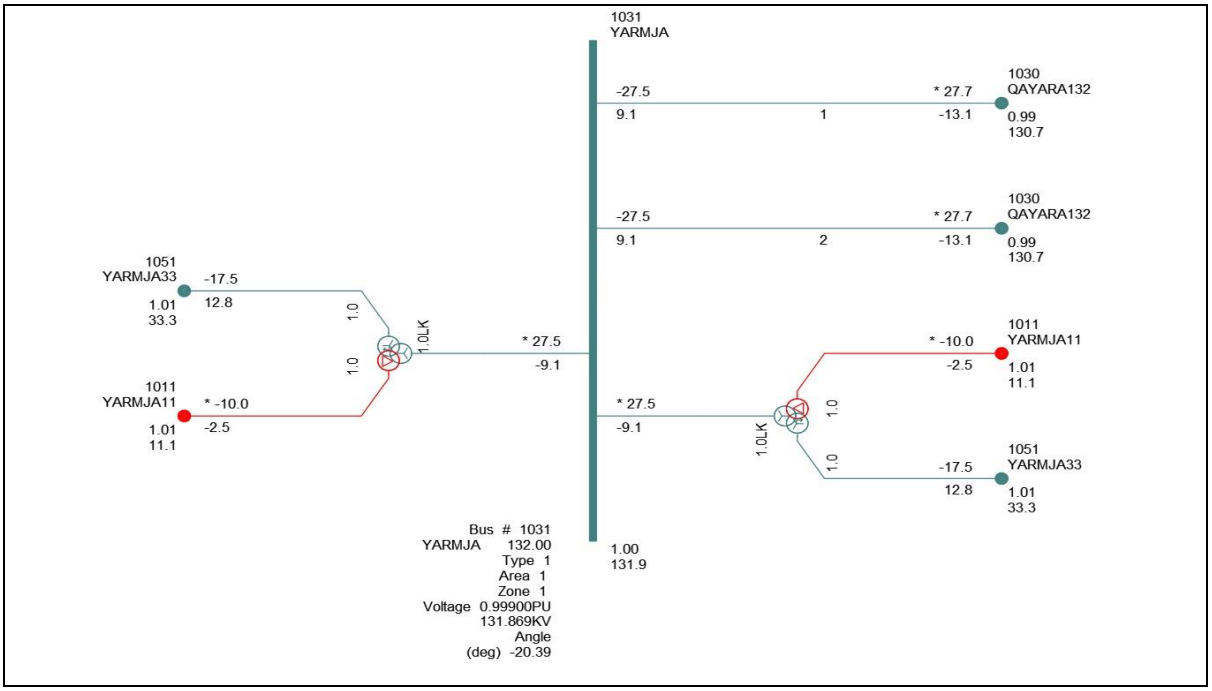

Figure 3.8: Yarmja 132 Kv Substation by Using PSS/E Program

Figure (3.9) shows the Gayara Old 132 kV substation implementation by using PSS/E program with two three winding transformers, while the Shiraqat 132 kV implementation with two winding transformer is shown in Figure (3.10)

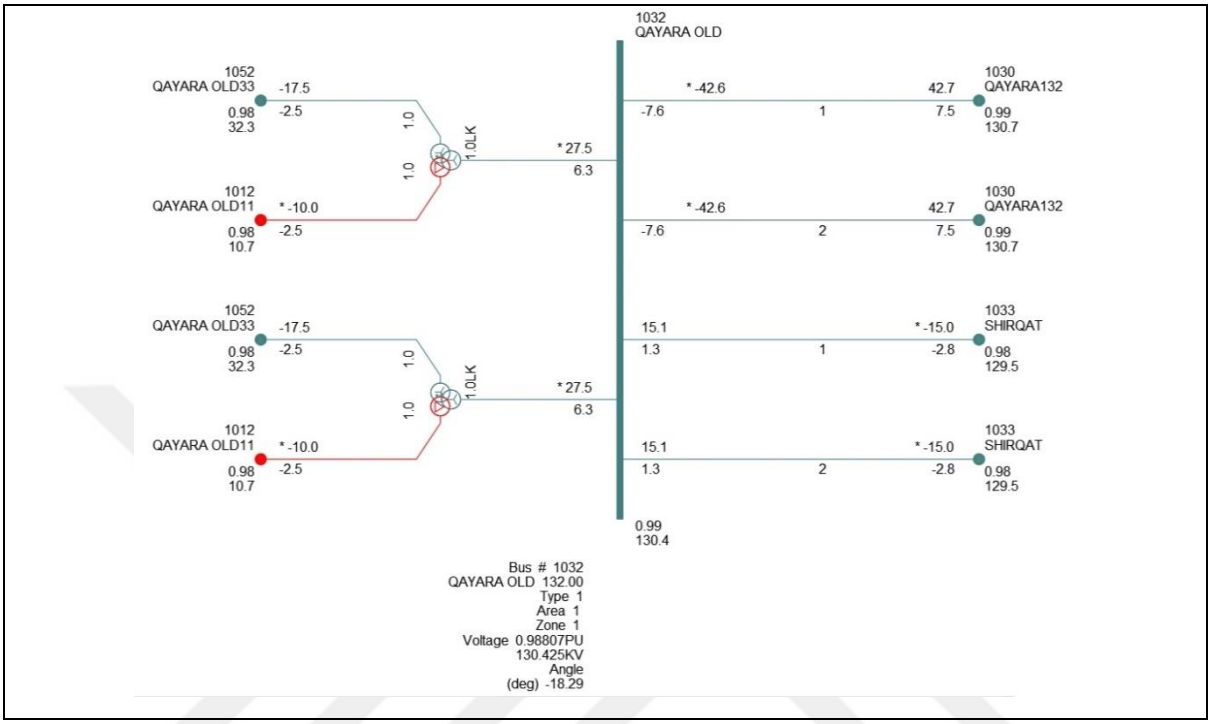

Figure 3.9: Gayara Old 132 Kv Substation by Using PSS/E Program

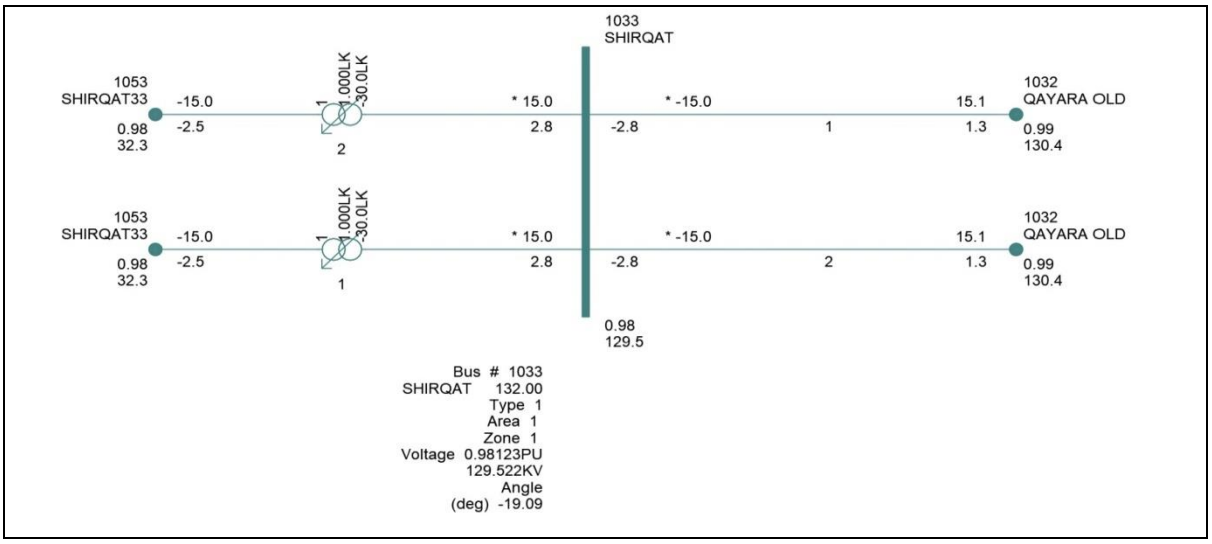

Figure 3.10: Shirqat 132 Kv Substation by Using PSS/E Program

Figure (3.11) shows the Mishraq 132 kV substation implementation by using PSS/E program with one two winding transformer, while the Adaya 132 kV implementation with two winding transformer is shown in Figure (3.12)

