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Transient Stability For Multi_Machine Power System

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Thanks and dedication

TO our family,

TO our friends,

TO mention all our teachers who contributed and participated in our formation, from primary
to present,

TO all those whom we love, who love us and all those whom we have known,

AND to those who share good memories.

we dedicate this work.

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ملخص

تركزت دراستنا على الجانب الحاسم للاستقرار في أنظمة متعددة الماكينات، حيث يتفاعل عدة مولدات وأحمال.
استخدمنا محاكاة كوندر لتقييم استقرار الشبكة، مع استخدامها أيضًا كأداة لنمذجة وتقييم استقرار الشبكة. من خلال دراسة استقرار العبور في أنظمة متعددة الماكينات، فحصنا التأثيرات على الشبكة وتحليل سلوكها الديناميكي بشكل مفصل. لقد قمنا بتغيير مواضع الخلل وقصر الدائرة التالية في بداية الشبكة ووسطها ونهايتها، كما قمنا بتغيير قيم الأحمال وزمن الانتقال في حالة الخلل في النهاية، تمكنا من تقييم النتائج المحصل عليها .

الكلمات المفتاحية: الشبكة الكهربائية ، الاستقرار ، الاستقرار العابر ، الآلات المتعددة ، محاكاة كوندر.

Abstract

Our study focused on the crucial aspect of stability within multi-machine systems, where multiple generators and loads interact. We used Kunder simulation to assess network stability, while using it as a tool to model and assess network stability. By examining the transient stability in multi-machine systems, we studied the impacts on the network and analyzed the dynamic behavior in detail. We have chosen different ways to observe the changes in our network, changing the short circuit position of the breakdown at the beginning, center and end of the network. We also changed the values of the loads and the transition time in the purlin. In the end, we were able to evaluate and analyze the results obtained.

Key words : Electrical network, Stability, transient stability, multimachine, kundur simulation.

Résumé

Notre étude s'est concentrée sur l'aspect crucial de la stabilité au sein des systèmes multi-machines, où plusieurs générateurs et charges interagissent. Nous avons utilisé la simulation Kundur pour évaluer la stabilité du réseau, tout en l'utilisant comme outil pour modéliser et évaluer la stabilité du réseau. En examinant la stabilité transitoire dans les systèmes multi-machines, nous avons étudié les impacts sur le réseau et analysé en détail le comportement dynamique. Nous avons choisi différentes manières d'observer les changements dans notre réseau, en modifiant la position de court-circuit de la panne au début, au centre et à la fin du réseau. Nous avons également modifié les valeurs des charges et le temps de transition dans la panne. En fin de compte, nous avons été en mesure d'évaluer et d'analyser les résultats obtenus.

Mots clés :Réseau électrique ,Stabilité, stabilité transitoire, multi_machine ,la simulation de kundur.

Contents

generaL introduction **1**

1 General information on electrical networks and the different types of faults **3**
1.1 Introduction: . . . 4
1.2 Electricity Systems Overview: . . . 4
1.3 Production of electrical energy: . . . 4
1.3.1 Main components are : . . . 5
1.3.2 Advantages of Electrical energy: . . . 5
1.3.3 Types of Generation: . . . 5
1.4 the types of central energy: . . . 5
1.4.1 Renewable Energy: . . . 5
1.4.2 Renewable Energy types: . . . 5
1.4.2.1 Wind energy: . . . 5
1.4.2.2 Hydro energy: . . . 6
1.4.2.3 Solar energy: . . . 6
1.4.3 Non-renewable energy: . . . 7
1.4.4 non-Renewable Energy types: . . . 7
1.4.4.1 Natural Gas: . . . 7
1.4.4.2 Nuclear energy: . . . 8
1.4.4.3 coal energy: . . . 8
1.5 Electrical Network construction: . . . 9
1.5.1 Transport networks: . . . 9
1.5.1.1 Transmission High Tension (THT) or Extra High Voltage (EHV): 9
1.5.1.2 High Tension (HT) or High Voltage (HV): . . . 9
1.5.1.3 Medium Tension (MT) or Medium Voltage (MV): . . . 9
1.5.2 Interconnection and transmission networks: . . . 10
1.5.3 Dispatch Network: . . . 10
1.6 Distribution networks (MT): . . . 10
1.6.1 Type of distribution networks: . . . 11
1.6.1.1 Medium Voltage Distribution Systems: . . . 11
1.6.1.2 Low voltage distribution systems: . . . 11
1.7 Classification and structure of electricity networks: . . . 11
1.7.1 Looped Network: . . . 11
1.7.2 Mesh Network: . . . 12
1.7.3 Radial or star networks: . . . 12
1.7.4 Master networks: . . . 13
1.8 Electrical System Topology: . . . 13
1.9 Defects in transmission lines: . . . 14
1.9.1 Presentations: . . . 14
1.9.2 The different types of defects: . . . 14

1.9.2.1 Single Phase Defects: . . . 14
1.9.2.2 Two-phase ground defects: . . . 14
1.9.2.3 Isolated two-phase defects: . . . 14
1.9.2.4 Three-phase defect: . . . 14
1.9.3 The different types of defects: . . . 15
1.9.3.1 Auto-extinguisher fault: . . . 15
1.9.3.2 Default rebooting: . . . 15
1.9.4 The most common defects: . . . 15
1.9.4.1 Overload: . . . 16
1.9.4.2 The short circuit: . . . 16
1.9.4.3 Surge: . . . 17
1.9.4.4 Lack of tension: . . . 18
1.9.5 The effects of defects: . . . 18
1.9.6 Elimination of defects: . . . 18
1.10 Conclusion: . . . 18

2 stability of electrical networks 20
2.1 Introduction: . . . 21
2.2 power System Stability: . . . 21
2.3 Stability of electrical energy networks: . . . 22
2.4 Stability classification: . . . 22
2.4.1 Power system stability : . . . 23
2.4.2 Voltage stability: . . . 23
2.4.2.1 Dielectric strength for small disturbances: . . . 24
2.4.2.2 Dielectric strength against large disturbances: . . . 24
2.4.3 Frequency stability: . . . 24
2.4.3.1 Transient Stability: . . . 24
2.4.3.2 small signal stability: . . . 25
2.4.3.3 rotor angle stability: . . . 25
2.5 instability in a power grid: . . . 26
2.6 Electricity System Instability Classification: . . . 26
2.7 solution of stability: . . . 27
2.8 Transient stability analysis method: . . . 28
2.8.1 numerical integration: . . . 28
2.8.1.1 Euler Method: . . . 28
2.8.1.2 Modified Euler method: . . . 29
2.8.1.3 Comparison between the modified Euler method and than the Euler method: . . . 30
2.8.1.4 Runge-Kutta Method Order 4 (RK4): . . . 30
2.8.1.5 Park's Transformation: . . . 31
2.8.2 Advantage of digital integration methods: . . . 31
2.8.3 Disadvantages of numerical integration methods: . . . 31
2.9 Conclusion: . . . 31

3 Multi machine system 32
3.1 Introduction: . . . 33
3.2 The Single Machine system: . . . 33
3.3 synchronous machine: . . . 34
3.3.1 Definition: . . . 34
3.3.2 The synchronous machine overviews: . . . 35

3.3.3 Construction of synchronous machines : . . . 36
3.3.3.1 Stator : . . . 36
3.3.3.2 rotor: . . . 37
3.3.4 Flux Linkage Equations: . . . 38
3.3.5 Voltage Equations: . . . 38
3.3.6 Torque Equation : . . . 39
3.3.7 Park's Transformation : . . . 40
3.4 Asynchronous machine: . . . 41
3.4.1 Definition: . . . 41
3.4.2 Construction of asynchronous machines: . . . 41
3.4.2.1 Stator: . . . 41
3.4.2.2 Rotor: . . . 42
3.5 The multi Machine system: . . . 42
3.5.1 Definition: . . . 42
3.6 the types of multi machines system: . . . 42
3.6.1 Power Grid Systems: . . . 43
3.6.2 Industrial Power Systems: . . . 43
3.7 Mechanical control: . . . 43
3.7.1 Structure of voltage regulator: . . . 43
3.7.2 speed control structure: . . . 44
3.7.3 power system stabilizer (PSS): . . . 44
3.8 Network performance equations during default: . . . 44
3.9 Network Modeling in the State Space: . . . 46
3.9.1 Second order model: . . . 46
3.9.2 Two-axis model with voltage and speed regulators: . . . 47
3.10 Conclusion: . . . 47

4 Kundur Simulation in MATLAB and the results 49
4.1 Introduction: . . . 50
4.2 The simulation : . . . 50
4.2.1 The role of the network elements: . . . 51
4.2.1.1 two-zone: . . . 51
4.2.1.2 the two-line: . . . 51
4.2.1.3 the four machines: . . . 51
4.2.1.4 the faults: . . . 51
4.2.2 An error occurred when starting the network: . . . 52
4.2.2.1 Voltage drop: . . . 52
4.2.2.2 Power surge: . . . 52
4.2.2.3 vibration: . . . 52
4.2.3 Errors in the middle of the network: . . . 52
4.2.3.1 Voltage instability: . . . 52
4.2.4 Error at end of network: . . . 52
4.2.4.1 Local effect: . . . 52
4.2.4.2 Changing the charges in the network multiplied in 0,1from Pa in the charge : . . . 60
4.2.4.3 Changing the charges in the network multiplied in 10 from Pa in the charge : . . . 66
4.2.4.4 changing in the transition time in the short circuit the fault : . . . 73
4.3 Conclusion : . . . 79

General conclusion **80**

List of Figures

1.1 diagram simplifies an electric network 4
1.2 general structure of Wind energy 6
1.3 diagram of Hydro power plant 6
1.4 diagram of Solar energy 7
1.5 Gas Energy Center 8
1.6 diagram of coal energy 9
1.7 Electricity System Structure 11
1.8 Looped Network Structure 12
1.9 Mesh network structure. 12
1.10 Radial network structure. 13
1.11 Magisterial network structure. 13
1.12 Different types of defects 15
1.13 Resetting defect 15
1.14 general form of a short circuit current. 16
1.15 Types of short circuits. 17

2.1 System (Time Rotation Angle Plot) 22
2.2 Power System Stability Classification.[20] 23
2.3 variation of rotor angle 26
2.4 Instability events in an electrical grid. 27
2.5 Graphical interpretation of the Euler method. 29

3.1 A single machine system 34
3.2 Excitation system 34
3.3 Diagram of synchronous machine 35
3.4 Synchronous machine 36
3.5 Stator of synchronous machine 37
3.6 a synchronous machine parts 37
3.7 Structure of the voltage regulator 43
3.8 Speed control structure [26] 44
3.9 PSS power stabilizer model. 44

4.1 Kundur simulation of a two-section power system 51
4.2 Kundur simulation of a two-section power system with the fault in the begging . 53
4.4 the simulation Results :The fault In the begging 54
4.5 Kundur simulation of a two-section power system with the fault in the center . . 55
4.7 the simulation Results :The fault In the middle 57
4.8 Kundur simulation of a two-section power system with the fault in the end . . . 58
4.10 the simulation Results :The fault In the end 59
4.11 Kundur simulation of the area1 (the charge X0.1) 60
4.13 the simulation Results : the network multiplied in 0,1(area1) 62
4.14 Kundur simulation of the area2 63

4.16 the simulation Results : the network multiplied in 0,1(area2) 65
4.17 Kundur simulation of the area1 (the charge X10) 66
4.19 the simulation Results : the network multiplied in 10(area1) 68
4.21 the simulation Results :the network multiplied in 10(area2) 70
4.23 the simulation Results :the network multiplied in 10(both) 72
4.25 the simulation Results :default duration of t = +10 74
4.27 the simulation Results :default duration of t = +100 76
4.29 the simulation Results :default duration of t = +1000 78

Dictionary of technique termes

H	*Inertia constant*
MMF	*Magnetomotive Force*
f	*frequency*
$\mathbf{p}_m$	*Mechanical power (pu)*
δ	*Rotor angle Rotor angle*
V	*voltage*
P	*active power regulation*
Q	*the reactive power*
AGC	*Automatic Generation Control*
AVR	*automatic voltage regulator*
θ_m	*The mechanical angle*
θ	*the rotor angle*
U3	*is a unit matrix of dimension 3*
Te	*is the electrical torque opposing the mechanical torque*
$\mathbf{T}_m$	*is the mechanical torque in the direction of rotation*
D	*is the damping (assumed to be viscous) coefficient*
J	*is the combined moment of inertia of the rotor*

general introduction

Over the past two decades, power systems have encountered significant challenges that have necessitated adaptation and innovation. The introduction of electricity market liberalization has introduced a higher level of complexity in system operation compared to the past. The continuous growth in society's reliance on electricity has resulted in power systems operating at their maximum capacity while ensuring utmost safety. Moreover, the quality of electric power has emerged as a critical aspect of concern for both consumers and suppliers. Consequently, stringent criteria for system development and operation are increasingly demanded.[16]

Given these circumstances, ensuring the stability of power systems has become a paramount priority for electricity providers. These systems must maintain stability even in the face of minor deviations near operating points, as well as during severe conditions. Consequently, extensive research is being conducted to explore novel methods and technologies aimed at enhancing system stability. These endeavors are of utmost importance to address the evolving challenges and ensure the reliable operation of power systems. Several of the modern methods have already been the subject of industrial applications in advanced fields such as aeronautics and robotics. We are therefore entitled to wonder about their effectiveness with regard to the problem of the design of voltage and speed regulators which ensure the stability of electrical networks.

In the field of power systems engineering, the Kundur model is a widely used reference for studying stability transients in multi-machine systems.this model provides a comprehensive framework for analyzing the dynamic behavior of power systems during transient events.

Multi-machine systems, consisting of interconnected generators, loads, and transmission lines, form the backbone of power grids. However, disturbances such as faults, sudden load changes, or generator outages can disrupt the equilibrium of these systems, leading to stability transients. Transient stability refers to the ability of a power system to maintain synchronism and stability following a disturbance, such as a fault or sudden change in load conditions. It is a short-term phenomenon that occurs immediately after the disturbance and involves the response of the system to the disturbance. The Kundur model helps in understanding and assessing the transient stability of such systems As is represents generators as complex electromechanical devices, accounting for both electrical and mechanical dynamics. It captures the detailed behavior of synchronous generators, including their rotor dynamics, electrical characteristics, and excitation control systems. By considering the interplay between these components, the model enables a thorough analysis of the transient response of multi-machine systems.

This work consists of four parts:

In the first chapter, we present in general about electrical networks ,structure of electricity networks , the types of central energy Renewable Energy and non- Renewable and the different types of faults.

In the second chapter, we talked about stability of electrical networks and the classification of it Which consists of three important things voltage stability, frequency stability and rotor angle stability we touched instability in a power grid and the Solution of stability.

In the third chapter, we explained the multi machine which is composed of a lot of single machines the synchronous and asynchronous machines the stypes of the multi machines and we saw the methods and equation of it.

In the fourth chapter, we present the results and interpretations of the analysis of Curves and results provided that give it to us kundur.

Our work is finalized by a general conclusion.

Chapter 1

General information on electrical networks and the different types of faults

1.1 Introduction:

An electrical network is the set of components required to drive the electrical energy from the source (generator) to the load (consumer). This set includes transformers, transmission lines, towers, generators, motors, reactors, capacitors, Measurement and control equipment, lightning and short circuit protection, etc.[42]

The purpose of electricity networks is to interconnect production centers such as hydroelectric, thermal power plants..., with consumption centers (cities, factories...). Electrical energy is transported in high voltage, see very high voltage to limit joule losses (losses being proportional to the square of the current) and minimized the voltage drop and then gradually lowered to the end-user voltage. [42]

Electrical systems are real-time energy delivery systems. This means that electricity is generated, transported, and provided when you turn on the light switch.

Power systems are not storage systems such as water systems and gas systems. Instead, generators produce energy that demand requires. [42]

In this first part, we will give a general and brief overview of power grids by defining them and giving their types and structures. Next, we will explain the various problems and disruptions that may occur in an electricity grid.

1.2 Electricity Systems Overview:

Electrical grids include all devices for the production, transmission and distribution of electricity from power plants to the most remote customers.

The purpose of the transmission system is to transport energy from the production centers to the points of consumption or delivery. It consists of overhead or underground lines forming a mesh star connecting different points of the territory allowing to pool the means of production that supply the end customers .This network consists of electrical nodes called "substations" whose function is threefold:

- Switching lines of the same voltage between them.
- The removal of energy from generation sources to the grid.
- Linking networks of different voltages.

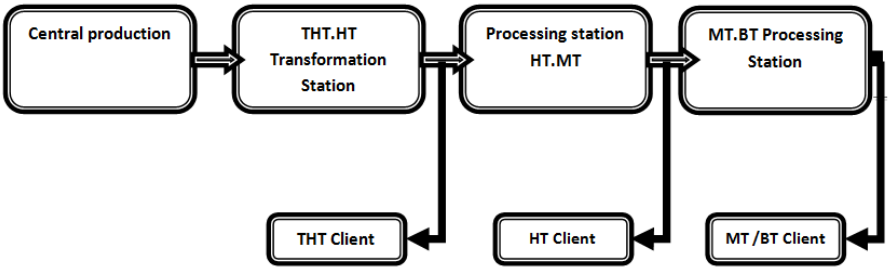


Figure 1.1: diagram simplifies an electric network

Electricity is a flexible and adaptable energy but it is hard to store, whereas the consumption of customers and the coincidence of demand are constantly variable. These requirements require continuity of transmission and delivery of power through a distribution network.[6]

1.3 Production of electrical energy:

It consists of all most all electrical equipment and they are placed at different locations

depends on requirement and all of them working together for the purpose of supplying electrical energy to consumer on economical [17]

1.3.1 Main components are :

- Generation
  - Transmission
  - Distribution

1.3.2 Advantages of Electrical energy:

- Efficiency is more
  - Reliability is high
  - Economical
  - Easy control

1.3.3 Types of Generation:

  - Conventional type
    - Non-conventional type

-Conventional type : Ex.: Thermal, Hydal, steam, Nuclear, Diesel , Gas etc.

- Bulk power generation in terms of MW kV
- Generate High voltages
- Installation cost is more and running cost is less
- Synchronous generators are used (Constant speed). Ex.: Alternators
- Transmission of power for long distances and then connected to distribution system

- Non-conventional type : Ex.: Solar, wind, tidal, Biomass, Geothermal etc.

- Generation in terms of kW Volts
- Generate Low voltages
- Installation cost is less and running cost is more
- Asynchronous generators are used (variable speed). Ex. : Induction generators
- question of transmission of power and only connected to distribution of power [5]

1.4 the types of central energy:

1.4.1 Renewable Energy:

It is considered that an energy is renewable, any source of energy that renews itself quickly enough to be considered inexhaustible (hence its name), that is, its speed of formation must be greater than its speed of use. Renewable energy comes from regular or constant natural phenomena caused mainly by the Sun (solar energy) ,but also hydraulic, wind and biomass...,[42]

1.4.2 Renewable Energy types:

1.4.2.1 Wind energy:

Wind energy is a wind-dependent energy source. The sun heats the Earth unevenly, creating zones of different temperatures and atmospheric pressure all around the globe. From

these pressure differences arise air movements, called winds. This energy makes it possible to manufacture electricity in wind turbines, also called wind generators, thanks to the force of the wind.[2]

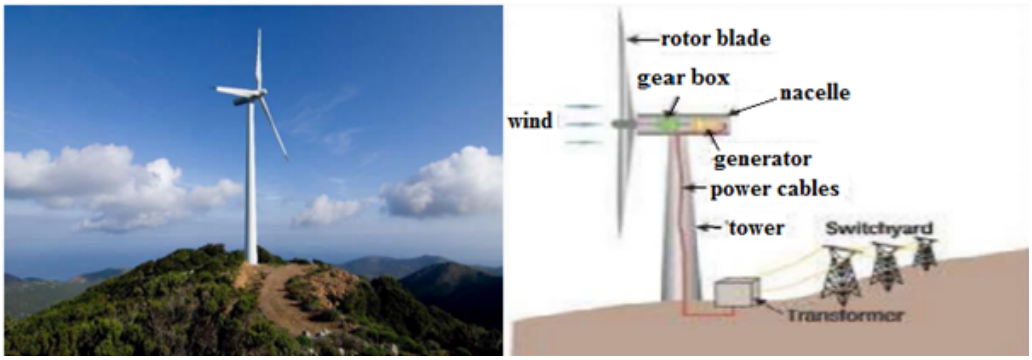


Figure 1.2: general structure of Wind energy

1.4.2.2 Hydro energy:

Water is also a renewable source as it regenerates through the evaporation cycle and precipitation It condenses into clouds that move with the wind. The drop in temperature over continents causes precipitation to feed the water of lakes, rivers and oceans. Its strength has been known and exploited for thousands of years through dams, water mills and irrigation systems. Several technologies make it possible to exploit the energy produced by the fall or movement of water. The paddle wheels can transform it directly into mechanical energy (water mill), while the turbines and electric generators transform it into electricity.[11]

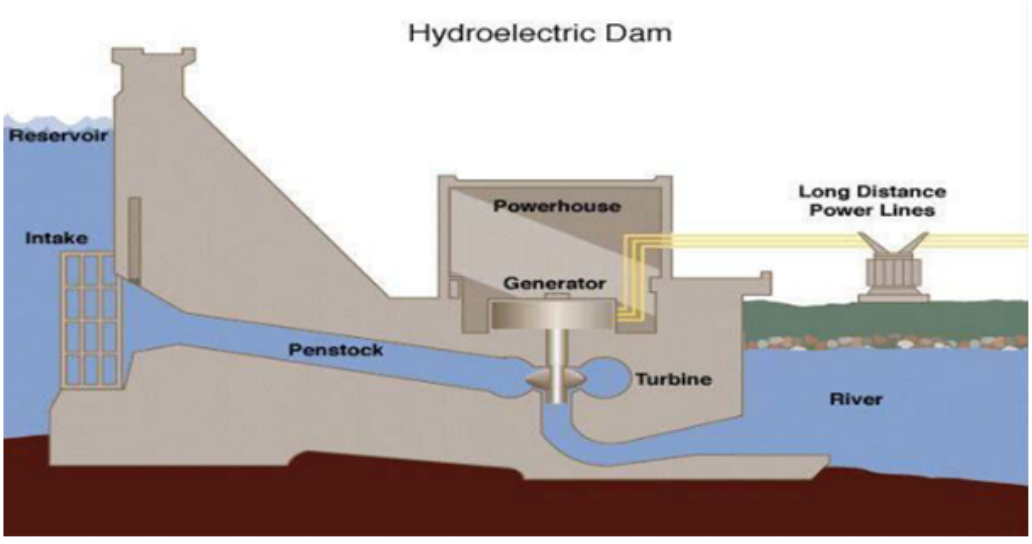


Figure 1.3: diagram of Hydro power plant

1.4.2.3 Solar energy:

Energy produced from the conversion of solar radiation is renewable energy.

It is also an intermittent energy source (no solar energy at night). Solar energy can be converted into heat or electricity. There are different types of solar energy first we will quote them and then explain them:

- Thermal energy
- Photovoltaic energy
- Thermodynamic energy [13]

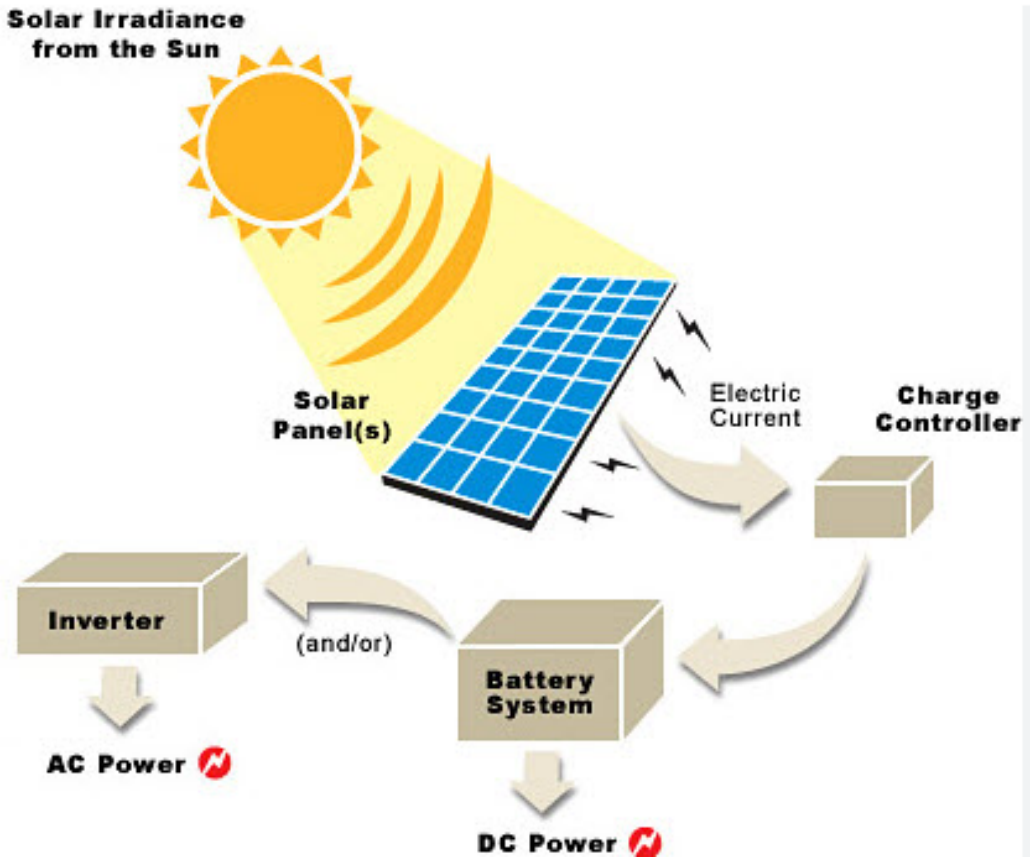


Figure 1.4: diagram of Solar energy

1.4.3 Non-renewable energy:

Non-renewable energy refers to energy sources that are finite in nature and cannot be replenished at the same rate they are consumed. These energy sources are typically derived from fossil fuels, which include coal, oil, and natural gas. Non-renewable energy has been the primary source of global energy production for many years due to its abundance and accessibility. However, it has significant environmental and sustainability drawbacks.

1.4.4 non-Renewable Energy types:

1.4.4.1 Natural Gas:

Natural gas is a fossil fuel composed mainly of methane. It is often used for heating, electricity generation, and as a fuel for vehicles. Compared to coal and oil, natural gas combustion produces fewer greenhouse gas emissions and air pollutants. However, methane, the main component of natural gas, is itself a potent greenhouse gas, contributing to climate change.



Figure 1.5: Gas Energy Center

1.4.4.2 Nuclear energy:

Nuclear energy is a form of energy generated through nuclear reactions, specifically the process of nuclear fission or fusion. Nuclear fission involves splitting the nucleus of an atom, typically uranium or plutonium, into two smaller nuclei, releasing a large amount of energy in the process. Nuclear fusion, on the other hand, involves the combination of light atomic nuclei, such as hydrogen isotopes, to form a heavier nucleus.

Nuclear power plants utilize nuclear fission to produce electricity. The process involves harnessing the heat generated from the nuclear reaction to produce steam, which drives a turbine connected to a generator. This generator then converts mechanical energy into electrical energy.

1.4.4.3 coal energy:

Coal energy refers to the energy generated by burning coal, a fossil fuel formed from the remains of plants that lived and died millions of years ago. Coal is primarily composed of carbon, along with various other elements such as hydrogen, sulfur, oxygen, and nitrogen.

Coal has been used as a significant source of energy for centuries, particularly in electricity generation and industrial processes.

It's important to note that the use of coal for energy production has both advantages and disadvantages, with significant environmental and health concerns. As the world seeks to transition to more sustainable and cleaner energy sources, coal's role is being reassessed in favor of alternatives that have lower carbon emissions and fewer environmental impacts.

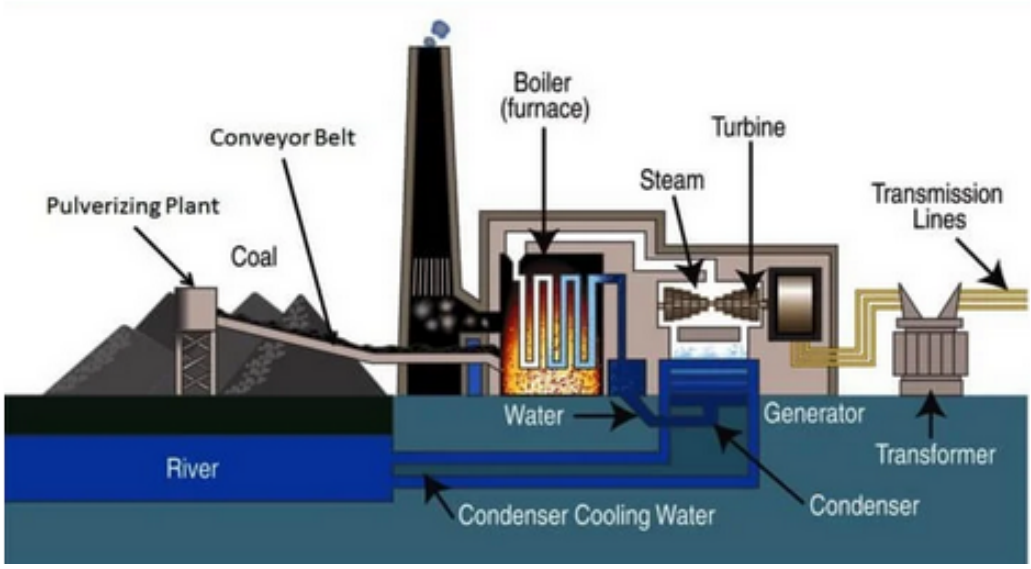


Figure 1.6: diagram of coal energy

1.5 Electrical Network construction:

Depending on the path of the energy from its production to its use, there are successively different types of networks whose missions are perfectly defined by:

1.5.1 Transport networks:

Electrical transport networks can be categorized into different voltage levels, including Extra High Voltage (EHV), High Voltage (HV), Medium Voltage (MV), and Low Voltage (LV). The specific voltage levels can vary depending on the region and electrical standards. Here's a brief description of the commonly used voltage categories: [30]

1.5.1.1 Transmission High Tension (THT) or Extra High Voltage (EHV):

This category typically refers to the highest voltage levels used for long-distance transmission of electricity. EHV systems usually operate at voltages above 220 kV or 275 kV and are responsible for transmitting power from power plants to substations over extensive distances. These networks utilize high-voltage transmission lines with specialized equipment to minimize losses during electricity transportation.

1.5.1.2 High Tension (HT) or High Voltage (HV):

HT or HV networks operate at voltage levels ranging from 66 kV to 220 kV, depending on the region. These networks are responsible for the primary distribution of electricity from substations to industrial areas, large commercial complexes, and some high-demand residential areas. HV lines are commonly supported by transformers to step down the voltage for further distribution.[14]

1.5.1.3 Medium Tension (MT) or Medium Voltage (MV):

MT or MV networks operate at voltage levels typically ranging from 3 kV to 66 kV. They serve as the intermediary between HV transmission lines and low-voltage distribution networks.

MV networks distribute electricity from substations to residential areas, small commercial establishments, and Localized industrial zones. Transformers are used to step down the voltage further for safe consumption.

It's important to note that these voltage levels are approximate and can vary based on regional electrical standards and regulations. The purpose of these categories is to ensure efficient and reliable power transmission and distribution throughout the electrical transport network.[35]

1.5.2 Interconnection and transmission networks:

These networks provide very high voltage and high voltage transmission and interconnection to consumption and distribution points. These networks include power stations as well as lines and processing stations, their roles are:

• Collect the energy produced by the plants and route it to the consumption areas (transport function).

• Enable economic exploitation.

•Compensate for the various gaps (interconnection function).

These are generally networks that allow conveying great flows of power between regions of a country or between countries. Interconnection lines improve the security of network operation.

1.5.3 Dispatch Network:

Distribution networks are power networks for the entire customer base, that is, they are the most important architecture of the electrical system. They ensure the distribution of electrical energy at the local level.

Their role is to provide networks with the power they need. They use two voltages:

• Medium Voltage Lines (MV or HV) powered by HV/MV substations and providing electrical power either directly to major consumers or to individual MV/LV substations.

•Low voltage lines that supply users with either single-phase or three-phase power.

•MT networks are virtually all part of the distribution networks.

The structure of this network is generally aerial, sometimes underground near urban sites. [39]

1.6 Distribution networks (MT):

These networks include transmission lines and intermediate processing stations between the transmission network and the distribution network. These are high-voltage grids, and their role is to distribute electrical energy regionally. They can be aerial or underground.

It is the network that provides the function between the distribution network and the clientele, and the management of these networks is provided by the distribution department. The distribution networks are divided into two levels:

•The medium voltage distribution network.

