Transient Stability Analysis in Nine Bus Power System

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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Declaration

I hereby declare that this project " **Transient Stability Analysis in Nine Bus Power System**" represents my own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. I have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and safety approval (where applicable) and acknowledged my obligations and the rights of the participants.

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APPROVAL

The project entitled "**Transient Stability Analysis in Nine Bus Power System**" submitted by **Md. Nahid Hasan (191-33-820)** & **Antara Ghosh (191-33-904)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and Electronic Engineering** in **April, 2023.**

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Dedicated To

Our Parents

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LIST OF ABBREVIATIONS

CCT	critical clearing time
MATLAB	matrix laboratory
STATCOM	static synchronous compensator
MRAD	maximum rotor angle deviation
PSS	power system stabilizers
AGS	automatic generation control
WAMS	Wide area monitoring system
AVR	automatic voltage regulators
GUI	Graphical user interface
CLI	command-line interface
UI	User interface
Pu	Per unit
KV	Kilo volt
MVA	megavolt-amperes
W	watt
VAR	Volt-Amps Reactive
Km	Kilo meter
GDP	Gross domestic product
BPDB	Bangladesh Power Development Board
HVDC	High-voltage direct current

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ABSTRACT

This thesis presents a comprehensive study on the transient stability analysis of a 9-bus power system using MATLAB. The transient stability analysis is a crucial component of power system analysis. The 9-bus system is a well-known benchmark system commonly used to evaluate different power system stability analysis techniques. The study starts by reviewing the fundamental concepts of power system stability, including voltage stability and transient stability. It also presents a detailed mathematical model of synchronous generators, transmission lines, and loads. The transient stability analysis of the 9-bus system is conducted using MATLAB/Simulink software. The study analyzes the response of the system to various fault conditions such as three-phase short-circuits, line-to-line faults, and single-phase faults. The study evaluates the performance of the system under different fault conditions by analyzing the critical clearing time (CCT) and maximum rotor angle deviation (MRAD). The study also incorporates different control strategies such as excitation systems, power system stabilizers (PSS), and FACTS devices, to improve the system's transient stability. The study compares the system's performance with and without the control strategies to evaluate their effectiveness. The results indicate that the 9-bus system is highly vulnerable to different fault conditions, and the use of appropriate control strategies can significantly enhance the system's transient stability. The study provides valuable insights into designing and implementing control strategies to improve power system stability.

Keywords: Critical Clearing Time (CCT), power system stabilizers (PSS), maximum rotor angle deviation (MRAD)., Frequency Stability, 9 Bus Test System, Transient Stability.

Chapter 1

INTRODUCTION

1.1 Introduction

1.1.1 Introduction

The stability of a power system is the capacity of a power system to maintain a constant and reliable supply of electricity in the face of disturbances, such as shifts in load demand or the loss of a generator or transmission line. Stability is essential for ensuring the efficient and secure operation of the electrical grid.

Several factors can influence the stability of a power system, such as the design and operation of the system's components, the characteristics of the power sources and demands, and the control strategies employed by operators. There are various forms of stability, such as transient stability, which pertains to the system's ability to maintain stable operation following a disturbance, and steady-state stability, which describes the system's ability to maintain stable operation under normal operating conditions.

A combination of technical knowledge, advanced modeling and simulation tools, and effective control strategies are required to ensure power system stability. Engineers of power systems must constantly monitor and analyze the system's behavior, identify potential problems, and implement measures to prevent instability. This may include designing and implementing new equipment as well as adjusting the parameters of existing devices and control systems. A power system may experience a variety of instabilities, including rotor angle instability, voltage instability, and frequency instability, among others. Each of these categories of instabilities necessitates unique analytical methods and system representations in order to comprehend and address them.

To analyze and enhance the stability of a power system, it is essential to simplify the problem by making appropriate assumptions and categorizing stability issues accordingly. This enables a more targeted and efficient method of stability analysis and control.

The proposed classification of power system stability is based on the following factors:

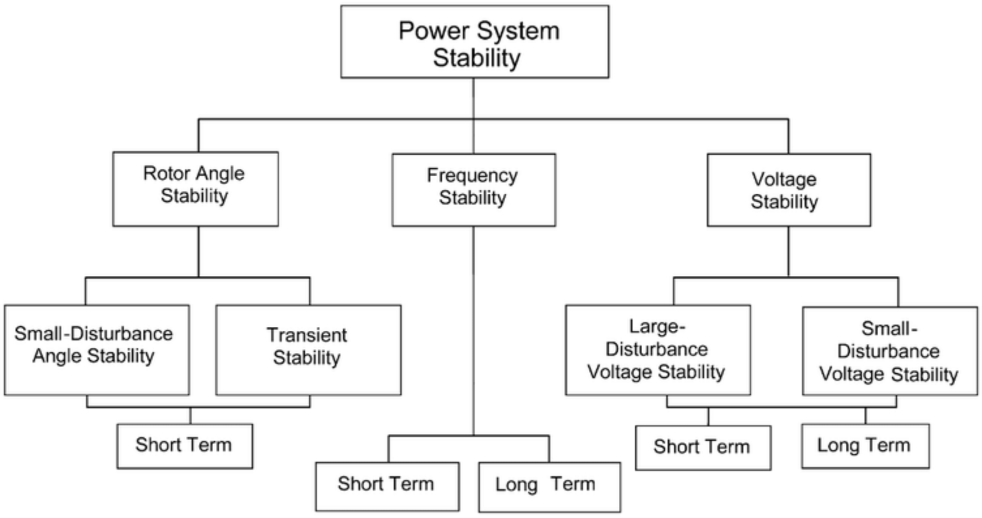


Fig1.1: Classification of Stability

A. **Rotor Angle Stability**: Rotor angle stability refers to the capacity of synchronous machinery in an interconnected power system to maintain synchronization following a disturbance. It depends on the ability of each synchronous machine to maintain/restore equilibrium between electromagnetic torque and mechanical torque. The rotor angle stability problem entails the investigation of the inherent electromechanical oscillations of power systems. Under steady-state conditions, there is –

   Small-disturbance rotor angle stability: It is an important concept in power systems engineering. It refers to the ability of a power system to maintain stable operation even in the face of small disturbances to the rotor angles of synchronous generators. Such disturbances can be caused by changes in load demand, generator output, or network topology. In a power system, synchronous generators are interconnected through transmission lines and operate in a coordinated manner to meet the load demand. The rotor angle of a synchronous generator represents the phase angle between the generator's rotor and the network voltage. In normal operation, the rotor angles of all generators in the system remain synchronized, ensuring that the generators operate in concert and maintain stable operation [24-26]. However, small disturbances to the rotor angles can cause generators to fall out of synchronization, leading to instability and potentially cascading failures in the power system. To prevent this, power system operators employ various control measures to detect and mitigate disturbances and maintain stable operations. These control measures include automatic generation control (AGC) to regulate generator output and maintain frequency, power system stabilizers (PSS) to dampen oscillations in the power system, and the deployment of wide-area monitoring systems (WAMS) to provide real-time information on system stability and performance. Overall, small-disturbance rotor angle stability requires ongoing monitoring, analysis, and control to ensure the reliability and resilience of the power grid.

Large-disturbance rotor angle stability or transient stability: Large-disturbance rotor angle stability, also known as transient stability, is an essential aspect of power system operation. It ensures that a power system can maintain stable operation during significant disturbances, such as faults or major system outages. During such disturbances, the rotor angles of generators in the power system can experience substantial deviations, which can result in synchronization loss and cascading failures. Transient stability analysis is a crucial technique used to assess the power system's response to such disturbances and identify measures to maintain stable operation. Power system operators implement various control measures to maintain transient stability, such as protective relays to isolate faults, automatic voltage regulators (AVRs) to regulate generator voltage, and dynamic braking resistors to absorb excess energy during disturbances. Transient stability analysis is an important tool for power system planning and operation. It allows operators to identify potential stability issues and design control measures to maintain stable operations during significant disturbances. The analysis involves simulating the power system's response to various disturbance scenarios and evaluating the effectiveness of different control measures [28-30]. In summary, transient stability is critical for ensuring the power grid's reliability and resilience. In the absence of effective measures to maintain transient stability, significant disturbances can cause widespread power outages with significant economic and social consequences.

B. **Frequency Stability:** Frequency stability is the ability of a power system to maintain a constant frequency after a large disturbance causes a significant imbalance between generation and demand. In normal operation, power generation and load demand are balanced, resulting in stable frequency. However, disturbances such as changes in load demand, generator outages, or network faults can lead to frequency deviations [24,25]. Frequency stability analysis is a critical tool used by power system operators to assess the power system's response to frequency deviations and identify measures to maintain a stable frequency. Control measures used to maintain frequency stability include automatic generation control (AGC) to regulate generator output and maintain frequency, load shedding to reduce load demand, and frequency-responsive reserves to provide additional power when frequency drops.

C. **Voltage Stability**: Voltage stability is a crucial component of power system security. Unbalanced reactive power between supply and demand is the primary contributor to voltage instability. Voltage stability or collapse is a dynamic problem that can become more complicated when associated with out-of-phase rotor angles [27].

1.1.2 Motivation

To keep the stability and synchronous functioning of the power system after a disturbance, transient stability analysis is a vital procedure in power system engineering. This is because to the failures and blackouts, which can have serious economic and societal repercussions, when there is a loss of stability.

The working conditions of the electrical machinery and equipment may alter significantly when a disruption in the power supply occurs. These modifications may cause departures from the typical operating condition, which eventually produces instability. Blackouts, safety risks, and equipment damage can all result from power system instability. As a result, maintaining transient stability is crucial for preserving the power system's safety and dependability.

The operation and planning of power systems both need careful consideration of transient stability analysis. As power systems developed in size and complexity, the potential of instability and cascade failures increased, necessitating transient stability analysis [7]. Major blackouts like the Northeast Blackout in 1965 and the Great Northeast Blackout in 1977 showed the need for improved techniques for identifying and addressing stability problems in power networks. The increasing dependence on renewable energy sources, such as wind and solar power, which can be less consistent and more variable than conventional sources and result in stability problems in the power system, further led to the need for transient stability analysis.

In power systems, transient stability is crucial because the loss of stability can result in blackouts and cascade failures, which can have serious economic and societal repercussions.

For instance, the 2003 Northeast blackout, which impacted more than 50 million people, caused economic losses of nearly $6 billion. Thus, it is essential to maintain transient stability under all operational circumstances to guarantee the dependable and secure functioning of power systems. This makes it necessary to apply cutting-edge analytical tools and mitigation techniques to deal with stability concerns as they materialize. Hence, transient stability analysis is a crucial component of designing and planning a power system.

The power system is modeled as a collection of connected synchronous machines for transient stability analysis, and the system's dynamic response to disturbances is computed. Software for simulation and mathematical models of the parts of the power system can be used to achieve this [8]. Engineers can spot possible stability concerns and create mitigation plans to make sure the system is stable in all operating circumstances by examining the system's response to various shocks.

1.2 Problem Statement and Proposed Solution

An essential aspect of power system operation, transient stability analysis ensures the system's reliability and stability following large disturbances. The IEEE 9 bus system is a common test system for validating transient stability analysis methodologies. This study's objective is to examine the effect of a STATCOM (Static Synchronous Compensator) on the transient stability of the IEEE 9 bus system. STATCOM is a power electronic device that offers reactive power compensation and voltage regulation, thereby enhancing the power system's transient stability. Various techniques, such as time-domain simulation and eigenvalue analysis, will be used to evaluate the effect of STATCOM on the system's stability. To evaluate the efficacy of STATCOM in enhancing the system's transient stability, the study will consider various fault scenarios, including three-phase faults, single-phase faults, and line faults. Additionally, the analysis will determine the optimal location and magnitude of STATCOM in order to enhance the system's stability. The study's findings will shed light on the efficacy of using STATCOM to enhance the transient stability of the IEEE 9 bus system. The results can be used to influence the design and operation of power systems in order to assure their dependability and stability.