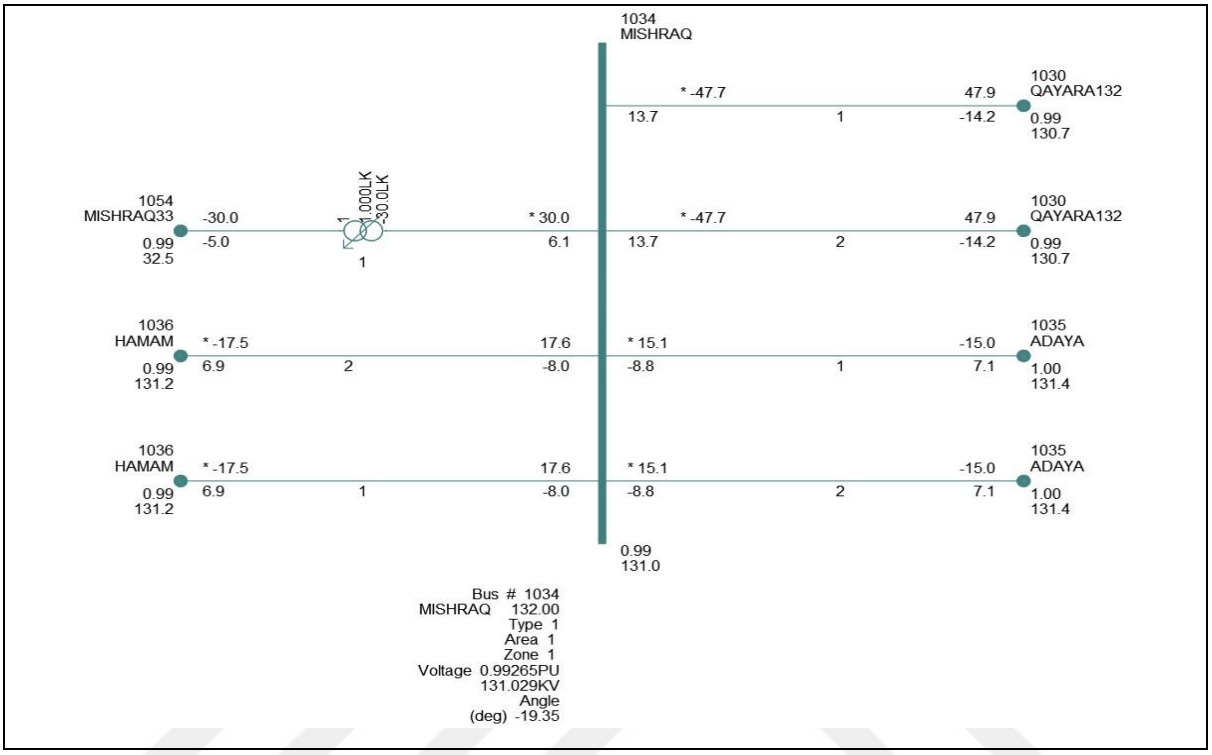

Figure 3.11: Mishraq 132 Kv Substation by Using PSS/E Program

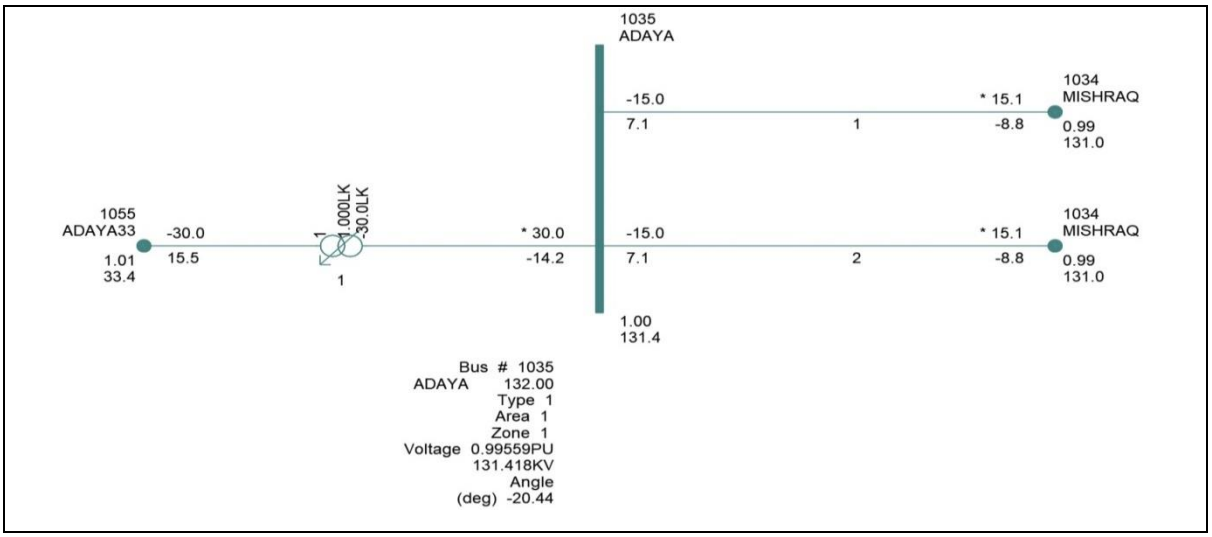

Figure 3.12: Adaya 132 Kv Substation by Using PSS/E Program

Figure (3.13) shows the Hamam 132 kV substation implementation by using PSS/E program with one two winding transformer, Figure (3.14) shows the tertiary winding of the Gayara 400 kV auto transformer is shown in Figure (3.14)

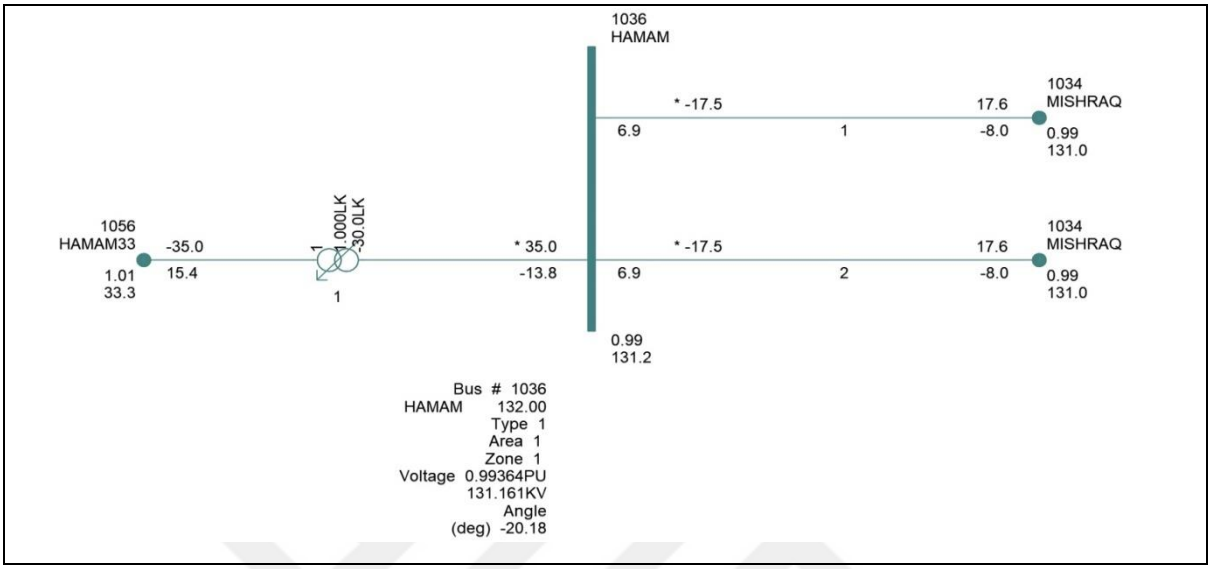

Figure 3.13: Hamam 132 Kv Substation by Using PSS/E Program

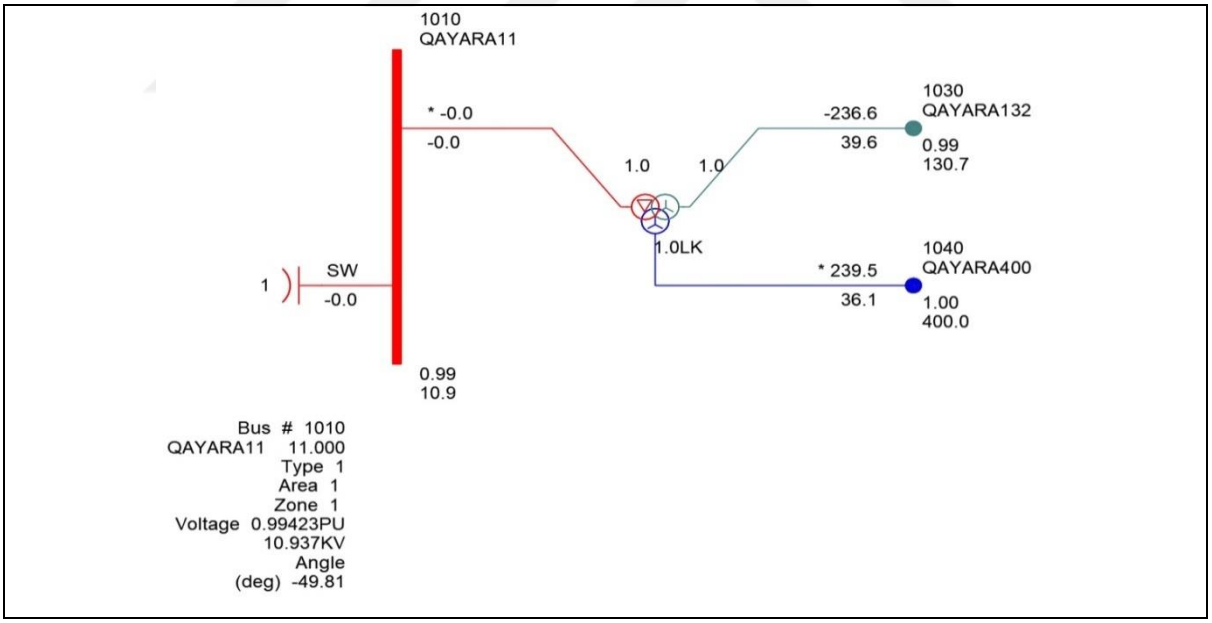

Figure 3.14: Tertiary of The Autotransformer by Using PSS/E Program

To ensure the proposed system is work properly, the load flow analysis must be done before the short circuit is applied in the next chapter. The power flow results of the case study system can be given in Table (3.12), the fixed slop decoupled Newton-Raphson method is used in the load flow analysis. The result shows that, all the branches (two winding

transformers, three winding transformers, transmission lines, generators) are work within operation limits and ratings as shown in Figure (3.15). The codes of the buses in the PSS/E program are classified as: 1 for load bus, 2 for generation bus, 3 for swing bus, and 4 for isolated bus.