• The low voltage distribution system. [39]

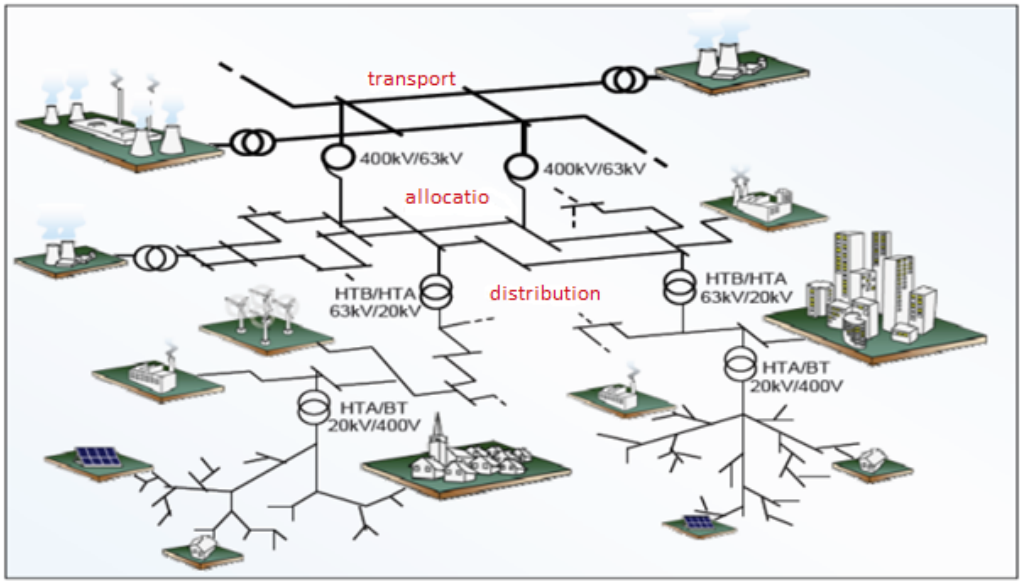


Figure 1.7: Electricity System Structure

1.6.1 Type of distribution networks:

1.6.1.1 Medium Voltage Distribution Systems:

Medium voltage lines allow the transmission of electricity at local level to small HTA ndustries (30 and 10 kV most common).

- Neutral to the ground by a resistance.
- Limitation to 300 A for air networks.
- Limit to 1000 A for underground networks.
- Open loop underground networks.

1.6.1.2 Low voltage distribution systems:

Low voltage lines are the smallest lines in the network, they are the ones we use every day to power our BT appliances (230/ 400 V):

-Neutral directly to the earth,

-Radial, mesh and looped networks.[18]

1.7 Classification and structure of electricity networks:

There are essentially several types of structure, the best known are:

- Curly structure.
- Mesh structure.
- Radial structure.
- Masterful structure

1.7.1 Looped Network:

Looped distributions consist of one or more pipes which, starting from a source and returning after supplying the various subscribers. Complex or mesh loops can be formed, with transverse loops allowing successive loops.

The network looped at a reduction of joule losses, and it has a special connection to the leads and that each lead can at most power two circuits.

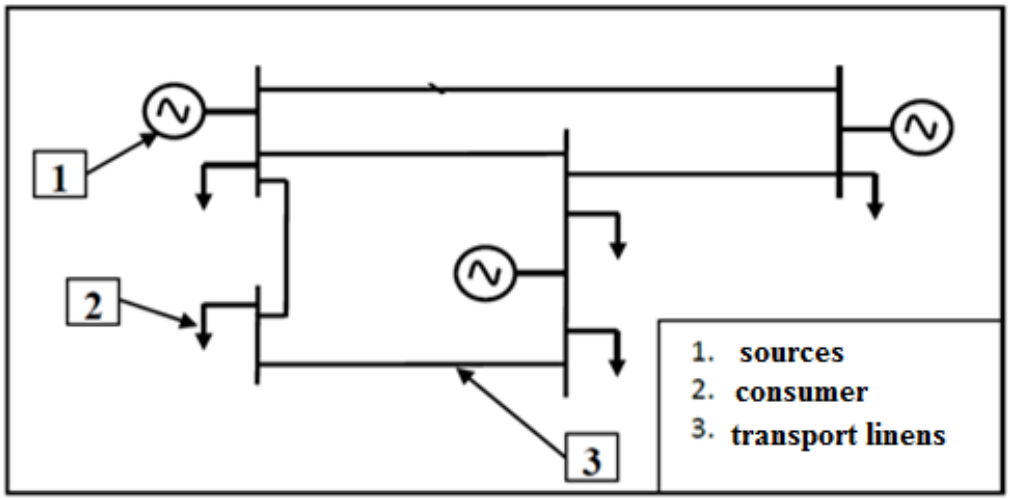


Figure 1.8: Looped Network Structure

1.7.2 Mesh Network:

This network consists of a set of nodes connected by power transmission lines allowing the choice between several routes from a network input to an output.

For this network we can find branches whose opening leads us to a radial network, this radial network is called mesh network tree, it is represented by the following diagram: [6]

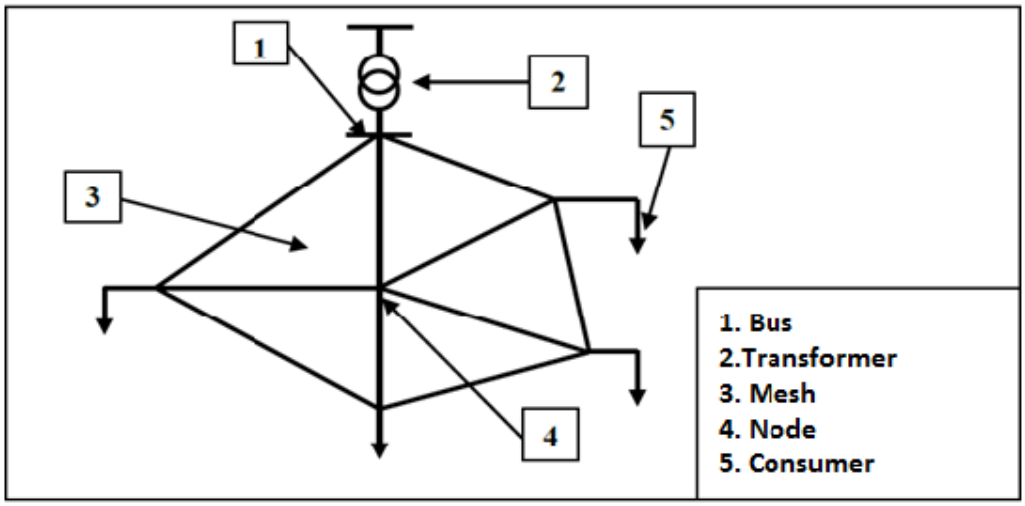


Figure 1.9: Mesh network structure.

1.7.3 Radial or star networks:

The transmission of energy to a customer is done by a single route as shown in the diagram below, the radial distribution, by its name is a network arranged in radius from the source to the customers. In addition it has good power security and an increase in convenience, it requires low voltage distribution stations, in addition it does not take into account the change in technology.

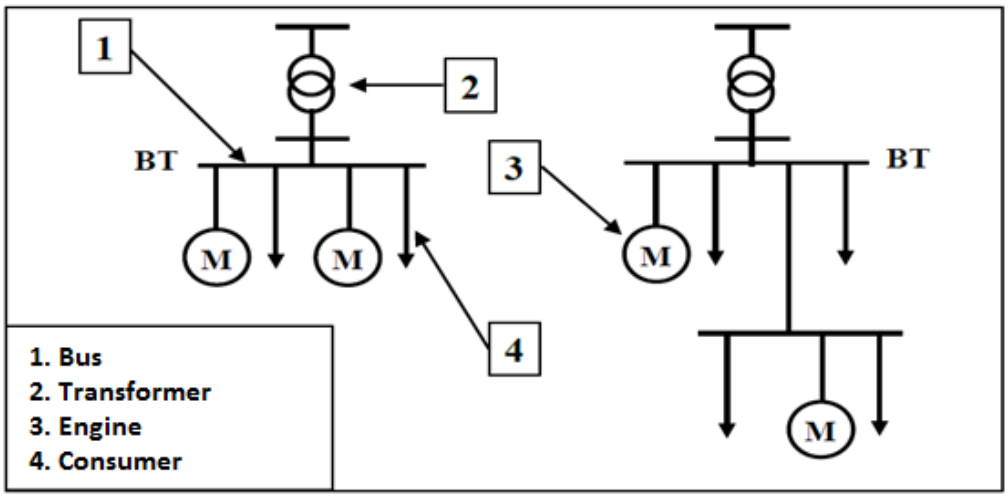


Figure 1.10: Radial network structure.

1.7.4 Master networks:

The magisterial network is represented in the diagram below, makes the distribution stations very simple and takes account of changes in technological processes.

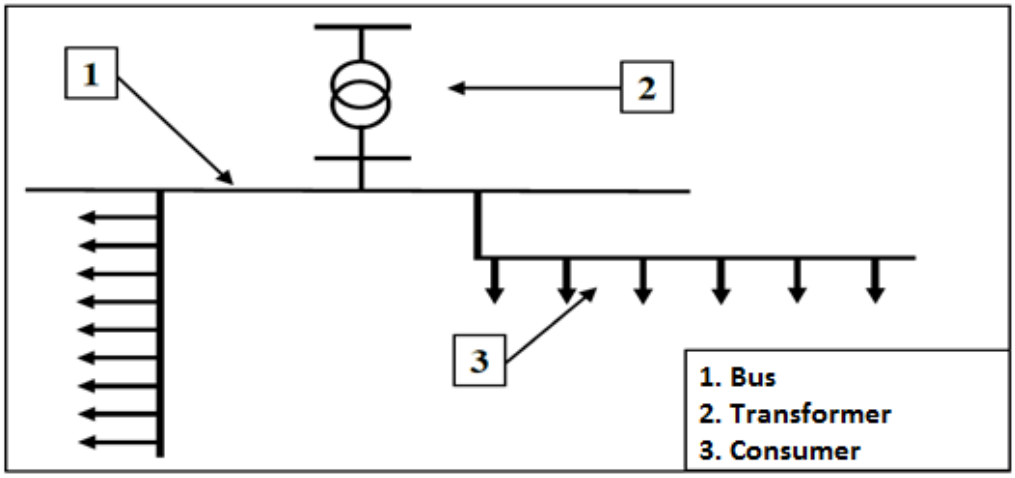


Figure 1.11: Magisterial network structure.

1.8 Electrical System Topology:

A configuration or topology represents a "network" state in which each element has a defined state: in service or out of service.

-Comparison between overhead lines and underground cables:

a)Airlines:

Overhead lines consist of bare aluminum conductors (often an alloy to reinforce mechanical properties), sometimes with a steel core.

Lines are subject to short-term interruptions more frequently than cables.

b)Underground networks:

They are mainly found in areas with a high population density, consisting of cables insulated by impregnated or submerged paper, rubber or chemical components, the whole being covered with a sealed envelope of lead or aluminum. These cables are placed in trenches or galleries.

Underground cables require a longer repair time than lines, which can have an adverse effect on system safety.

1.9 Defects in transmission lines:

1.9.1 Presentations:

Transmission lines are built with bare conductors; these conductors are installed in special metal structures "towers" in which these conductors are separated from the tower itself by insulating components and separated from each other by sufficient spaces for air to act as insulation.

Different types of defects can occur (defects with soil or between phases). However the most common defects are power surges, most occur temporarily resulting in a short circuit in the insulation due to environmental factors such as lightning (lightning). They can also occur by a defect in the insulation due to the deterioration of the insulation material itself.

1.9.2 The different types of defects:

Defects affecting transmission lines can be divided into four types (Figure I.12).

1.9.2.1 Single Phase Defects:

These are defects between a phase and the earth.

1.9.2.2 Two-phase ground defects:

These are short circuits between two phases of the transmission line and land.

1.9.2.3 Isolated two-phase defects:

These are short circuits between two phases of the transmission line.

1.9.2.4 Three-phase defect:

A three-phase fault is caused by a short circuit between the three phases of the transmission line.

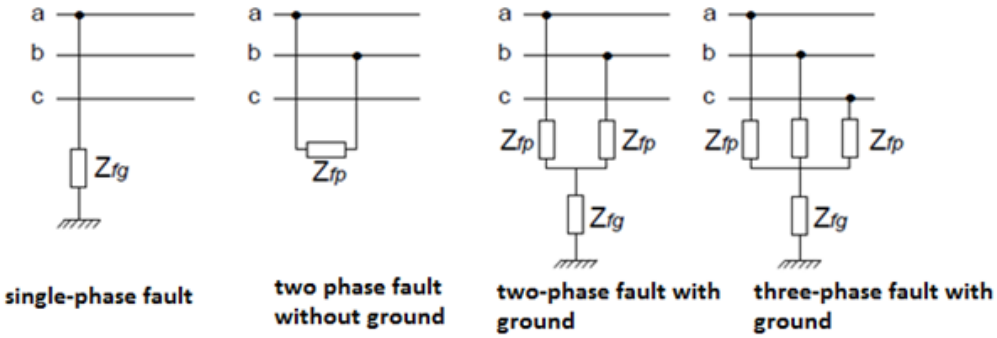


Figure 1.12: Different types of defects

1.9.3 The different types of defects:

1.9.3.1 Auto-extinguisher fault:

A single-phase auto-extinguisher defect is a defect that eliminates itself without interrupting power or closing a circuit breaker. These defects exist on neutral networks with impedance (about 10% offset networks in significant proportions (up to 80%).

1.9.3.2 Default rebooting:

A reset defect is a single-phase auto-extinguisher defect, which reappears periodically (in about 90% of cases, the single-phase auto-extinguisher defect is a single boot). The time between reboots can vary from a few milliseconds to a few hundred milliseconds. If the time between two successive reboots is less than 200 ms, we consider this sequence of defects as the same defect (Figure I.13)

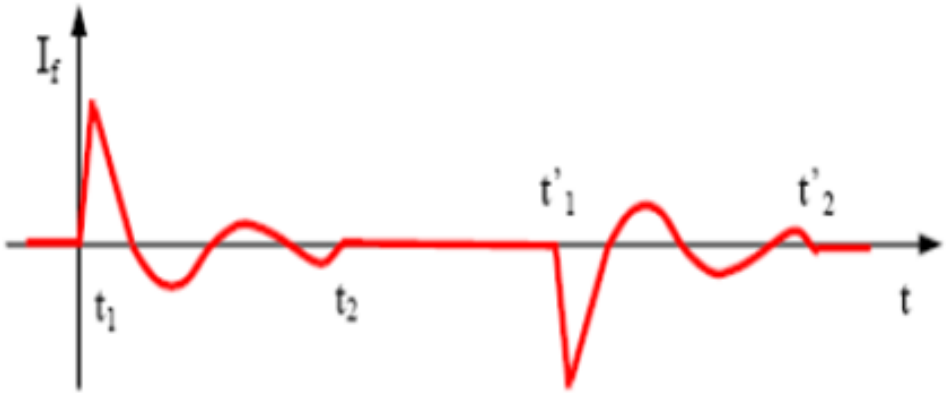


Figure 1.13: Resetting defect

1.9.4 The most common defects:

The different types of defects are caused by:

- •Overcurrent by overload,
- •Over current per short circuit,
- •A decrease or lack of tension,
- •A power surge.

1.9.4.1 Overload:

a)Definition:

Increase in load, it is translated by an increase in intensity of 1 to 10 In of a network due for example to an overabundance of receptors.

b)Consequences:

- Slow and progressive heating of active parts, metal masses, insulation.
- Protective means: Thermal relay, fuse, thermal trip of circuit breaker.

1.9.4.2 The short circuit:

a)Definition:

Elevation and sudden increase in intensity from 10 to 1000 In in an electrical installation due to an accidental connection of two different potential points (PH and N).

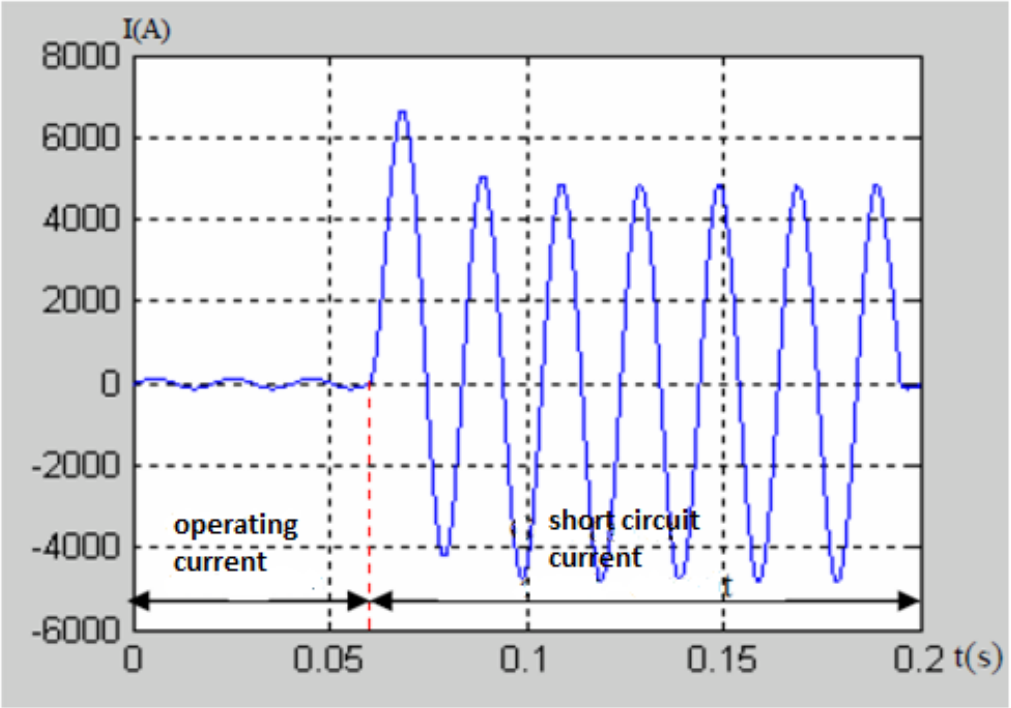


Figure 1.14: general form of a short circuit current.

b)Characteristic:

In electrical installations different short circuits can occur. They are mainly characterized by:

- Their duration,
- auto fire extinguisher,
- fugitive,
- permanent,
- Their origin,
- Mechanical,
- external or internal surge,
- Degradation of isolation.
- Type of defect,

- Three-phase: only 05% from the start,
- Two-phase: 15% of cases,
- Single phase: 80% of cases,

These different short-circuit currents are shown in (Figure I.14).

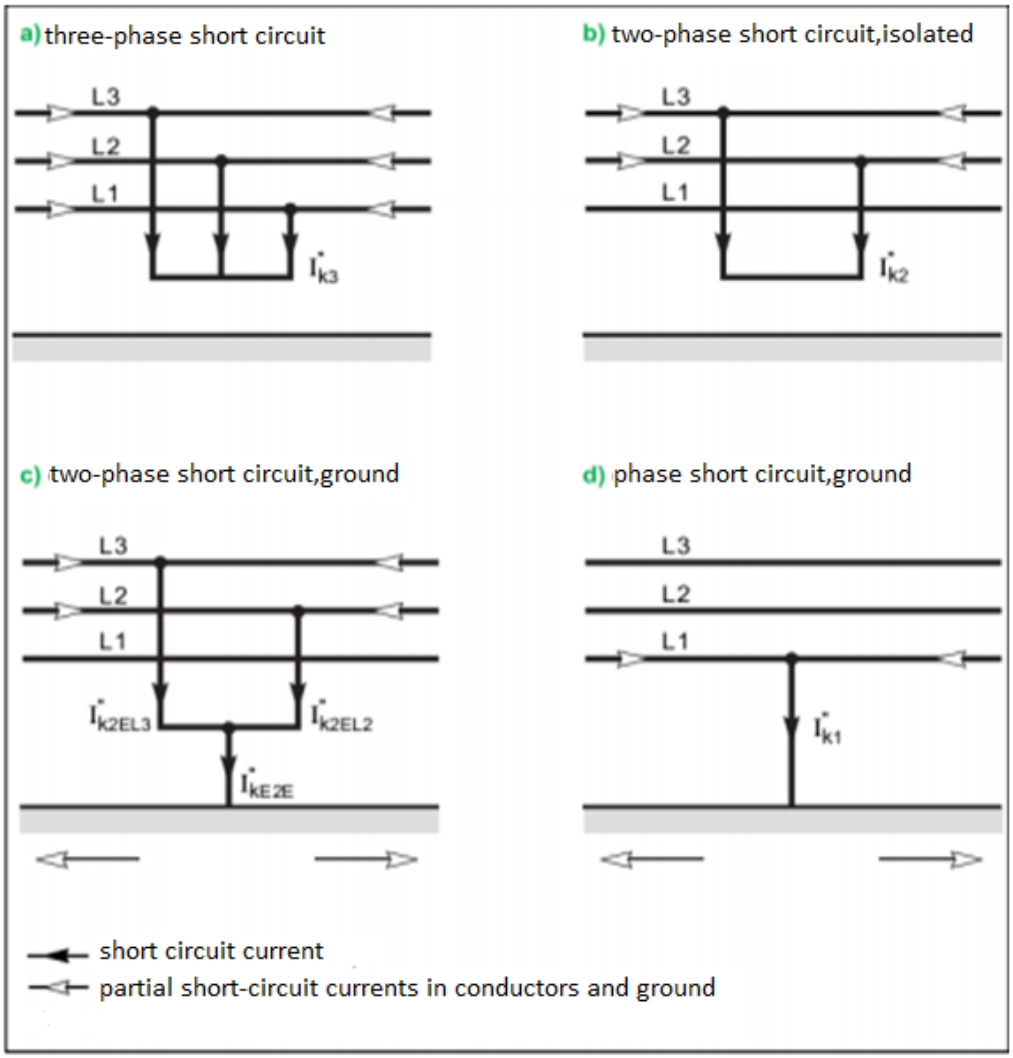


Figure 1.15: Types of short circuits.

c)Consequences:

Electric arc, significant heating which may lead to the fusion of the active parts (welding of the contacts, particle projection).

d)Protective means:

Circuit breaker, fuse.

1.9.4.3 Surge:

a)Definition:

Sudden and significant increase in tension due for example to a lightning strike. Consequences: Breakdown of insulation for example. Means of protection: lightning conductor, surge protector, surge relay, lightning arrester.

1.9.4.4 Lack of tension:

a)Definition:

Excessive voltage drop in a network, imbalance of a three-phase distribution network.

b)Consequences:

Receptor malfunction.

c)Protective means:

Relay with minimum voltage, stand-alone power supply.

1.9.5 The effects of defects:

The effects of faults are especially to be feared on high and very high voltage networks (H.T and T.H.T). Faults have effects on:

- The proper functioning of networks.
- The dielectric properties of materials.
- Quality of energy supply.
- Telecommunications circuits.
- Safety of persons.

1.9.6 Elimination of defects:

Short circuits are incidents that must be eliminated as quickly as possible. This is the role of protections whose speed of operation is one of the priority performances.

It will not be forgotten that the defect elimination time consists of two main components:

- The operating time of the protections (a few tens of milliseconds).
- The opening time of the circuit breakers.

The protection of a power grid consists in detecting any fault (ground or phase fault) that would occur on the grid in order to protect the elements of the grid from destructive overcurrent. Once the fault is detected, it must be possible to locate it as well as possible so that only the part of the network closest to the fault can be switched off.

-Protections must:

- Detect the presence of a defect.
- Identify the affected work.

Order the disconnecting devices, the opening of which will lead to the isolation of this work (and only this one) from the rest of the network.

1.10 Conclusion:

The networks being present in many points of the public domain; In this chapter, a general overview on the architectures of the electricity network Types of distribution networks, as well as the most known structures of the latter are presented. In addition we presented an overview of defects in transmission lines.

The distributor must provide the electricity transmission service on the distribution networks at the best level of quality and at the best cost under optimum safety conditions. Indeed,

it is the distribution networks that are at the origin of an essential part of the quality actually received by the user at the terminals of his power supply. In addition, the HTA and BT share of the networks represents a significant part ,, of the total cost of the infrastructure needed to serve a customer.[14]

Chapter 2

stability of electrical networks

2.1 Introduction:

Stability is the most significant feature needed in the modern power system. Stability problem in power system has been noticed during the recent years, because of the fast growth in electric and electronic loads. However, the developments and improvements in generation and distribution systems have not met yet this fast growing loads and the increasing in the number of important and sensitive devices in power system. Disturbances and short outages in generators or transmission lines always have negative effect on power system. In addition, a rapid variety in loads in the plant leads to voltage and frequency fluctuations. These disturbances and fluctuations that occur during the transient process cause stability and quality issues in power system . [35]

Power system stability is subjected to changes in system or loads levels that may be sudden or gradual and severe or small changes. Stability is an important concept that determines the power system stable operation. In general, rotor angle stability is taken as index, but the concept of transient stability, which is the function of operating condition and disturbances deals with the ability of the system to remain intact after being subjected to abnormal deviations. A system is said to be synchronously stable (i.e., retain synchronism) for a given fault if the system variables settle down to some steady-state values with time, after the fault is removed . [9] Electric power system stability analysis has been recognized as an important and challenging problem for secure system operation. When large disturbances occur in interconnected power system, the security of these power systems has to be examined. Power system security depends on detailed stability studies of system to check and ensure security. In order to determine the stability status of the power system for each contingency of any disturbance occurs in power system, many stability studies are defined. Power system stability analysis may involve the calculation of Critical Clearing Time (CCT) for a given fault, which is defined as the maximum allowable value of the clearing time for which the system remains to be stable. The power system shall remain stable if the fault is cleared within this time. However, if the fault is cleared after the CCT, the power system is most likely to become unstable. Thus, CCT estimation is an important task in the transient stability analysis for a given contingency [1] . Over the past decades, the energy storage technologies have grown and provided some economic and environmental benefits for business and the society. The energy storage system, which is an electrical storage technology, is applied in many electrical and electronic power applications for improving and enhancing stability and the performance of modern power systems [35].

2.2 power System Stability:

For years, various and complex research was carried out to understand the stability problems of power systems. Thus many definitions of the stability of power systems were proposed with emphasis on the various aspects that reflect the manifestation of the stable state of system. The most recent definition we will adopt is the result of an IEEE working group [20]

The stability of a power system is the ability of an electrical energy system, for a given initial operating condition, to return to the same or another near steady state after undergoing a physical disturbance, keeping most system variables within their limits, so that the entire system remains virtually intact.

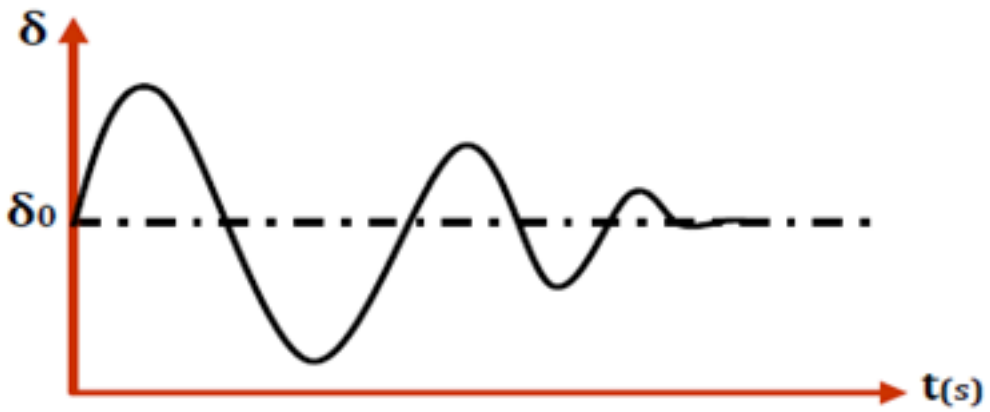


Figure 2.1: System (Time Rotation Angle Plot)

2.3 Stability of electrical energy networks:

From a physical point of view, stability is defined as a state of equilibrium of opposing forces. In the case of power grids, these forces are related to the interaction of machines connected to power grids. The IEEE/CIGRE working group has proposed a definition of the stability of electricity networks.

Instability can take many forms, depending on operating conditions and network configuration, but maintaining synchronization on the network remains a primary goal.

It is therefore necessary to follow the dynamics of the generators through the angles of the rotor and the powers.

2.4 Stability classification:

The various forms of instability that result cannot be both properly understood and effectively addressed. Because stability problems are high dimensional and complex, taxonomy helps simplify the terminology for analyzing a particular type by using an appropriate level of detail for system representation and analysis techniques. Stability analysis, including identification of key factors contributing to instability, is greatly facilitated by stability classification. Classification is therefore essential for meaningful and practical analysis and solution of power grid stability problems.

The stability classification proposed here is based on the physical properties of the instability, the time domain of the phenomenon, and the amplitude of the disturbance.

Therefore, the types of stability can be categorized as:

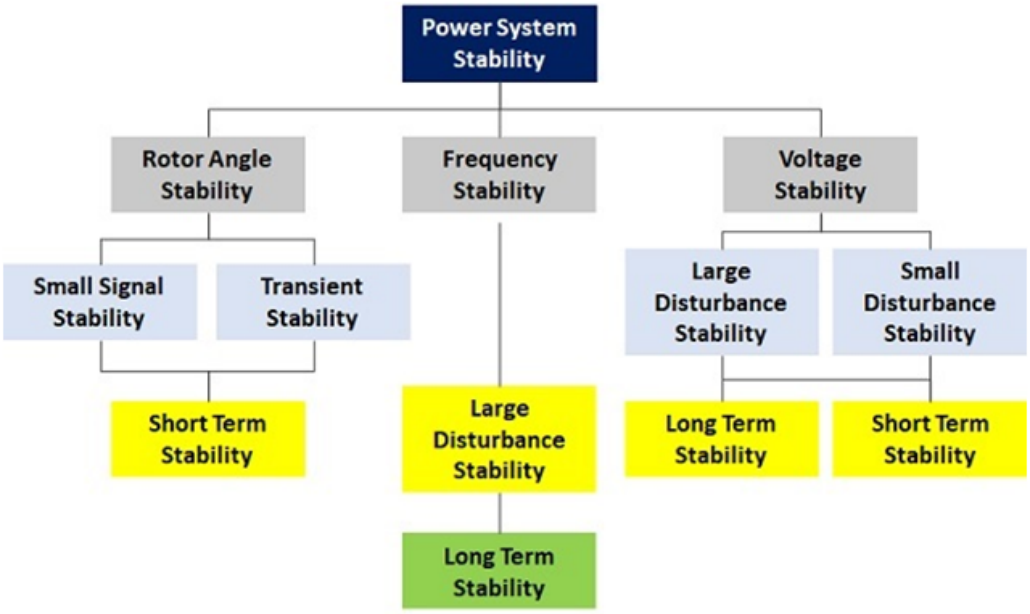


Figure 2.2: Power System Stability Classification.[20]

2.4.1 Power system stability :

The stability of a power system is the capacity of a system electrical energy. For a given initial operating condition; to recover the same or other steady state after experiencing a physical disturbance, keeping most system variables within their limits, so that the entire system remains virtually intact. Commonly, we can say that a system is stable if it remains in a state equilibrium under normal operating conditions, or if it returns to another condition acceptable equilibrium after any disturbance. The stability analysis of a electrical system then consists in studying the character of electromechanical oscillations of alternators and to maintain synchronous operation after the occurrence of a fault.[3]

We note that stability depends not only on initial operation but also on the physical nature and amplitude of the disturbance. The mechanism or chain event leading to electrical blackouts is directly related to the loss processes of stability: this instability manifests mainly through the instability of the angle of the frequency or voltage.

2.4.2 Voltage stability:

Voltage stability, by definition, refers to the capacity of a power system, for a given initial operating condition, to maintain acceptable voltage values at all system nodes after a Disturbance. Voltage stability therefore depends on the ability to maintain/restore the balance between load demand and supply of power to load, the resulting instability very often occurs in the form of a gradual decrease in tensions at a few knots.

Generally, tension instability occurs when a disturbance causes a increased reactive power requested beyond the possible reactive power.

Several changes in the power system can contribute to the instability of tension, we quote for example:

- An increase in load.
- A generator failure, loss of a heavy load or a line trip.
- A loss of a reactive power source (capacitors, synchronous machines, etc.)
- A loss of a reactive power source (capacitors, synchronous machines ,..)

The time range of voltage instability ranges from a few seconds to several minutes, thus, voltage instability can be considered as:

• A short-term phenomenon (of the order of several seconds): the collapse of voltage occurs immediately after the disturbance.

• A long-term phenomenon (of the order of several minutes): the instability of tension in the long term develops during a gradual lack of reactive power of a node or part of the system. It is also important to note that tension instability does not always occur while only; often tension instability and rotor angle instability occur together, one of which could lead to the other.[7]

2.4.2.1 Dielectric strength for small disturbances:

Voltage stability under small disturbances relates to the power system's ability to maintain voltage within an acceptable range in the presence of disturbances such as:
for example :Such as small variations in load, production, etc.

2.4.2.2 Dielectric strength against large disturbances:

It is defined as the ability of an electrical system to maintain node voltages within permissible operating limits in the presence of major disturbances, i.e. transmission or production equipment failures, short circuits, etc.

2.4.3 Frequency stability:

The stability of the frequency of a power system is defined by the ability of the system to maintain its frequency close to the nominal value following a severe disturbance leading to a significant imbalance between the power produced and consumed. [36]
Critical Fault Isolation Time (TCID) Determination:

This is the most decisive parameter in the analysis of the transient stability of an electrical network. Mathematically it is the solution of the non-linear second order differential equation known as the Swing equation or motion equation. Physically, it represents the maximum time during which our network can support a fault (short circuit, overload, overcurrent surge...) without losing its stability.
According to the machine motion equation:[15]

$$t_c = \sqrt{\frac{2H(\delta_c - \delta_0)}{90fpm}} \tag{2.1}$$

H : Inertia constant
f : frequency
pm : Mechanical power (pu)
δ :Rotor angle Rotor angle

2.4.3.1 Transient Stability:

It concerns the ability of the power system to maintain synchronization after undergoing a severe transient disturbance such as a short circuit on a transmission line or a loss of a significant portion of the load or generation. The system response involves large variations in rotor angles. It depends on the nonlinear torque-angle relationship.

