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IMPROVE LEVELS OF POWER AND VOLTAGE AT THE NASSEREYA PUMP STATION OF WATER BY CONTROLLING PARAMETERS OF HIGH VOLTAGE NETWORKS

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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JUMAN HADI ISSA ALJASSANI

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By Juman Hadi Issa ALJASSANI

February 2023

We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science

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ABSTRACT

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Master of Science in Electrical and Electronics Engineering
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This paper's research focuses on the real problems which suffer from pumps station during their connection with the national electric network, in our paper, we will take negative effects that appear in the pump stations with power flow parameters, voltage, active and reactive power current loading, and total losses. Using the electric network have 28 Buses (test 2) as a simulation of Iraq's electric network. Firstly we will connect the pump station has a capacity of power equal to 75 MVA and do an analysis by the Neplan program which uses Newton Raphson method to calculate load flow, after that, we are solving problems by using FACT'S system (SVC, UPFC, and capacitor bank) also taken the problem of power equality as an effect of Harmonic which production from electronic device soft start of a pump station and method treatment by passive filter first order. At last, we are studying the effect of fault current and how to reduce the effect by using the Current Limiting Reactor (CLR).

2023, 149 pages

Keywords: Power flow analysis, Power quality,Short circuit analysis, FACT’S system, NEPLAN program, 220/110/6.6 kV substation

ÖZET

YÜKSEK GERİLİM ŞEBEKELERİNİN PARAMETRELERİNİ KONTROL EDEREK NASSEREYA SU POMPA İSTASYONUNDA GÜÇ VE GERİLİM SEVİYELERİNİN İYİLEŞTİRMELERİ

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Elektirik & Elektronik Mühendisliği, Yüksek Lisans

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Bu araştırmada pompa istasyonunun ulusal elektrik şebekesine bağlıyken karşılaşan sorunları inceleyerek ele alacağız. Çalışmamızda Irak elektrik şebekesini simüle etmek için 28 otobüslü bir elektrik şebekesi kullanarak (Test 2) pompa istasyonlarında ortaya çıkan olumsuz etkileri, voltaji ve güç akış parametreleri, aktif ve reaktif güç akım yüklemesini ve toplam kayıpları ele alacağız. Başta 75 MVA'ya eşit güce sahip pompa istasyonunu bağlayıp yük akışını hesaplamak için Newton Raphson yöntemini kullanan Neplan programı ile analiz yapacağız. Ardından FACT'ın sistemini (SVC, UPFC ve kapasitör bankası) kullanarak problemleri çözeceğiz, aynı zamanda pompa istasyonunun elektronik cihazdan yumuşak yolverme (Soft Starter) ve pasif filtre birinci dereceden arıtma yönteminden üretilen Harmonik'in etkisi olarak güç eşitliği sorunu da ele alınacaktır. Son olarak, arıza akımının etkisini ve akım sınırlama reaktörünü (CLR) kullanarak etkinin nasıl azaltılacağını inceleyeceğiz.

2023, 149 sayfa

Anahtar Kelimeler: Güç akışı analizi, Güç kalitesi ,Kısa devre analizi, FACT'S sistemi, NEPLAN programı, 220/110/6,6 kV trafo istasyon

PREFACE AND ACKNOWLEDGEMENTS

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Juman Hadi Issa ALJASSANI
Çankırı-2023

CONTENTS

LIST OF SYMBOLS

°C	Degree celsius
km	Kilometer
kV	kilovolt
m	Meter
MVA	Megavolt ampere

LIST OF ABBREVIATIONS

BB	Bus bar
BC	Bus cupler
CB	Circuit breaker
CLR	Current limiting reactor
CT	Current transformer
N-R	Technique - newton-raphson technique
OLTC	On load tap changer
P.F.	Power flow
PCC	Point of common connection
THD	Total harmonic distortion
TL	Transmission line
Tr	Transformer
U	Phase-to-Phase Voltage
V	Phase-to-neutral Voltage
VT	Voltage transformer
Bio	Susceptance of transformer
Gio	Conductance of transformer
$I''k$	Initial symmetrical short circuit current
Ib	Short circuit breaking current
Ik	Steady state short circuit current
KG	Corrected generator impedance
KS	Corrected power station unit impedance
KT	Corrected transformer impedance
Rik	Resistance of transformer
Rk	Sum of series resistances of positive sequence system
Sk	Short-circuit power
Xd	Reactance of generator
Xik	Reactance of transformer
Xk	Sum of series reactances of positive sequence system
Zik	Impedance of transformer
Zk	Sum of series impedances of positive sequence system
ip	Peak short circuit current
yio	Admittance of transformer

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1. INTRODUCTION

The work includes two main parts:

Part I: Studying the level of power flow in a network consisting of 28 buses (Eremia *et al.* 2006), where this part is classify into 4 sections:

- The first section is a study of voltage levels, active and reactive power, and total circuit losses without the presence of power transformers in the network.
- The second section: connected the transformers to work, calculated the power flow parameter, and studied the increase in the impedance of the network without the presence of a voltage regulator and its effect on the parameters of power flow.
- The third section: Tap-changers have been operated and all previous calculations have been repeated.
- The fourth section includes supporting the weak power transmission lines with double lines and calculating the impedance and its effect on the details of the power flow (Saadat 2011).

Part II: The second part has been added to the pumping station network with all its details of transformers, transmission lines and 12 pumps and totally load with a capacity of 75 MVA to simulate the pumping station in southern Iraq and the work included three sections:

- The first section of part II is a study levels of power flow, voltage levels, active and reactive power in transmission lines and losses with present pump-station then using FACT'S (capacitor bank, SVC, UPFC) systems to solve problem of power flow (McDonald 2016).
- The second section taken effect of Harmonic sources in the pumps, represented by soft start electronic systems, and mitigation its effect by adding passive filters in our system.

- The third one simulates the fault current as a three-phase short-current and reduce its effect by adding series impedances.

1.1 Background

Generating electricity transmission system consists of elements, the most important of which are transmission lines on electric towers or underground cables, and electrical transformers of both types, lower and upper. Errors occur in this system, which in turn leads to interruption of service for a certain period and problems in the operation of water pumping stations. We will raise these problems and try to solve them because of their importance in our lives that cannot be overlooked. We are very accurate when we mention that the development of technology and the economy of countries definitely depends on providing energy, producing it and maintaining it without problems for the longest period, transferring it with the least losses, and maintaining the levels of required voltages and currents. Power move from customers and power stations is usually ensured by distribution and transmission areas and the standards that decide the type of power system are:

- Destination: transmission, reconnection, and distribution of load into electrical networks;
- Voltage nominal for highest voltage (400 kV. 750 kV), high voltage (35 kV to 220 kV), middle voltage (10 to 35 kV) & low level of voltage (<1 kV);
- Covered area, which can be represented by national distribution networks, regions, urban and rural;
- The arrangement can be radial network, close path, and complex close path (meshwork) grids;
- A condition of ground: grids with a neutral ground insulated by directly earthling solidly and networks with treatment neutral;
- An available of the neutral conductor: with presented or not presented neutrally;
- Current frequency: Circuits of Alternative current and DC current.

The requirement for destination grids take a consideration the practical region of the power system so the transmission networks supply methodical power transfer from the generation zones to the costumer zones. a timed power transfer identically to the imperative element of the estimating valuable (Eremia *et al.* 2006). A bus is a point at with the one which or more transmission lines, demands, as well as power stations are linked between them. Buses type:

a. Slack Bus

The reference bus is using in command to meet the power equilibrium state. A slack bus is generally a generating unit that is able to be modified to accommodate however is wanted to verify the power balance (Eremia *et al.* 2006).

b. Generator (PV) Bus

It's a bus for a voltage regulator. The bus is linked to a generator part in which can control the This bus's power output can be managed by regulating It is possible to regulate both the voltage and the prime mover by regulating the generator excitation (Kempner 2008).

c. Load (PQ) Bus

This is a without-generator bus that is able to be got from data histories, measurements, or estimates.

1.2 The Matter Announcement

The process of operating the synchronous machines needs accuracy and stability in the details and contents of the power systems, including voltage and frequency, as well as effective and ineffective capacity, in order to reach a synchronous speed between the files of the stator and the rotary part, and therefore any disturbance in the electrical system leads to the stopping of the synchronous machines, and this The unstable situation causes non-selective stops in the water pumping stations, causing many malfunctions in the synchronized machines and large economic losses, which necessitates us to study the problems and find appropriate technical solutions. by using a simulation of working similar conditions in Iraq, by designing an electrıc network from IEEE have six power plant its power generation equal to 2856 MVA, with a total load equal to 1570.66 MVA. 28 buses make up our power network; 14 buses are 220 kV and 14 are 110 kV. The primary high voltage buses are connected to one another by single circuit transmission lines. The bus from the power plant RO1 is referred to as the SLACK bus, and the buses from the PV generation (2, 5, 7, 10, 13) are the generations buses connected to the load buses (1, 3, 4, 6, 8, 9, 11, 14) by transmission lines. Having a pump station with a 75MVA capability. By using the above network and NEPLAN software we will discuss the below problems.

- The first step Discuss performance load flow analysis in data input from transmission line and transformer input data. The nodal calculation for a power system network using a Y bus can be written as follows. I=Y_BUS V. For an n-bus system, the nodal equation can be expressed in a general way, Equation (1.1), Equation (1.2), Equation (1.3)

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad \text{For i = 1, 2, 3,} n \tag{1.1}$$

$$P_i + jQ_i = V_i I_i^*; I_i = \frac{P_i + jQ_i}{V_i} \tag{1.2}$$

$$\frac{P_i + jQ_i}{V_i} = V_i \sum_{j=1}^{n} Y_{ij} - \ j = 1 \tag{1.3}$$

The equation applies Newton Raphson numerical method to tackle load flow issues in Neplan analysis.

- In the second one, we will discuss the harmonic currents generated by the operators' apparatus flow back on the way to the power source, they increase nonlinear loads by adding resistance from various power distribution devices., such as transmission and distribution lines, transformers, cables, busbars. Since inductive reactance is linearly relative to frequency, especially high-order harmonic currents source severe voltage distortion levels with small current amplitudes, Equation (1.4), Equation (1.5)

$$v(t) = \sqrt{2}.\ (V_1 + \sum_{=2}^{\infty} V_n.\ \sin\ (\mathrm{n}w_1\mathrm{t} + \theta_n)) \tag{1.4}$$

$$i(t) = \sqrt{2}.\ (i_1 + \sum_{=2}^{\infty} i_n.\ \sin\ (\mathrm{n}w_1\mathrm{t} + \delta_n)) \tag{1.5}$$

Where Vn and In are the active values of voltage and current for the nth harmonic level, respectively. θ_n And δ_nare respectively phase angels of voltage and current for the nth harmonic component with respect to a reference angle. ω1=2πf1 is the angular frequency of the fundamental frequency f1.

- Finally, we will discuss fault is an abnormal or unpremeditated joining of live elements of an electrical network to each other or to earth. Such links frequently have very limited impedances, which causes enormous currents to flow. Short circuits contain energy that can rapidly heat up parts, generate excessive stresses, and cause destructive device accidents. We often deal with three different kinds of faults:

➢ Three Phase Faults
➢ Phase to Phase Faults
➢ Earth Faults

1.3 Purposes and Objectives

After 2003 in Iraq, there was a significant expansion in the field of electricity (generation, transmission, and distribution). This expansion did not take into account the impact of network expansion on parameters of power flow such as (voltage, active power, reactive power, and current of load). This leads to a negative impact on these parameters and thus increased losses in the National Network of Iraq. In this paper, we take this problem and solve it by acting extension and modifying a sample of an Electric network from IEEE because all its data are available and reliable. The project of the public outfall pumping station in Nasiriyah, which is the main clause governing the operation of the public outfall stream with the required design efficiency for the purpose of reducing groundwater levels within the sewage networks linked to the public outfall, which serves an agricultural area of (6) million dunums in central and southern Iraq, as the station contains (12) A giant pump with a design discharge of (200) m^3/sec. In addition, it transports water to the marshes in southern Iraq and maintains a water level within the marshes of not less than 1 meter. Therefore, any malfunction in the synchronous pumps, whether from the effect of voltage drops or from the soft star systems, leads to a malfunction in the station's work and a significant impact on the environment.

2. LITERATURE REVIEW

By studying the research and articles mentioned below, the necessity of studying the active and reactive power flow and the levels of voltage and current in power transmission lines and improving them in many ways has been emphasized because of its great impact on the sustainability of the work of industrial loads for the longest possible period, especially synchronous motors because we need to stability about power flow parameters, the Scientific literature wide worldly taken this field and continuous depending on the conditions and requirements of the work where notting some studies work through reactive power compensation, which suggests a distributed voltage control in electricity distribution networks. Whereas, the researcher's strategy included maintaining the voltages of the main busbars, and through them, with the help of the communication system, the adjacent busbars are controlled to ensure the stability of the ineffective capacity (Qu and Li 2019). Some research may go to the analysis of the behavior of the ineffective ability and confirm that the change of ability for each busbar individually increases the state of un controlling flow reactive power inside the high electrical grid and modifies the systematic and formal of the load viewed from it. Under these circumstances, maintaining the power system's effective and secure operation depends on the synchronized operations of the moderate and high voltage grids (Ilo *et al.* 2015). The change in electric power networks recently works to produce capacitive reactive power transfer from low-voltage networks to high-voltage networks which effects transmission lines' reactive power and the level of voltage in buses (Tazky *et al.* 2021). Some research depends on reactive power tracing, besides defining power losses in distribution networks, which have a direct response to the source of the losses, and determining a new factor to connection points for compensators are identified.

The best capacity can be calculated by combining the theory of most economical operation with the 2nd loss sensitive. Application of the suggested methodology aids in power loss reduction and reactive power distribution optimization. The outcome of the IEEE 39-bus system simulation demonstrates the accuracy and efficiency of the suggested approach (Yang *et al.* 2015). Some researchers depend on the generation sites in the distribution as well as the power grid technology in terms of stability of the voltage and power losses, where relied on three types of distribution generator technology, active and passive power injection, active power injection, and passive absorption, only active power injection. The position of distributed generation is also considered. The most appropriate one was determined by participation criteria in modal analysis. These inclusion criteria point to sensitive system components linked to reactive and active power. Then the 33 and 65 bus systems included in the investigation serve as regional representations of Brazil. The study shows that the locations and type of distributed generation technology have a substantial impact on power network stability of the voltage and power losses. The existence of distributed generating may potentially worsen power losses and voltage stability (Angelim and Affonso 2016).

In order to identify the corresponding process disruptions, a method for calculating the weighting factors of distinct types of dips with varying magnitudes and durations is proposed. The procedure is based on a study of the real power loss caused by different voltage dips that are tracked at the main stations of MV distribution systems. When assessing the price of voltage dips in the entire MV distribution system or for a commercial client linked to a section of the network, this can be useful (Weldemariam *et al.* 2016). A domain dynamic simulation is run to evaluate the stability of the short-term voltage. Sensitivity analysis is carried out during dynamic simulations to determine whether dynamic VAR sources are required. This work focuses on a reactive power compensation technique to identify system voltage convergence rates by locating FACTS in a metropolitan area as efficiently as possible. The goal of this study is to identify the best location for installing dynamic VAR sources while meeting a set of criteria for transient voltage drop and voltage stability margin. New understandings are provided regarding the effect of FACTS controllers on the reactive power compensation, which helps with voltage recovery. creation of the compensation method and control mechanism to keep the system's voltage within predefined bounds are the suggested method's criteria elements (Lee and Song 2019). Since the use of electronic devices has risen, power engineers' concerns about power quality have grown. High Harmonic levels are the main cause of declining Power Quality. Variable Frequency Drives and Rectified Loads are the two main drivers of harmonic glitches in the industry. For a dependable power system to operate, it is crucial to identify harmonic components, recognize all consequences related to harmonics, and analyze the quality of the power system using methods and technology that are readily available soft start, Harmonics create a variety of undesirable impacts. Utilizing a Fluke Power Analyser, the harmonic analysis will be shown in the application. Using simulation for both harmonics reduction and Power factor correction (PFC), the recorded THD values for the voltage and current will be utilized to model and assess overall harmonics in the entire three-phase distribution network (Riaz *et al.* 2021). Also, there are some studies are working on how inverter-based DGs affect system harmonics. When determining how the DGs harmonic spectrum affects system distortion and filter design, two instances are taken into consideration. On the IEEE 69-bus distribution system, the proposed technique is put to the test. When significant harmonic distortion reductions are achieved, the usefulness of the proposed planning approach is shown. fixing the distribution systems' power quality issues. In particular, the recently developed Water Cycle Algorithm develops the recommended In the absence of inverter-based DGs, single-tuned harmonic filters (STFs) should be planned as efficiently as possible (WCA).The goals of this planning issue are to reduce total harmonic distortion (THD), power loss, filter investment cost, and voltage profile improvement while taking various restrictions into account in order to adhere to IEEE 519 standards (Abbas *et al.* 2021). In addition to the effect of electronic equipment in the network, the presence of nonlinear loads is also considered one of the reasons for the appearance of harmonics. When non-linear loads are connected, harmonics are created that impair rise times and distort the voltage waveform (PCC). Thus, harmonics must be reduced in order to maintain good grid quality. This study provides a thorough analysis of each of the concerned, obligations and the appropriate criteria for the most popular types of filters in this situation. Last but not least, In three various grid configurations, active power filters that are readily accessible commercially were deployed. to demonstrate that they allow for preserving optimum power quality throughout forms of the grid (Lumbreras *et al.* 2020). We are focusing on Neplan software to comparison with our study and other networks because it is utilized extensively in recent research, notably that dealing with the analysis of power networks and enhancing their effectiveness employing Facts systems (Etab, Neplan, and DIgSILENT). Firstly by using the FACTS device, a transmission line's active and reactive power flows can be managed. To make investigations involving this gadget easier, it is crucial to have a model for it. This paper proposes a straight forward model for the

NEPLAN power system analysis program that primarily relies on the power injection technique. This model is created in order to be used in research using the FACTS device(SSSC) in the NEPLAN program because the software lacks a model of this kind. To assure this model's performance, quality in various load flow calculations, and effectiveness in the NEPLAN software, it is tested on the industry-standard IEEE 30 bus and IEEE 14-bus systems under a variety of circumstances (Awad *et al.* 2019). The second one with the IEEE 14 Bus power system network's voltage is increased using the static synchronous compensator (STATCOM). In the IEEE 14-bus system with constant loads, we concentrate on the voltage levels of the most significant problems. First, using the normal test data, we have examined the IEEE-14 bus system. Next, by moving the static synchronous compensator around the buses, we examined the system. The system under study was simulated using NEPLAN software. To select the ideal location for STATCOM to enhance the voltage profile of every bus, Every one of the outcomes were compared to the original power flow of the IEEE-14 bus network. (Moufid *et al.* 2021). Finally, with UPFC, the electricity transmission system in Nigeria is made more stable (Unified Power Flow Controller). The UPFC model is a power electronics application that enhances a system's voltage stability and control of power flow under static conditions. NEPLAN's Newton-Raphson iterative method is used to produce power flow solutions, which are then simulated on the country's current 41-bus 330KV composite power network. Both UPFC and without it were used to generate the simulated findings. The Network's previous normal condition existed in the absence of UPFC. The network's use of UPFC demonstrates a considerable decrease in line losses. Reactive line loss decreased by 70%, while active line loss on the network was greatly reduced, resulting in increased capacity for the users. In this way, the system's effectiveness is improved when the voltage falls are extended and repeated are minimized (Obukowho *et al.* 2020). All of this research and literature is concerned with obtaining a system with high reliability by ensuring the permanence of power supply to consumers and minimal losses.

3. ELECTRIC NETWORKS OF CLASSIFICATION & ARCHITECTURE

We will study and analyze the types of electrical networks, classify them according to voltage levels, share their common problems at work, and solve them using mathematical methods and reliable software.

3.1 Analysis of Sequence Emphasizes Plans the Following Features Configuration of the Power System

- Details of a network are put in different parallel planes, depending on their character functional; the farthest between planes equals the variance of the voltage levels;
- Linking between planes is main by the coupling magnetic circuit at the transformers (at different voltage levels, or by un sequential levels at the equal level of rated voltage) as autotransformers;
- The plane contains a longitudinal at the electrical system; the transversal ingredients are linked into these neutral points and plans;
- Networks of electrical from the high planes served for transmission power, and the networks in the last planes served as power consumers;
- Generators at power stations insert energy inside the network as (Figure 3.1); if the power generator is upper, the injection is done at a level higher voltage;
- Level of networks (excepting the generator busbar) are made from the lower level busbar and networks connected to them;
- The power consumption taken to high, low, and medium voltage planes by the coupling transformers;
- At upper levels of voltage the system coverage up greater zones and the power transfer grows, whereas decreasing a network's density;
- Networks at low plan are high density and transmission less power on middle smaller distances;

- Electrical network regulars are in transversal connected between the bases of medium voltage levels and the level of 0 kV; the absorbed power through the consumer and a node voltage is lesser (Eremia *et al.* 2006) (Figure 3.2).

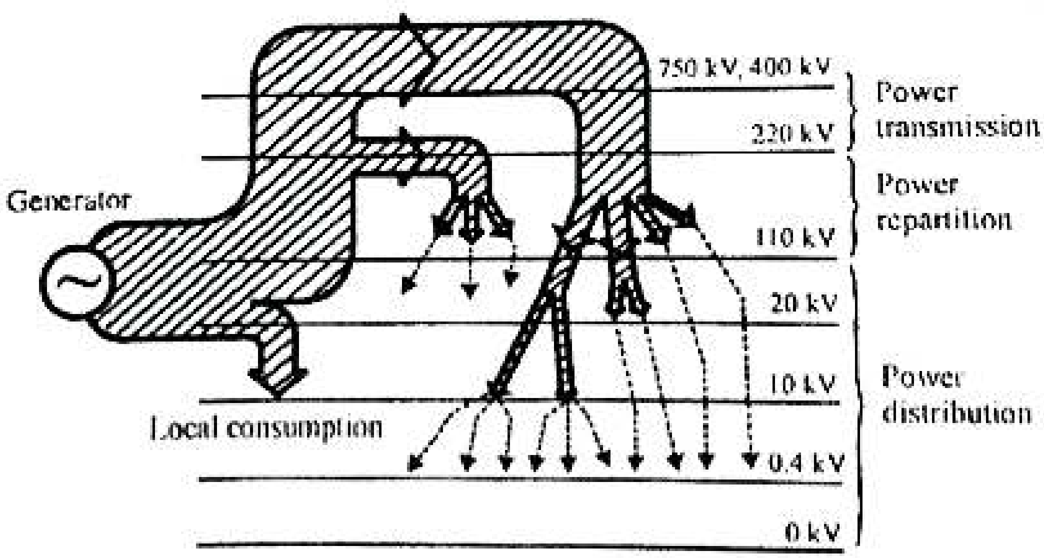

Figure 3.1 Power distribution

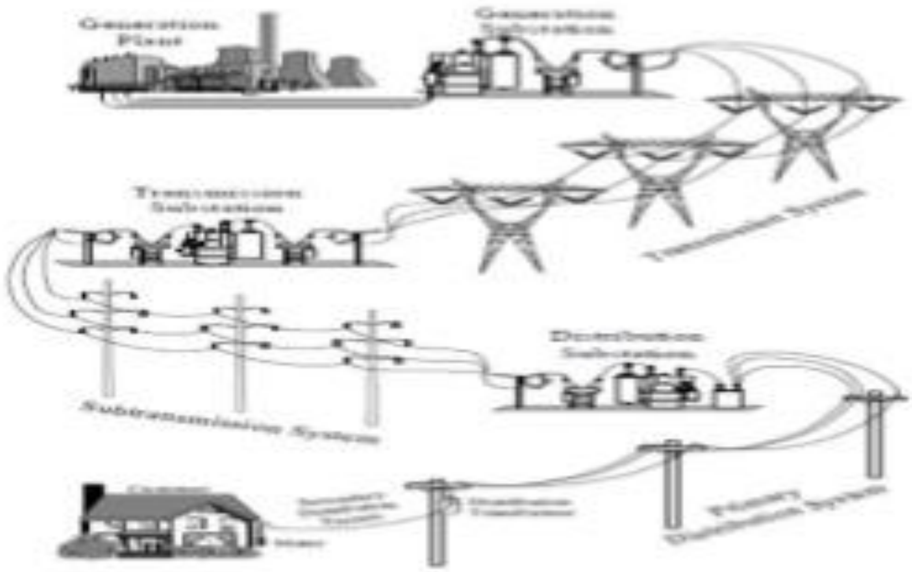

Figure 3.2 Generation

3.2 Typical Power Network

A sub-transmission represents the connecting point of a distribution level to a transmission system. Feeders outgoing as of a sub-transmission, the substation is usually feeding primary substations distribution, often built-up load types and regulars directly. We can inquire about considered to be the voltage level of a transmission and sub-transmission substation which varies by country and is dependent on the overall structure of the electricity network. As well as organizational and historical issues. In terms of voltage give a few types of a photo levels, and the case below is in point with reference to the system stage part in a specific state. Transmission 220 kV, Sub-transmission110 kV, and 66 & 33 & 11 kV distribution. Knowledge of the principles of the basic design is required for the electric power systems operation. This section will include definitions of transmission, and distribution systems (primary and secondary), then it will continue with a discussion regarding backup and emergency energy (Figure 3.3).

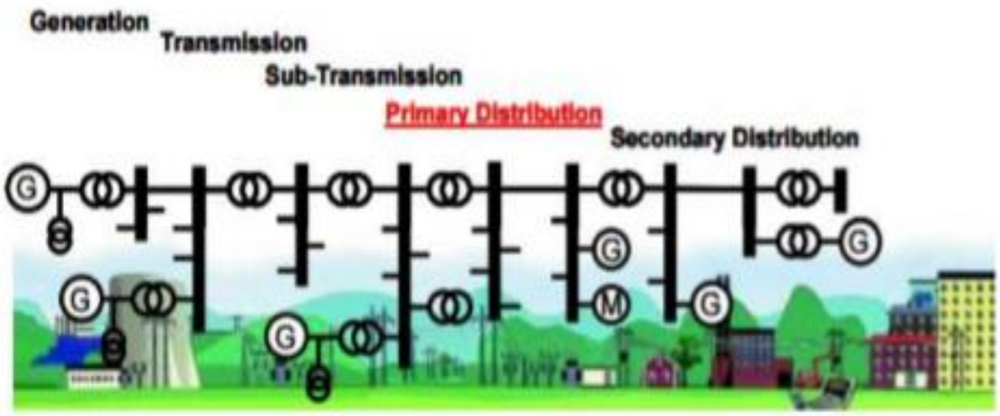

Figure 3.3 Distribution and transmission typical electrical power generation one-line

3.2.1 System of power transmission alternating current

This method of transmission is the big transfer power of system flanked by the power generation plant at the system of distribution as of the power it is approved to client points and it considers transformers increase and-decrease at the varies stations. The transmission system is usually an element from an electrical utility's system. The systems transmission Power usually contain sub-transmission level it provides in-between levels of voltage, which are generally used to get a more economic transition amid distribution with transmission systems (Mo 1990).

3.2.2 Nominal voltage for electric power network

Forever, in a substation generated power is transformed, placed in generating place, to 46 kV or additional to transmission. Typical insignificant system of transmission voltages is, 115 kV, 138 kV, 161 kV, and 230 kV. A few of the transmission in voltages might be at 23 kV to 69 kV, limited in general class there are as distribution voltage at primary system. Too little networks transmission working in the-highest- class voltage (345 Kv to 765 Kv) (Kersting 2018).

3.2.3 Systems types

Radial and network are two elementary types of distribution high-level systems. A structure radial has only one instantaneous pathway of power stream to the consumer, while a system has extra than one instantaneous pathway. Both two types of networks have a figure of variations in shape, for instance, loop, tie, radial, and parallel connected feeders. Many other extra compound network, that is the high-level system (connection substations through feeder’s formation network) & dual-service system (AC feeder at together load). These networks are variations of the two fundamental feeder preparations. The functions and properties of the simpler feeder preparations are discussed in the following paragraphs (Mo 1990).

3.2.4 Loop feeder

This loop feeder has split ends linked to a supplier and it’s the purpose of this role is to provide more of one of the load points in linking. From there, every load point can be filled. Each way; any section of the circle can be removed starting work without causing a transfer at other consumer levels. The ring path can be operated usually ON or usually

OFF (Figure 3.4). Most ring paths into networks are typically transferred to the OFF position at a little point via a control. The work system of two radial feeders is very similar (Short 2003).

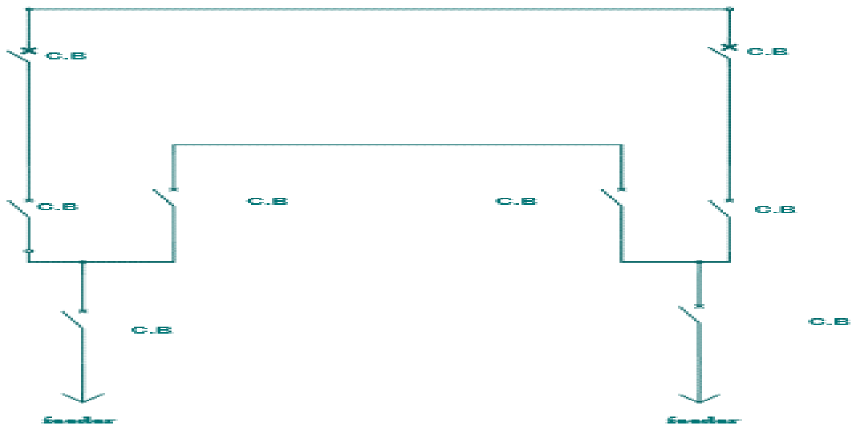

Figure 3.4 Loop feeder

3.2.5 Radial feeder

Distribution radial feeders are characterized by including just one pathway for power to stream starting the source to every consumer. As shown in Figure 3.5, it may also provide one or many additional consumer points linking the two feeders. Everyone's point of the load be able to be filled in one way; these are mostly extensively used via the Navy since the system is easy, protects easily, and is a little price (Brown 2009).

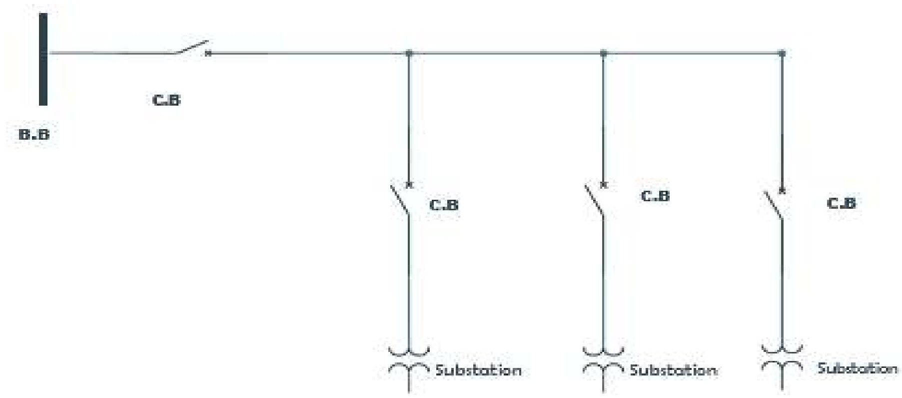

Figure 3.5 Radial feeder

3.2.6 Parallel feeder

The parallel coming feeders link the load with a source or midpoint as well as suppling the ability of power supply to the consumer during one or more parallel feeders, as shown in Figure 3.6. Parallel feeders form preservation of feeders provided (with no rupture up service to consumer) and fast return of repair in case one of the feeders fails (Mo 1990).

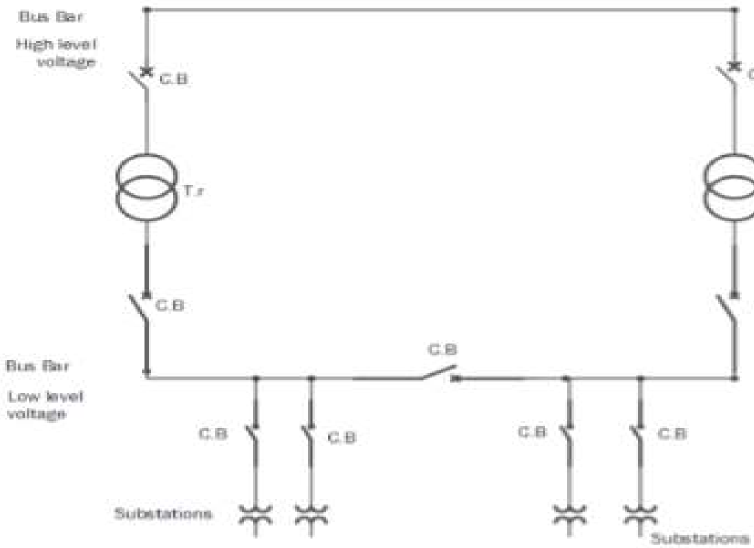

Figure 3.6 Parallel feeder

3.3 Transmission Lines

Transmission lines provided transformers to distribution substations, allowing the high voltages to be stepped down to the next stage. At the top level, great amounts of power delivered across great distances are more reasonably priced. The level of voltage is able to be consummated by the minimum value of currents, lowering the losses of power and reducing the go reduction in voltage the use of smaller conductors as a result necessitates a lower initial expenditure. The typical being 3-phase, 3-conductor for in the clouds lines by or not including a conductor to earth. Lines of Transmission are classed as unorganized due to the fact that The producing system's voltage is regulated. just for keeping the operation of feeders inside standard facilitate power flow and to voltage limits (Mo 1990).

3.4 Electrical Substation

Nowadays electrical power is an important demand and for satisfying it more stations are needed, such as hydro–electric, warm or nuclear. Is imperative to transmit this power gigantic hinders from the producing station of electric to heap focuses. High and Long transmission voltage systems are requisite since energy is created relatively in a stage low voltage, and it is quite useful to control transmitting at a high voltage stage. Diffusion of electrical energy is ready at the minimum voltage stage as determined by purchasers. In order to maintain the voltage levels and give more prominent strength various changes must be made, such as electrical substations (Mo 1990).

3.4.1 Step up substation

Generation stations are linked to step-up substations. Because of the alternators, the generator of electricity is only partial at low voltage levels rotate. These generators have voltages that should be stepped up for the economical transmission of power more lengthy distances, which is why it is important to have a step-up substation that is connected to a power plant (Brown 2009).

3.4.2 Substation step down

Voltages stepped up should be ventured to lose at load focuses, to various voltage stages for various purposes and the progression down substations are further divided into subcategories.

3.4.3 Substation of primary step down

Principal step-down substations are built beside the principal transmission lines, closer to the load level center. Which are stepped to a down level for varies suitable voltages for transmission secondary function.

3.4.4 Secondary step down substation

The length of the auxiliary transmission lines, and the optional transmission voltages level at load focus are further ventured down for an essential dissemination reason, at the optional stride-down substation (Mo 1990).

3.4.5 Distribution substation distribution

Substations have many sizes and configurations. A small urban Distribution substation usually has a nominal capacity rating of 5 MVA while a big urban station may be over 200 MVA. The substation is located where the primary transmission and voltages are backed down. This is made in order to supply power for feeding to load during a system of distribution (Short 2003).

3.4.6 Industrial substation

A manufacturing substation is mostly a distribution sub–station devoted to feeding a single consumer. A manufacturing consumer of big or middle provide might be selected as a large supply customer to which a singular substation steps down is devoted.

3.4.7 Outdoor type substation

A substation air insulated has the isolation high and air medium. High-voltage buses Are bares ringing tubing or cable, Insulated by nearby conductors, structures ground, and substation rank via air, and supported by insulators. Disconnect switches are used in this type of substation, and while they are open, they rely on the air to provide insulation over the open gap of the switch. Electrical energy is routed into the circuit breaker or transformer using porcelain or compound bushings. Outside substations are built outdoors and every one of the (132, 220, 400, 750) kV substations are open-air sort substations (Kempner 2008).

3.4.8 Indoor substation

A sulfur hexafluoride (SF6) substation of gas-insulated is a substitute to an unlock-substation air (GIS). The conductors of high-voltage are enclosed in a sharp cover filled through pressurized SF6 gas. The metallic tinny cover has earth potential also be able to be located on or nearby the earth. Designed for phase-to-ground and open-gap insulation, SF6 gas is utilized, with disconnect control positioned within the enclosure. Metallic sheath. Rushes strength arresters, signal traps, transformers, couple capacitor voltage, and line insulator switches are typically air-insulated transmission lines and their related devices. This equipment's air-insulated leads are running scared to air-to-gas bushings. The substations are developed indoors, as their name says it and they usually have (11, 33) kV and at some point 132 kV (Kempner 2008).

3.5 Substation arrangements

A substation is made up of one or more, a simple one consisting usually of just one incoming line and one transformer, as well as the appropriate voltage regulation equipment, buses, and switchgear. More complex substations have more than one or three income reserved lines, three transformers of power, otherwise a complicated system bus.

- **Electrical Bus System and Electrical Substation Layout.**
- **A bus is a device that connects There are at least two entering and outgoing circuits.**

One supply source or supplier system and one additional feeder network make up the most basic bus arrangement. A set of circuits. Mostly variations are intentional to improvement the service level, bus must be reliable. During scheduled maintenance or unplanned power outages, all or part of the load will be taken off. These arrangements can be referred to as single-breaker arrangements or either multiple-breaker arrangements.

3.5.1 The single bus system

This is a simpler bus agreement; a single bus is connected to every feeder and the power transformer, as shown in Figure 3.7, and all feeders and power transformers are linked to a single bus. Even with proper relay safety, the dependability of a single bus design is minimal; on the main bus, there was a single bus failure. Set between the leader bus and the C.B can result in an interruption of the improves capability (McDonald 2016).

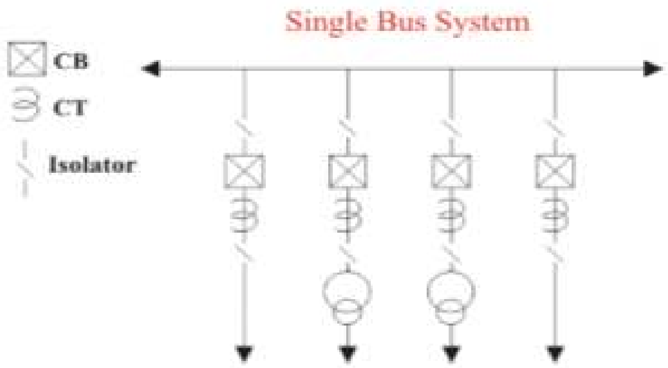

Figure 3.7 System of single bus

3.5.2 System of single bus with bus sectionalize

The HV bus has a single bus-bar configuration with a bus coupler circuit breaker. With this clarification, there are some possible operating concepts. The HV bus coupler can be opened, with each section of the busbar receiving its own power transformer, or both bus bar sections receiving a single power transformer. One feeder, while keeping the other feeder operation idly or de-energized as seen in Figure 3.8. When a single bus-bar is sectionalized by C.B it is probable to obtain profit, also if there are more than one incoming and also feeders of outgoing are equally into sections distributed, system intermission can be extremely difficult (Kempner 2008).

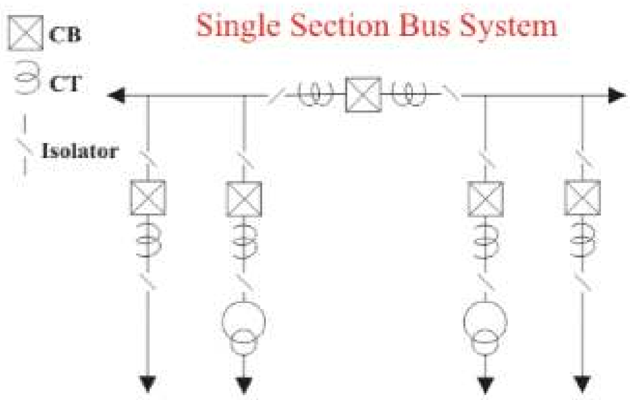

Figure 3.8 System of single bus with bus coupler

3.5.3 Double bus-bar

Each circuit is connected by a double bus-bar of a single breaker arrangement. There are two buses connected by a coupler breaker. The bus coupler allows any circuit to be real feeds from the other bus through its control because it operates normally closed. A double bus bar level has two matching bus bars that can be used to feed either outgoing or incoming feeders. Busses, every feeder being linked to the Parallel operation of both buses via individual isolators (McDonald 2016), as can be seen in the case in point from Figure 3.9.

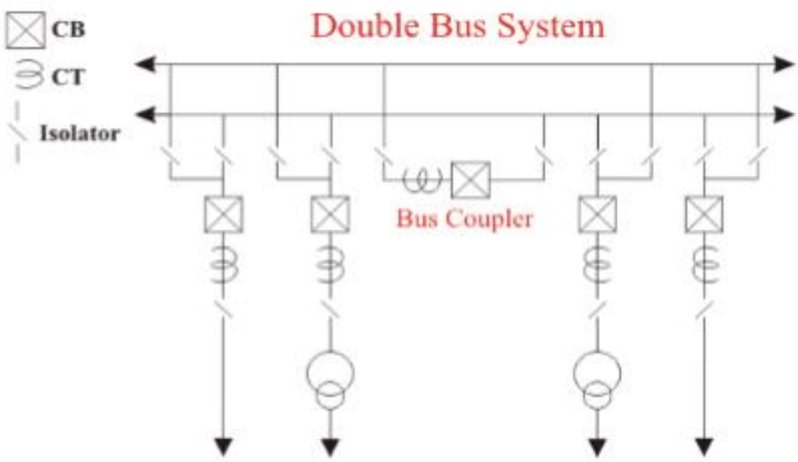

Figure 3.9 Double-bus

3.5.4 Double breaker bus system

For each trip, two breakers and two buses are used in the double bus with a double breaker arrangement. Through two breakers & two bus-bar for each network, a single bus-bar breakdown we able to be isolated with no stopping every network or equipment (McDonald 2016). The twice breaker at a system of bus-bar has two of the same bus bars that can be used to take either an outgoing or an incoming feeder from any of the buses running parallel to it. With the little differentiation that each feeder requires, a system of twice bus bar is used all feeder is linked to together of the parallel buses in during character breaker, unlike the just-alone isolator which is seen in the example from Figure 3.10.