Table 3.12: Load Flow Analysis Base on The Fixed Slop Decoupled Newton-Raphson Method by Using PSS/E Program

Bus Number	Bus Name	Base kV	Code	Voltage (pu)	Angle (deg)
1010	QAYARA11	11	1	0.9942	-49.81
1011	YARMJA11	11	1	1.0101	-52.98
1012	QAYARA OLD11	11	1	0.9772	-51.34
1030	QAYARA132	132	1	0.9899	-18.07
1031	YARMJA	132	1	0.999	-20.39
1032	QAYARA OLD	132	1	0.9881	-18.29
1033	SHIRQAT	132	1	0.9812	-19.09
1034	MISHRAQ	132	1	0.9926	-19.35
1035	ADAYA	132	1	0.9956	-20.44
1036	HAMAM	132	1	0.9936	-20.18
1040	QAYARA400	400	3	1	0
1051	YARMJA33	33	1	1.0105	-22.39
1052	QAYARA OLD33	33	1	0.9796	-20.58
1053	SHIRQAT33	33	1	0.9782	9.91
1054	MISHRAQ33	33	1	0.9864	8.67
1055	ADAYA33	33	1	1.0122	7.64
1056	HAMAM33	33	1	1.01	7.57

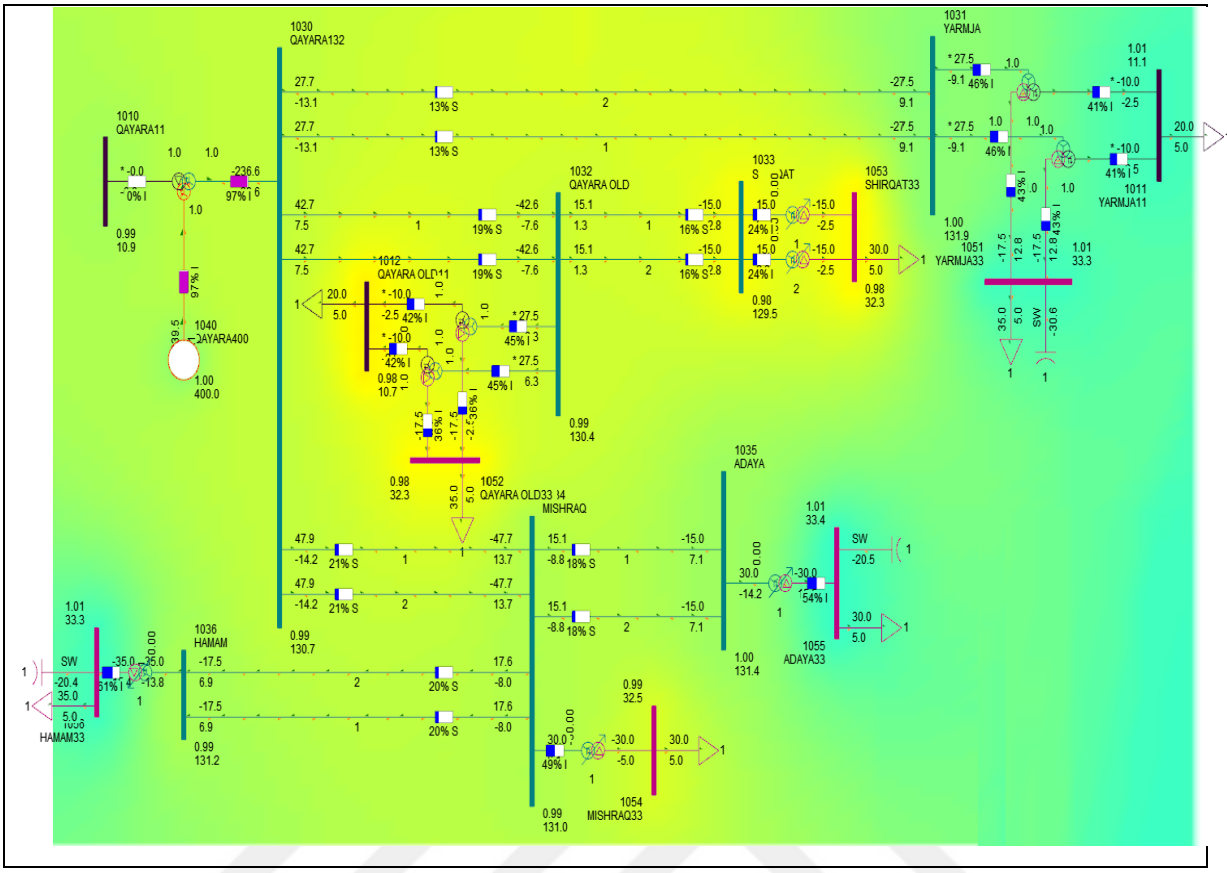

Figure 3.15: The Loading and Voltage Profile Results of The Proposed System Which Shows all The System Components Within Operation Limits.

The load flow results are identical to the collected data from the planning and studies office, now the PSS/E model can be considered as a base case for the short circuit simulation as will done in next chapter.

3.5 GROUNDING OF THE IRAQI POWER SYSTEM

According to the transformer neutral grounding method that explained in Chapter two, the neutral grounding method in Iraq is effectively grounding system. The high voltage neutral side is contain switch with solidly grounding wire i,e. then it can be close or open. As we explained the grounding system is referred to as solid grounding or effective grounding whenever the system's neutral is linked directly to the earth with little resistance and reactance among both. A system is considered to be solidly grounded if, even under circumstances and for any generator capacity, the proportion of zero sequence reactance X0 to positive sequence reactance X1 doesn't really exceed three for all of the system's points

and the proportion of zero sequence resistance to positive sequence resistance doesn't really exceed one [48].

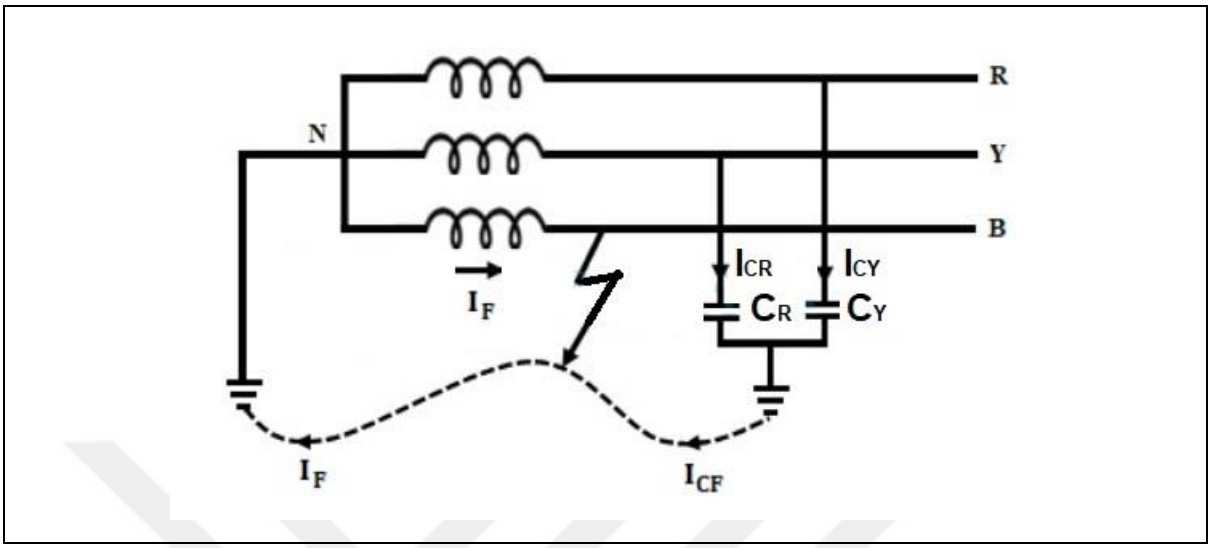

Figure 3.16: The Phase System With Fault on B Phase

Consider a three-phase electrical system with a grounded neutral and a ground fault in phase (B) as shown in Figure (3.16), as seen in the following diagram. The voltage of the neutral and phase (B) will be at ground potential when an earth fault develops above any phase, resulting in a zero phase-to-earth voltage for that phase, and then the voltages from healthy phases to ground stay the same during this fault. Given that the fault current (I_F) is in phase as opposed to the capacitive current (I_{CF}), it can be shown that the latter will be entirely neutralized (I_{CF}). Under earth fault situations, the voltages of healthy phases in a system with the solid ground will not be more than 80% of the line-to-line voltage. Following Figure (3.17) is the phasor graph of the three-phase system when fault occurred at phase B.