Transient stability deals with the effects of sudden disturbances of high amplitude and short durations. The intervention of regulators and network automation is essential to restore

stability during the transitional period. In this case, the problem is described by a system of nonlinear differential and algebraic equations.

2.4.3.2 small signal stability:

Small signal stability refers to the ability of a power system to maintain stable operation under small perturbations or oscillations around its operating point. These small disturbances can arise from various factors such as changes in load demand, fluctuations in generation output, or system parameter variations.

When a power system experiences small disturbances, such as slight changes in generator output or load fluctuations, the system may exhibit oscillatory behavior. This behavior can be characterized by small variations in voltage magnitudes, phase angles, and power flows. Small signal stability analysis aims to assess the system's response to these oscillations and determine whether it will remain stable or undergo instability.

2.4.3.3 rotor angle stability:

The stability of the rotor angle concerns the ability of synchronous machines in an interconnected power system to remain in sync following a disturbance. It depends on the ability to maintain/restore balance between the electromagnetic and mechanical torque acting on the rotor of each synchronous machine in the system. The resulting instability occurs as an increase in the angular oscillations of some generators which can lead to a loss of synchronization with other generators.

Depending on the magnitude of the disturbance, we can characterize the stability of the rotor angle in two subcategories.[31]

a)Angular stability at small disturbances (in small signals):

It is defined by the ability of the power system to maintain synchronization in the presence of small disturbances. Disturbances are considered small enough to allow linearization of system equations for analysis. The resultant instability manifests itself in the form of an increasing gap, oscillatory or non-oscillatory, between the rotor angles.

b)Angular stability at large disturbances (transient stability):

It concerns the ability of the power system to maintain synchronization after undergoing a severe transient disturbance such as a short circuit on a transmission line or a loss of a significant portion of the load or generation. The system response involves large variations in rotor angles. It depends on the non-linear torque-angle relationship. Transient stability depends not only on the amplitude of the disturbances and the initial operating point but also on the dynamic characteristics of the system. It manifests itself in the short term in the form of an increasing a periodic deviation of certain rotor angles. If the instability manifests itself directly as a result of the disturbance (more precisely in the first second after the elimination of the defect), it is called the first oscillation instability (First Swing Instability), and it extends over 3 to 5 seconds.

Transient instability can also manifest otherwise, it can result from the superposition of the effects of several slow oscillation modes excited by the disturbance, thus causing a significant variation of the rotor angle beyond the first oscillation (multi-oscillation instability). The associated time range is 10 to 20 seconds. [31]

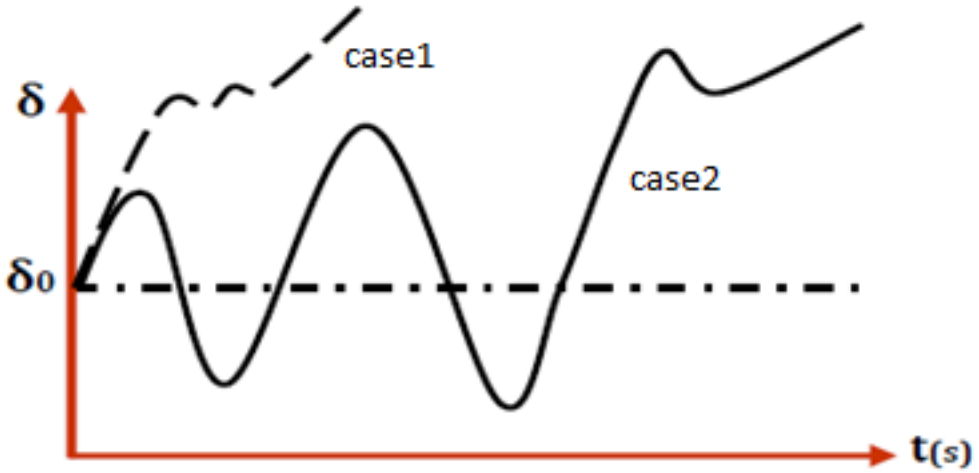


Figure 2.3: variation of rotor angle

Case 1: first oscillation instability

Case 2: instability of several oscillations

2.5 instability in a power grid:

The study of electricity networks has always been seen as an objective for planners or operators. To do this, several software or programs have been developed to satisfy this need . [15]

Generally, three major objectives govern the operation of electrical systems:

- Safe operation must be guaranteed.
- Promoting economic performance and opening up the electricity market.
- Meet contractual commitments to customers connected to the network.

The stability of electrical systems has been and continues to be a major challenge in the operation of electrical networks. The stability of an electrical system is defined as the capacity of the electricity system to maintain balance within operation permitted in the presence of disturbances .[25]

In modern electricity grids, the growing size of electrical systems interconnected at a high complexity, and the installation of a large number of production and very high voltage connection lines can degrade the frequency and voltage performance. To evaluate the stability of the power system for a given initial operating condition and return to a steady state of operation after a disturbance, the energy production must respect certain minimum standards.

2.6 Electricity System Instability Classification:

The phenomena of instability of a power grid are usually divided into three Main levels, as shown in Figure.I.4:

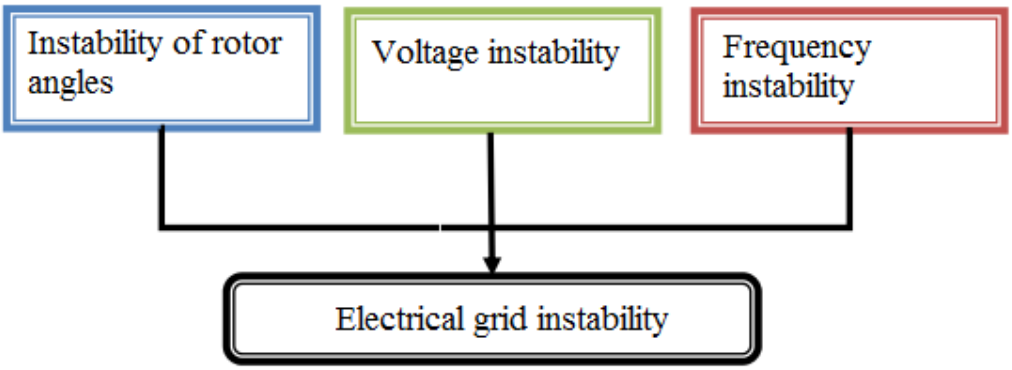


Figure 2.4: Instability events in an electrical grid.

a)Rotor Angle Instability:

Inability of the System to Maintain synchronization after a disturbance and as a solution, the power system (PSS) are used.

b) Voltage Instability:

The case where the power system is unable to maintain stable voltages at all system nodes around an initial equilibrium point assumed after being subjected to a defect, the automatic voltage regulator (AVR) is proposed to correct this instability.

c) Frequency instability:

is the inability to maintain system frequency in the specified operating limits, as the primary control solution by the system governor and additional loop control also named charge-frequency (Load Frequency Control (LFC)) are proposed to solve this problem.

In addition, the management of the electricity network must guarantee the maintenance of the safety of operation and stability of the system in the face of different risks, and control and regulation means called auxiliaries (the secondary setting).[12]

2.7 solution of stability:

In an electrical network frequency (f) and voltage (V) are considered as important for the proper functioning of electrical equipment, namely: energy transmission and distribution equipment, as well as the industrial and household expenses [12]. For their optimal operation all the electrical equipment of the network must operate at a frequency (f) of 50±0.5Hz and normal voltage TBT, BT, MT, HV according to power of the material.

The regulation of maintaining these quantities at their values of this regulation remains the objective of quality of service for system operators (dispatchers) .[27]

The change of load causes frequency and voltage drifts which, in turn, result in loss of generation due to line trip and also failures. These deviations can be minimized to the smallest possible value. Large variations in frequency are also ineligible for the proper operation of turbines whose production groups, which withdraw from the network for frequency deviations of 5%. The frequency control (f) is carried out by the action on the production units via the active power regulation (P) [43]. Maintaining the frequency at its value of In order to maintain the production-consumption balance in the adapting the level of production to that of the demand (supply equal to demand). For this reason, and to ensure frequency stability, all synchronous generators must be synchronized after any disturbance, while ensuring voltage

stability; The voltages close to the loads must approximate the equilibrium values of the past disturbances. On the other hand, the voltage control (V) is based mainly on the action of the regulation of the reactive power (Q) of power stations by acting on excitation current and reactive power compensators installed on the network.

In order to regulate the output power of each production group at the levels prescribed while maintaining frequency and voltage fluctuations within limits predetermined, a control strategy called Automatic Generation Control (AGC) is used. In fact, the AGC becomes an important function of the power system operation where these main objectives are to regulate fluctuations of frequency and voltage. The AGC controls the frequency by acting on the control loop charging frequency (LFC) and controlling the excitation voltage through the automatic voltage regulator (AVR). The coupling between LFC and AVR is generally known as automatic generation control (AGC) .[8]

2.8 Transient stability analysis method:

The method is based on numerical integration of differential equations describing the network in state space. There are various consolidation algorithms. The most commonly used are those of Euler and those modified by Euler. The differential equations describing the behavior of the system are discredited in quasi-linear form. This approach has the advantage that very complete models (saturation, prediction, regulator, etc.) can be taken into account. The result is excellent accuracy. However, it remains incompatible with online stability assessment due to its computational time.[35]

Modeling electrical networks leads to differential equations that are solved with mathematical tools that consist of studying the evolution of the charge angle (δ)as a function of time using a variety of methods.

2.8.1 numerical integration:

The study of stability using this method consists in finding a mathematical model capable of representing the network and dynamics of machines during three important phases: before, during and after any disturbance. Equations are solved in the time domain using numerical integration methods.

2.8.1.1 Euler Method:

Also called the "tangent method", it is the simplest of the methods of numerical resolution of differential equations, we consider that, h being small[34]

$$x(t+h) \approx x(t) + hx'(t) = x(t) + hf(x(t), y(t)) \tag{2.2}$$

$f(x_t, y_t)$ is the value of the derivative function at the i-th step.
and the same for y(t + h). We therefore consider:

$$X_0 = x_0, \quad Y_0 = y_0, \quad X_{k+1} = X_k + h_f(X_k, Y_k), \quad Y_{k+1} = Y_k + h_g(X_k, Y_k).$$

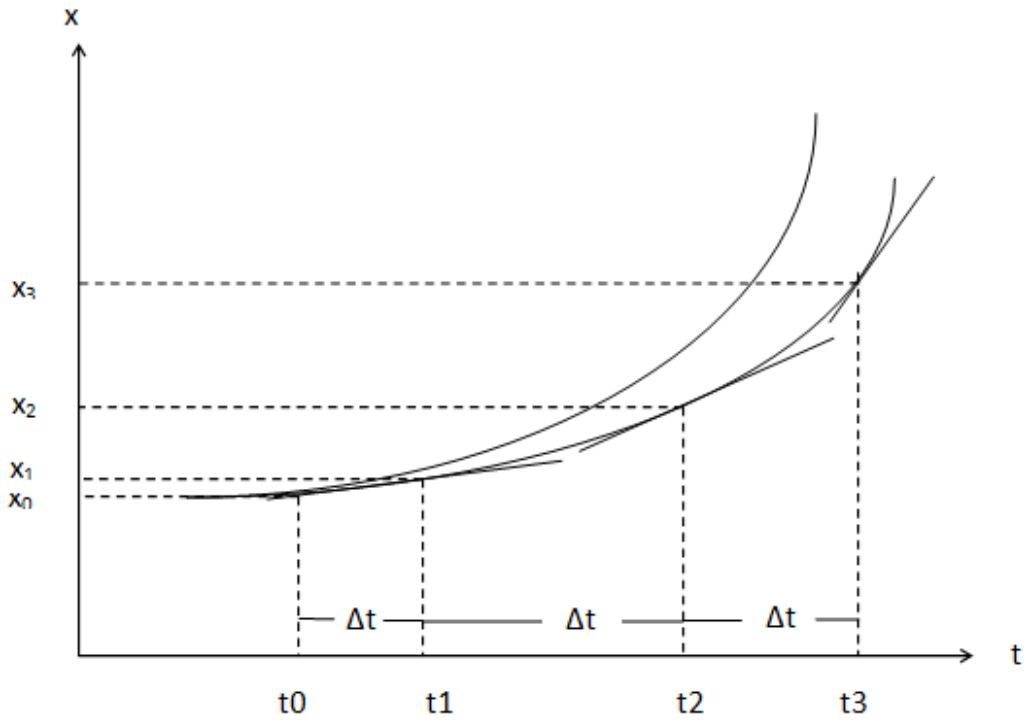


Figure 2.5: Graphical interpretation of the Euler method.

For a variation in time known as t, the increment of x is such that:

$$\Delta x \approx \left|\frac{dx}{dt}\right|_{x_0} \Delta t = f(x_0, t_0)\Delta t \tag{2.3}$$

Or $\left|\frac{dx}{dt}\right|_{x_0} = f(x_0)$ is the slope of the curve at (t_0, x_0).

The value from x to t=$t_0 + tissuchthat$:

$$x_1 = x_0 + \Delta x = x_0 + \left|\frac{dx}{dt}\right|_{x_0} \Delta t \tag{2.4}$$

This approximation represents the Taylor series expansion of f(x) with respect to the point (t0,x0), ignoring higher-order terms.

This method is iterative, so the values of $x_(i+1)are$:

$$x_{i+1} = x_i + \left|\frac{dx}{dt}\right|_{x_i} \Delta t \tag{2.5}$$

2.8.1.2 Modified Euler method:

Euler's method assumes that the slope is constant during the time interval t, so the error increases as t increases. To reduce this error and improve the integration result, the slopes are calculated at the beginning and end of the time interval t and the average slope is calculated. This method is known as the modified Euler method.

Using the derivative at the beginning of the interval, the predicted value at the end of the interval is :

$$x_i^p = x_0 + \left|\frac{dx}{dt}\right|_{x_0} \Delta t \tag{2.6}$$

From the predicted value, the derivative calculated at the end of the interval is such that:

begincenter $\left|\frac{dx}{dt}\right|_{x_i^p} = f(t_i, x_i^p)$

The corrected value is obtained by calculating the average value of the two slopes.

$$x_i^c = x_0 + \frac{1}{2}\left(\left|\frac{dx}{dt}\right|_{x_0} + \left|\frac{dx}{dt}\right|_{x_i^p}\right)\Delta t \tag{2.7}$$

It is also an iterative method, the value $\mathrm{x}_(i+1) issuchthat$:

$$x_{i+1}^c = x_i + \frac{1}{2}\left(\left|\frac{dx}{dt}\right|_{x_i} + \left|\frac{dx}{dt}\right|_{x_{i+1}^p}\right)\Delta t \tag{2.8}$$

The inaccuracy of Euler's method is basically due to the neglect of higher-order terms in the expansion of the Taylor series. It can be seen that with the latter method the accuracy is improved compared to the Euler method by the correction of the estimate.

2.8.1.3 Comparison between the modified Euler method and than the Euler method:

The modified Euler method is more strictly specified than the Euler method.

For Euler's method, using a large Δt slope, the generated curve shows that the system is unstable. Using the same data and a small Δt slope yields a curve showing that the system is stable.

The smaller the Δt interval, the more accurate the result. On the other hand, in the modified Euler method, the method is tolerant of small and large steps.

2.8.1.4 Runge-Kutta Method Order 4 (RK4):

The Euler method uses only the derivative at the beginning of each interval $[kh, (k+1)h]$ to deduce X_{k+1} and Y_{k+1} at the end of the interval from the X_k and Y_k values at the beginning of the interval.

Now we will calculate values of the derivative at 4 points of the interval, in order to achieve greater precision.

In detail, we only modify the iterative step of the Euler method, which becomes [40]

$$X_{k+1} = X_k + \frac{1}{6}h(K_1 + 2K_2 + 2K_3 + K_4), \tag{2.9}$$

$$Y_{k+1} = Y_k + \frac{1}{6}h(L_1 + 2L_2 + 2L_3 + L_4) \tag{2.10}$$

with:

$$K_1 = F(X_k, Y_k),\ L_1 \ = G(X_k, Y_k), \tag{2.11}$$

Then:

$$K_2 = F\left(X_k + \frac{1}{2}h_{k_1}, Y_k + \frac{1}{2}hL_1\right),\ L_2 \ = G\left(X_k + \frac{1}{2}h_{k_1}, Y_K + \frac{1}{2}h_{l_1}\right) \tag{2.12}$$

$$K_3 = F\left(X_k + \frac{1}{2}h_{k_2}, Y_k + \frac{1}{2}hL_2\right),\ L_3 \ = G\left(X_k + \frac{1}{2}h_{k_2}, Y_K + \frac{1}{2}h_{l_2}\right) \tag{2.13}$$

Finally:

$$K_4 = F\left(X_k + h_{k_3}, Y_k + \frac{1}{2}h_{l_3}\right),\ L_4 \ = G\left(X_k + h_{k_3}, Y_k + \frac{1}{2}h_{l_3}\right) \tag{2.14}$$

The most commonly used methods are the modified Euler method and the Runge-Kutta method of order 4.

2.8.1.5 Park's Transformation:

The two-axis decomposition method applied to the synchronous machine can solve a large number of transient speed problems (oscillation disturbances, asynchronous operation). The Park transformation allows the synchronous machine to be represented by an equivalent bipolar machine where the stator windings a, b, c will be transferred to the rotor referential consisting of orthogonal windings on both axes [9].

The Park transform is given by:

$$\mathrm{A} = \begin{bmatrix} i_d \\ i_q \\ i_o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta - 4\pi/3) \\ \sin\theta & \sin(\theta - 2\pi/3) & \sin(\theta - 4\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

It is important to note that the transformation of PARK is particularly interesting in the case of symmetric disturbances ($i_0 = 0$).

2.8.2 Advantage of digital integration methods:

- To provide important information on transient phenomena, in particular on the behavior of their salient parameters and the temporal evolution of the system (rotor angles, speeds, power. etc.).

- Can achieve the required degree of accuracy, assuming good modeling and correct values of system parameters.

2.8.3 Disadvantages of numerical integration methods:

- Does not provide a margin of stability to indicate how far the system is at instability and to facilitate sensitivity calculation.

- Does not provide effective control tools, i.e. unstable scenario stabilization Finally, It is very important to note that the dramatic advances in programming have contributed to making digital integration methods much faster than they were in the early days: simulations requiring an hour of time barely 20 years ago only take a few seconds.

2.9 Conclusion:

In this chapter, we have discussed the importance of stability issues when studying power grids. Next, we present different types of stability, including angular stability, and show the different types that can be met. The transient stability of an electrical network is its ability to maintain synchronization when it is subjected to a great disturbance such as a defect on transmission equipment, loss of a generating machine, loss of a high load, loss of line(s) transmission or a combination of these different phenomena [Kundur, 1941. The response of the system (network) subjected to such disturbances can cause large dispersions of the internal angle of the generators, as well as power flows, voltages, angles and frequencies at the rods, and other variables [Kundur, 1941. The stability of the network is influenced by its nonlinear characteristics, by its topology at each given moment, and also by the particular distribution of power across all its branches. If the resulting gap between the internal angles of the machines remains limited, the system synchronization is maintained [Kundur, 19941. The loss of synchronization due to transient instability very often occurs a few seconds after the initial disturbance. Even on systems with sophisticated control equipment, the time taken to observe the loss of synchronization after instability is about 10 seconds [Anderson and Fouad, 1971. Next, we showed how to analyze transient stability. [18]

Chapter 3

Multi machine system

3.1 Introduction:

Machines may be physically located in different parts of the world and connected via a network, or they may be located in the same data center and connected via a high-speed internal network.

The concept of a multi-machine system is important because it allows organizations to achieve levels of computing power and processing speed that would be impossible with a single machine. By distributing computational tasks across multiple machines, a multi-machine system can handle larger and more complex workloads, while also providing fault tolerance and redundancy.

However, designing and implementing a multi-machine system can be a complex and challenging task. One of the main challenges is ensuring that the various machines in the system are able to communicate with each other effectively and efficiently. This requires careful network design and configuration, as well as software development that can take advantage of the distributed computing environment.

Another challenge is ensuring that the system is able to scale effectively as the workload grows. This requires careful monitoring and management of system resources, as well as the ability to add new machines to the system as needed.

Despite these challenges, a multi-machine system can offer numerous benefits. For example, it can provide increased processing power, faster data processing, improved fault tolerance and redundancy, and greater flexibility in managing workloads. In addition, a multi-machine system can be more cost-effective than a single machine, as it allows organizations to take advantage of the resources of multiple machines without having to purchase and maintain a large number of individual machines.

3.2 The Single Machine system:

In the field of electrical engineering, the term "single machine" typically refers to a single generator or a synchronous machine connected to a power system. It is also known as a single generator-infinite bus system. The term "machine" here refers to a rotating electrical machine, such as a synchronous generator.

In power systems, synchronous generators are responsible for converting mechanical energy into electrical energy. They are connected to an electrical grid or bus system, which represents the overall power network. The single machine model simplifies the analysis of power systems by considering only one synchronous generator and assuming an infinite bus, which means that the voltage and frequency of the bus remain constant.

The single machine model is often used for stability analysis and control design in power systems. It helps in understanding the dynamic behavior of the generator and the overall system under different operating conditions and disturbances. By studying the single machine model, engineers can assess the stability of the power system and design appropriate control strategies to maintain stable and reliable operation.[33]

It's important to note that in practice, power systems consist of multiple interconnected machines, each with its own characteristics and dynamics. However, the single machine model is a useful simplification for initial analysis and system-level studies.

In the field of electrical engineering, the term "single machine" usually refers to a single generator or synchronous machine connected to the power grid. Also called single generator infinite bus system. The term "machine" as used herein refers to a rotating electrical machine, such as a synchronous generator.

In power systems, synchronous generators are responsible for converting mechanical energy into electrical energy. They are connected to a power grid or bus system that represents the entire power grid. The single-machine model simplifies power system analysis by considering only one synchronous generator and assuming an infinite bus where the bus voltage and frequency remain constant.[33]

Single-machine models are widely used in power system stability analysis and control design. This helps us understand the dynamic behavior of the generator and the overall system under different operating conditions and disturbances. By examining single-machine models, engineers can assess power system stability and design appropriate control strategies to maintain stable and reliable operation.

It is important to note that in reality, a power system consists of multiple interconnected machines, each with their own characteristics and dynamics. However, the single-machine model helps simplify initial system-level analysis and research. [33]

Consider a single machine system shown in (Figure III.1) For simplicity, we will assume a synchronous machine represented by' model 1.0 neglecting damper windings both in the d and q axes. (It is possible to approximate the effects of damper windingss by a nonlinear damping term, if necessary). Also, the armature resistance of the machine is neglected and the excitation system represented by a single time-constant system shown in (Figure III.2)

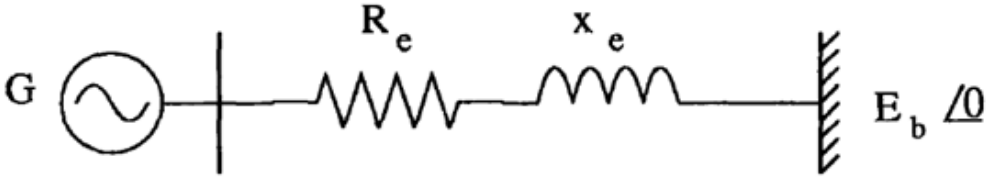


Figure 3.1: A single machine system

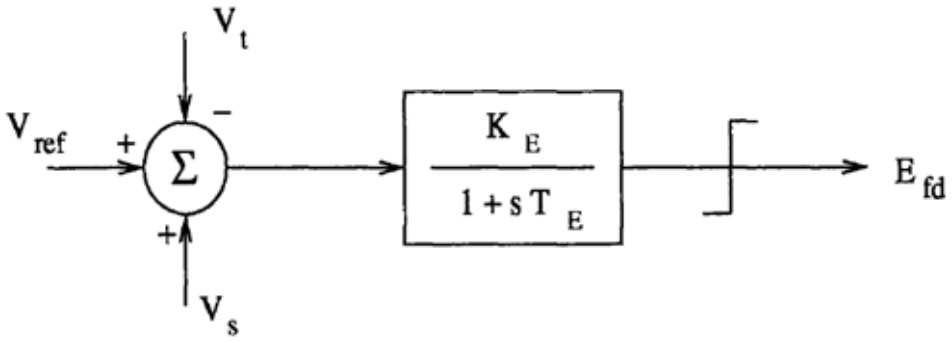


Figure 3.2: Excitation system

3.3 synchronous machine:

3.3.1 Definition:

A synchronous machine is an ac rotating machine whose speed under steady state condition is proportional to the frequency of the current in its armature. The magnetic field created by the stator currents rotates at the synchronous speed ,and that created by the field current on the rotor is rotating at the synchronous speed also, and a steady torque results. So, these machines are called synchronous machines because they operate at constant speeds and constant frequencies under steady- state conditions. Synchronous machines are commonly used

as generators especially for large power systems, such as turbine generators and hydroelectric generators in the grid power supply. Because the rotor speed is equal to the synchronous speed of stator magnetic field, synchronous motors can be used in situations where constant speed drive is required. Since the reactive power generated by a synchronous machine can be adjusted by controlling the magnitude of the rotor field current, unloaded synchronous machines are also often installed in power systems for power factor correction or for control of reactive kVA flow. Such machines, known as synchronous condensers, and may be more economical in the large sizes than static capacitors.[23]

The bulk of electric power for everyday use is produced by polyphase synchronous generators (alternators), which are the largest single-unit electric machines in production. For instance, synchronous generators with power ratings of several hundred megavolt-amperes (MVA) are fairly common, and it is expected that machines of several thousand megavolt- amperes will be in use in the near future. Like most rotating machines, synchronous machines are capable of operating both as a motor and as a generator. They are used as motors in constant-speed drives, and where a variable-speed drive is required,a synchronous motor is used with an appropriate frequency changer such as an inverter. As generators, several synchronous machines often operate in parallel, as in a power station. While operating in parallel, the generators share the load with each other; at a given time one of the generators may not carry any load. In such a case, instead of shutting down the generator, it is allowed to "float" on the line as a synchronous motor on no-load [10]

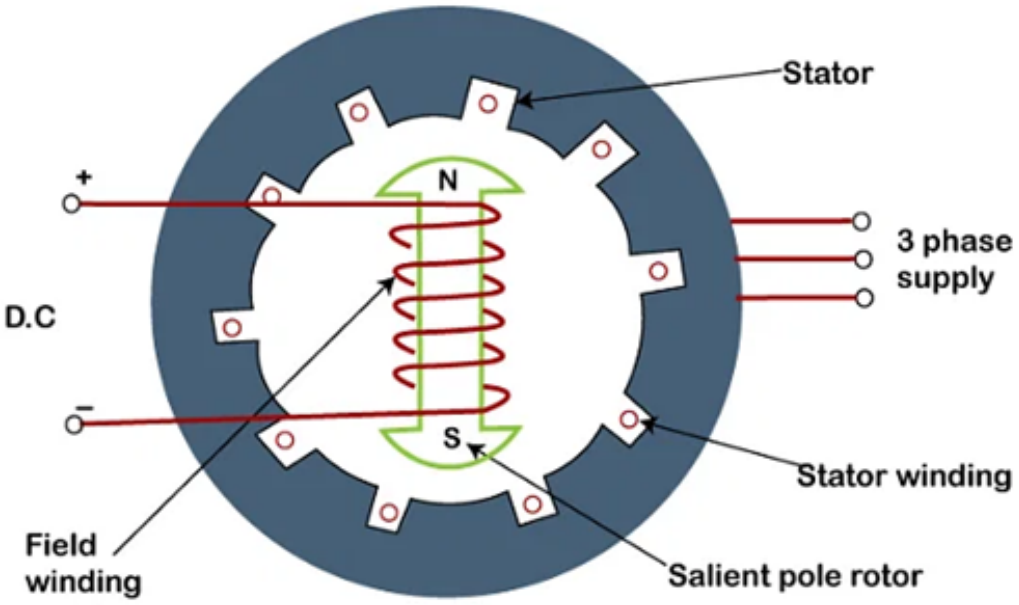


Figure 3.3: Diagram of synchronous machine

3.3.2 The synchronous machine overviews:

The synchronous machine the synchronous machine under consideration is shown in (Figure 3.4) this shows 3 Phase armature windings (a, b, c) on the stator and four windings on the stator Rotor containing field winding 'f'. The amortizer (or damper) turns on the eddy current effects of salient pole machines or rotors are displayed. By a set of coils with constant parameters. 3 damper coils, 'h' on D axis (Figure 3.4) shows g and k on the q-axis. Number of dampers the coils shown vary from zero (the simplest model) to 5 or more. We use the Jackson Winchester model [22]. However, the most detailed model was used Methods commonly used in the study of dynamic energy systems are limited to three damper coils. (that is It is also easy to obtain parameters for this model and simpler models).

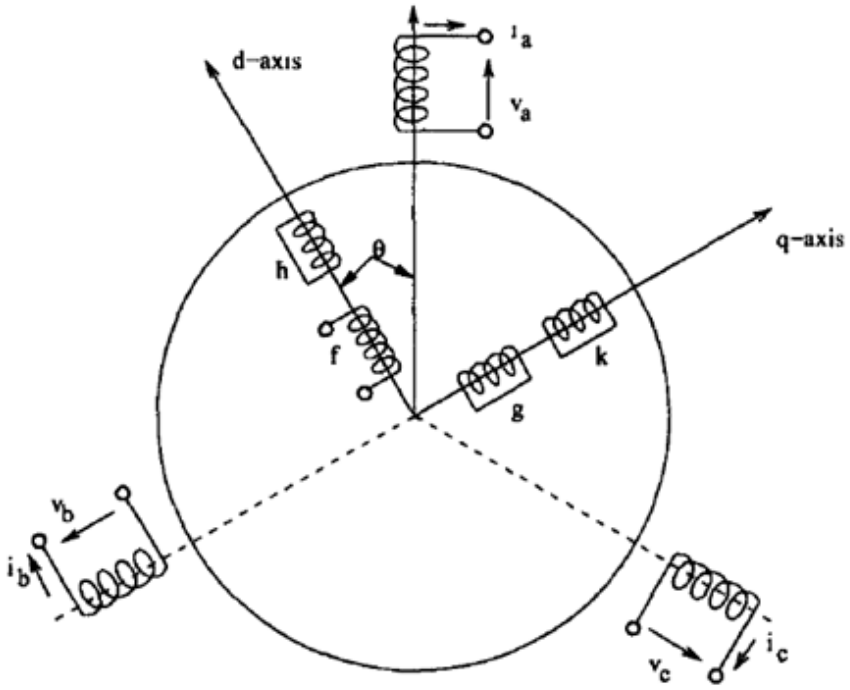


Figure 3.4: Synchronous machine

The following assumptions are used in the derivation of the basic equations of the machine.
- The mmf in the air gap is distributed sinusoidally and the harmonics are neglected.
- Saliency is restricted to the rotor. The effect of slots in the stator is neglected.
- Magnetic saturation and hysteresis are ignored.

The representation of the saturation will be considered later in this chapter. In what follows, the machine is assumed to have two poles. There is no loss of generality in doing this as the rotor angle θ with respect to a stationary axis is assumed to be the electrical angle and the equations are invariant with respect to the number of poles. The mechanical angle m m is related to θ by:

$$\theta_m = \frac{2}{P}\theta \tag{3.1}$$

θ_m : The mechanical angle
θ : the rotor angle

3.3.3 Construction of synchronous machines :

The synchronous machine has 3 phases winding on the stator and a d.c. field winding on the rotor.

3.3.3.1 Stator :

It is the stationary part of the machine and is built up of sheet-steel laminations having slots on its inner periphery. A 3-phase winding is placed in these slots. The armature winding is always connected in star and the neutral is connected to ground.

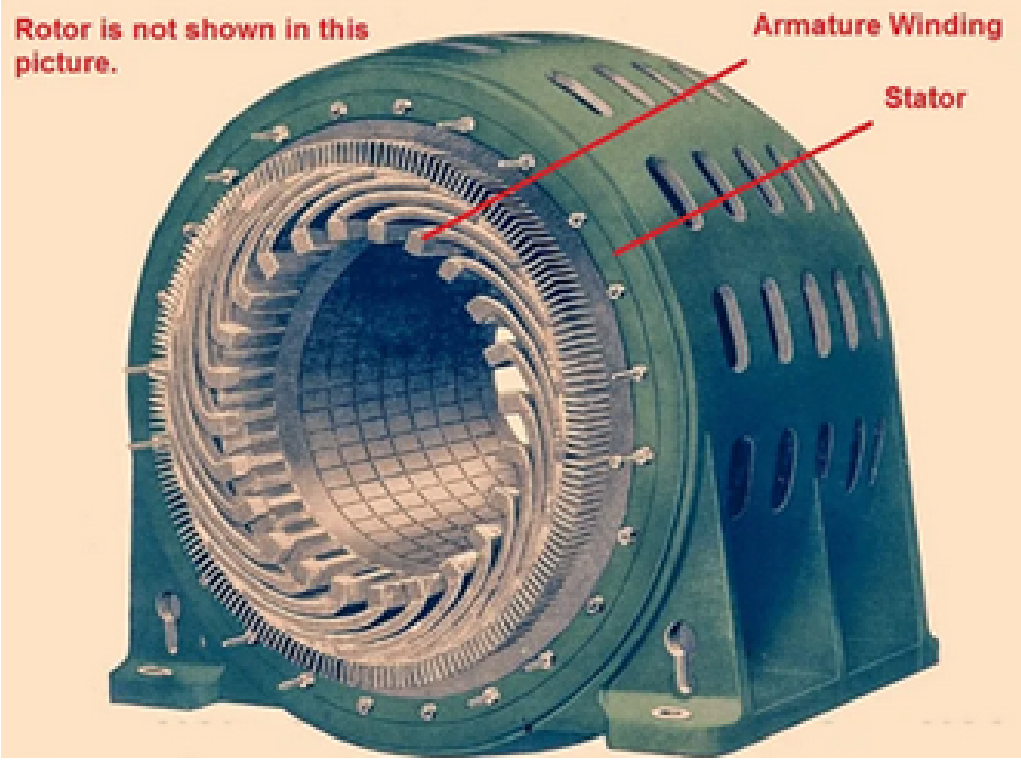


Figure 3.5: Stator of synchronous machine

3.3.3.2 rotor:

The rotor carries a field winding which is supplied with direct current through two slip rings by a separate d.c. source. Rotor construction is of two types, namely:

- Salient (or projecting) pole type . - Non-salient (or cylindrical) pole type.