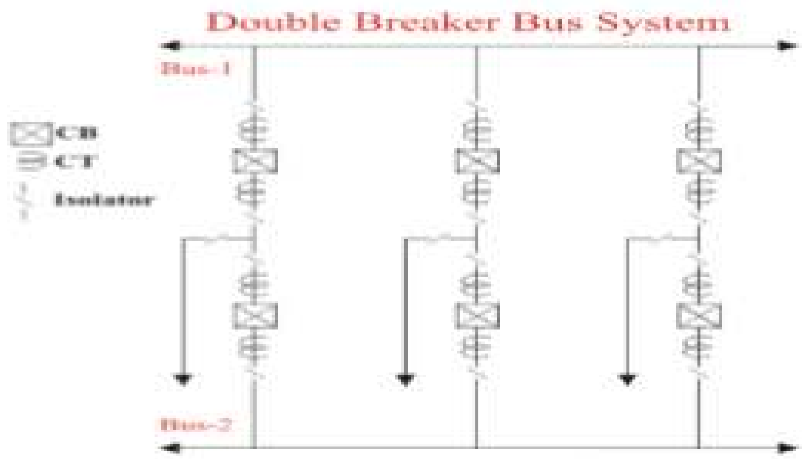

Figure 3.10 Double breaker bus system

3.5.5 System of one and half breaker bus

This bus system represents an expansion resting on the twice breaker system, reducing the number of circuit breakers. In this type of bus system, only one spare breaker is given for every two circuits (Figure 3.11) (Kersting 2018).

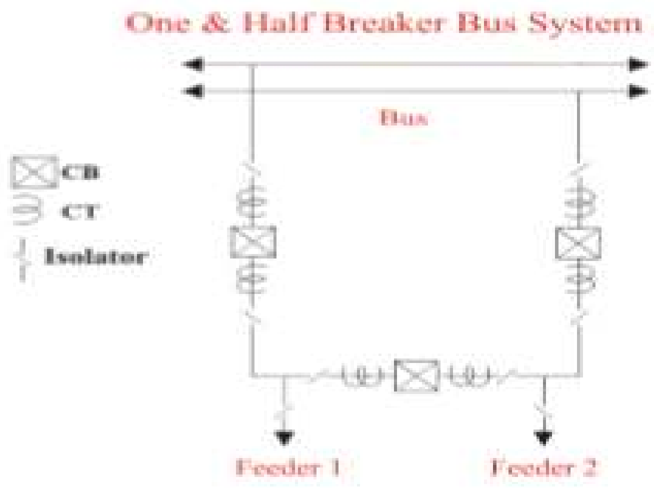

Figure 3.11 System of one and half breaker bus

3.5.6 Main & transfer bus system

The architecture of the main and transfer buses links the whole system between the transfer buses and the main. In certain cases, a bus tiebreaker is employed, whereas, in others, the strap between the two buses is simply switched. Every part of the circuits is linked to the main buses during this arrangement, which is comparable to the single bus layout. Normal operations. As a result, operational dependability is lower; a major bus failure will be a result of opening every part of the circuits. In this type of bus system, all feeder is linked to the next bus called a transfer bus through an insulator. During this situation, the bypass insulator is located between the transfer buses also the line of the feeder. Each feeder is connected to the main bus via a bay made up of C.B. As well as connected isolators at both sides of the breaker. One B.C bay couples the transfer bus with the main bus over a CB and connected isolators at together sides on the breaker. One B.C bay consisting transfer bus with the main bus during a C.B and connected in together sides isolators of the breaker. Figure 3.12 if importin, by closing the coupler of transfer bus isolators and subsequently closing the breaker, the transfer bus be able to be powered by the main bus. In this situation, the power from the transfer bus might be delivered straight to the feeder of the line via close the isolator of the bypass. If the incomer feeder C.B is switched OPEN on the other side, or isolated of the network, then the feeder is able to stay fed to the transfer bus via transferring (McDonald 2016).

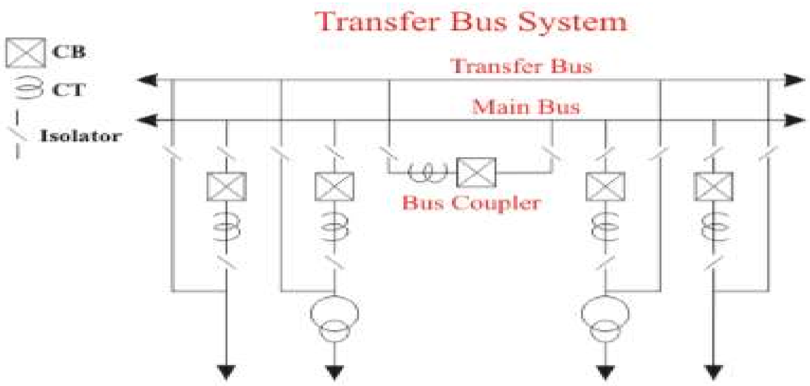

Figure 3.12 Main and bus system transfer

3.5.7 Ring of system bus

This bus system can be easily understood from the schematic diagram in Figure 3.12. During maintenance, it provided a twice feed at both feeders of a circuit, making OFF one breaker. The biggest disadvantage of this bus system is that it is a make-ON network system, which means it cannot be expanded in the future, making it inappropriate for a growing system. Also, if any of these occur as following through protection & maintenance or for any other causes, if every of the C.B in the circle ring is switched off, the dependability of the system drops due to the fact that the closed loop becomes open. In the event that every breaker in the open loop trips, there will be an interruption. Is caused in everyone the feeders set between the breaker of the tripped and open ending of the ring Figure 3.13.

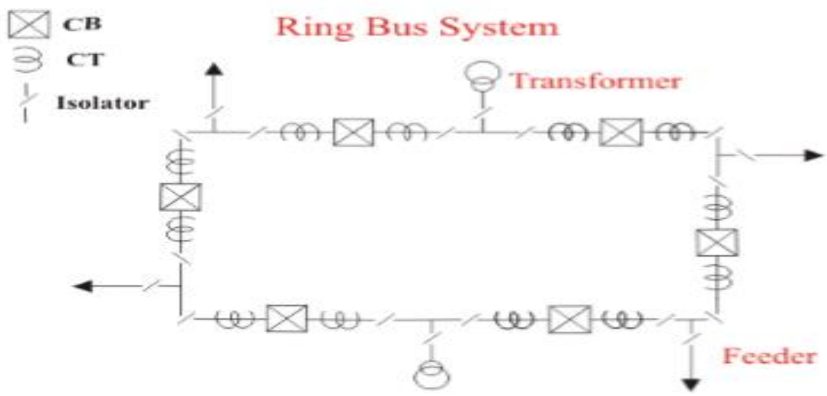

Figure 3.13 Ring bus system

3.6 Substation Operation

The operators might be present at the substations, or they can be used to control the switching and voltage-regulating equipment automatically or remotely. The majority of bigger new stations are moreover built automatically or manually or controlled remotely.

- **Substation automatic**

Controlling operations switched are controlled through a separate system control has been mounted transformers and conversion devices are automatically put into or taken out of operation. Feeder circuit breakers may be make-ON by relays of protection or through the control circuit itself after they have been opened.

- **Substations of remote control**

These are frequently located contained by a reasonable distance. Receiving circuit breaker communication is provided through attendance stations and pilot-wire cables or switch location indications and transmitting control changes as required. At distances greater than the economic reach of pilot wire networks, lines of telephone, microwave radio, and current carriers can be used designed for links connections for remote control at a range bigger than the financial reach of pilot wiring systems.

4. TRANSFORMERS

4.1 Transformers Modelling

The presence of electric transformers and autotransformers at electric nets produces conceivable the attaining of dissimilar voltage levels (Figure 4.1). In real electric networks, the transferred power could incur 4-5 voltages, and current transformations that produce a nominal capacity of whole transformers of the network be 4-5 times higher than the nominal capacity of whole generators. One winding is selected because numerous transformers in of network are applied for voltage and reactive power controllers.

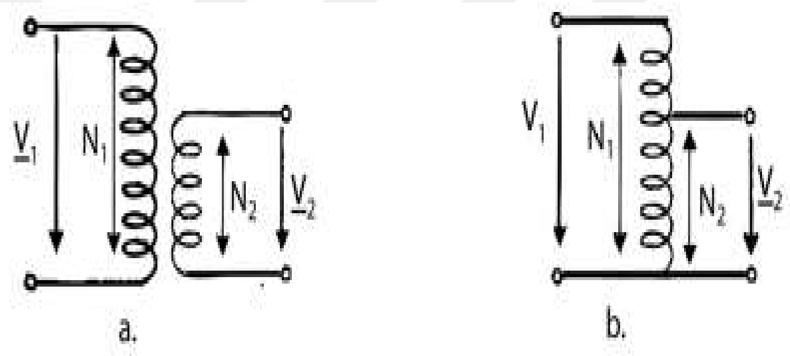

Figure 4.1 Simplified equivalent circuits of transformer (a) and autotransformers (b)

Autotransformers are applied with the transformer have a ratio of winding is little. a transformer has a tertiary coil of a small nominal capacitor, delta-connected, founding close pathway for current of the 3rd harmonic and multiple of 3, decreasing at that method have of these harmonics at the system. A lot, the third winding of Autotransformers is applied to linking synchronous compensators for reactive power adjustment. Today electrical system, high-level voltage, and ultra-high voltage circles habitually happen. The loading flow controller in these circles and precluding of transmission lines have overcapacity are done by using special transformers with the compound turn's ratio that changed not only the phasor and value of voltage. The transformers from the electrical network are able to be arranged in three kinds:

- Step-up transformers, through which generators are connected to the transmission system and transformers that provide auxiliary services.
- Coupling transformers: Which connects all components of a transmission system, in general, at different levels of voltage, or that connects transmission and distribution system.
- Step-down transformers of distribution; reduces the voltage level according to the required value of customer voltage (El-Hawary 2008).

4.1.1 Equivalent circuits and mathematical model

The characteristic of a single-phase transformer can be typical of consideration when studying two-winding three-phase transformers. The single-phase transformer's corresponding direct-sequence circuit can be used to study three-phase transformers that are lower than the symmetrical system of phases a, b, and c. This method is dependent on the observation that magnetic cores and electric circuits are regularly used in industrial settings. The magnetic flux of a transformer's two-winding circuit exclude it in the permanent magnet circuit in use today. keep it away from the magnetic core, an unitary magnetic circuit is considered and represented in(Figure 2.2) by treaty, the winding that receives the energy as of the network is named primary winding and the one that sends is on the way to the system is named secondary winding (Figure 4.2) (Brown 2009).

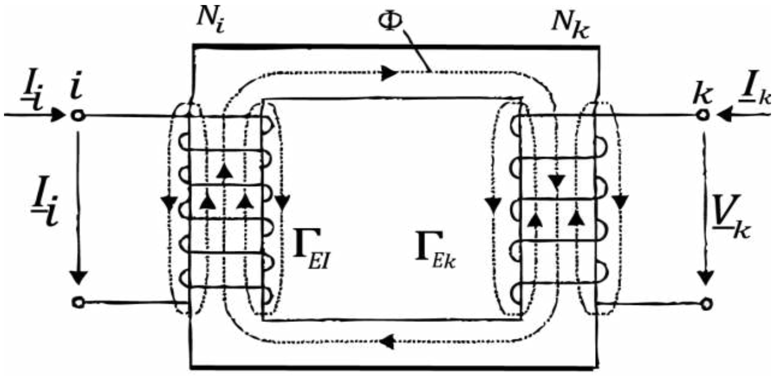

Figure 4.2 Model of transformer "Two-winding"

By using the question of electromagnetic induction lengthwise the magnetic core, Equation (4.1)

$$\int_{\Gamma_E} \bar{E} d\bar{S} = \frac{\mathrm{d}\varphi}{\mathrm{d}t} \tag{4.1}$$

Applying the end result at two loops conforming with two windings and using as consider the path of the current $\underline{I}_{i,}$ for instantaneous amounts next order of law explain as Equation (4.2):

$$\begin{cases} -v_i + R_i i_i = \frac{\mathrm{d}\varphi_i}{\mathrm{d}t} \\ -v_k + R_k i_k = \frac{d\varphi_k}{dt} \end{cases} \tag{4.2}$$

Magnetic fluxes φ_i, φ_k It is the total of the benefit and the dropout Equation (4.3):

$$\begin{cases} \varphi_i = N_i \, \Phi + L_{i,\sigma} \, i_i \\ \varphi_k = N_k \, \Phi + L_{k,\sigma} \, i_k \end{cases} \tag{4.3}$$

Where N_i, N_k Are the total number of primary and secondary turns;

R_i, R_k– primary and secondary winding resistance;

$L_{i,\sigma}$, $L_{k,\sigma}$– the primary and secondary windings' leakage inductances;

Φ– Common fascicular flux between the two windings;

Represent sin-wave stationery as phasor form, we obtain Equation (4.4), Equation (4.5):

$$\begin{cases} -\underline{V}_i + R_i \underline{I}_i = -j\omega(N_i \, \underline{\phi} + L_{i,\sigma} \, \underline{I}_i) \\ -\underline{V}_k + R_k \underline{I} = -j\omega(N_k \, \underline{\phi} + L_{k,\sigma} \, \underline{I}_k) \end{cases} \tag{4.4}$$

$$-\underline{V_i} + \underline{z_i}\underline{I_i} = N_i, \underline{E}$$
$$-\underline{V_k} + \underline{z_k}\underline{I_k} = N_k, \underline{E} \quad (4.5)$$

Where $\underline{E} = -j\omega\phi$ is Electromagnetic force (e.m.f.) per winding turn and winding impedance is Equation (4.6):

$$\begin{cases} \underline{z_i} + R_i + j\omega L_{i,\sigma} \\ \underline{z_k} + R_k + j\omega L_{k,\sigma} \end{cases} \quad (4.6)$$

Based on the system of equations a simplified model can be drawn of the two-winding transformer (Figure 4.3):

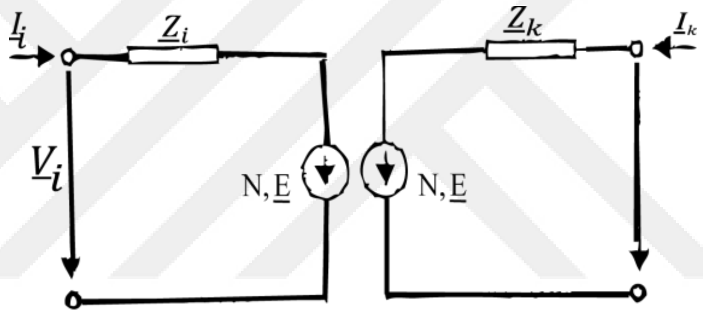

Figure 4.3 Simplified transformer model

On the hypothesis of $\underline{z_i} = \underline{z_k} = 0$, the equations of the ideal transformer can be obtained, Equation (4.7):

$$\begin{cases} -\underline{V_{i0}} = N_i, \underline{E} \\ -\underline{V_{k0}} = N_k, \underline{E} \end{cases} \quad (4.7)$$

The transformer turns ratio is at case reality; usually, this is complicated there for a phase angle between the winding of a transformer. In repetition, the two-coils transformer is defined either as an equivalent circuit with magnetic linking or as an equivalent circuit with a transformer operator as Figure 2.4 (El-Hawary 2008)

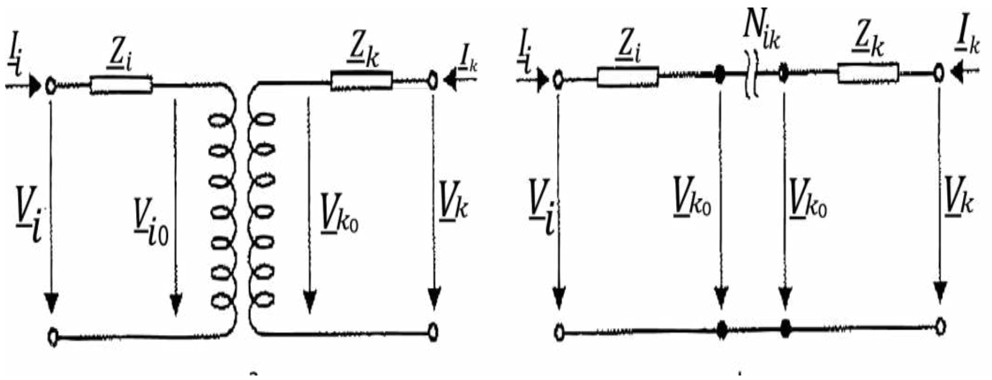

Figure 4.4 Two-winding transformer equivalent circuit: (a) circuit with magnetic coupling; (b) circuit with transformer operator

Additionally, if the contour connecting the magnetic circuit is using Kirchhoff's law for magnetic circuits, Equation (4.8):

$$\int \overline{H}\, d\,\overline{S} = \Theta \tag{4.8}$$

We get the expression for the total current intensity (ampere-turns), Equation (4.9):

$$\Theta_{ik} = N_i \underline{I}_i + N_k \underline{I}_k \tag{4.9}$$

If we accept that Θ_{ik} stay constant, therefore the permeability of the magnetic circuit of the transformer is supposed unlimited, at the load system ($\underline{I}_k \neq 0$), in addition to for without load system ($\underline{I}_k = 0$), we can write $\Theta_{ik} \cong N_i\, I_{i0}$ and write $\Theta_{ik} \cong N_k\, I_{k0}$. respectively. In the above Equation (4.11) I_{i0} is the no-load current if the Tr. is provided with winding *i,* and I_{k0} is no-load current if the Tr. is provided at winding *k.* (Eremia *et al.* 2006).

$$N_i \underline{I}_i \cong -N_k \underline{I}_k \tag{4.10}$$

and the turn's ratio gets the expression, Equation (4.11)

$$N_{ik} = \frac{N_i}{N_k} \cong -\frac{\underline{I}_k}{\underline{I}_i} \tag{4.11}$$

where, Equation (4.12)

$$\begin{cases} \underline{z}_{ik} = z_i + N^2{}_{ik}\underline{z}_k \\ \underline{z}_{ki} = \underline{z}_k + N^2{}_{ki}\underline{z}_i \end{cases} \quad (4.12)$$

with these conditions, a two-winding transformer can be both modular and resistive series with an ideal transformer, are two types specified:

a. Corresponding system with transformer operation N_{ik} and impedance $\underline{z}_{ik}$ Referred to winding *I* (impedance $\underline{z}_{ik}$ is Galvanically linked to busbar i)

b. Equivalent circuit with transformer operators N_{ki} and impedance $\underline{z}_{ki}$ referred to winding k (impedance $\underline{z}_{ki}$ is galvanic ally linked to node *k*) (Figure 4.5)

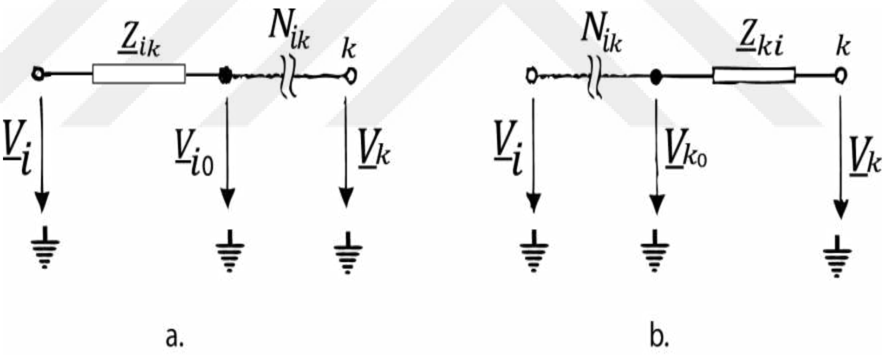

Figure 4.5 Two-winding transformer equivalent circuit, with transformer operator: (a) step-up transformer; (b) step-down transformer

As result, the two-winding transformer is explained as a branch characterized by two details: another impedance $\underline{z}_{ik}$ and turns ratio N_{ik} or impedance $\underline{z}_{ki}$ and turns ratio N_{ki}satisfying the circuit of the relationship. In literature, the turns ratio is also determined as a: 1 where$a = N_{ik}$, respectively 1: a where$a = N_{ik}$, respectively 1: a Where $\frac{1}{a} = N_{ki}$. Traditionally, the transformer actuator changes the ideal transformers (Eremia *et al.* 2006).

If express $\underline{z}_k$ from the first and second equations, we get, Equation (4.13):

$$\underline{z}_i + N_{ik}^2 \left(\underline{z}_{ki} - N_{ki}^2 \underline{z}_i\right) = \underline{z}_{ik} \tag{4.13}$$

Knowing that $N_{ik} \times N_{ki} = 1$ we can get the relation between impedances and admittances indicated to the two windings, Equation (4.14):

$$\begin{cases} \underline{z}_{ik} = N_{ik}^2 \underline{z}_{ki} \\ \underline{z}_{ki} = N_{ki}^2 \underline{z}_{ik} \end{cases} \tag{4.14}$$

and Equation (4.15)

$$\begin{cases} \underline{y}_{ik} = N_{iki}^2 \underline{y}_{ki} \\ \underline{y}_{ki} = N_{ik}^2 \underline{y}_{ik} \end{cases} \tag{4.15}$$

Where $\underline{z}_{ik}$=1/$\underline{y}_{ik}$ and $\underline{z}_{ki}$=1/$\underline{y}_{ki}$If the admittance $\underline{y}_{i0} = \underline{I}_{i0}/\underline{V}_{i0}$, Equation (4.16) (Figure 4.6):

$$N_{ik} = \frac{N_i}{N_k} \cong -\frac{\underline{I}_k}{\underline{I}_i - \underline{I}_{i0}} \tag{4.16}$$

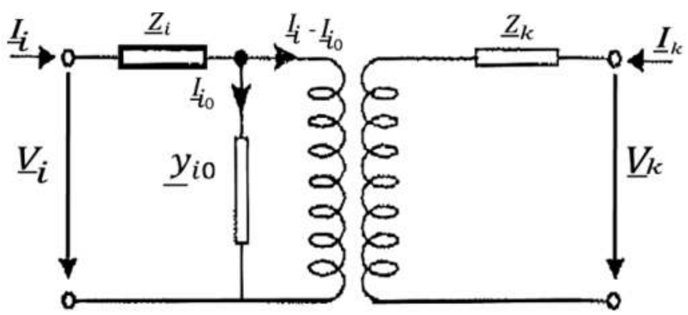

Figure 4.6 The modelling of no-load power-losses in the two-winding transformer

Additionally, if the admittance $\underline{y}_0$ is motivated by The perfect transformer terminals located at the exact transformer terminals., the product $\underline{z}_i, \underline{I}_{i0}$ can be removed as compared with the product $\underline{z}_i, \underline{I}_i$. Keeping the no-load admittance $\underline{y}_{i0}$ Linked at i-0 terminals, then we get the equivalent Γ circuit of a two-winding single-phase transformer (Figure 4.7) (Eremia *et al.* 2006).

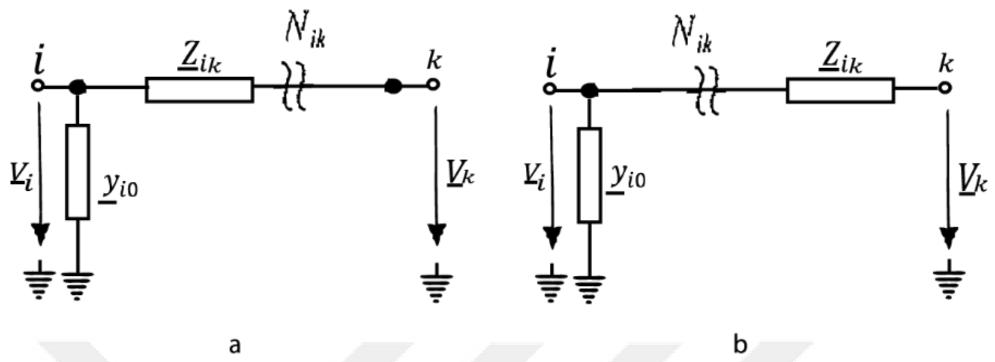

Figure 4.7 Equivalent Γ circuit of two-winding transformer with transformer operators

From a large electrical system to transformers from a connected substation, through another operating system, the load flow could vary in its way. At this state, for a more precise evaluation of electrical losses, the equivalent Π circuit of the transformer is operating, For the admissions modeling the power losses originate at the input and output terminals. Both of the shunt accepts have unequal values because the acceptance $\underline{y}_{ki0}$ will refer to the winding i while the admittance $\underline{y}_{ki0}$ may be considered to winding *k*. (Figure 4.8) (El-Hawary 2008).

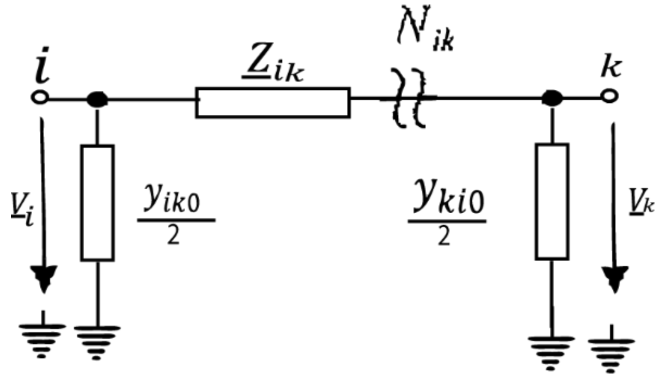

Figure 4.8 Equivalent Π circuit of two-winding transformer with transformer operator

Autotransformers are generally put in the loops of electricity systems where the way of load flow could be changed. Three-phase transformers and autotransformers can be factory-made in order to supply control of both voltage magnitude and phase angle (El-Hawary 2008).

Phase-shift transformers supply a phasor shift of secondary vectors $\underline{V}_k$, $\underline{I}_k$ Related to the primary ones$\underline{V}_i$,$\underline{I}_i$. with these cases, a transformer has real and imaginary turn's ratio $\underline{N}_{ik}$ and supply a phasor shift of angles resolute by the contact type, Equation (4.17) (Figure 4.9):

$$\underline{N}_{ik} = N_{ik}e^{j\Omega ik} = N_{ik}(\cos\Omega_{ik} + j\ \sin\Omega_{ik}) \quad (4.17)$$

Ω_{ik}=transformer turns ratio, angle (radian).

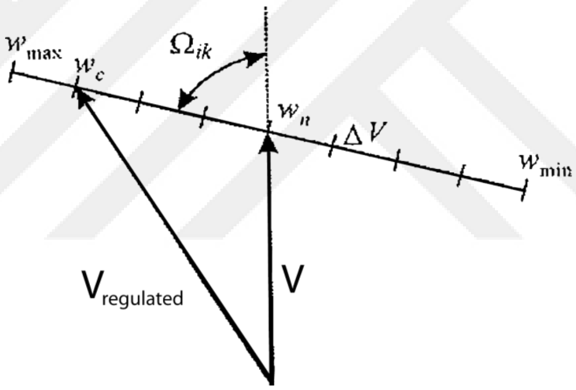

Figure 4.9 Regulating voltage diagram of phase-shift transformer

The step-up transfer, by the secondary winding *k* kind, the prospect of adjusting the number of turns - the regulating coil - and the regulating voltage and the values of the ratio of turns that are calculated by the following formula (El-Hawary 2008) Equation (4.18), Equation (4.19):

$$\underline{V}_{k,regulated} = V_k + (w_a + w_n)V_k\ \frac{\Delta V}{100}\ (\cos\Omega_{ik} + j\ \sin\Omega_{ik}) \quad (4.18)$$

$$\underline{N}_{ik} = \frac{V_{i,n}}{\underline{V}_{k,regulated}} \quad (4.19)$$

Step-down transformer, With the primary winding you have compressed, with the possibility of adjusting the number of turns (the regulating winding), A regulating volt, and the values of the ratio of turns are calculated by the formula, Equation (4.20), Equation (4.21):

$$\underline{V}_{k,regulated} = V_i + (w_a + w_n)V_k \frac{\Delta V}{100} (\cos \Omega_{ik} + j \sin\Omega_{ik}) \quad (4.21)$$

$$\underline{N}_{ik} = \frac{V_{i,n}}{V_{k,n}} \quad (4.22)$$

where V_i, V_k Are the transformer windings' rated voltages linked at $nodes\ i\ and\ k$

w_a–Actual tap level

w_n–Median tap level

ΔV– Step size in percentage of voltage

- If Ω_{ik}=0, transformer simply controls voltage;
- If $\Omega_{ik} = \pi/2$, Transformer only provides active power and shift in phase angle control. re- dispatching;
- If 0<Ω_{ik}<$\pi/2$, Transformers offer active power and voltage regulation..

It consumes to indicate that, generally, the winding with voltage control we can with a level of higher voltage to get more accessible and the current is small. The circuit has an equivalent Π case by impedance $\underline{z}_{ik}$. Referred to *i* node, and complex turns ratio $\underline{N}_{ik}$, the existence of the case of a step-up transformer, at that, we can plan the general equivalent circuit (Eremia *et al.* 2006) (Figure 4.10).

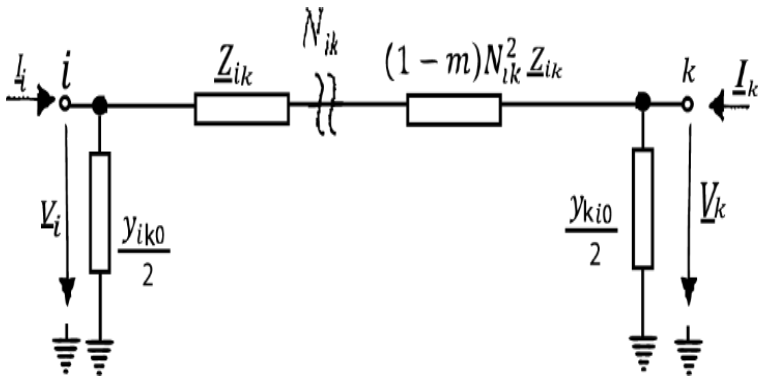

Figure 4.10 Generalized equivalent circuit with transformer operator

A mathematical model of a two-winding transformer in a professional program for calculating the load flux, a galvanic equivalent circuit can be used. with regard, we reflect the equivalent circuits of a two-winding transformer, by the real turns ratio N_{ik} and equations. If the current $\underline{I_i}$ is expression as of the first equation to which we add and deduct the term $\underline{y_{ik}}N_{ik}\underline{V_i}$, later rearranging the terms we obtain, Equation (4.22):

$$\underline{I_i} = \underline{y_{ik}}\,(1 - N_{ik})\,\underline{V_i} + \underline{y_{ik}}\,N_{ik}\,(\underline{V_i} - \underline{V_k}) = \underline{I_{i0}} + \underline{I_{ik}} \tag{4.22}$$

In a similar manner, we can write the current $\underline{I_k}$ to which we add and subtract the term$y_{ik}N_{ik}V_k$, then we obtain, Equation (4.23):

$$\underline{I_k} = \underline{y_{ik}}\,N_{ik}\,(N_{ik} - 1)\underline{V_k} + \underline{y_{ik}}\,\underline{V_i} + N_{ik}\,(\underline{V_k} - \underline{V_i}) = \underline{I_{k0}} + \underline{I_{ki}} \tag{4.24}$$

Where the equality $\underline{y_{ik}}N_{ik} = \underline{y_{ki}}N_{ki}$ has been used. Following this, the galvanic equivalent circuit of a two-winding transformer is done (Figure 4.11).

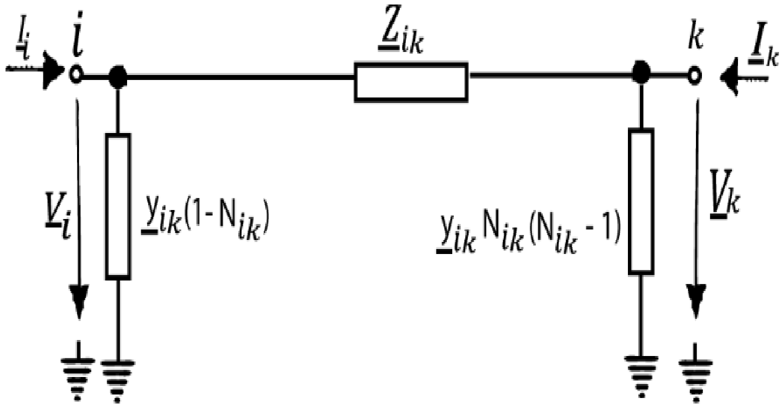

Figure 4.11 Galvanic equivalent circuit of two-winding transformer

4.1.2 Transformer parameters

Two-winding transformer

For an equivalent circuit with a transformer actuator of the transformer with details indicated by coil *i,* we take the two working systems: no load and short-circuit can be found (Eremia and Shahidehpour 2013). Transformer parameters, series impedance $\underline{z}_{ik}$=$R_{ik}+jX_{ik}$ and shunt admittance $\underline{y}_{i0}=G_{i0}-jB_{i0}$ Straight, are calculated in terms of its manufacturing details.

getting the term of active energy losses, Equation (4.24):

$$\Delta P_{sc}^{nom}=3R_{ik}I_{i,n}^2 \tag{4.24}$$

Taking into consideration the relationship, Equation (4.25):

$$I_{i,n}=\frac{S_n}{3V_{i,n}}=\frac{S_n}{\sqrt{3U_{i,n}}} \tag{4.25}$$

the transformer resistance is calculated with Equation (4.26):

$$R_{i,k} = \Delta P_{sc}^{nom} \frac{U_{i,n}^2}{S_n^2} [\Omega] \tag{4.26}$$

To determine the equivalent reactance X_{ik} of the transformer, departed by the short-circuit voltage values, Equation (4.27):

$$V_{sc} = \frac{u_{sc}[\%]}{100} V_{i,n} \tag{4.27}$$

and taking that into consideration, Equation (4.28):

$$V_{sc} = z_{ik} I_{i,n} \tag{4.28}$$

its results, Equation (4.29)

$$z_{ik} = \frac{u_{sc}[\%]}{100} \frac{U_{i,n}}{\sqrt{3}} \frac{1}{I_{i,n}} = \frac{u_{sc}[\%]}{100} \frac{U_{i,n}^2}{S_n} [\Omega] \tag{4.29}$$

knowledge of the two parts R_{ik} and z_{ik}. We can get the equivalent reactance of the transformer by Equation (4.30):

$$X_{ik} = \sqrt{z_{ik}^2} - R_{ik}^2 \cong z_{ik} [\Omega] \tag{4.30}$$

Note: for transformers of extra-rated power $z_{ik} \gg R_{ik}$, because that reactance X_{ik} is known by impedancez_{ik}this situation of autotransformers with a tap of windings using percentage impedance to calculate the short-circuit, the tap position is Equation (4.31):

$$u_{sc} = A(w_n - w_a)^2 + B(w_n - w_a) + G_i \tag{4.31}$$

A, B, C, as constants specific in autotransformer's catalogs. In actuality, the equivalent inductive susceptance B_{i0} is determined leaves in a transformer magnetizing losses, then, Equation (4.32)

$$y_{i0} = \frac{I_0}{V_{i,n}} = \frac{i_o[\%]}{100} I_{i,n} \frac{1}{\frac{U_{i,n}}{\sqrt{3}}} = \frac{i_0[\%]}{100} \frac{\sqrt{3}U_{i,n}I_{i,n}}{U_{i,n}^2} = \frac{i[\%]}{100} \frac{S_n}{U_{i,n}^2} [S] \tag{4.32}$$

and the susceptance is resolute by a formula, Equation (4.33)

$$B_{i0} = \sqrt{y_{i0}^2 - G_{i0}^2 \cong y_{i0}} [S] \tag{4.33}$$

4.2 Line Model

A transmission line in electricity has a model as series impedance has resistance and inductance with shunt (parallel to the ground) capacitance, and shunts conductance. It is required to have line resistance and inductive reactance. The shunt capacitance and conductance could be neglected. Consequently, the corresponding circuit is significantly simplified. We deal here with facets of determining these parameters on the basis of the length of the line, the type of conductor used, and the space of the conductors as they are installed on the supportive structure of the transmission towers. A wire or group of wires not insulated from one a different is named a conductor. A stranded conductor is made up of several wires that have been twisted or tied around. Each new layer of a coaxially stranded conductor has six more wires than the one before it. The one-wire core and the three-wire core are the two fundamental structures (McDonald 2016).

The overhead transmission lines are categorized as three types:

- Short transmission line: The line voltage is relatively modest, less than 20 kV, and the line length is up to 60 kilometers..

- Medium transmission line: The line voltage ranges from 20 kV to 110 kV, and the line length ranges from 60 km to 160 km.
- Long transmission line: The line's length exceeds 160 km, and its high voltage exceeds 110 kV.

At all may be the kind of transmission line, the main idea is to transfer energy from one node to another. As with other electrical networks, The performance of the transmission line depends on its efficiency & voltage control since there will also be some power loss and voltage drop when electricity is being transmitted from sending node to receiving node.

$$\text{Efficiency of transmission line} = \frac{\text{power delivered at receiving end}}{\text{power sent from sending end}} 100\%$$

Voltage regulation is represented by a percentage of change of receiving end voltage from no-load to full load condition.

$$\%\ \text{regulation} = \frac{\text{no load receiving end voltage} - \text{full load receiving end voltage}}{\text{full load receiving end voltage}} 100\%$$

There are three main electrical criteria for transmission lines. Electrical resistance, inductance, and capacitance all exist in the conductors of the line. The transmission line's consistently distributed impedance results from the conductors' running from one zone to another while being maintained by towers. The electrical power has a speed of transmission equal to 3×10^8 m/sec with a frequency is 50 Hz. also, The wavelength of the voltage and current of the power can be calculated by the relationship given below, $f.\lambda = \nu$ where, f is power frequency, λ is wavelength and υ is the speed of light. Therefore $\lambda = \frac{\nu}{f}$, $\lambda = \frac{3*10^8}{50} = 6x10^6$ m.

Therefore, if The transmission line is not more than 160 km long., the parameter is anticipated short transmission lines (up to 60 km in length), and middle transmission lines are categories for electrically short transmission lines (length between 60 and 160 km). For short transmission lines, the capacitive parameter is neglected, however for medium-length lines, the capacitance is supposed to be collected in the middle, or half of the capacitance could be thought of as being lumped at either end. The parameters are regarded as being dispersed along lines longer than 160 km. A long transmission line is the name of this (Kersting 2018).

4.2.1 In the short line model

The equivalent circuit of a short transmission line is shown in Figure 4.12, where Is is the sending end and IR is receiving end currents, also Vs is the sending end and VR is receiving end phase voltage. We can solve this circuit as a simple series Ac circuit. So (the line has a length of up to 60 km), it is assumed that the effect of the shunt capacitance will appear as (π) while is so a small transmission line it is Neglected. This leaves only the series RL branch (Das 2005).

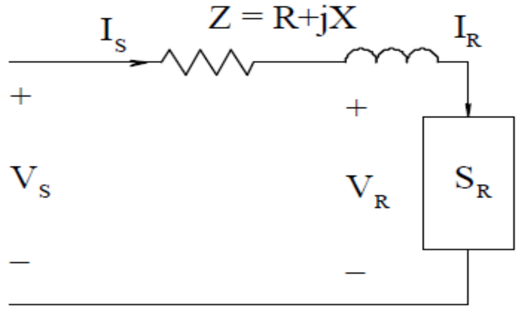

Figure 4.12 Equivalent circuit of a short transmission line

In the figure to the right, a brief line with a load is displayed (per phase). Circuit theory applied we have Equation (4.34)

$$I_R = \frac{S*_R}{V*_R} \tag{4.34}$$

We also know Equation (4.35):

$$V_s = V_R + ZI_R \tag{4.35}$$

where Z is zl, the total series impedance of the line and $I_S = I_R$. We will now determine the short line's transmission parameters, often known as (ABCD parameters): a 2-port indicated as "ABCD"the equations are as follows Equation (4.36) (Figure 4.13):

$$\begin{bmatrix} V_s \\ I_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{matrix} V_R \\ I_R \end{matrix} \tag{2.36}$$

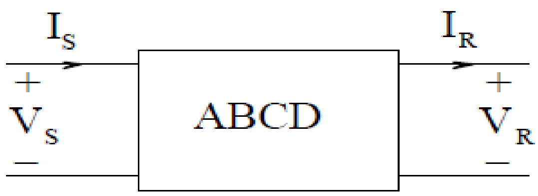

Figure 4.13 Transmission parameters

Matching with the equations for the short line above, we see that:

A=1, *B*=Z, *C*=0 and D=1. These relationships are required to represent the short line. The influence of the load's difference power factor on a line's ability to regulate its voltage is simply agreed upon by short lines, so it will be taken into consideration at this time. Explained in terms of percent of full-load voltage, voltage regulating of a transmission system is the rise in voltage at the receive side. When full load at a definite power factor is removed while the sending-end voltage is caught constant (Short 2003). The voltage regulation in percent as below Equation (4.37):

$$\text{Percent } VR = \frac{|V_{R(NL)}||V_{R(FL)}|}{V_{R(FL)}} \times 100 \tag{4.37}$$

At no-load IR=0 and thus $VS = AV_{R\,(NL)}$, and since A =1, $VR_{(NL)} = V_S$.

4.2.2 Lumped parameter transmission line models

A representation of the lumped details of transmission lines is required for a more thorough analysis of interlinked electric power systems. Its use allows the development of simpler algorithms to solve complex networks including transmission lines. Now we are involved to obtain values of the circuit elements of a $\boldsymbol{\pi}$ circuit, to denote correctly the terminal characteristics of the line given by V_S=AV_r+ BI_r; I_S=CV_r+ DI_r.