1.3 Objectives

To ensure that the system is stable under all operating circumstances, the ultimate objective is to detect possible stability concerns and establish mitigation solutions.

1. To accomplish this goal, the project should try to:
2. Create a thorough model of the power system, including the loads, transmission lines, transformers, and generators.
3. Use MATLAB to simulate how the system would react to different disruptions, such as malfunctions and abrupt changes in load.
4. Examine the simulation data to find any oscillations or voltage instability that could be a problem with stability.
5. Construct and assess mitigation plan to deal with stability difficulties, such as the usage of excitation control and stabilizers for power systems.
6. Use real-world data to validate the simulation results, and compare them to transient stability analysis techniques currently in use.
7. The accuracy of the model, the capacity to recognize potential stability problems, and the efficiency of the mitigation techniques in preserving system stability are a few examples of key performance indicators that may be used to measure the project's success.

1.4 Brief Methodology

We have use MATLAB for our simulation. MATLAB is widely used for power system transient stability research, including the IEEE nine bus system. MATLAB is good for this for several reasons:

1. **Powerful and flexible computer language:** MATLAB can build complex power system models. The language allows matrices, vectors, structures, and many built-in functions and toolboxes for complex computations.
2. **User-friendly interface:** MATLAB makes modeling setup and analysis easy. The GUI lets users build models and view results, while the CLI lets them run scenarios.
3. **Built-in functions and toolboxes:** MATLAB have many powers system analysis-specific functions and toolboxes. These features and toolboxes allow generator, load, transformer, and transmission line modeling.

4. **Effective simulation engine**: MATLAB’s simulation engine can manage large-scale models of complex systems. It simulates the IEEE nine-bus system because it can manage systems with many buses and generators.

MATLAB’s flexible programming language, user-friendly UI, built-in functions and toolboxes, fast simulation engine, and community help make it ideal for modeling transient stability analysis of the IEEE nine bus system.

1.5 Gantt Chart

A schedule of implementation is a tool that allows us to effectively manage our time and finish our thesis on time. To ensure that we conduct high-quality research, we must be adaptable and modify our schedule accordingly.

Stages of research week	1	2	3	4	5	6	7	8	9	10	11
Selection of topic	🟦										
Data collection from secondary sources	🟦	🟦									
Literature review			🟦	🟦							
Research methodology plan				🟦	🟦						
Selection of appropriate research techniques					🟦	🟦	🟦				
Simulation and designing							🟦	🟦	🟦	🟦	
Findings and recommendations									🟦	🟦	
Final research project										🟦	🟦

1.6 Structure of the Report

In the first chapter, we have given a comprehensive introduction to transient stability, covering a variety of topics such as its categorization and the role it plays in power systems. Moving on to the second chapter, we took a look at the relevant research and analyzed how it stacked up against our own work using comparison and contrast. In the third chapter, which was dedicated to the design process, we discussed the simulation in detail and examined the way in which we approached the design. In the fourth chapter, we discussed the findings by presenting them in the form of instructive graphs. In the fifth chapter, we went into detail about the learnings we gained from the experiment as well as how we successfully handled the project. In chapter six, we discussed the economic, societal, and global effects of this subject, as well as the ethical considerations and codes of conduct that are associated with it. In addition, we looked at the global implications of this issue. In the last segment, which served as a conclusion, we discussed the accomplishments of our project and offered suggestions for directions for additional study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The capacity of a power system to maintain stable operation following a significant perturbation, such as a fault or an abrupt loss of generation, is referred to as its transient stability. During a perturbation, the power system experiences transient oscillations that can contribute to instability, cascading failures, and equipment damage. Consequently, it is essential to ensure that power systems have adequate transient stability to maintain stable operation and prevent outages.

The purpose of this literature review on transient stability was to assess the current state of research and development in this field. The purpose of the review was to identify the challenges and opportunities for enhancing transient stability, the modeling and analysis techniques used, and the efficacy of various solutions proposed in the literature. The purpose of the review was also to identify the voids in the literature and the areas where additional research is needed to enhance the understanding and management of transient stability in power systems.

Overall, the literature review sheds light on the current state of research and development in transient stability, highlighting the need for innovative solutions to improve the stability of power systems, particularly in the context of increasing renewable energy levels and rising electricity demand.

2.2 Related Research

Ramandeep Kaur, Er. Divesh Kumar (2016) designed the paper on the transient stability analysis of IEEE 9 bus system in the Power World Simulator. We must comprehend the security of the power structure in this essay. The modeling and transient reliability of the power system are assessed using the power world emulator program. This study compares the Euler and Runge-Kutta methods for determining equilibrium. The system may also enter a steady condition as a result of the load's effect [10].

Thesis on Voltage Stability Analysis Using Simulated Synchro Phasor Measurement by Allan Agate pet et al. (2013) put forth the notion that as demand rises, our transmission system must be run under duress in recent years, which is also near unstable limits [12]. Most substations use synchronized phasor technology through relay instances, which can quickly determine the voltage and current phasor synchronization in real-rehearsal-time simulator and MATLAB are use in this study to simulate energy movement and calculate indices. Manoj Kumar and Renuka Kamdar (2014) offer a study on the analysis of transient stability and its improvement in the IEEE-9 bus system, which also provides faults on various buses and analyzes transient stability on load and generation systems [11]. The stability of the system must be investigated when a disruption happens. In order to the critical clearing time using an equivalent area criterion, voltage and frequency variations are estimated at the problem site. The critical clearing time is the utmost amount of time the system can stay stable in the event of an unstable operation. Therefore, for a secure and safe margin in the event of transients, the CCT is the most crucial element.

2.2.1 Essential Concepts

1. The research suggests several techniques to increase transient resilience, including:
2. Excitation control: Per [4], "Excitation control is a technique that can be used to enhance transient stability by varying the excitation voltage of synchronous generators in reaction to changes in system circumstances."
3. Power system stabilizers (PSS): Per [5], a PSS is a tool that can be used to enhance transient stability by adding extra damping to the system, thereby decreasing the magnitude of the oscillations.
4. High-speed circuit breakers: Following [6], high-speed circuit breakers can be used to increase transient stability by rapidly isolating faults, thereby minimizing the effects of disruptions on the power system.

2.3 Compare and Contrast

For electric power networks to remain dependable and secure, it is essential to keep the temporary stability of power systems. To guarantee temporary stability, numerous systems, tools, approaches, and procedures have been created. Utilizing generators with excitation devices to control voltage, keep synchronism, and maintain stability is one of the major techniques used. However, this approach has drawbacks and might be unable to manage significant disruptions. High-speed circuit breakers are expensive and might not always work, but they can rapidly block fault currents and stop compounding failures. Power system stabilizers (PSSs) can modify the generator's output based on measurements of the system's frequency and voltage, but they are difficult to build and put into practice, and in some operating circumstances, their efficacy is restricted. Too ensure transient stability, computer models and real-time tracking are used to model and simulate the behavior of the power system under different working circumstances. The efficacy of the measures can, however, be impacted by the simulations' and real-time tracking systems' quality. Although some of the current methods and technologies are successful, they have drawbacks and might not be appropriate in all situations. Real-time monitoring systems and the creation of more dependable and efficient PSSs are among the research voids. Using machine learning methods to increase the precision and efficiency of PSSs and real-time monitoring systems is probably the best way to close these study gaps. Machine learning is able can data in order to spot patterns and trends, create predictive models, and take action before disruptions happen. To ascertain the viability and efficacy of machine learning for intermittent stability in power networks, more investigation is necessary.

2.4 Summary

The steps in the design procedure for enhancing transient stability are the analysis of the power system to identify potential stability issues, the selection of suitable solutions based on the needs of the system, and the implementation of the solutions. This process is supported by prior training in power systems and control theory, which provides the knowledge and abilities needed to develop and apply methods for enhancing transient stability.

Chapter 3

SYSTEM DESIGN

3.1 Introduction

In this design assignment, we'll use STATCOM to examine the temporal stability of the IEEE 9 bus system. (Static Synchronous Compensator). A STATCOM is a FACTS (Flexible AC Transmission System) instrument that can be used to increase a power system's transient reliability. It can support the system with reactionary power and aid in preserving voltage stability during significant disruptions.

This project's main objective is to determine whether STATCOM can improve the temporal reliability of the IEEE 9 bus system. To examine how the IEEE 9 bus system responds to various working circumstances and disturbance situations, we will create a MATLAB simulation model of the system with a STATCOM.

The crucial clearing time, or the amount of time needed for the system to recoup from disruption and resume steady operation, will be used to measure the system's reaction. In the effect of the STATCOM on the system's transient stability, we will evaluate the system reaction with and without one.

The outcomes of this endeavor will shed important light on how using a STATCOM can improve the transient reliability of a power system. It will show how to analyze and simulate power systems using MATLAB, with an emphasis on FACTS gadgets like STATCOM. For power system engineers, researchers, and students interested in power system stability analysis and management, this undertaking will be helpful.

3.2 System Design and Components

I. Power System Stabilizer (PSS)

The power system stabilizer (PSS) is an essential device that plays a significant role in ensuring the stability of the electricity grid. By regulating the excitation based on the power output fluctuations of the generator, the PSS can quickly reduce power swings and dampen generator rotor oscillations caused by electromechanical dynamics [13]. It is a feedback controller that is integrated into the control system for a synchronous generator, modulating the field voltage by adding a signal to the excitation system. There are two types of power system stabilizers: the generic power system stabilizer model, which employs acceleration power, and the multi-band power system stabilizer, which employs speed deviation.

The generic power system stabilizer model consists of a low-pass filter with general gain, a high-pass filter with discharge, a phase-compensation system, and an output limiter. The input to the power system stabilizer is the deviation of synchronous machine speed from nominal or acceleration power, while the input to the excitation system is the stabilization voltage. On the other hand, the multi-band power system stabilizer is connected to the synchronous machine and uses speed deviation to stabilize the system.

The block diagram of a power system stabilizer includes a sensor block, global gain, washout, lead-lag filters 1 and 2, and a limiter. The washout block helps reduce the over-response of the damping during multiple events and serves as a high-pass filter that allows the signal associated with rotor speed oscillations to pass unchanged. The phase lead blocks compensate for the delay between the PSS output and control action and electric torque. The gain of the PSS is crucial because the damping it provides is directly proportional to the gain up to a certain point, after which the damping begins to decrease.

Overall, the power system stabilizer is an essential device that enhances system stability by regulating the excitation of the generator. It helps to prevent power swings and dampen rotor oscillations caused by electromechanical dynamics, ensuring the reliable and safe operation of the electricity grid.

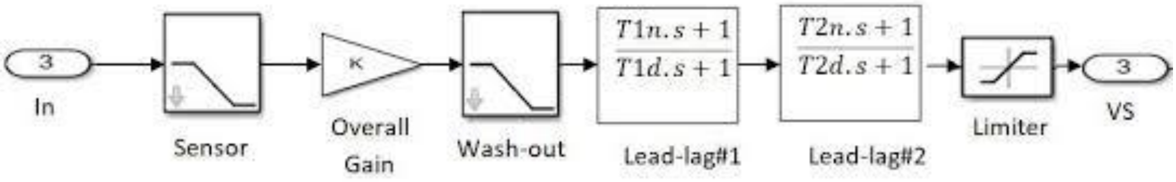


Fig 3.1: Structure of a power system stabilizer (PSS)

II. STATCOM

STATCOM is a shunt-connected solid-state switching device with independently controllable real and reactive power generation and absorption. It is based on a voltage-source converter and is used for voltage maintenance in power systems. It can inject leading or lagging current into an AC system and provide active power when connected to a power source. Typically, STATCOMs are implemented in power systems with weak voltage regulation or power quality [14]. They have a modest active power capacity, but this can be increased with the addition of an appropriate energy storage system. They can provide reactive power compensation on high voltage transmission networks, thereby enhancing voltage and power stability following faults. In this study, a phasor STATCOM with and without a controller was simulated, and a new PSS was designed to inject voltage externally to enhance power system stability [27]. The use of thyristor based STATCOM with a PSS controller was addressed, and it was determined that any rating of STATCOM is adequate for the stabilization of various conditions.