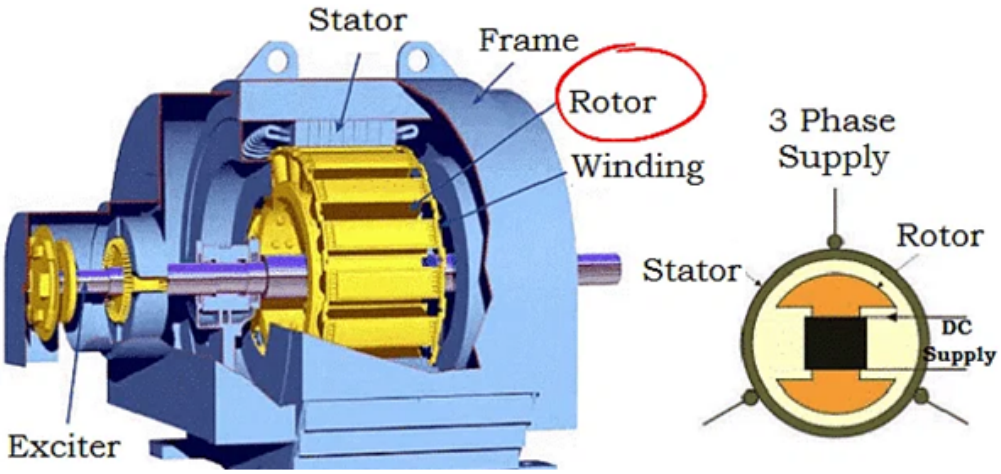


Figure 3.6: a synchronous machine parts

a)Rotor Operation:

In a synchronous machine, the rotor rotates at the same speed as the rotating magnetic field in the stator. The rotor in a synchronous machine has a separate set of windings (known as field windings) that are excited with direct current (DC). This creates a magnetic field in the rotor that synchronizes with the rotating magnetic field produced by the stator. The rotor's speed is precisely controlled to maintain synchronism with the stator field.

a)Speed Control:

Synchronous machines can operate at precisely controlled speeds, matching the frequency of the AC power supply or other external control signals. The speed control of synchronous machines is achieved by adjusting the field current supplied to the rotor windings.[33]

3.3.4 Flux Linkage Equations:

The stator and rotor flux linkages are given by:

$\varphi_s = [L_{ss}]i_s + [L_{sr}]i_r$

$\varphi_r = [L_{rs}]i_s + [L_{rr}]i_r$

Where

$$i_{ts} = \begin{bmatrix} i_a & i_b & i_c \end{bmatrix}, \qquad \varphi_{ts} = \begin{bmatrix} \varphi_a & \varphi_b & \varphi_c \end{bmatrix}$$

$$i_{tr} = \begin{bmatrix} i_f & i_h & i_g & i_k \end{bmatrix}, \qquad \varphi_{tr} = \begin{bmatrix} \varphi_f & \varphi_h & \varphi_g & \varphi_k \end{bmatrix}$$

The matrices $[L_{ss}]$ and $[L_{rr}]$ are symmetric, and also $[L_{rs}] = [L_{sr}]^T$. From two reaction theory, it is possible to express the inductance coefficients as follows.

$$[L_{ss}] = \begin{bmatrix} L_{aao} & L_{abo} & L_{abo} \\ L_{abo} & L_{aao} & L_{abo} \\ L_{abo} & L_{abo} & L_{aao} \end{bmatrix} + L_{aa2} \begin{bmatrix} \cos 2\theta & \cos(2\theta - 2\pi/3) & \cos(2\theta + 2\pi/3) \\ \cos(2\theta - 2\pi/3) & \cos(2\theta + 2\pi/3) & \cos 2\theta \\ \cos(2\theta + 2\pi/3) & \cos 2\theta & \cos(2\theta - 2\pi/3) \end{bmatrix}$$

$$[L_{rr}] = \begin{bmatrix} L_f & L_{fh} & 0 \\ L_{fh} & L_h & 0 \\ 0 & 0 & L_g \end{bmatrix}$$

$$[L_{sr}] = \begin{bmatrix} M_{af}\cos\theta & M_{ah}\cos\theta & M_{ag}\sin\theta & M_{ak}\sin\theta \\ M_{af}\cos(\theta - 2\pi/3) & M_{ah}\cos(2\theta - 2\pi/3) & M_{ag}\sin(2\theta - 2\pi/3) & M_{ak}\sin(2\theta - 2\pi/3) \\ M_{af}\cos(\theta + 2\pi/3) & M_{ah}\cos(2\theta + 2\pi/3) & M_{ag}\sin(2\theta + 2\pi/3) & M_{ak}\sin(2\theta + 2\pi/3) \end{bmatrix}$$

Note that $[L_{sr}]$ is a function of θ and is time varying if the rotor rotates at a constant speed. $[L_{ss}]$ is also a function of θ if $L_{aa2} \neq 0$. This is true for salient pole machines.

3.3.5 Voltage Equations:

The voltage equations for the stator and rotor coils are given below.

$$-\frac{d\varphi_s}{dt} - [R_s]i_s = v_s \tag{3.2}$$

$$-\frac{d\varphi_r}{dt} - [R_r]i_r = v_r \tag{3.3}$$

where

$$v_{ts} = [v_a \quad v_b \quad v_c], \quad v_{tr} = [-v_f \quad 0 \quad 0 \quad 0]. \tag{3.4}$$

$$[R_s] = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_a & 0 \\ 0 & 0 & R_a \end{bmatrix} = R_a[U_3] \tag{3.5}$$

$$[L_{rr}] = \begin{bmatrix} Lf & Lfh & 0 & 0 \\ Lfh & Lh & 0 & 0 \\ 0 & 0 & Lg & Lk \end{bmatrix} \tag{3.6}$$

$[U_3]$ (a unit matrix of dimension 3)

3.3.6 Torque Equation :

It is assumed that the inertia of the turbines (prime mover) can be clubbed with that of the generator'rotor (by assuming the shaft to be rigid). In this case, the equation of motion of the rotor is given by:

$$J\frac{d^2\theta_m}{dt^2} + D\frac{d\theta_m}{dt} = T_m - T_e \tag{3.6}$$

Where

J is the combined moment of inertia of the rotor (s)
D is the damping (assumed to be viscous) coefficient (pu)
T_m is the mechanical torque in the direction of rotation (pu)
T_e is the electrical torque opposing the mechanical torque (pu)
θ_m is the mechanical angle (rad).

Note that for a two-pole machine, $\theta_m = \theta$. For $P \neq 2$, the equation (3.6) can be transformed to

$$\frac{P}{2}\left(J\frac{d^2\theta_m}{dt^2} + D\frac{d\theta_m}{dt^2}\right) = T_m - T_e \tag{3.7}$$

The electrical torque Te is given by:

$$T_e = -\frac{\partial w'}{\partial \theta_m} = -\frac{P}{2}\frac{\partial w'}{\partial \theta} = \frac{P}{2}T'_e \tag{3.9}$$

Where
$T'_e = -\frac{\partial w'}{\partial \theta}$ is the electrical torque of the equivalent two-pole machine, where W' is the co-energy expressed as.

$$W' = \frac{1}{2}\begin{bmatrix} i_{ts} \\ i_{tr} \end{bmatrix} = \begin{bmatrix} L_{ss} & L_{sr} \\ L_{rs} & L_{rr} \end{bmatrix}\begin{bmatrix} i_s \\ i_r \end{bmatrix} \tag{3.8}$$

Substituting Eq. (3.9) in Eq. (III.8) and noting that $[L_{rr}]$ is a constant matrix, we get

$$T'_e = -\frac{1}{2}\left[i_{ts}\left(\frac{\partial L_{ss}}{\partial \theta}\right)i_s + 2i_{ts}\left(\frac{\partial L_{sr}}{\partial \theta}\right)i_r\right] \tag{3.10}$$

Substituting Eq. (3.10)in Eq. (3.8)we get

$$J'\frac{d^2\theta}{dt^2} + D'\frac{d\theta}{dt} = T'_m - T'_e \tag{3.11}$$

where

$J' = J \cdot \left(\frac{2}{P}\right)^2$ is the equivalent inertia.

$D' = D \cdot \left(\frac{2}{P}\right)^2$ is the equivalent damping coefficient.

$T'_m = 2 \cdot \frac{T_m}{P}$ is the mechanical torque of the equivalent two-pole machine.

The above equation represents the transformation of a 'P' pole machine to a 2 pole machine. The mechanical torque is reduced by a factor of $\frac{2}{P}$. The inertia and damping are reduced by a factor of $\left(\frac{2}{P}\right)^2$. However, since all the equations are expressed in per unit (to be introduced later), there is no loss of generality in assuming that the machine has two poles (as stated earlier) [22].

3.3.7 Park's Transformation :

The combined voltage equations (for the stator and the rotor) can be expressed as:

$$\frac{d\varphi}{dt} = -[R][L]^{-1}\varphi - v \tag{3.12}$$

$$i = [L]^{-1}\varphi \tag{3.13}$$

where:

$$[L] = \begin{bmatrix} L_{ss} & L_{sr} \\ L_{rs} & L_{rr} \end{bmatrix}, \quad [R] = \begin{bmatrix} R_s & 0 \\ 0 & R_r \end{bmatrix}$$

$$\phi^T = [\phi_s^T \ \phi_r^T], \quad i^T = [i_s^T \ i_r^T]$$

$$v^t = [v_s^t \quad v_r^t] \tag{3.14}$$

Alternatively, the voltage equations can also be expressed as:

$$\frac{di}{dt} = [L]^{-1}\left(-[R]i - \frac{d\theta}{dt}\left[\frac{\partial L}{\partial \theta}\right] i - v\right) \tag{3.15}$$

$$\phi = [L]i \tag{3.16}$$

It is possible to solve the equations (III.12) or (III.14) numerically. However, obtaining an analytical solution is nearly impossible, even when = d/dt is constant. This difficulty arises from the time-varying nature of the inductance matrix [L] and the need to compute its inverse.

To simplify calculations for both steady-state and transient conditions, it would be advantageous to transform the time-varying machine equations into a time-invariant set. R.H. Park [4] introduced the following transformation:

$$\begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} = [c_p] \begin{bmatrix} f_d \\ f_q \\ f_o \end{bmatrix} \tag{3.17}$$

Where f_a can be either stator voltage, current, or flux linkage of the stator winding α ($\alpha = a, b,$ or c). $[C_p]$ is defined by:

$$[C_p] = \begin{bmatrix} k_d \cos\theta & k_q \sin\theta & k_0 \\ k_d \cos(\theta - \frac{2\pi}{3}) & k_q \sin(\theta - \frac{2\pi}{3}) & k_0 \\ k_d \cos(\theta + \frac{2\pi}{3}) & k_q \sin(\theta + \frac{2\pi}{3}) & k_0 \end{bmatrix} \tag{3.18}$$

where k_d, k_q, and k_0 are constants appropriately chosen. In the original Park's transformation, $k_d = 1.0$, $k_q = -1.0$, and $k_0 = 1$.

The inverse transformation is given by:

$$\begin{bmatrix} f_d \\ f_q \\ f_o \end{bmatrix} = [c_p]^{-1} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \tag{3.19}$$

Where

$$[c_p]^{-1} = \begin{bmatrix} k_1 \cos\theta & k_1 \cos\left(\theta - \frac{2\pi}{3}\right) & k_1 \cos\left(\theta + \frac{2\pi}{3}\right) \\ k_2 \sin\theta & k_2 \sin\left(\theta - \frac{2\pi}{3}\right) & k_2 \sin\left(\theta + \frac{2\pi}{3}\right) \\ k_3 & k_3 & k_3 \end{bmatrix} \tag{3.20}$$

$$k_1 = \frac{2}{3K_d}, \quad k_2 = \frac{2}{3K_q}, \quad k_3 = \frac{1}{3K_0}$$

3.4 Asynchronous machine:

3.4.1 Definition:

An asynchronous machine, also known as an induction machine or induction motor, is an electrical machine that operates at a speed slightly below the synchronous speed of the rotating magnetic field generated by the stator. It is the most common type of electric motor used in various industrial and residential applications.

In an asynchronous machine, the rotor does not rotate at the same speed as the rotating magnetic field. Instead, the rotor operates at a speed called slip, which is the difference between the synchronous speed and the actual rotor speed. The slip is necessary for the machine to generate torque and rotate.

The operation of an asynchronous machine is based on electromagnetic induction. When the stator windings are energized with a three-phase alternating current (AC) power supply, a rotating magnetic field is created. This rotating magnetic field induces currents in the rotor bars or squirrel cage conductors, generating a magnetic field in the rotor. The interaction between the rotating magnetic field and the induced rotor currents produces a torque that drives the rotor in motion.

Asynchronous machines are known for their simplicity, reliability, and robustness. They are widely used in various applications such as pumps, fans, compressors, conveyor systems, and household appliances. They offer advantages such as self-starting capability, high torque-to-inertia ratio, and relatively low cost. Additionally, asynchronous machines do not require direct electrical connections to the rotor, simplifying their design and maintenance.[21]

3.4.2 Construction of asynchronous machines:

3.4.2.1 Stator:

The stator is the stationary part of the machine. It consists of a laminated core made of high-quality silicon steel to reduce magnetic losses. The stator core is designed with slots to hold the stator windings. The stator windings are typically made of copper and are placed

in these slots. The stator windings are connected in a three-phase configuration to produce a rotating magnetic field.

3.4.2.2 Rotor:

The rotor is the rotating part of the machine. In an asynchronous machine, there are two common types of rotors:

a)Squirrel Cage Rotor:

This is the most common type of rotor used in asynchronous machines. It consists of laminated iron cores stacked together, forming a cylindrical shape. Conductive bars are placed in the rotor slots, and the bars are short-circuited at the ends by conducting rings. This configuration resembles a squirrel cage, hence the name. The squirrel cage rotor does not have any windings, and the rotor currents are induced by the rotating magnetic field.

b)Wound Rotor:

In some applications, a wound rotor is used. The wound rotor consists of a laminated core with rotor windings that are connected to external resistors or other control devices. The wound rotor allows for more control over the machine's operation, such as variable speed control and improved starting characteristics.

3.5 The multi Machine system:

3.5.1 Definition:

A multimachine system, in the context of electrical engineering, refers to a network or system that consists of multiple interconnected electrical machines. These machines can be synchronous machines, asynchronous machines, or a combination of both.

In a multimachine system,the electrical machines are typically connected in parallel or series configurations, forming an interconnected network. This network can include generators, motors, transformers, and other devices that collectively work together to generate, transmit, distribute, or consume electrical power.

Multimachine systems are commonly found in power generation plants, electrical grids, industrial complexes, and large-scale commercial facilities. These systems are designed to efficiently and reliably generate, transmit, and distribute electrical energy to meet the demands of various consumers and maintain grid stability.

Coordinating and controlling the operation of the machines within a multimachine system is crucial to ensure proper synchronization, load sharing, voltage regulation, and overall system stability. Control systems and communication protocols are employed to monitor and manage the performance of individual machines and the system as a whole.

Multimachine systems play a vital role in providing reliable and stable electrical power supply for industrial, commercial, and residential applications. They facilitate the efficient generation, transmission, and distribution of electrical energy, enabling the functioning of modern societies.[4]

3.6 the types of multi machines system:

The main types of multimachine systems in electrical engineering are:

3.6.1 Power Grid Systems:

Power grid systems encompass the interconnected network of generators, transmission lines, transformers, substations, and distribution lines. They are responsible for the transmission and distribution of electrical power from power plants to consumers. Power grids often involve multimachine systems to ensure reliable power supply and grid stability across a large geographical area.

3.6.2 Industrial Power Systems:

Industrial power systems are multimachine systems designed for the power requirements of industrial facilities and complexes. They typically involve generators, motors, transformers, and other electrical equipment interconnected to meet the specific power demands of industrial processes and machinery.

3.7 Mechanical control:

3.7.1 Structure of voltage regulator:

The excitation system of a synchronous machine has a significant impact on transient stability Proper tuning of this system can greatly improve stability. In steady state, this system supplies voltage and direct current, which it must be able to do.

You can also quickly change the excitation voltage in case of network failure [22]. Voltage regulators affect the power produced machine. Consider IEEE-ST1A static excitation system for control voltage; the block diagram for this controller looks like this:

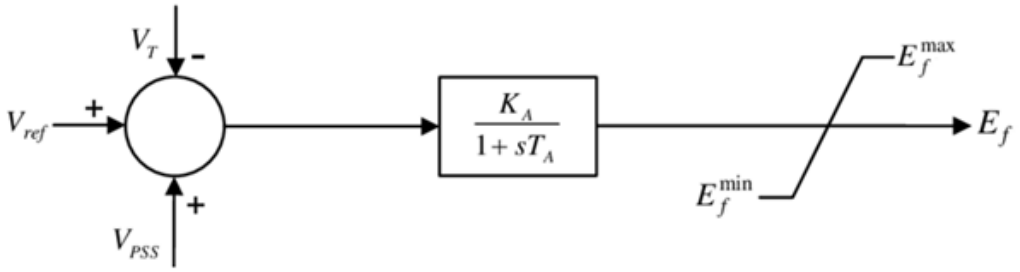


Figure 3.7: Structure of the voltage regulator

The differential equation governing the dynamics of the exciter voltage is given by The following expression:

$$\frac{dE_f}{dt} = \frac{1}{T_A}\left[K_A(V_{\text{ref}} - V_t + V_{\text{pss}}) - E_f\right] \tag{3.21}$$

Where:
K_A: Static gain.
T_A: Regulator time constant.
V_t: Terminal voltage to stator module.
V_{ref}: Reference voltage module.
V_{pss}: Output signal from a PSS.
E_{fmax}: Threshold of over-excitation.
E_{fmin}: Subexcitation threshold.

3.7.2 speed control structure:

The principle of cruise control is to adjust the frequency (or speed) of the generator. Match the mechanical power supplied to the generator to the power requested (Fig.2.8).

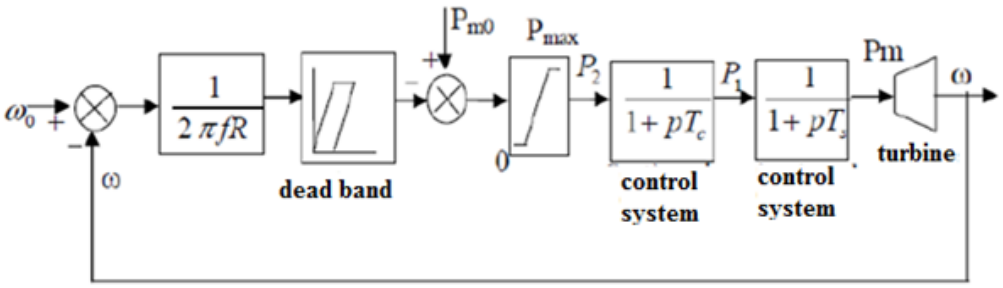


Figure 3.8: Speed control structure [26]

The two-axis representation of the dynamics of the machines during the transition allows taking into account the variation of the transient f.e.m and allows the consideration of the voltage and speed regulators.[41]

3.7.3 power system stabilizer (PSS):

The stabilizer has the function of improving the damping of generator rotor oscillations by controlling its excitation, using auxiliary stabilizer signals. The PSS exists under several types and with different input signals. The most common input signals are: Rotor speed, acceleration power, frequency, active output power, voltage at machine terminals and/or a combination of them. The PSS will be an inseparable part of modern excitation systems [3] [26]. The PSS block diagram is that of (Figure 3.9)

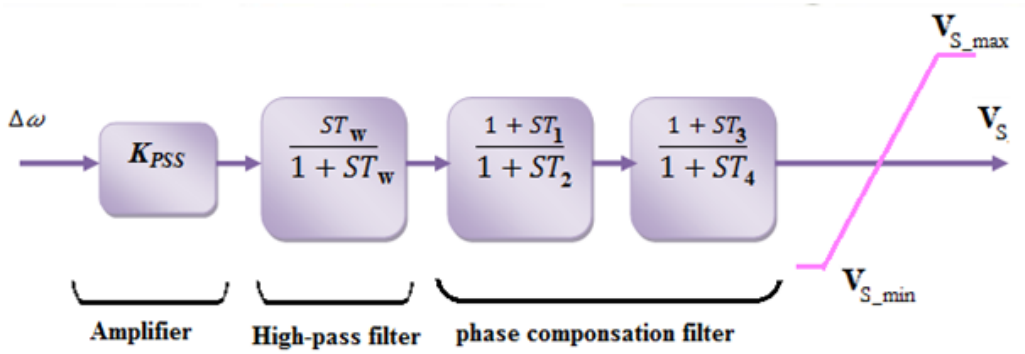


Figure 3.9: PSS power stabilizer model.

3.8 Network performance equations during default:

The grid can be modeled by a linear equation system connecting the injected currents to the nodes and the voltages at the generator terminals .[41]

$$I = YV \tag{3.22}$$

With:

- **I**: current vector at $(n+m)$ elements.
- **V**: voltage vector at $(n+m)$ elements.
- **Y**: square nodal matrix of dimension $(n+m)\times(n+m)$, determined by adding to the matrix Y.

-(Equation (3.21)) the elements representing the system loads.

The size of the electricity network can be reduced,in fact it is possible to eliminate all the nodes where there are no power injection except internal generator nodes by the Kron method [3] .Equation (3.22)is then written as:

To write the given expression in LaTeX with numbering, you can use the following code:

$$\begin{bmatrix} I_n \\ 0 \end{bmatrix} = \begin{bmatrix} y_{nn} & y_{nm} \\ y_{mn} & y_{mm} \end{bmatrix} \begin{bmatrix} V_n \\ V_m \end{bmatrix} \tag{3.23}$$

-We then deduce the reduced matrix relationship to the machine nodes:

$$I_n = Y_r V_n \tag{3.24}$$

$$Y_r = y_{nn} - y_{nm} y_{mm}^{-1} y_{mn} \tag{3.25}$$

-Equation (III.18) represents the reduced network at these machine nodes.

The relationship (III.18) can also be written according to the transient voltages of the machines. We can also write the relation (II.82) according to the transient tensions of the machines, including the transient reactantsin the Y_r matrix. We then have the following expression that binds currents injected at the generating nodes at the transient voltages of the machines:

$$I_n = Y_r E' \tag{3.26}$$

With :

I_n: Vector of injected currents at nodes producing n elements.

E': Vector of transient electromotive forces (f.e.m.) of machines with n elements.

Y_r: Admittance matrix reduced to the generating nodes of the network with dimensions $(n \times n)$. .

The elements of Y_r are given by:

$$Y_{rij} = G_{ij} + jB_{ij}, \quad i,j = 1,\ldots,n \tag{3.27}$$

G_{ij} (respectively B_{ij}) being the conductance (respectively the susceptance) of transfer between the node i and node j.

Currents and transient f.e.m will satisfy the following reports:

$$\hat{I}_n = I_n e^{j\delta_i}, \quad \text{for } i = 1,2,\ldots,n \tag{3.28}$$

$$\hat{E'} = E' e^{j\delta_i}, \quad \text{for } i = 1,2,\ldots,n \tag{3.29}$$

By using the same approach for all network settings, we will have :

$$[\hat{I}] = [\mathrm{e}^{j\delta}] \cdot [I] \tag{3.30}$$

$$[(E')^{\widehat{}}] = [\mathrm{e}^{j\delta}] \cdot [E'] \tag{3.31}$$

Applying equations (III.8) we can write:

$$[\hat{I}] = [\mathrm{e}^{j\delta}] \cdot [Y] \cdot [\mathrm{e}^{-j\delta}] \cdot [E'] \tag{3.32}$$

We obtain the current expressions of the I_{nd} machine following the direct axis and the one in quadrature:

$$I_{di} = G_{ii}E'_{di} + \sum_{\substack{n \\ i\neq k,k=1}} (F_G + B)(\delta_{ik})E'_{dk} - B_{ii}E'_{qi} + \sum_{\substack{n \\ i\neq k,k=1}} (F_G - B)(\delta_{ik})E'_{qk} \tag{3.33}$$

$$I_{qi} = B_{ii}E'_{di} + \sum_{i\neq k}^{n}(F_G + B)(\delta_{ik})E'_{dk} + G_{ii}E'_{qi} + \sum_{i\neq k}^{n}(F_G - B)(\delta_{ik})E'_{qk} \tag{3.34}$$

With :

$$FG + (\delta_{ik}) = G_{ik}\cos(\delta_{ik}) + B_{ik}\sin(\delta_{ik}) \tag{3.35}$$

$$D_{ik} = E'_{di}E'_{qk} - E'_{qi}E'_{dk} \tag{3.36}$$

3.9 Network Modeling in the State Space:

A power system can be described by a set of differential and algebraic equations expressed as follows:

$$\dot{x} = f(x, y, u) \tag{3.37}$$
$$0 = g(x, y) \tag{3.38}$$

The differential equations correspond to the dynamic functions of the generators, the excitation systems and other elements of the system. The algebraic equations correspond equations of transport networks and stators of generators. The solution of these two sets of equations determine the electromechanical state of the system at each moment.[38]

3.9.1 Second order model:

The equations describing the classic power system model for a machine i, are the following:

$$\frac{2H_i}{\omega_s}\frac{d\omega_i}{dt} = P_{mi} - P_{ei} \tag{3.39}$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_s \tag{3.40}$$

$$P_{ei} = E_i^2 G_{ii} + \sum_{i\neq k}^{n} E_i E_k [B_{ik}\sin(\delta_i - \delta_k) + G_{ik}\cos(\delta_i - \delta_k)] \tag{3.41}$$

ω is the pulsation of stator currents frame in rd/s.
H is the inertia constant of the machine.

3.9.2 Two-axis model with voltage and speed regulators:

When we consider the two-axis representation with the voltage and speed, the system dynamic equations for a machine i , are as follows:

$$\frac{2H_i}{\omega_s}\frac{d\omega_i}{dt} = P_{mi} - P_{ei} \tag{3.42}$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_s \tag{3.43}$$

$$\frac{dE'_{qi}}{dt} = \frac{1}{T'doi}\left(-E'_{qi} - (x_{di} - x'_{di})I_{di} + E_{fi}\right) \tag{3.44}$$

$$\frac{dE'_{di}}{dt} = \frac{1}{T'qoi}\left(-E'_{qi} - (x_{qi} - x'_{qi})I_{qi}\right) \tag{3.45}$$

$$\frac{dP_{mi}}{dt} = \frac{1}{T_{mi}}\left(-P_{mi} + P_{mrefi} - K_{vi}(\omega_i - \sigma_i\frac{d\omega_i}{dt})\right) \tag{3.46}$$

$$\frac{dE_{fi}}{dt} = \frac{1}{T_{Ai}}\left(K_{Ai}(V_{refi} - V_{ti} + V_{pssi}) - E_{fi}\right) \tag{3.47}$$

$$P_{ei} = E'_{qi}I_{qi} + E'_{di}I_{di} + (x'_{qi} - x')I_{qi} \tag{3.48}$$

$$I_{di} = G_{ii}E'_{di} + \sum_{i\neq k}(F_G + B(\delta_{ik}))E'_{dk} - B_{ii}E'_{qi} - \sum_{i\neq k}(F_G - B(\delta_{ik}))E'_{qk} \tag{3.49}$$

$$I_{qi} = B_{ii}E'_{di} + \sum_{i\neq k}(F_G - B(\delta_{ik}))E'_{dk} - G_{ii}E'_{qi} + \sum_{i\neq k}(F_G + B(\delta_{ik}))E'_{qk} \tag{3.50}$$

$$V_{di} = -r_{ai}I_{di} + x'_{qi}I_{qi} + E'_{di} \tag{3.51}$$

$$V_{qi} = -r_{ai}I_{qi} + x'_{di}I_{di} + E'_{qi} \tag{3.52}$$

$$V_i = \sqrt{(V_{di})^2 + (V_{qi})^2} \tag{3.53}$$

3.10 Conclusion:

In a power system, a multi-machine system refers to a network of interconnected generators or power plants, each of which may have different characteristics and parameters. A multi-machine system can be found in large-scale power systems, such as those used for industrial .

A key conclusion about multi-machine systems in power systems is that they can pose significant challenges for system stability and control. This is because the behavior of each individual machine can interact with and influence the behavior of the entire system. As a result, engineers and operators must carefully design and manage multi-machine systems to ensure stability and reliability.

One important consideration in multi-machine systems is the need for coordinated control and protection. This involves developing control and protection strategies that account for the

interactions between machines, and ensuring that these strategies are properly implemented and maintained.[29]

Another key conclusion is the importance of modeling and simulation in designing and analyzing multi-machine systems. Advanced modeling and simulation tools can be used to simulate the behavior of individual machines and the system as a whole, allowing engineers to identify potential stability issues and develop effective solutions.

While multimachine systems deal with interconnected machines, synchronous machines, and asynchronous machines are individual types of electrical machines. Synchronous machines have a fixed synchronous speed and are commonly used in power generation, while asynchronous machines operate at a slightly lower speed and are widely used in various applications.

Chapter 4

Kundur Simulation in MATLAB and the results

4.1 Introduction:

In this chapter we will talk about the kundur system ; kundur simulation with two area and four machine and we going to see the result with explanation to what we got .

Kundur simulations are often used in energy system analysis to study the dynamic behavior of connected energy systems. [24] Simulation analyzes the reaction of various signals to transient events such as errors and disturbances. Although specific signals and their properties may vary between simulation scenarios, we can provide a general comparison of some common signals in Kundur simulations [19] These signals include voltage, current, and power related measurements.

These signals encompass voltage, current, and power-related measurements. The voltage signal includes the bus voltage, which signifies the magnitude and phase angle of power grid buses, playing a vital role in analyzing system stability and voltage regulation. Additionally, the generator terminal voltage is crucial for evaluating generator performance, encompassing aspects such as voltage regulation and the supply of reactive power. The current signal comprises the line current, which represents the current flow through transmission lines and cables, aiding in the analysis of power flow and transmission system stability. Furthermore, the generator current reflects the current output of the generator, providing valuable information for evaluating generator performance, including available power and rotor angular stability. Lastly, the power signal encompasses active power (P), which represents the actual power generated or consumed within the system, serving as a key factor in analyzing power flow, generator performance, and load balancing. The reactive power (Q) represents the reactive power generated or consumed, playing a crucial role in evaluating voltage regulation, system stability, and providing reactive power support. Moreover, the apparent power (S) indicates the complex power in the system, combining active and reactive power, thereby aiding in determining the overall current draw and system load.[44] [37] [32]

During Kundur simulations, these signals are typically monitored and analyzed to understand system behavior, identify potential instabilities, and assess the effectiveness of control strategies [32].

The specific values, waveforms, and trends of these signals provide valuable insight into system dynamics, voltage stability, and overall power system performance.

4.2 The simulation :

In a Kundur simulation of a two-area power system with four machines, various signals behave differently depending on the location of faults (disturbance) in the network. Below is a comparison of the signals in three different cases.

network first error, middle error, and network end error.

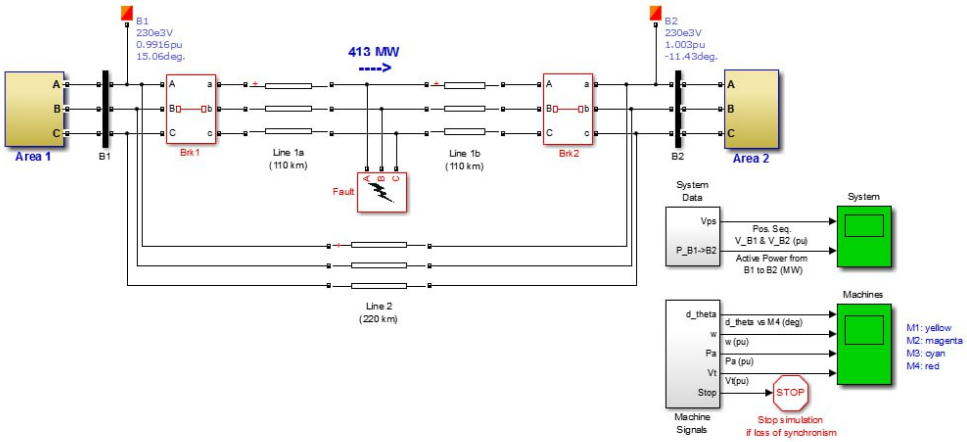


Figure 4.1: Kundur simulation of a two-section power system

4.2.1 The role of the network elements:

4.2.1.1 two-zone:

the concept of "two-zone" refers to a specific protection and control scheme used to detect and respond to abnormal conditions in the power system. The two-zone scheme is commonly used for generator protection and involves the division of the protection system into two distinct zones, each with its own set of protection functions.

4.2.1.2 the two-line:

the two-line model is to capture the essential dynamics and interactions between generators, transmission lines, and loads in a simplified manner. It helps simulate the response of the system to various disturbances, such as faults or changes in load, and assess the system's stability.