It is simple to verification that the elements of the equivalent circuit are getting in terms of the "ABCD" constant of the line by Z_π=B; $Y_\pi = \frac{A-1}{B}$ (El-Hawary 2008)

4.2.3 In the medium line model

The shunt admittance, generally neat capacitance, is involved in the determination of a line of medium length. If the total shunt admittance of the line is parted into two equal parts located at the sending and receiving ends of the line, the circuit is named a nominal π (Short 2003) (60 km to 160 km), it is supposed that the capacitance may be the admittance Y and impedance Z below are shown in Figure 4.14, for all line, per-phase (and not per km). For the "pi" model below we can explain the next relationship, Equation (4.38):

$$I_L = I_R + \frac{Y}{2} V_R \; and \; V_S = V_R + ZI_L \quad (4.38)$$

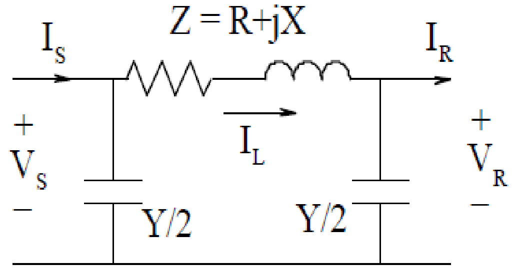

Figure 4.14 Admittance Y and impedance Z

Using the 1st equation in the second, we have Equation (4.39):

$$V_S = \left(1 + \frac{ZY}{2}\right) V_R + \ ZI_R \tag{4.39}$$

at the same time, we can see that Equation (4.40), Equation (4.41), Equation (4.42)

$$I_S = \ I_L + \frac{Y}{2}\ V_S \tag{4.40}$$

$$I_S = \ I_R + \frac{Y}{2} V_R + \frac{Y}{2}\left[\left(1 + \frac{ZY}{2}\right) V_R + ZI_R\right] \tag{4.41}$$

$$= Y\left(1 + \frac{ZY}{4}\right) V_R + \left(1 + \frac{ZY}{2}\right) I_R \tag{4.42}$$

Thus, the ABCD parameters are Equation (4.43), Equation (4.44):

$$A = \ \left(1 + \frac{ZY}{2}\right)\ and\ B = Z \tag{4.43}$$

$$C = Y\ \left(1 + \frac{ZY}{4}\right) and\ D = \left(1 + \ \frac{ZY}{2}\right) \tag{4.44}$$

Typically for a symmetrical 2-port A=D and AD-BC=1 (in this instance, the determinant of the "ABCD" matrix is one). As a result, the inverse relationships can be easily found., Equation (4.45):

$$\begin{bmatrix} V_R \\ R \end{bmatrix} = \begin{bmatrix} D & -B \\ -C & A \end{bmatrix} \begin{matrix} V_S \\ I_S \end{matrix} \tag{4.45}$$

g is conductance to ground per unit length, while f is a frequency in Hz (In the particular example of the medium line model, zero.). Also keep in mind that $r, g, z,$ and y are all per line. $Z = \ (r \ + \ jwL)\ l \ = \ R \ + \ jX$ is the series impedance, while $Y = (g \ + \ jwC)\ l$ is the shunt admittance (El-Hawary 2008).

4.2.4 In the long line model

The line length is greater than 160 km, it is assumed that the line has distributed parameters in a state of lumped parameters. This produces exact results. At we find the precise model, an equivalent π is found. Because it uses lumped parameters to make it comparable to the precise distributed parameter model, this model is known as the equivalent model (Kersting 2018). This line has a distributed parameter model. Out from receive side to the transmitting end, the distance x is calculated. The following ABCD factors are included in the long-line calculations. if x=ℓ (the length of the line), Equation (4.46), Equation (4.47):

$$A = \cosh \gamma\ell \ and \ B = Z_C \sinh \gamma\ell, \tag{4.46}$$

$$C = \frac{1}{Z_c} \sinh \gamma\ell \ and \ D = \cosh \gamma\ell \tag{4.47}$$

Zc Is the line characteristic impedance given by Equation (4.48):

$$Z_c = \sqrt{\frac{z}{y}} \ and \ \gamma = \alpha + j\beta = \sqrt{zy} \tag{4.48}$$

Now that it is possible to get a model that is realistic and whose ABCD parameters are equivalent to those listed above, the results are listed below without evidence. Equation (4.49), Equation (4.50):

$$Z' = Z_c sinh \ \gamma\ell = Z \frac{\sinh \gamma\ell}{\gamma\ell} \tag{4.49}$$

$$\frac{Y\prime}{2} = \frac{1}{Z_c} \tanh \gamma\ell = \frac{Y}{2} \frac{\tanh \gamma\ell/2}{\gamma\ell/2} \tag{4.50}$$

At which non-primed values are those for the basic π form and the primed values are those for the real or equivalent model. We can convert the nominal in this manner to an actual or equivalent π (Kersting 2018).

4.3 Generation

A power station contains one or many generating units that turns up mechanical moving to electricity by rotating a prime mover coupled to an electric generator. Most prime movers are driven by different systems as the steam produced in a boiler fired by coal, oil, natural gas, or nuclear fuel. Or by driven non-thermal sources such as hydro-powerful and wind turbines. Usually, Line-to-line voltages generated by generators range from 11 kV to 30 kV. a plant's capacity to generate energy to supply all of the power consumers by clients is referred to as system capacity. To guarantee system capacity, three requirements must be satisfied. First, the current generation capacity needs to be more than the total of system losses plus the requested load. The system needs to be able to deliver needed electricity to clients without overloading machinery, which is the second need. Thirdly, a sufficient voltage range should be used to serve clients (Kempner 2008).

4.3.1 Model of synchronous generator at steady-state

Under steady state, the rotor quantities are also constant, thus all-time derivative terms are set to zero, whereas the zero-sequence components are absent and $\omega_r = \omega_s = 1 \text{ p.u.}$ Equation (4.51), Equation (4.52).

$$0 = R_D I_D + \frac{d\psi_D}{d_t} \tag{4.51}$$

$$0 = R_Q I_Q + \frac{d\psi_Q}{d_t} \tag{4.52}$$

$R_D I_D = R_Q I_Q = 0$. Therefore, the damping currents I_D and I_Q are zero. This situation is to be expected since, under the spinning magnetic field, and steady-state circumstances due to the rotor and stator currents are both stationary. (Mo 1990). Equivalent circuit and phasor diagram taking into account the previous considerations, the equations of stator and rotor voltages and flux linkages become, Equation (4.53), Equation (4.54), Equation (4.55), Equation (4.56), Equation (4.57) and Equation (4.58):

$$V_d = -RI_d - \omega_r \psi_q = -RI_d + X_q I_q \tag{4.53}$$

$$V_q = -RI_q - \omega_r \psi_q = -RI_q - X_q I_q + X_{md} I_f = -RI_q - X_d I_d + E_f \tag{4.54}$$

$$V_f = R_f I_f \tag{4.55}$$

$$\psi_d = -L_d I_d + L_{md} I_f \; ; \psi_q = -L_q I_q \tag{4.56}$$

$$\psi_f = L_{md} I_f - L_{md} I_d \tag{4.57}$$

$$\psi_D = L_{md} I_f - L_{md} I_d ; \; \psi_Q = -L_{mQ} I_q \tag{4.58}$$

Where $X_d = \omega_0 L_d \; and \; X_q = \omega_0 L_q$ are called direct-axis and quadrature-axis synchronous

Reactance, respectively Equation (4.59);

$$E_f = X_{md} I_f = \omega_0 L_d \frac{V_f}{R_f} \tag{4.59}$$

the emf induced by the field current if under no-load conditions of the synchronous generator. The steady-state Equation (4.55) and Equation (4.56) were written in the (*d, q*) reference frame attached to each generator. In order to use them in the algebraic-differential equations of the power system mathematical model, it is necessary to transform these equations to the (+1, +j) reference frame of the grid. For this, the connection between the two reference frames is therefore considered, in Equation (4.60) (Mo 1990):

$$\underline{A} = \overline{A}e^{j(\delta-(\pi/2))} \tag{4.60}$$

The voltage and current vectors at the generator terminals are defined as Equation (4.61):

$$\overline{V} \triangleq V_d + jV_q \; ; \overline{I} \triangleq V_d + jl_q. \tag{4.61}$$

Substituting the expressions of V_d and $V_{q,}$ in Equation (4.54) and Equation (4.55) give $\overline{V} = -R\left(I_d + jI_q\right) + jE_f + X_qI_q - jX_dI_d$

If we add and subs tract $jX_q\overline{I} = jX_q\,(I_d + jI_q)$ then, Equation (2.62):

$$\overline{V} = -R\overline{I} + jE_f + jX_q\overline{I} - jX_q\overline{I} + X_qI_q - jX_dI_d = -\left(R + jX_q\right)\overline{I} - j\,[\,E_f - \left(X_d - X_q\right)I_d \tag{4.62}$$

Finally, the steady-state Equation (4.63) of the synchronous generator in the (d, q) reference frame can be written as Equation (4.64):

$$\overline{V} = \overline{E} - \left(R + jX_q\right)\overline{I} \tag{4.63}$$

$$E_q = E_f - \left(X_d - X_q\right)I_d \tag{4.64}$$

$X_d > X_q$ so $E_f > E_q$ Equation (4.65)

$$\underline{V} = \underline{E} - (R + jX_q)\,\underline{I} \tag{4.65}$$

If one assumes that R<Xq, the synchronous generator can be represented in steady

State by an emf orientated along the q-axis, Equation (4.66):

$$\underline{V} = \underline{E} - jX_q\underline{I} \tag{4.66}$$

In the case of isotropic synchronous generators (round rotor generators), $X_d = X_q = X_s$, we have:

$E_q = E_f = X_{md}I_f$. Based on Equation (4.66) and the equivalent circuit of Figure 4.15, the phasor diagram of the synchronous machine with balanced case stability can be drawn, where δ_i (internal rotor angle) is the phase shift between the emf E_q and the terminal voltage $\underline{V}$, while φ(power factor angle) is the phase shift between the terminal voltage $\underline{V}$ and the load current $\underline{I}$ (Figure 4.16) (Mo 1990).

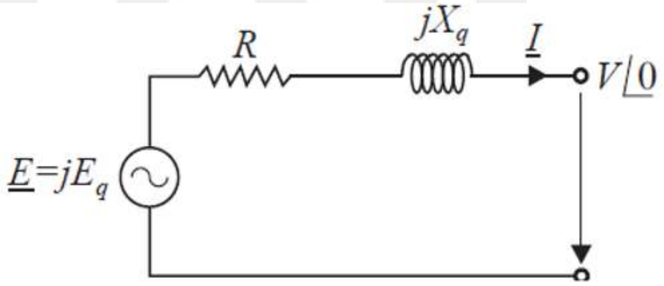

Figure 4.15 The equivalent circuit of the synchronous generator.

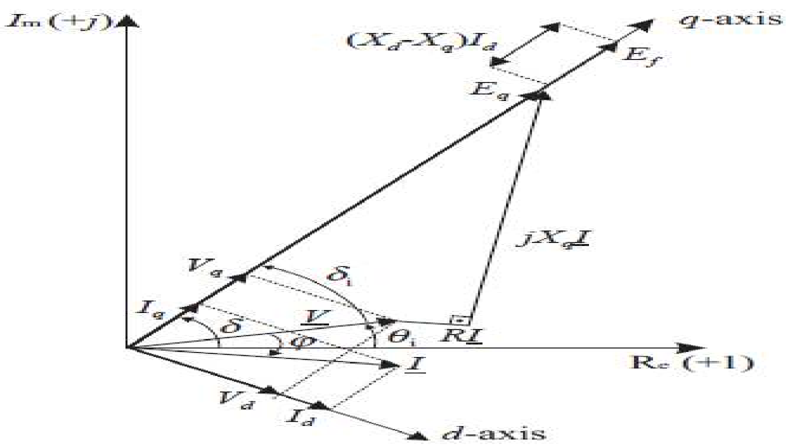

Figure 4.16 Phasor diagram of the synchronous machine under balanced steady state.

5. POWER FLOW

5.1 Power Flow Analysis

Generality common method to denote a power flow is by using the node-voltage method. Knowing all impedances of machines and loads and also the voltages of generators at all generator busbars the solution of all currents can be made by using busbar voltage analysis and Kirchoff's current law. The generators are substituted by equivalent current sources and knot equations can display as Equation (5.1) (Das 2005):

$$I = YV \tag{5.1}$$

- I- The current vector injected,
- Y-Admissions matrix
- V-Node voltage vector

These equations are written by inspection of the circuit. The complex power is usually known at load nodes, and from time to time on generator nodes, only the active power and voltage are known. They're not sufficient known variables to solve a relationship of the form $I = YV$.

The power is a nonlinear relationship of the voltage and current and , which is why the answer to the resulting relationship is complex, since there is no analytical method available in order for us to be able to find the solution, therefore we are used reiterated methods to find the result (voltages, currents, etc.). The nonlinear set of generated relationships is named power flow equations (Kersting 2018).

5.1.1 Load flow study

There four quantities of interest associated with each bus are: (P, Q, V, $Voltage\ Angle$, θ_{Bus}, $and\ Plosses$)

At all nodes of the system, two of these four relationships will be definite and the residual two will be unknown. Each of the system nodes is classified according to which of the two relationships is definite (Das 2005).

5.1.2 System constraints

There are two different kinds of constraints.

- Equality constraints
- Inequality constraints

Additionally, inequality constraints are divided into two groups:

Hard Type, which has fixed and finite values for ex- Tapping range to change the tap when loading the transformer, has very rigid values and does not entertain changes in them.

Soft Type, which is not as rigid as hard type, offers instead, flexibility in varying their values for nodal voltages and ex-phase angles. (Kersting 2018).

5.1.2.1 Equality constraints

The basic equality constraints are the following Equation (5.2), Equation (5.3):

$$P_i = G_{ii}U_i^2 + U_i \sum_{k=1,k\neq 1}^{n} U_k \left[G_{ik} \cos\ (\theta_i - \theta_k) + B_{ik} \sin\ (\theta_i + \theta_k)\right] \tag{5.2}$$

$$Q_i = -B_{ii}\, U_i^2 + U_i \sum_{k=1,k\neq 1}^{n} U_k \left[\ G_{ik}\ \sin(\theta - \theta_k) - B_{ik}\ \cos(\theta + \theta_k)\right] \tag{5.3}$$

5.1.2.2 Inequality constraints

The primary categories of inequality constraints are the following ones:

- Generator constraints.
- Voltage constraints
- Transformer tap changer settings.
- Transmission line constraints (Eremia and Shahidehpour 2013)

5.1.2.3 Generator constraints

$Pgmin \leq Pg \leq Pgmax \text{ and } Qgmin \leq Qg \leq Qgmax$

The mechanical limit of turbine respect, limits the maximum active power generation, whereas the flaming instability of a boiler constrains the minimum active power generation. Also the highest and lowest levels of reactive power generation is constrained by high Limited by the high temperature of the rotor and the stability limit of the machine respectively (Eremia and Shahidehpour 2013).

5.1.2.4 Voltage constraints

$|U_{BUS} \text{ min}| \leq | U_{BUS} |\leq| U_{BUS} \text{ max}|$

The change in voltage magnitude must be within an approved constraint for acceptable work of the instrument linked to the network else extra employment of voltage regulators produce the system price ineffective (Eremia and Shahidehpour 2013).

5.1.2.5 Running spare capacity constraints

These running spare capacity constraints are used when an accident forced failures of one or more system alternators occurs and when there is a sudden load in the system. The purpose of total generation is to meet in addition the load demand and losses at minimum spare (Kersting 2018).

5.1.2.6 Transformer tap setting constraints

The lower tap setting in an autotransformer has a value equal to zero and the maximum value should be 1 (0≤t≤1). In the case in which tappings are supplied on the secondary side of a two-winding transformer then the same scenario applies, with the sole modification that the maximum value should be *n*, where *n* represents the ratio of transformation (0≤t ≤n) (Eremia and Shahidehpour 2013).

5.1.2.7 Transmission line constraints

The thermal loading and stability constrain the increase in the instrument of transmission temperature, due to the capability of the circuit to constrain the transmission line's active and reactive power flow. The thermal limit specified by the current loading capacity is denoted by $I_{thermal,}$ $S_{thermal} = 3U_{ratED} * I_{thermal}$ (El-Hawary 2008).

5.2 Analysis of Power System

Before doing a power flow analysis, the entire network must be modeled with all the power plant, consumer, and transmission lines. An electric grid is collected of transmission lines, transformers, consumers, and power stations. A transmission line is specified as an equivalent π circuit with a series impedance ($R + jX$) from busbar i to busbar k as shown as Figure 5.1 (Afolabi *et al.* 2015).

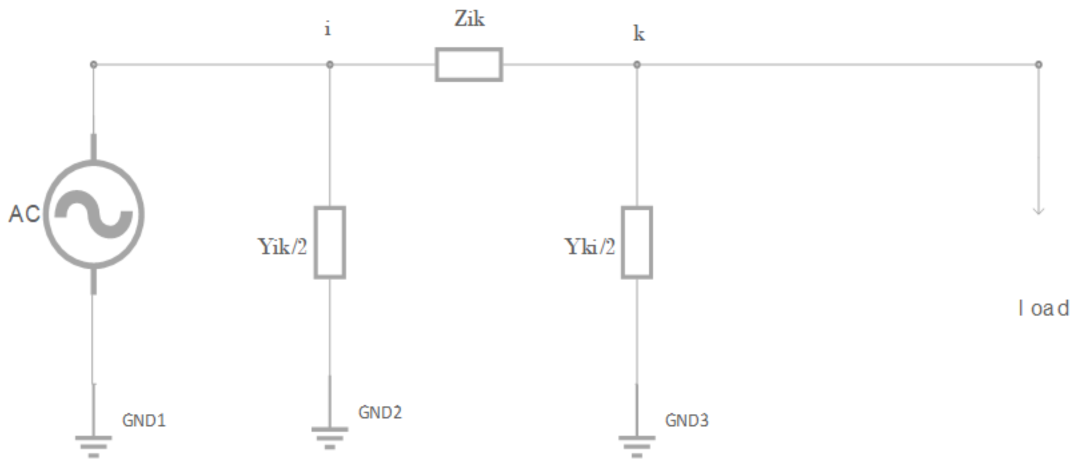

Figure 5.1 Circuit model of an electric network

The point on the left position is a power plant and the point on the right position is a consumer. Rik And Xik and node$k$. Yik Is the shunt capacitors of the transmission line? In a short line having level low voltage (e.g., up to 60 km), the shunt capacitor might ignore it. In a medium-length high voltage line (e.g., up to 160 km), the nominal shunt capacitor is separated evenly at both sides as below in Figure 5.1. Represent transmission line by series resistance and reactance between nodes. The most general formula of the system relationship is established on the shunt capacitors format since the system relationship is nonlinear and then there is no direct result is conceivable. In its place, iterative methods have to use in order to get a result. Hence good start estimations of the result are essential. There are a lot of perfect mathematical solve methods for the resolution of the load flow issue. One of the most has a large-ranging using a Newton-Raphson method. Considering the system of Figure 5.1. The current out- coming of (nodes) i and $k$can be explained as Equation (5.4) and Equation (5.5): (Grainger and Spencer 1994).

$$I_i = V_i \frac{y_{ik}}{2} + (V_i - V_k).(G_{ik} + B_{ik}) \tag{5.4}$$

$$I_k = V_k \frac{y_{ik}}{2} + (V_k - V_i).(G_{ik} + B_{ik}) \tag{5.5}$$

$Gik + Bik$ is the transmission line's admission linking buses i and $k$and is the inverse of the impedance $Rik + Xik$. Equations (5.4), and (5.5) can be re-written as Equation (5.6) and Equation (5.7):

$$I_i = V_i\left(\frac{y_{ik}}{2} + (G_{ik} - B_{ik})\right) - V_k.(G_{ik} + B_{ik}) \tag{5.6}$$

$$I_k = V_k\left(\frac{y_{ik}}{2} + (G_{ik} - B_{ik})\right) - V_k.(G_{ik} + B_{ik}) \tag{5.7}$$

n the matrix form it can be explained as follows in Equation (5.8):

$$\begin{bmatrix} \mathrm{I}_i \\ \mathrm{I}_k \end{bmatrix} = \left[\begin{pmatrix} (\frac{y_{ik}}{2} + G_{ik} - B_{ik}) - (G_{ik} + B_{ik}) \\ - (G_{ik} - B_{ik}) (\frac{y_{ik}}{2} + G_{ik} + B_{ik}) \end{pmatrix}\right] \cdot \begin{bmatrix} \mathrm{V}_i \\ \mathrm{V}_k \end{bmatrix} \tag{5.8}$$

Equation (5.8)$'s$ matrix is also referred to as the Y matrix and the nodal admittance matrix..

5.3 Active and Reactive Power

We can model the leakage impedance of the transformer as in short-circuit calculations; however, in the calculation of a transformer can doing as a control element for load flow.:

- Voltage control is getting by using of taps changer to change the ratio of winding. The tap changer can be adjusted with loading conditions, by providing automatic control of voltage. The under-loading condition taps usually provide 10-20% voltage regulations around the rated transformer voltage, in 12, 17, or 21 some types of transformers. Off-load taps changer regulates 5$\%$ voltage. These regulations of transformers as off-load tap changers must be operating before commissioning, because cannot be modified with load.

- Phase-shift of winding of transformers can be controlled to improve the stability limits.
- The relationship between reactive power flow and voltage change because the voltage alterations give reactive power control indirectly. (McDonald 2016).

The transformers which supplied a few modifications to the value of voltage, in the range of ± 10%, and those that shift the angle of the voltages line are necessary elements of a power plant. many transformers adjust both the value of voltage and angle and all supplied steps of windings to regulate the turn-ratio by replacing steps when the transformer is off-condition. Load-tap-changing (LTC) transformers are transformers that when energized, the moving the tap at the tap-changer (Mo 1990)

The component of the admittance matrix associated to the buses linked to the transformers varies with the tapping when the regulation of transformers is present in the system (Figure 5.2).

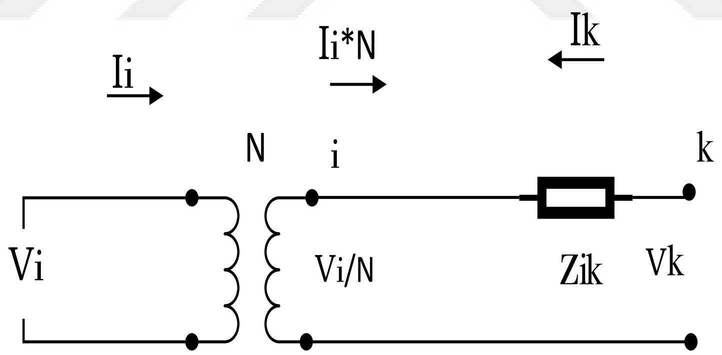

Figure 5.2 Tap changing of transformers

At the shown network, the tap ratio is N: 1 per unit. The current entering the system from node i is NI i when the system is being experimented with of the transformer (right side). From the secondary side, the voltage at node$i$ is V i $/N$. Following that, the system nodal admittance equation is expressed as Equation (5.9) and Equation (5.10) (El-Hawary 2008)

$$\begin{bmatrix} NI_i \\ I_k \end{bmatrix} = \begin{bmatrix} Y_{ii} & Y_{ik} \\ Y_{ki} & Y_{kk} \end{bmatrix} \cdot \begin{bmatrix} V_i/\ N \\ V_k \end{bmatrix} \tag{5.9}$$

$$\begin{bmatrix} I_i \\ I_k \end{bmatrix} = \begin{bmatrix} Y_{ii}/\ N^2 & Y_{ik} \\ Y_{ki} & Y_{kk} \end{bmatrix} \cdot \begin{bmatrix} V_i \\ V_k \end{bmatrix} \tag{5.10}$$

then, the presence of a voltage regulator alterations in transformers the Y admission matrix the flow of power, both reactive and active from a node can explain by the Y matrix as the load flow relationship (5.11). Such as:

$$P_i + j\ Q_i = \ V_i\ .\textstyle\sum_k (V_k . Y_{ik}) \tag{5.11}$$

Expanding yields, Equation (5.12) and Equation (5.13)

$$P_i = \ \textstyle\sum_j (|V_i||V_k|\ |V_{ik}|\ \cos(\ \theta_{ik} + \ \delta_k + \ \delta_i)) \tag{5.12}$$

$$P_i = \ -\textstyle\sum_j (|V_i||V_k|\ |Y_{ik}|\ \sin\theta_{ik} + \ \delta_k + \ \delta_i) \quad) \tag{5.13}$$

The voltage at busbar i lead to the voltage at busbar k. by angle δ. Then the power flowing from buses ik is given by to node, Equation (5.14) (Mo 1990)

$$P + jQ = \frac{V_i . (V_i - V_k\ (\cos\delta + j\ \sin\delta) *}{(R - jX) *} \tag{5.14}$$

For a long or medium-length transmission line $X >> R$. For easy we will neglect R in Equation (5.15) and Equation (5.16)

$$P + j\ Q = \frac{V_i . V_k\ \sin\delta + j\ V_i\ (V_i - V_k\ \cos\delta)}{(X)} \tag{5.15}$$

$$P = \frac{V_i . V_k\ \sin\delta}{(X)}\ and\ Q = \frac{V_i . (V_i - V_k\ \cos\delta)}{(X)} \tag{5.16}$$

The active power formula displays that amount of active power Phas proportional with the power angle δ rises. Because the rotor speed increases as a result in eliminating prime move, keeping the excitation voltage constant, and power angle, the yield of the generator also increases, resulting in a rise in active power output P. The output of reactive power is likewise decreasing. The rise in P is significantly greater than drop in Q when is less than 15 degrees. The reactive power equation shows that as the excitation voltage V rises, the reactive power output Q of the generator also rises, as does the reactive power output Q of the generator when the excitation voltage V rises (McDonald 2016).

The power-flow issue is about getting the not-dynamic operating settings of an electric power transmission network and at the same time appropriate limits for power and/or voltage at the system buses, defending as slack bus, PV buses, PQ buses, and Generator buses. The parts of the definition gave in below:

- Slack bus- One bus, a slack or swing bus, is used as a standard when the voltage's magnitude and phase angle are specific. This bus picks up the "slack" by balancing the power equation following the specification of the powers of other buses. This bus will $be\ bus\ \#1.P\ And\ Q$ are required for this bus.
- Load buses - The active and reactive powers are a favor. The voltage magnitude and angle are necessary to be found. These buses are also known as $PQ\ buses$.
- Generator buses ($PV\ buses$, regulated buses, and voltage-controlled buses) - At these buses, the voltage magnitude and real power are a favor. These buses also go by the titles: The reactive power Q on such buses is the unidentified element. and the voltage $angle\ \delta$ (Grainger and Spencer 1994).

5.4 Newton Power Flow Method

The Newton-Raphson (NR) method is applied to the nonlinear equations. The main nonlinear problem is changed into a series of linear problems whose results approximate the solution of the original problem (Grainger and Spencer 1994).

G=F(x, y) is considered a relationship where x and y are the functional arguments of F.

G is a set amount.

If F is nonlinear. Typically there may be an indirect solution to obtain the values of x and y for a special value of G. At this case, a Preliminary estimation of x and y is taken and repeatedly solves the actual values of x and y until the difference in the value of G and the studied, the value of F (with the assessment of x and y) ΔF is less than a tolerance value, as follows (Saadat 2011):

a starting estimate of x and y be x^0 and y^0, using Taylor series, Equation (5.17):

$$G = F\,(x^0, y^0) + \Delta x_1^0 \,\frac{\partial F_n}{dx_1} \left| + \cdots + \Delta x_n^0 + \frac{\partial F_n}{dx_n} \right| \tag{5.17}$$

And $\frac{\partial F}{\partial x}$ and $\frac{\partial F}{\partial x}$ are calculated at x^0 and y^0, Equation (5.18)

$$-F\,(x^0, y^0) = \Delta F = \frac{\partial F}{\partial x}\,.\,\Delta x + \frac{\partial F}{\partial y}\,.\,\Delta y \tag{5.18}$$

It can be rewritten in matrix form Equation (5.19)

$$[\,\Delta F] = \left[\frac{\partial f}{\partial x}\frac{\partial F}{\partial y}\right] . \begin{bmatrix}\Delta x \\ \Delta y\end{bmatrix} \tag{5.19}$$

Next In the first iteration, x and y are updated to $x1 = x0 + \Delta\, x \; and \; y1 = y0 + \Delta\, y$, respectively. The stage is continued until both ΔF are smaller than a tolerance value after a certain number of iterations. The values of x and y following the previous iteration's last updates are regarded as function F's result (Kempner 2008).

The non-linear equations are explian by Equation (5.14). Equation (5.18) can then be replaced as Equation (5.20)

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix} \cdot \begin{bmatrix} \Delta \delta \\ \partial |V| \end{bmatrix} \tag{5.20}$$

or Equation (5.21)

$$\begin{bmatrix} \Delta \delta \\ \partial |V| \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix} \cdot \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{5.21}$$

The Jacobian matrix, typically abbreviated J, is the matrix of Equation (5.20) using partial differentials.

ΔP is the variance between the computed amount of P using the estimations of and |V| from a past iteration and the known value of P (Psp). We arrive at ΔQ in a similar way (Kempner 2008).

Newton's method using power flow is generally a powerful load flow algorithm used in practice. Recalculating the Jacobian matrix's terms is necessary for each iteration, and then the whole group of linear Equations (5.20) must also be resolute for each iteration. Other ways to speed up this process were inventive

- Active power P was little affected by variations in voltage magnitude$V$. This effect is combined in the algorithm, so all the derivatives as to be zero.
- All the derivatives are also taken to be zero since Q was comparatively insensitive to variations.
- Since $(\delta i - \delta k)$ between two adjacent buses $i \, and \, j$ is typically little, $cos\ (\delta i - \delta k)$ is viewed as same as well.
- Approximations like Gik sin (δi–δk) << Bik are also considered, since for medium length to long transmission lines Xik >>Rik, leading to Equation (5.22), Equation (5.23): (Saadat 2011):

$$\Delta\, P_i = -|V_i|.|V_k|.B_{ik}.\Delta\delta_k \tag{5.22}$$

$$\Delta\, Q_i = -|V_i|.|V_k|.B_{ik}.\frac{\Delta|V_k|}{|V_k|} \tag{5.23}$$

Additional simplification can be achieved by

- Dividing Equation (5.22) by $|Vi|$
- Assuming $|Vj|$=1.0 pu

So Equation (5.22) and Equation (5.23) can be rewritten as Equation (5.24) and Equation (5.25):

$$\frac{\Delta P_i}{|V_i|} = -B_{ik}.\Delta\delta_k \tag{5.24}$$

$$\frac{\Delta Q_i}{|V_i|} = -B_{ik}.\Delta|V_i| \tag{5.25}$$

Equation (5.25) can be divided into two sets of linear equations by all these simplistic and $P - V\ and\ Q$-separate as follows Equation (5.26):

$$\begin{bmatrix} \frac{\Delta P_i}{|V_i|} \\ \frac{\Delta P_k}{|V_k|} \\ \vdots \end{bmatrix} = \begin{bmatrix} -B_{ii} & -B_{ik} & \dots \\ -B_{ki} & -B_{kk} & \dots \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} \Delta\delta_i \\ \Delta\delta_k \\ \vdots \end{bmatrix} \tag{5.26}$$

and Equation (5.27)

$$\begin{bmatrix} \frac{\Delta Q_i}{|V_i|} \\ \frac{\Delta Q_k}{|V_k|} \\ \vdots \end{bmatrix} = \begin{bmatrix} B_{ii} & B_{ik} & \dots \\ B_{ki} & B_{kk} & \dots \\ \vdots & \vdots & \vdots \end{bmatrix} \begin{bmatrix} \Delta|V_i| \\ .\Delta|V_k| \\ \vdots \end{bmatrix} \tag{5.27}$$

More simplifications can be performed in the Jacobian matrix of Equation (5.26) for the ΔP–$\Delta\delta$:

- Rik Can be neglected while calculatingBik.
- All shunt reactance to the ground can be neglected, Equation (5.28):

$$-B_{ik} = -\frac{1}{X_{ik}} \; and \; -B_{ii} = \sum_{k}^{n} \frac{1}{X_{ik}} \quad (3.28)$$

5.5 FACT'S System

5.5.1 SVC static var compensator

The Static Var Compensator (SVC) is a system of the Flexible AC Transmission Systems (FACTS) group to control power flow on power grids using power electronics. The SVC regulates the voltage at its terminal through regulating the quantity of reactive power inserted into or taken in from the power system (McDonald 2016).

One of the problems facing the operation of pumping stations is low voltage in the substations of the national network resulting from the failure of the voltage regulator of the power transformer as the chart (Eremia and Shahidehpour 2013) or from a source of generation, resulting from there is a gap between load and generation approximately equal to 35 % which negatively affects the voltage levels, exactly in peak load time and decrease the value of voltage operation to less than 6000v, while the limits areas of operation of the excitation control system in pump station within ±5% from rated voltage.

which is opposite to ± 330v mean failure operation of pumps many times, this study includes some solutions to improve level voltage and operate with optimal reactive power flow according to the network conditions. First, from this solution we are using a capacitor bank, adding a capacitor to reduce reactive power losses by injecting capacitor current with lead power factor reverse reactive current which leads to reduced total losses in our network (Afolabi *et al.* 2015). Capacitors have below Equation (5.29):

$$I_c = \frac{V_c}{X_c}; X_c = \frac{1}{2\pi f c} Q_C = I_C * V_C \, Q_t = Q_c - Q_l \tag{5.29}$$

The SVC acts like a parallel -linked flexible reactance, that as generates or takes in reactive power to control the value of voltage at the level of joining the power network. It is frequently used to allow voltage modulation and enable rapid reactive power. The SVC may respond practically instantly speed of response. to the thyristor's firing angle control. Figure 5.3 provides a diagrammatic illustration of the SVC's design. It shows an SVC as a parallel-linked tools made up of several units with a uniform capacitance working together with both a thyristor-controlled reactor.

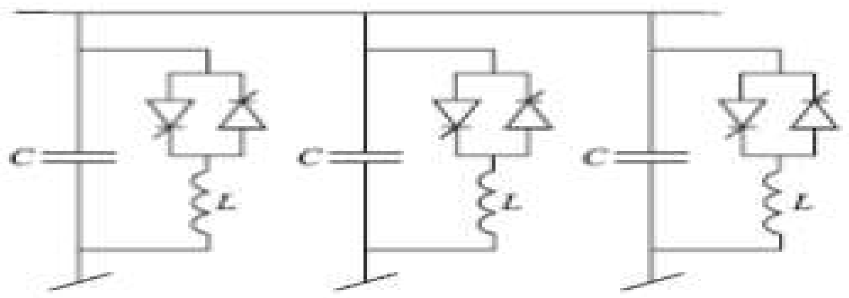

Figure 5.3 Structure of an SVC

5.5.2 Control and limits of the SVC the steady state control law for the SVC

Usually current-voltage characteristic of the V-I characteristic is a description by the three equations:

$V = Vref + XsI = SVC$ is in regulation range ($-Bc\ max<B<B\ l\ max$)

$V = \frac{I}{Bcmax}$ SVC is fully capacitive ($B = B\ c\ max$)

$V = \frac{I}{Blmax}$ SVC is fully inductive ($B = B\ l\ max$)

where:

- V: A positive voltage sequence (pu)
- Vref: Reference voltage (pu)
- I: Reactive current (pu/pbase) (I> 0 indicates an inductive current)
- Xs: Droop or slop reactance (pu/pbase).
- Bc max: Maximum capacitive susceptibility (pu/pbase) with no TSR or TCR active and all TCSs in service.
- Bl max: Maximum inductive susceptance

Usual values for the slope Xs are in the range of 0.02 to 0.05 p.u. with regard to the SVC base. The slope is necessary to prevent hitting limits for little changes in the node voltage. At the voltage limitations, the SVC is transformed into a fixed reactance. The controlled voltage range usually has a value of 10 % (Bekri and Fellah 2008) (Figure 5.4).

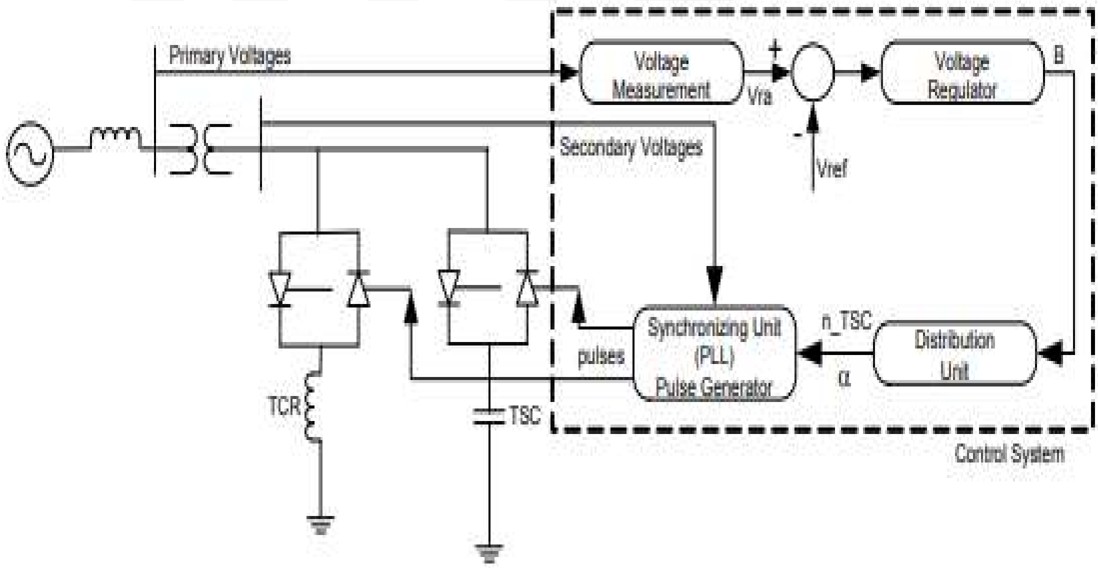

Figure 5.4 Single line diagram of an SVC and its control system block diagram

5.6 Unified Power Flow Controller (UPFC)

The unified power flow controller (UPFC) understands real-time control over power flow in transmission lines by regulating the line parameters, counting node voltages, phase angle, and line impedance, which cover all adaptable parameters of other FACTS (Short 2003).

The UPFC is a device that can control simultaneously all three elements of line power flow (line impedance, voltage, and phase angle). $P = \frac{V_i.V_k \sin\delta}{(X)}$ $and\ Q = \frac{V_i.(V_i - V_k \cos\delta)}{(X)}$ (McDonald 2016). UPFC devices by equations of power can increase the operational limit of the transmission network extremely. Especially when δ=90°. The transmission system has achieved its maximum stable operating position, and also increases the level of voltage (Bekri and Fellah 2008).

6. SHORT CIRCUIT CURRENT CALCULATION

6.1 The Behaver of Faults

A fault in an electric network is an unnatural case involving electrical failures of the electrical network, effective at one of the primary voltages. There are two general kinds of failure that usually happen.

Types of Faults

The main kinds of short-circuits that can happen in the electrical system have the following primary characteristics are:

- Duration (self-extinguishing, transient and steady-state).
- Origin
  - Mechanical (conductor break, unintentional electrical contact between two conductors via a foreign conducting body (tool or an animal) .
  - Overvoltage (Internal/atmospheric).
  - deterioration of insulation brought on by heat, humidity, or a corrosive environment.
- Position (inside or outside a machine or an electrical switchboard) Short-circuits can be:
  - Phase-to-earth (80% of faults)
  - Phase-to-phase (15% of faults). This type of fault often degenerates into a three phase fault.
  - Three-phase (only 5% of initial faults) These different short-circuit currents (Kersting 2018).

6.2 Main Causes of Faults

The faults with open circuits can be produced by failures of links on cables, transmission lines, or the failure of equipment or network with the case open close, such as would be if two poles may correctly open but the third pole might stay fixed in the closed position. The majority of short-circuit faults are climate-related followed by tool failure, except on mainly underground systems (Das 2005).

The weather factors causing thunderstorms, snow or ice buildup, torrential rain, severe winds, or gale force winds are examples of short-circuit faults., salt pollutants accumulating at distribution systems, on insulators in overhead lines, around electrical equipment in flooding, and in burning. Vandalism could sometimes be a cause of short-circuit faults. Another cause might be contacted with breaking of minimum gaps between overhead lines and trees due to current overload.

Lightning attacks discharge currents of a few kilo amps up to 100 or 200 kA in several microseconds, so if hitting an overhead line or its neutral wire, the voltage generation through the insulator could be so larger a flashover and fault current might happen, involving one or all three phases of a three-phase electrical circuit resulting in currents flow in short-circuits at rapid power frequencies. (Short 2003).

A 132 kV overhead three-phase transmission line of steel tower structure and one ground wire, also the tower, line phase conductors, and ground wire's respective surge impedances are 220, 350, and 400, and the tower's grounding or earth resistance is 50 Ω would represent one case. When lightning strikes one of the phase conductors close to a tower and the shielding of the earth wire fails, then the voltage generated across the line's insulator would be equal to 10 kA×175 Ω=1750 kV.

In this situation, a lightning current of 3.8 kA would be enough to start a short-circuit defect and a back-flashover. Even "indirect" lightning strikes on lower voltage distribution lines might result in an insulator flashover and a short circuit fault.

Fires are another common cause since their smoke below the upper lines consists of small particles which promote the collapse of the exposed air to the powerful power line's high-voltage electric field. Compared to air at ambient temperature, heated air is less effective as an insulator, so in this case, a flashover through an insulator to earth or from a phase conductor to a tree is likely to happen (Short 2003).

Tools failure is another common cause for many short-circuit faults, for example, failure of interior insulation due to aging and disintegration, breakdown due to high switching or lightning overvoltage, mechanical occurrences, or unsuitable installation. Age-related degradation of a cable's polymer insulator or technical force-induced void formation in the insulator It is used by mistake to represent the cable another common scenario (Tleis 2007).

Human errors can also cause circuit faults, starting from a classical scenario where a group of maintenance left unintentionally isolated equipment connected through safety earth clamps when maintenance work is completed to a three-phase to earth short-circuit fault occurring when the equipment is energized to return it to service.