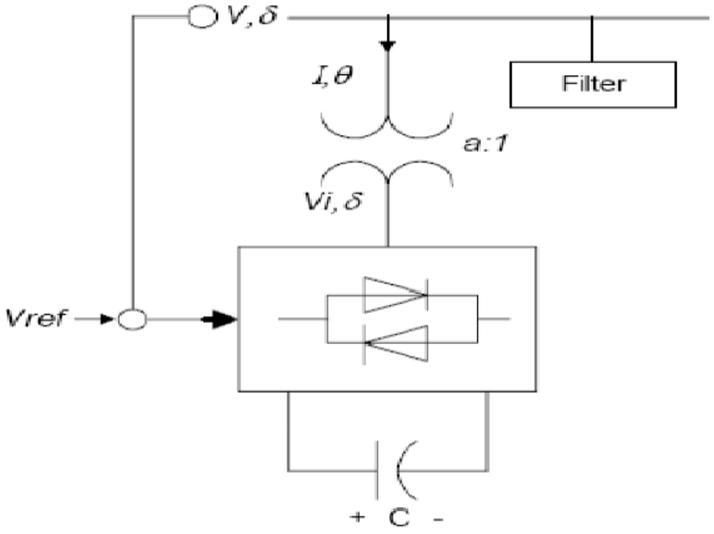


Fig 3.2: Structure of a STATCOM

III. Transmission line:

The Transmission Line block represents, in terms of its tangible parameters, the transmission line described in the block dialog window [15]. Lossy or lossless, the transmission line is regarded as a two-port linear network. The block allows you to simulate the transmission line with or without a fragment.

IV. Three-Phase Transformer:

This block implements a three-phase transformer using three single-phase transformers. For a detailed description of the electrical model of a single-phase transformer, see the Linear

Transformer block [16]. When activated, the saturation characteristic is the same as the one described for the Saturable Transformer block. If the fluxes are not specified, the initial values are automatically adjusted so that the simulation starts in steady state.

The leakage inductance and resistance of each winding are given in pu based on the transformer nominal power Pn and on the nominal voltage of the winding (V1 or V2). For a description of per units, refer to the Linear Transformer and to the Saturable Transformer.

V. Load:

The Three-Phase number RLC Load block uses a number of RLC elements to create a balanced three-phase load. The load has a constant resistance at the given frequency. The load takes in an amount of active and reactive power that is proportional to the square of the voltage that is applied [17].

VI. Three-Phase Fault:

The Three-Phase Fault block uses a three-phase circuit breaker whose opening and closing periods can be set by either an internal control schedule or an external Simulink signal.

Phase-to-phase faults, phase-to-ground faults, or a mix of phase-to-phase and ground faults can all be programmed using the Three-Phase Fault block, which employs elimination procedure is the same as the Breaker Block's. For information on the design of the single-phase breakers, see the Breaker block [18].

VII. Excitation System:

Without the exciter's saturation function, the Excitation System block implements a DC exciter as explained in [15]. The voltage regulator and the exciter are the fundamental components of the Excitation System block.

The Synchronous Machine is engineered using fundamental parameters in pu units, the fundamental block depicts a synchronous machine in the generator or motor mode. The mechanical power sign dictates the mode of operation (positive for generator mode or negative for motor mode). The electrical component is represented by a sixth-order state-space model, while the mechanical component is identical to the Simplified Synchronous Machine block.

VIII. Synchronous Machine p.u. Fundamental:

The Synchronous Machine was engineered using fundamental parameters in p.u. units, the fundamental block depicts a synchronous machine in generator or motor mode. The mechanical power sign dictates the mode of operation (positive for generator mode or negative for motor mode). The electrical component is represented by a sixth-order state-space model, while the mechanical component is identical to the Simplified Synchronous Machine block

3.3 Design Specifications, Standards and Constraints

Instabilities in the electrical system can be caused by transmission line short circuits, generator and load losses, and transmission line brief circuits. They all result in a significant deviation of the generator's rotor angle and influence power flow, bus voltage, and other system variables, resulting in a partial or complete failure of the transmission network. Transient stability is concerned with both operating environments and disturbances, whereas steady state stability is only concerned with operating environments. Describing the different of disturbances demand a frequent investigation. Classification of electrical power system stability is indispensable for a complete comprehension of power reliability [20]. We have examined such instances. In this instance, we have examined three-phase defects.

Below is shown the single-line diagram of a three-machine electrical system. There are three generators, transformers, and charges in this paper. This system involves generators, transformers, and charges in its appendix. Generator G2 is linked to slack bus 2, while generators G1 and G3 are linked to the PV bus. The loads A, B, and C are respectively connected to bus bars 5, 6, and 8. We will add a three-phase fault at bus 7 [19]. As a realistic power system, there will also be some transmission lines that will have some specific values. In this case, to compensate for the effect of fault we will use a power system stabilizer (PSS) and STATCOM.

The entire system will be depicted using Simulink components in a single comprehensive model. It is self-explanatory based on the single-line case described below. Interaction capacity is one of the most essential characteristics of a Simulink model [21].

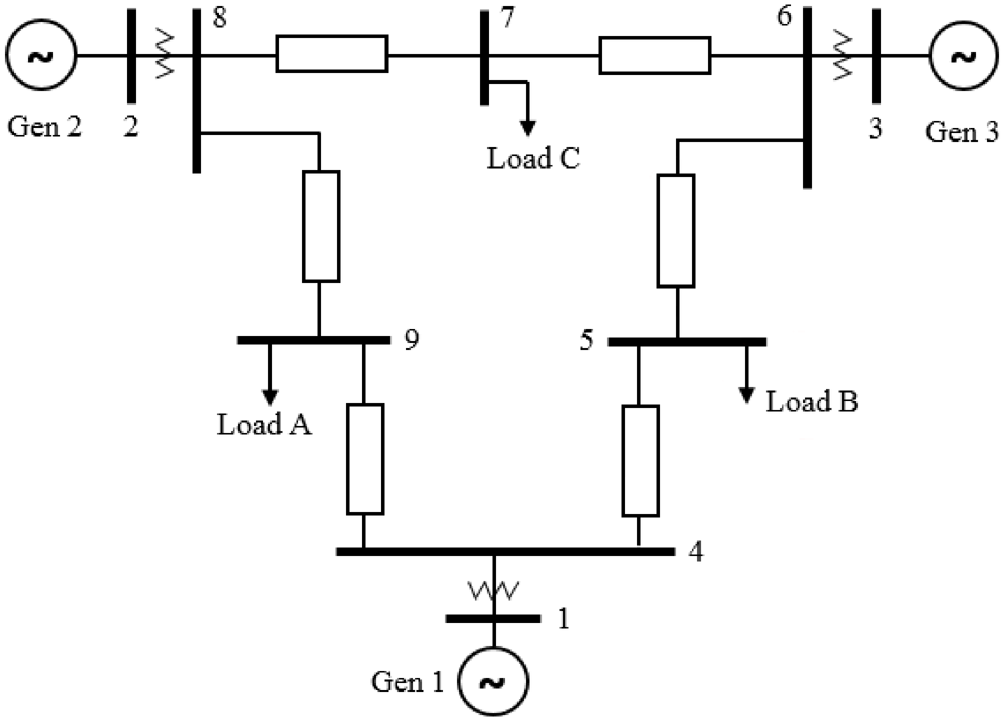


Fig 3.3: Single line diagram of the system

3.4 Design Analysis

Launch PowerGrid, and choose 'Machine Initialization' from the menu. A fresh window will open up. The 'Bus type' of the machine is set to 'PV generator' during the initialization process. This indicates that the machine is the one controlling the active power and its terminal voltage during the process of initialization. The active Voltage parameter is set to 187e6, and the intended terminal voltage parameter is set to 13800.

These two blocks are given their starting values in accordance with the calculations made by the tool for machine initialization so that the simulation can begin in steady state with the HTG and the stimulation system connected. As long as you connect either Constant blocks or regulatory blocks from the machine library to the P_m and V_f inputs of the machine, this initialization will be carried out automatically (HTG, STG, or Excitation System). When you open the menu for the HTG block, you will see that the utility preconfigured the starting mechanical power to be 0.7516 p.u. which is equivalent to 150.32 MW. Once you have opened the menu for the Excitation System block, you will see that the starting terminal voltage and field voltage have been adjusted to 1.0 and 1.29071 p.u. respectively.

Open each of the four scopes and then resume the simulation. It is important to note that the terminal voltage V_a is 1.0 p.u. when the experiment first starts. It drops to about 0.4 pu during the fault, but it rapidly returns to its normal level once the problem has been resolved. This rapid reaction in terminal voltage is due to the fact that the Excitation System output V_f is capable of going as high as 11.5 p.u. which it does when there is a fault in the system. During the malfunction, the speed of the machine increases to 1.01 p.u., and then it returns to its normal speed of 1 p.u. as the regulator system begins to moderate it. The terminal voltage takes significantly longer to normalize than the speed, and this is primarily due to the fact that the regulator system has a maximum rate of valve opening/closing of 0.1 p.u./s.

PSS is connected to the rotor speed deviation of all three generators. Which will significantly contribute to the system's stability.
Here we are using STATCOM as a device which will stabilize the system. STATCOM will be connected to BUS 7, Where the fault has occurred and LOAD C is connected.

After designing the generator (G2), rotor speed (p.u.), rotor speed deviation (p.u.), and output active power can be measured using scopes. G2 will be directly linked to BUS 2. A scope, which is directly connected to BUS 2, measures the magnitude of each of the three phases. Transformer 3 is connected to bus 2 for the purpose of increasing the voltage generated by G2. These increased voltages will be transmitted through a transmission line connected to BUS 8 and BUS 7. To render the system unstable, a fault is connected to BUS 7. At the same bus is connected LOAD C. The voltages for LOAD C are being measured by a multimeter. BUS 7 and BUS 6 are linked by an additional transmission line. TRANSFORMER 3 will be directly connected to BUS 6. Which is associated with BUS 3 A second scope is connected to BUS 3 in order to measure the magnitude of its voltages. BUS 3 is linked to an additional synchronous Generator (G3). From generator 3, the rotor angle can be determined. Using scopes, we will determine the rotor speed (p.u.), rotor speed deviation (p.u.), and output active power from the generator 3 (G3). BUS 3 scope measures the magnitude of each of the three phase voltages. BUS 8 and BUS 9 are interconnected via transmission line. The BUS 9 is connected to a second LOAD A. Through a transmission line, BUS 9 is connected to BUS 4. Due to the symmetry of the design, it is evident that BUS 6 and BUS 5 are connected by another transmission line. Here, LOAD B is coupled with BUS 5. BUS 5 and BUS 9 are now connected to BUS 4, which has six connection ports. Now that BUS 4 is connected to transformer 1, which is connected to

BUS 1, and we are measuring the voltages of BUS 1, we are also measuring the voltages of BUS 1. BUS 1 is connected directly to G1.