4.2.1.3 the four machines:

the inclusion of four machines refers to modeling multiple synchronous generators in the power system. Each machine represents a generator connected to a specific bus or area within the system. The role of the four machines is to capture the dynamics and interactions of multiple generators and their impact on the overall stability and behavior of the power system.

The presence of multiple machines in the simulation allows for a more realistic representation of a power system with interconnected generators. Each machine has its own dynamic characteristics, such as inertia, damping, and control systems, which contribute to the overall system response.

4.2.1.4 the faults:

the inclusion of faults plays a crucial role in studying the dynamic behavior and stability of power systems. A fault refers to a temporary abnormal condition in the system, typically caused by a short circuit or other electrical disturbances. Analyzing the response of the system to faults helps in understanding its stability limits and designing protective measures.

4.2.2 An error occurred when starting the network:

4.2.2.1 Voltage drop:

A failure in the first part of the network causes a significant voltage drop, especially in the affected areas. The voltage at the point of fault will drop significantly, causing a temporary failure of the system.

4.2.2.2 Power surge:

A fault causes a sudden increase in fault current at the fault location. This increased current flows through the affected power lines and machinery, temporarily increasing current levels.

4.2.2.3 vibration:

After a fault, the system can exhibit oscillatory behavior due to the interaction between the generator rotor angle and power system dynamics. This fluctuation can continue until the system stabilizes.

4.2.3 Errors in the middle of the network:

4.2.3.1 Voltage instability:

A failure in the middle of the network will affect both areas, causing voltage instability in both areas. The voltage profile of the affected bus will change significantly and may continue to fluctuate until the system stabilizes. - Interruption of power transmission:

This error can interrupt power transmission between the two areas. Affected transmission lines could experience a sharp drop in power flow, causing an imbalance between power supply and demand.

4.2.4 Error at end of network:

4.2.4.1 Local effect:

Errors at the edge of the network primarily affect the local area where the error occurred. Voltage and current fluctuations are more local and may not propagate well to other areas of the system.

- Voltage recovery:

A fault can cause a temporary voltage drop in the affected area. However, the impact on other areas is relatively limited and the system recovers faster than failures in more critical locations.

It is important to note that the specific behavior of the signal can change depending on factors such as system topology, fault impedance, protection scheme, and control strategy used in the simulation. The above comparison gives a general understanding of the signal jitter for a particular fault location in his Kundur simulation of a two-section, four-machine power system.

we chose to take three positions to the short circuit the begging the center and the and of the network .

and to change in the active power in charge with several cases

a) Putting the fault in the begging of the network:

The following figure shows the fault in the begging of the network:

- we consider that the figures as a function of time

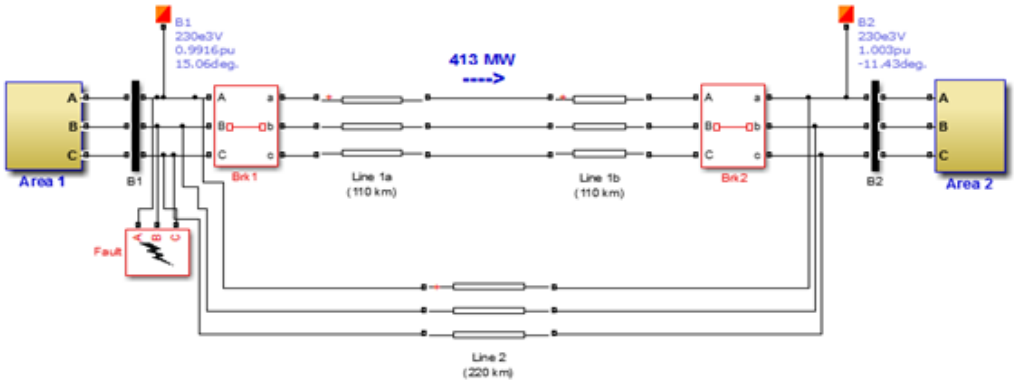
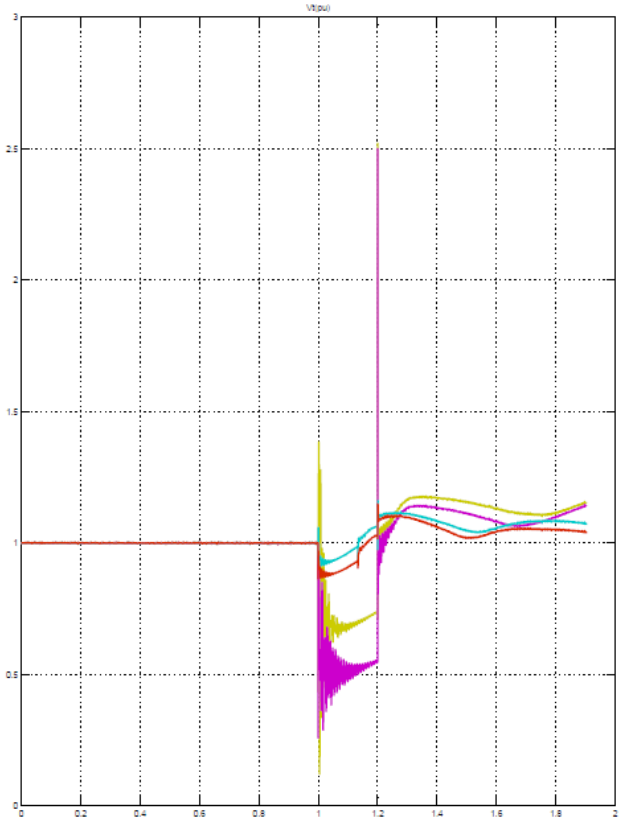
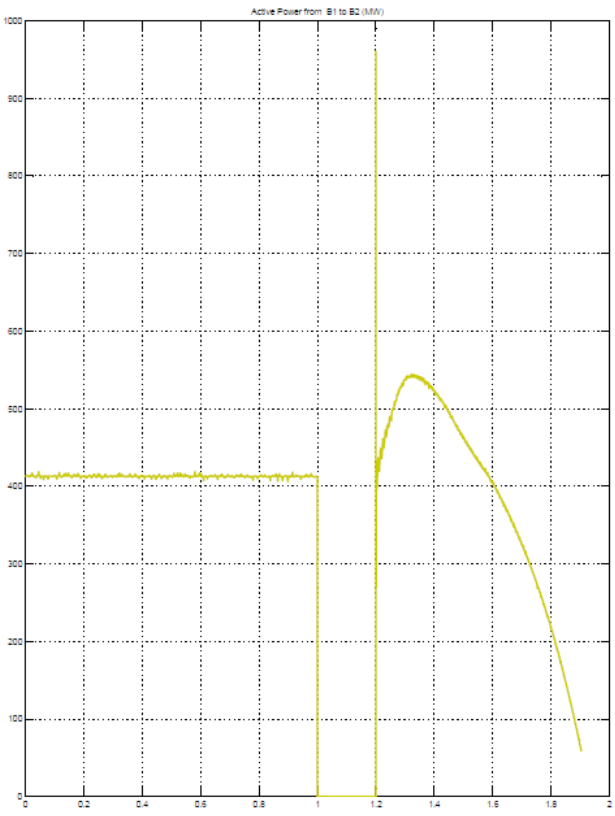


Figure 4.2: Kundur simulation of a two-section power system with the fault in the begging

The following figures show the curves of the the voltage in Bus 1 and Bus 2 (system data)the active power from bus 1 to bus2(system data) , d theta vs M4 (deg) (machine), W (Pu) (machine), Pa (pu) (machine) and Vt (pu) (machine) respectively.

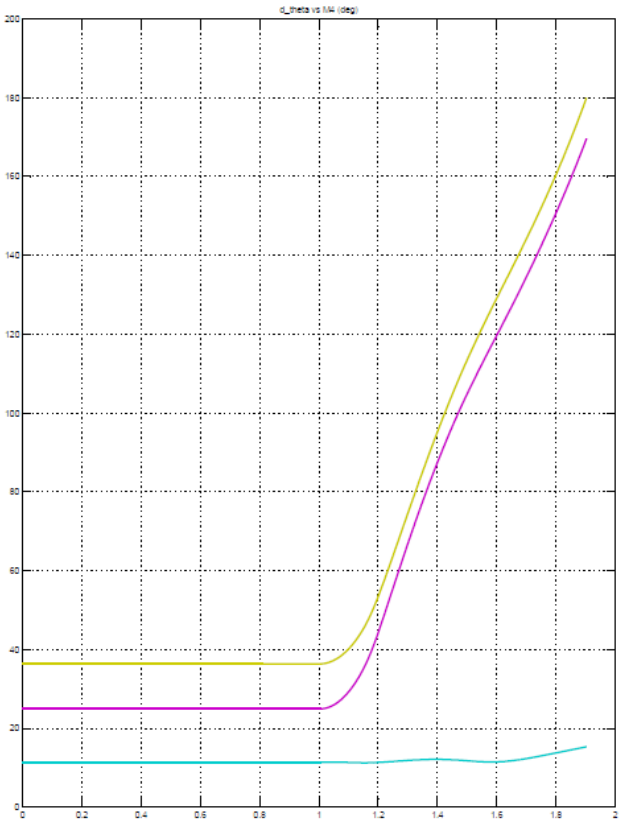


(a) the voltage in Bus 1 and Bus 2 (system data)

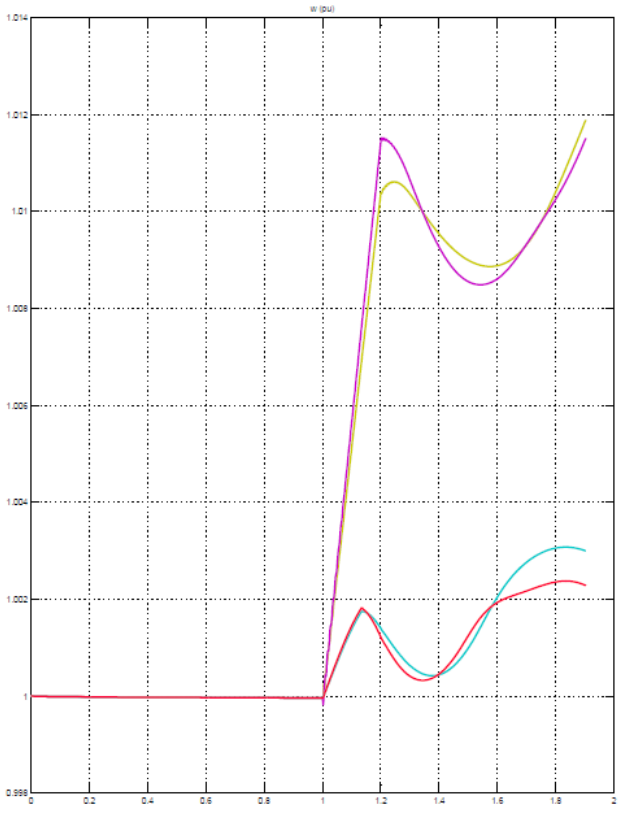


(b) Vt (pu) (machine)

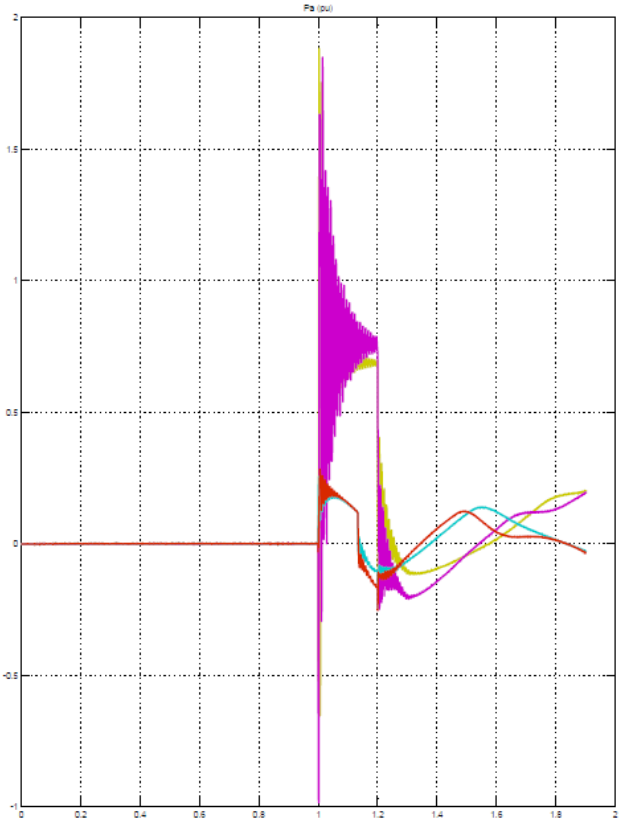
In the initial scenario, the first issue we encounter is a network fault at the beginning. Within the range of [0, 1], our network remains stable. However, as the range extends to [1,



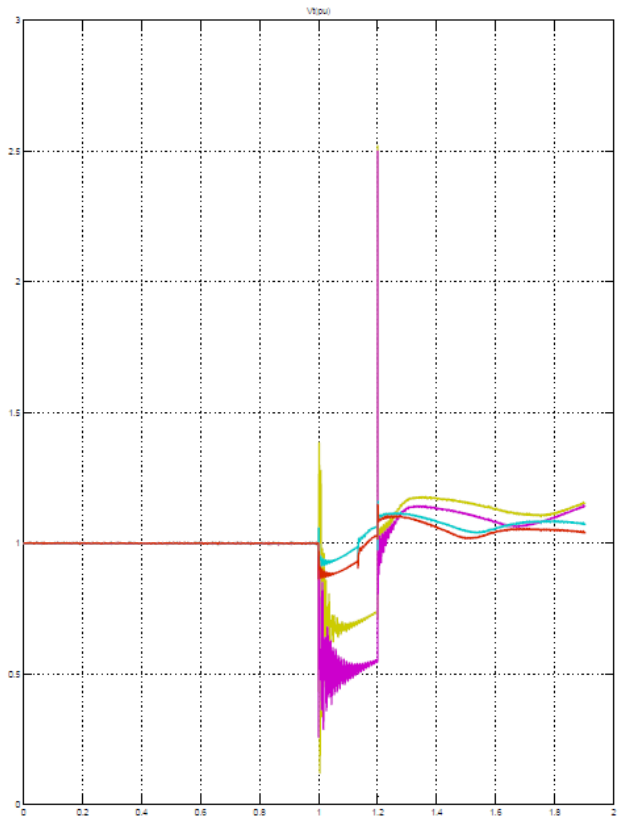
(a) the voltage in Bus 1 and Bus 2 (system data)



(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)

Figure 4.4: the simulation Results :The fault In the begging

1.2], the network becomes unstable. Fortunately, between [1.2, 2], the network manages to stabilize once again.

This fault primarily affects the first area, impacting machine a and b. We can observe this in figures c, d, e, and f. As the fault progresses, it gradually moves towards the second area, although its impact is comparatively less severe than in the initial region.

b)Putting the fault in The fault In the center :

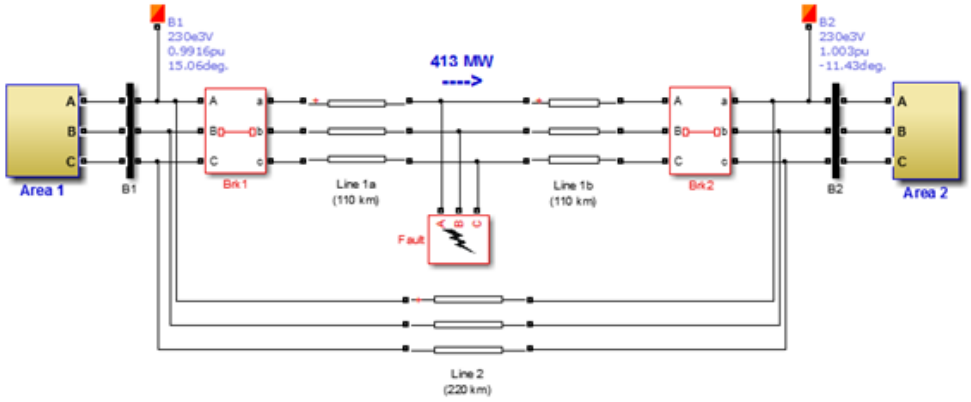


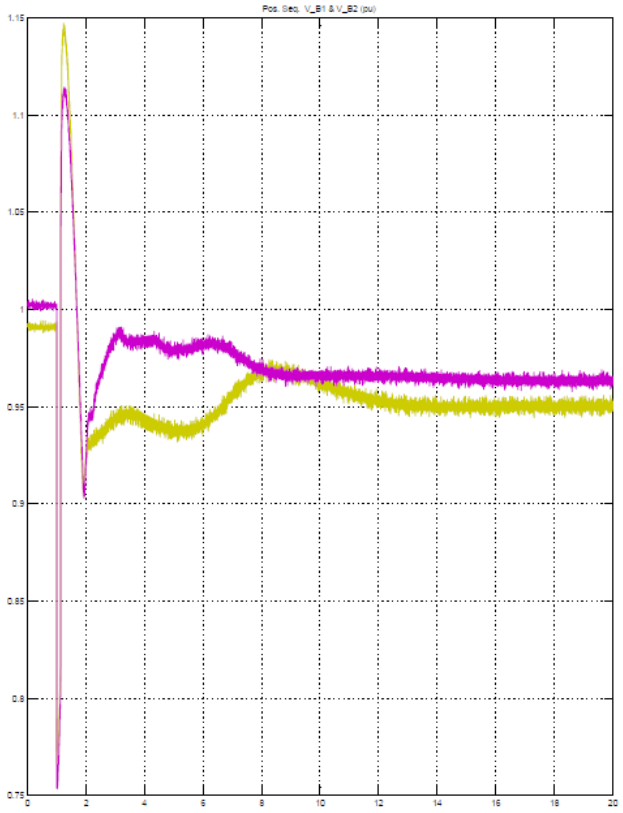
Figure 4.5: Kundur simulation of a two-section power system with the fault in the center

The second scenario involves a fault occurring in the center of the network. Initially, within the range of [0, 1],

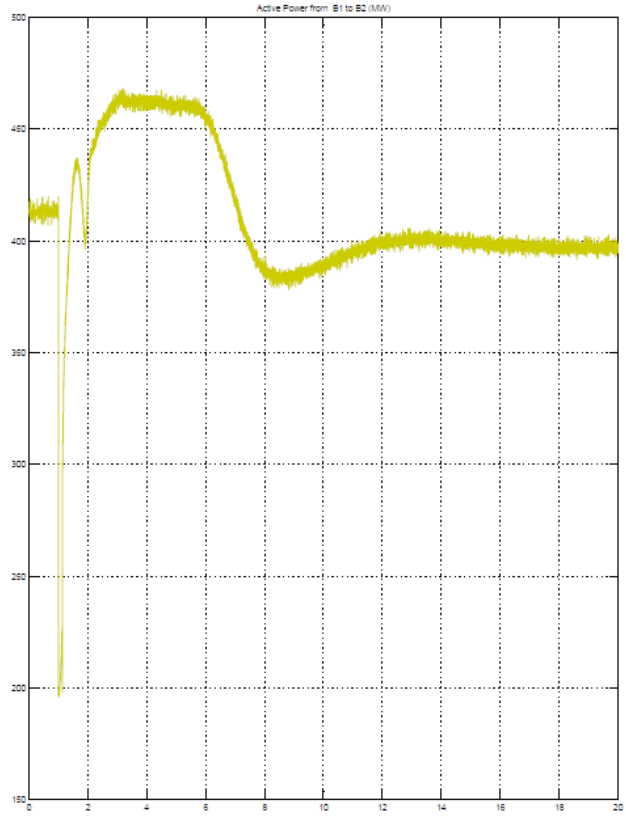
the network remains stable. However, as the range extends to [1, 2], the network becomes unstable. Fortunately, between [2, 20], the network manages to stabilize once again.

In this case, the fault affects both voltage and active power. Within the range of [1, 2], the fault impacts the voltage in bus 1 and bus 2, but they eventually return to stabilization between [2, 20]. Subsequently, within the range of [1, 8], the fault affects the active power, but it also returns to stabilization between [8, 20].

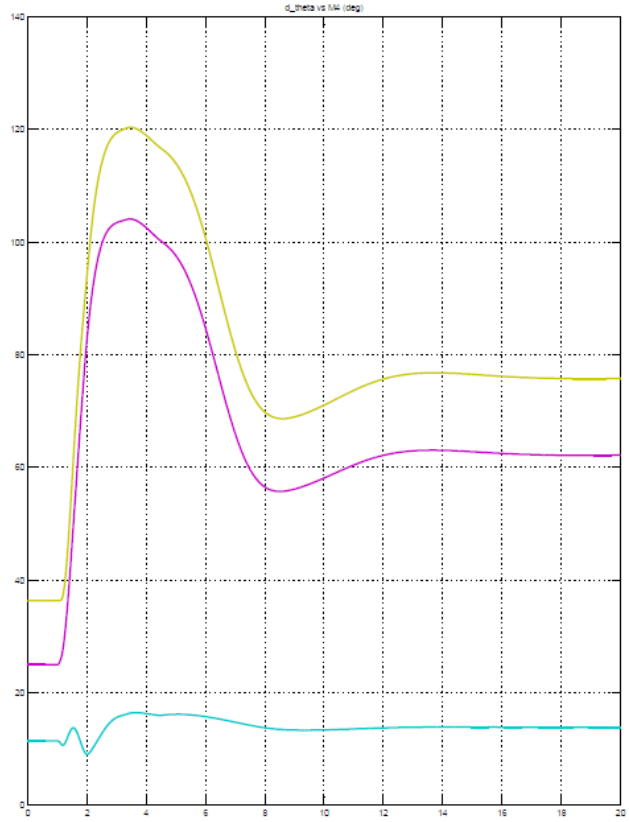
This short circuit impacts four machines within the network, as depicted in the previously mentioned figures. The fault continues to propagate in both directions, affecting different areas of the network.



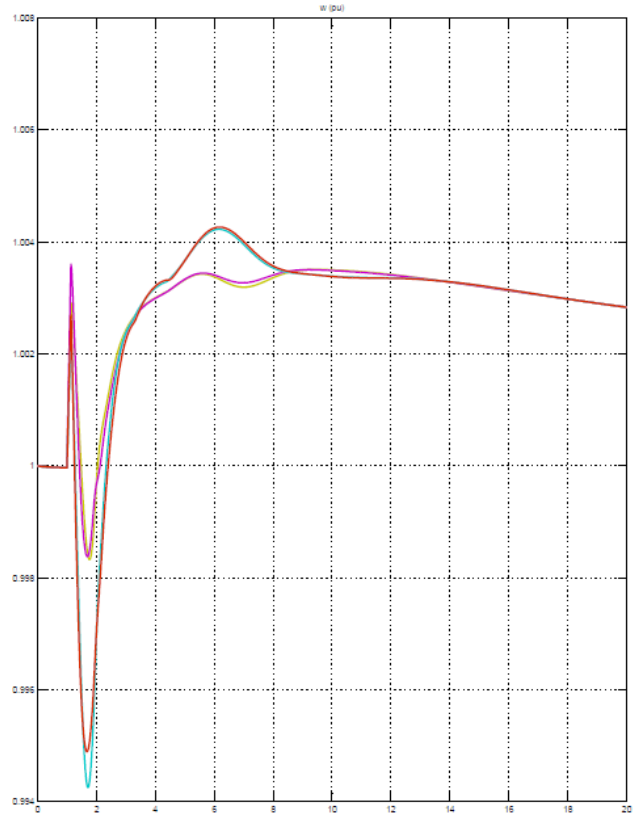
(a) the voltage in Bus 1 and Bus 2 (system data)



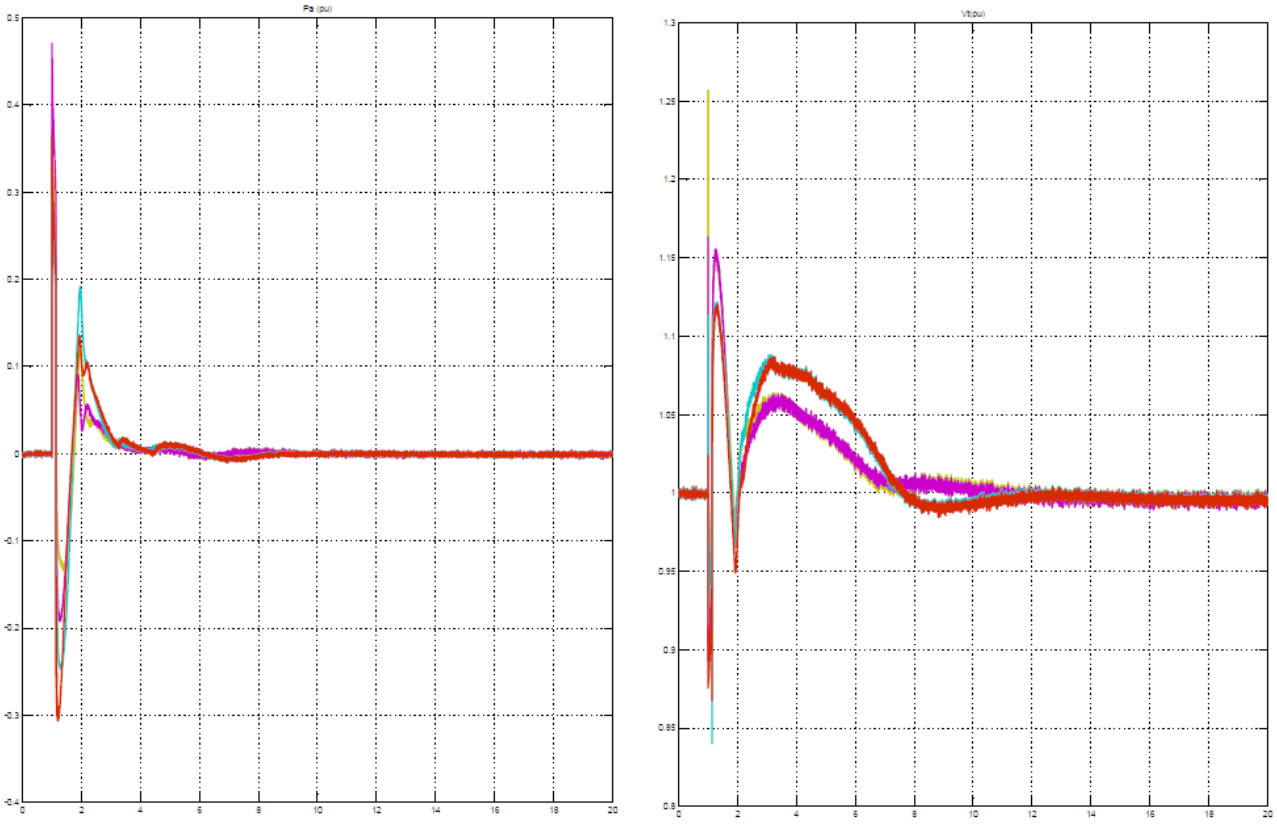
(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)



(a) the voltage in Bus 1 and Bus 2 (system data) **(b)** Vt (pu) (machine)

Figure 4.7: the simulation Results :The fault In the middle

c)Putting the fault in the end of the network:

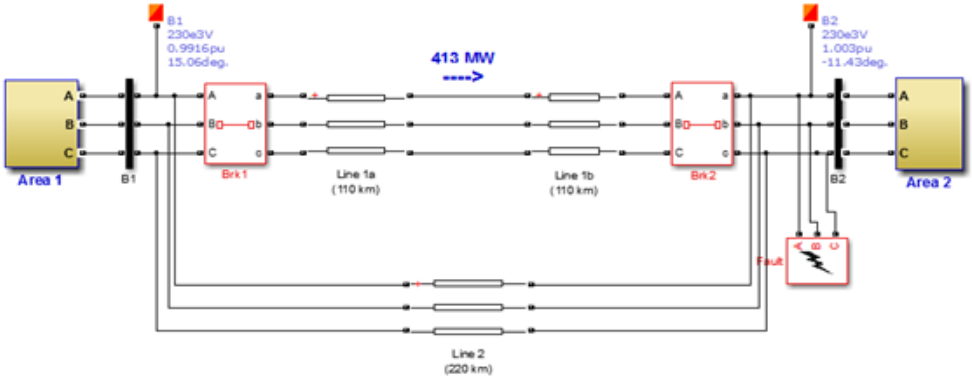
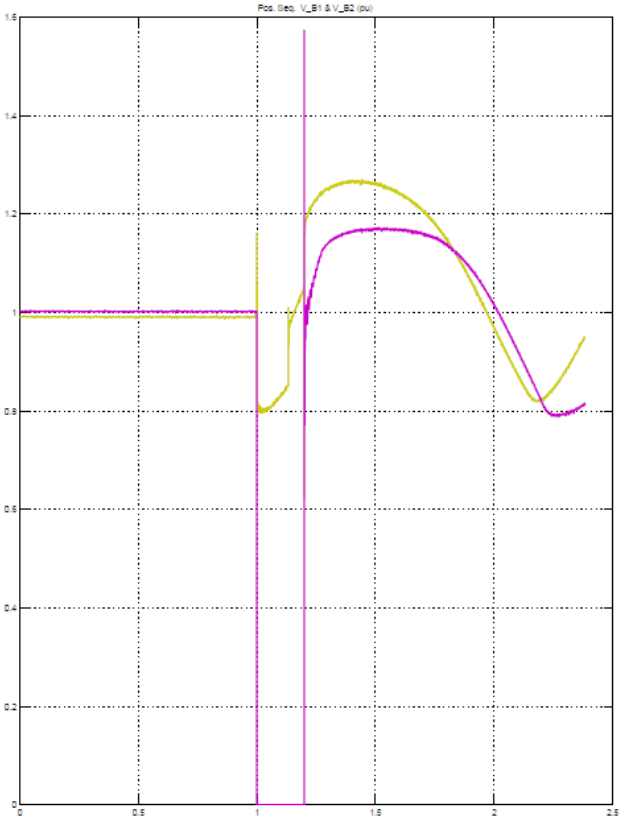


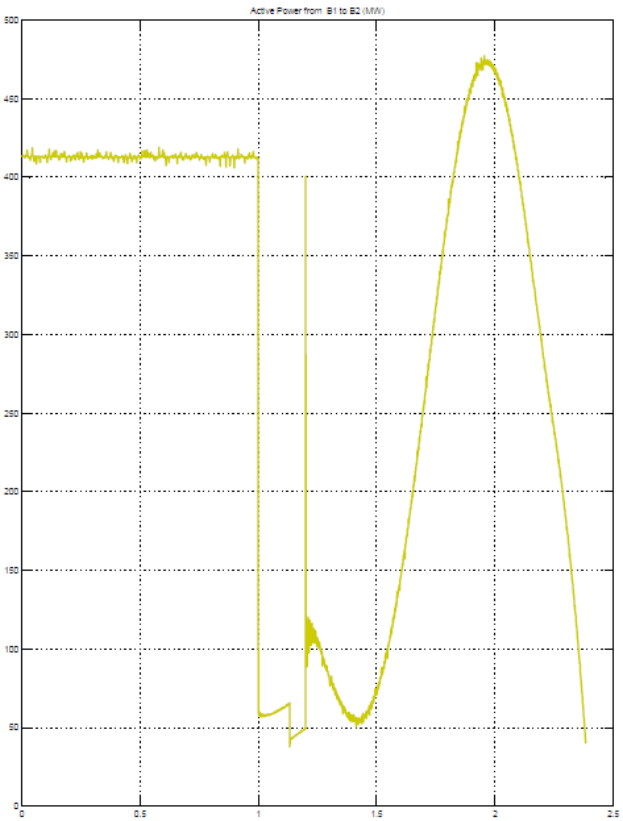
Figure 4.8: Kundur simulation of a two-section power system with the fault in the end

The third scenario involves a fault occurring at the end of the network. Initially, within the range of [0, 1], the network remains stable. However, as the range extends to [1, 1.2], the network becomes unstable. Fortunately, between [1.2, 2], the network manages to stabilize once again.

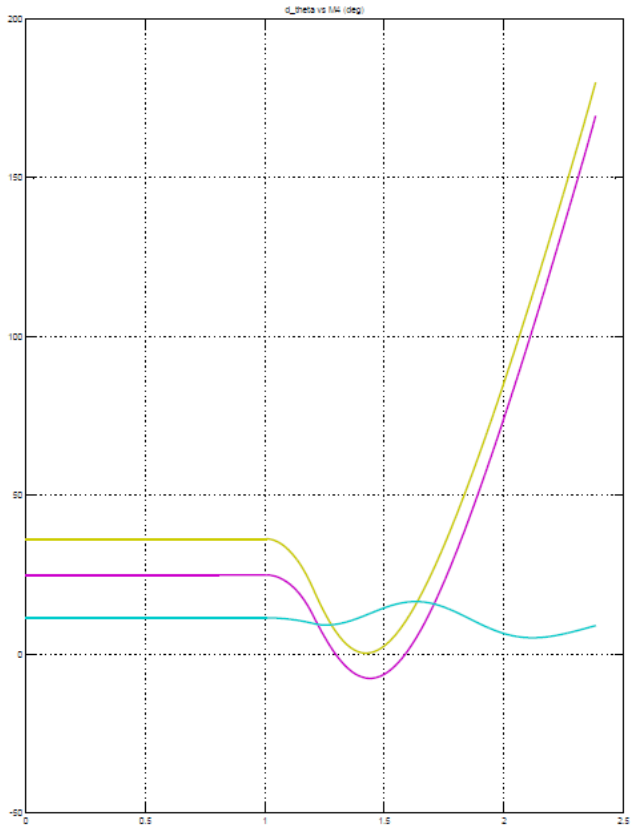
In this case, the short circuit primarily affects the second area, impacting machine 3 and 4. This effect can be observed in figures a, b, c, and d. As the fault progresses, it gradually moves towards the first area, although its impact is comparatively less severe than in the second area.