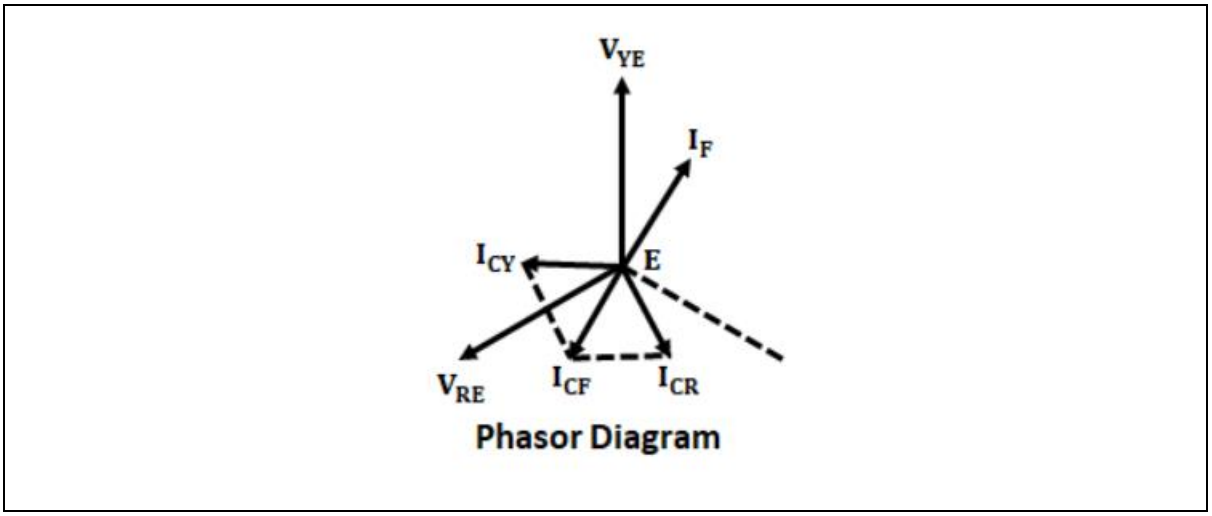

Figure 3.17: The Phasor Diagram of The Three-Phase System With B Phase Faulty

The phase Voltages (V_{RE}) and (V_{YE}) have remained at original (pre-fault) levels notwithstanding a fault in phase B. The healthy phases' capacitive currents (I_{CR}) and (I_{CY}) would lag their respective voltages by a 90° angle. Owing to primarily inductive impedance, ground faults current (I_F) lags the defective phase's phase to a neutral voltage by 90 degrees. (I_{CF}) is a resulting in the total capacitive current of (I_{CR}) and (I_{CY}).

4. RESULTS

4.1 INTRODUCTION

Single line-to-ground (SLG), line-to-line (LL), double line-to-ground (DLG), and three-phase short-circuit are examples of short-circuit faults in a power grid (3SC). The SLG happens much more frequently between these fault types, although the 3SC is typically regarded as the most serious one with the biggest amount of fault current, having a considerable impact on the choice of equipment and protective relay settings for the design and operation of power systems. There are, nevertheless, certain limitations. When SLG currents occur close to a machine or transformer that is solidly grounded, their size may approach 3SC current. The voltage insulation of neutral, however, requires a more careful assessment since a ground fault could result in a voltage change between neutral and ground [49][50].

The connection to the high voltage system (132 kV) in the Iraqi power system is star connected (solidly grounded with a switch), whilst the connection to the distribution voltage system (33 and 11 kV) will be made using resistance or Zig-Zag earthing transformers. While Star-Delta-Star is utilized in all Iraqi governorates with the exception of Baghdad city, the three winding transformers that are used in the country's electricity system are connected Star-Star-Delta with vector group Y0yn0d1. While the resistance used in 11 kV systems is around 22, that utilized in 33 kV systems is roughly 19. To ground the transformers' delta side, zig-zag transformers are employed.

The two winding transformers are used to connect the high voltage system (132 kV) star connected (solidly grounded with switch) with distribution voltage system (33 kV) with Star-Delta connection. the neutral grounding method in Iraqi power system is effectively grounding system. The high voltage neutral point contains a switch with solidly grounding wire i,e. it can be closed or opened. As we explained the grounding system is referred to as solid grounding or effective grounding whenever the system's neutral is linked directly to the earth with little resistance and reactance among both. A system is considered to be solidly grounded if, even under circumstances and for any generator capacity, the proportion of zero sequence reactance X0 to positive sequence reactance X1 doesn't really exceed three for all

of the system's points and the proportion of zero sequence resistance to positive sequence resistance doesn't really exceed one.

A system or part of a system could indeed be considered to be effectively grounded if, including all points on the system or a defined significant fraction thereof, the ratio of zero-sequence reactance to positive sequence reactance is not greater than three and the ratio of zero-sequence resistance to positive reactance is not greater than one for any condition of operation and for any amount of generator capacitance, according to another definition of an effectively grounded system previously discussed [51].

4.2 SHORT CIRCUIT ANALYSIS WITH PSS/E SOFTWARE

PSS/E software one of the most important program that can be used to simulate the power system analysis such as, load flow, short circuit, stability, etc. In this work PSS/E software is used to analysis the short circuit of the proposed system with two types (Single-Line-to-Ground) fault and (Three-Phase) fault. The main importance of the PSS/E program in this work it can give the Theveien impedances that can be used to determine the X0/X1 ratio.