On essentially transmission line systems, 80–90% of short circuit faults incline to happen on transmission lines and the break on substation equipment and buses combined. On a high voltage substatıon system with transmission line steel tower structure, such as the England and Wales transmission system, the long-term average short-circuits fault statistics show that around 300 short-circuit faults happen per annul of that which 67% are one-phase to earth, 25% are phase on phase, 5% are 3ph to earth and three-phase clear of the earth, and 3% are two-phase to earth. Thunderstorms account for around 77% of one-phase-to-earth faults, following by winds and gale force winds and salty contamination of insulating. These faults are usually occurred because of snow/ice followed by wind/gales, resulting in the clash of two line conductors. Lightning, wind, and gales are the main contributors to three-phase-to-earth faults and two-phase-to-earth faults in England and Wales. Between 50% and 67% of short-circuit, failures on wood-pole overhead wires are two-phase and three-phase faults (Short 2003).

6.3 Short-Circuit Current

Voltages generated in the electrical network are of the sine-wave form, so the current from the lines is of sine-wave form, or “AC current”. AC currents could be “Symmetrical” or “Asymmetrical”. When a short circuit happens, a new circuit is recognized with lower impedance and the current and thus growths. In the situation of an installed short circuit, the impedance is drastically reduced and the current rises to an extreme value in a fraction of a cycle. Figure 4.1 depicts a wave of short-circuit current that is symmetrical, that is, one whose axis is the same as the normal current that was flowing prior to the fault. happened. To yield a symmetrical short-circuit current (In normal circumstances the short-circuit power factor is basically zero) The fault has to happen while the usual voltage is at its highest. In Figure 6.1 the system voltage is supposed to stay constant, although the current changes (Kempner 2008).

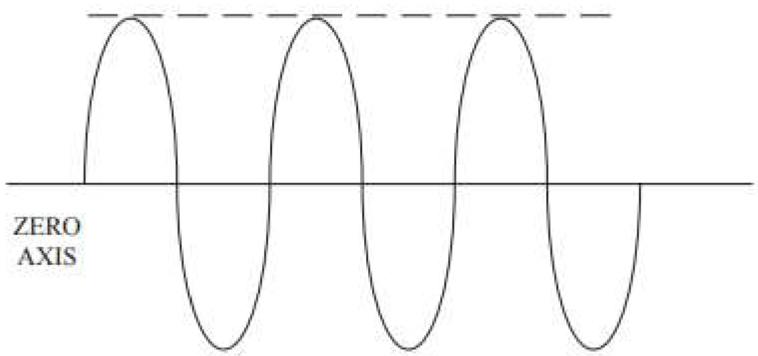

Figure 6.1 Symmetrical AC current

As seen in above Figure 6.2, the AC current wave with the same amplitude below and above zero. A "symmetrical current" is one in which the waveform is symmetrical about the zero-axis, whereas a "asymmetrical current" is one in which the waveform is not. (Kersting 2018).

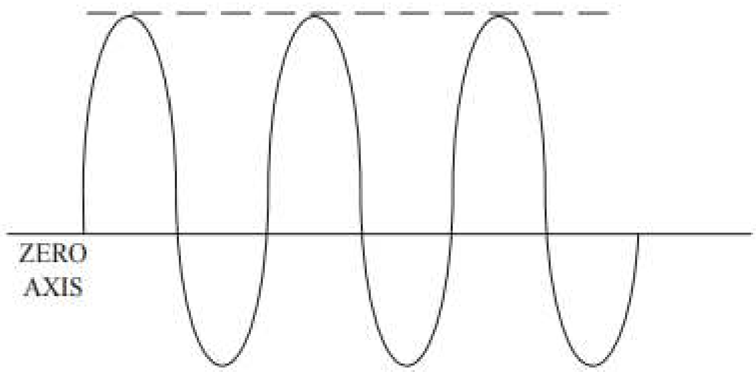

Figure 6.2 Asymmetrical AC current

A wave of the current has a difference of magnitude above and below the zero-axis (Figure 6.3)

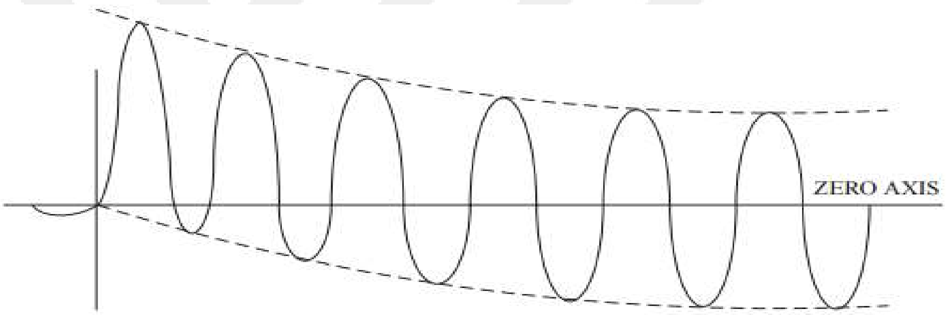

Figure 6.3 Short-circuit current

Fault currents are a mix of symmetrical and asymmetrical currents, being asymmetrical through the first few periods afterward fault current happens and progressively becoming symmetrical after a few periods. The alternation of a usual fault current with a maximum peak occurring through the first period of the fault current when the current is asymmetrical, the extreme value of the peak slowly decreases to a constant value as the current symmetry develops. AC and DC components are thought to exist in asymmetrical currents. Due to the DC component's short lifespan and quick disappearance, short-circuit currents have a decaying character. The DC component appears with the AC system, depending upon the resistances and the reactance of the circuit. The rate of decay is identified as “Decrement”. Due to the fact that the Since short-circuit currents were either symmetrical nor asymmetrical, the RMS possible fault current is treated as being the same after the DC component is zero. (Kersting 2018).

6.4 The Method of Equivalent Voltage Source

Assuming the outline of the voltage source at the fault current place, the voltage source would be the system's sole active voltage. All synchronous or asynchronous machine-based network feeding are domestic replacement impedance.

Additionally probable to determine the fault current at the faulty location F by using a voltage apply. Operating information and the load of clients, regulator location of transformers, expanded of power plant are unnecessary while extra determine with whole the several conceivable load flows at the instant of short circuit are unnecessary (Eremia and Shahidehpour 2013). Figure 6.4 shows the equivalent voltage source at the fault current position F as being a transformer's sole active voltage, whether it has an on-load tap changer or not. The system's other active voltages are all presumed to be at zero. If a A system feeds a three-phase short circuit, and the system's equivalent impedance is Z S. (positive-sequence short-circuit impedance),Equation (6.1)

$$Z_S = \frac{cU_{nS}}{\sqrt{3I"_{kS}}} \tag{6.1}$$

If the short circuit is fed by a transformer the equivalent impedance $Z_{ST}$of the network is Equation (6.2)

$$Z_{ST} = \frac{cU_{nS}}{\sqrt{3I"_{kS}}}.\frac{1}{N_r^2} \tag{6.2}$$

c is the voltage factor for medium voltage (1-35) kV and high voltage greater than 35 kV equal 1.1 (Eremia and Shahidehpour 2013).

nS is the feeder connecting point's nominal system voltages S (Figure 6.4).

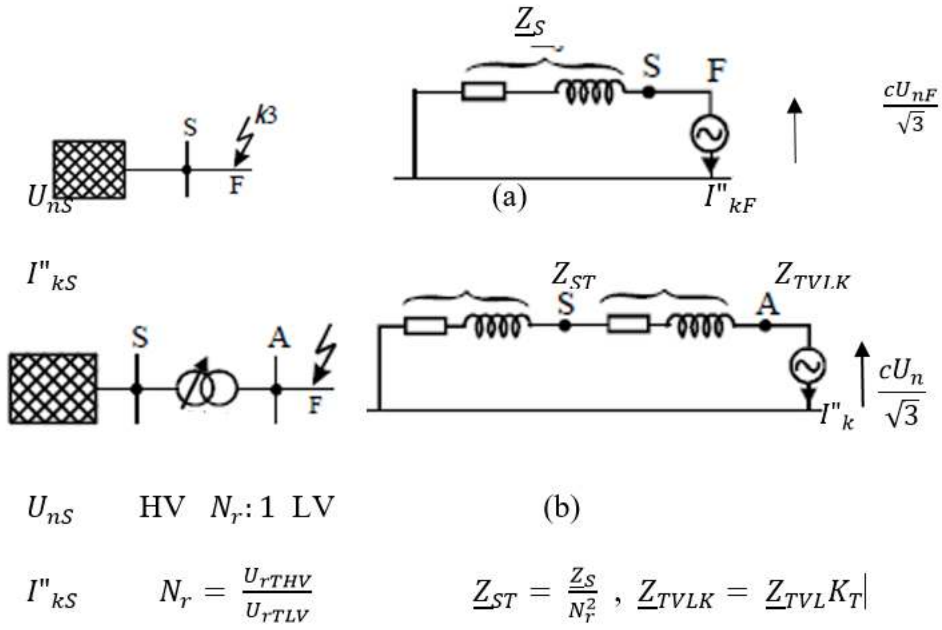

Figure 6.4 System diagram and equivalent circuit diagram for network feeders: (a) without transformer; (b) with transformer

6.5 Parameters of Three-Phase Short Circuit

The impedances calculate from the fault location to a load, specify as impedance (Figure 6.5). In a real network $Z_k$is made of the impedances of all elements upstream of the short circuit, such as generators, transformers, transmission lines, circuit breakers, and metering systems (Tongsrichantra *et al.* 2009).

If a linking with negligible impedance happens from point A to point B of a circuit, it results in a short circuit current $I_k^{"}$ restricted just by the impedanceZ_k. $I_k^{"}$. Develops in passing conditions according to the relative between the reactance X and the total resistance R which gives Z. If the circuit is resistive, the waveform of the current is following the waveform of the voltage. However, if there are inductances in the system then the waveform of the current will be different from the waveform of the voltage during a transient time of the process. In an inductive circuit, the current starts with zero, and the effect of Inductances is defined by reactance X in AC circuits with a constant voltage frequency. Low voltage circuits can be considered of as primarily resistive because cables and conductors make up the majority of the Impedance. Networks for distributing power the Reactance is much larger than the resistance. The total Z_k Is calculated using the following relation: $Z_k = \sqrt{R_k^2 + X_k^2}$, where R_k represents total resistance measured in ohms and X_k represents the total Reactance measured in ohms (Tleis 2007).

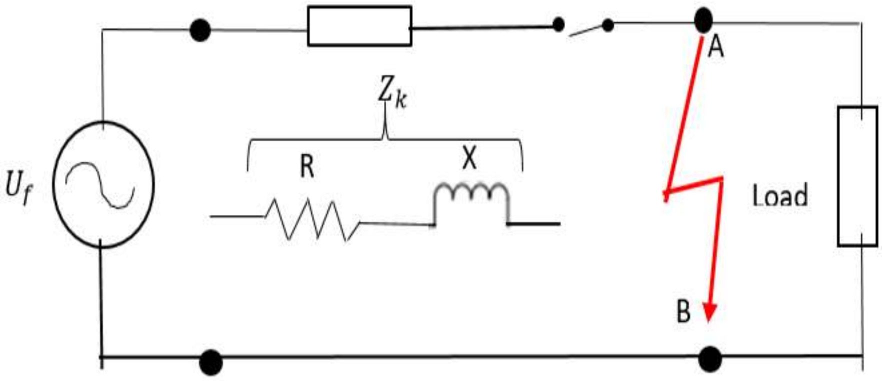

Figure 6.5 Simplified network diagram

6.6 Calculation of Short-Circuit Current Components

In the short-circuit currents calculation in a node, if the thermal and mechanical stresses and the power quality are involved, the maximum and minimum values should be calculated.

6.6.1 Initial symmetrical short-circuit current $I_k^{''}$

In the case in which Z^o> Z^+=Z^-, the highest starting fault current happens for them, symmetrical fault whereas in the fault circuits nearby transformers with low zero-sequence impedance, Z_o maybe lesser than Z^+, so the highest start fault current $I_{kE2E}^{''}$ happen for a phase-to-phase short circuit with ground linking (Figure 6.4) for$Z^-/Z^+ = 1$ and Z^-/Z^o>1, where Z^-=Z^+ (McDonald 2016).

6.6.1.1 Three-phase short circuit

A start symmetrical fault current $I_k^{"}$ must be determined by the equivalent voltage source (cUn/$\sqrt{3}$) at the fault position and the short-circuit impedance ($Z_k = \sqrt{R_k^2 + X_k^2}$). Impedance Z_k is calculated using $Z_k = \sqrt{R_k^2 + X_k^2}$, $where\ R_k$ Represents the total resistance in ohms and X_k represents the total reactance in ohms, Equation (6.3), Equation (6.4)

$$R_k = R_{St} + T_{TK} + R_L \tag{6.3}$$

$$X_k = X_{St} + X_{TK} + X_L \tag{6.4}$$

- R_k and X_k - the sumation of impedance
- R_L-The line resistance for a conductor temperature of 20°C (Eremia and Shahidehpour 2013), Equation (6.5).

$$I"_k = \frac{cU_n}{\sqrt{3Z_k}} = \frac{1}{\sqrt{3}} \cdot \frac{cU_n}{\sqrt{R_k^2 + X_k^2}} \tag{6.5}$$

- Z_{TK}=K_T(R_T+X_T) represents the corrected transformer impedance;
- K_T represents the impedance correction factor=0.95* $\frac{C_{max}}{1+0.6+x_T}$
- x_T=$\frac{X_T}{U_{rT}^2/S_{rT}}$, R_k less than 0:3 _ $X_k$is neglectable
- $Z_{sk} = R_{st} + jX_{st}$ reffers to the voltage of the transformer side which is then connected to the short-circuit location (F) (Kim and Harley 2016).
- The start symmetrical the following formula is used to compute fault current using the adjusted generator and power plant unit impedances in series with a line impedance
  :$Z_L = R_L + jX_L$

- The impedances of a generator (G), system transformer (T), and power station units (S) must be multiplied with K_G , K_T , and K_S , respectively, $K_{s∘}$ when calculating fault currents with the equivalent voltage source at the short-circuit position depending on Standard IEC 60909-4. The short-circuit impedances for these examples are given by below relationship Equation (6.6), Equation (6.7), Equation (6.8), Equation (6.9), Equation (6.10) and Equation (6.11): (De Metz-Noblat *et al.* 2005):

$$Z_k = Z_{GK} + Z_L = K_G (R_G + JX_d^{"}) + Z_L \qquad (6.6)$$

$$Z_k = Z_S + Z_L = K_S (N_r^2 * Z_G + Z_{THV}) + Z_L \qquad (6.7)$$

$$Z_{Gk} = K_G * Z_G = K_G (R_G + JX_d^{"}) \qquad (6.8)$$

$$K_G = \frac{U_n}{U_{rG}} \cdot \frac{c_{max}}{1 + X"_d \sin \varphi_{rG}} \qquad (6.9)$$

$$K_S = \frac{U_{nG}^2}{U_{rG}^2} \cdot \frac{U_{rTLV}^2}{U_{rTHV}^2} \frac{c_{max}}{1 + |X"_d - X_t| \sin \varphi_{rG}} \qquad (6.10)$$

$$K_{S0} = \frac{U_{nS}}{U_{rG}(1 + p_G)} \cdot \frac{U_{rTLV}}{U_{rTHV}} \cdot (1 \pm p_T) \frac{c_{max}}{1 + X"_d \sin \varphi_{rG}} \qquad (6.11)$$

PG is the range of generator voltage regulation and PT is the range of transformer voltage adjustment;

c_{max} is the factor voltage for determining maximum fault currents

$Z_{THV} = R_{THV} + jX_{THV}$ depending to below the equations, K_T is referred to the high-voltage side as follows Equation (6.12), Equation (6.13), and Equation (6.14)

$$Z_T = \frac{u_{kr}}{100\%} \cdot \frac{U_{rT}^2}{S_{rT}} \qquad (6.12)$$

$$R_T = \frac{u_{Rr}}{100\%} \cdot \frac{U_{rT}^2}{S_{rT}} \tag{6.13}$$

$$X_T = \sqrt{Z_T^2 - R_T^2} \tag{6.14}$$

where

- u_{Kr} - percentage of short-circuit voltage at rated current;
- u_{Kr} - percentage rating for the short-circuit voltage's resistive component;
- U_{rT} -either the high-voltage or low-voltage side of the transformer's rated voltage;
- S_{rT} - Transformer's rated apparent power.

6.6.1.2 Short circuits in meshed networks in meshed networks

A short-circuit impedance $Z_k = Z^+$ is usually determined by circuit decrease (series connection, parallel connection, and delta-star transformation) utilizing the electrical system's positive-sequence fault impedances element. The impedances in the network connected over transformers to the system should be converted by the square of the nominal transformation ratio and the arithmetic mean value can be used if there are transformers with different rated transformation ratios ($NrT1, NrT2, NrTn$), with two systems. The start symmetrical fault current must then be recalculated with the equivalent voltage source (cUn/$\sqrt{3}$) at the fault position using the subsequent relationship, Equation (6.15):

$$I"_k = \frac{1}{\sqrt{3}} \cdot \frac{cU_n}{\sqrt{R_k^2 + X_k^2}} \tag{6.15}$$

6.6.2 Peak short-circuit current i_P

The influence on the peak fault current from each branch (the fault in no meshed networks for symmetrical fault current fed from no meshed networks) can be expressed by Equation (6.16) (De Metz-Noblat 2005)

$$i_p = k\sqrt{2}\ .\ I"_k \tag{6.16}$$

The factor k for the $R/_X$ or $X/_R$ a ratio can be netted as follows Equation (6.17) (Figure 6.6):

$$k = 1.02 + 0.98e^{-R/X} \tag{6.17}$$

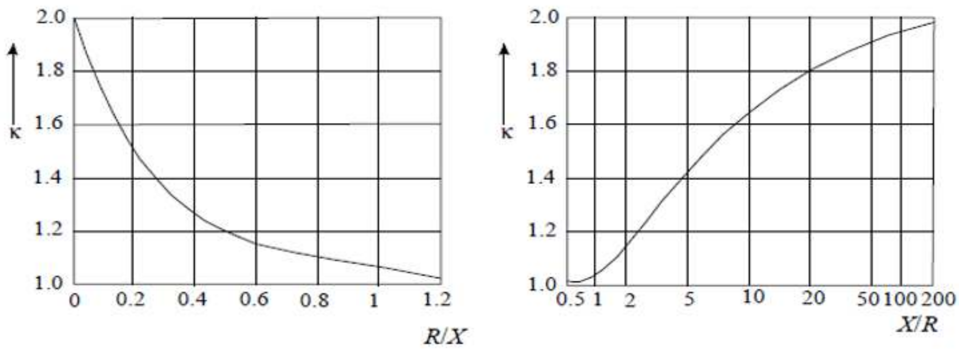

Figure 6.6 Factor k for series circuit as a function of ratio R/X

In the case of short circuits in meshed networks, the peak short-circuit current i_p can be calculated with k, determined using one of the following methods:

a) Uniform ratio $R/_X$ or $X/_R$ -k is determined by taking the smallest ratio of $R/_X$ or the largest ratio of $X/_R$ of all branches of the network, having values between 1.6 and 1.9 in high-voltage networks and 1.3 and 1.5 in low-voltage networks. It is important to select the branches carrying partial fault currents at the rated voltage identical to the fault current position and branches with transformers neighboring the fault place. Every part may be a series combination of several impedances (Eremia and Shahidehpour 2013).

b) Ratio R/X or X/R at the fault current position-k is multiplied by a factor of 1.15 to cover inaccuracy that occurs By the ratio R/X from a network reduction with complex impedances: $i_{p(b)} = 1.15\, k_b\sqrt{2I''_k}$. As long as R/X Remains smaller than 0.3 in all branches, the factor 1.15 is not needed. 1.15 k_b does not need to override 1.8 in low-voltage networks or to override 2.0 in medium- and high-voltage networks. The factor k_b is get from Figure 4.6 for the ratio R_k/X_k given the fault impedance Z_k=$R_k + jX_k$ at the fault current position F, calculated for frequency $f = 50HZ\ OR\ 60HZ$.

c) Equivalent frequency f_c-assuming a frequency f_c=20 Hz (for a nominal frequency of f =50 Hz)

d) Or f_c=24 Hz (for a nominal frequency of f=60 Hz), the equivalent impedance Z_C of the system as seen from the short-circuit. The R/X or X/R the ratio is then determined according to $\frac{R}{X} = \frac{R_C}{X_C}.\frac{f_C}{f}$ and $\frac{X}{R} = \frac{X_C}{R_C}.\frac{f_C}{f}$, where Z_C=$R_C + jX_C$ represents the equivalent impedance of the network as seen from the fault current position for the assumed frequency f_c; R_c is generally not equal to R at nominal frequency, X_c is usually not equal to X at rated frequency and k is found by using the R/X or X/R the ratio from the above equations (McDonald 2016).

6.6.3 DC component of the short-circuit current

The maximum decaying aperiodic component $i_{d.c}$ of the fault current can be calculated using the following Equation (6.18):

$$i_{d.c.} = \sqrt{2}\, I_k^{"} e^{-2\pi f t\, R/X} \qquad (6.18)$$

where $I_k^{"}$ -the initial symmetrical fault current; f is the nominal frequency; t is the time and $R/_X$ represents the ratio according to the methods above from (a) and (c) (Kersting 2018).

T_{dc}=$\frac{X/_R}{2\pi f}$, Both IEC and IEEE specify a standard DC time constant *T*dc=45 ms

Additionally, IEC offers special case time constants relating to the circuit breaker's rated voltage. These recognize the potential for encountering higher time constants at a position near to power plan (Short 2003).

6.6.4 Symmetrical short-circuit breaking current I_b

The breaking current at the fault place consists in general, of the three-phase current I_b and an aperiodic current $i_{d.c}$ at the time $tmin$. for some not far from the generator fault current, the amount of $id.c.$ At $tmin$ may override the peak value of I_b, leading to missing current zeros (Eremia and Shahidehpour 2013).

6.6.4.1 Far-from-generator short circuit

The flux throughout the air gap in a synchronous machine is just not identical at the instantaneous the fault happens as it is a few periods later. The collective defended the flux change. Action on the rotor's field, armature, and damper windings or iron components. After a fault happens, the sub-transient, transient, and steady-state, periods are characterized by the sub-transient reactance $x_d^{"}$ the transient reactancex_d', and the steady-state reactance x_d, respectively. This reactance has increasing values that are ($x_d^{"}$<x_d'< x_d) and the accompanying short-circuit current components have dwindling magnitudes ($I^{"}$>I'>I).

The starting symmetrical rms current is equal to the rms value of the Ac section with the DC component deleted. of the fault current immediately after the fault occurs. In the case of far-from-generator short circuits, the fault breaking currents are equal to the start fault currents, Equation (6.19):

$$I_b = I"_k;\ I_{b2} = I"_{k2};\ I_{b2E} = I"_{k2E};\ I_{b1} = I"_{k1} \quad (6.19)$$

6.6.4.2 Near-to-fenerator short circuit

For location beside the to-generator fault, in the case of a single fed short circuit or from no meshed network, according to the relation $I_b = \mu I"_k$, the decay to the symmetrical breaking current is in view of an account by the factor m which be determined by the minimum time delay $tmin$ and the ratio $I"_{KG}/I_{rG}$, where I_{rG} is the rated generator current. (McDonald 2016). The values of μ apply if the synchronous machines are activated by rotating exciters or by static converter exciters, if the minimum $time$ delay $tmin$ is less than 0.25 s and the maximum excitation voltage is less than 1.6 times rated load excitation voltage, otherwise, μ=1, if the accurate value is indefinite. When the unit transformer is connected to the generator and the fault position, the partial short-circuit current $\boldsymbol{I"_k}$ at the high-voltage aspect of the unit, a transformer can be transferred by using the nominal transformation ratio to the terminal of the generator $I"_{kG} = N_r I"_{kS}$ before calculating μ using the following relations, Equation (6.20), Equation (6.21), Equation (6.22) and Equation (6.23):

$$\mu = 0.84 + 0.26\, e^{-0.26\frac{I"_{kG}}{I_{rg}}}\ for\ t_{min} = 0.02\ s \quad (6.20)$$

$$\mu = 0.71 + 0.51\, e^{-0.30\frac{I"_{kG}}{I_{rg}}}\ for\ t_{min} = 0.05\ s \quad (6.21)$$

$$\mu = 0.62 + 0.72\, e^{-0.32\frac{I"_{kG}}{I_{rg}}}\ for\ t_{min} = 0.10\ s \quad (6.22)$$

$$\mu = 0.56 + 0.94\, e^{-0.38\frac{I"_{kG}}{I_{rg}}}\ for\ t_{min} \geq 0.25\ s \quad (6.23)$$

In the case in which I''_{KG}/I_{rG} ≤2, μ=1 applies for the whole amount of the minimum time delay $t_{min.}$ (McDonald 2016).

6.6.5 Steady-state three-phase short circuit

The accuracy of calculating the steady-state short-circuit current I_k is not as good as when calculating the initial fault currentI''_K. In the case of beside-to-generator three-phase fault current taken solely through one power plant unit or one synchronous generator, the steady-state short-circuit current $\boldsymbol{I_k}$ instant on the excitation unit, the tap-changer action, and saturation effects. The time-delayed 30-cycle (steady state) fault current is used when the transient influence has completely decayed. In using this current, C37.010 recommends using the network that involves exclusively either the transient reactance of the generators or a higher reactance that accounts for the AC component deterioration. The Dc component is supposed to have degraded to zero (Short 2003). No contribution is made by synchronous machines (generators, motors, or compensators) with terminal-fed static exciters to $\boldsymbol{I_k}$ in the case of a fault at the machine's terminals, they do only if there is an impedance between the terminals and the point of the short circuit. Support is also set if the fault happens on the high-voltage side of the unit transformer (Eremia and Shahidehpour 2013). The synchronous generator can be set at the maximum excitation for the calculation of the maximum steady-state short-circuit current: I_{kmax}=λ_{max}*I_{rG} λ_{max} , based on the greatest achievable For circular rotor machines, the ignition voltage should be set at 1.3–1.6 times the rated excitation at rated apparent power and power quality, or 1.6–2.0 times the nominal excitation for salient pole powerplants.

7. POWER EQUALITY IN POWER SYSTEM

7.1 Definition of Power Quality

Power quality in electrical has become a very necessary part of the power plan. Power quality is usually intended to rapidly the quality of voltage and the quality of current also can be defined as the examination and an increase in bus voltage for keeping fundamental a sinusoidal waveform with nominal voltage and frequency. This description involves all temporary and constant states of phenomena. The concept of voltage and current harmonics entirely with the power plan. Figure 7.1 explains the effect of current harmonics generated with a nonlinear load upon a power plan having linear loads. Divide the distortion sources into three types: the first one is small and expected (residential consumers generating harmonics), the second one represents as (Voltage-producing arc furnaces) massive and random oscillations and flicker), and the last one as) (Massey 1994).

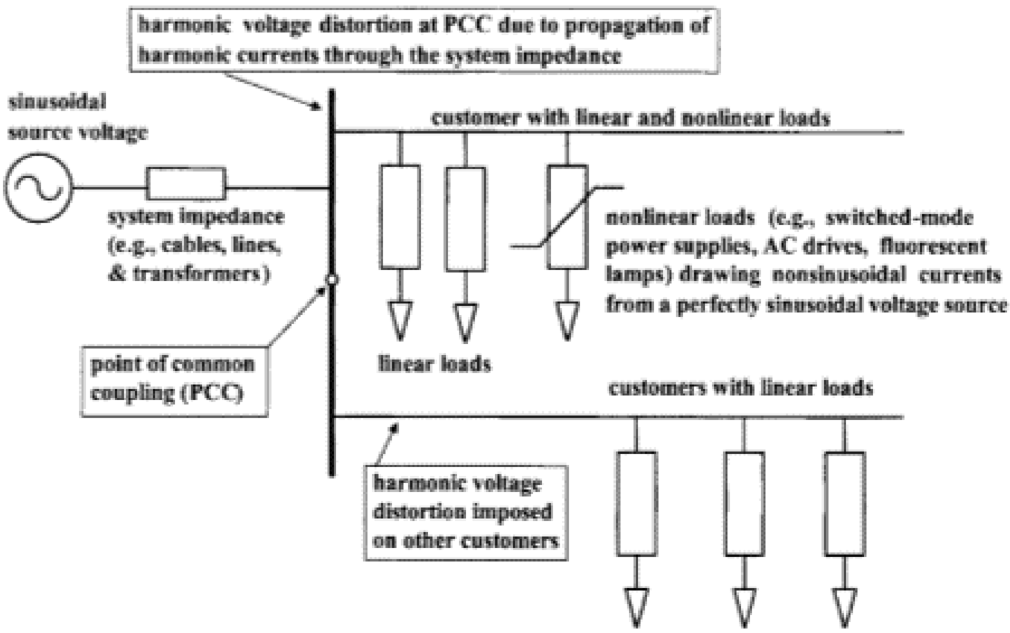

Figure 7.1 Propagation of harmonics (generated by a nonlinear load) in power systems

7.2 Harmonic Effect

As the harmonic currents generated by the operators’ apparatus flow back on the way to the power source, Due to the impedance of different power distribution equipment, such as transmission and distribution lines, they generate additional harmonic distortions, transformers, cables, and busbars (Fuchs and Masoum 2011). Inductive reactance is linearly relative to frequency, especially high-order harmonic currents that source severe voltage distortion levels with small current amplitudes. Harmonic is a method of explaining the distortion of voltage and current waveforms. The expression harmonics denotes a sinusoidal component of a periodic waveform that has an integer multiple of the fundamental frequency (Massey 1994). The harmonics issue is produced by non-linear loads such as DC or AC motor drives, inverters, DC converters, electric arc furnaces, and switch-mode power supplies. If a load's impedance changes when voltage was supplied, such load is known as being non-linear. Despite being supplied by a sinusoidal voltage, the load current waveform is not sinusoidal due to the fluctuating impedance. Further, the non-sinusoidal current that reacts with the impedance of the power system makes voltage distortion. The distorted voltage may impact each utility system equipment and also client loads. The presence of harmonics in the electrical system creates several significant impacts and symptoms. The major influence of The rise in machine and transformer temperature brought on by higher iron and copper losses is known as voltage and current harmonics. A greater number of harmonics sometimes can result in malfunctioning of the system which eventually results in downtime and increased operational rate. Other issues associated with harmonics include the malfunction of electronic devices, interference with variable speed drives, resonance, and light flashing that is visible to the human eye (Fuchs and Masoum 2011).

7.3 The Average Value of a Nonsinusoidal Waveform

The average value of a sinusoidal waveform is explained as Equation (7.1) and Equation (7.2)

$$I_{ave} = \frac{1}{T}\int_0^T i(t)\,dt \tag{7.1}$$

$$I_{ave} = \frac{1}{T}\int_0^T [i^1(t) + i^2(t) + i^3(t) + \cdots\cdots\cdots]dt\,. \tag{7.2}$$

Since all harmonics are sine waves, a nonsinusoidal function's average value is proportional to its direct current value: $I_{ave} = I_{DC}$ (Ishak *et al.* 2018)

7.4 The RMS Value of a Nonsinusoidal Waveform

A sinusoidal waveform's RMS value is determined.. as Equation (7.3):

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt\,.} = \sqrt{\frac{1}{2\pi}\int_0^T I^2{}_{max}\cos^2(wt)\,dt\,.} = \frac{I_{max}}{\sqrt{2}} \tag{7.3}$$

for the non-sinewave current of Equation (7.4) and Equation (7.5)

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt\,.} \tag{7.4}$$

$$= \{\frac{1}{T}\int_0^T [I^{(1)}{}_{max}\cos(\omega\tau + \beta_1) + I^{(2)}{}_{max}\cos(\omega\tau + 2\beta_2) + I^{(3)}{}_{max}\cos(\omega\tau + 3\beta_3)]^2.\,dt\,\}^{½} \tag{7.5}$$

The nonsinusoidal waveform has DC values of component of the vale, then Equation (7.6)

$$I_{rms} = [I_{DC} + \left(I^{(1)}{}_{rms}\right)^2 + \left(I^{(2)}{}_{rms}\right)^2 + \left(I^{(3)}{}_{rms}\right)^2 + \cdots\cdots \left(I^{(H)}{}_{rms}\right)^2\,]^{½} \tag{7.6}$$

7.5 Form Factor (FF)

The waveform's figure is measured by the form factor (FF), which is defined as (Equation (7.7)

$$FF=\frac{I_{rms}}{I_{ave}} \quad (7.7)$$

Since a sine wave's average value is zero, equation uses the sine wave's average across a half-cycle of form factor. The waveform's FF will rise as the harmonic content of the waveform rises.

7.6 Ripple Factor (RF)

The ripple of the waveform is measured by the ripple factor (RF), which is defined as Equation (7.8) (Eroğlu *et al.* 2021)

$$RF=\frac{I_{AC}}{I_{DC}} \quad (7.8)$$

where Equation (7.9)

$$IAC=\sqrt{(\mathrm{Irms})^2-(\mathrm{Idc})^2} \quad (7.9)$$

It is easy to show Equation (7.10) and Equation (7.11)

$$RF=\frac{\sqrt{(\mathrm{Irms})^2-(\mathrm{Idc})^2}}{I_{DC}}=\sqrt{\frac{(\mathrm{Irms})^2}{I_{DC}{}^2}-\frac{(\mathrm{Idc})^2}{I_{DC}{}^2}} \quad (7.10)$$

$$RF=\sqrt{FF^2-1} \quad (7.11)$$

7.7 Harmonic Factor (HF)

The harmonic factor (HF) of the nth harmonic, which is a determination of the add harmonic contribution, is defined as Equation (7.12)

$$HF_h = \frac{I^{(h)}{}_{rms}}{I^{(1)}{}_{rms}} \tag{7.12}$$

7.8 Total Harmonic Distortion (THD)

The wide word used to identify the harmonic content of a distorted signal's harmonic index and pollution waveform with a single number is the total harmonic distortion (THD). Is calculated of the effective value of a component of a distorted waveform's harmonic is described as the harmonics' rms given as a percentage. of the original waveform's frequency.

The fundamental current component Equation (7.13):

$$\text{THD}_i = \frac{\sqrt{\sum_{h=2}^{\infty} I^{(h)^2}}}{I^{(1)}} \tag{7.13}$$

The main advantages of total harmonic distortion (THD) are:

- It is frequently used for a rapid assessment of harmonic noise and degradation.
- It is simple to compute.

Disadvantages of total harmonic distortion THD are:

- It doesn't offer data on amplitude.
- The spectrum's fine-grained information is lost.

7.8.1 Passive harmonic filter

A passive filter is one of the most popular and efficient harmonics mitigation techniques (Massey 1994). To provide harmonic currents with a low-impedance shunt channel, passive filters are built (Fuchs and Masoum 2011). The earth receives the harmonic currents in this situation. By setting the passive elements to produce resonance at a single frequency or a range of frequencies, passive filters also have the ability to reduce the passage of harmonic currents between various system components. Typically, passive harmonic filters are made up of resistors, inductors, and capacitors. To create various topologies, an array of these components is organized in one or more shunt arms. Single-tuned, second-order, third-order, and C-type filters are some common topologies for passive filters (Massey 1994). Figure 7.2 depicts the schematic configuration of these filters.

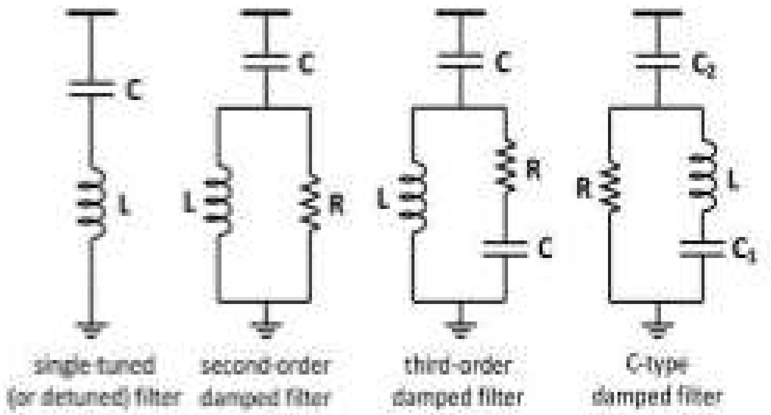

Figure 7.2 Types of passive filter

7.8.2 Calculation of filter

- Calculate the size of Qc (MVAr) needed to opposite the reactive power of the harmonic source
- Calculate the capacitor's reactance $X_c = \frac{kv^2}{Q_c}$
- Determine the value of inductive reactance by Equation (7.14) and Equation (7.15)

$$XL = \frac{X_c}{h_n^2} \quad (7.14)$$

$$XL = 2\pi fl \quad (7.15)$$

- Calculate the characteristic reactance X_n and the resistance of reactor R
- Find the size MVAr of the filter $Q_{filter} = \frac{kv^2}{X_c - XL}$ (Grainger and Spencer 1994)

8. CASE STUDY

In this part of the thesis, we will conduct a simulation of all the previously presented and compare all the results.

8.1 Cases of Substation Operation

Our network match information to the network IEEE test 2 with the updated number of generators, buses, transmission lines, and loads. It has 14 buses. Single-circuit transmission lines link to all the main high-voltage buses. The buses are taken to be the SLACK bus and the generator RO1 (2, 5, 7, 10, 13) PV buses are coupled to load buses as generations buses (1, 3, 4, 6, 8, 9, 11, 14)by transmission lines. The data from Table 8.1, Table 8.2, Table 8.3, and Table 8.4 has all details regarding the generators, transmission lines, transformers, and load. Figure 8.1 represents a single-line diagram of the network.

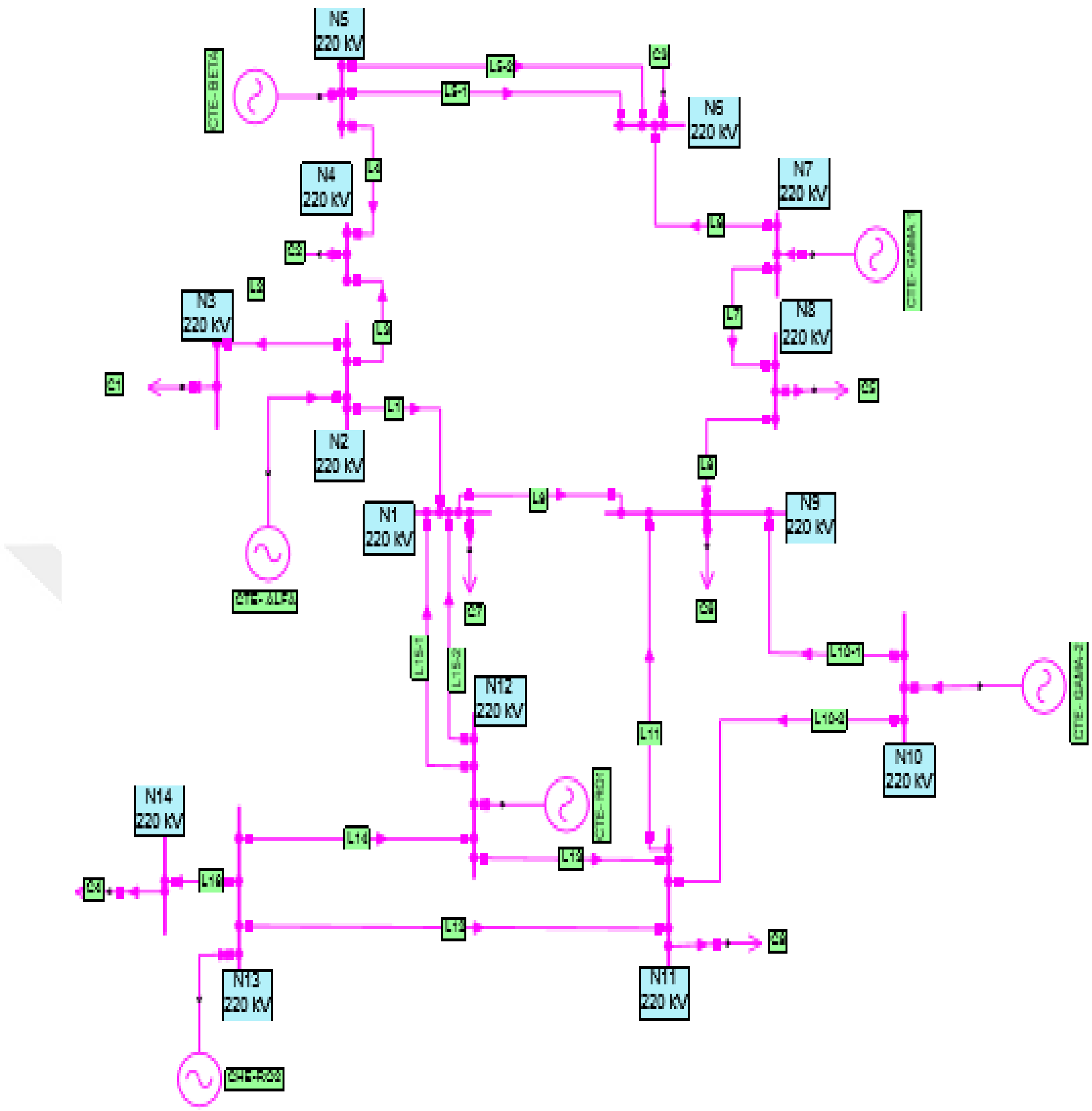

Figure 8.1 Single line diagram of the network

Table 8.1 Data of generators

Generator	S_{ng} [MVA]	P_{ng} [MW]	U_{ng} [kV]	Reactance (relative to S_{ng}) [%]						Time constant [S]		
				X_d	X_q	X'_d	X'_q	X''_d	X''_q	T'_d	T''_d	H
RO1	388	330	24.00	215	215	36.4	26.9	25	22	0.9	0.03	6.1
RO2	190	175	15.75	114	84	38.0	28.0	24	21	0.8	0.025	8.1
ALFA	235	210	15.75	185	185	27.0	27.0	21	21	0.7	0.021	5.8
BETA	235	200	15.75	192	192	27.0	27.0	21	21	0.7	0.021	6.7
GAMA1	125	100	10.50	206	206	31	31	21	21	0.7	0.021	7.9
GAMA2	125	100	10.50	206	206	31	31	21	21	0.7	0.021	7.9

Table 8.2 Data of buses

Node	Type	U_n [kV]	P_g [MW]	P_c [MW]	Q_c [MVAr]	U_{imp} [kV]	Q_{min} [MVAr]	Q_{max} [MVAr]
1	PQ	220	0	250	155	-	-	-
2	PU	220	255	0	0	230	0	190
3	PQ	220	0	130	70	-	-	-
4	PQ	220	0	190	130	-	-	-
5	PU	220	240	0	0	225	0	180
6	PQ	220	0	220	135	-	-	-
7	PU	220	240	0	0	225	0	180
8	PQ	220	0	130	70	-	-	-
9	PQ	220	0	200	135	-	-	-
10	PU	220	240	0	0	225	0	180
11	PQ	220	0	150	90	-	-	-
12	EC	220	-	0	0	235	0	300
13	PU	220	165	0	0	233	60	160
14	PQ	220	0	65	35	-	-	-

Table 8.3 Data of power transformers

STATION	S_n [MVA]	U_{nF} [kV]	U_m [kV]	u_{sc} [%]	ΔP_{sc}^{nom} [kW]	i_0 [%]	ΔP_0 [kW]	Regulation [%]
RO1	2x400	24	231	14.1	1150	0.45	280	±12x1.33
RO2	2x190	15.75	242	11.1	500	0.6	150	±12x1.25
ALFA	2x250	15.75	242	10.9	500	0.8	150	±12x1.40
BETA	2x250	15.75	242	14.0	947	1.2	282	±12x1.40
GAMA1	3x125	10.5	231	13.5	375	1.2	107	±13x1.25
GAMA2	3x125	10.5	231	13.5	375	1.2	107	±13x1.25
C1	2x100	121	231	10.5	275	0.8	65	±12x1.25
C2	2x200	121	231	10.5	485	0.8	105	±12x1.25
C3	2x200	121	231	10.5	485	0.8	105	±12x1.25
C4	2x100	121	231	10.5	275	0.8	65	±12x1.25
C5	2x100	121	231	10.5	275	0.8	65	±12x1.25
C6	2x200	121	231	15.5	708	0.7	147	±11x1.45
C7	2x200	121	231	15.5	708	0.7	147	±11x1.45
C8	2x200	121	231	15.5	708	0.7	147	±11x1.45

Table 8.4 Data of transmission lines

Line	Node	Node	R	X	B_o	I max (Amper)
	i	k	[Ω]	[Ω]	[µs]	
L1	1	2	9.9	60.6	416	875
L2	2	3	4.6	28.3	195	875
L3	2	4	7.4	45.2	311	875
L4	4	5	4	24.2	167	875
L5	5	6	3.3	20.9	544	1750
L6	6	7	6.65	37.9	243	805
L7	7	8	4	24.2	167	875
L8	8	9	5.3	32.3	222	875
L9	1	9	5.5	31.5	202	805
L10-1	9	10	5.3	32.3	222	875
L10-2	11	10	5.3	32.3	222	875
L11	9	11	7.9	48.5	333	875
L12	11	13	5.3	32.3	222	875
L13	11	12	3.6	22.2	153	875
L14	12	13	5.5	33.5	230	875
L15	1	12	4.9	31.4	812	1750
L16	13	14	4.6	28.3	195	875

8.2 Details of Electric Network

Our electric network test 2 variant, matches to information and nominal data of the Electric network test (Eremia and Shahidehpour 2013). With the modifying number of generators, buses, transmission lines, and loads, the test 2 variant have six power plant its power generation equals 2856 MVA, with a total load equal to 1570.66 MVA, as shown in Figure 8.2. The principal high voltage buses in our electricity network are connected to one another by single circuit transmission lines. Our electricity network has 28 buses, 14 busbars on the 220 kV side. The bus from the power plant RO1 is referred to as the SLACK bus, and the buses from the PV generation (2, 5, 7, 10, 13) are the generations buses connected to the load buses (1, 3, 4, 6, 8, 9, 11, 14) by transmission lines. 75MVA is the capacity of the pump station.