Table 3.1: Generator Data

Generator	1	2	3
Rated MVA	100	187	80
KV	18.8	13.8	16.8
Power Factor	1.0	0.85	0.85
Type	Hydro	Hydro	Hydro
X_d	0.1460	0.8958	1.3125
X_d'	0.0608	0.1198	0.1813
X_q	0.0969	0.8645	1.2578
X_q'	0.0969	0.1969	0.25

Table 3.2: Load Data

Load	A	B	C
Active powers (W)			
Pa	8000	7000	10000
Pb	9000	6000	9000
Pc	10000	5000	11000
Inductive reactive powers (VAR)			
	100	100	100
QLa	90	90	90
QLb	110	110	110
QLc			

Table 3.3: Transmission line Data

Transmission Line	**1**	**2**	**3**	**4**
Resistance per unit length	0.01273	0.01273	0.01183	0.01773
Inductance per unit length	0.9337e-3	0.9337e-3	0.90037e-3	0.97737e-3
Capacitance per unit length	12.74e-9	12.74e-9	19.74e-9	11.74e-9
Length(km)	100	200	250	300

3.5 Simulation Setup

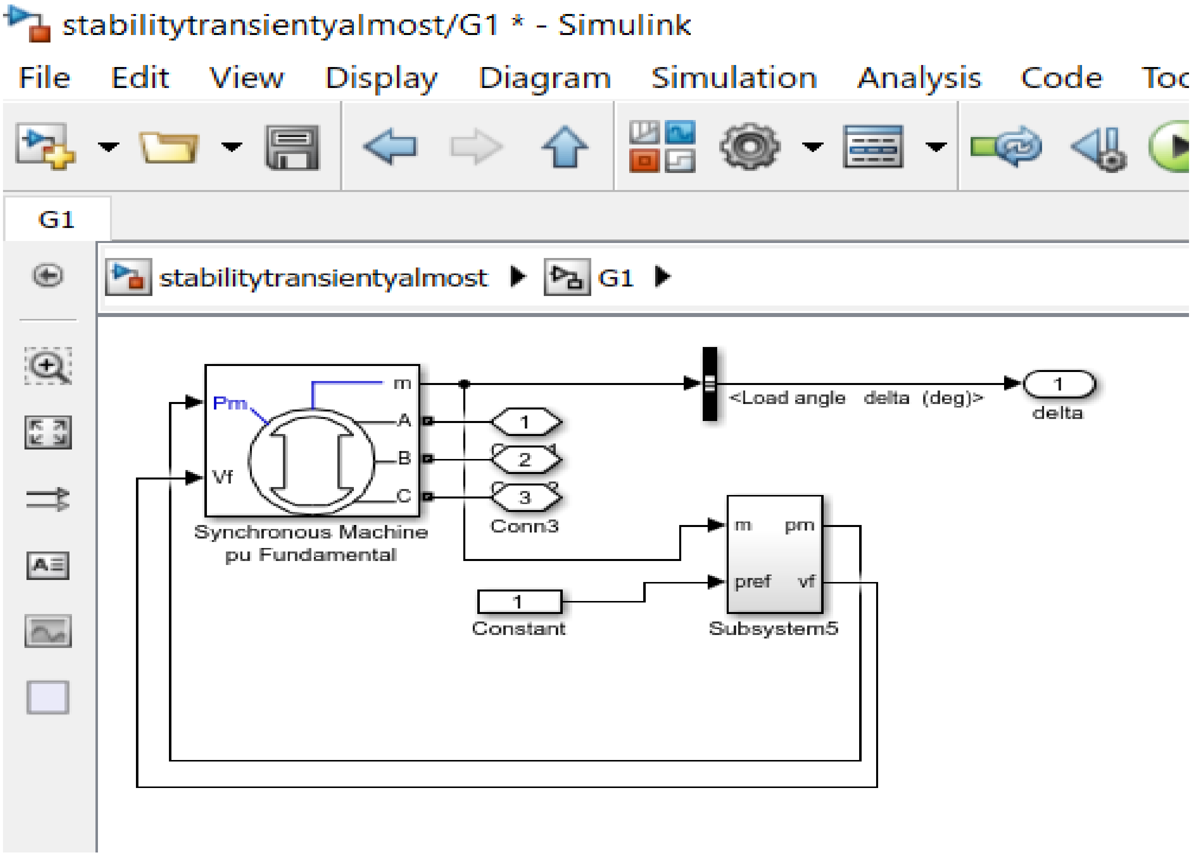


Fig 3.4: Internal structure of Generator

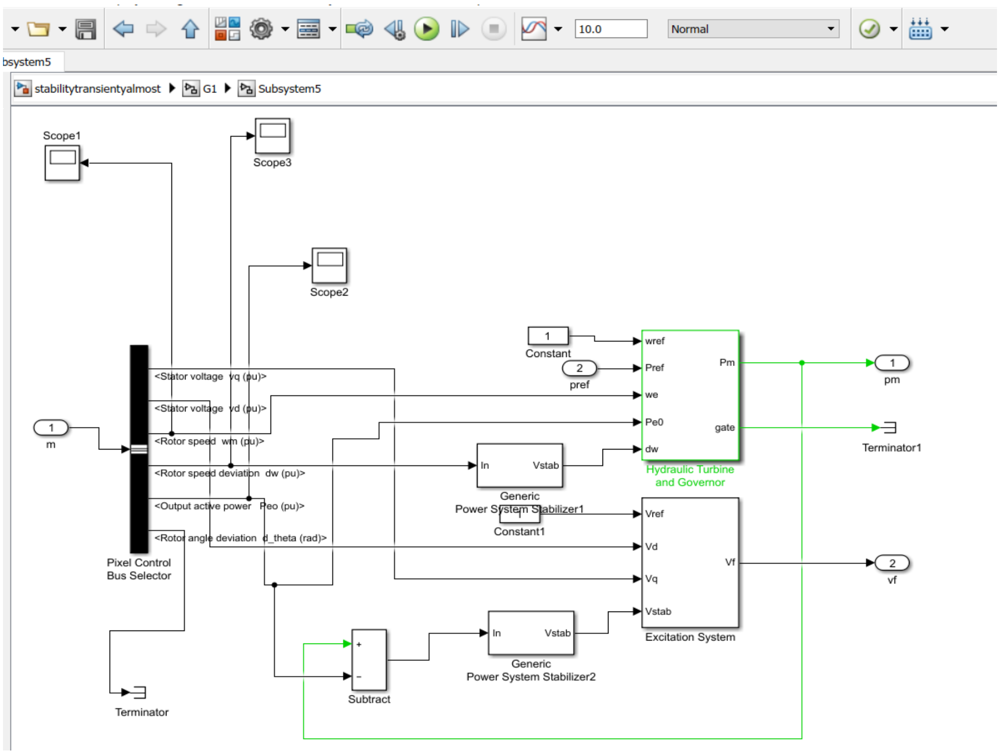


Fig 3.5: Internal structure of subsystem

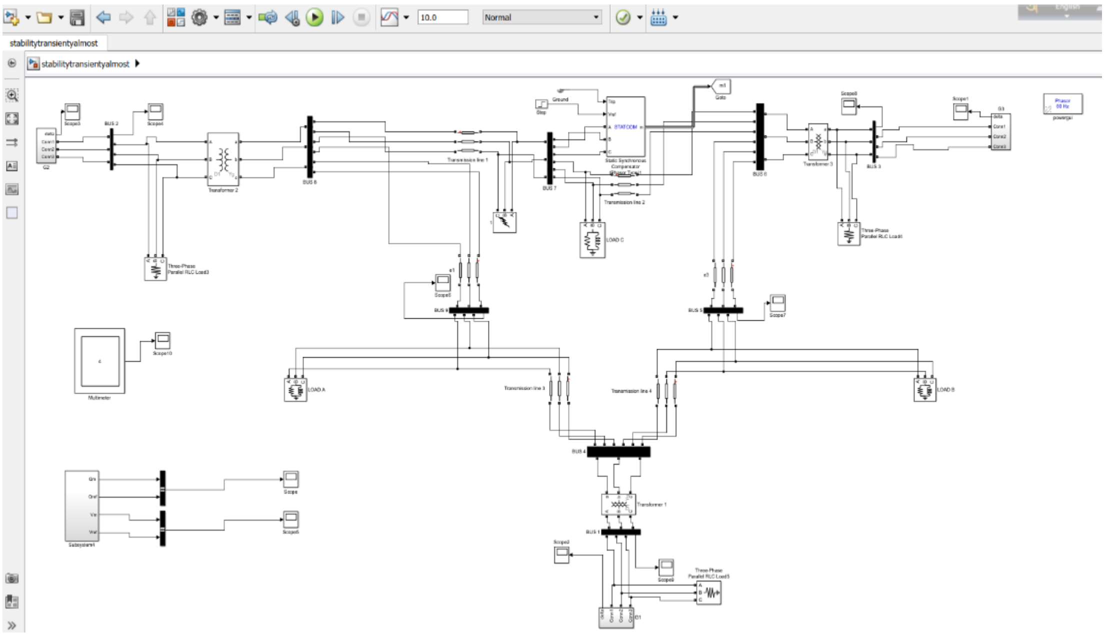


Fig 3.6: IEEE 9 bus power system without STATCOM

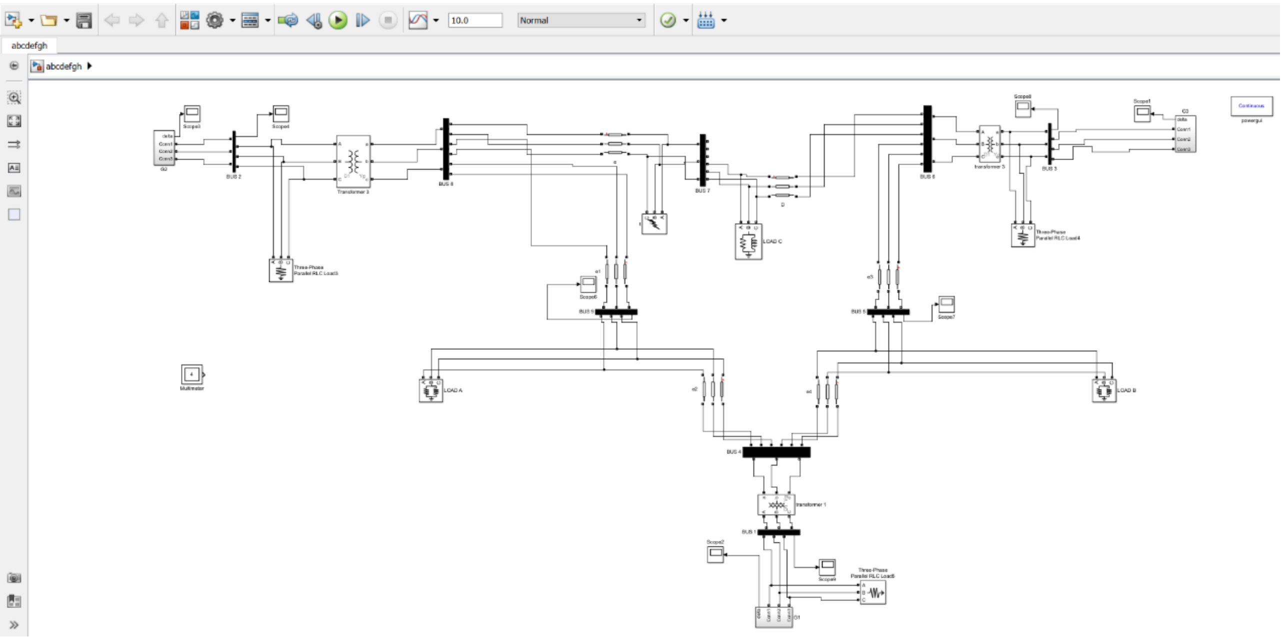


Fig 3.7: IEEE 9 bus power system with STATCOM

3.6 Summary

Using MATLAB, model the power system mathematically. The model should include system generators, loads, transformers, transmission links, and control devices. Next, define system initial conditions like generator voltages and rotor angles to initialize the model. Steady-state power flow study provides it. After a fault, the model is recreated. Time-domain modeling is recommended. Simulation results decide power system stability. This involves rotor angle stability and frequency stability testing. Performance metrics can measure system stability. If the system is unstable, control measures can enhance stability. PSSs or load-shedding systems may be needed. Finally, simulations and testing verify that the model and control measures enhance system stability.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results:

One of the most important aspects of keeping a dependable and safe electrical infrastructure is the transient reliability of power systems. In order to improve the stability of power systems during transient events like faults, generator trips, or load shifts, this thesis will look into the transient stability of those systems and suggest remedies. The findings of our investigation into transient stability analysis and improvement are presented in this chapter. We start off by outlining the methods used to model the behavior of the power system during transient occurrences. The outcomes of our models, including crucial clearance periods and stability limits for different situations, are then presented.