According to the proposed system that shown in Figure (6.3) in chapter three, and in case of all the transformers are grounded, then the short circuit analysis of the PSS/E program of this case is given as below:

```
                                          <-SCMVA-> <-Sym I''k rms-->
                                                       /I/    AN(I)
 X------------ BUS ------------X             MVA        AMP      DEG
   1030     [QAYARA132   132.00] 3PH       244.02     1067.3   -29.35
                                  LG       330.88     1447.2   -31.93

 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:69.348+j13.819, 0.19927
Z-:69.348+j13.819, 0.19927
Z0:13.199+j9.814, 0.74350

 ------------------------------------------------------------------------
-
                                           <-SCMVA-> <-Sym I''k rms-->
                                                       /I/    AN(I)
 X------------ BUS ------------X             MVA        AMP      DEG
   1031     [YARMJA      132.00] 3PH       227.14     993.5    -35.67
```

```
                                    LG      266.28     1164.7    -49.03

 THEVENIN IMPEDANCE, X/R  (OHM)
Z+:73.958+j20.192, 0.27303
Z-:73.958+j20.192, 0.27303
Z0:24.280+j53.634, 2.20900

 ------------------------------------------------------------------------
-
                                          <-SCMVA-> <-Sym I''k rms-->
                                                      /I/    AN(I)
 X------------ BUS ------------X            MVA        AMP      DEG
   1032     [QAYARA OLD  132.00] 3PH      243.16     1063.5    -29.73
                                    LG      329.14     1439.6    -32.40

 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:69.426+j14.042, 0.20226
Z-:69.426+j14.042, 0.20226
Z0:13.400+j10.169, 0.75888

 ------------------------------------------------------------------------
-
                                          <-SCMVA-> <-Sym I''k rms-->
                                                      /I/    AN(I)
 X------------ BUS ------------X            MVA        AMP      DEG
   1033     [SHIRQAT     132.00] 3PH      229.74     1004.8    -34.66
                                    LG      305.51     1336.3    -34.35

 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:71.716+j19.991, 0.27876
Z-:71.716+j19.991, 0.27876
Z0:18.595+j4.242, 0.22810

 ------------------------------------------------------------------------
-
                                          <-SCMVA-> <-Sym I''k rms-->
                                                      /I/    AN(I)
 X------------ BUS ------------X            MVA        AMP      DEG
   1034     [MISHRAQ     132.00] 3PH      238.76     1044.3    -30.96
                                    LG      325.90     1425.5    -31.55

 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:70.988+j14.582, 0.20542
Z-:70.988+j14.582, 0.20542
Z0:13.704+j4.498, 0.32822
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-


                                        <-SCMVA-> <-Sym I''k rms-->
                                                     /I/    AN(I)

 X------------ BUS ------------X          MVA        AMP      DEG
   1035     [ADAYA       132.00] 3PH     222.00     971.0   -36.11
                                 LG     286.66    1253.8   -37.48
 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:75.269+j21.112, 0.28049
Z-:75.269+j21.112, 0.28049
Z0:23.117+j10.974, 0.47471

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-


                                        <-SCMVA-> <-Sym I''k rms-->
                                                     /I/    AN(I)
 X------------ BUS ------------X          MVA        AMP      DEG
   1036     [HAMAM       132.00] 3PH     227.62     995.6   -34.43
                                 LG     298.38    1305.1   -35.83

 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:73.754+j18.722, 0.25384
Z-:73.754+j18.722, 0.25384
Z0:20.186+j9.519, 0.47156

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-


                                        <-SCMVA-> <-Sym I''k rms-->
                                                     /I/    AN(I)
 X------------ BUS ------------X          MVA        AMP      DEG
   1040     [QAYARA400   400.00] 3PH     275.50     397.7   -29.61
                                 LG     200.30     289.1   -65.08

 THEVENIN IMPEDANCE, X/R  (OHM)

Z+:505.134+j286.963, 0.56809
Z-:505.134+j286.963, 0.56809
Z0:0.000+j1600.000, 9999.999

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4.3 SHORT CIRCUIT ANALYSIS IN DIFFERENT SCENARIOS

Different scenarios are proposed in this work, the first scenario start with all transformers are grounded, then we will open one transformer to find the short circuit currents, then we will two transformers and find the short circuit current and so on.

4.3.1 All Transformers are Grounded