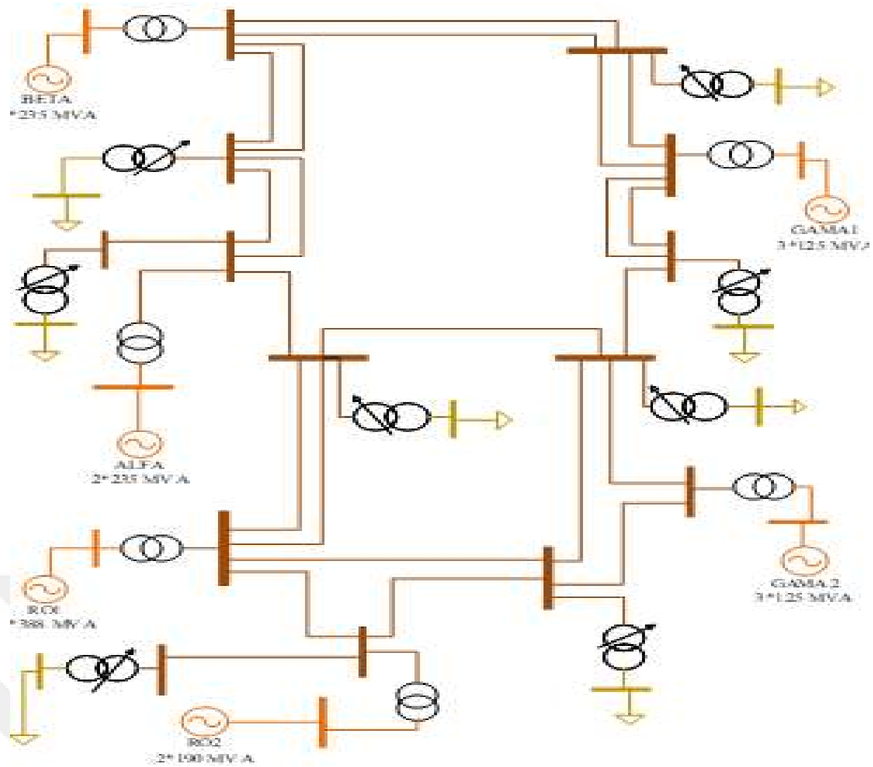

Figure 8.2 Single line diagram of the network

8.3 Case Study (1) Circuit without Transformer

After building the network, which is without power transformers in the first case, we run the power flow analysis (Figure 8.3). From the results Table 8.5 and the Figure 8.4 of the results of the first case. We note the following points.

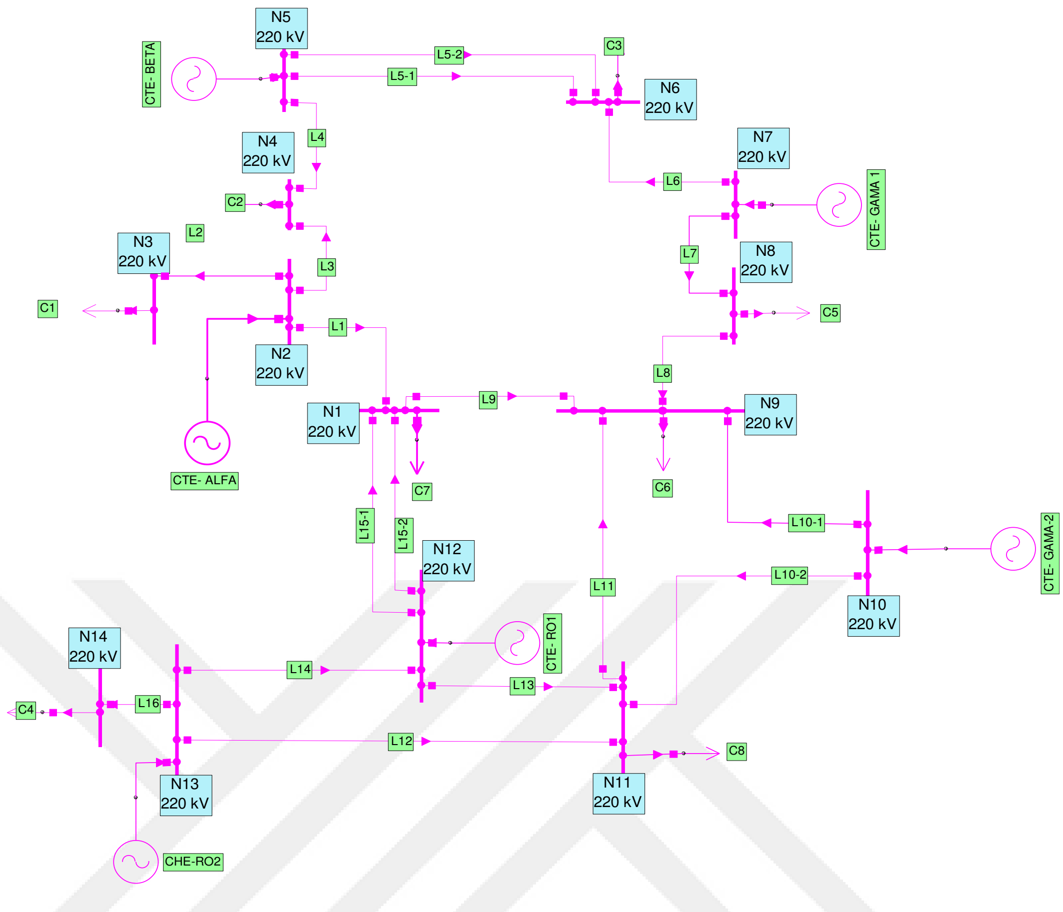

Figure 8.3 Single line diagram circuit without transformer

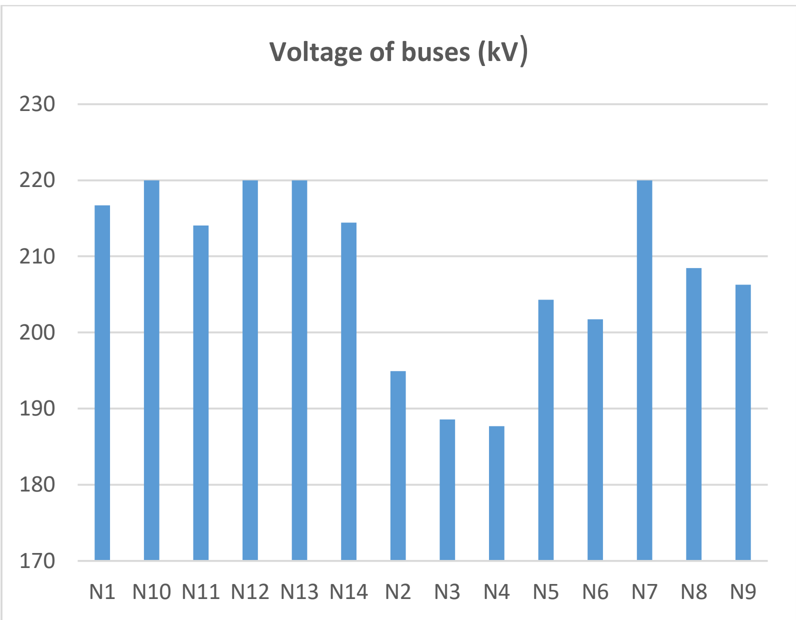

Figure 8.4 Results voltage of buses 220 kV before connecting transformers

Table 8.5 Results voltage of buses 220 kV without transformers

Name	U	U	U angle
	kV	%	°
N1	216.717	98.51	-1.9
N10	220	100	4.1
N11	214.051	97.3	-0.6
N12	220	100	0
N13	220	100	1.6
N14	214.435	97.47	-0.5
N2	194.926	88.6	-11.3
N3	188.555	85.71	-13.7
N4	187.692	85.31	-15.3
N5	204.31	92.87	-11.2
N6	201.749	91.7	-11.9
N7	220	100	-4.8
N8	208.461	94.76	-6.8
N9	206.263	93.76	-4.5

Power flow has converged in 3 iterations

- The generated voltage value is 100% because it depends upon the speed of the generators which is within the synchronous speed also the DC field excitation is 100% and the power factor of the system is lead to the absence of power transformers and produces reactive power from transmission lines.
- All buses have their voltage magnitude within recommended drop voltage, where the voltage drop for AC networks should total not more than $\mp 10\%$ under full load as shown a Table 8.6, the drop voltage which represents the difference voltage between buses, is directly proportional with an impedance of lines and active and reactive current pass through the lines.
- The angle shift (δ) between the phasor sending voltage and phasor receiving voltage in all buses into the network is less than 10 degrees as shown in the table (voltage), the phase shift across any line is small and directly proportional with smaller drop voltage between buses. Generally, the power angle goes up, the active power P goes up, the rotor speed goes up while maintaining a constant excitation voltage, and the power angle likewise increases, increasing the output of the generator's active power. The increase in P is significantly greater than the reduction in Q, though, when is less than 10 degrees.

Table 8.6 Results of active and reactive power of transmission lines without transformers

Name	type	P	Q	I	Angle	Loading	P Loss	Q Loss
		MW	MVAr	KA	°	%	MW	MVAr
L9	Line	74.932	55.554	0.249	-38.5	30.87	1.0833	-2.8362
L15-2	Line	-104.929	-46.345	0.306	154.3	34.92	0.6132	-34.7894
L10 -1	Line	114.62	28.621	0.31	-9.9	35.43	2.9594	0.5026
L10-2	Line	125.38	19.63	0.333	-4.8	38.06	1.7899	0.45
L11	Line	65.698	18.119	0.184	-16	21.01	0.8585	-9.4417
L15-1	Line	105.542	11.555	0.279	-6.2	31.84	0.6132	-34.7894
L14	Line	-38.35	1.27	0.101	-178.1	11.51	0.1724	-10.0816
L13	Line	31.954	50.201	0.156	-57.5	17.85	0.2921	-5.4066
L12	Line	60.961	26.214	0.174	-21.7	19.9	0.5162	-7.3122
L16	Line	-65	-35	0.199	151.2	22.72	0.5158	-6.0289
L1	Line	-120.693	-48.895	0.386	146.6	44.08	4.2332	8.2404
L2	Line	-60	-35	0.213	136	24.31	0.5944	-3.5139
L4	Line	-130.711	-106.148	0.518	125.6	59.19	3.1494	12.6269
L3	Line	-59.289	-23.852	0.197	142.8	22.47	0.8093	-6.443
L5-1	Line	-52.889	-51.892	0.212	123.7	24.23	0.1809	-21.2791
L5-2	Line	-52.889	-51.892	0.212	123.7	24.23	0.1809	-21.2791
L6	Line	-154.222	-66.216	0.48	144.9	59.66	4.4993	14.8164
L7	Line	81.278	88.572	0.315	-52.3	36.05	1.2548	-0.0783
L8	Line	-49.976	18.65	0.148	-166.4	16.88	0.3718	-7.28

Reactive power flow across the network is calculated by the difference in the voltage phasor magnitude between buses and the suseptance of lines.

Active power losses in the transmission line represent the difference in active power value between buses, which are supposed to be small cording to the impedance of lines and the current passing it through. In this scenario the quantity of reactive power produced by transmission lines becomes greater than the quantity of reactive power absorbs by the reactance $Qo=3\ (WCV^2-WLI^2)$

- Increased reactive power flow on the line reduces the voltage at the receiving bus and also increases reactive power losses note the lines in the table
- All transmission lines have the value of the active power flow greater than the reactive power flow we can show that from table $P_{ik}>>Q_{ik}$
- Total reactive power losses=-184.48MVAr.
- Total active power losses=17.30 MW

- Power engineers frequently use load flow to construct electrical networks, estimate how well they will run, and trade power with other utility companies. Using the transmission line and transformer input data, the Y-bus entrance is formed as the initial stage in performance load flow analysis (Eremia and Shahidehpour 2013). The following formula can be used to calculate the nodes in a power system network utilizing a Y bus. The nodal equation for an n-bus system can be expressed in a generalized form as I=Y BUS V (Kersting 2018), Equation (8.1), Equation (8.2) and Equation (8.3)

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \qquad \text{For i=1, 2, 3, } n \tag{8.1}$$

$$P_i + jQ_i = V_i I_i^*; \; I_i = \frac{P_i + jQ_i}{V_i} \tag{8.2}$$

$$\frac{P_i + jQ_i}{V_i} = V_i \sum_{j=1}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij} V_j \text{ j=1} \tag{8.3}$$

The equation applies Newton Raphson iterative methods to solve load flow issues in NEPLAN analyses. (Kempner 2008) (Figure 8.5) (Figure 8.6).

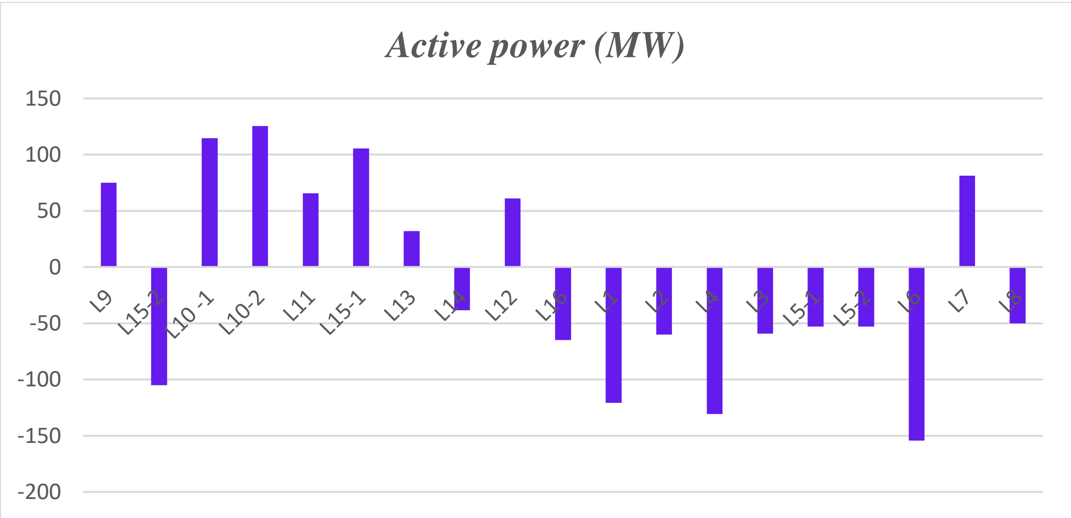

Figure 8.5 Result of active power flow in transmission lines before connecting transformers

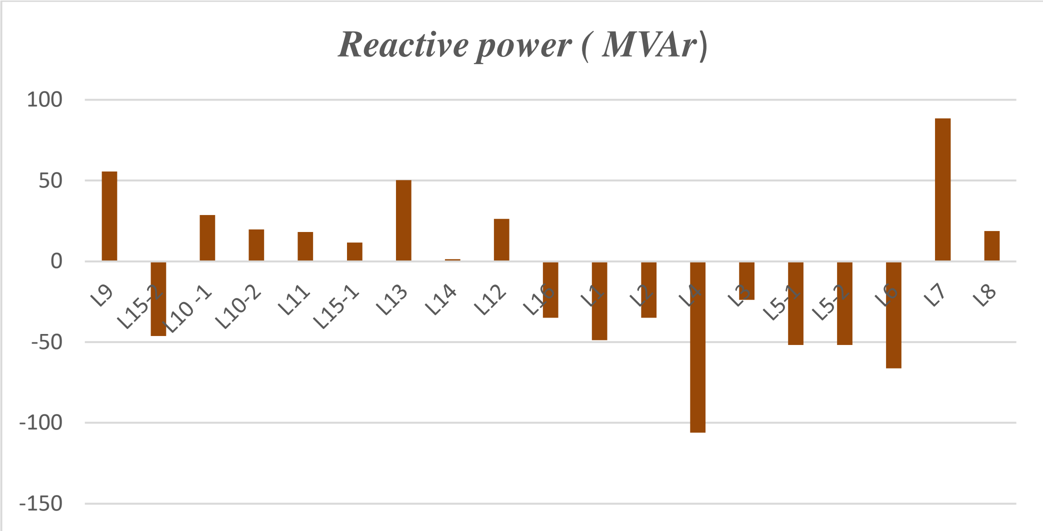

Figure 8.6 Result of reactive power flow in transmission lines before connecting

8.4 Case Study (2) Power Transformer Absence Tap Changer

A second case from a scenario of power flow represents adding the power transformers with the absence effect of the Tap changer into our system. The type of these transformers will be:

- Step up transformers are connected to generators.
- Step down transformers are connected to the loads

That connects power transformers to buses of a generation and buses of load, with the absence of Tap Changer, leading to a group of results, This result, based on the changing series impedance of the path between buses, after adding the impedance of the transformer, where we will observe the effect of absence the tap changer on voltage of buses, real and reactive power as the Figure 8.7 and the following results.

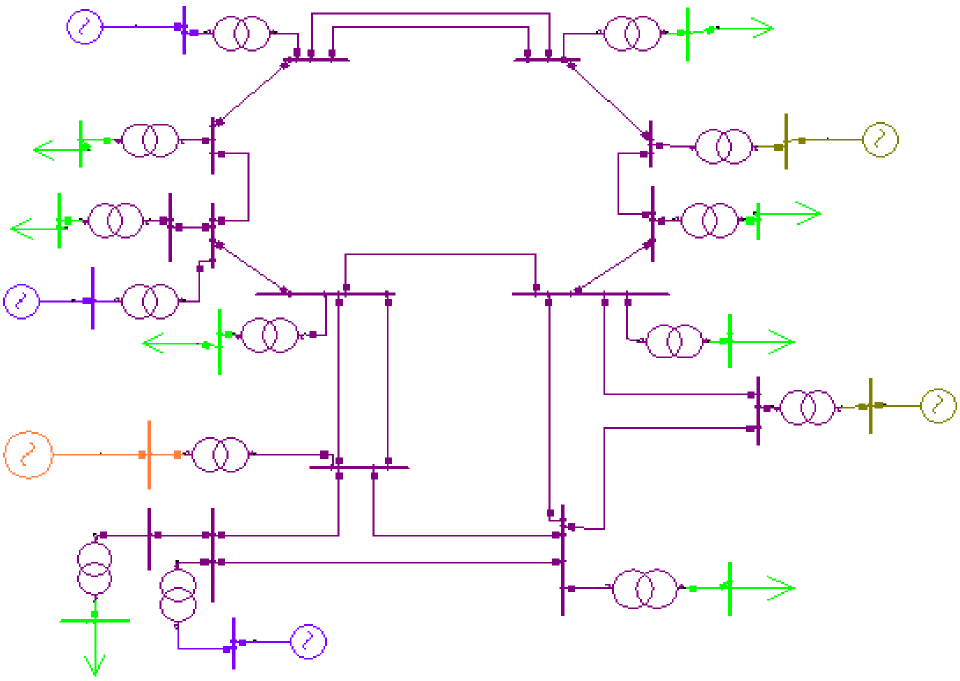

Figure 8.7 Single line diagram of the electrical network with power transformer absence Tap changer

The power flow doesn't converge

There is a voltage collapse relative to Equation (8.4)

$$Z_{Tot}=Z_{BUSi}+Z_{LINE}+Z_{BUSk}+Z_{Tr} \qquad (8.4)$$

Tr; Fixed part, Equation (8.5)

$$Q_{\circ} = \sqrt{3}\, U_n * I_{\circ}. \qquad (8.5)$$

The part which is approximately proportional to the square of the apparent power flow Equation (8.6)

$$Q = u_{sc}\frac{S^2}{S_n} \qquad (8.6)$$

There is a voltage collapse at the buses of center load (1, 3, 4, 5, 6, 7, 8, 9) also buses of generation as shown in tables, because the increased series impedance of a system between buses after connecting transformers with absence tap changer, where that leads to increase the total impedance of the path between buses thus increase drop voltage where relative to Z_{Tot}=Z_{BUSi}+Z_{LINE}+Z_{BUSk}+Z_{Tr}. Where it becomes greater than the impedance of the center load, which leads to increased power losses (Table 8.7) (Figure 8.8) (Figure 8.9) (Table 8.8) (Figure 8.10) (Figure 8.11).

Table 8.7 Results voltage of buses after connecting power transformers with absence Tap changer

Name	U	U	U angle		Name	U	U	U angle
	kV	%	°			kV	%	°
B-ALFA	14.847	94.27	4.1		N1	212.409	96.55	-4.1
B-BETA	13.501	85.72	1.8		N10	229.488	104.31	2
B-C1	108.178	89.4	-3.5		N11	218.622	99.37	-2.5
B-C2	91.937	75.98	-10.4		N12	222.451	101.11	-2.2
B-C3	97.109	80.26	-10.1		N13	230.219	104.65	-0.9
B-C4	97.423	80.52	-10.1		N14	224.375	101.99	-2.8
B-C5	96.843	80.04	-11.5		N2	217.797	99	0.5
B-C6	109.346	90.37	-6.4		N3	211.704	96.23	-1.4
B-C7	100.328	82.92	-11.6		N4	186.75	84.89	-5.9
B-C8	114.948	95	-4.9		N5	193.851	88.11	-3.6
B-GAMA1	11	100	6.7		N6	189.973	86.35	-4.7
B-GAMA2	10.119	91.99	5.3		N7	207.855	94.48	-0.3
B-RO1	24	100	0		N8	198.003	90	-4.6
B-RO2	15.75	100	2.1		N9	202.307	91.96	-5.2

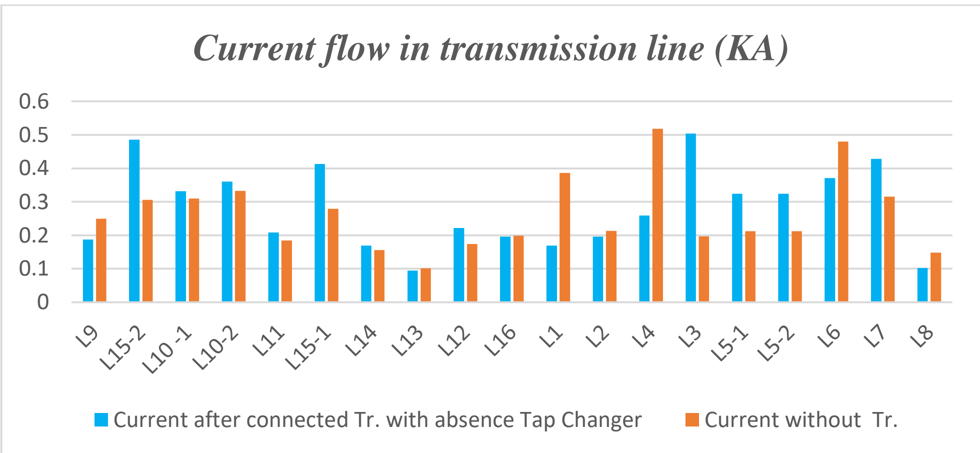

Figure 8.8 Results of current before and after connecting Tr with absence Tap changer

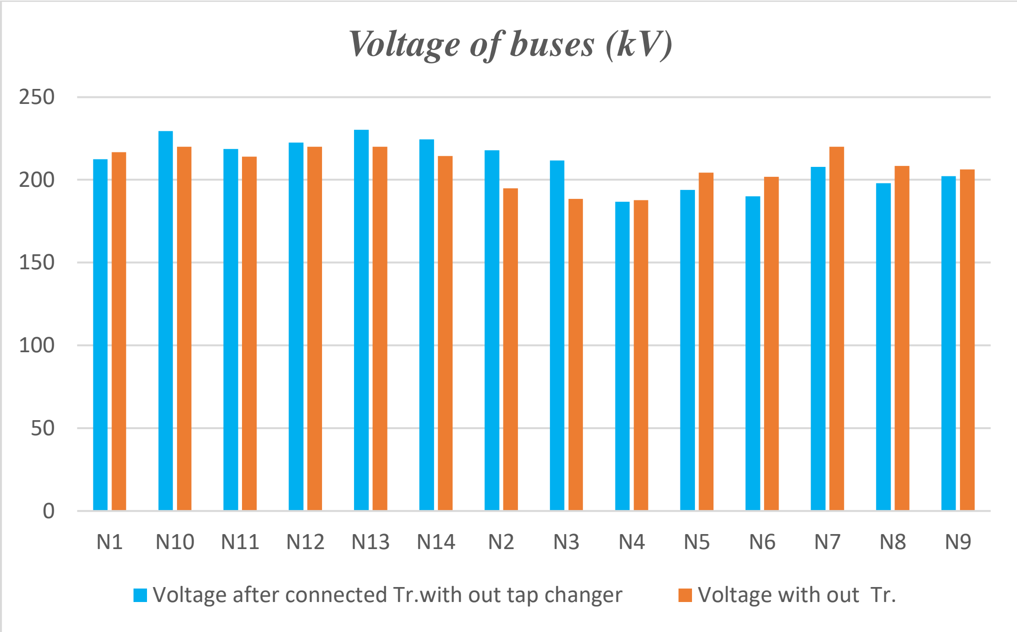

Figure 8.9 Results of voltage 220 kV before and after connecting Tr with absence Tap changer

Table 8.8 Results of power flow of transmission lines after connected power transformer with absence Tap changer

Name	Type	P	Q	I	Angle	Loading
		MW	MVAr	KA	º	%
L9	Line	37.405	57.559	0.187	-61.1	23.18
L15-2	Line	-117.853	-134.623	0.486	127.1	55.58
L10 -1	Line	106.613	77.969	0.332	-34.2	37.98
L10-2	Line	132.446	54.512	0.36	-20.4	41.18
L11	Line	53.46	58.068	0.208	-49.9	23.82
L15-1	Line	119.299	105.492	0.413	-43.7	47.24
L14	Line	-41.882	-50.066	0.169	127.7	19.36
L13	Line	18.334	31.686	0.095	-62.2	10.86
L12	Line	56.362	68.208	0.222	-51.3	25.36
L16	Line	-65.205	-39.675	0.196	145.9	22.45
L1	Line	63.858	0.004	0.169	0.5	19.35
L2	Line	-60.191	-39.469	0.196	145.4	22.43
L4	Line	-71.006	-44.496	0.259	142	29.61
L3	Line	-119.655	-110.769	0.504	131.3	57.61
L5-1	Line	-83.021	-66.806	0.324	136.4	37.01
L5-2	Line	-83.021	-66.806	0.324	136.4	37.01
L6	Line	-94.971	-76.546	0.371	136.4	46.05
L7	Line	141.569	61.144	0.428	-23.6	48.95
L8	Line	8.818	-33.839	0.102	70.8	11.65

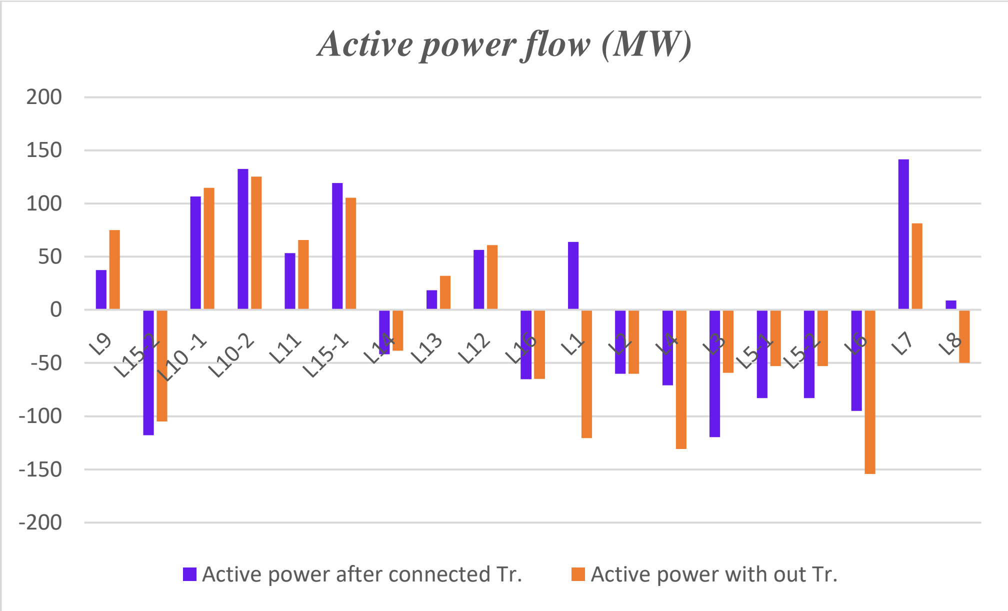

Figure 8.10 Results of Active power before and after connecting Tr with absence Tap changer

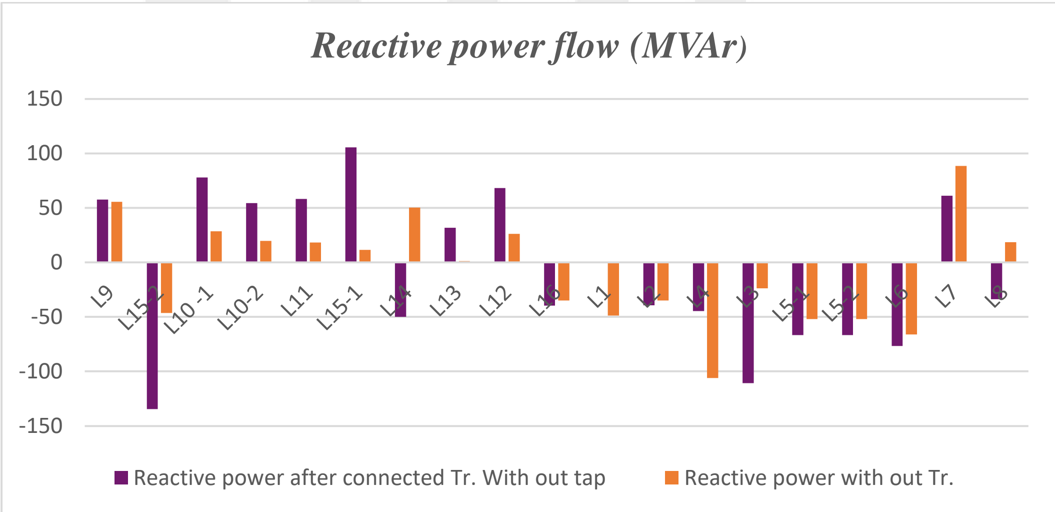

Figure 8.11 Results of reactive power before and after connecting Tr with absence Tap changer.

8.5 Case Study (3) Power Transformer with Operate Tap Changer

Case 3 from a scenario of power flow represented by the present power Tr. with operating Tap changer into our network as the Figure 8.12, where we will note the following points from Table 8.9, Table 8.10, Figure 8.13, Figure 8.14, Figure 8.15 and Figure 8.16.

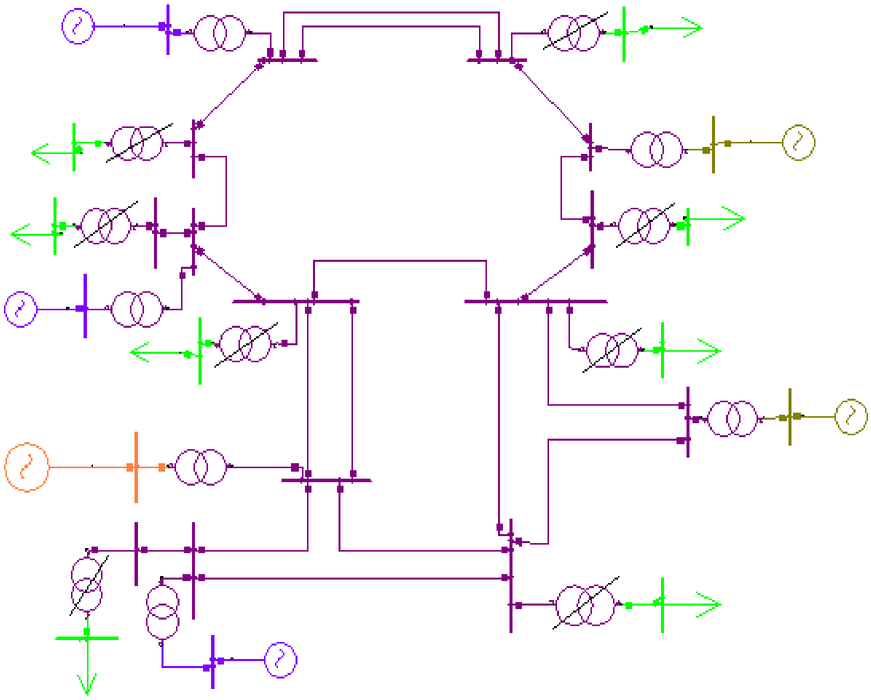

Figure 8.12 Network with power transformers and operating Tap changer.