I. Rotor speeds:

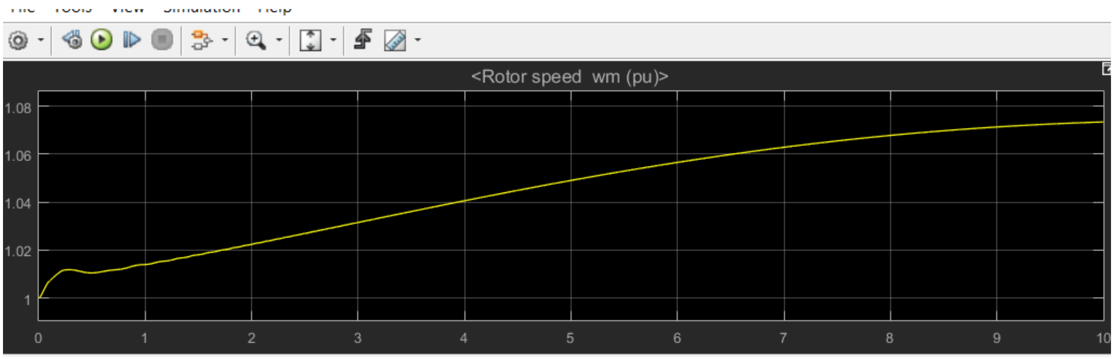


Fig 4.1: Rotor speed of Generator 2.

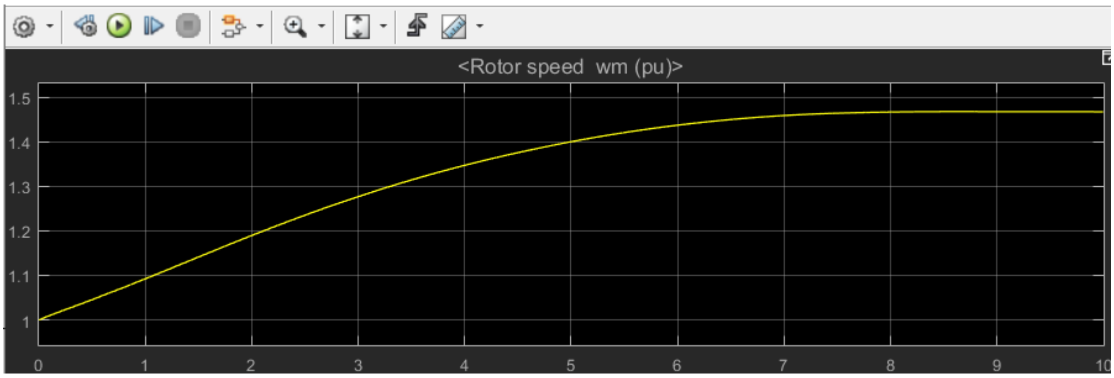


Fig 4.2: Rotor speeds of Generator 1 and Generator 3.

II. Load angle of Generators:

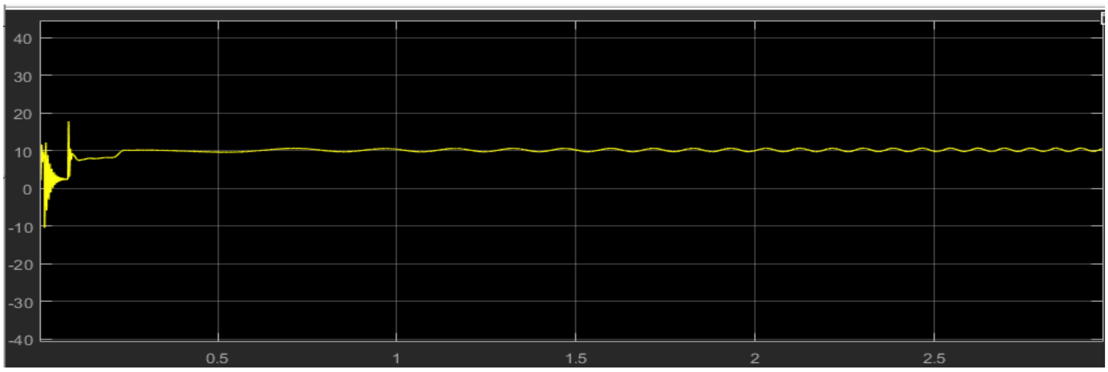


Fig 4.3: Load angle of Generator 2 with STATCOM.

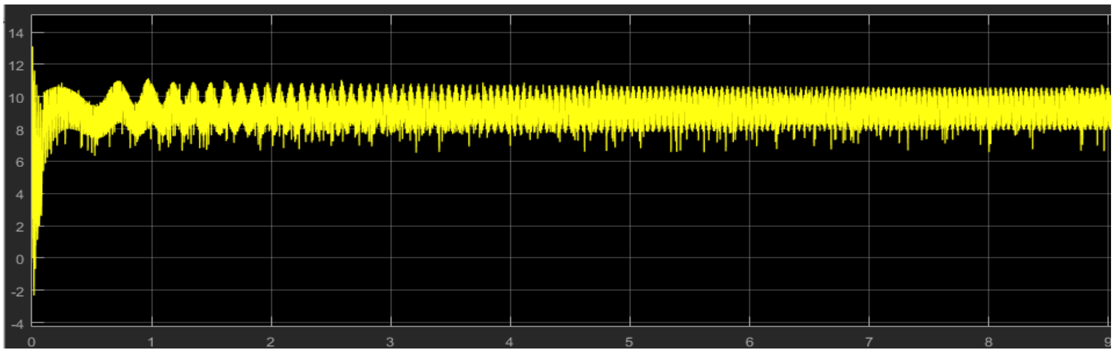


Fig 4.4: Load angle of Generator 2 without STATCOM.