In case of the all transformers are grounded, the value of the single-line-to ground fault current will be higher than the three-phase fault current, and the values of the X0/X1 ratio it will less than 1 in different points. The value of the healthy phase's voltages will be less than the 1.732 times of the nominal voltage. The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.1), while the zero to positive impedance ratio at each substation it given in Table (4.2).

Table 4.1: Three Phase and Single Line to Ground Fault When All Transformers are Grounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	1447
1031	YARMJA	132	993	1165
1032	QAYARA OLD	132	1063	1439
1033	SHIRQAT	132	1004	1336
1034	MISHRAQ	132	1044	1426
1035	ADAYA	132	971	1254
1036	HAMAM	132	995	1305

Table 4.2: Zero to Positive Impedance Ratio At Each Substation When all Transformers are Grounded

Bus Code	Bus Name	Bus Voltage	R0	X0	X1	X0/X1	R0/X1
1030	QAYARA132	132	13.19	9.81	13.81	0.71	0.95
1031	YARMJA	132	24.28	53.63	20.19	2.66	1.20
1032	QAYARA OLD	132	13.40	10.17	14.04	0.72	0.95
1033	SHIRQAT	132	18.59	4.24	19.99	0.21	0.92
1034	MISHRAQ	132	13.07	4.45	14.58	0.31	0.89
1035	ADAYA	132	23.10	10.97	21.11	0.52	1.09
1036	HAMAM	132	20.18	9.51	18.72	0.51	1.07

Figure (4.1) Shows The Three-Phase Short Circuit Current With Single Line to Ground Fault Current When All Transformers are Grounded.

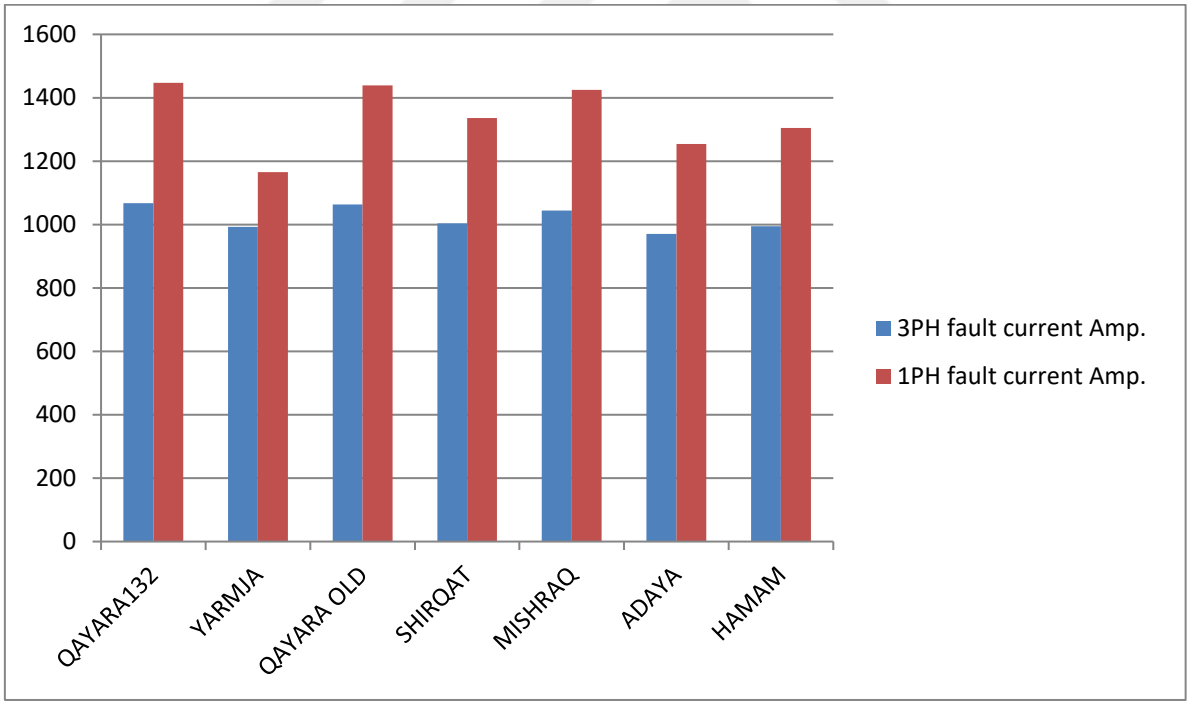

Figure 4.1: Three Phase and Single Line to Ground Fault When all Transformers are Grounded

4.3.2 One Transformer is Ungrounded

In this scenario, one 132/33 kV transformer in Shirqat 132 kV substation will be ungrounded (neutral point will be open). The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.3), while the zero to positive impedance ratio at each substation it given in Table (4.4).

Table 4.3: Three Phase and Single Line to Ground Fault When One Transformer is Ungrounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	1418
1031	YARMJA	132	993	1147
1032	QAYARA OLD	132	1063	1406
1033	SHIRQAT	132	1004	1259
1034	MISHRAQ	132	1044	1420
1035	ADAYA	132	971	1257
1036	HAMAM	132	995	1307

Table 4.4: Zero to Positive Impedance Ratio at Each Substation When One Transformer is Ungrounded

Bus Code	Bus Name	Bus Voltage	R0	X0	X1	X0/X1	R0/X1
1030	QAYARA132	132	16.43	10.12	13.81	0.73	1.19
1031	YARMJA	132	27.5	53.94	20.19	2.67	1.36
1032	QAYARA OLD	132	17.08	10.92	14.04	0.78	1.22
1033	SHIRQAT	132	27.23	11.7	19.99	0.59	1.36
1034	MISHRAQ	132	14.61	3.33	14.58	0.23	1.00
1035	ADAYA	132	22.87	10.04	21.11	0.48	1.08
1036	HAMAM	132	20.18	8.37	18.72	0.45	1.08

Figure (4.2) shows the three phase short circuit current with single line to ground fault current when one transformer is ungrounded.

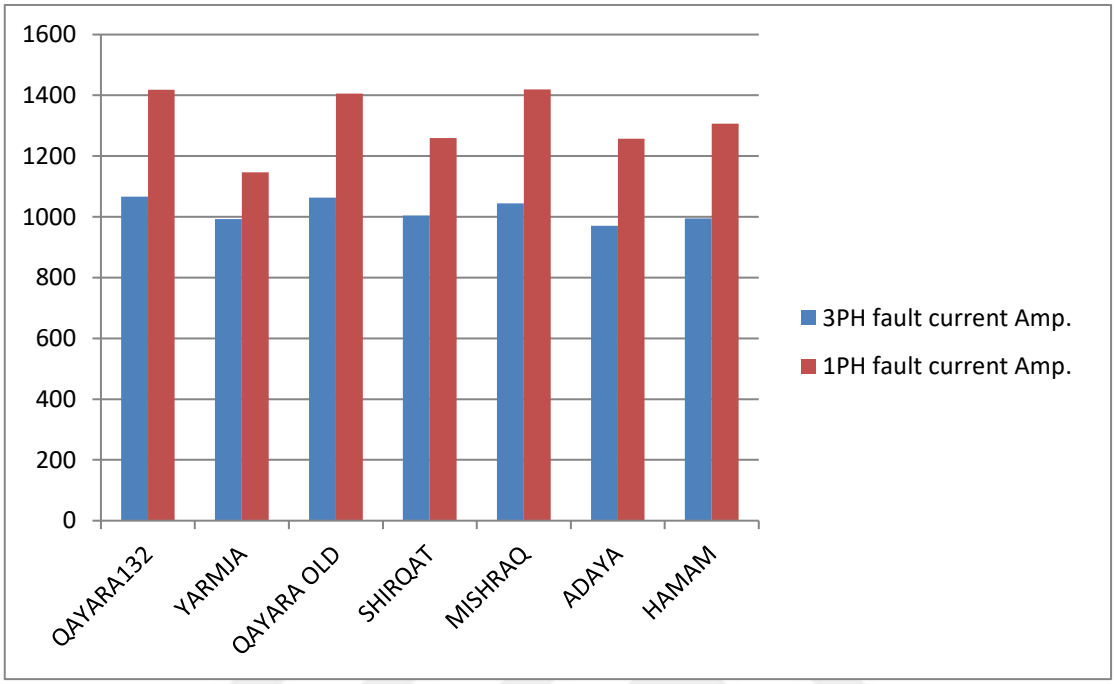

Figure 4.2: Three Phase and Single Line to Ground Fault When One Transformer is Ungrounded

4.3.3 Two Transformers are Ungrounded

In this scenario, two 132/33 kV transformers in Shirqat 132 kV substation will be ungrounded (neutral point will be open). The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.5), while the zero to positive impedance ratio at each substation it given in Table (4.6).

Table 4.5: Three Phase and Single Line to Ground Fault When Two Transformers are Ungrounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	1357
1031	YARMJA	132	993	1102
1032	QAYARA OLD	132	1063	1340
1033	SHIRQAT	132	1004	1167
1034	MISHRAQ	132	1044	1387
1035	ADAYA	132	971	1253
1036	HAMAM	132	995	1296

Table 4.6: Zero to Positive Impedance Ratio at Each Substation When Two Transformers are Ungrounded

Bus Code	Bus Name	Bus Voltage	R0	X0	X1	X0/X1	R0/X1
1030	QAYARA132	132	22.17	16.85	13.81	1.22	1.60
1031	YARMJA	132	33.25	60.67	20.19	3.00	1.65
1032	QAYARA OLD	132	22.98	19.38	14.04	1.38	1.64
1033	SHIRQAT	132	30.08	42.77	19.99	2.14	1.50
1034	MISHRAQ	132	18.61	2.76	14.58	0.19	1.28
1035	ADAYA	132	24.17	7.74	21.11	0.37	1.14
1036	HAMAM	132	22.36	6.12	18.72	0.33	1.19

Figure (4.3) shows the three phase short circuit current with single line to ground fault current when two transformers are ungrounded.

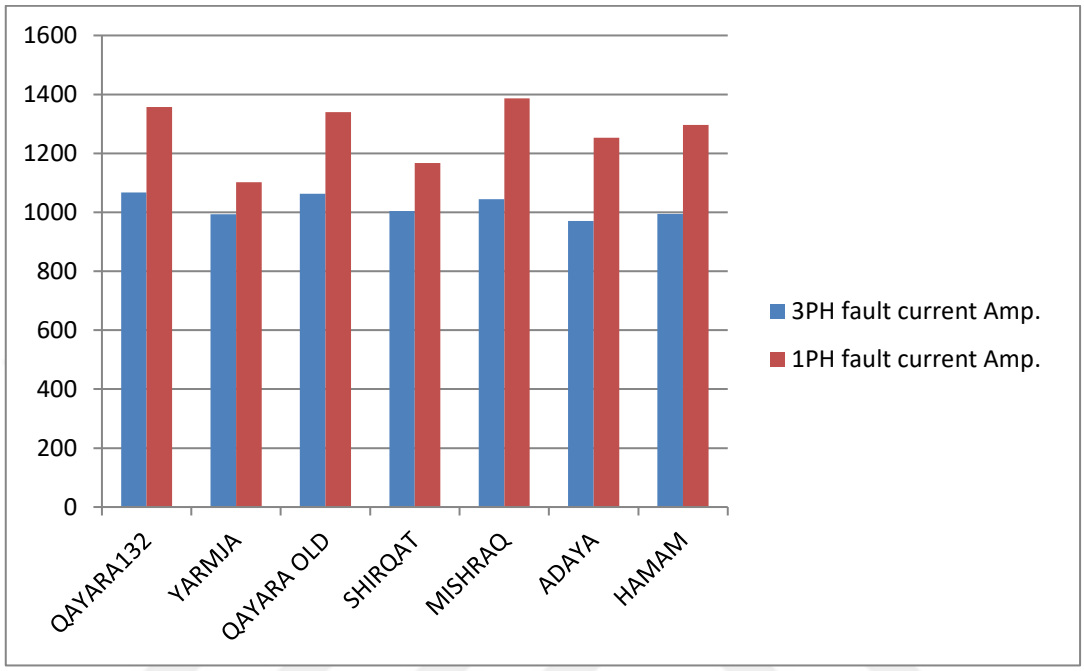

Figure 4.3: Three Phase and Single Line to Ground Fault When Two Transformers are Ungrounded

4.3.4 Three Transformers are Ungrounded

In this scenario, two 132/33 kV transformers in Shirqat 132 kV substation will be ungrounded (neutral point will be open) and one 132/33 kV transformer at Mishraq 132 kV substation will be ungrounded also. The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.7), while the zero to positive impedance ratio at each substation it given in Table (4.8).

Table 4.7: Three Phase and Single Line to Ground Fault When Three Transformers are Ungrounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	1274
1031	YARMJA	132	993	1045
1032	QAYARA OLD	132	1063	1260
1033	SHIRQAT	132	1004	1104
1034	MISHRAQ	132	1044	1303
1035	ADAYA	132	971	1214
1036	HAMAM	132	995	1239

Table 4.8: Zero to Positive Impedance Ratio at Each Substation When Three Transformers are Ungrounded

Bus Code	Bus Name	Bus Voltage	R0	X0	X1	X0/X1	R0/X1
1030	QAYARA132	132	31.75	22.58	13.81	1.62	2.28