Table 8.9 Results of power flow of transmission lines after connect transformers with present Tap changer

Name	Type	P	Q	I	Angle	Loading	P loss	Q loss
		MW	MVAr	KA	º	%	MW	MVAr
L9	Line	35.429	42.056	0.146	-53.9	18.12	0.4003	-6.9498
L15-2	Line	-116.519	-104.541	0.415	134.1	47.45	1.0781	-32.9358
L10 -1	Line	106.759	58.606	0.303	-26.8	34.67	2.9604	-0.8926
L10-2	Line	132.355	47.443	0.35	-17.7	40.02	2.0095	0.813
L11	Line	52.243	38.942	0.169	-39.2	19.37	0.7939	-10.6775
L15-1	Line	117.597	71.605	0.353	-33.5	40.33	1.0781	-32.9358
L13	Line	17.247	26.725	0.082	-59.3	9.32	0.0876	-7.1123
L14	Line	-42.351	-42.739	0.154	132.6	17.62	0.342	-9.9357
L12	Line	56.006	56.372	0.198	-46	22.61	0.6924	-7.2177
L16	Line	-65.21	-39.53	0.195	146.1	22.25	0.4901	-7.2105
L1	Line	64.655	29.863	0.178	-24.8	20.37	1.0894	-14.2574
L2	Line	-60.197	-39.269	0.184	145.1	21.07	0.4362	-7.4422
L4	Line	-70.368	-53.16	0.247	137.1	28.25	0.6991	-3.1107
L3	Line	-120.171	-94.251	0.428	136.1	48.93	3.8597	8.7041
L5-1	Line	-83.458	-70.106	0.3	135.1	34.3	0.3882	-21.8742
L5-2	Line	-83.458	-70.106	0.3	135.1	34.3	0.3882	-21.8742
L6	Line	-93.89	-58.819	0.305	143.1	37.89	1.7657	-1.3139
L7	Line	143.348	87.557	0.435	-32.3	49.73	2.3322	6.2525
L8	Line	10.574	-1.831	0.029	5.1	3.36	0.0145	-9.7413

Table 8.10 Results voltage of buses after connect transformers with present Tap changer

Name	U	U	U angle		Name	U	U	U angle
	kV	%	º			kV	%	º
B-ALFA	15.655	99.39	3.2		N1	217.691	98.95	-4
B-BETA	14.705	93.36	0.7		N10	231.788	105.36	2
B-C1	116.848	96.57	-3.6		N11	221.989	100.9	-2.5
B-C2	120.609	99.68	-8.5		N12	225.277	102.4	-2.2
B-C3	120.464	99.56	-8.5		N13	231.862	105.39	-0.8
B-C4	121.217	100.18	-8.4		N14	226.091	102.77	-2.7
B-C5	121.55	100.45	-9.2		N2	230.685	104.86	0
B-C6	120.713	99.76	-5.6		N3	225.035	102.29	-1.7
B-C7	120.047	99.21	-9.4		N4	205.958	93.62	-5.8
B-C8	120.583	99.66	-4.6		N5	213.28	96.95	-3.8
B-GAMA1	11	100	6.6		N6	209.693	95.32	-4.8
B-GAMA2	10.767	97.88	4		N7	222.86	101.3	-0.9
B-RO1	24	100	0		N8	210.79	95.81	-4.7
B-RO2	15.75	100	2.2		N9	210.054	95.48	-5.1

The power flow has converged in 18 iterations

Improving in the level of voltages at most buses due to the connecting Tr with the present Tap changer, Equation (8.7)

$$\Delta V = \frac{RP_{\circ} + X_{Q_{\circ}}}{N_r V_2} \tag{8.7}$$

The voltage drop decrease and voltage increase are dominant which leads to a decrease reactive power flow relative to Equation (8.8)

$$\Delta V \approx \frac{X_{Q_{\circ}}}{V_2} \tag{8.8}$$

Load Flow converged after 18 iterations

Network MW Losses=30.867697

Network MVAR Losses=124.953713

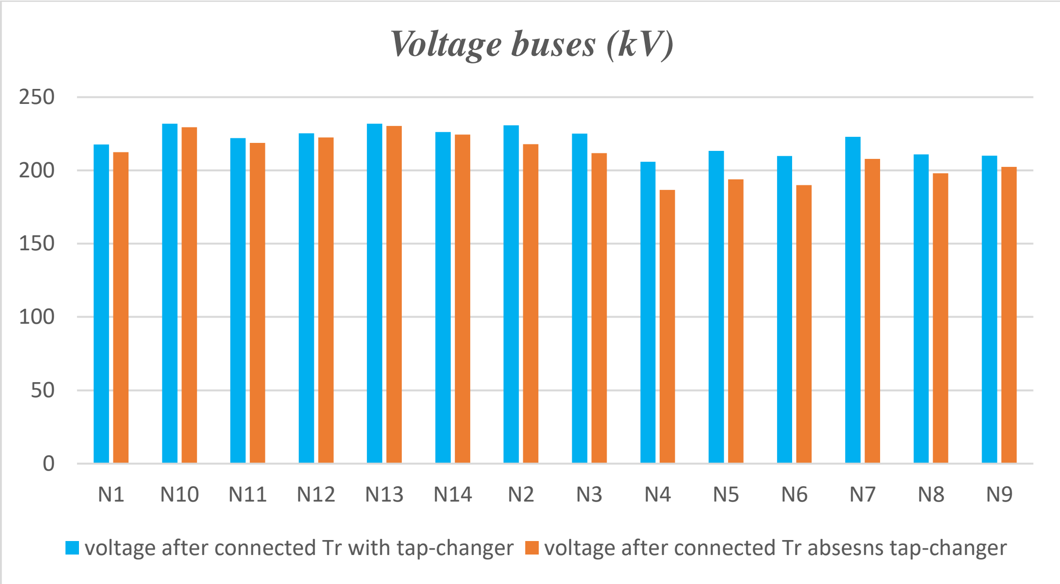

Figure 8.13 Results voltage buses 220 kV with &without effect of Tap Changer

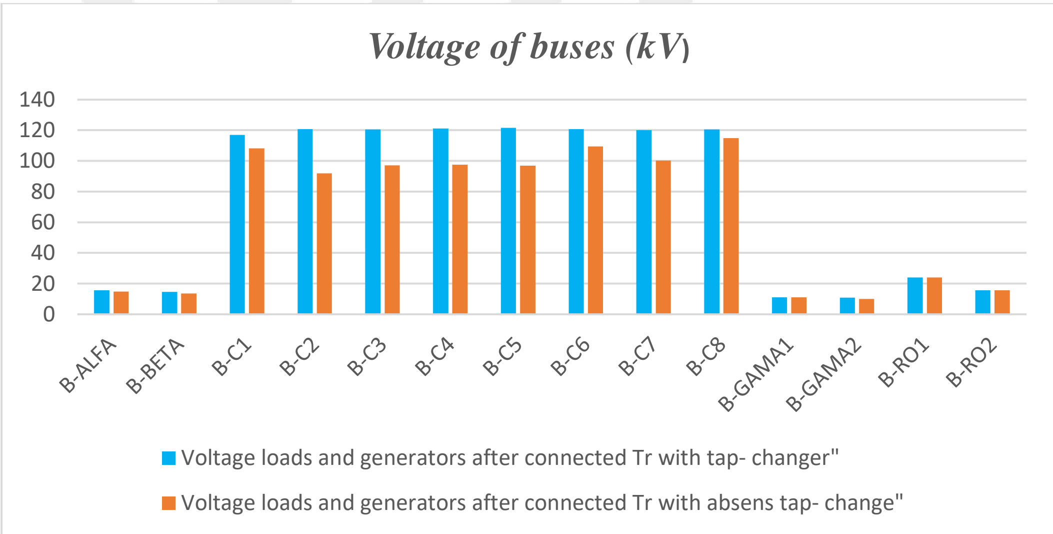

Figure 8.14 Results voltage of buses 110 kV and buses of generation with &without the effect of Tap changer

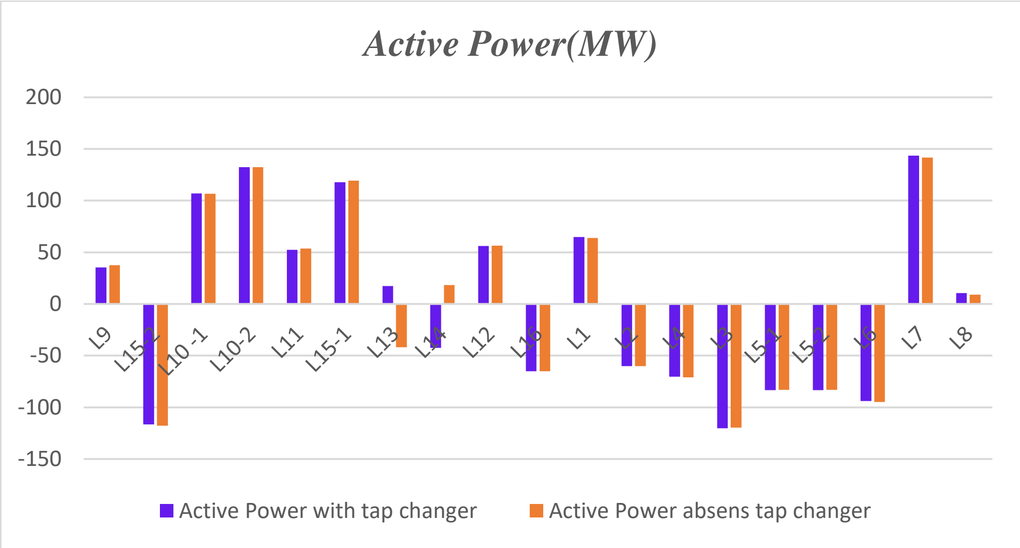

Figure 8.15 Results of active power flow of lines with &without the effect of Tap changer

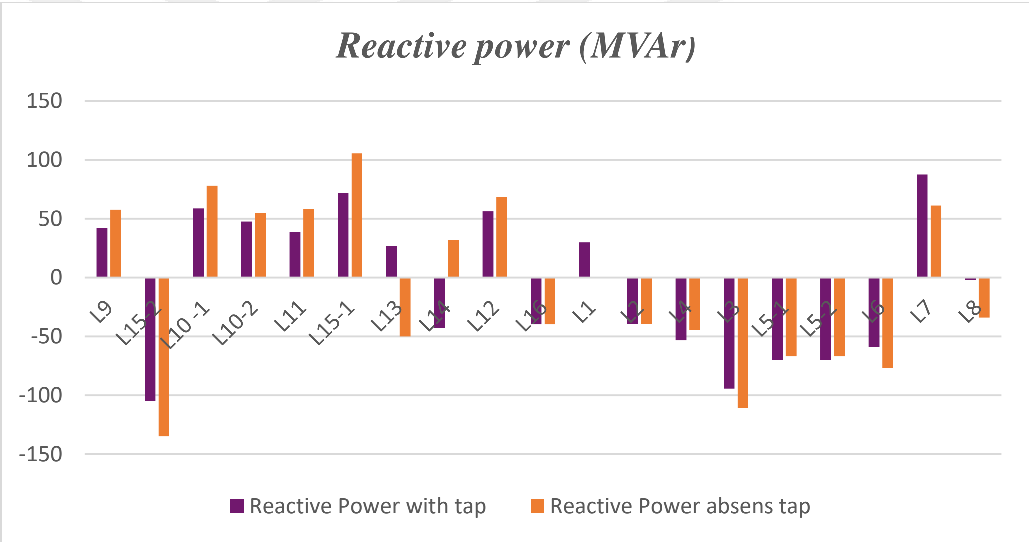

Figure 8.16 Results of reactive power flow of lines with&without effect of Tap changer

8.6 Case Study (4) Double Transmission Lines

We will decrease the impedance of the system by supporting weak transmission lines (3, 4, 6, 7) at zone (2) in the previous case by converting into a double circuit as in Figure 8.17, where note the following observations from results for this case. Decrease value of phase shift between the phasor sending voltage and phasor receiving voltage in all buses into the network where it is directly proportional with voltage drop and impedance (Table 8.11).

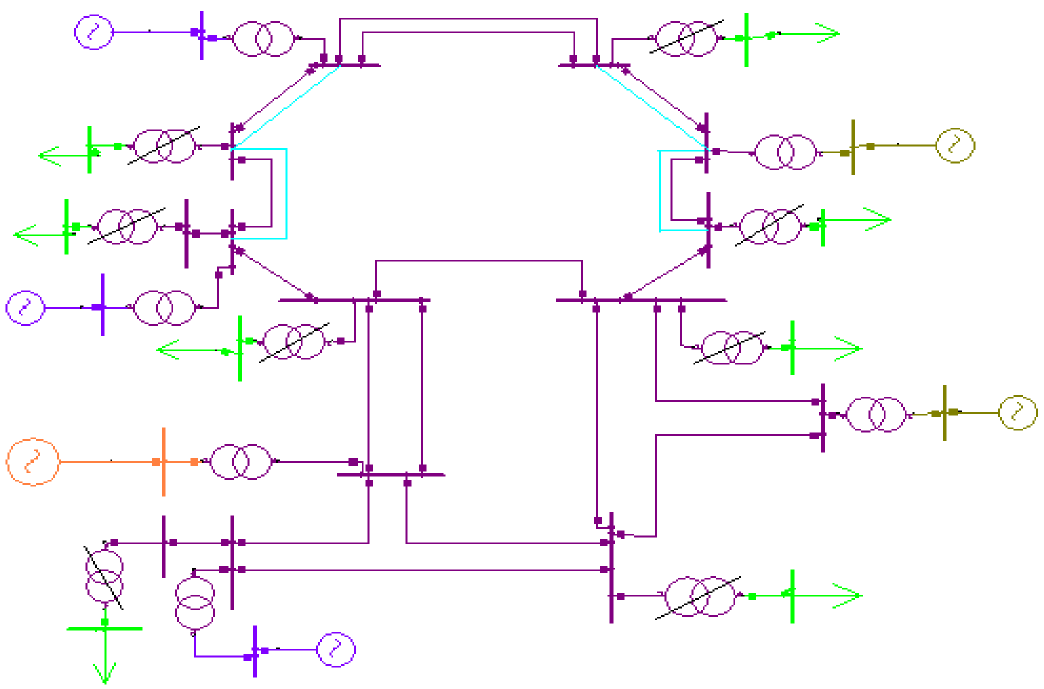

Figure 8.17 Electrical network test 2 varia.

Table 8.11 Results voltage of buses after modify transmission lines.

Name	U kV	U %	U angle °		Name	U kV	U %	U angle °
N1	219.985	99.99	-4		B-ALFA	15.75	100	2.5
N10	233.168	105.99	2.1		B-BETA	15.652	99.38	1.1
N11	223.836	101.74	-2.3		B-C1	118.876	98.24	-4.2
N12	226.566	102.98	-2.1		B-C2	121.286	100.24	-6.3
N13	232.693	105.77	-0.7		B-C3	121.011	100.01	-7.6
N14	226.95	103.16	-2.5		B-C4	120.491	99.58	-7.9
N2	234.304	106.5	-0.7		B-C5	120.184	99.33	-9
N3	228.775	103.99	-2.4		B-C6	121.801	100.66	-5.4
N4	225.033	102.29	-3.6		B-C7	121.527	100.44	-9.2
N5	228.552	103.89	-3		B-C8	121.061	100.05	-4.4
N6	224.975	102.26	-3.9		B-GAMA1	11	100	6.8
N7	229.184	104.17	-2.3		B-GAMA2	11	100	2.4
N8	221.61	100.73	-4.1		B-RO1	24	100	0
N9	215.02	97.74	-4.8		B-RO2	15.75	100	2.3

The power flow converges after 10 iterations. Improve the voltage levels at all buses as shown in Table 8.11, because of the decreased impedance of the network which leads to reduced drop voltage between buses (Figure 8.18) (Figure 8.19).

Network MW Losses=24.685811

Network MVAR Losses=13.088821, Equation (8.9)

$$Z_{Tot}=Z_{BUSi}+\frac{Zlin}{2}+Z_{BUSk}+Z_{Tr} \qquad (8.9)$$

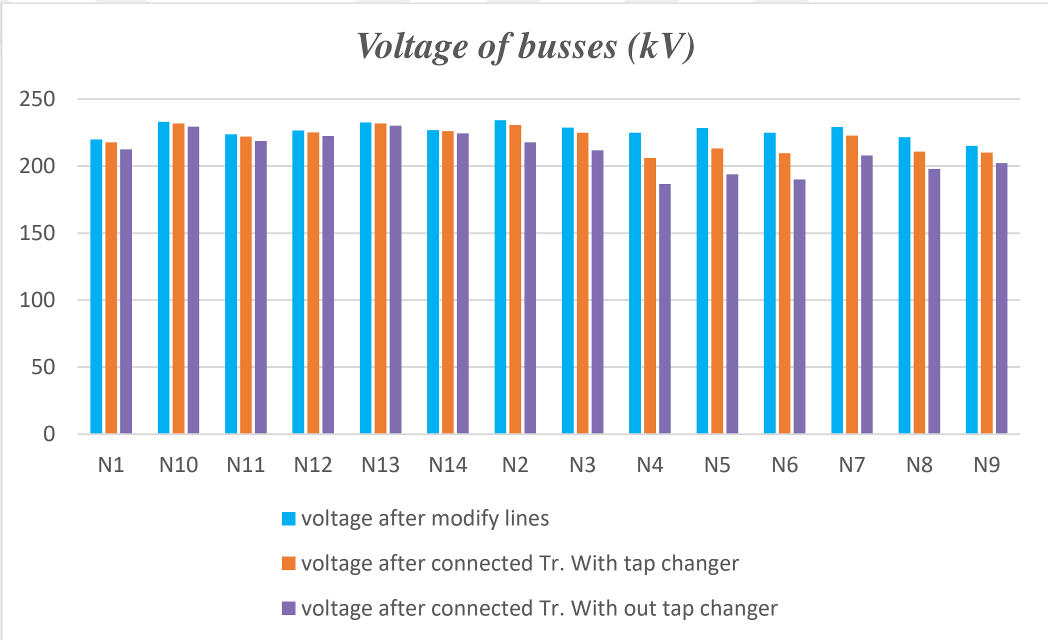

Figure 8.18 Results voltage of buses 220 kV before &after modifying.

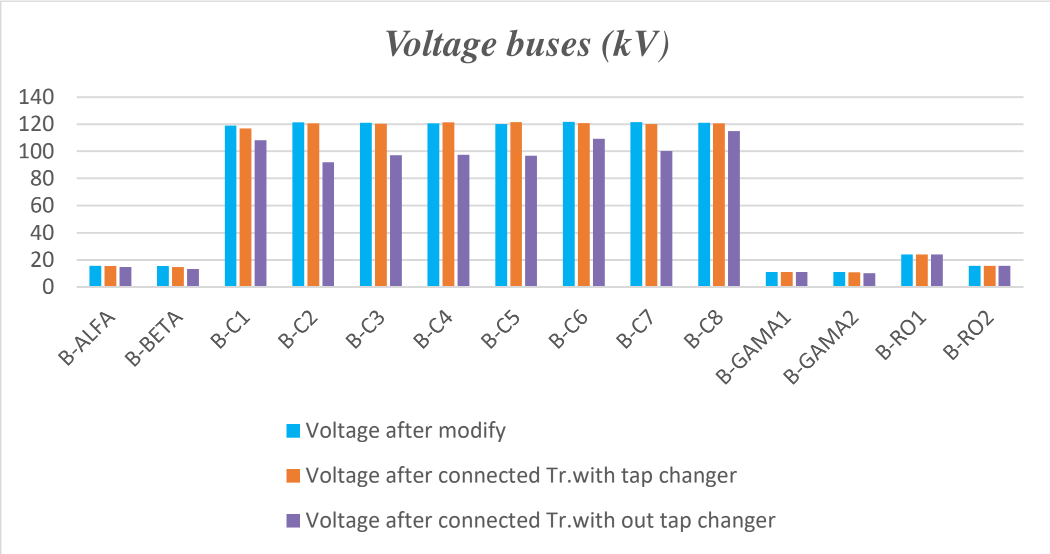

Figure 8.19 Results voltage of buses 110 and generators before & after modifying.

The phenomenon of improving voltages can be attributed to the decreased current and the Loading of the other working 220 kV lines, where decreased loading implies decreased reactive power absorption from generators, shown in Figure 8.19, and in transmission lines shown in Table 8.12.

Table 8.12 Results of power flow of transmission lines after modify

Name	Type	P	Q	I	Angle	Loading	P loss	Q loss
		MW	MVAr	KA	°	%	MW	MVAr
L9	Line	26.684	25.284	0.096	-47.4	11.98	0.1844	-8.5013
L15-2	Line	-116.261	-91.978	0.389	137.7	44.47	0.9492	-34.4062
L10 -1	Line	105.335	45.76	0.284	-21.3	32.5	2.5815	-3.8793
L10-2	Line	133.808	44.261	0.349	-16.2	39.88	1.992	0.5439
L11	Line	48.504	25.381	0.141	-29.9	16.14	0.5503	-12.6617
L15-1	Line	117.21	57.572	0.333	-28.2	38.03	0.9492	-34.4062
L13	Line	13.263	21.799	0.065	-60.8	7.43	0.0588	-7.3975
L14	Line	-43.741	-39.692	0.151	135.7	17.2	0.3273	-10.1362
L12	Line	54.653	49.466	0.183	-42.8	20.9	0.5936	-7.9538
L16	Line	-65.21	-39.52	0.194	146.3	22.17	0.4861	-7.3107
L1	Line	56.302	36.132	0.165	-33.4	18.84	0.9794	-15.4896
L2	Line	-60.199	-39.229	0.181	144.6	20.72	0.4209	-7.8663
L4	Line	-29.838	-31.865	0.112	129.5	12.8	0.1307	-7.7997
L3	Line	-65.431	-41.781	0.199	143.8	22.76	0.7936	-11.5637
L5-1	Line	-89.04	-76.08	0.301	135.6	34.35	0.385	-25.5365
L5-2	Line	-89.04	-76.08	0.301	135.6	34.35	0.385	-25.5365
L6	Line	-41.362	-23.336	0.122	146.7	15.14	0.2636	-11.0291
L7	Line	77.898	55.565	0.241	-37.8	27.55	0.7358	-4.0349
L8	Line	23.88	35.947	0.112	-60.5	12.85	0.2465	-9.081

Decreased loading implies decrease active& reactive power losses into the system. Improve reactive power flow in all lines due to improved voltages in buses and decrease drop voltage between buses which attributed to the decreased impedance of the system (Figure 8.20) (Figure 8.21) (Figure 8.22).

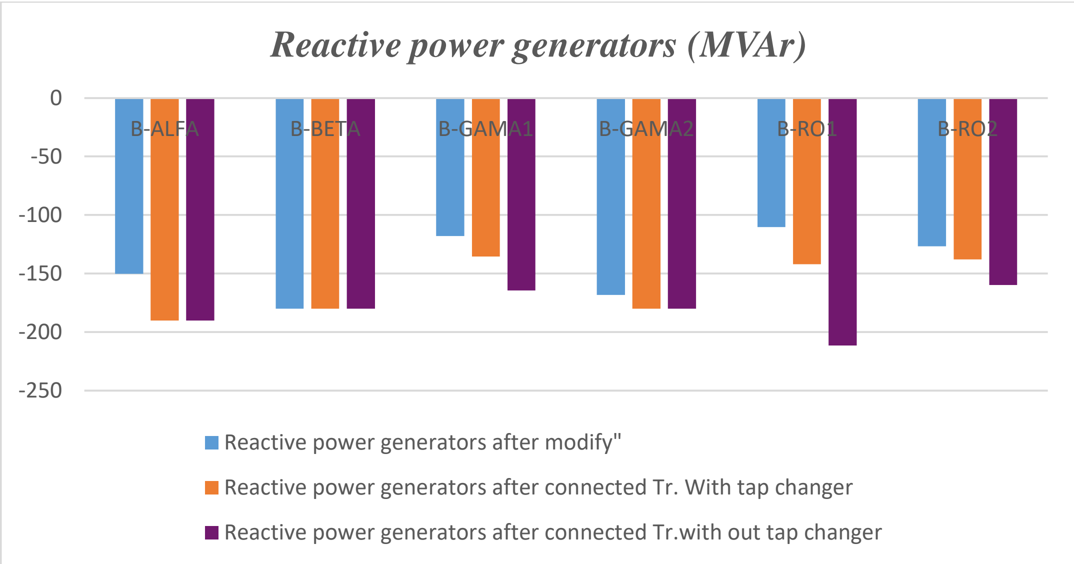

Figure 8.20 Results of reactive power of generators before & after modifying.

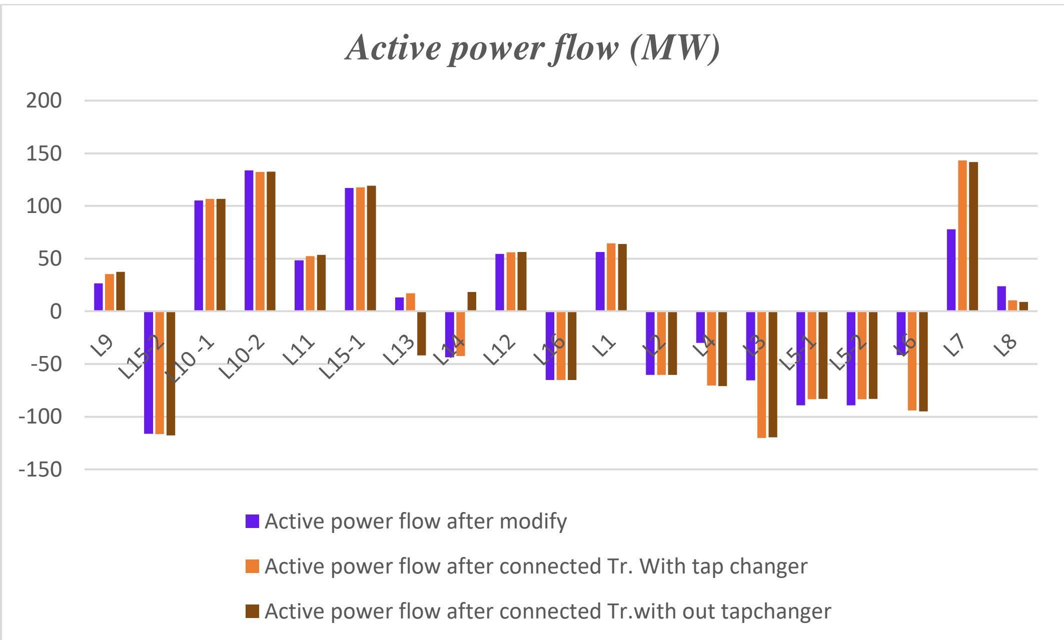

Figure 8.21 Results of active power flow in lines before & after modifying system.

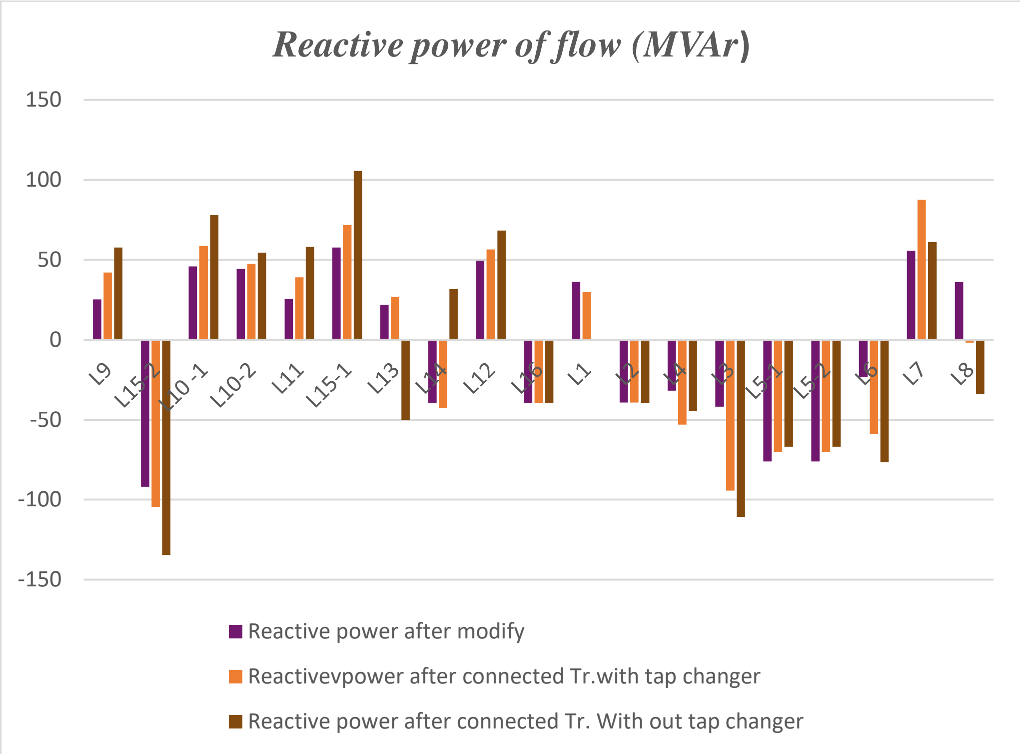

Figure 8.22 Results of reactive power into lines before & after modifying system.

8.7 Case Study (5) Electrical Network with Pump-Station

A New case from a scenario of power flow represent by adding the power transformers with the effect of a Tap changer and we add a pump station that has a capacity of 24 MW including 12 synchronization Machin as pump motor into our system (Figure 8.23). The type of these transformers will be:

- Step up transformers are connected to generators.
- Step down transformers are connected to the loads (Figure 8.24) (Table 8.13)

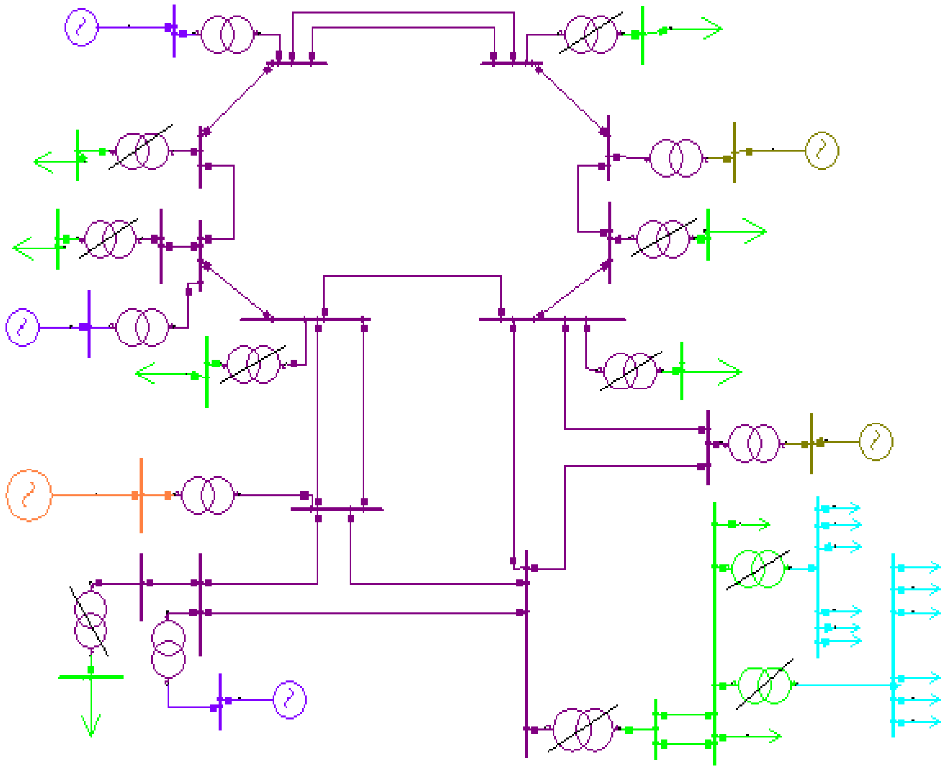

Figure 8.23 Single line diagram of the electrical network with 12 synchronous machine with Tap changer.

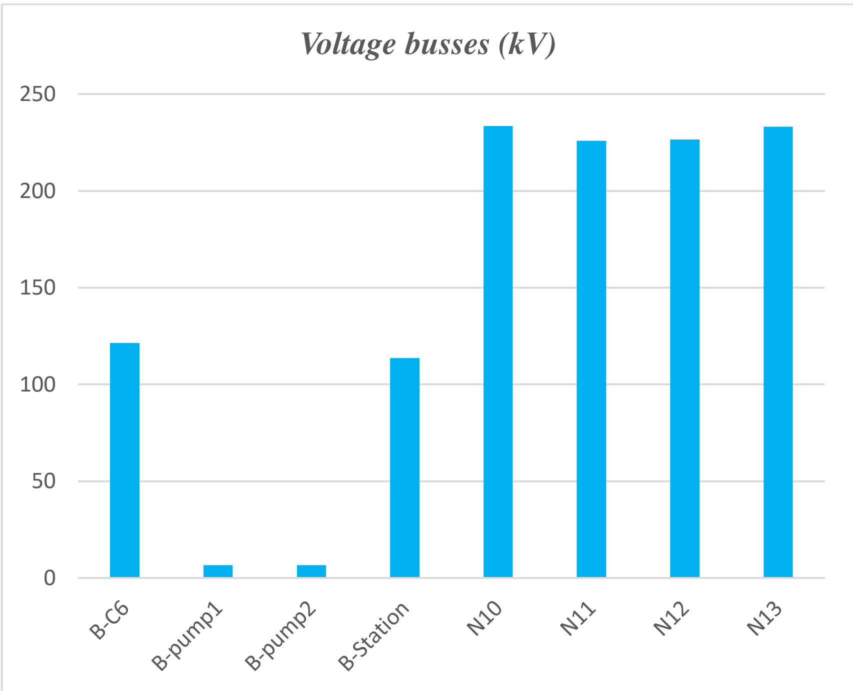

Figure 8.24 Results voltage busses with synchronous Machine with Tap changer.

Table 8.13 Results voltage 220 kV of buses after connecting synchronous Machine & Tap changer.

Name	**U**	**U**	**U angle**
	kV	**%**	**º**
B-C6	121.423	100.35	-2.3
B-pump1	6.615	100.23	-8.4
B-pump2	6.615	100.23	-8.4
B-Station	113.614	93.9	-6.8
N10	233.443	106.11	3.Haz
N11	225.976	102.72	-0.6
N12	226.557	102.98	-1.4
N13	233.263	106.03	0.5

Load Flow converged after 11 iterations, Network MW Losses=31.792407, Network MVAR Losses=97.821662 (Figure 8.25) (Figure 8.26) (Table 814).

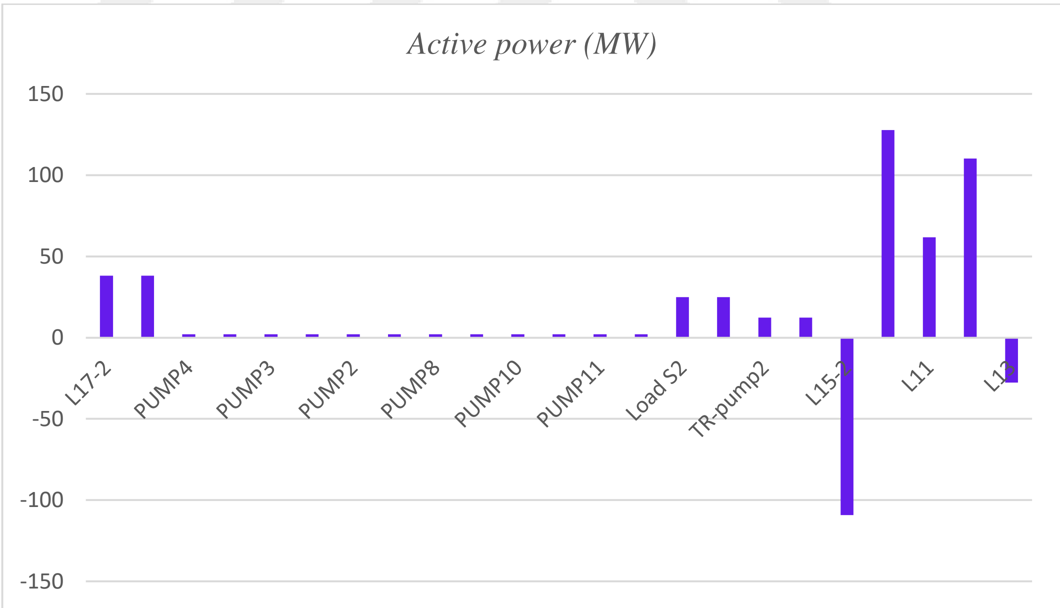

Figure 8.25 Results active power synchronous machine.

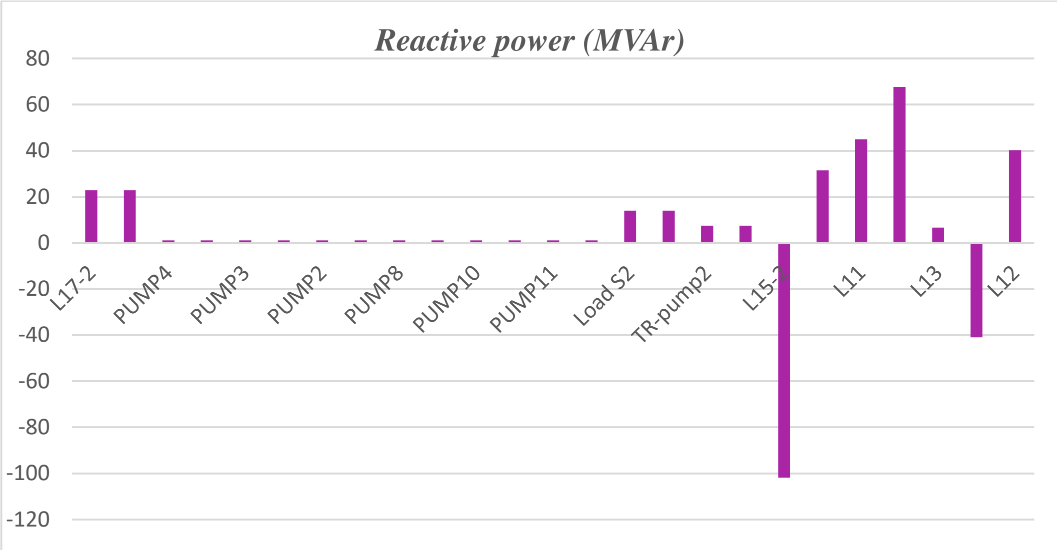

Figure 8.26 Results reactive power with synchronous machine.

Table 8.14 Results of transmission lines after connected pump station.

Name	**Type**	**P**	**Q**	**I**	**Angle**
		MW	**MVAr**	**KA**	**º**
L17-2	Line	38.107	22.829	0.211	-33.2
L17-1	Line	38.107	22.829	0.211	-33.2
PUMP4	Load	2	1.1	0.199	-37.2
PUMP1	Load	2	1.1	0.199	-37.2
PUMP3	Load	2	1.1	0.199	-37.2
PUMP6	Load	2	1.1	0.199	-37.2
PUMP2	Load	2	1.1	0.199	-37.2
PUMP5	Load	2	1.1	0.199	-37.2
PUMP8	Load	2	1.1	0.199	-37.2
PUMP7	Load	2	1.1	0.199	-37.2
PUMP10	Load	2	1.1	0.199	-37.2
PUMP12	Load	2	1.1	0.199	-37.2
PUMP11	Load	2	1.1	0.199	-37.2
PUMP9	Load	2	1.1	0.199	-37.2
Load S2	Load	25	14	0.146	-36.1
Load-S1	Load	25	14	0.146	-36.1
TR-pump2	2W Transformer	12.369	7.406	0.073	-37.8
TR-pump1	2W Transformer	12.369	7.406	0.073	-37.8
L15-2	Line	-109.315	-101.869	0.393	133.9
L10-2	Line	127.745	31.486	0.325	-10.2
L11	Line	61.849	44.94	0.195	-36.6
L15-1	Line	110.269	67.61	0.33	-32.9
L13	Line	-27.696	6.678	0.073	-167.8
L14	Line	-57.708	-40.927	0.18	143.3
L12	Line	40.54	40.266	0.141	-44.3

8.8 Case Study (6) Pump-Station without Tap Changer in Substation of Pump

That connects power transformers to buses of a generation and buses of load, with the absence Tap changer, leading to a group of results, This result, is based on the changing series impedance of the path between buses, after adding the impedance of the transformer, where we will observe the effect of absence the tap changer on voltage of buses, real and reactive power as the Figure 8.27 and the following results (Figure 8.28) (Table 8.15):

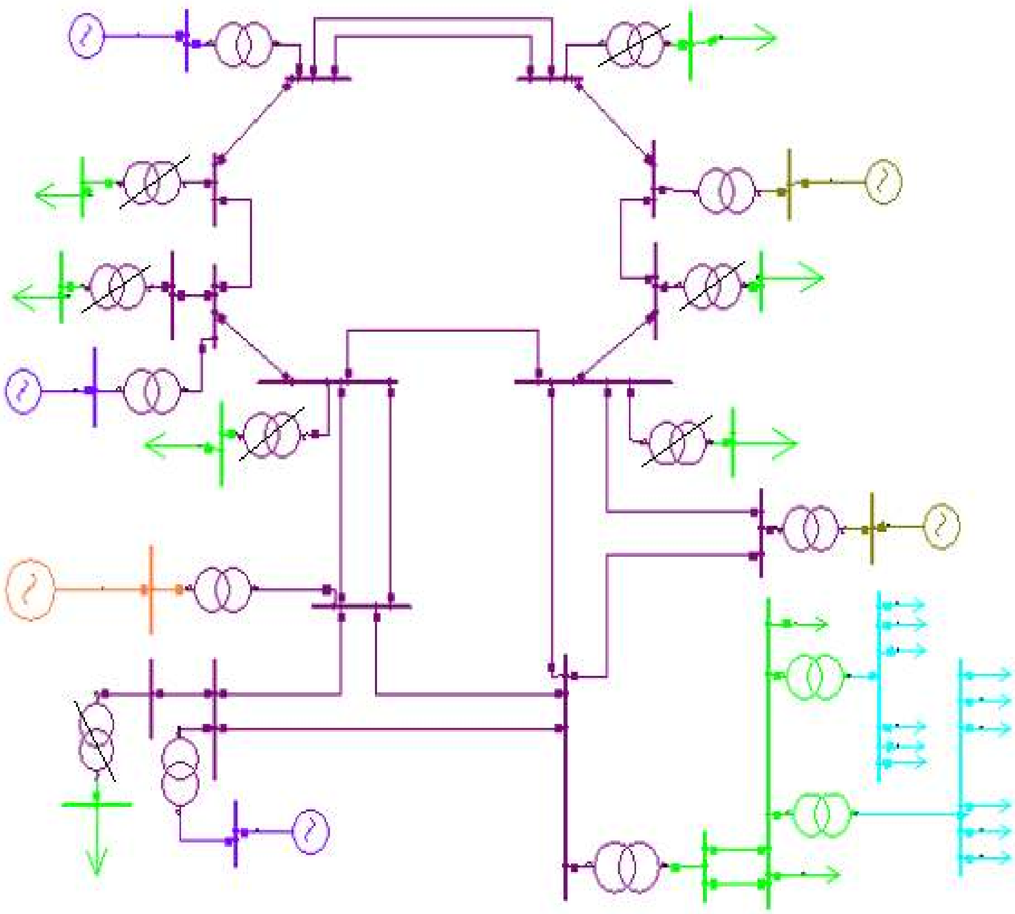

Figure 8.27 Single line diagram of the electrical network with 12 synchronous machine without Tap changer.

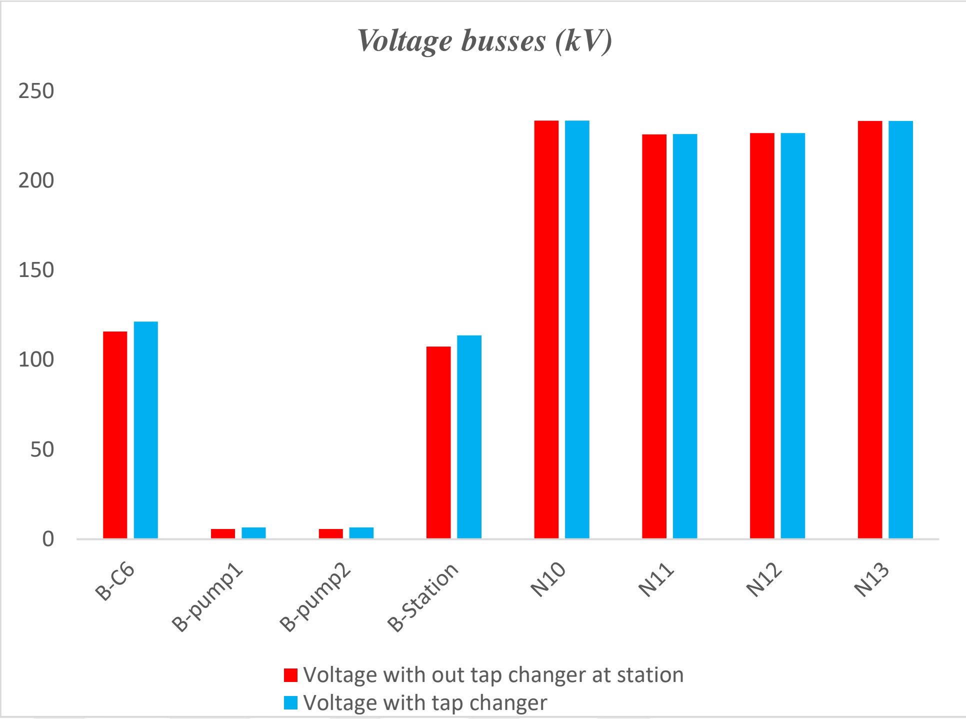

Figure 8.28 Results voltage busses of pump station with &without Tap changer.

Table 8.15 Results voltage 220 kV of buses after connecting transformers without Tap-changer.

Name	U	U	U angle
	kV	%	o
B-C6	115.774	95.68	-2.4
B-pump1	5.697	86.32	-9.5
B-pump2	5.697	86.32	-9.5
B-Station	107.406	88.76	-7.5
N10	233.393	106.09	3.6
N11	225.856	102.66	-0.6
N12	226.515	102.96	-1.4
N13	233.22	106.01	0.5

Load Flow converged after 11 iterations, Network MW Losses=31.876395, Network MVAR Losses=100.346216 (Figure 8.29) (Table 8.16) (Figure 8.30) (Figure 8.31)

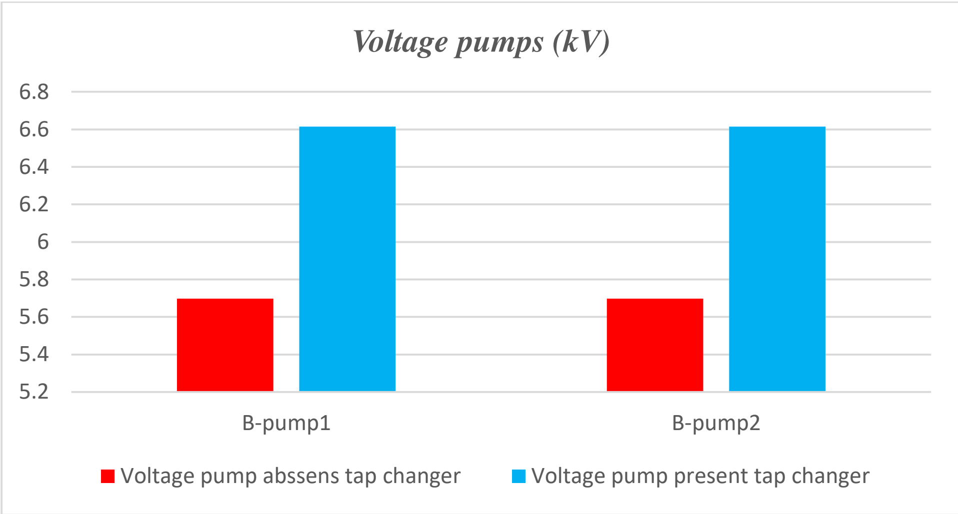

Figure 8.29 Results voltage buses 6.6 kV synchronous machine with &without Tap changer.