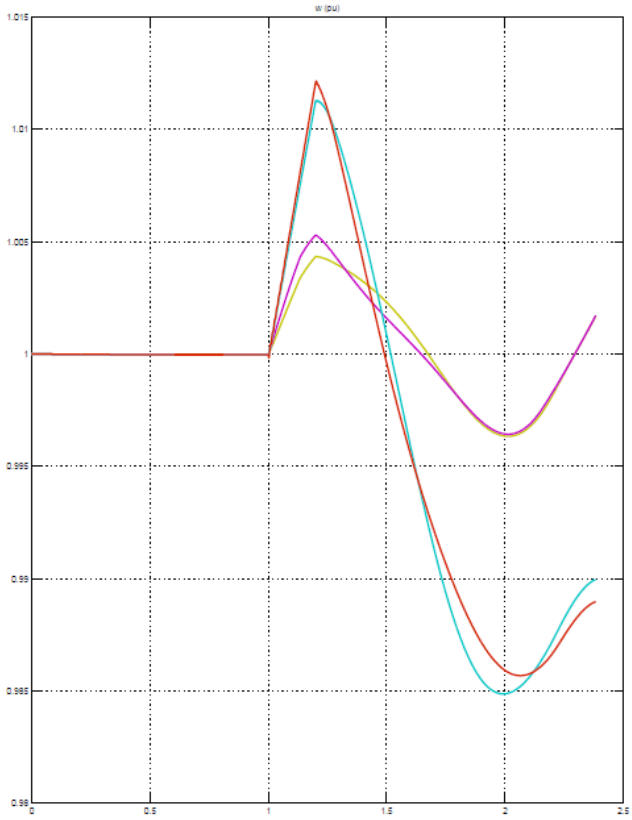
(a) the voltage in Bus 1 and Bus 2 (system data)



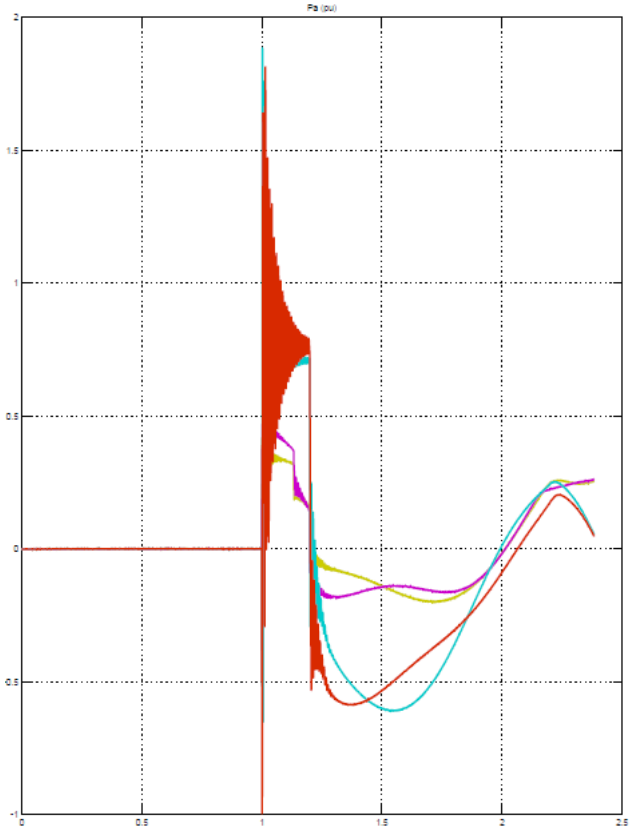
(b) Vt (pu) (machine)



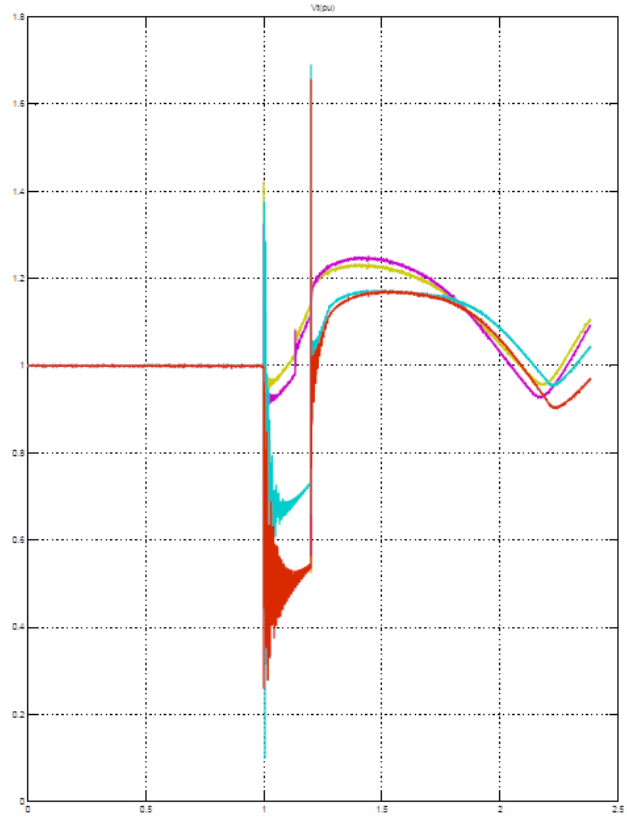
(a) the voltage in Bus 1 and Bus 2 (system data)



(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)

Figure 4.10: the simulation Results :The fault In the end

4.2.4.2 Changing the charges in the network multiplied in 0,1from Pa in the charge :

a)Area 1 :

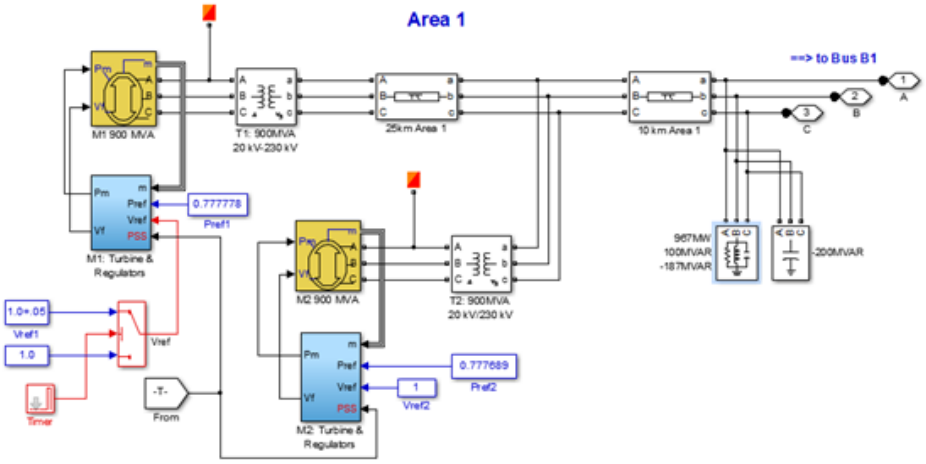
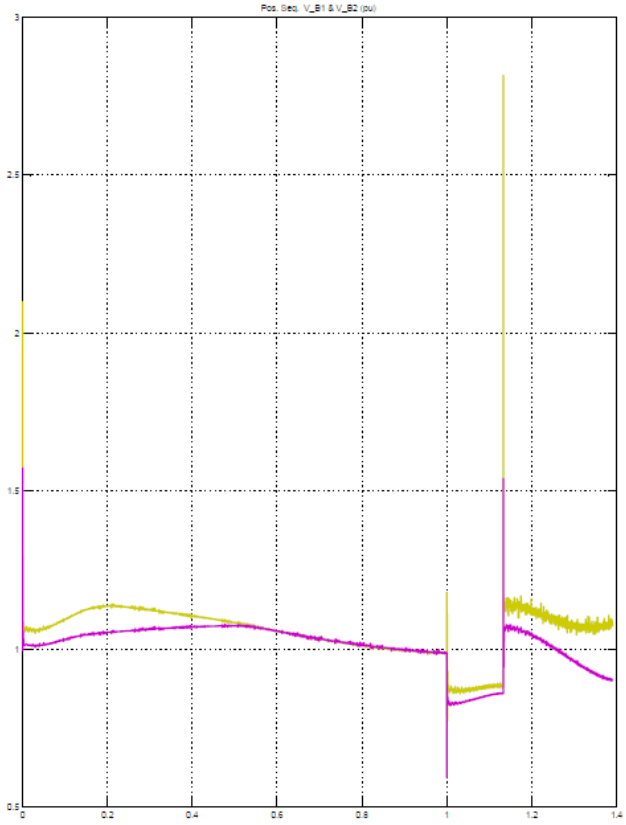


Figure 4.11: Kundur simulation of the area1 (the charge X0.1)

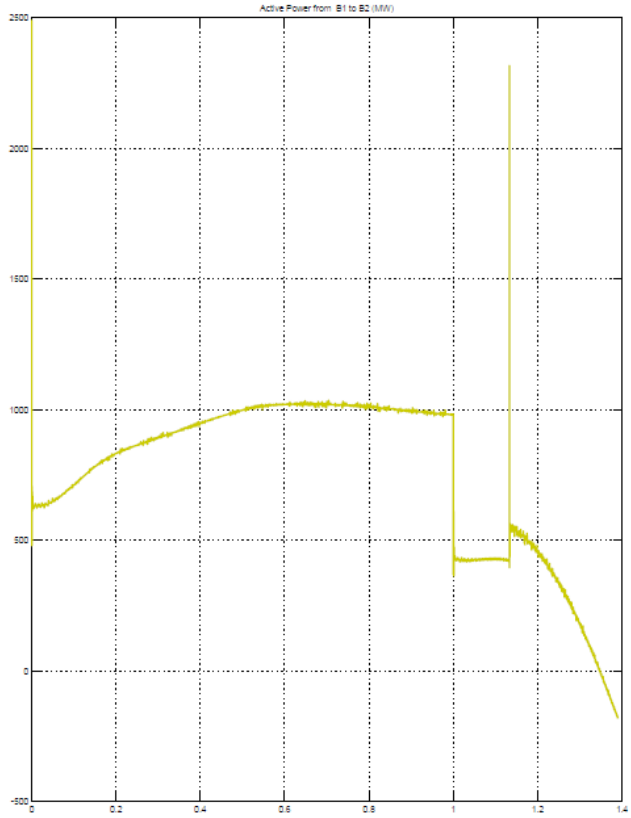
In the given scenario, we introduce a change in the charge within the first area while maintaining a fault in the center of the network. Initially, within the range of [0, 1], our network remains stable. However, as the range extends to [1, 1.2], the network becomes unstable. Fortunately, between [1.2, 2], the network manages to stabilize once again.

However, within the range of [1, 1.2], an additional complication arises as the voltage in bus 1 and 2 experiences a drop, indicating an inclusion of the fault.

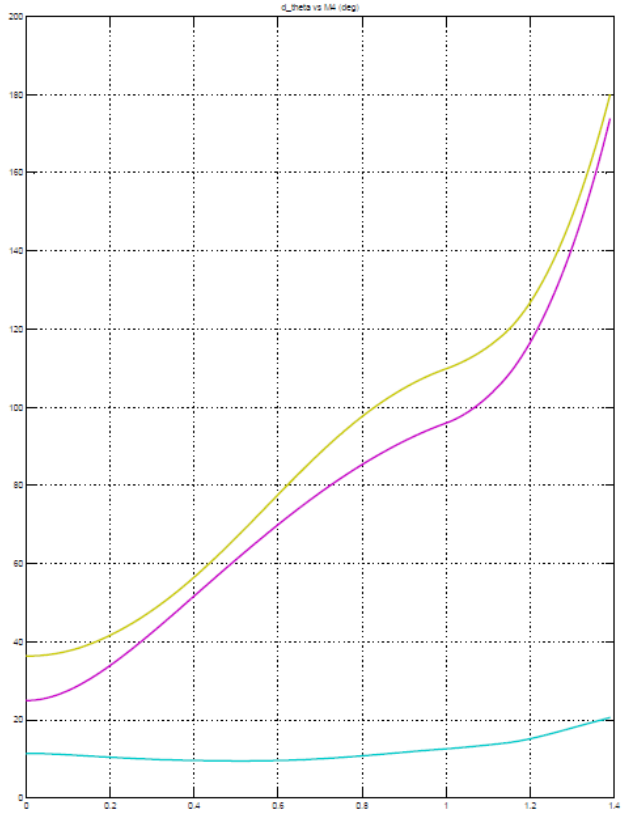
This short circuit simultaneously affects both the first and second areas. The four machines in these areas are impacted by both the change in charge and the presence of the short circuit, as depicted in the corresponding figures we have maintained.



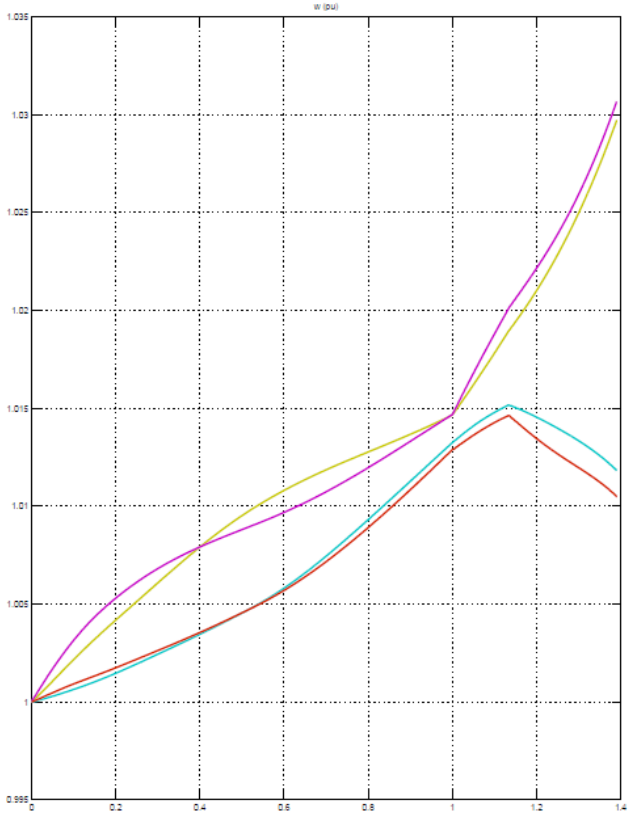
(a) the voltage in Bus 1 and Bus 2 (system data)



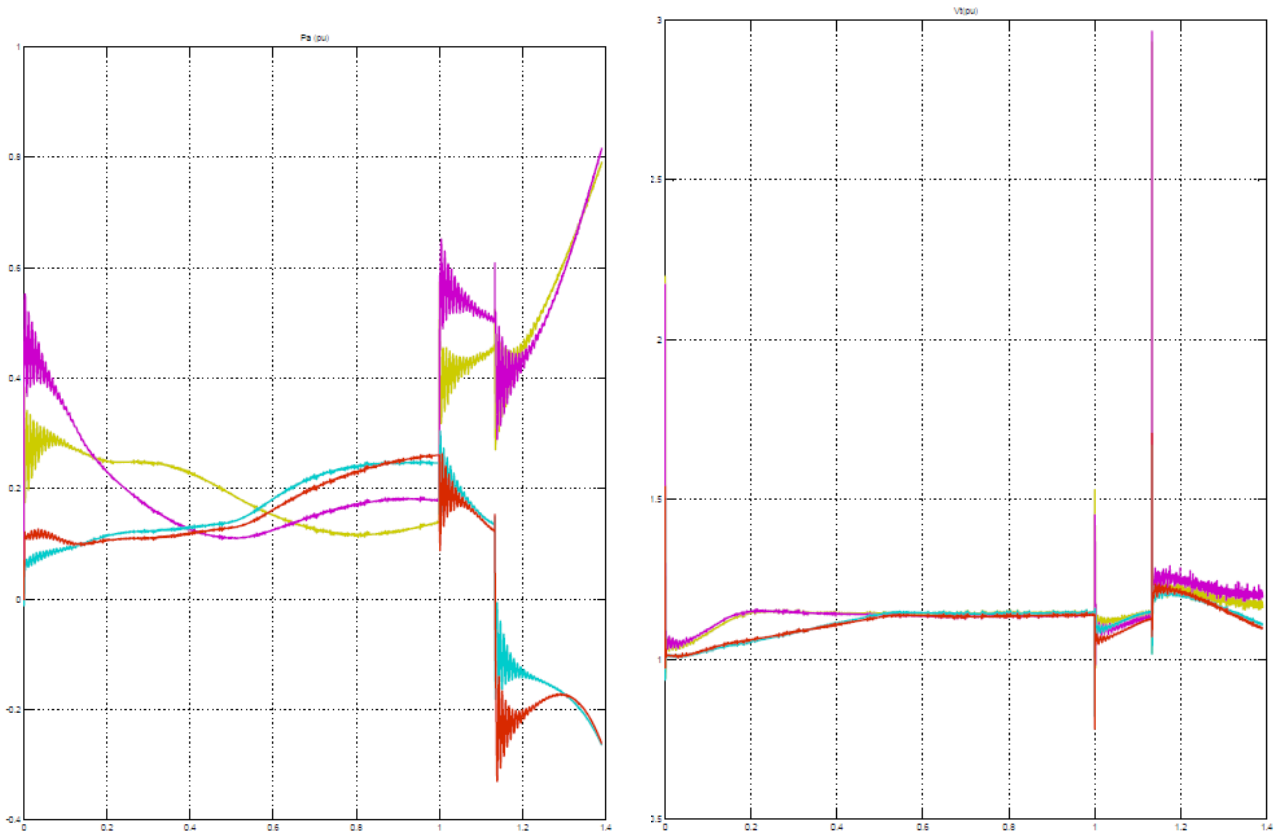
(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)



(a) the voltage in Bus 1 and Bus 2 (system data) **(b)** Vt (pu) (machine)

Figure 4.13: the simulation Results : the network multiplied in 0,1(area1)

b)Area 2 :

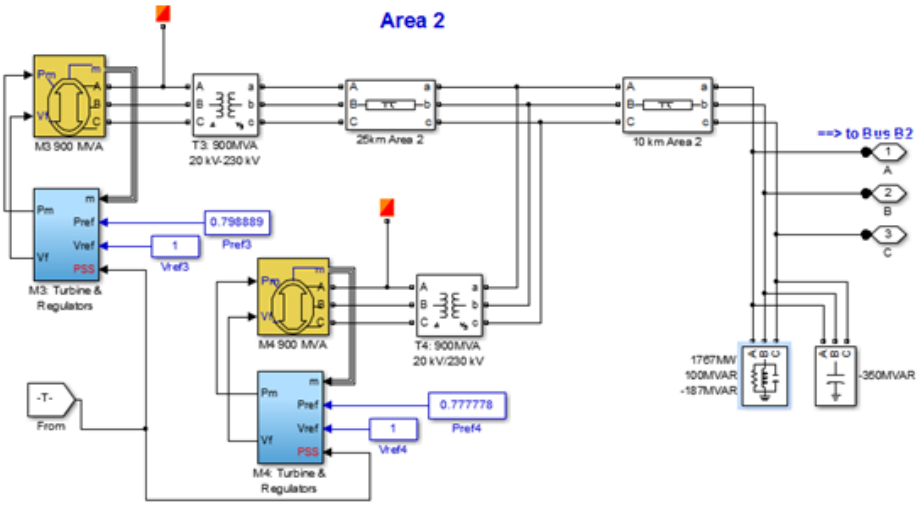


Figure 4.14: Kundur simulation of the area 2

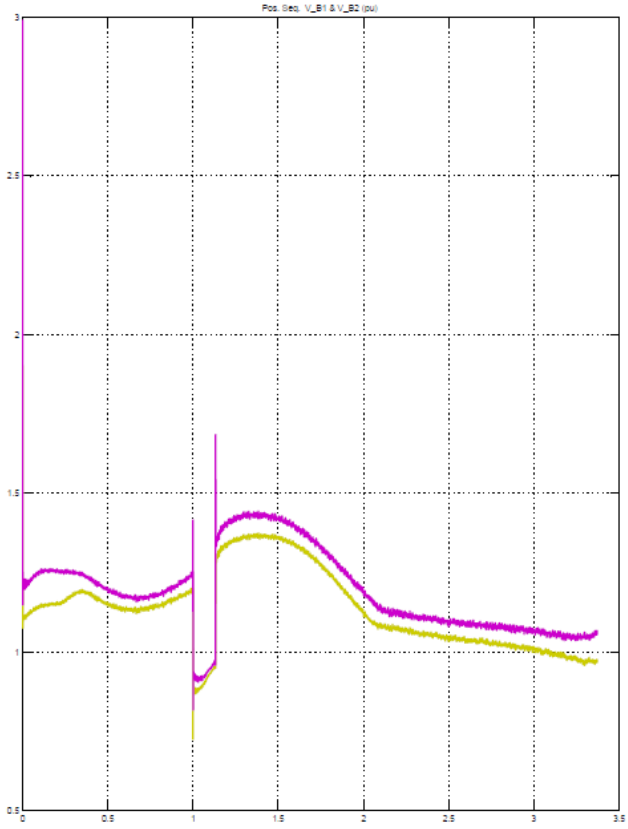
In this particular case, we introduce a change in the charge within the second area while keeping the fault in the center of the network. Initially, within the range of [0, 1], our network remains stable. However, as the range extends to [1, 1.5], the network becomes unstable. Fortunately, between [1.5, 2], the network manages to stabilize once again.

Furthermore, during the range of [0, 1], the voltage in bus 1 and bus 2 remains stable. However, between [1, 1.5], the voltage in bus 1 and bus 2 becomes unstable due to the short circuit. Nevertheless, between [1.5, 2.5], the voltage in bus 1 and bus 2 returns to stabilization.

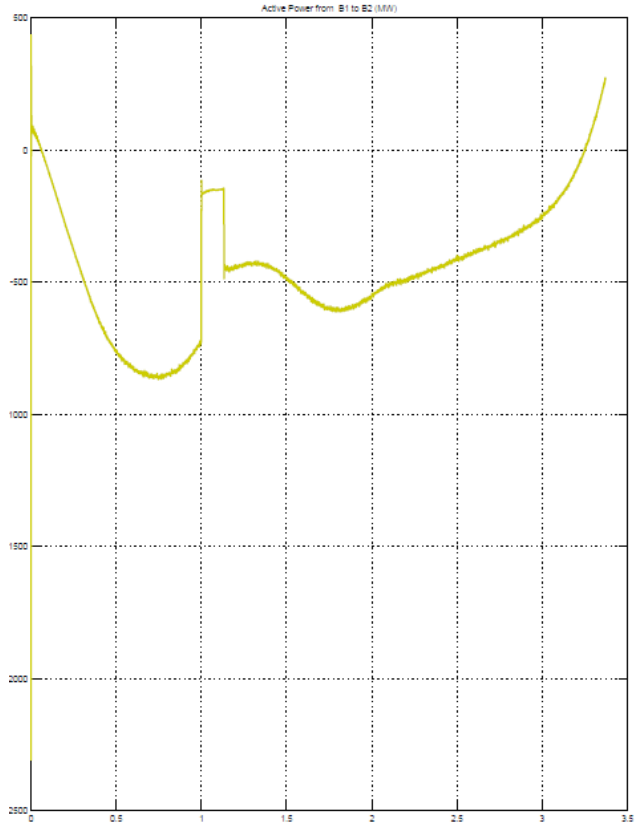
Similarly, the active power from bus 1 to bus 2 follows a similar pattern. It remains stable within the range of [0, 1], becomes unstable between [1, 1.5] due to the short circuit, and eventually returns to stabilization between [1.5, 2.5].

Moreover, the active power in the four machines initially remains stable within the range of [0, 1]. However, it becomes unstable between [1, 1.5] due to the presence of the short circuit. Fortunately, between [1.5, 2.5], the active power in the four machines returns to stabilization.

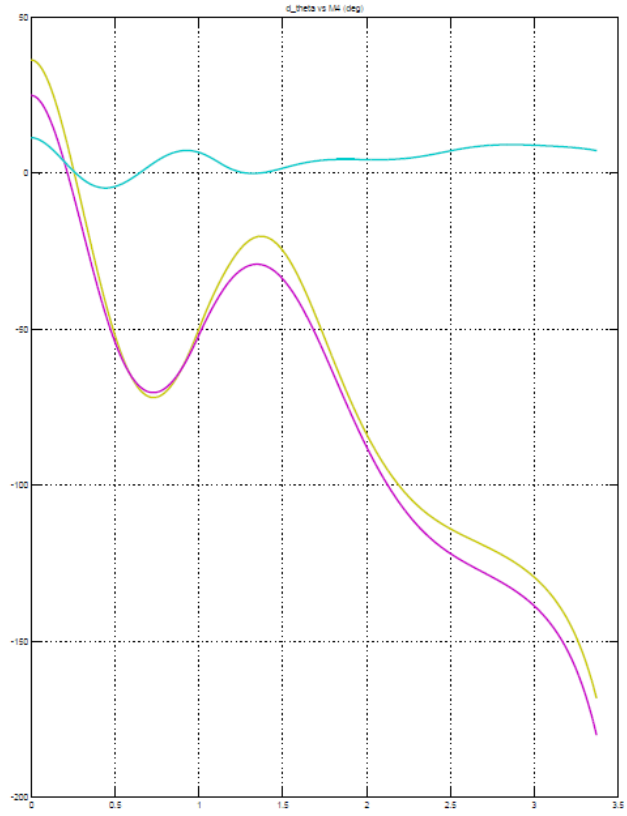
In this scenario, the short circuit impacts both the first and second areas simultaneously. The four machines are affected by both the change in charge and the presence of the short circuit, as depicted in the figures we have maintained



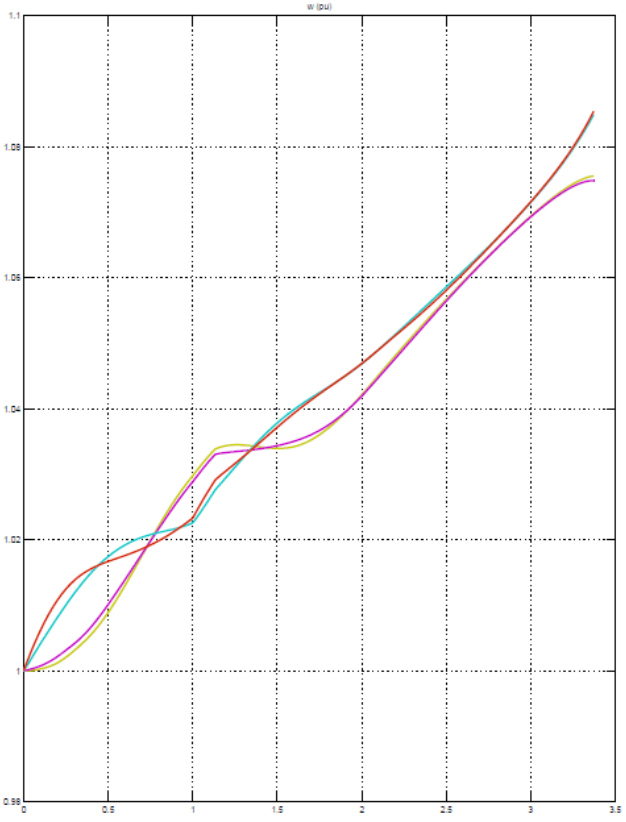
(a) the voltage in Bus 1 and Bus 2 (system data)



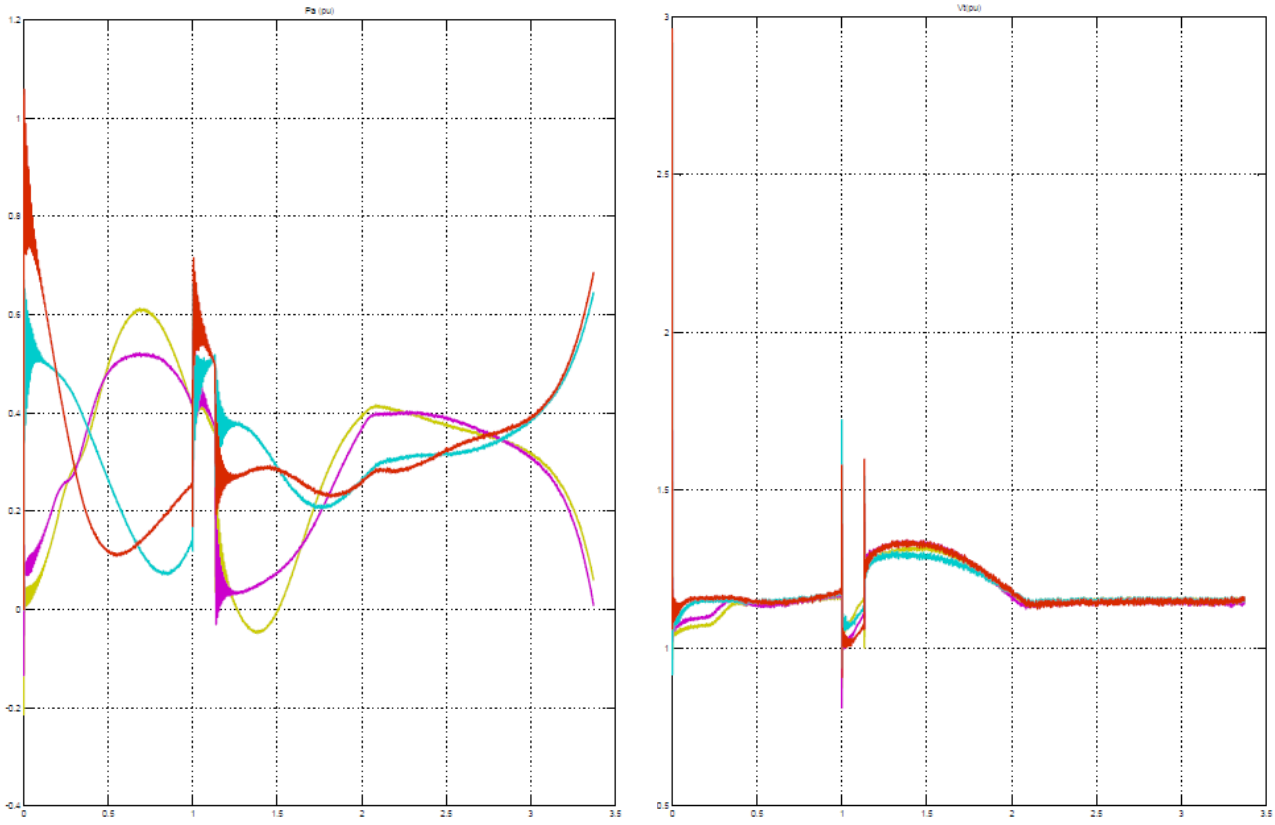
(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)



(a) the voltage in Bus 1 and Bus 2 (system data) **(b)** Vt (pu) (machine)

Figure 4.16: the simulation Results : the network multiplied in 0,1(area2)

4.2.4.3 Changing the charges in the network multiplied in 10 from Pa in the charge :

a)Area 1 :

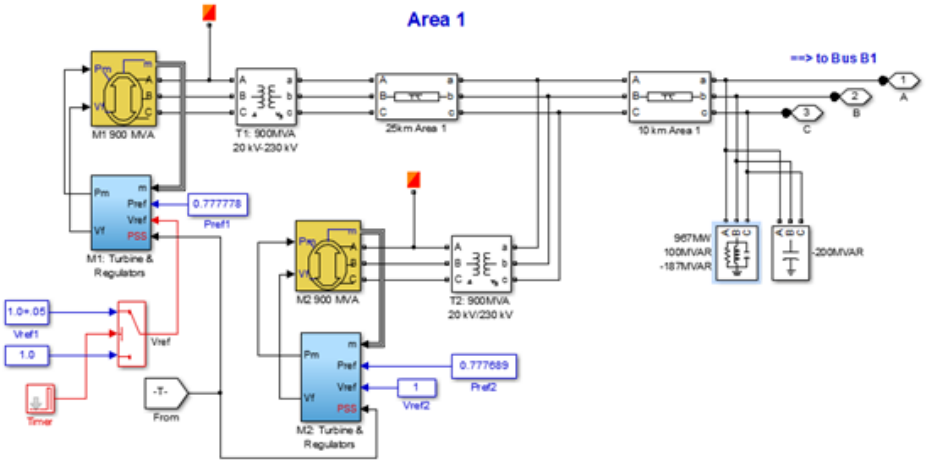
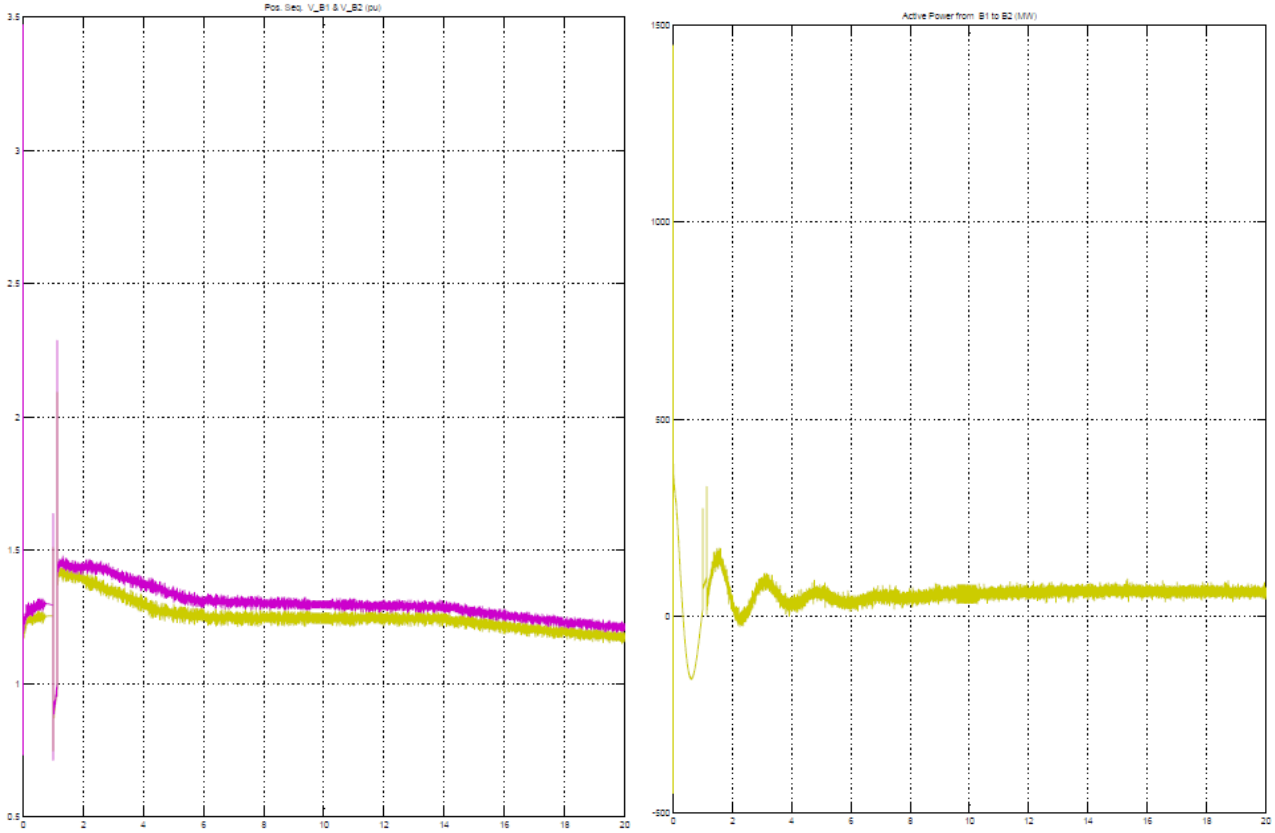


Figure 4.17: Kundur simulation of the area1 (the charge X10

In the given scenario, we introduce a change in the charge within the first area while maintaining a fault in the center of the network. Initially, within the range of [0, 1], our network remains stable. However, as the range extends to [1, 1.2], the network becomes unstable. Fortunately, between [1.2, 2], the network manages to stabilize once again.