1031	YARMJA	132	42.83	66.40	0.19	3.29	2.12
1032	QAYARA OLD	132	32.48	25.11	14.04	1.79	2.31
1033	SHIRQAT	132	39.66	48.50	19.99	2.43	1.98
1034	MISHRAQ	132	27.19	8.50	14.58	0.58	1.86
1035	ADAYA	132	30.94	5.06	21.11	0.24	1.46
1036	HAMAM	132	30.49	5.06	18.72	0.27	1.63

Figure (4.4) shows the three-phase short circuit current with single line to ground fault current when three transformers are ungrounded.

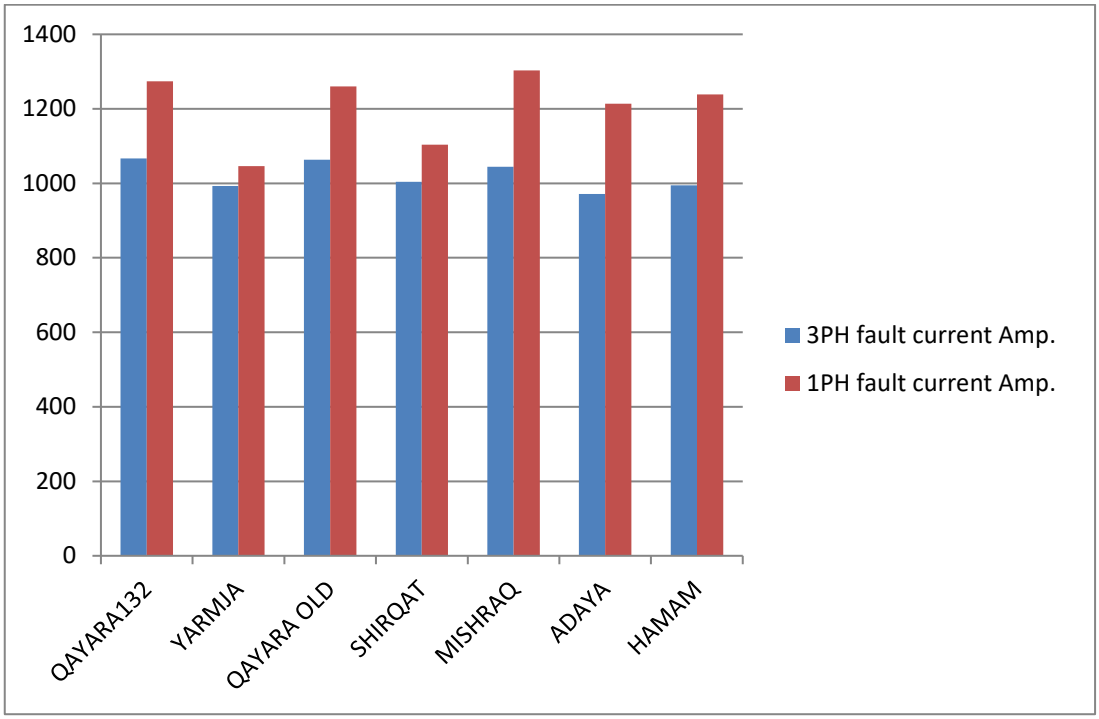

Figure 4.4: Three Phase and Single Line to Ground Fault When Three Transformers are Ungrounded

4.3.5 Four Transformers are Ungrounded

In this scenario, two 132/33 kV transformers in Shirqat 132 kV substation will be ungrounded (neutral point will be open) and one 132/33 kV transformer at Mishraq 132 kV substation will be ungrounded. And one 132/33 kV transformer at Adaya 132 kV substation will be ungrounded also The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.9), while the zero to positive impedance ratio at each substation it given in Table (4.10).

Table 4.9: Three Phase and Single Line to Ground Fault When Four Transformers are Ungrounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	1107
1031	YARMJA	132	993	936
1032	QAYARA OLD	132	1063	1096
1033	SHIRQAT	132	1004	978
1034	MISHRAQ	132	1044	1128
1035	ADAYA	132	971	996
1036	HAMAM	132	995	1139

Table 4.10: Zero to Positive Impedance Ratio at Each Substation When Four Transformers are Ungrounded

Bus Code	Bus Name	Bus Voltage	R0	X0	X1	X0/X1	R0/X1
1030	QAYARA132	132	58.41	27.03	13.81	1.96	4.23
1031	YARMJA	132	69.49	70.58	20.19	3.50	3.44
1032	QAYARA OLD	132	59.13	29.57	14.04	2.11	4.21
1033	SHIRQAT	132	66.32	52.96	19.99	2.65	3.32
1034	MISHRAQ	132	54.85	12.94	14.58	0.89	3.76
1035	ADAYA	132	62.98	39.40	21.11	1.87	2.98
1036	HAMAM	132	49.36	4.9	18.72	0.26	2.64

Figure (4.5) shows the three phase short circuit current with single line to ground fault current when four transformers are ungrounded.

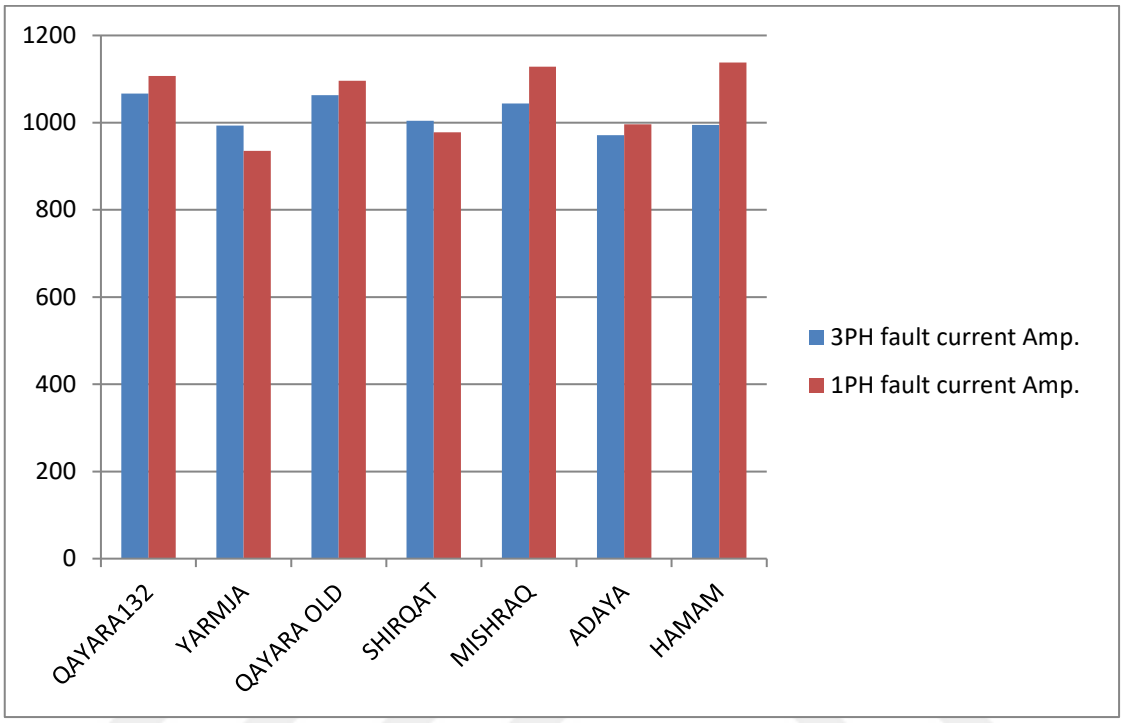

Figure 4.5: Three Phase and Single Line to Ground Fault When Four Transformers are Ungrounded

4.3.6 Only One Transformer Grounded

In this scenario, only one transformer (three winding transformer Autotransformer 400/132/11 kV) is grounded at 132 kV side. The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.11), while the zero to positive impedance ratio at each substation it given in Table (4.12).

Table 4.11: Three Phase and Single Line to Ground Fault When One Transformer is Grounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	983
1031	YARMJA	132	993	858
1032	QAYARA OLD	132	1063	975
1033	SHIRQAT	132	1004	889
1034	MISHRAQ	132	1044	944
1035	ADAYA	132	971	847
1036	HAMAM	132	995	879

Table 4.12: Zero to Positive Impedance Ratio at Each Substation When One Transformer is Grounded

Bus Code	Bus Name	Bus Voltage	R0	X0	X1	X0/X1	R0/X1
1030	QAYARA132	132	87.12	17.42	13.81	1.26	6.30
1031	YARMJA	132	98.2	61.24	20.19	3.03	4.86
1032	QAYARA OLD	132	87.84	19.96	14.04	1.42	6.26
1033	SHIRQAT	132	95.02	43.34	19.99	2.17	4.75
1034	MISHRAQ	132	90.68	31.51	14.58	2.16	6.22
1035	ADAYA	132	98.81	57.97	21.11	2.75	4.68
1036	HAMAM	132	96.16	49.36	18.72	2.64	5.14

Figure (4.6) shows the three phase short circuit current with single line to ground fault current when one transformer is grounded

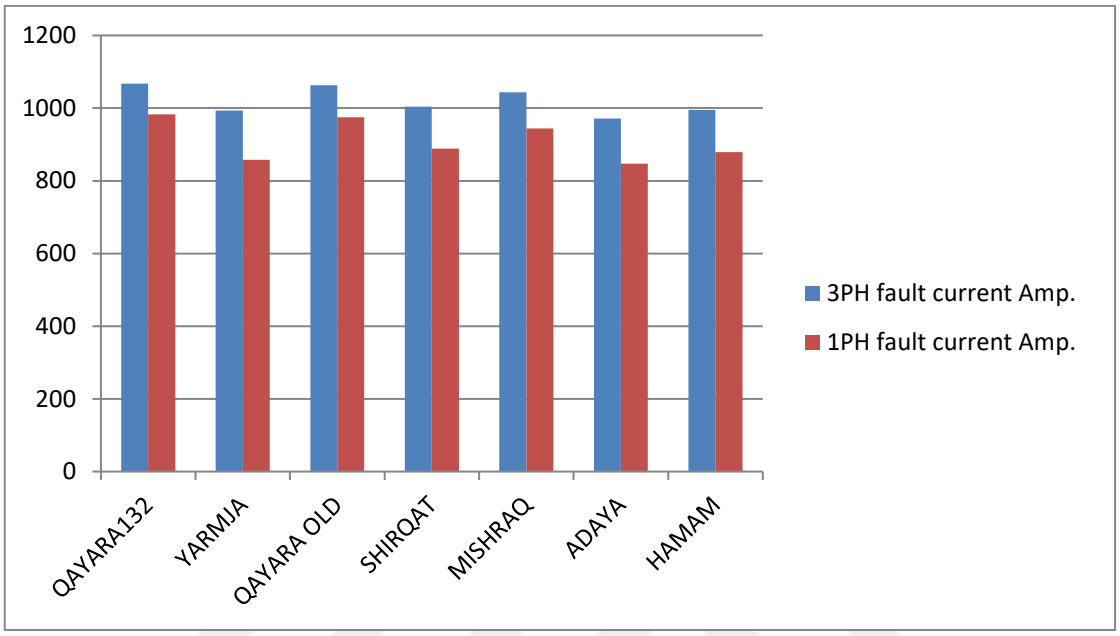

Figure 4.6: Three Phase and Single Line to Ground Fault When One Transformer is Grounded

4.3.7 No Transformer is Grounded

In this scenario, there is no any transformer is grounded. The three-phase and single line to ground fault current of the 132 kV substations are given in Table (4.13).

Table 4.13: Three Phase and Single Line to Ground Fault When One Transformer is Grounded

Bus Code	Bus Name	Bus Voltage	3PH fault current Amp.	1PH fault current Amp.
1030	QAYARA132	132	1067	0
1031	YARMJA	132	993	0
1032	QAYARA OLD	132	1063	0
1033	SHIRQAT	132	1004	0
1034	MISHRAQ	132	1044	0
1035	ADAYA	132	971	0
1036	HAMAM	132	995	0

Figure (4.7) shows the three phase short circuit current with single line to ground fault current when no transformer is grounded

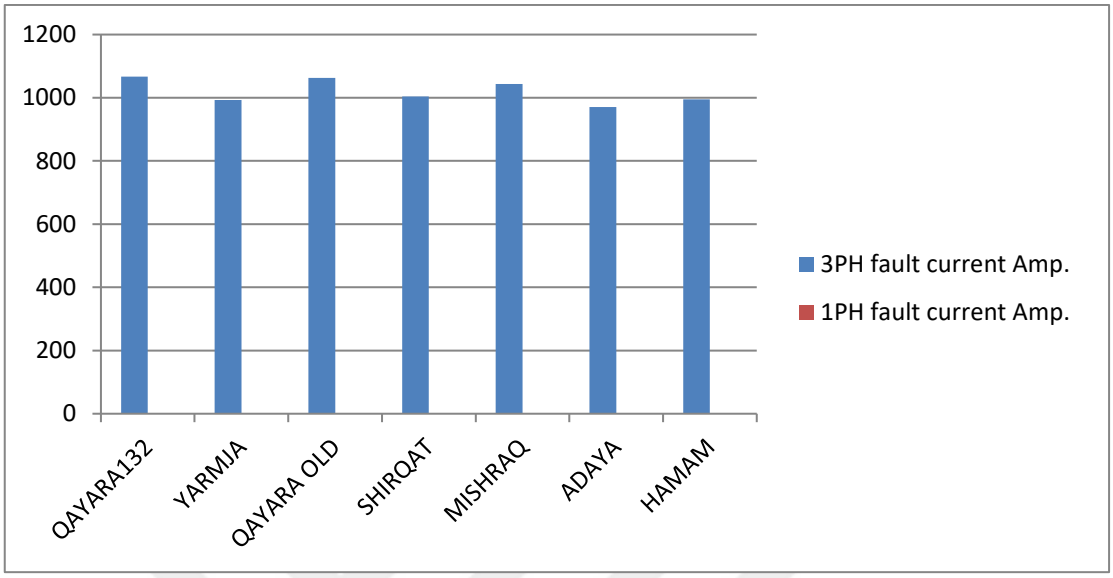

Figure 4.7: Three Phase and Single Line to Ground Fault When No Transformer is Grounded

4.4 IMPEDANCE AT FAULT POINTS

The power system can be call effectively grounded if the following relationships are approved [34], [43].

$$X_0/X_1 < 3 \quad (4.1)$$

$$R_0/X_1 > 1 \quad (4.2)$$

For case only one transformer (three phase transformer) is grounded, and then the ration of the R0/X1 it can be given in Table (4.14).

Table 4.14: Zero Resistance to Positive Impedance Ratio at Each Substation When One Transformer is Grounded

Bus Code	Bus Name	Bus Voltage	R0	X1	R0/X1
1030	QAYARA132	132	523.06	13.81	37.87
1031	YARMJA	132	534.19	20.19	26.45
1032	QAYARA OLD	132	523.9	14.04	37.3
1033	SHIRQAT	132	530.97	19.99	26.55
1034	MISHRAQ	132	526.63	14.58	36.11
1035	ADAYA	132	534.76	21.11	25.32
1036	HAMAM	132	532.11	18.72	28.42