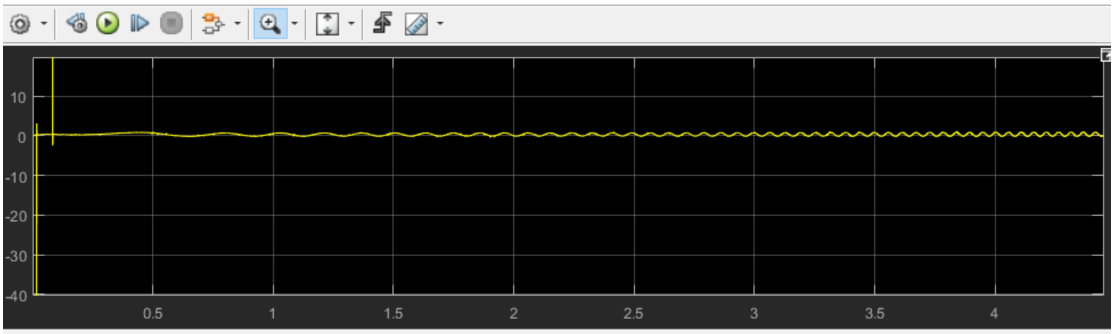


Fig 4.5: Load angle of Generator 3 with STATCOM

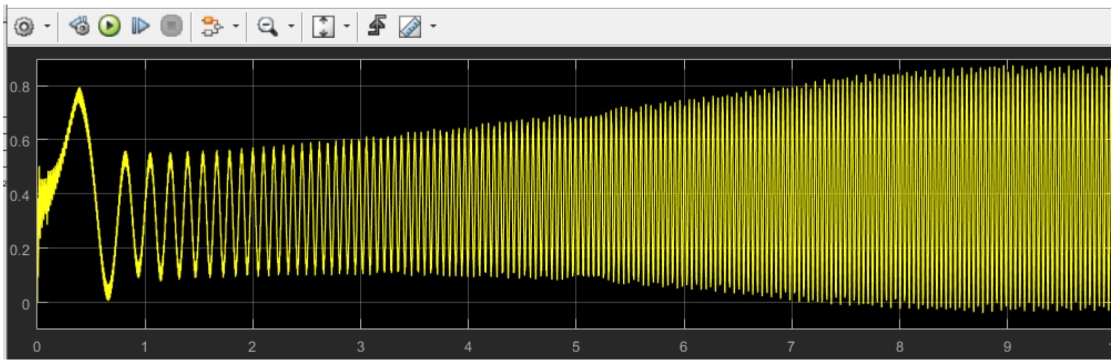


Fig 4.6: Load angle of Generator 3 without STATCOM

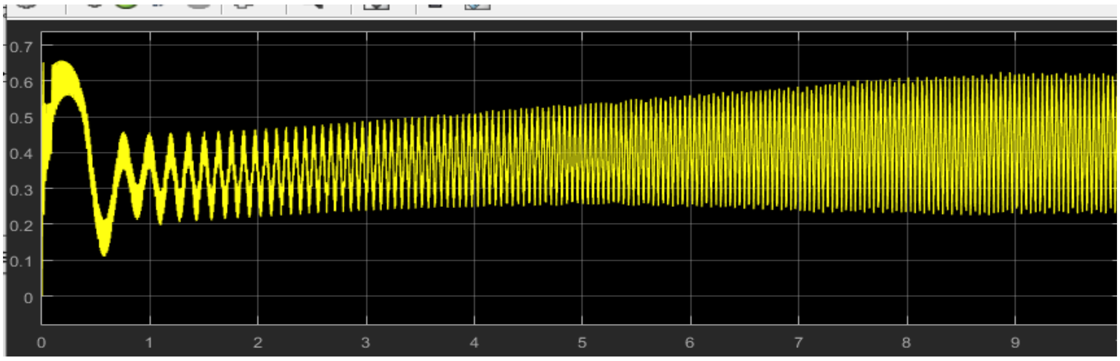


Fig 4.7: Load angle of Generator 1 with STATCOM

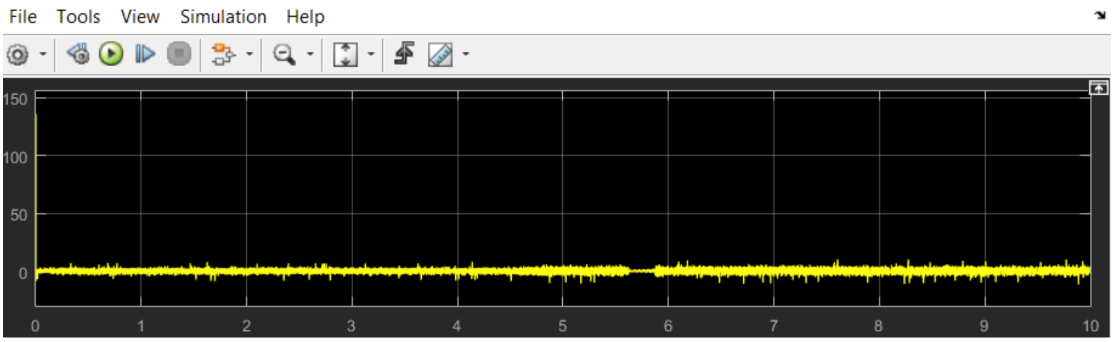


Fig 4.8: Load angle of Generator 1 without STATCOM

III. Fault current

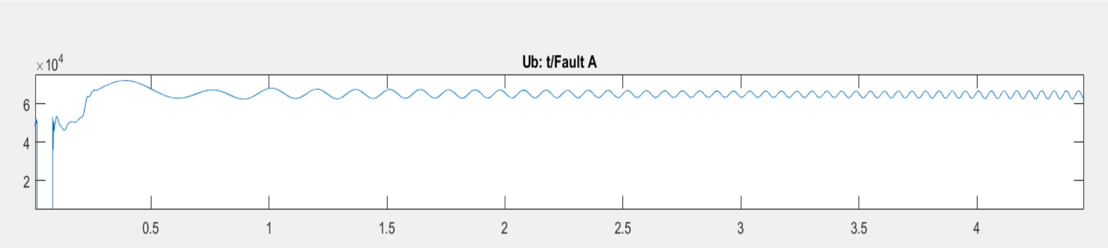


Fig 4.9: Fault current with STATCOM

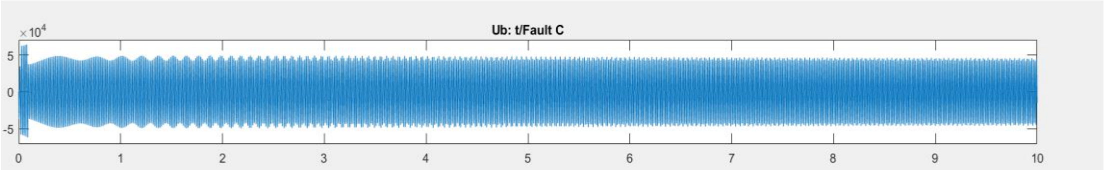


Fig 4.10: Fault current without STATCOM

IV. Bus Voltages:

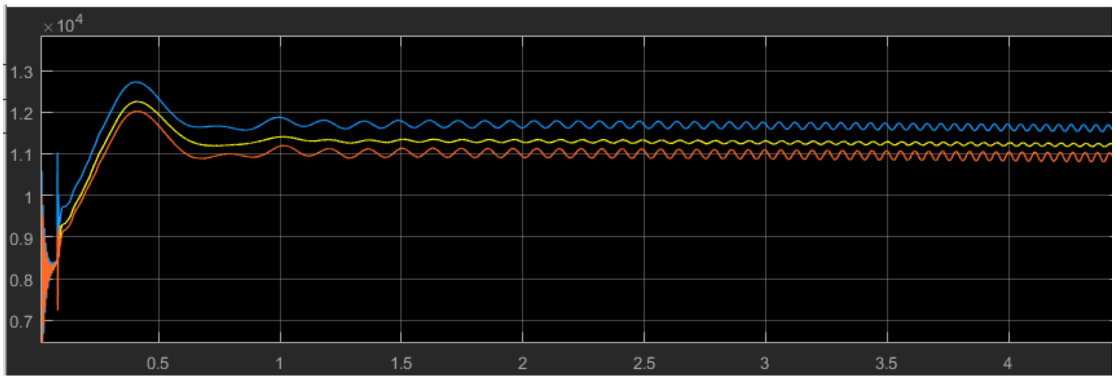
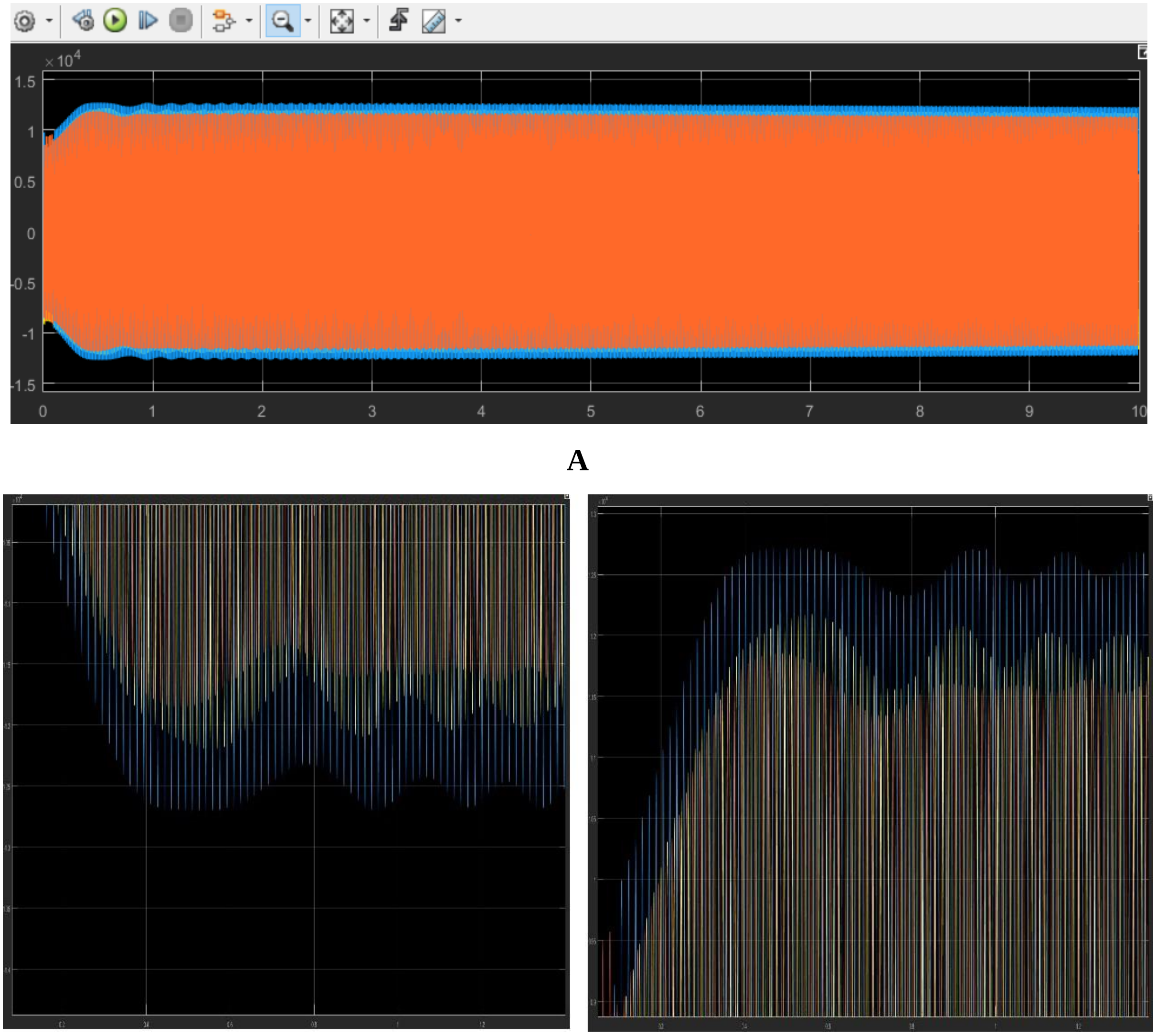


Fig 4.11: Voltage of BUS 2 with STATCOM.



A

B **C**

Fig 4.12: Voltage of BUS 2 without STATCOM (A, B, C)

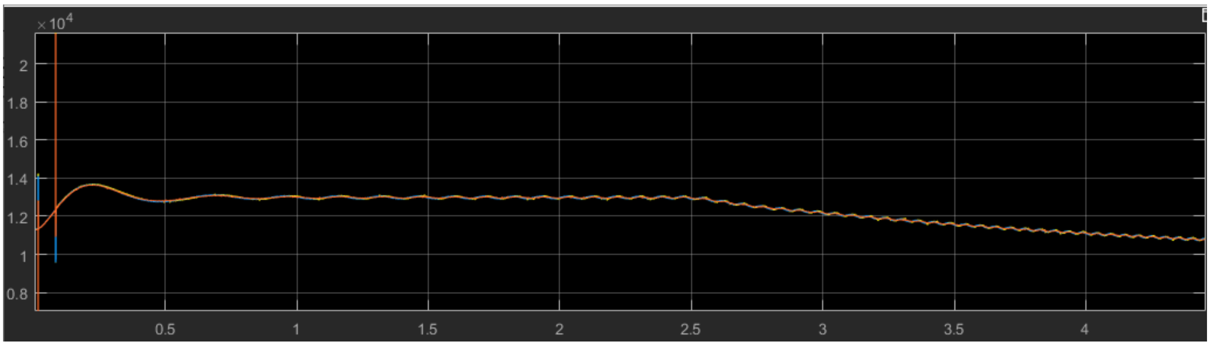
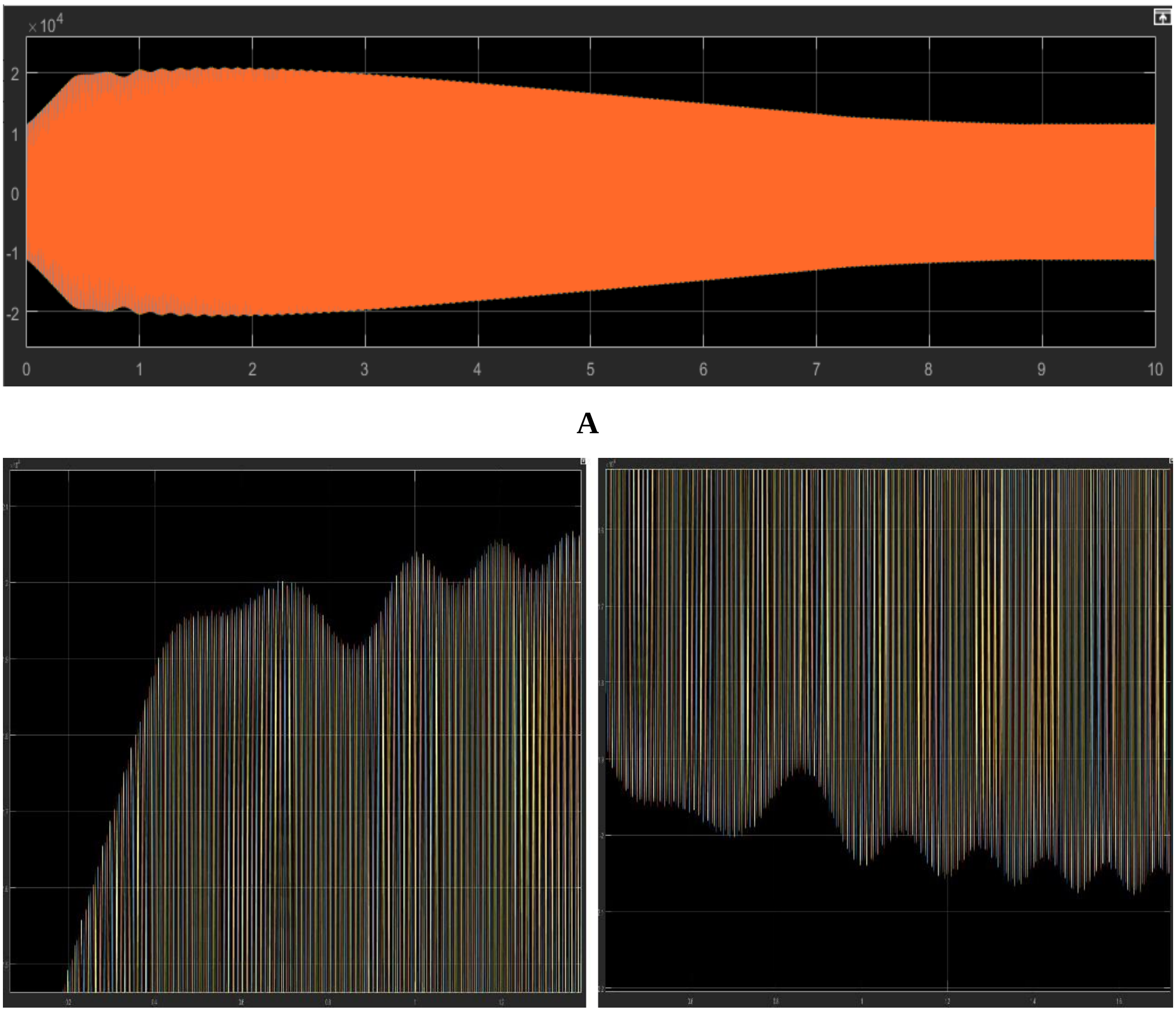


Fig 4.13: Voltage of BUS 3 without STATCOM.