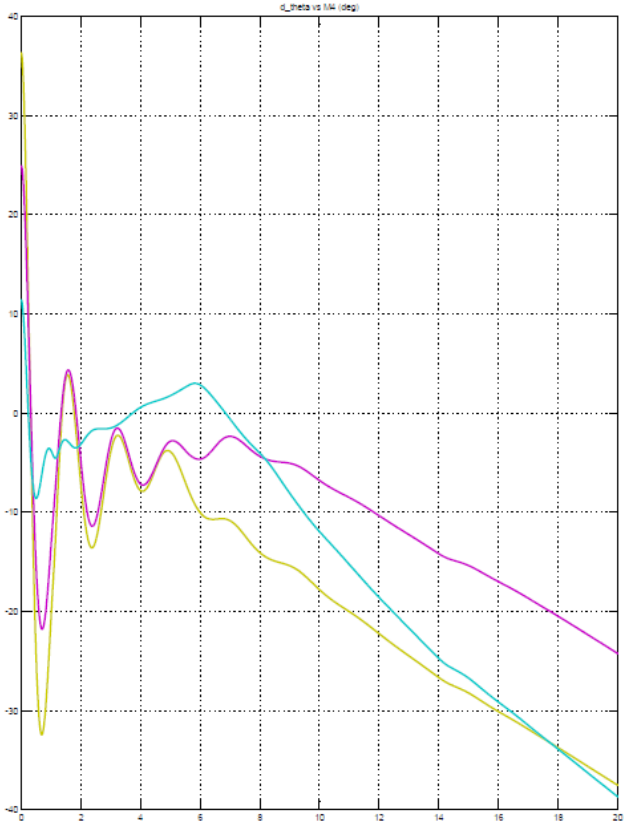
However, within the range of [1, 1.2], an additional complication arises as the voltage in bus 1 and 2 experiences a drop, indicating an inclusion of the fault.

This short circuit simultaneously affects both the first and second areas. The four machines in these areas are impacted by both the change in charge and the presence of the short circuit, as depicted in the corresponding figures we have maintained.

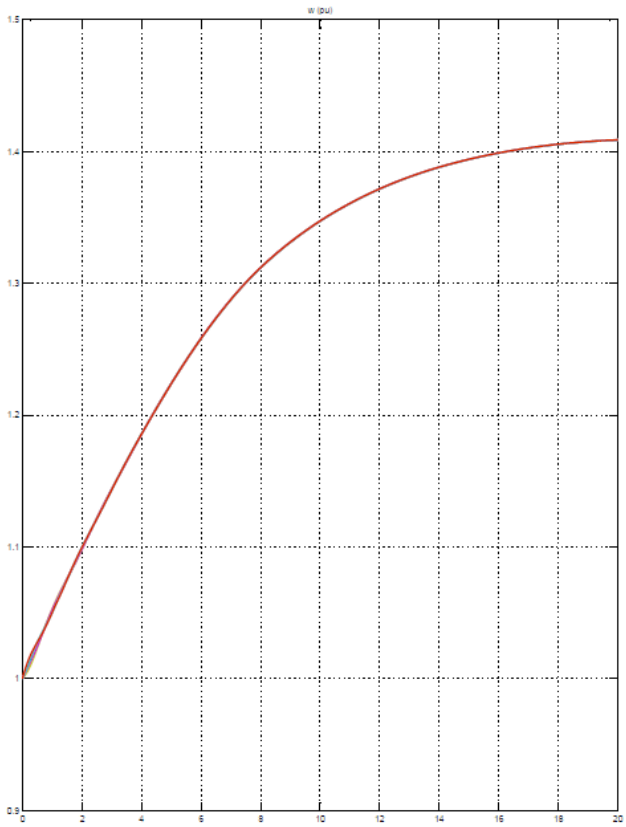


(a) the voltage in Bus 1 and Bus 2 (system data)

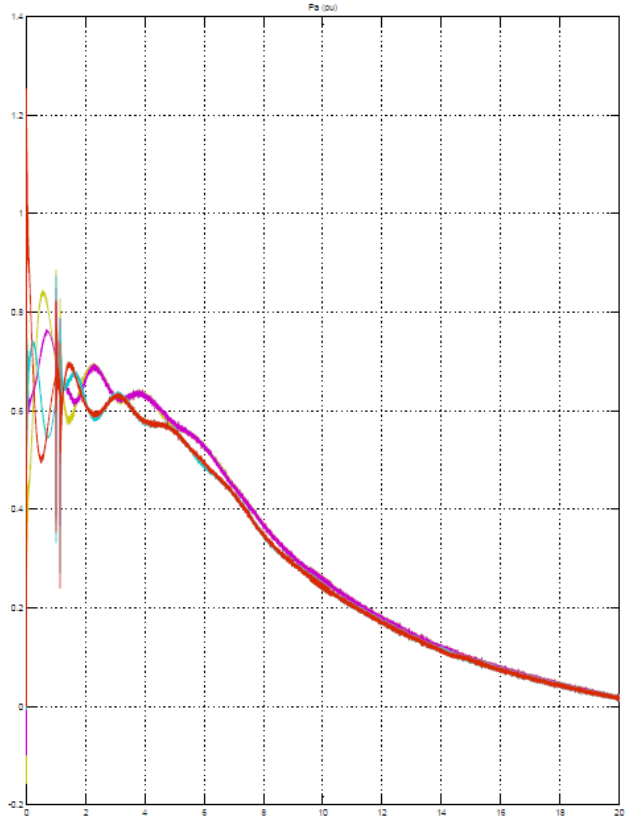
(b) Vt (pu) (machine)



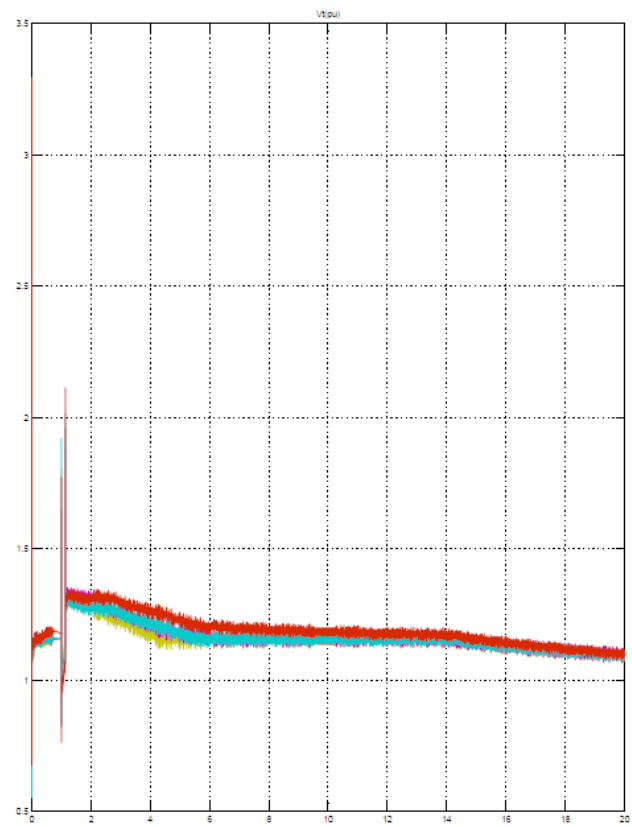
(a) the voltage in Bus 1 and Bus 2 (system data)



(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)

Figure 4.19: the simulation Results : the network multiplied in 10(area1)

b)Area 2 :

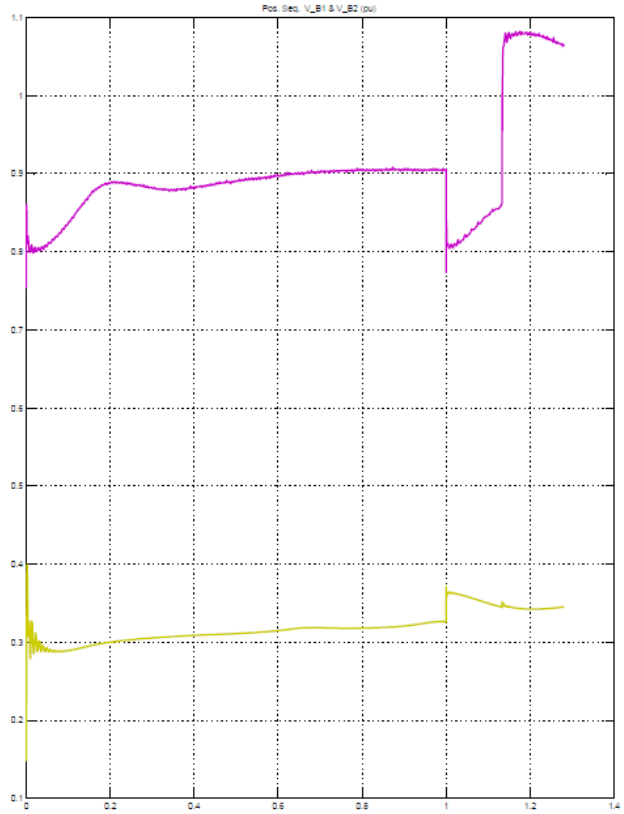
In this particular case, we introduce a change in the charge within the second area while keeping the fault in the center of the network. Initially, within the range of [0, 1], our network remains stable. However, as the range extends to [1, 1.5], the network becomes unstable. Fortunately, between [1.5, 2], the network manages to stabilize once again.

Furthermore, during the range of [0, 1], the voltage in bus 1 and bus 2 remains stable. However, between [1, 1.5], the voltage in bus 1 and bus 2 becomes unstable due to the short circuit. Nevertheless, between [1.5, 2.5], the voltage in bus 1 and bus 2 returns to stabilization.

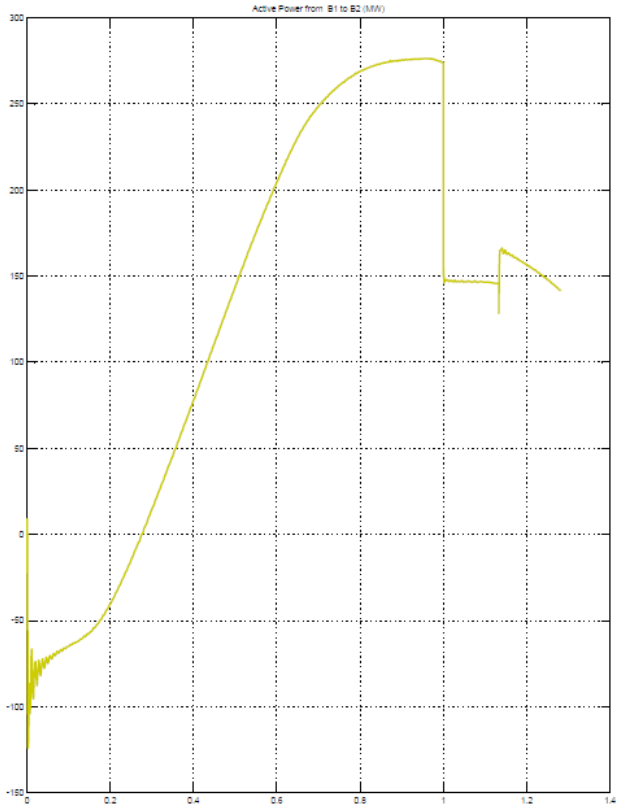
Similarly, the active power from bus 1 to bus 2 follows a similar pattern. It remains stable within the range of [0, 1], becomes unstable between [1, 1.5] due to the short circuit, and eventually returns to stabilization between [1.5, 2.5].

Moreover, the active power in the four machines initially remains stable within the range of [0, 1]. However, it becomes unstable between [1, 1.5] due to the presence of the short circuit. Fortunately, between [1.5, 2.5], the active power in the four machines returns to stabilization.

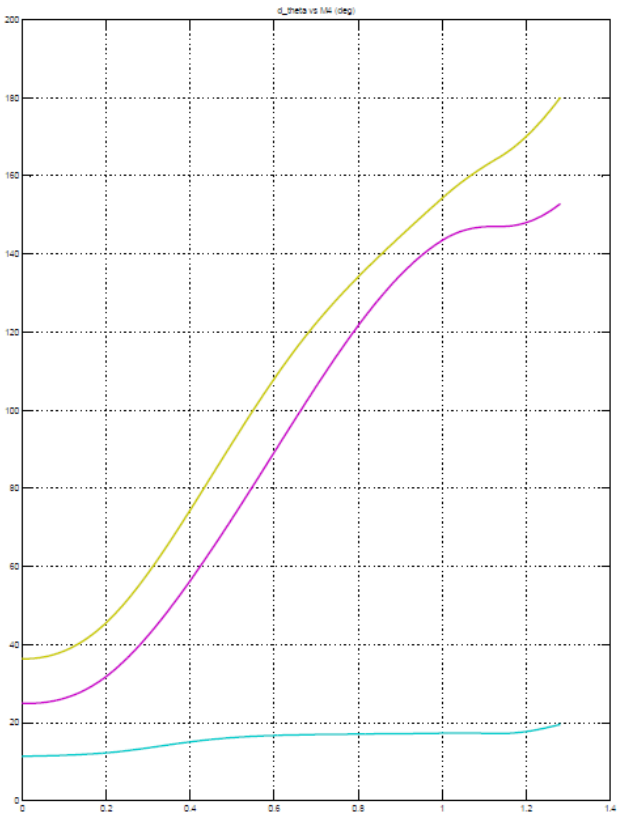
In this scenario, the short circuit impacts both the first and second areas simultaneously. The four machines are affected by both the change in charge and the presence of the short circuit, as depicted in the figures we have maintained.



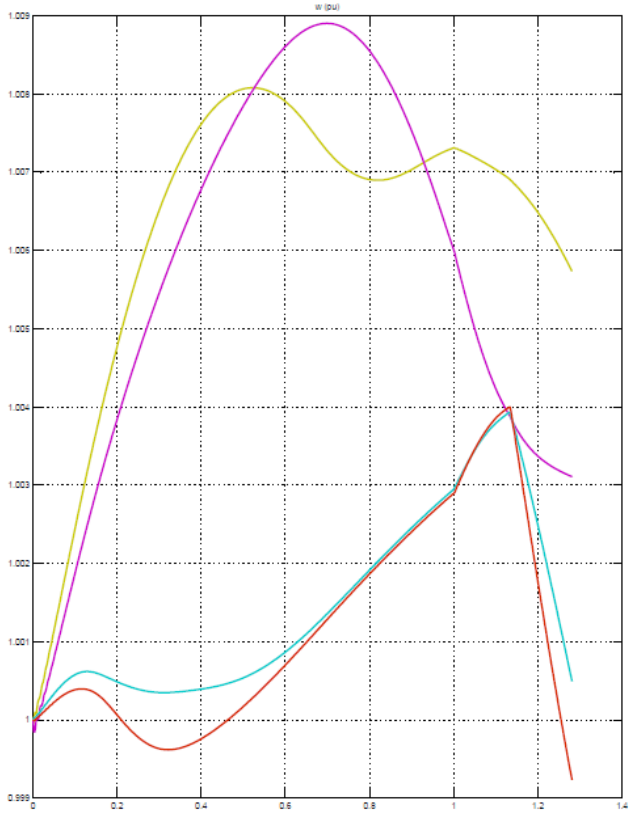
(a) the voltage in Bus 1 and Bus 2 (system data)



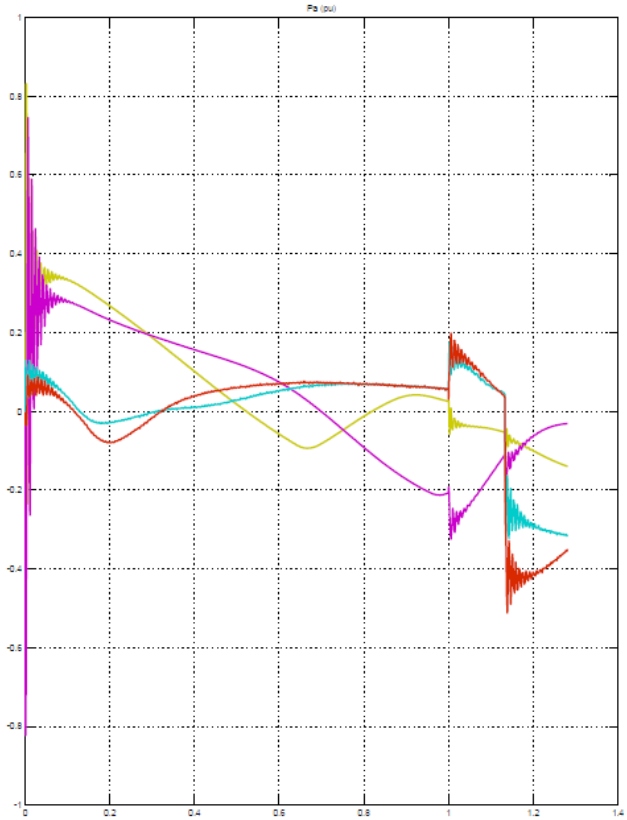
(b) Vt (pu) (machine)



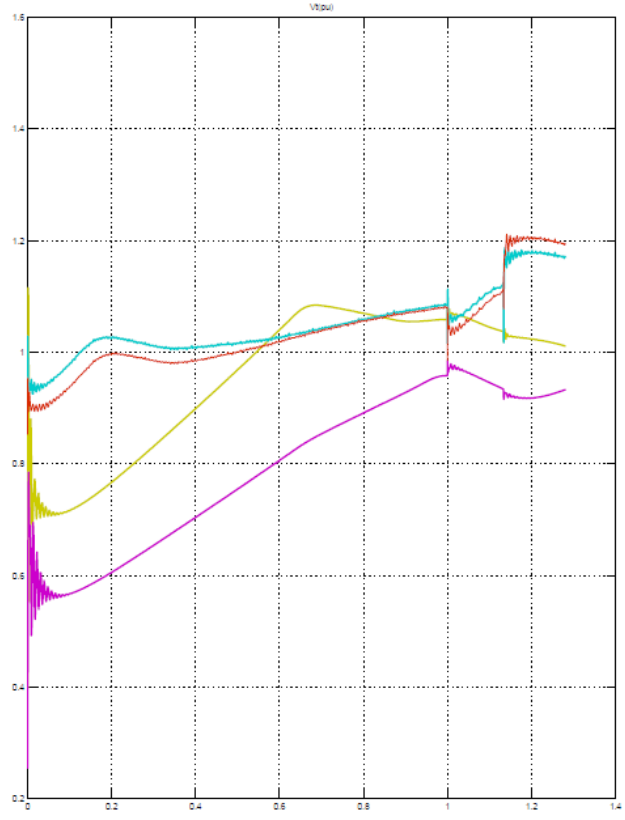
(a) the voltage in Bus 1 and Bus 2 (system data)



(b) W (pu) (machine)



(c) Pa (pu) (machine))



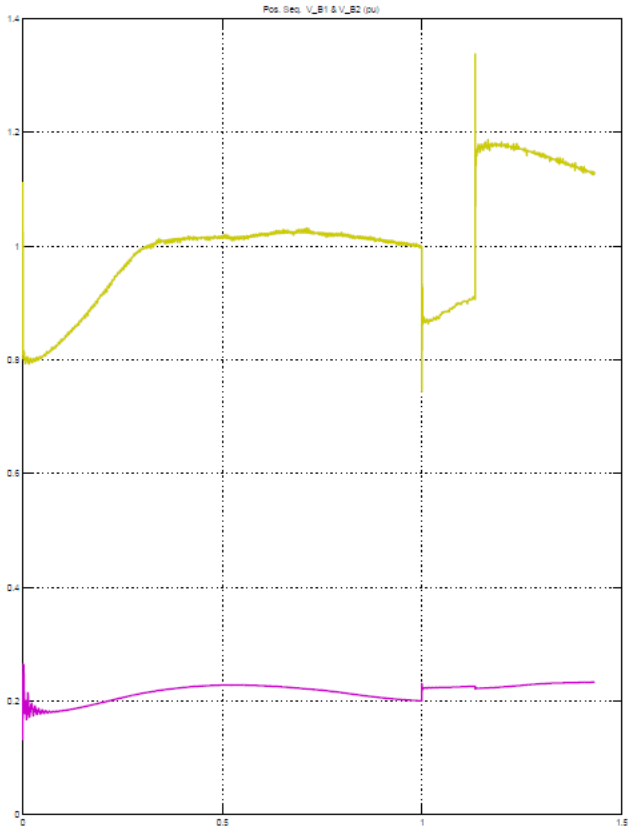
(d) Vt (pu) (machine)

Figure 4.21: the simulation Results :the network multiplied in 10(area2)

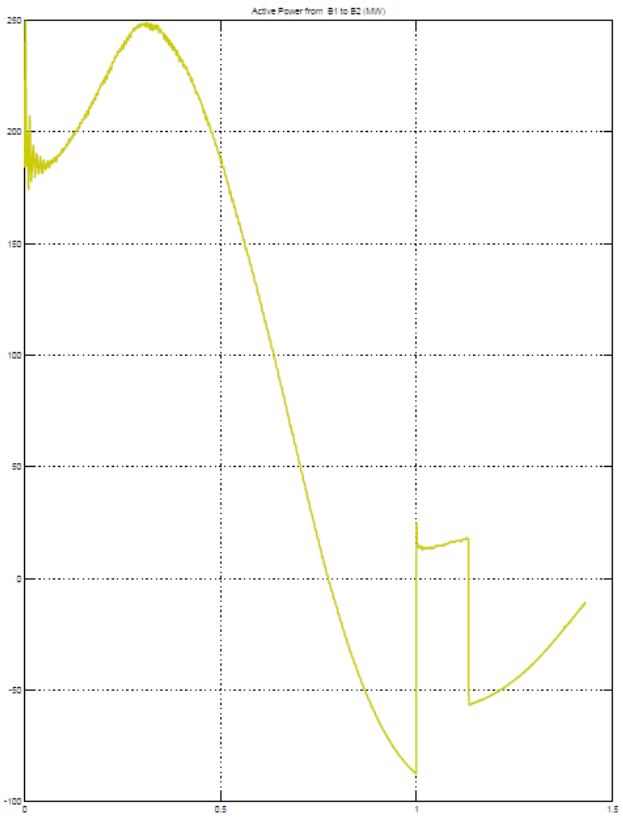
c)Both area :

In the third case, we introduce a change in the charge within the first area while keeping the fault in the center of the network. Initially, within the range of [0, 1], our network remains stable. However, as the range extends to [1, 1.2], the network becomes unstable. Fortunately , between [1.2, 2], the network returns to stabilization.

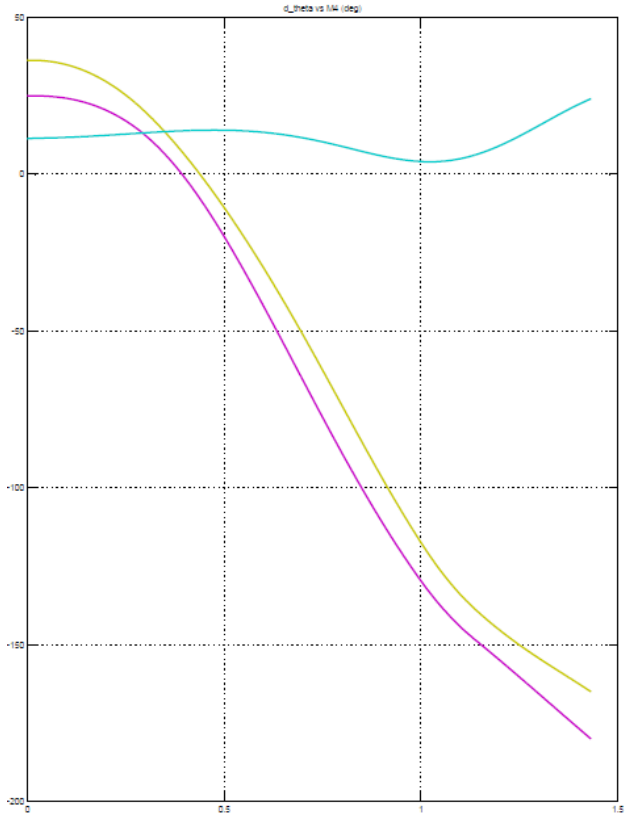
Interestingly, in this scenario, the short circuit affects both areas simultaneously. All four machines within the network are impacted by both the change in charge and the presence of the short circuit. The effects on these four machines can be observed in the figures we have maintained.



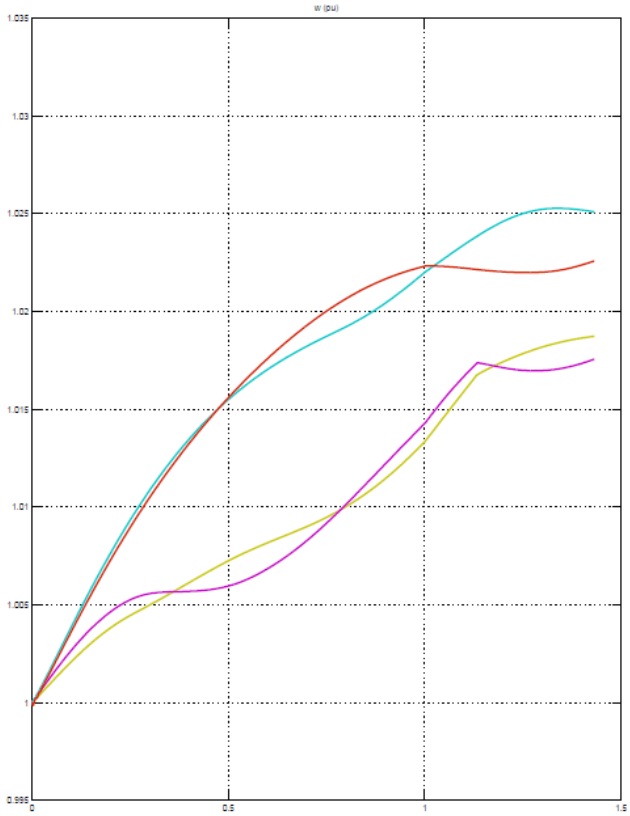
(a) the voltage in Bus 1 and Bus 2 (system data)



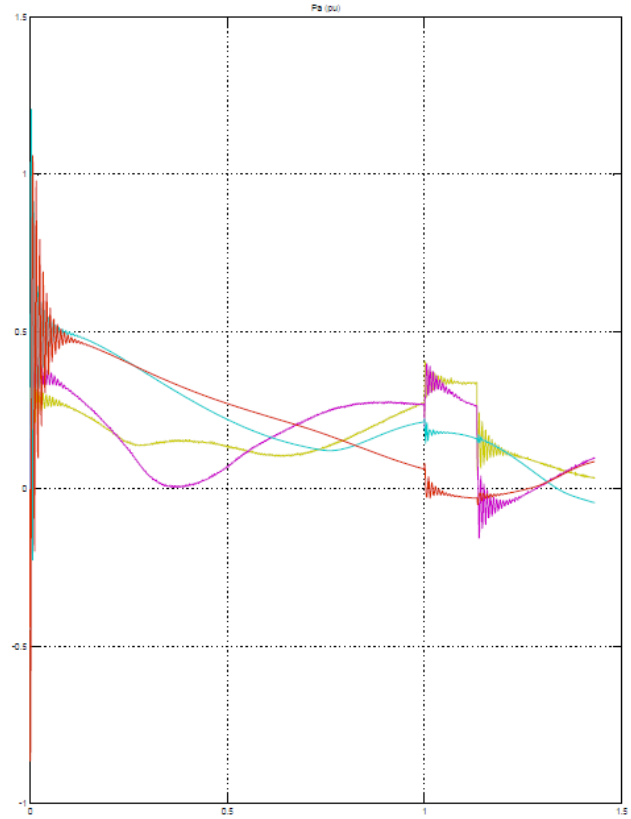
(b) Vt (pu) (machine)



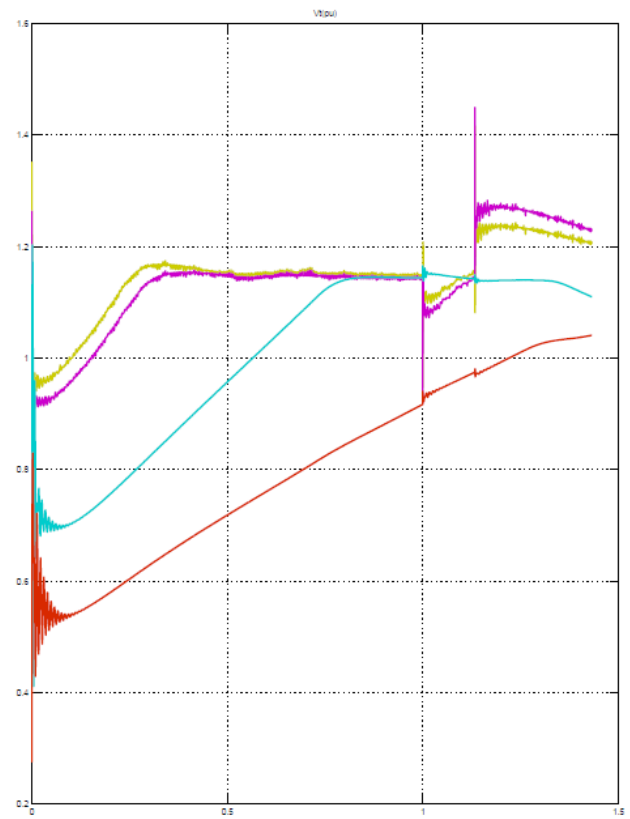
(a) the voltage in Bus 1 and Bus 2 (system data)



(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)

Figure 4.23: the simulation Results :the network multiplied in 10(both)

4.2.4.4 changing in the transition time in the short circuit the fault :

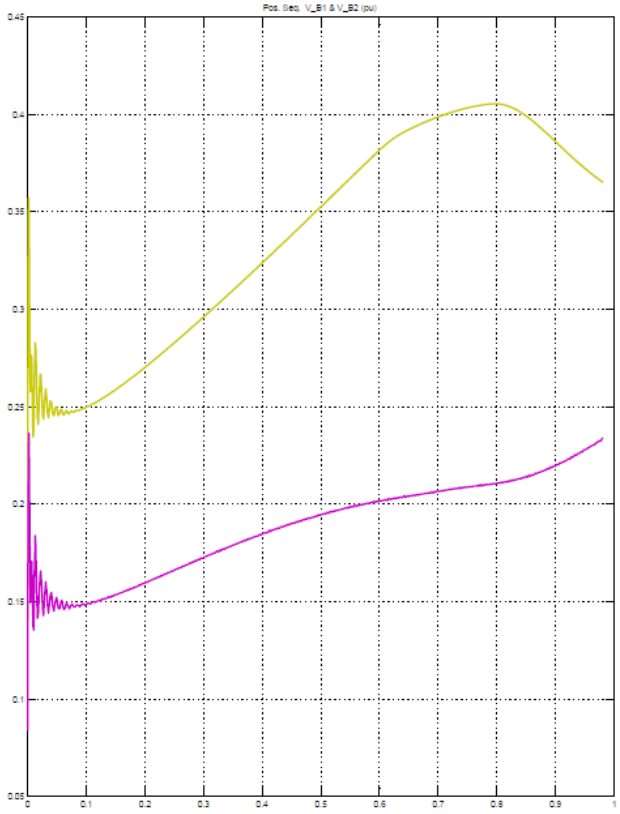
The situation involves a fault emerging at the center of the network. We have modified the transition time using three different durations. Initially, the fault, which is a short circuit, affects the network within the range of [0, 1]. During this period, the network remains stable. However, when the range extends to [1, 2], the network becomes unstable. Thankfully, between [2, 20], the network manages to stabilize once again.