Table 8.16 Results of transmission lines and pump after tap changer off.

Name	Type	P	Q	I	Angle
		MW	MVAr	KA	°
L17-2	Line	38.143	23.752	0.224	-34.3
L17-1	Line	38.143	23.752	0.224	-34.3
PUMP4	Load	2	1.1	0.231	-38.3
PUMP1	Load	2	1.1	0.231	-38.3
PUMP3	Load	2	1.1	0.231	-38.3
PUMP6	Load	2	1.1	0.231	-38.3
PUMP2	Load	2	1.1	0.231	-38.3
PUMP5	Load	2	1.1	0.231	-38.3
PUMP8	Load	2	1.1	0.231	-38.3
PUMP7	Load	2	1.1	0.231	-38.3
PUMP10	Load	2	1.1	0.231	-38.3
PUMP12	Load	2	1.1	0.231	-38.3
PUMP11	Load	2	1.1	0.231	-38.3
PUMP9	Load	2	1.1	0.231	-38.3
Load S2	Load	25	14	0.154	-36.7
Load-S1	Load	25	14	0.154	-36.7
TR-pump2	2W Transformer	12.316	7.479	0.077	-38.8
TR-pump1	2W Transformer	12.316	7.479	0.077	-38.8
L15-2	Line	-109.332	-101.922	0.394	133.9
L10-2	Line	127.739	31.982	0.326	-10.4
L11	Line	61.824	44.719	0.195	-36.5
L15-1	Line	110.287	67.686	0.33	-32.9
L13	Line	-27.654	7.476	0.073	-166.2
L14	Line	-57.702	-40.906	0.18	143.3
L12	Line	40.545	40.813	0.142	-44.7

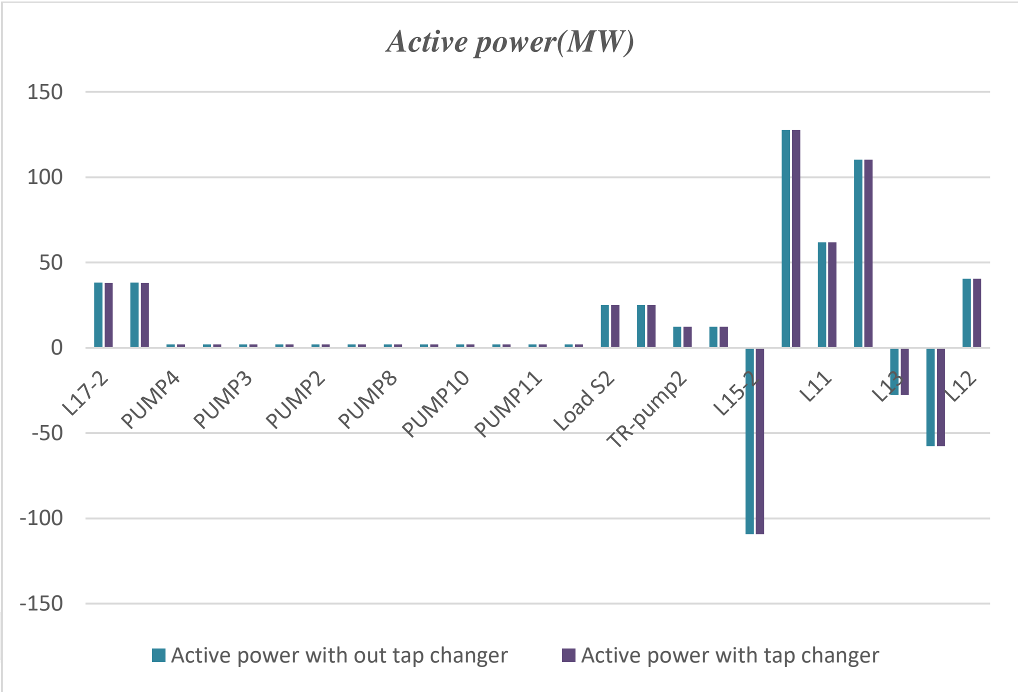

Figure 8.30 Results active power synchronous machine with& without Tap changer

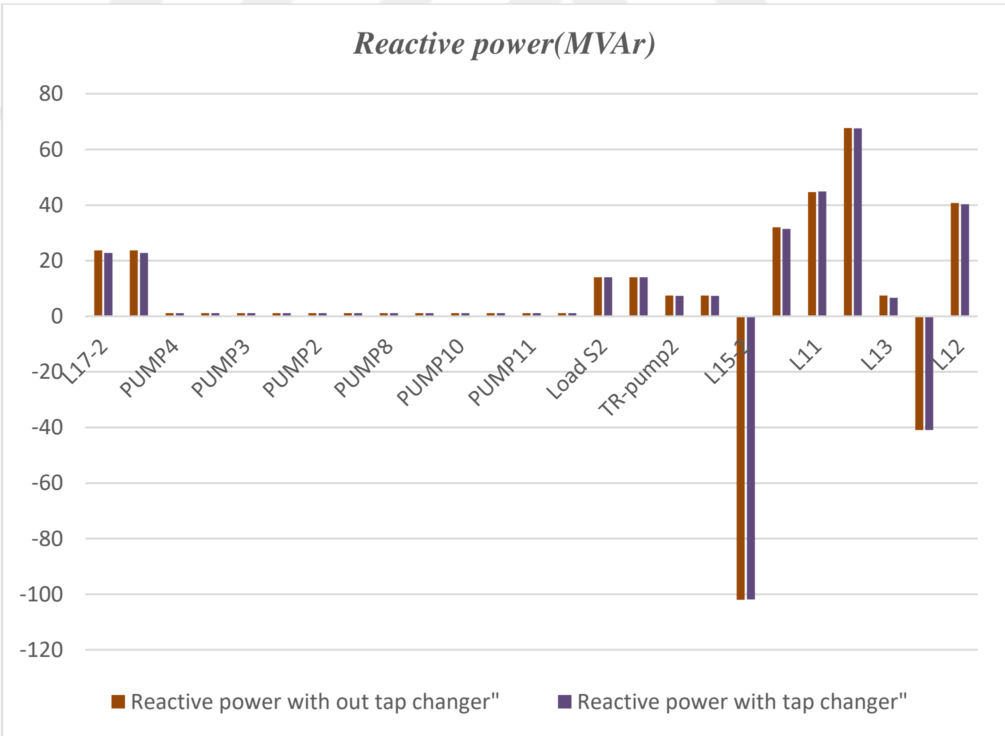

Figure 8.31 Results reactive power with synchronous machine with & without tap changer.

8.9 Case Study (7) Pump-Station with Capacitor

From the scenario of power flow represented by the present power Tr with Tap changer into our network and on tap changer at load transformer adding a capacitor. to reduce reactive power losses by injection current with lead power factor reverse lagging current which leads to reduced total losses in our network (Figure 8.32)

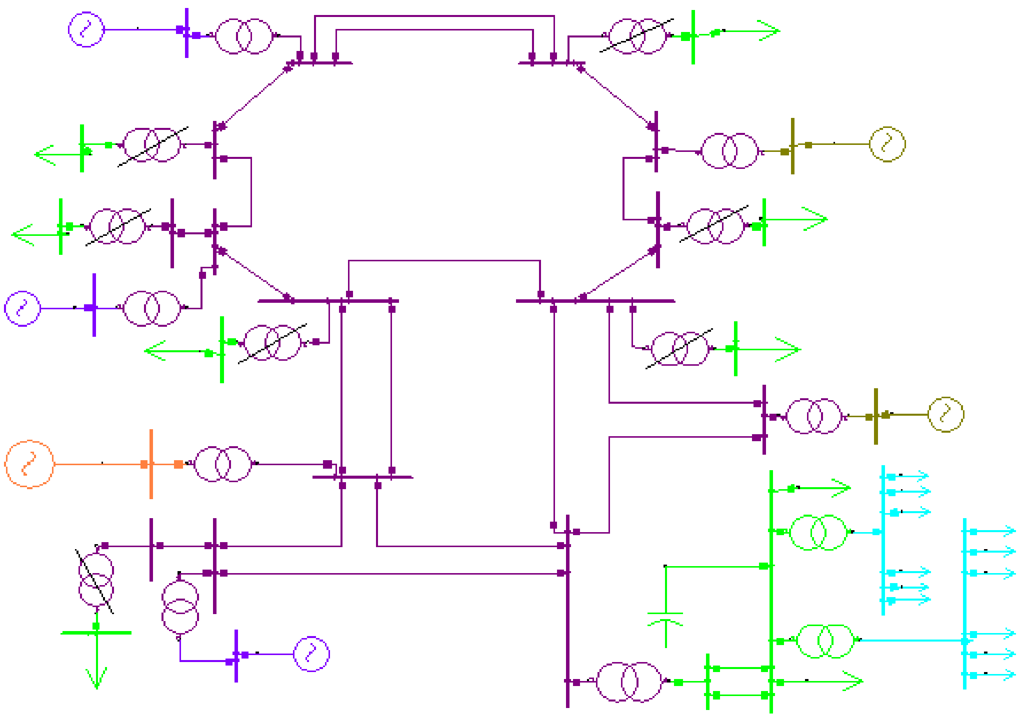

Figure 8.32 Single line diagram of the electrical network with 12 synchronous machine with Tap changer & adding capacitor.

Load Flow converged after 12 iterations, Network MW Losses=47.990014, Network MVAR Losses=237.351352 (Figure 8.33) (Table 8.17) (Figure 8.34) (Table 8.18) (Figure 8.35) (Figure 8.36).

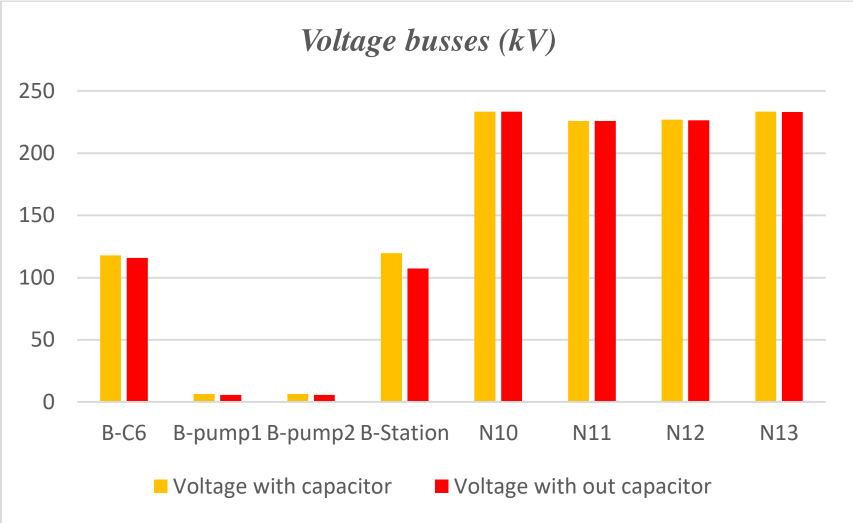

Figure 8.33 Results voltage buses synchronous machine with &without capacitor.

Table 8.17 Results voltage 220 kV of buses pump buses after connecting capacitor.

Name	**U kV**	**U %**	**U angle º**
B-C6	117.873	97.42	-12.7
B-pump1	6.388	96.79	-33.6
B-pump2	6.388	96.79	-33.6
B-Station	119.76	98.98	-32
N10	233.491	106.13	-1.3
N11	225.914	102.69	-6.1
N12	226.945	103.16	-3.6
N13	233.321	106.05	-3.3

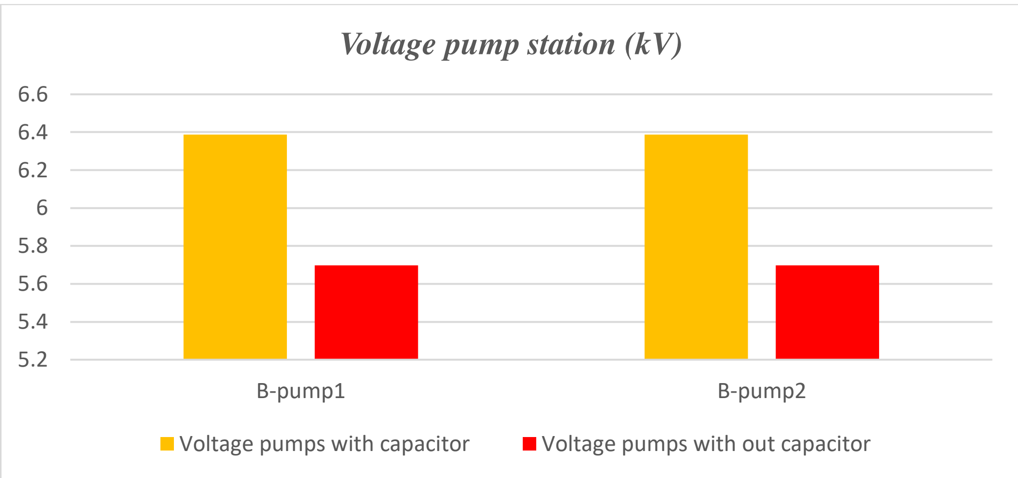

Figure 8.34 Results voltage buses 6.6 kV with &without effect capacitor.

Table 8.18 Results of P&Q of transmission lines and pump with capacitor

Name	Type	P	Q	I	Angle
		MW	MVAr	KA	o
L17-1	Line	143.145	-7.472	0.702	-9.8
L17-2	Line	143.145	-7.472	0.702	-9.8
PUMP1	Load	2	1.1	0.206	-62.4
PUMP4	Load	2	1.1	0.206	-62.4
PUMP5	Load	2	1.1	0.206	-62.4
PUMP2	Load	2	1.1	0.206	-62.4
PUMP6	Load	2	1.1	0.206	-62.4
PUMP3	Load	2	1.1	0.206	-62.4
PUMP7	Load	2	1.1	0.206	-62.4
PUMP8	Load	2	1.1	0.206	-62.4
PUMP11	Load	2	1.1	0.206	-62.4
PUMP12	Load	2	1.1	0.206	-62.4
PUMP10	Load	2	1.1	0.206	-62.4
PUMP9	Load	2	1.1	0.206	-62.4
Load S2	Load	25	14	0.138	-61.3
TR-pump1	2W Transformer	12.354	7.416	0.069	-63
TR-pump2	2W Transformer	12.354	7.416	0.069	-63
Load-S1	Load	25	14	0.138	-61.3
L15-2	Line	-128.925	-99.341	0.428	136.7
L10-2	Line	141.688	31.113	0.359	-13.7
L11	Line	35.94	46.68	0.151	-58.5
L15-1	Line	130.092	66.32	0.371	-30.6
L14	Line	-13.517	-46.883	0.124	102.5
L13	Line	100.219	-7.455	0.256	0.7
L12	Line	85.022	35.384	0.228	-25.9

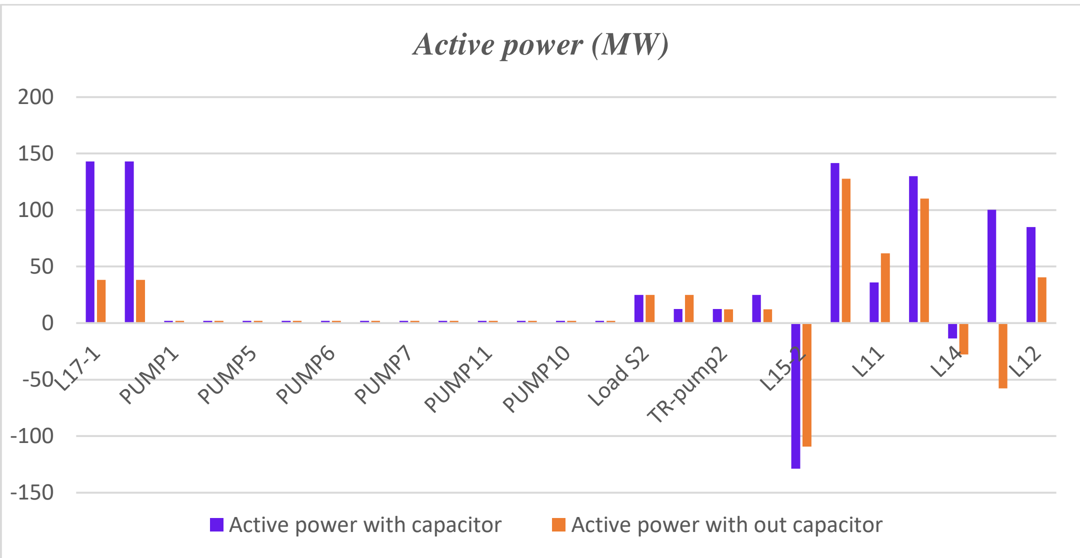

Figure 8.35 Results active power synchronous machine with &without capacitor.

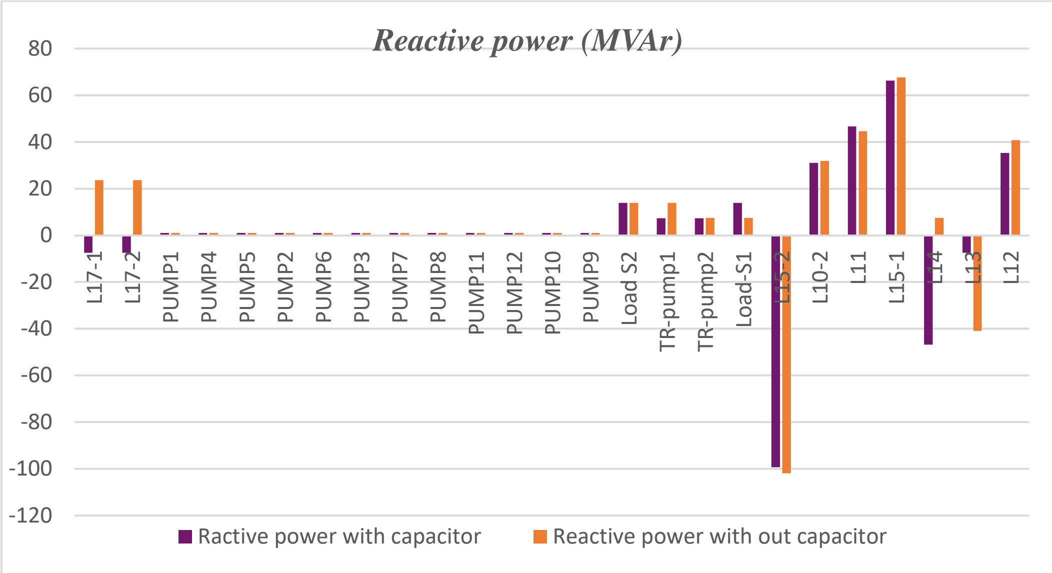

Figure 8.36 Results reactive power synchronous machine with &without capacitor.

8.10 Case Study (8) Pump-Station with SVC

From the scenario of power flow represented by the present power Tr with Tap changer into our network and off tap changer at load transformer adding SVC static at Power electronics are used by the SVC Static Var Compensator (SVC), a power quality device, to regulate the reactive power flow of the electrıcal network to which it's attached. On electrical systems, it can offer quick reactive power correction (Figure 8.37).

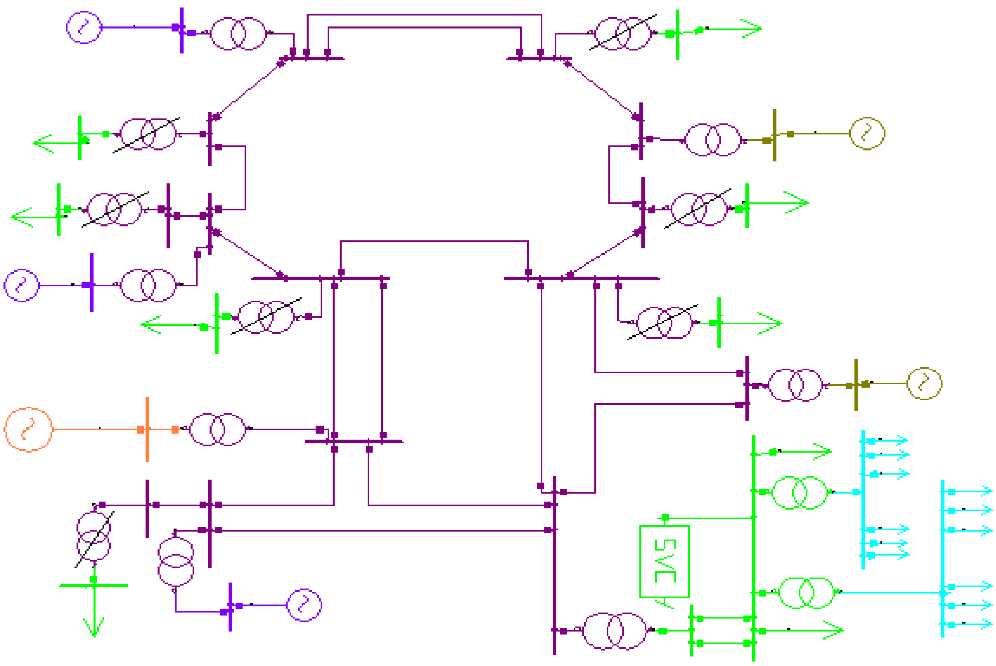

Figure 8.37 Single line diagram of the electrical network with 12 synchronous machine without Tap changer and adding SVC.

Load Flow converged after 12 iterations, Network MW Losses=30.672734, Network MVAR Losses=79.548672 (NEPLAN guide) (Figure 8.38) (Table 8.19) (Figure 8.39) (Figure 8.40) (Table 8.20) (Figure 8.41).

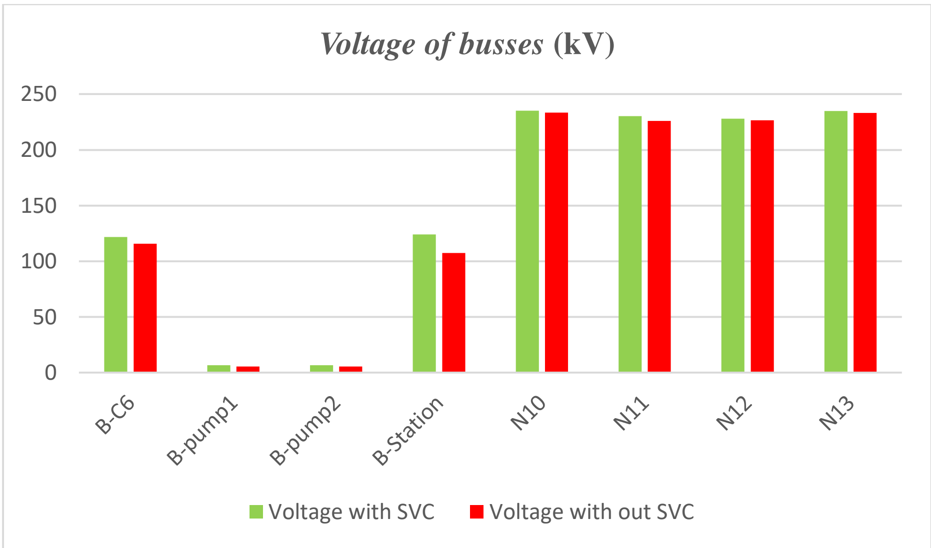

Figure 8.38 Results voltage busses synchronous Machin with &without SVC.

Table 8.19 Results voltage 220 kV of buses after connecting transformers present Tap changer and tap off and adding SVC.

Name	U	U	U angle
	kV	%	°
B-C6	121.818	100.68	-2.4
B-pump1	6.626	100.4	-8.9
B-pump2	6.626	100.4	-8.9
B-Station	124.025	102.5	-7.4
N10	235.247	106.93	3.5
N11	230.368	104.71	-0.8
N12	228.03	103.65	-1.4
N13	234.824	106.74	0.5

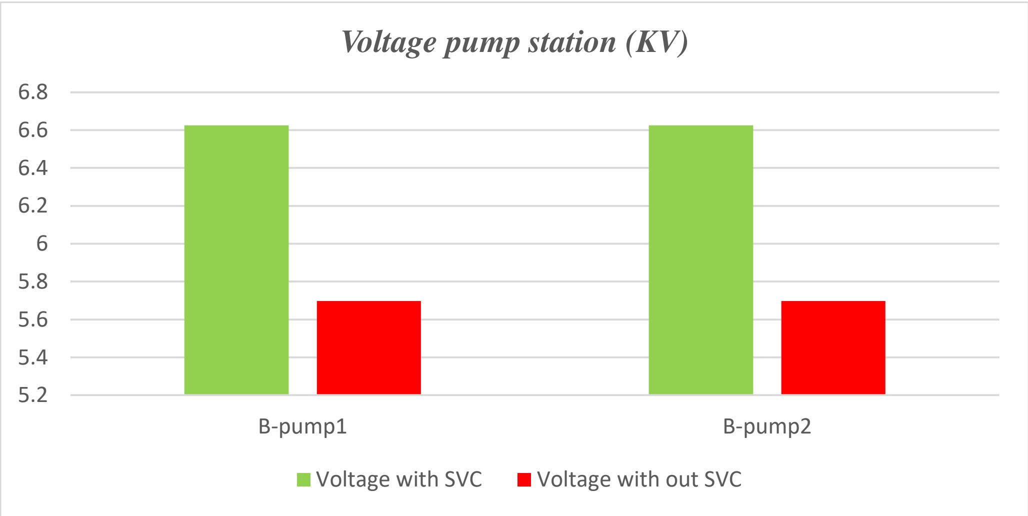

Figure 8.39 Results voltage buses 6.6 kV with &without effect SVC.

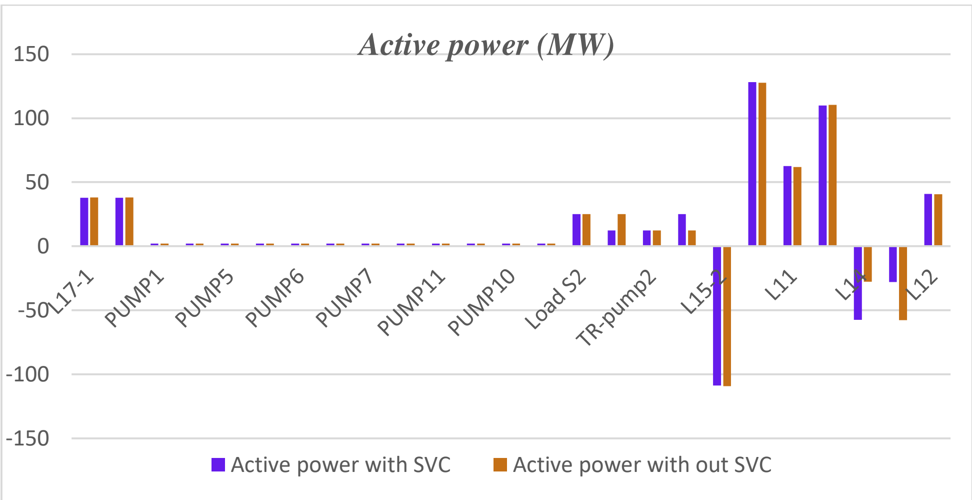

Figure 8.40 Results active power into lines before & after connected SVC.

Table 8.20 Results voltage buses and pump after connect transformers without-tap and adding SVC system.

Name	Type	P	Q	I	Angle
		MW	MVAr	KA	º
L17-1	Line	37.943	-14.477	0.192	18.4
L17-2	Line	37.943	-14.477	0.192	18.4
PUMP1	Load	2	1.1	0.199	-37.7
PUMP4	Load	2	1.1	0.199	-37.7
PUMP5	Load	2	1.1	0.199	-37.7
PUMP2	Load	2	1.1	0.199	-37.7
PUMP6	Load	2	1.1	0.199	-37.7
PUMP3	Load	2	1.1	0.199	-37.7
PUMP7	Load	2	1.1	0.199	-37.7
PUMP8	Load	2	1.1	0.199	-37.7
PUMP11	Load	2	1.1	0.199	-37.7
PUMP12	Load	2	1.1	0.199	-37.7
PUMP10	Load	2	1.1	0.199	-37.7
PUMP9	Load	2	1.1	0.199	-37.7
Load S2	Load	25	14	0.133	-36.6
TR-pump1	2W Transformer	12.37	7.405	0.067	-38.3
TR-pump2	2W Transformer	12.37	7.405	0.067	-38.3
Load-S1	Load	25	14	0.133	-36.6
L15-2	Line	-108.924	-100.621	0.387	134.2
L10-2	Line	128.083	13.039	0.316	-2.3
L11	Line	62.561	53.818	0.207	-41.5
L15-1	Line	109.846	65.598	0.324	-32.2
L14	Line	-57.553	-41.944	0.18	142.6
L13	Line	-28.104	-23.299	0.092	139
L12	Line	40.733	19.993	0.112	-25.7

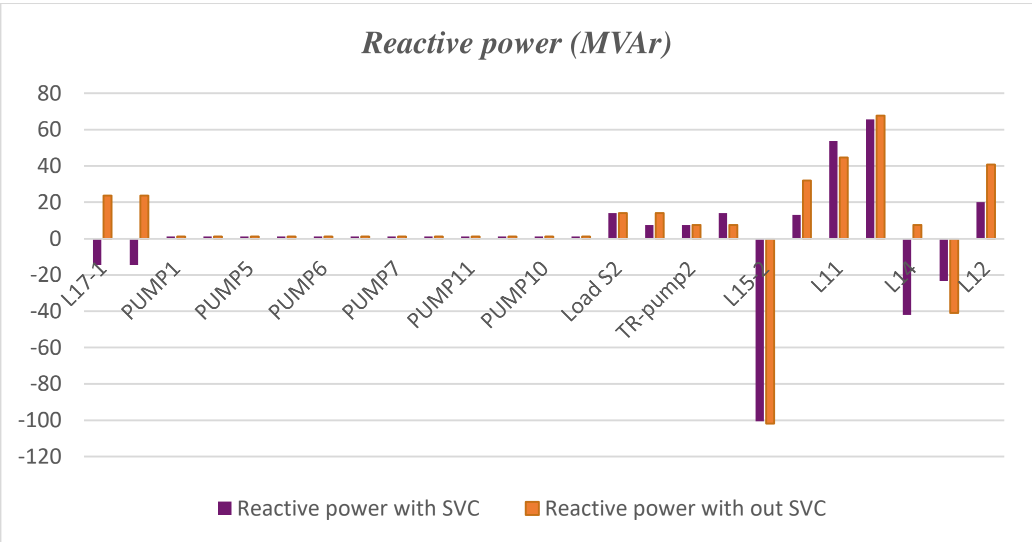

Figure 8.41 Results of reactive power into lines before & after connected SVC.

8.11 Case Study (9) Pump-Station with UPFC

From the scenario of power flow represented by the present power Tr with Tap changer into our network and off tap changer at load transformer and adding UPFC. The UPFC is a device which use to control same time all three parameters of line power flow (line impedance, voltage, and phase angle) (Figure 8.42) (Figure 8.43) (Table 8.21) (Figure 8.44) (Table 8.22) (Figure 8.45) (Figure 8.46).

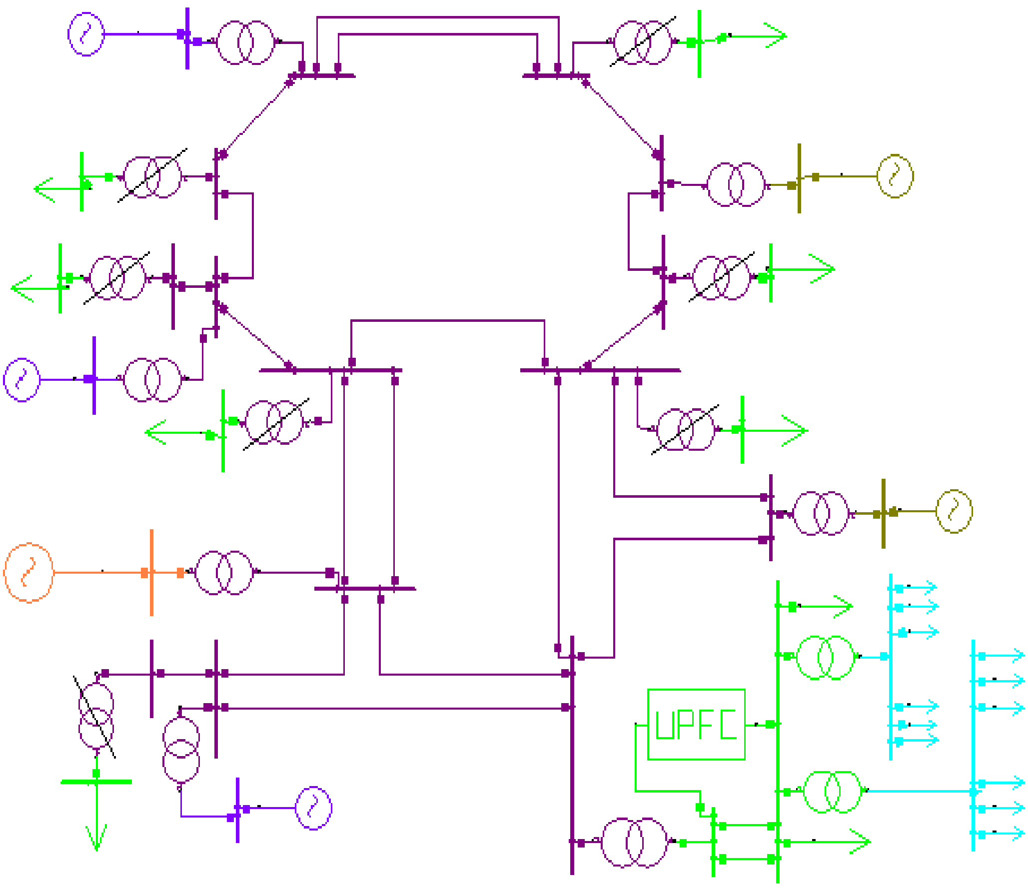

Figure 8.42 Single line diagram of the electrical network with 12 synchronous machine without Tap changer and adding UPFC.

Load Flow converged after 19 iterations, Network MW Losses=30.720203, Network MVAR Losses=25.627707 (Neplan guide).

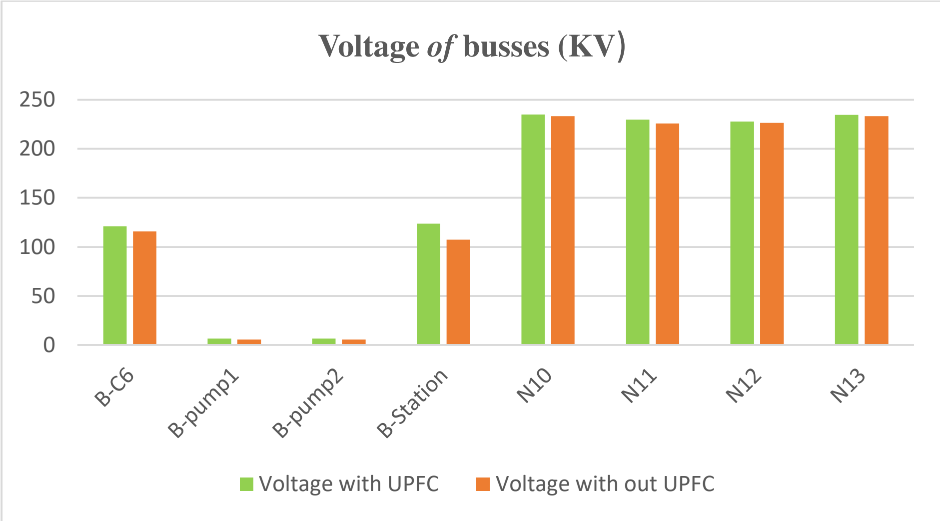

Figure 8.43 Results voltage busses synchronous machine with &without UPFC.

Table 8.21 Results voltage 220 kV of buses pump after connecting transformers present Tap changer and adding UPFC.

Name	U kV	U %	U angle °
B-C6	121	100	-2.4
B-pump1	6.6	100	0.3
B-pump2	6.6	100	0.3
B-Station	123.557	102.11	1.8
N10	234.942	106.79	3.5
N11	229.701	104.41	-0.7
N12	227.77	103.53	-1.4
N13	234.578	106.63	0.5

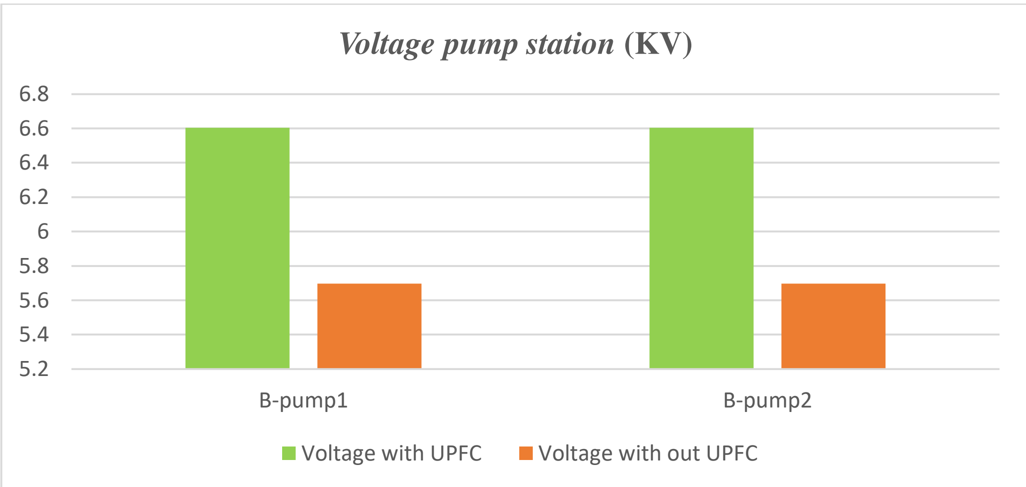

Figure 8.44 Results voltage buses 6.6 kV with &without effect UPFC.

Table 8.22 Results voltage buses and pump after connect transformers with present Tap changer and adding UPFC.

Name	Type	P	Q	I	Angle
		MW	MVAr	KA	º
L17-1	Line	-34.693	-4.243	0.167	170.6
L17-2	Line	-34.693	-4.243	0.167	170.6
PUMP1	Load	2	1.1	0.2	-28.2
PUMP4	Load	2	1.1	0.2	-28.2
PUMP5	Load	2	1.1	0.2	-28.2
PUMP2	Load	2	1.1	0.2	-28.2
PUMP6	Load	2	1.1	0.2	-28.2
PUMP3	Load	2	1.1	0.2	-28.2
PUMP7	Load	2	1.1	0.2	-28.2
PUMP8	Load	2	1.1	0.2	-28.2
PUMP11	Load	2	1.1	0.2	-28.2
PUMP12	Load	2	1.1	0.2	-28.2
PUMP10	Load	2	1.1	0.2	-28.2
PUMP9	Load	2	1.1	0.2	-28.2
Load S2	Load	25	14	0.134	-27.1
TR-pump1	2W Transformer	12.369	7.406	0.067	-28.8
TR-pump2	2W Transformer	12.369	7.406	0.067	-28.8
Load-S1	Load	25	14	0.134	-27.1
L15-2	Line	-109.048	-101.448	0.39	134
L10-2	Line	128.032	15.624	0.317	-3.4
L11	Line	62.537	53.378	0.207	-41.2
L15-1	Line	109.982	66.606	0.326	-32.6
L14	Line	-57.609	-41.958	0.181	142.6
L13	Line	-28.149	-19.081	0.086	144.5
L12	Line	40.67	23.02	0.115	-29

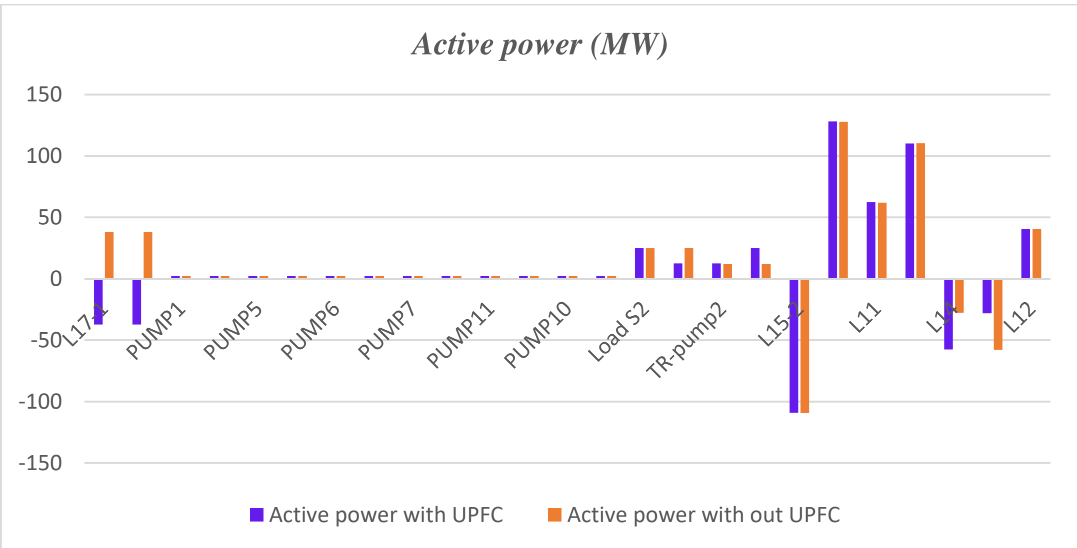

Figure 8.45 Results of active power into lines before & after connected UPFC.