A

B

C

Fig 4.14: Voltage of BUS 3 with STATCOM (A, B, C)

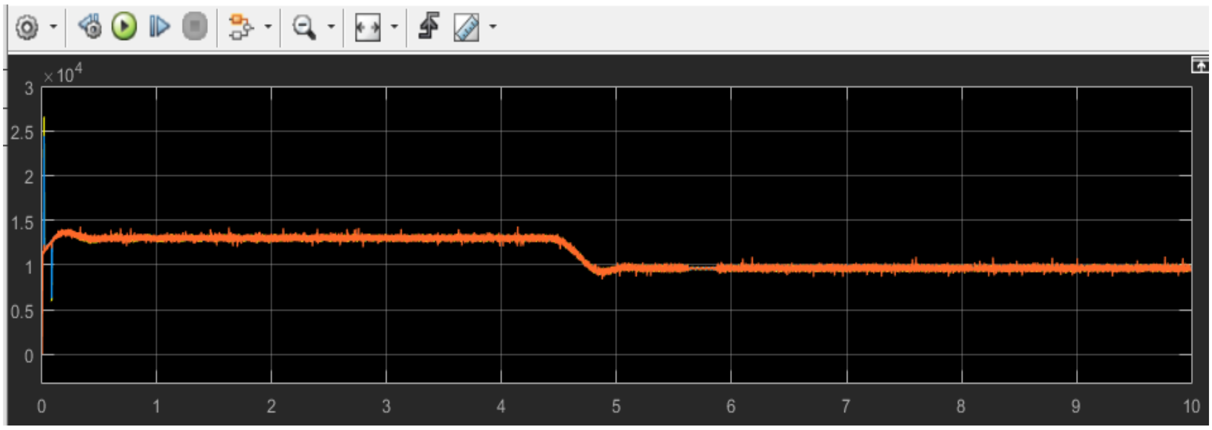
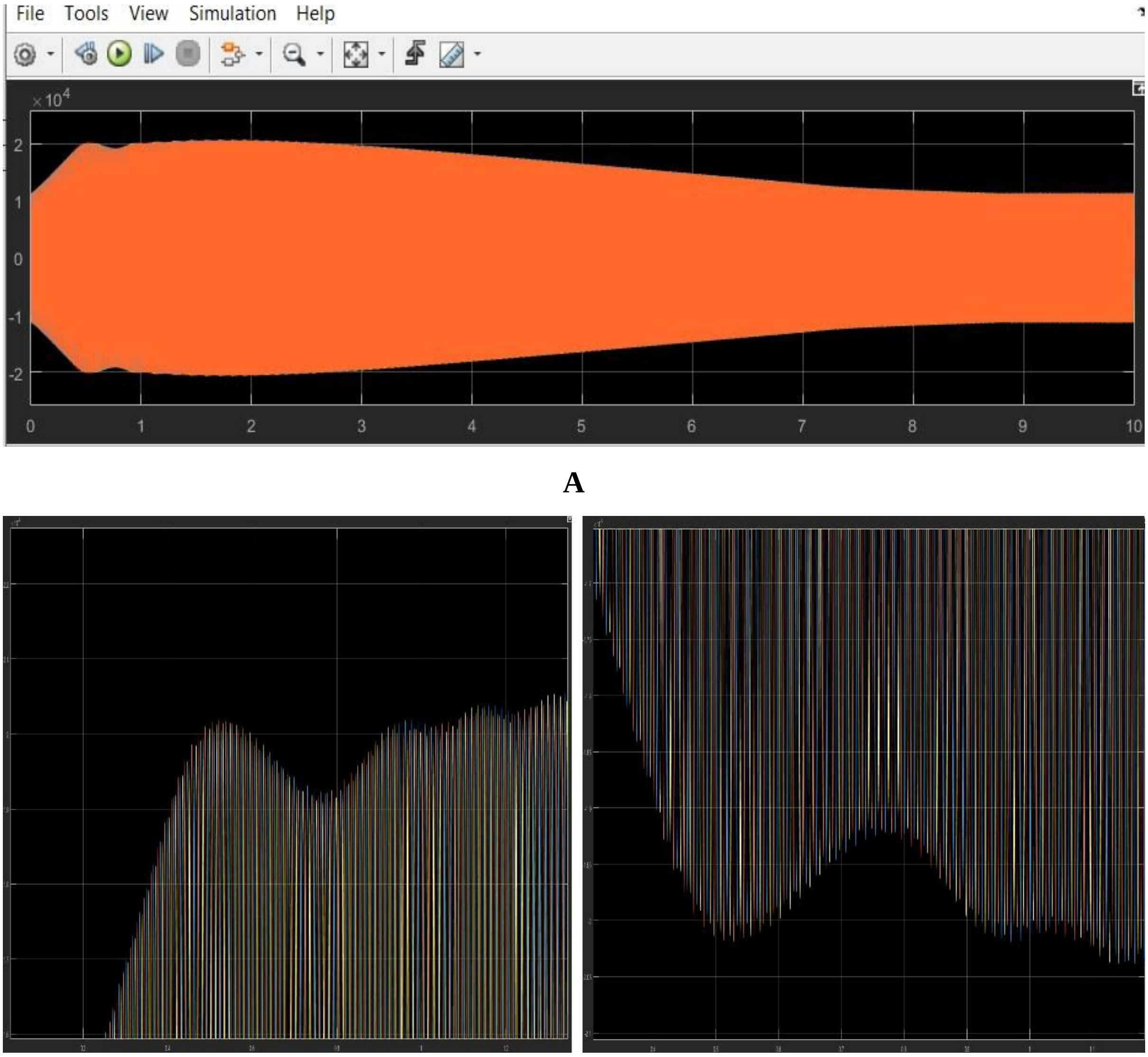


Fig 4.15: Voltage of BUS 1 with STATCOM



A

B

C

Fig 4.16: Voltage of BUS 1 without STATCOM (A, B, C)

IV. Load Voltages:

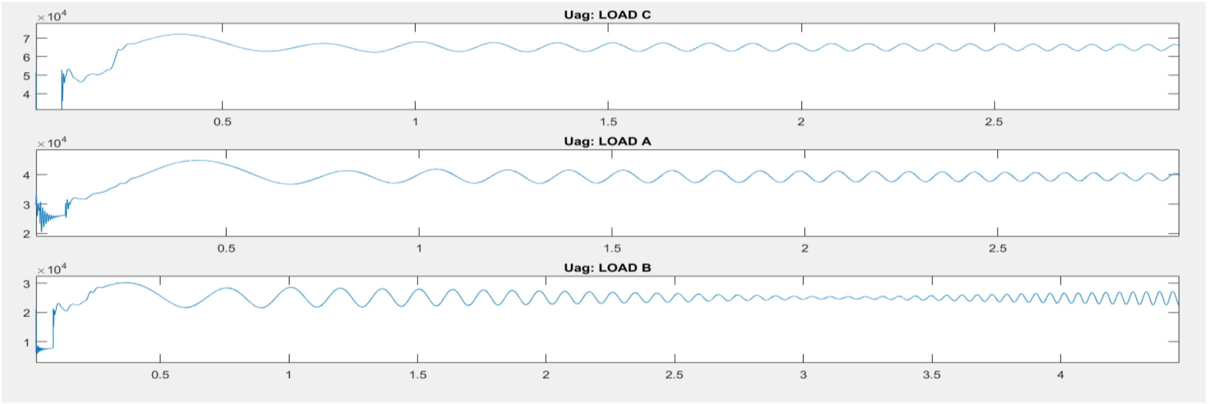
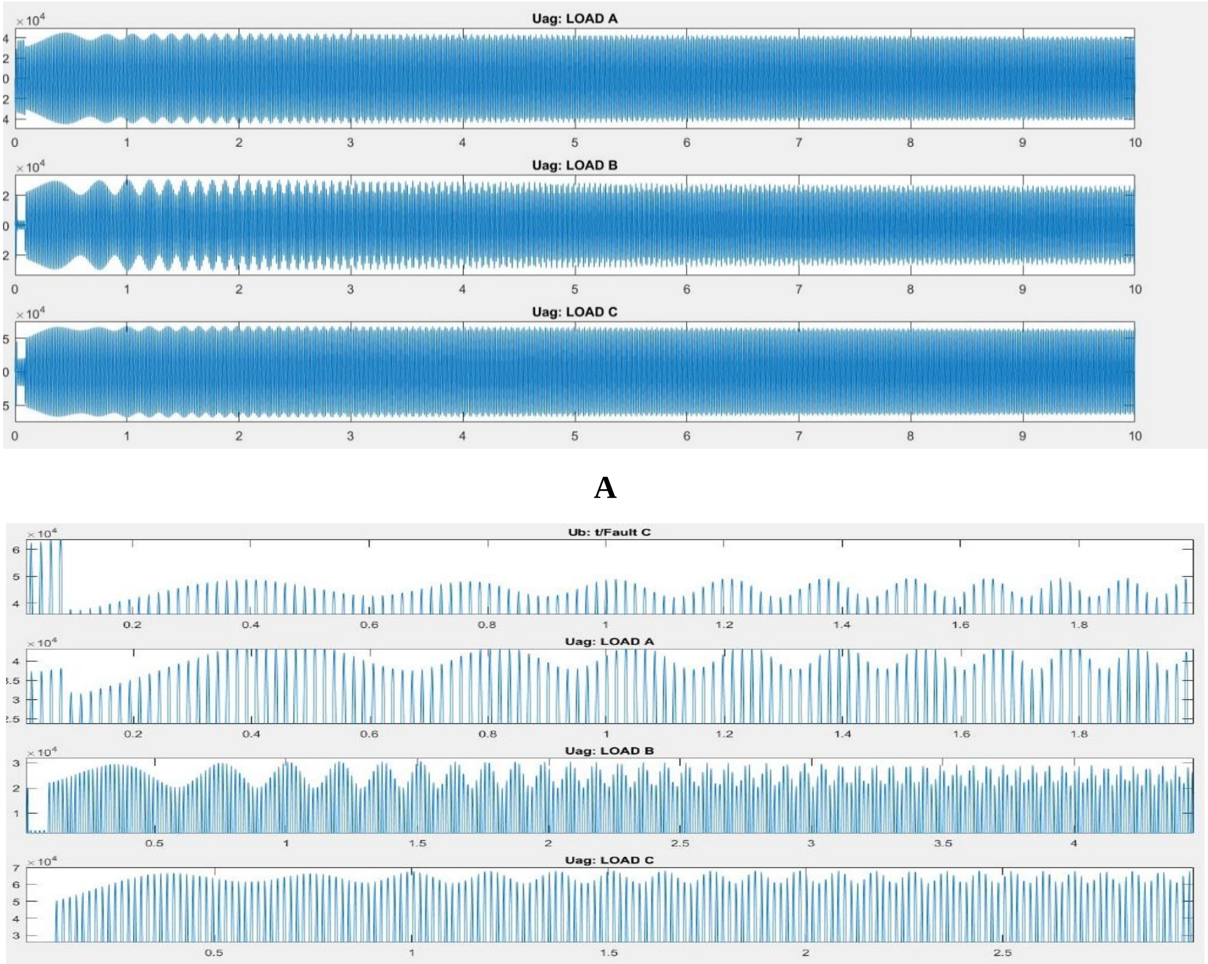


Fig 4.17: Load voltages with STATCOM



A

B

Fig 4.18: Load voltages without STATCOM (A, B)

4.2 Discussions

The outcome of the simulation demonstrates that the gadget has increased the line's transmission capability. The fault magnitude has decreased due to STATCOM's existence, which has also decreased primary system losses. Reactive power compensation is a specialty of STATCOM, and it has demonstrated power compensation to some extent.

This study showed that STATCOM modeling can manage reactive power and improve power transmission line voltage profiles. It improves power source voltage response. MATLAB virtual models show how the IEEE 9Bus Test System with STATCOM transient stability has improved. STATCOM is tested to lessen power fluctuations in a multi-machine power system. STATCOM significantly affects intermittent security in the electricity grid. STATCOM reduces voltage and power fluctuations and transient time for the transmission line parameters. Thus, STATCOM improves IEEE 9bus test system transient reliability under varied situations.