According to the Tables (4.12) and (4.14) the equations (4.1) and (4.2) are satisfied, and the ratio of the single line to ground fault is within acceptable limits.

Figure (4.8) shows the ratio of the zero to positive sequence impedances at all substations with different scenarios that mentioned in section 4.3. Only the scenario with one transformer is grounded give the X0/X1 ratio less than three and R0/X1 more than one. Figure (4.9) shows the zero resistance to positive impedance ratio.

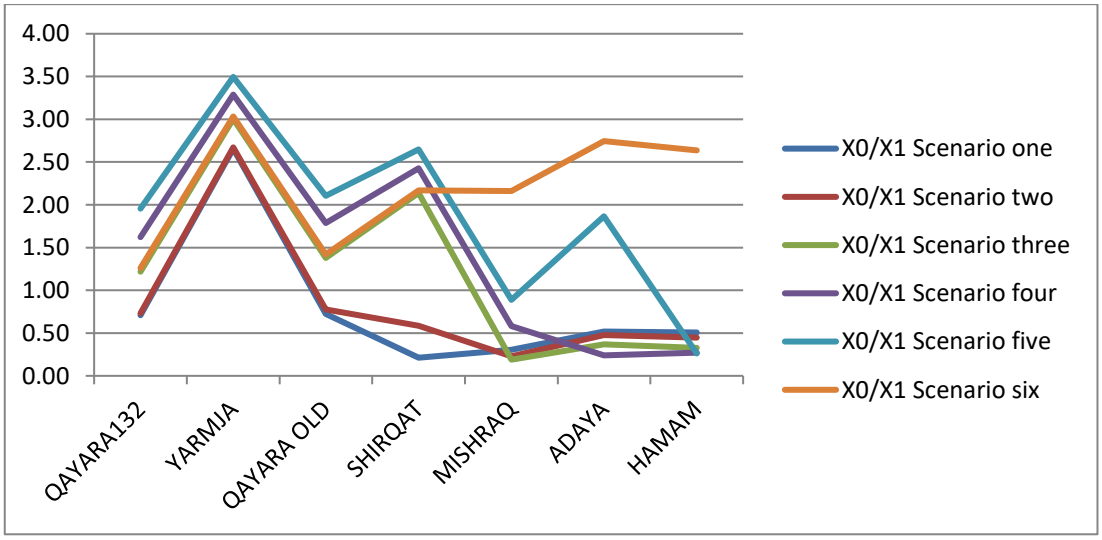

Figure 4.8: The X0/X1 Ratio During Different Scenarios

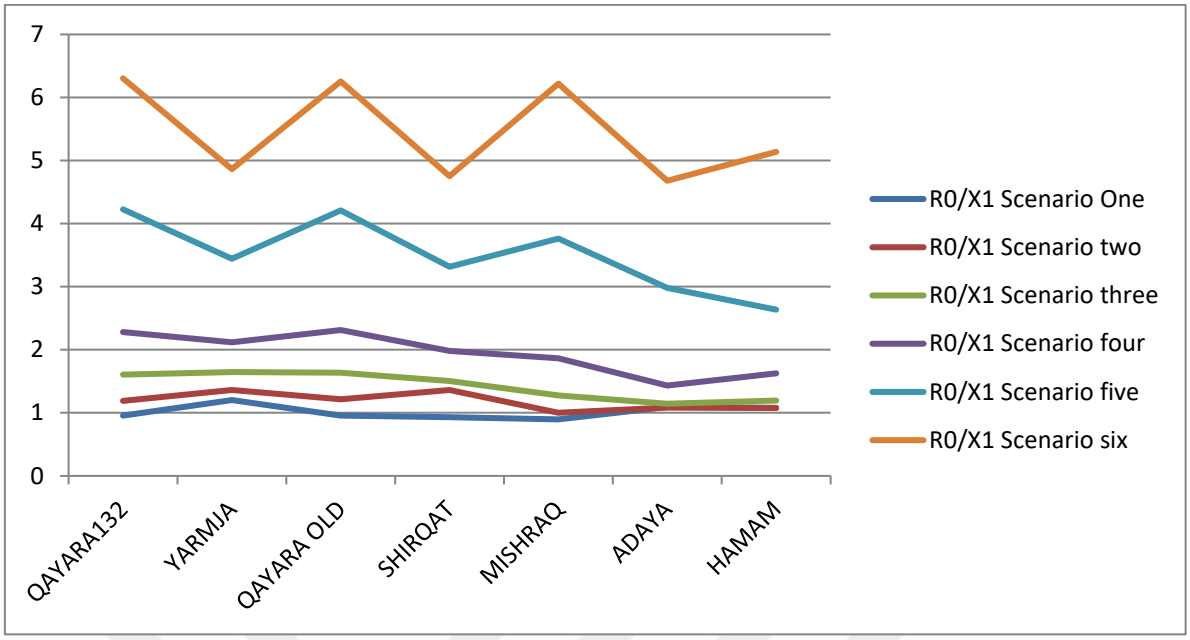

Figure 4.9: The R0/X1 Ratio During Different Scenarios

5. CONCLUSION AND FUTURE WORKS

5.1 CONCLUSION

In order to ensure safety and prevent faults, a grounding system must be used to generate a small amount of resistance channel to the earth. The grounding system is essential to completing an electrical path to the ground when there are non-designed or unexpected above-normal potential current or voltage spikes while the system is operating.

Power systems may employ a variety of grounding techniques. The protection devices cannot detect the fault current during fault circumstances in an unground system since there is no fault current that may flow in the neutral channel. In addition, the voltages of the healthy phases will be greater than the rated value, which might cause equipment damage.

However, in a system that is solidly grounded, the protection devices on the neutral point are able to detect the ground fault current, and the voltage of the healthy phase is equal to the pre-fault voltages. However, the fault current value will be high because there is no impedance in the neutral path. In this instance, the neutral grounding pathways must be given more resistance. In order to demonstrate how the ground fault current (single line to a ground fault) becomes larger than three-phase faults, the thesis will analyse the short circuit current of a case study for the Iraqi power system with the current grounding system. The investigation of the ground fault will then be performed in various ground system scenarios to increase system stability and dependability under various grounding scenarios.

Through simulation analysis, this work can draw the following conclusions:

a. By using the PSS/E software program, the simulation was done for the proposed system that consists of a seven 132 kV substation that located in the Nineveh governorate.

b. The data base of the proposed system (line parameters, transformer parameters, etc. are collected from the Ministry of Electricity of Iraq- Planning and Studies Office

c. The load flow and short circuit studies are applied to the proposed system.

d. The simulation result show that when all the power transformers are grounded, then the ratio of X0/X1 will be less than three and R0/X1 will be less than one according to [34] and [43]. Thus mean the single line to ground fault will be higher than the three phase

fault current and that will make the choosing of the circuit breaker rating not economically.

e. In case of the transformer neutral grounding will open, and then the value of the X0/X1 will increase in addition R0/X1 will be increased also.

f. When all power transformer neutral grounding is open, then there is no ground fault current, then the line to ground fault current will be zero, but the voltage of the healthy phases will be high and thus will make distortion to the insulation level of the transformer and then damage them.

g. The proper chose of one 132kV transformer is grounded give reasonable values of X0/X1, R0/X1 with healthy phase voltage is less than the rated nominal value and then the system can be called effectively grounded.

The following notes are important to identify the fault current values with voltages of the healthy phases.

a. The single-line-to- ground fault current is about (0 to 3) of the three phase fault current neutral grounding method.

b. The voltage of the healthy phases is about (0.6 to 2) of the phase system voltage and also depend on the neural grounding method.

c. When $X_0 / X_1 < 3$ and $R_0 / X_1 > 1$ then the system can be called as effectively grounded system according to [34] and [43].

d. When $X_0 / X_1 > 40$ then the system can be called as ungrounded system.

e. When $3 > X_0 / X_1 > 40$ then the system can be called as resistance or reactance or other types of the grounding system.

f. When $X_0 / X_1 < 1$ then the system can be called as solidly grounded system.

5.2 FUTURE WORK

The aspects that need to be further studied are:

a. For more accuracy in results, the simulation should be for whole Iraqi power system.

b. The neutral point of the generation side should be implemented in the next works.

c. The implementation of the fault current limiter need to be investigated for the Iraqi power system.

d. The economic study of the effectively grounding system need to be introduced in the next future works.

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