In this particular scenario, the fault impacts both the voltage and active power. Within the range of [1, 2], the fault affects the voltage in bus 1 and bus 2, but they eventually return to stability between [2, 20]. Subsequently, within the range of [1, 8], the fault affects the active power, but it also returns to stability between [8, 20].

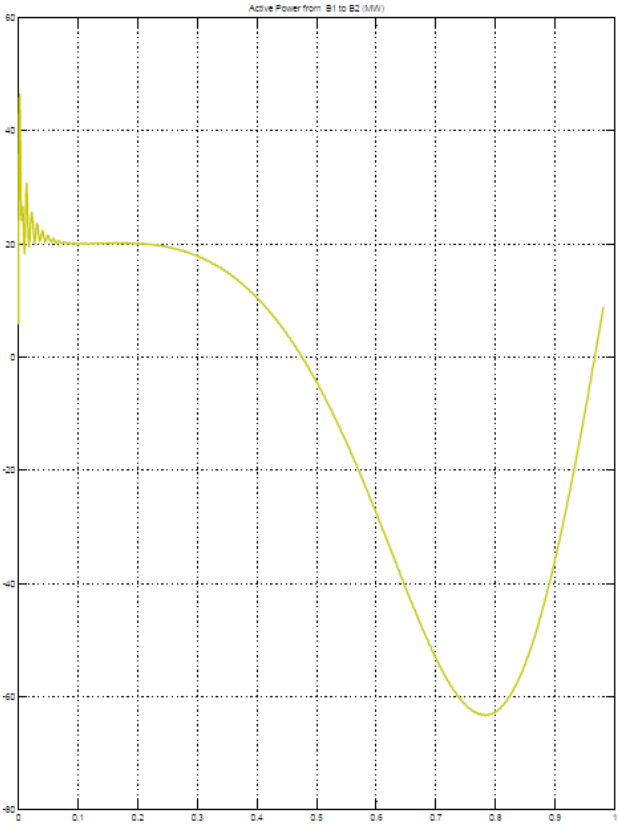
The short circuit has repercussions on four machines within the network, as illustrated in the previously mentioned diagrams. The fault propagates in both directions, impacting various regions of the network.

a)default duration of $\Delta_t = +10$

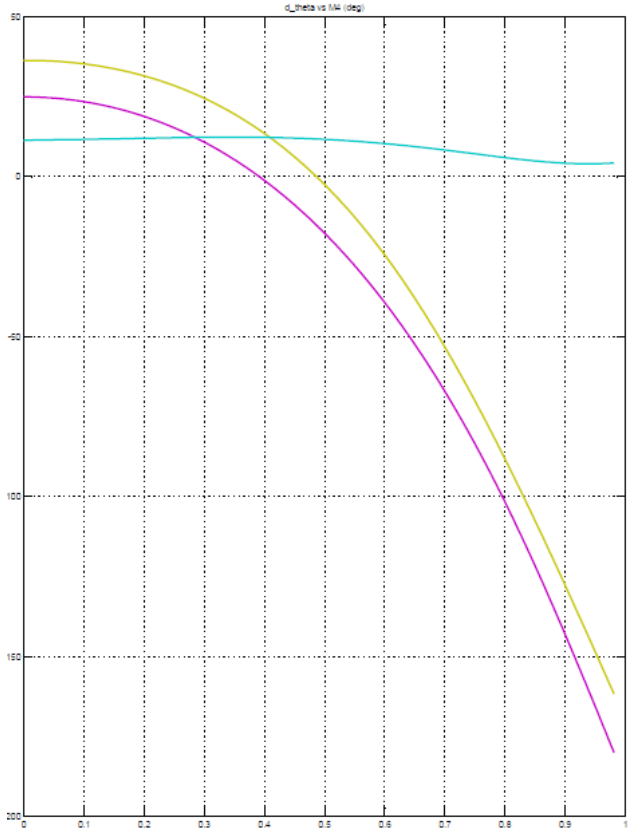
[1 10+12/60] :



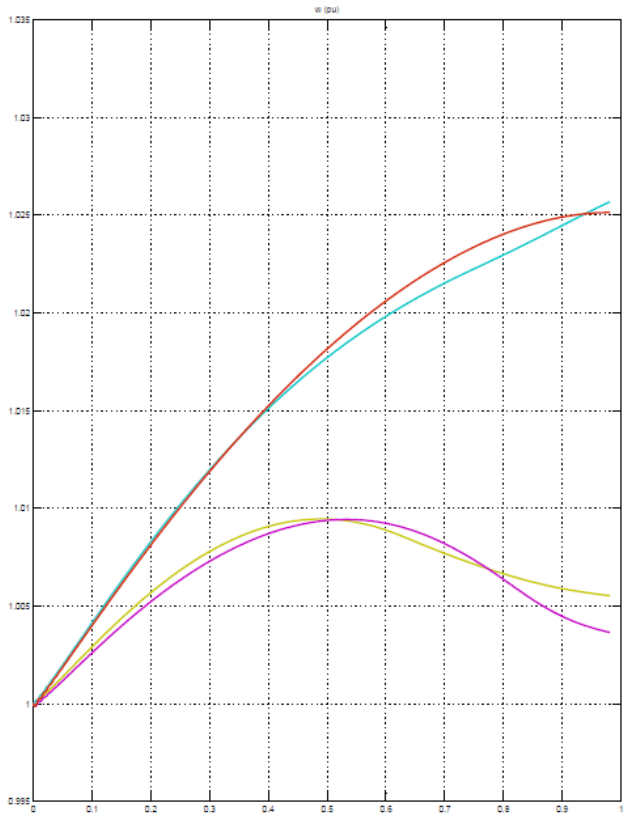
(a) the voltage in Bus 1 and Bus 2 (system data)



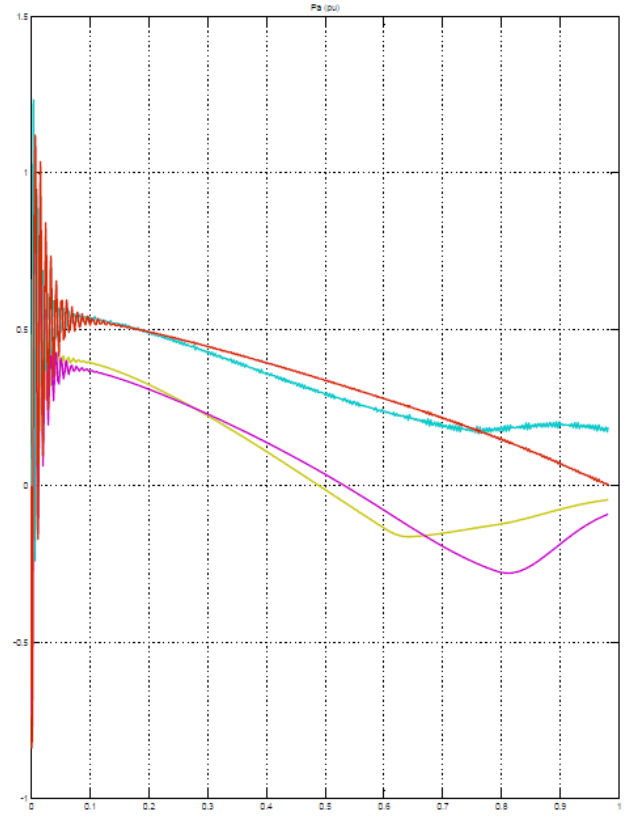
(b) Vt (pu) (machine)



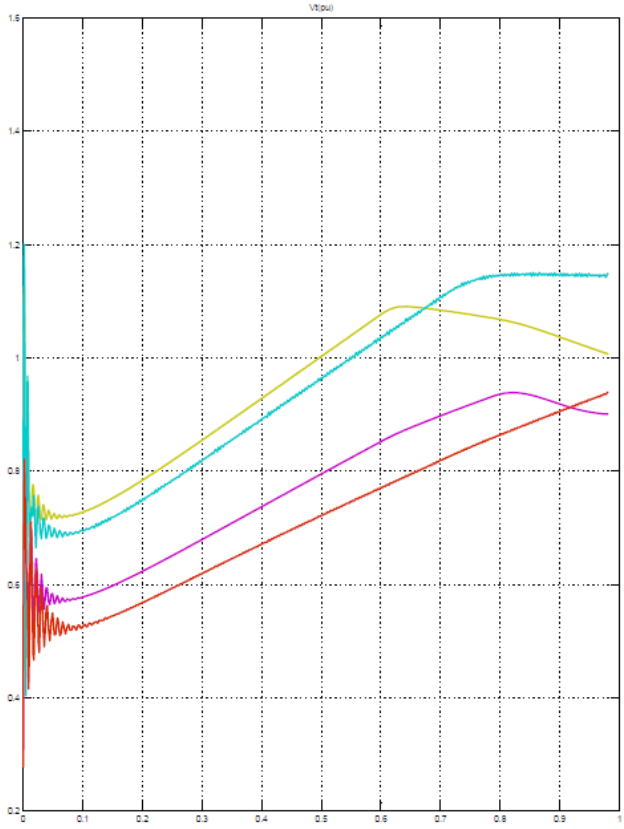
(a) the voltage in Bus 1 and Bus 2 (system data)



(b) W (pu) (machine)



(c) Pa (pu) (machine))

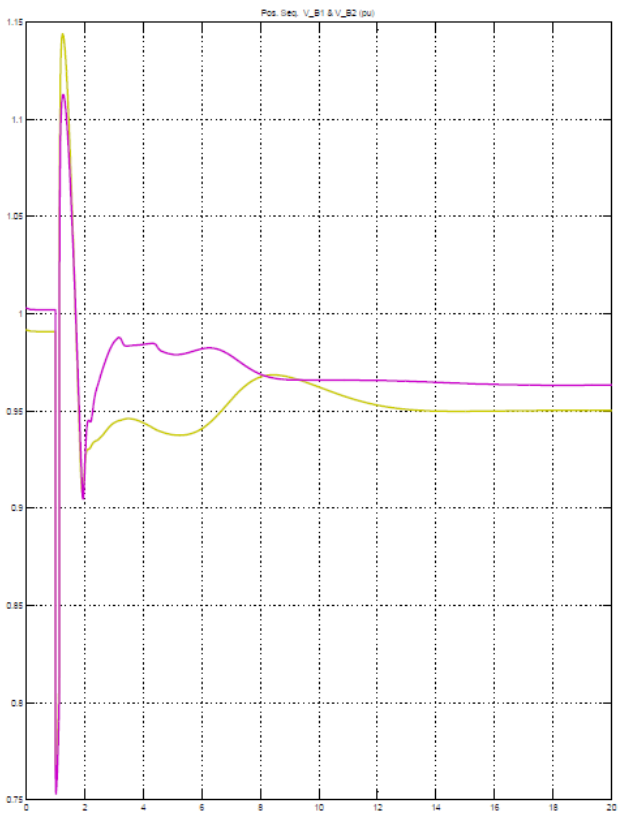


(d) Vt (pu) (machine)

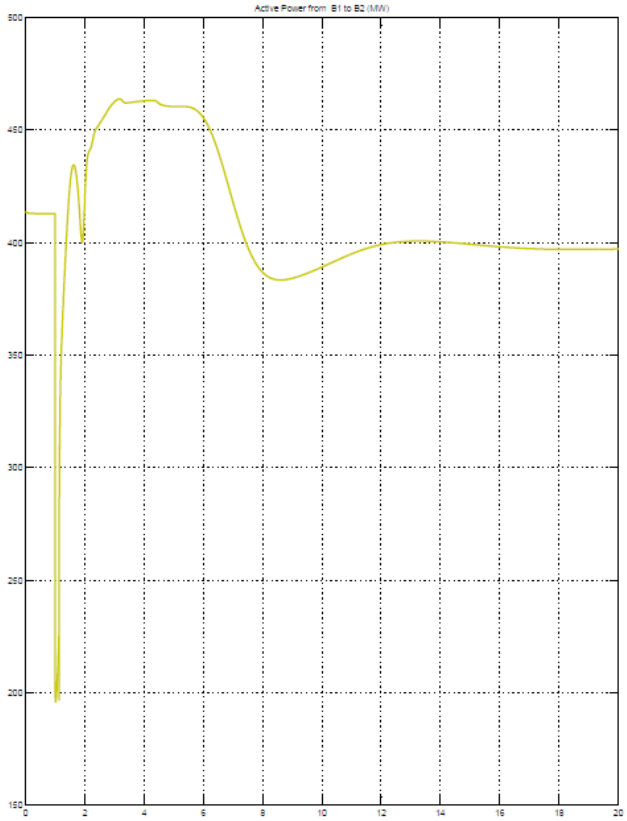
Figure 4.25: the simulation Results :default duration of t = +10

b)default duration of $\Delta_t = +100$

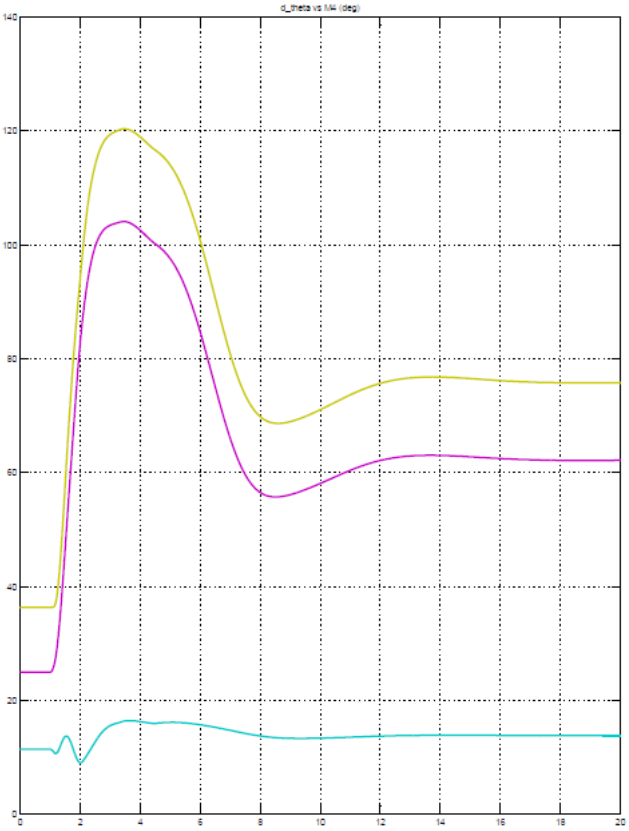
[1 100+12/60] :



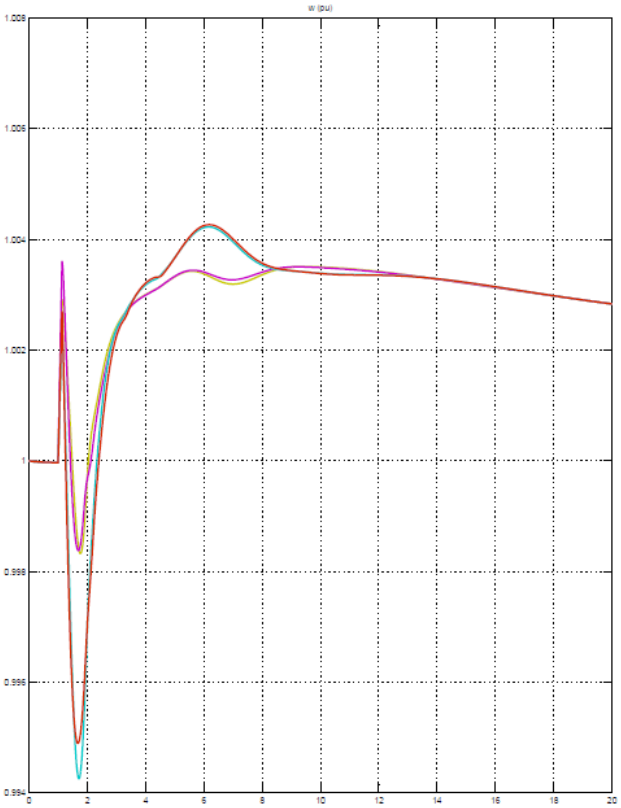
(a) the voltage in Bus 1 and Bus 2 (system data)



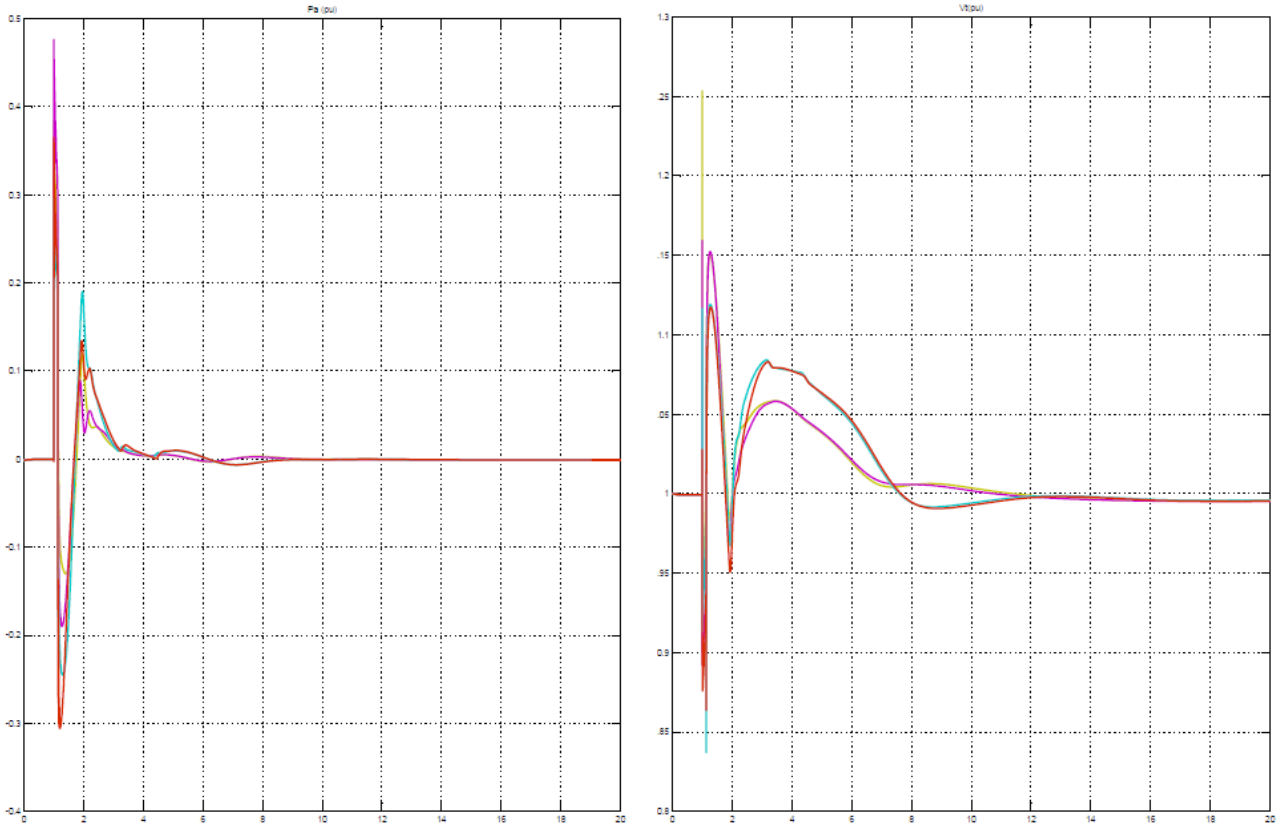
(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)

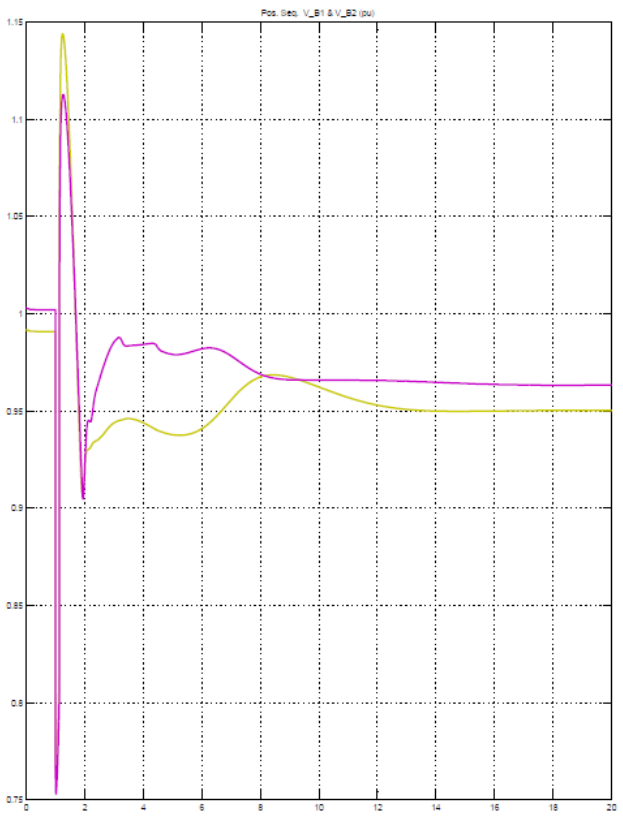


(a) the voltage in Bus 1 and Bus 2 (system data) **(b)** Vt (pu) (machine)

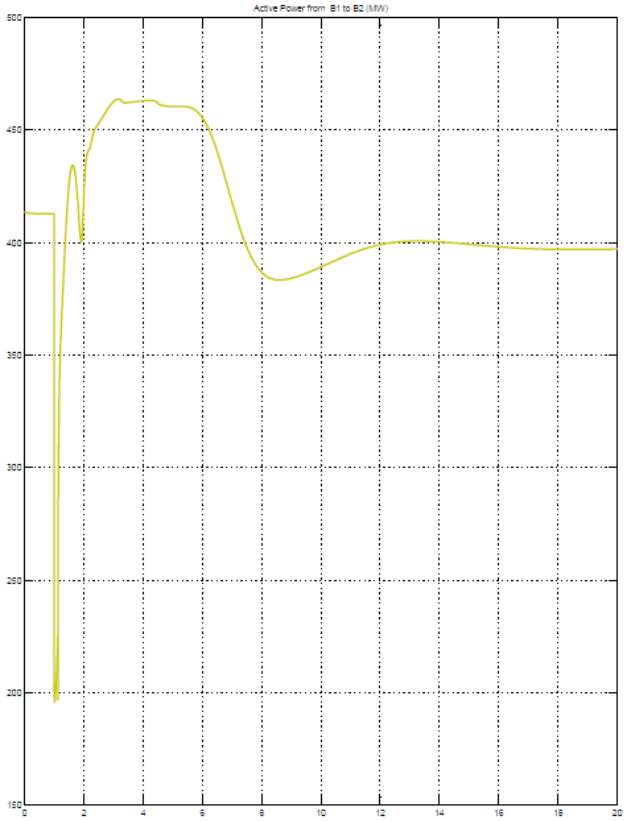
Figure 4.27: the simulation Results :default duration of t = +100

c)default duration of $\Delta_t = +1000$:

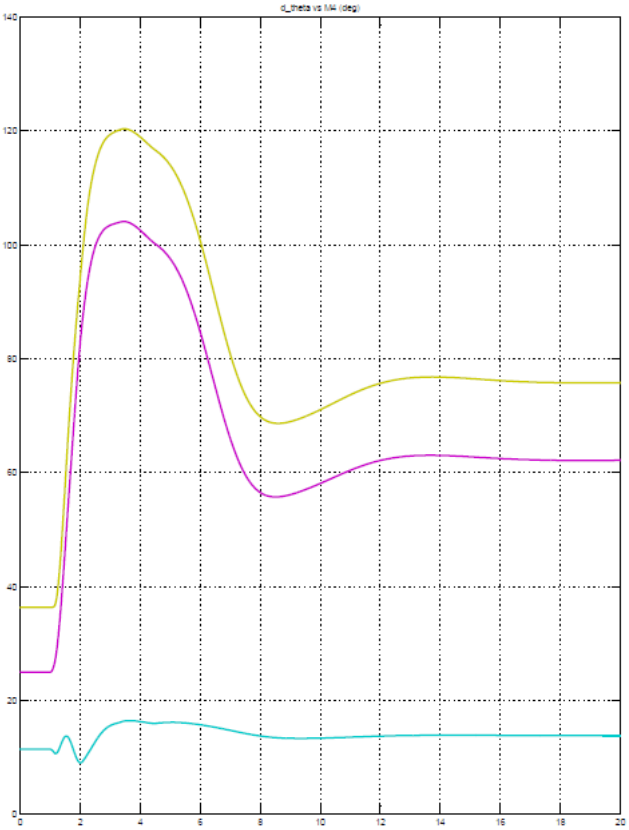
[1 1000+12/60] :



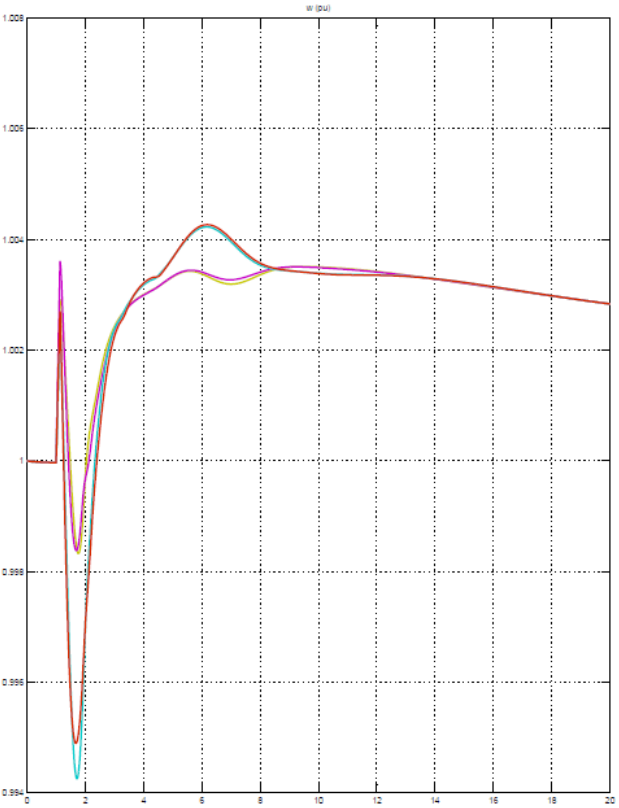
(a) the voltage in Bus 1 and Bus 2 (system data)



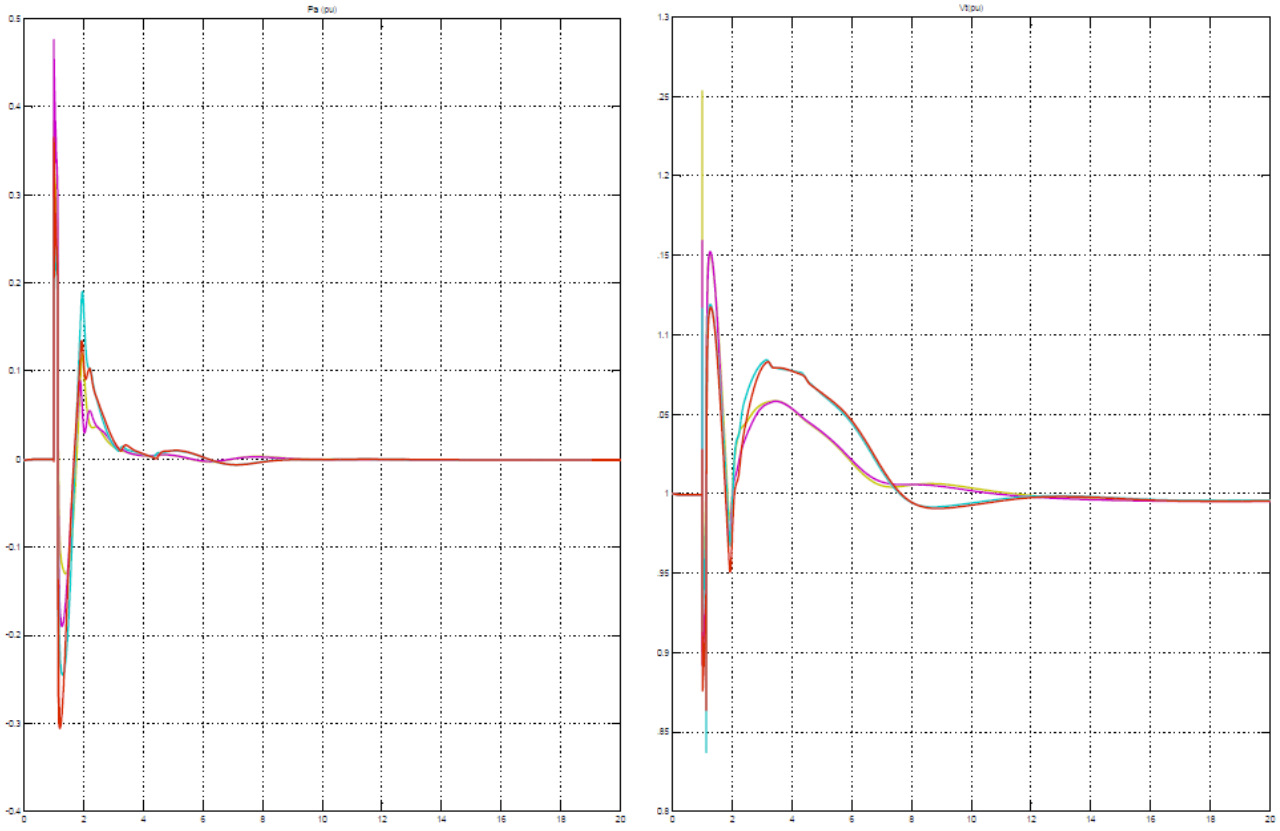
(b) W (pu) (machine)



(c) Pa (pu) (machine))



(d) Vt (pu) (machine)



(a) the voltage in Bus 1 and Bus 2 (system data) **(b)** Vt (pu) (machine)

Figure 4.29: the simulation Results :default duration of t = +1000

4.3 Conclusion :

In the conducted Kundur simulation with a two-area system and four machines, several conclusions can be drawn based on the results:

Fault Position; Placing the fault short circuit at different positions within the network (beginning, center, and end) resulted in varying effects on the stability of the system. The network remained after some time then returns to be stable when the fault occurred at the center, and we can see instability was observed when the fault was located at the beginning or end of the network.

Fault Severity, Changing the magnitude of the fault short circuit, specifically altering the fault impedance or charge, had an impact on the stability of the system. The severity of the fault affected the voltage and active power in the network, with instability occurring within certain ranges of fault severity.

Transition Time Modifying the transition time of the fault short circuit also influenced the stability of the system. The network experienced stability issues during specific time intervals, but it managed to stabilize again within certain ranges of transition time.

Machine Impact; The fault short circuit had consequences on the four machines within the network. The specific machines affected and the extent of the impact varied depending on the fault position, severity, and transition time.

Overall, these simulations highlight the importance of fault analysis and understanding the system's response to different fault scenarios. By considering fault position, severity, and transition time, engineers can assess and optimize the stability of the network to ensure reliable and efficient operation

General conclusion

The previously defined objective of this study is to study the transient stability in multi-machine system First, we presented the interest of the information that an introduction can provide, offering general information and basic notions on electrical networks and addressing the different types of faults that can occur.

Then we worked out and presented the stability of electrical networks. It delves into the concepts and theories surrounding transient stability, which is essential to ensure the reliable operation of electrical systems. This part explores stability analysis techniques and methodologies.

Afterwards, we dedicated to multi-machine systems, sheds more light on the behavior and dynamics of electrical systems made up of several interconnected machines. It examines the interactions between the generators and the impact on the stability of the system. This step highlights the importance of studying multi-machine systems for a comprehensive understanding of power system dynamics.

The last part of this thesis focuses specifically on the simulation of Kundur with a two-area system and four machines. Kundur simulation is a widely used tool in the analysis of power systems, allowing to evaluate the stability of the system and the effects of various factors. it probably involves the implementation and analysis of Kundur simulation with specific configurations.[28]

The simulation was performed using MATLAB.

The results of the Kundur simulation demonstrate the effectiveness of its protection capabilities in safeguarding the network against short circuits, overloads, and other potential disruptions. The simulation allows us to observe the impact of a short circuit the transmission time the possition of the fault on the network, providing valuable insights into its effects. From the results obtained, the following points were noted:

- Fault Position,Placing the fault short circuit at different positions within the network (beginning, center, and end)
- Fault Severity, Changing the magnitude of the fault short circuit.
- The severity of the fault affected the voltage and active power in the network, with instability occurring within certain ranges of fault severity.
- Transition Time Modifying the transition time of the fault short circuit also influenced the stability of the system.
- Machine Impact,The fault short circuit had consequences on the four machines within the network.

In summary, Kundur simulations are often used in energy system analysis to study the dynamic behavior of connected energy systems.During Kundur simulations, the displayed signals are typically monitored and analyzed for:

- understand the behavior of the system,
- identify potential instabilities,
- evaluate the effectiveness of control strategies.

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