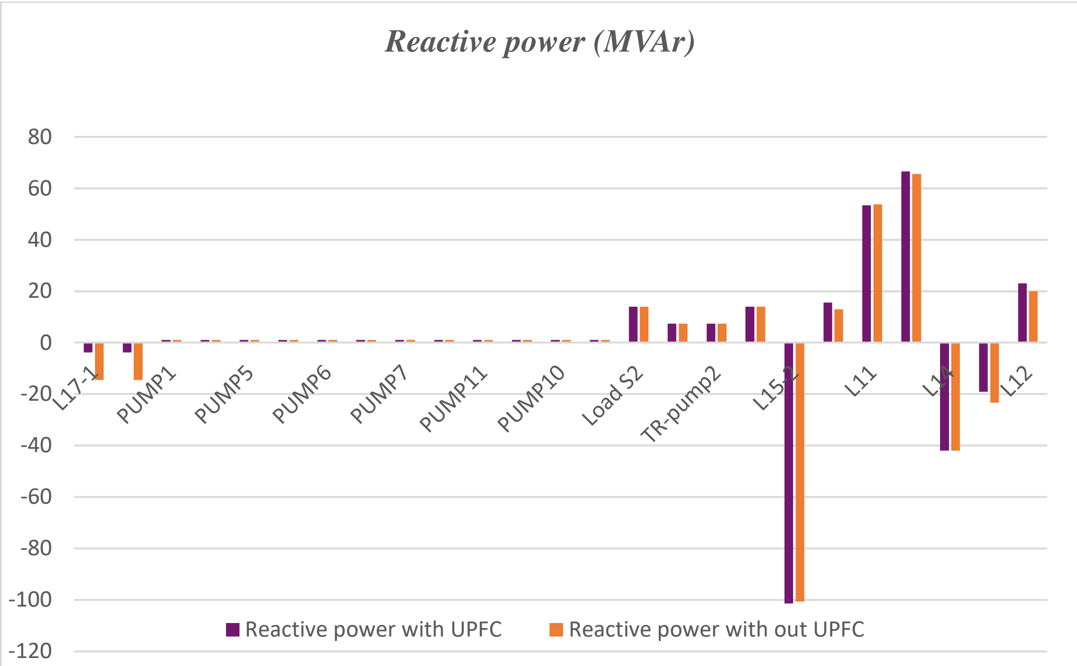

Figure 8.46 Results of reactive power into lines before & after connected UPFC.

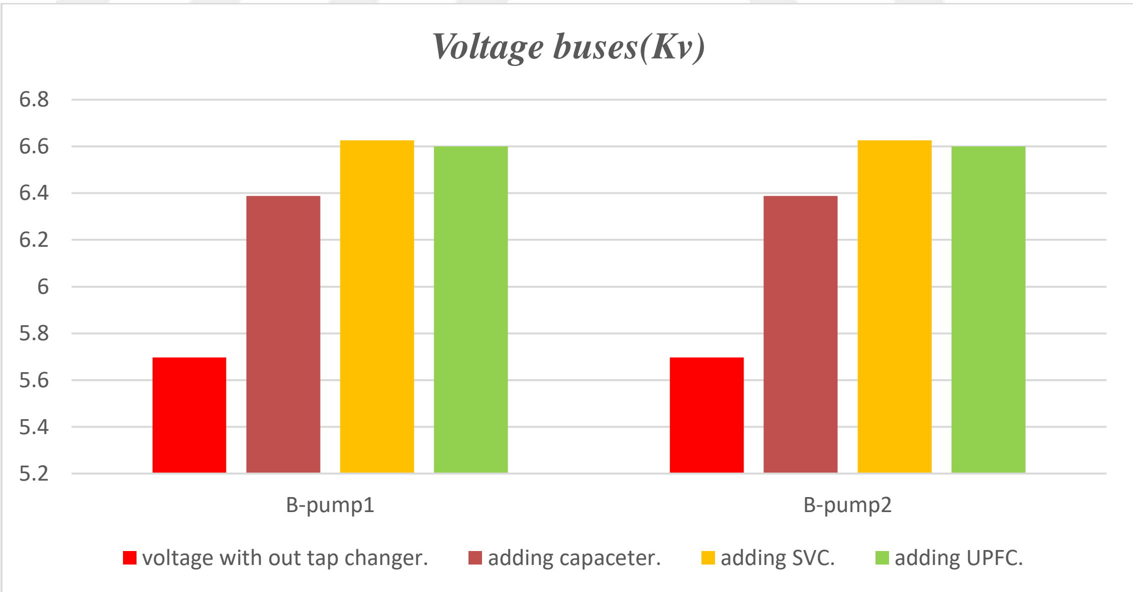

Figure 8.47 Results voltage busses synchronous Machine after modifying.

8.12 Case Study (10) Harmonic Analysis

From the scenario of power flow represented by the present power, This section deals with the problems of the appearance of harmonics in pumps due to the presence of soft start systems, power transformers, cables, and nonlinear load which leads to the pollution of voltages and the flow of harmonics to all buses of the electrical system as below in the Figure 8.48.

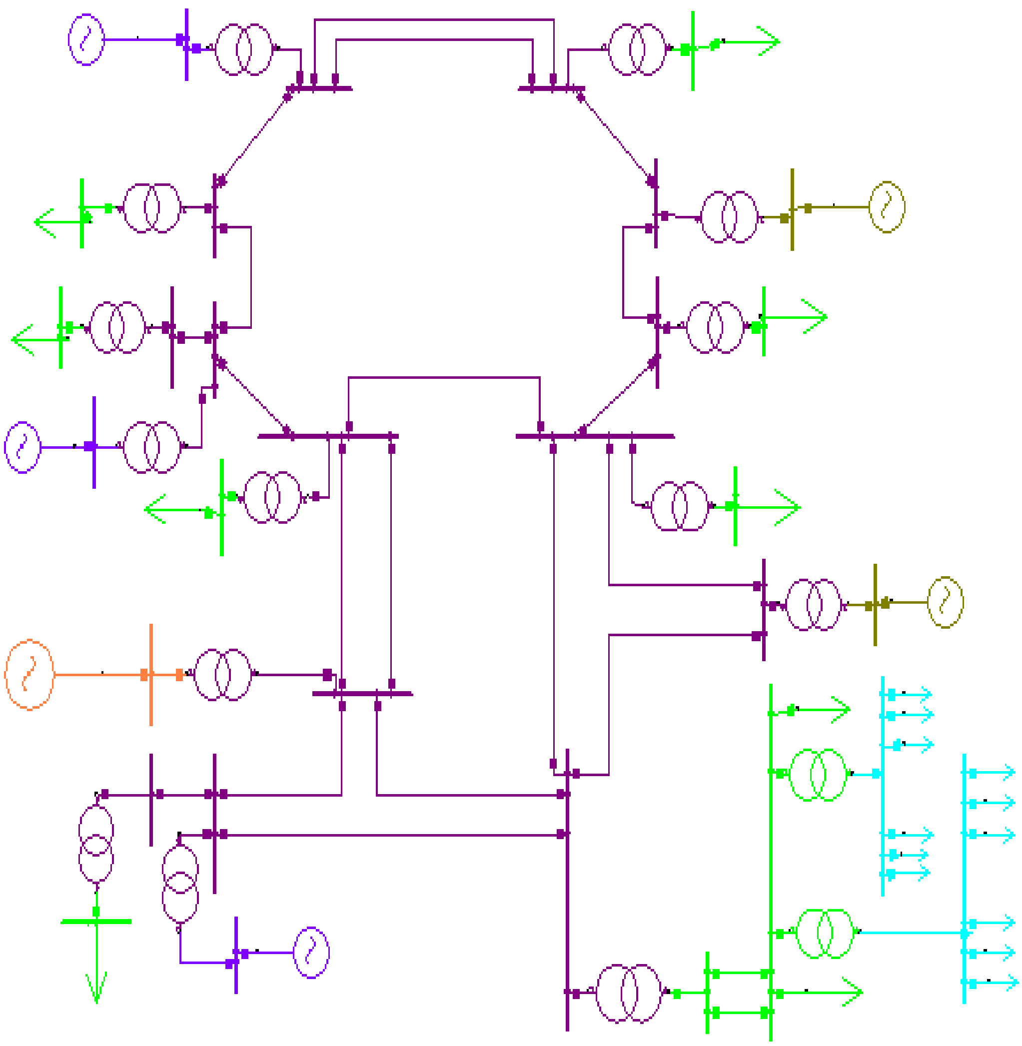

Figure 8.48 Single line diagram of the electrical network with 12 synchronous machine with harmonic analysis

Harmonics are a common power quality distortion that has gained daily popularity in recent years. They have various distorting effects in a wide in all aspects of life. In this case, we can note problems with the appearance of harmonics in pumps (1, 2, 4, 7, 8) shown in Figure 6.48 due to the presence of soft start systems electronic devices, which leads to the pollution of voltages and transfer harmonics to all buses of the electrical system as shown in the tables to solve the problem we are using 4 passive filters that connect each tow with the busbar of the pump after the Harmonic filter (Grainger and Spencer 1994) (Figure 8.52) (Figure 8.49) (Figure 8.50) (Figure 8.51).

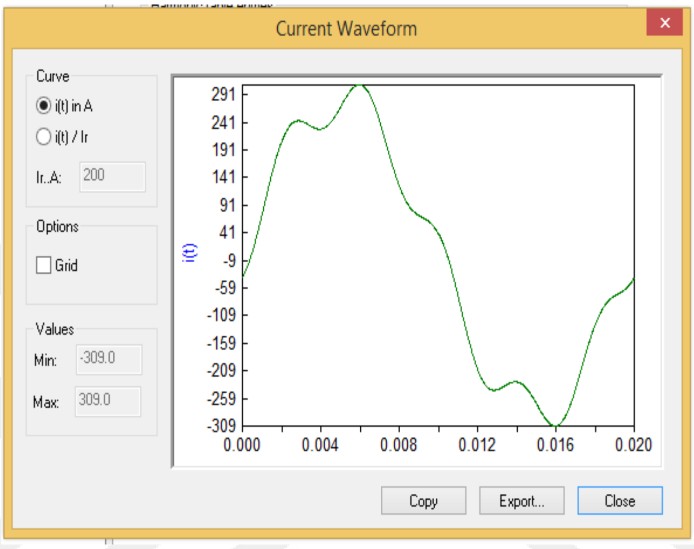

Figure 8.49 Curve of harmonic PUMP 1.

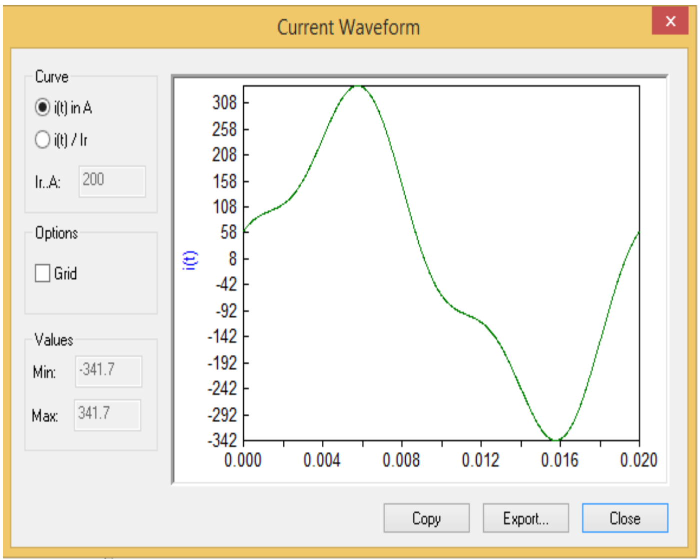

Figure 8.50 Curve of harmonic PUMP 2.

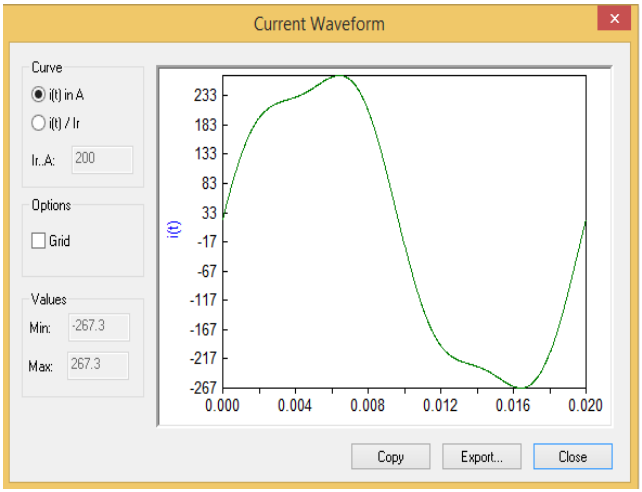

Figure 8.51 Curve of harmonic PUMP 3.

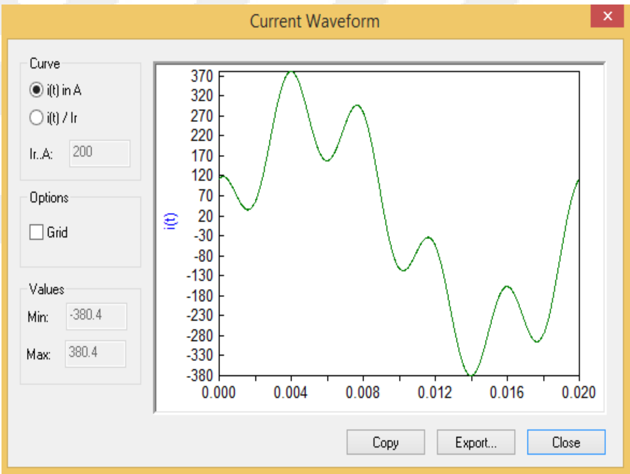

Figure 8.52 Curve of harmonic PUMP 4.

8.12.1 Effect of harmonic analysis

Harmonics are voltage and current distortions brought on by nonlinear network loads. Power electronics components in circuits such as Furthermore, non-linear electrical loads, properties that result in harmonic distortions are generally problematic. IEEE standard 519-2014 states that a low-voltage system must be assessed in terms of harmonics if the total harmonic distortion (THD) at the point of common connection (PCC) is greater than 8% (El-Hawary 2008) (Table 8.23) (Table 8.24). This is applicable to both voltage and current (Figure 8.52) (Table 8.25) (Table 8.26) (Figure 8.53) (Figure 8.54). The voltage's total harmonic distortion is stated as, Equation (8.10)

$$THDV=\frac{1}{U1}(\sum_{n=2}^{\infty} U_n^2) \quad (8.10)$$

Total harmonic distortion for current expressed as, Equation (8.11)

$$THDi=\frac{1}{I1}(\sum_{n=2}^{\infty} U_n^2) \quad (8.11)$$

Table 8.23 Parameters of harmonic in to Pump-motor.

Element	Type	THDi	Irms	f
Name		%	A	HZ
PUMP1	Load	15.06	201.45	250
PUMP11	Load	35.14	211.15	150
PUMP2	Load	25.1	205.39	150
PUMP3	Load	15.06	201.45	150
PUMP4	Load	23.09	204.45	150
PUMP6	Load	5.02	199.46	250
PUMP7	Load	40.16	214.67	250
PUMP9	Load	5.02	199.46	350

Table 8.24 Parameters of harmonic in to buses.

Name	THD	f	U	u	U angle
	%	HZ	V	%	º
B-pump1	1.56	150	102.438	1.55	194.83
B-pump2	2.07	150	74.655	1.13	233.5
B-Station	1.1	150	897.088	0.79	208.87
N1	0.64	150	217.946	0.1	203.09
N10	0.47	150	241.196	0.1	205.94
N11	0.62	150	381.716	0.17	206.17
N12	0.58	150	228.447	0.1	204.64
N13	0.51	150	246.153	0.11	205.23
N14	0.52	150	237.947	0.1	203.51
N2	0.33	150	80.936	0.03	201.29
N3	0.34	150	78.597	0.03	199.81
N4	0.35	150	58.652	0.03	196.59
N5	0.33	150	51.973	0.02	196.29
N6	0.35	150	55.38	0.03	196.05
N7	0.32	150	85.8	0.04	199.94
N8	0.46	150	143.688	0.07	200.31
N9	0.62	150	231.176	0.11	202.75

Adding filter to reduce effect of harmonic

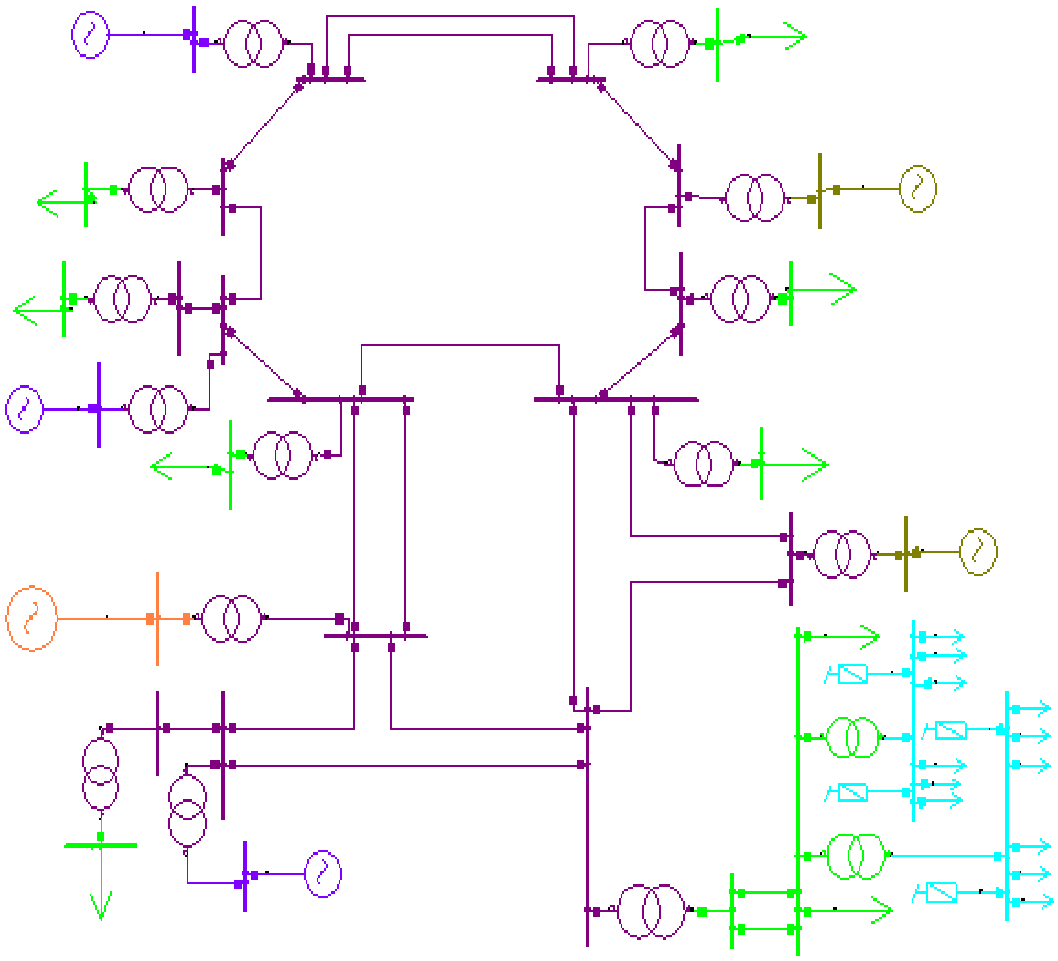

Figure 8.53 Single line diagram of the electrical network with 12 synchronous machine with harmonic analysis after adding filters

Table 8.25 Parameters of harmonic in to Pump-motor after adding filter

Element	Type	THDi	Irms	f
Name		**%**	**A**	**HZ**
PUMP1	Load	14.99	202.37	250
PUMP11	Load	34.98	212.03	150
PUMP2	Load	24.98	206.29	150
PUMP3	Load	14.99	202.37	150
PUMP4	Load	22.98	205.36	150
PUMP6	Load	5	200.39	250
PUMP7	Load	39.97	215.54	250
PUMP9	Load	5	200.39	350

Table 8.26 Parameters of harmonic in to of buses after adding filter

Name	THD	f	U	u	U angle
	%	HZ	V	%	°
B-pump1	1.16	150	75.913	1.15	184.44
B-pump2	1.47	150	50.393	0.77	230.55
B-Station	0.84	150	625.269	0.63	200.43
N1	0.41	150	151.908	0.07	194.66
N10	0.3	150	168.113	0.07	197.5
N11	0.41	150	266.056	0.12	197.74
N12	0.37	150	159.227	0.07	196.2
N13	0.32	150	171.568	0.07	196.79
N14	0.33	150	165.848	0.07	195.08
N2	0.21	150	56.412	0.02	192.85
N3	0.22	150	54.782	0.02	191.37
N4	0.23	150	40.88	0.02	188.15
N5	0.22	150	36.225	0.02	187.85
N6	0.23	150	38.6	0.02	187.61
N7	0.21	150	59.802	0.03	191.5
N8	0.3	150	100.15	0.05	191.88
N9	0.4	150	161.129	0.08	194.31

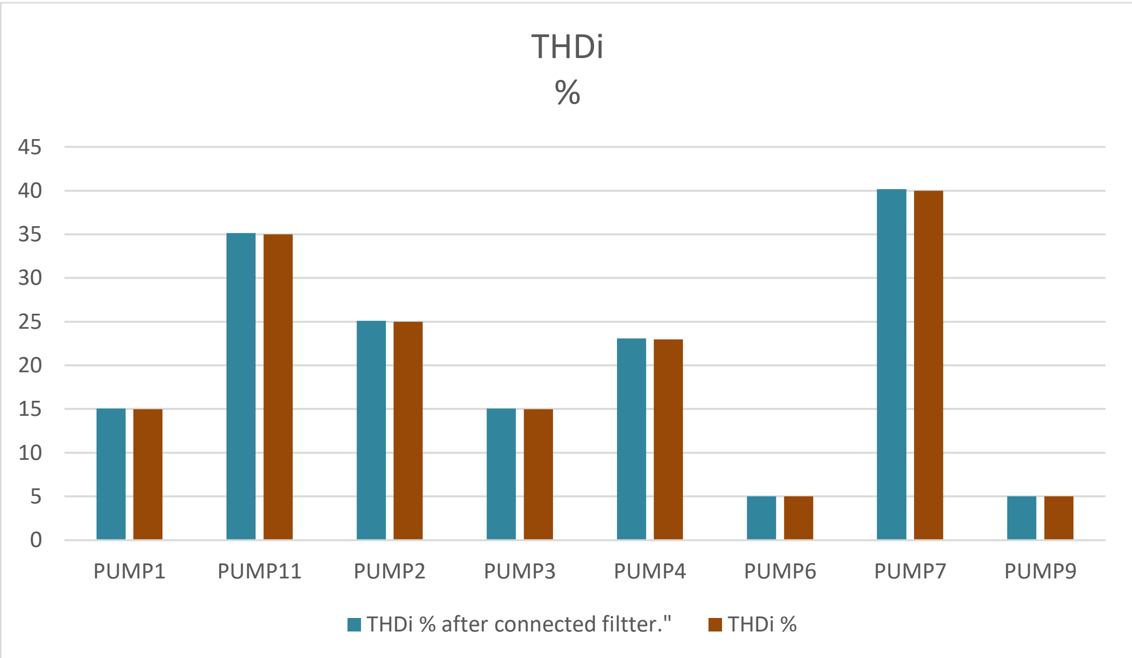

Figure 8.54 Results of THDi after and before adding filter at pumps.

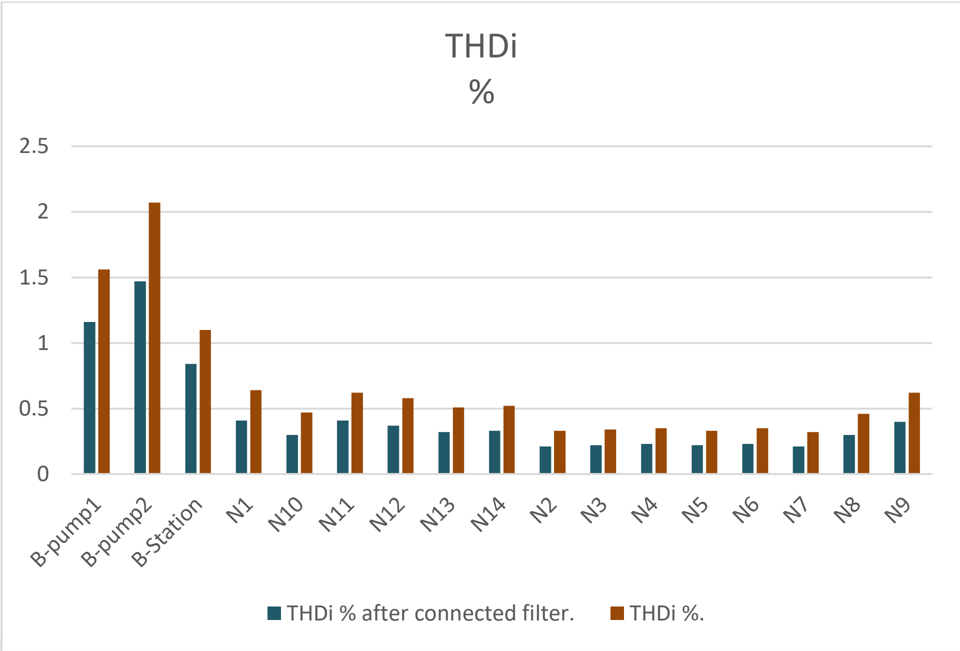

Figure 8.55 Results of THDi after and before adding filter at buses.

8.13 Case Study (11) Effect of Short Circuit:

Short circuit circumstances in the power system network are an example of a type of fault that causes important fiscal losses and decreases the electrical system's dependability. Rotating machines can cause an unusual condition known as an electrical fault. Human mistakes, and environmental factors such as transformer failure. These defects disturb electrical flows, harm equipment, and even lead to human deaths. In our system, we will use symmetric 3ph short circuit current, and symmetrical faults. These are extremely serious errors that rarely happen in power systems. Line-to-line faults and balanced faults are other names for them (L-L-L) (Figure 8.56) (Table 8.27).

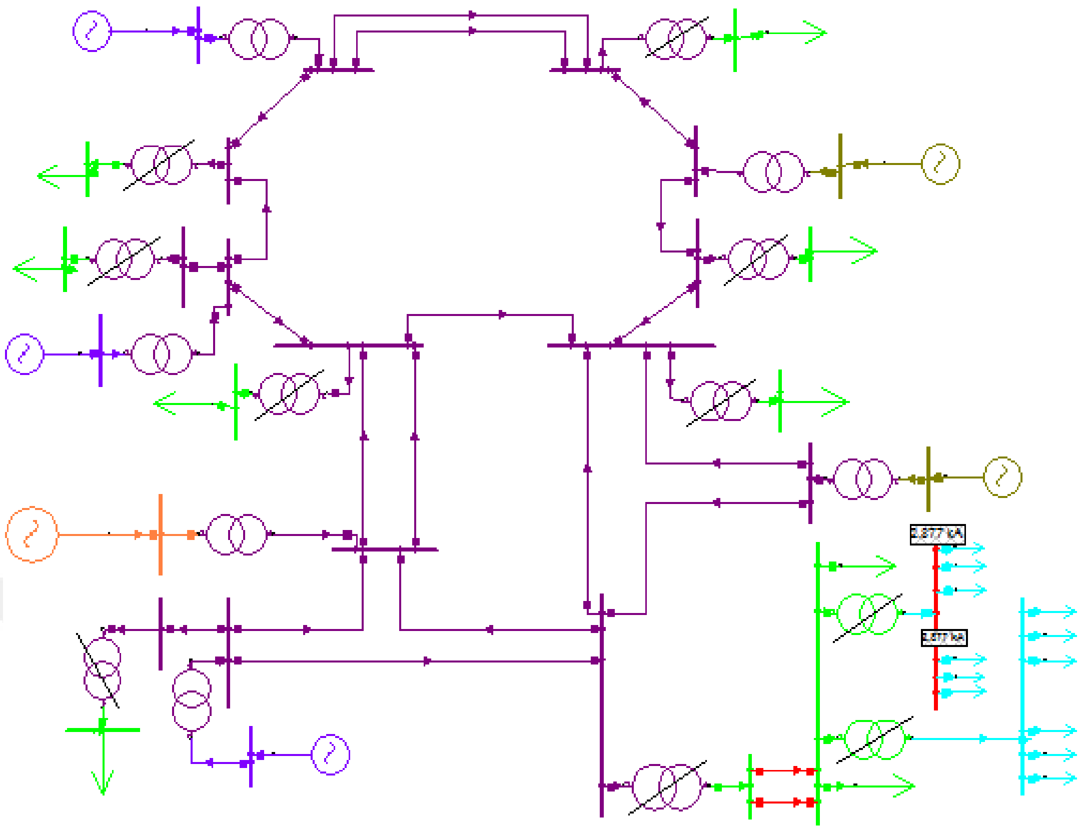

Figure 8.56 Single line diagram of the electrical network with 12 synchronous machine with short circuit.

Table 8.27 Results current short circuit and impedance.

From fault location	To Node Fault	Distance from fault	Element name	Un KV	IK"(RST) KA	ALK"(RST)	ip(RST) KA	Ib(RST) KA	IK(RST) KA	Ith(RST) KA	Idc(RST) KA	SK"(RST) MVA	Rf(012)	Xf(012)	R/X(012)	Fault Type	Method	CB delay	SC duration	SC duration
B-pump1	B-Station	0	TR-pump1	6.6	2.877	232.68	5.796	2.877	2.877	2.879	0.637	32.894	0.0374	0.0609	0.614	3phase fault	Superpos With LF	0.05	10	0.02

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We simulate a 3ph short current at the bus bar of pump1 and noted parameters of fault current as shown below (Figure 8.58) (Figure 8.57)

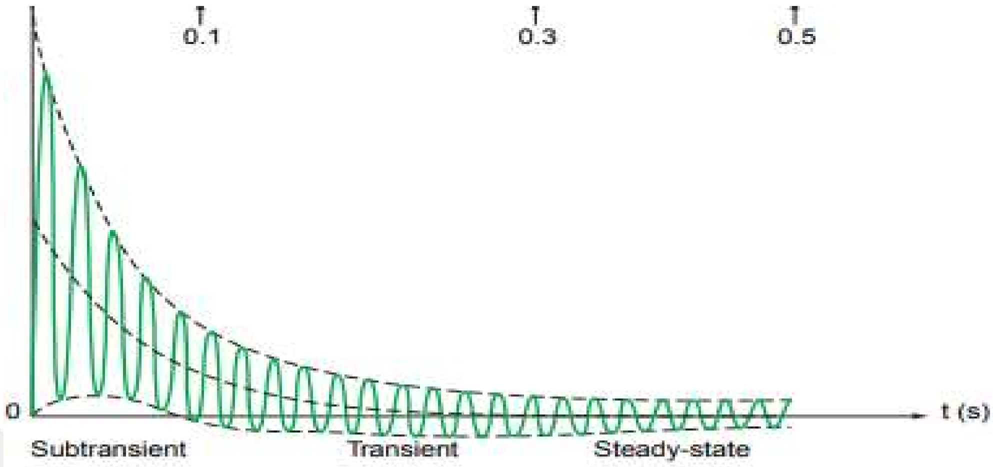

Figure 8.57 Parameters 3ph short current at bus of fault current.

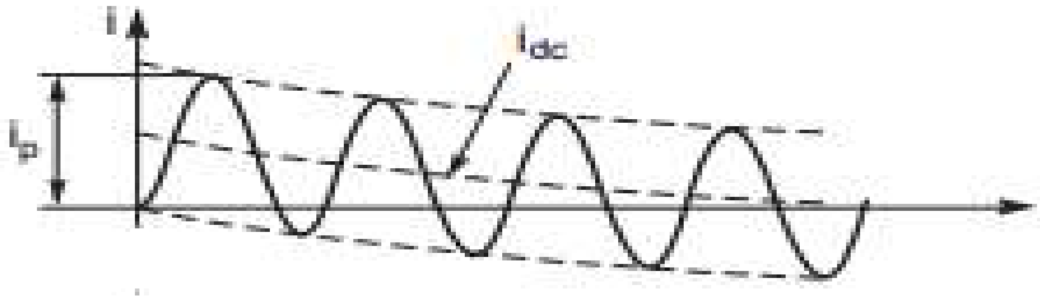

Figure 8.58 Symmetrical short circuit current.

Adding impedance has RLC as series impedance with the load which leads to an increase in the total impedance of the short circuit and reduced value of short circuit current as Figure 8.59 below (Figure 8.60) (Figure 8.61) (Table 8.28).

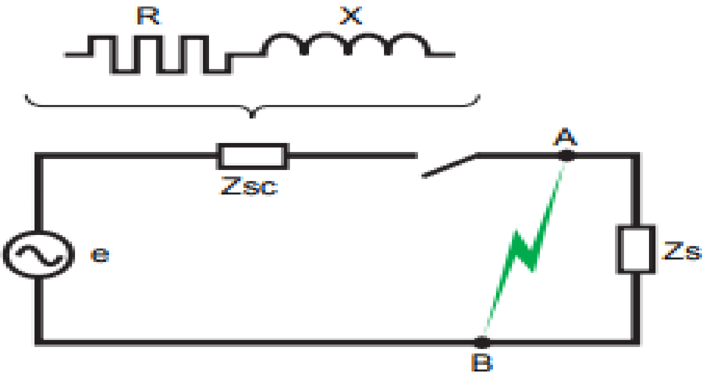

Figure 8.59 RLC as series impedance with load.

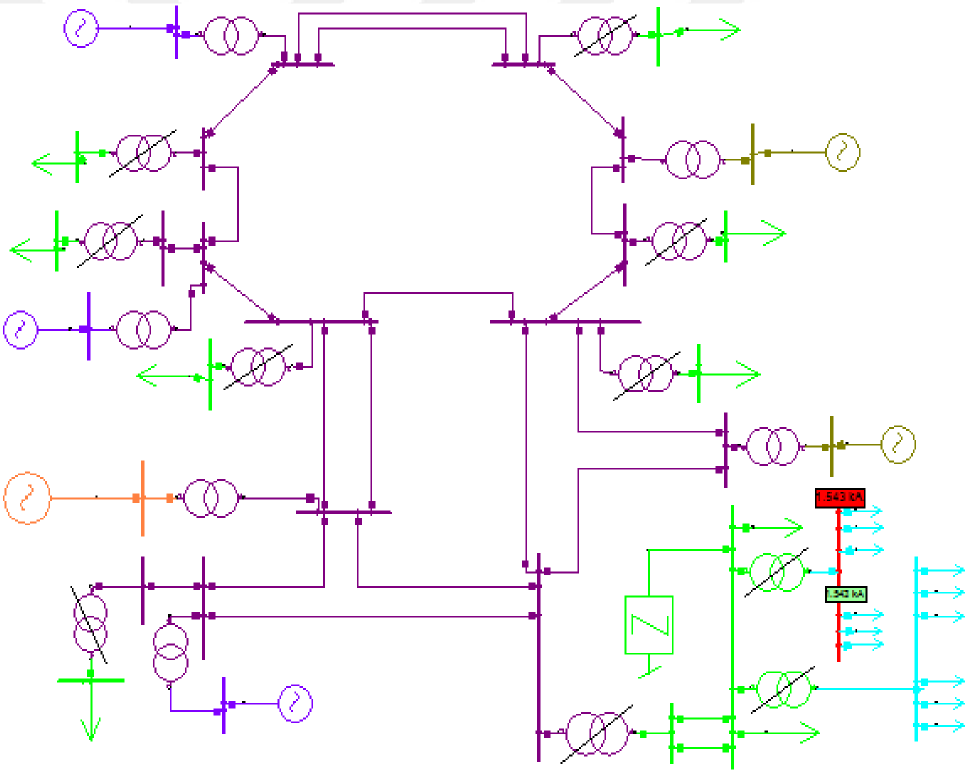

Figure 8.60 Single line diagram of the electrical network with 12 synchronous machine with short circuit after adding impedance.

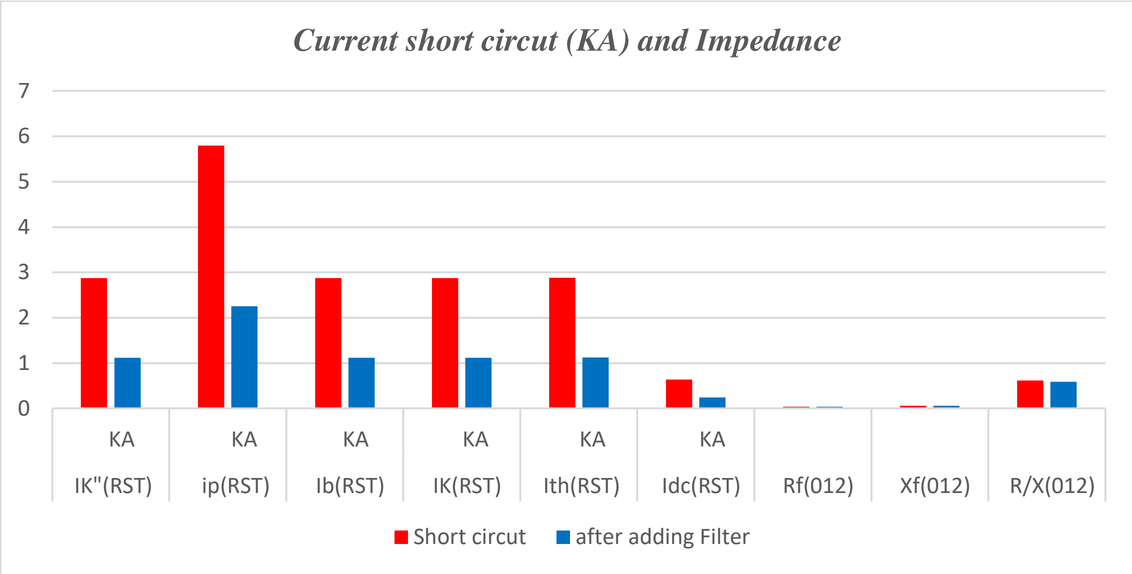

Figure 8.61 Results current short circuit and impedance after & before adding impedance.

Table 8.28 Results current short circuit and impedance after adding impedance .

From fault location	To Node Fault	Distance from fault	Element name	Un KV	IK"(RST) KA	ALK"(RST)	ip(RST) KA	Ib(RST) KA	IK(RST) KA	Ith(RST) KA	Idc(RST) KA	SK"(RST) MVA	Rf(012)	Xf(012)	R/X(012)	Fault Type	Method	CB delay	SC duration	SC duration
B-pump1	B-Station	0	TR-pump1	6.6	1.12	193.65	2.253	1.12	1.12	1.121	0.245	12.806	0.0354	0.0605	0.586	3phase fault	Superpos With LF	0.05	10	0.02

9. CONCLUSIONS AND RECOMMENDATION

9.1 Conclusion

- The network impedance calculation is necessary to determine the power flow vocabulary As the impedance is inversely proportional to both the active and reactive power, and the same applies to the rest of the details of the power flow through our observation of the practical results obtained by the NEPLAN program.
- It has been proven that reinforcing single-circuit transmission lines with dual-circuit transmission lines and reducing their impedance by half. This leads to increases in the active power flow and reduces the reactive power flow, thus reducing the losses resulting from the reactive power flow throughout the network.
- By reinforcing the power lines, the criterion (n-1) was proven, as the electrical circuit before strengthening the lines when any of the transmission lines were exposed to off-position due to an external accident or as a result of maintenance work, there is no alternative line that compensates for the loss of the lines out of work, and therefore we cannot achieve the standard (n-1) to transmit power.
- Synchronous machines used in pumping stations need a constant voltage of the stator and rotor to achieve synchronization between them and the pumps work with high reliability without stopping, the defective external ones, which causes an increase in the drop levels of the supplied voltage from the national network to more than 5% of the nominal value of the supplied voltage, and thus to the loss of synchronization Pumping system stopped.
- Voltage regular (Tap changer) stop in the power transformers feeding the pumping stations leads to a decrease in the voltage and an increase in the value of the current drawn from the transmission lines, and thus a rise in the temperatures of the electrical equipment in the pumping stations to values more than 55 degrees Celsius.
- The use of FACT’S systems that are more effective than the classic systems to compensate for ineffective capacity losses. The impact of FACT's controllers on reactive power compensation, which assists in voltage recovery, helps to develop control system and compensation technology, which maintains voltage level within acceptable bounds. Connecting (SVC, UPFC) systems at pumping stations to

maintain the induction voltage level when the pumps start running. Where both SVC and UPFC systems were used in our research to obtain a better performance of the characteristics of power flow, and the practical results proved to obtain a better performance with the presence of these systems, with a preference for the work of the UPFC system in the electrical circuit that is the subject of our research.

- The emergence of harmonics in the network is linked to the presence of electronic sources used in water pumps, represented by the soft star. Harmonics are a common power quality distortion. They have various distorting effects in a wide in all aspects of life. In our research, we can note problems with the appearance of harmonics in pumps (1, 2, 4, 7, 8) due to the presence of soft start systems electronic devices, which leads to the pollution of voltages and transfer harmonics to all buses of the electrical system as shown in the tables to solve the problem we are using 4 passive filters that connect each tow with the busbar of the pump after the Harmonic filter
- In our system, we will use symmetric 3ph short circuit current, and symmetrical faults. Adding impedance has RLC as series impedance with the load which leads to an increase in the total impedance of the short circuit and the reduced value of short circuit current is more effective than the use of systems to reduce the influence of the fault current.
- There are many problems that the synchronous motor operating system is exposed to, and one of these problems is the change of frequencies and their impact on the work of the motors. We can address solution of this problem in the future by using the FACT'S system. The second problem is when the synchronous motor is overloaded beyond its capacity, the synchronization between the rotating magnetic field and the stator is lost and the motor stops. The researcher can solve these problems in the future.

9.2 Scientific Benefit

Maintaining the continuity and permanence of pump work without interruption and overcoming the problems of Interruption of the induction voltage of the pumps. The fact that the stations represent the only source of drainage in Iraq, with a total capacity of 400 MVA throughout Iraq, and a water drainage capacity of 10 million cubic meters per second, and the continuation of their work is considered a practical necessity.

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