Chapter 5

PROJECT MANAGEMENT

5.1 Task, Schedule and Milestones

The transient stability of the 9BUS system using MATLAB was chosen as the topic for the project that was started with the intention of analyzing and enhancing the performance of the system while it was being subjected to transient events. In the first stage of the assignment, you were tasked with analyzing the behavior of the system under a variety of different operating conditions and determining the factors that influence the system's stability. After this, a quantitative model of the system was developed, and it was simulated using MATLAB. We have use STATCOM for improving stability.

During the course of the simulation, the system was subjected to a number of different transient events, including faults, sudden load changes, and switching procedures, in order to evaluate how it reacted. The results that were obtained from the simulation were analyzed so that flaws in the system could be pinpointed and strategies to enhance the system's stability could be developed.

The project has finally achieved its major milestone with the completion of the simulation and analysis phase. This achievement comes after several iterations of testing and improving the system. We have been successful in determining the important factors that have a negative impact on the 9BUS system's stability, and they have devised useful strategies to enhance the system's performance during transient events.

Moving forward, the project will advance to the next phase, which will consist of testing the effectiveness of the suggested strategies by implementing them in the actual system. A comprehensive report that provides a summary of the project's discoveries and recommendations for additional improvements will also be developed by the team as part of their ongoing work.

The project as a whole has been a significant accomplishment in the field of power system stability analysis, and the team is optimistic about the project's potential to contribute to the future development of power systems that are more reliable and efficient.

The following Gantt chart explains how the schedule and milestone vary from those mentioned in the introduction chapter. We spent more or less time on various initiatives:

Stages of research week	1	2	3	4	5	6	7	8	9	10	11
Selection of topic	🟦										
Data collection from secondary sources	🟦	🟦	🟦								
Literature review			🟦	🟦	🟦						
Research methodology plan				🟦	🟦	🟦	🟦				
Selection of appropriate research techniques					🟦	🟦	🟦				
Simulation and designing							🟦	🟦	🟦	🟦	🟦
Findings and recommendations									🟦	🟦	🟦
Final research project										🟦	🟦

5.2 Resources and Cost Management

Managers must effectively manage resources and adhere to the budget in order to successfully finish projects. Here are some tactics we've used:

I. **Write a comprehensive project strategy:** A comprehensive project plan includes information on the project's goals, timetable, important dates, deliverables, and resources required. By developing a comprehensive project plan, we have identified the resources needed for each stage of the project and distributed them properly. Resources have been used wisely and successfully in this way.

II. **Keep an eye on resource usage**: By routinely keeping an eye on resource usage, We could identify any potential problems before they escalate. Each task's time and effort requirements must be recorded, and they must be contrasted with the resources allocated in the plan. We had adjusted the resource allocation as needed when discrepancies were found in order to keep the project on track.

III. **Limit project scope**: Project scope expansion is frequently the root of budget overruns. The project's scope needed to be exactly defined, and any changes needed to be noted, approved, and reviewed. This helps prevent any unnecessary labor that could cause price overruns.

IV. **Control project costs:** It's challenging to gauge the effectiveness of the budget because we haven't worked in reality.

V. **Use project management tools**: We have managed resources and carried out the plan using tools like Gantt plots and resource planning software, among others. These tools allowed us to monitor the project's progress and resource consumption while ensuring that it continued to move forward.

5.3 Lesson Learned

Specific expertise is required for technical tasks. Here are some essential guidelines for managing technological tasks successfully:

I. **Create an accurate project plan**: A precise project plan is necessary for technical tasks. It needs to outline the project's objectives, timetable, metrics, resources, and anticipated outcomes. Everyone engaged in the endeavor benefits from having a thorough understanding of the goals and methods for achieving them.

II. **Communicate effectively**: Communication is crucial to successful projects. Effective communication with team members, clients, vendors, and management is essential. Keep everyone informed of the project status and any changes to the project plan.

III. **Manage project risks**: Risks are a part of every undertaking. Risk control and early discovery are essential. Make a comprehensive risk analysis and create a risk management strategy. Keep a regular eye out for new risks in the project and modify the risk management strategy as necessary.

IV. **Maintain organization**: Because technical tasks can be challenging, it's crucial to maintain organization. Documents, communications, and other project-related data should be kept on file. Keep all project data, such as designs, specifications, and other papers, in one central place.

Finally, Technological initiatives need organization, preparation, teamwork, risk management, project management tools, and a drive to learn.

CHAPTER 6

IMPACT ASSESSMENT OF TRANSIENT STABILITY

6.1 Economical, Societal and Global Impact

Power system design and operation include the examination of transient stability, and the creation of a 9-bus transient stability project system may have a big influence on society. The capacity of a power system to sustain synchronism after a disruption, such as a failure or an abrupt shift in demand, is referred to as transient stability. The design of a transient stability analysis tool for a 9-bus system has the potential to have a direct or indirect impact on a number of societal factors, including infrastructure, energy generation, and consumption, the creation of jobs, GDP contribution, and quality of life.

1. **Infrastructure:** The creation of a transient stability analysis tool for a 9-bus system may help the infrastructure of the power system. Power system planners and operators can proactively handle possible transient stability concerns by recognizing them and making necessary changes to the system's operating circumstances or upgrading equipment. A more dependable and robust power system infrastructure may arise from this.
2. **Energy consumption and generation**: Analysis of transient stability may have an effect on energy production and use. The establishment of a 9-bus transient stability project can prevent power outages and blackouts by maintaining the steady operation of the power system, minimizing the interruption to energy consumption patterns. Moreover, via enhanced system design and operation, transient stability analysis can aid in identifying possibilities to improve energy generation efficiency and decrease energy consumption.
3. **Employment creation:** The development of a transient stability analysis tool for a 9-bus system can also create employment opportunities. This can include employment in the development, maintenance, and operation of the analysis tool, as well as employment in the power system industry as a whole. By improving the stability and reliability of the power system infrastructure, more jobs can be created in related industries, such as manufacturing and construction.
4. **Contribution to GDP**: The creation of a project for 9-bus transient stability may also substantially increase GDP. The project can boost economic activity in connected businesses by generating job opportunities and enhancing the infrastructure of the

electricity system. Also, companies may run more effectively and efficiently, contributing to economic growth, by minimizing the disturbance brought on by power shortages and blackouts.

5. **Quality of life**: The creation of a tool for transient stability analysis in a 9-bus system can also directly affect people's quality of life. People can access essential services like healthcare, education, and communication with even more ease if power outages and blackouts become less disruptive. A more dependable and stable electrical supply can also result in a safer and more secure living environment, raising the quality of life overall.

   In conclusion, the creation of a project, module, or system for 9-bus transient stability has the potential to significantly affect society. The project can result in a more stable and robust power system infrastructure that will benefit people, companies, and the economy as a whole by enhancing infrastructure, energy consumption, and generation, providing employment opportunities, boosting GDP, and increasing the standard of living.

6.2 Environmental and Ethical Issues

Transient stability refers to the ability of a power system to maintain its equilibrium after a disturbance, such as a fault or sudden load change. The transient stability of a power system is essential to ensure the reliability and safety of the system. However, there are several environmental and ethical issues associated with the transient stability of power systems, particularly in the case of 9 BUS power systems.

6.2.1 Environmental Issues:

1. Carbon Emissions: The production of energy from fossil fuels like coal and oil has a substantial impact on greenhouse gas emissions. Studies on transient stability sometimes need very extensive simulations, which use a lot of energy. These simulations' energy requirements might lead to higher carbon emissions, which would worsen climate change.

2. Integration of Renewable Energy: To lessen their carbon impact, several nations are switching to renewable energy sources like solar and wind power. Transient stability, however, may be impacted by the incorporation of renewable energy into power networks. The fluctuation of various energy sources has the potential to make the electricity system unstable.

3. Resource Consumption: Studies on transient stability demand a substantial amount of memory and processing power. These resources have high energy requirements, and producing them can have a negative impact on the environment.

6.2.2 Ethical Issues:

1. **Public Safety:** Transient stability is essential for maintaining the electrical system's safety and stability. Failure to provide transient stability can result in equipment damage, blackouts, and possible dangers to the safety of the general population. When the public is harmed due to a failure to provide transitory stability, ethical issues arise.
2. **Social Justice**: Communities that are low-income and underprivileged are disproportionately affected by power outages. The negative effects of power outages, such as the loss of heating, cooling, and medical equipment, frequently affect these areas the most. When power system administrators put the demands of these populations beyond temporary stability, ethical issues arise.
3. **Fairness:** Transient stability studies need substantial resources, such as memory and processing power. For small or underdeveloped power system operators who do not have access to the required resources, this might provide a barrier to entry. Transient stability standards that provide power system operators an unfair advantage raise ethical questions.

In conclusion, ensuring the dependability and safety of the power grid depends on the transient stability of power systems. Transient stability, however, raises some moral and ethical questions, particularly in the context of 9BUS power systems. To attain transitory stability in a way that is both ethically just and environmentally sustainable, these problems must be addressed.

6.3 Utilization of existing standards

Transient stability analysis is a critical component in the development of power systems in Bangladesh to ensure that they are designed and operated safely and reliably. There are several standards, safety issues, codes, and laws related to transient stability analysis project development in Bangladesh. Some of them are:

Bangladesh Power Development Board (BPDB) Code: The BPDB is responsible for the planning, development, and operation of the power system in Bangladesh. The BPDB Code provides guidelines for the design, operation, and maintenance of the power system to ensure reliability and safety [24].

IEEE Standards: The Institute of Electrical and Electronics Engineers (IEEE) publishes several standards related to power system stability analysis. These standards are also applicable to the power system in Bangladesh. For example, IEEE Std 421.5-2013 provides guidelines for the assessment of transient stability and the design of control systems to ensure the stability of power systems [9].

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

STATCOM and PSS improved power system transient stability. Transient stability ensures power network reliability and safety, so this is a big achievement. We stabilized the power system's voltage, rotor angle, load voltage, and fault current with STATCOM, improving its resilience to outages. This may reduce power outages, system failures, and reliability. Using MATLAB to test and enhance SATCOM's performance shows the value of advanced modeling and simulation tools when analyzing and creating complex power systems. PSS and STATCOM improve transient stability and power system stability. PSS controls rotor tilt and speed, while STATCOM controls load voltage and fault current. The simulations show that PSS and STATCOM enhance stability more than either alone. PSS and STATCOM's stability depend on tuning. These aspects must be selected and tuned for optimal performance.

The study shows how PSS and STATCOM can improve power system transient safety and work conditions. The project stresses the importance of selecting and tuning factors for optimal performance.

7.2 New Skills and Experiences Learned

We have gained the following new skills and experiences:

1. The project has presented us with a deeper understanding of power systems stability concepts such as transient stability and rotor angle stability.
2. This task has helped us develop your MATLAB programming skills, such as the use of simulation tools and the implementation of control algorithms.
3. We have experience designing and implementing control systems for power systems, including the selection and refining of control parameters.
4. The project has helped us apply classroom-learned theoretical concepts to a real-world problem, thereby enhancing your understanding of the practical applications of power system stability and control.
5. The project has provided us with skills and experiences applicable to future academic or professional power system analysis and control activities.

7.3 Future Recommendations

Here are some suggestions for future effort to enhance the initiative further:

1. **Investigate the use of other advanced control strategies**: While PSS and STATCOM are successful in enhancing power system stability, other advanced management methods like FACTS devices and HVDC systems can also be explored in order to further enhance power system stability.
2. **Optimize the control parameters**: The control parameters of PSS and STATCOM are crucial to the efficiency of these systems. Therefore, additional research can be done to improve the efficacy of the control factors.
3. **Examine the effects of widespread blackouts**: They can significantly affect the reliability of the power system. Future studies can examine the influence of large-scale blackouts on power system stability and create control methods to avoid or mitigate the impacts of such events.

Overall, there are numerous possibilities for future work to further enhance the stability and management of the electricity system. Researchers can add to the creation of a more stable and dependable power system by continuing to look into new control methods and researching the effects of recent developments in technology and events.

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APPENDIX A

TURNITIN REPORT

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