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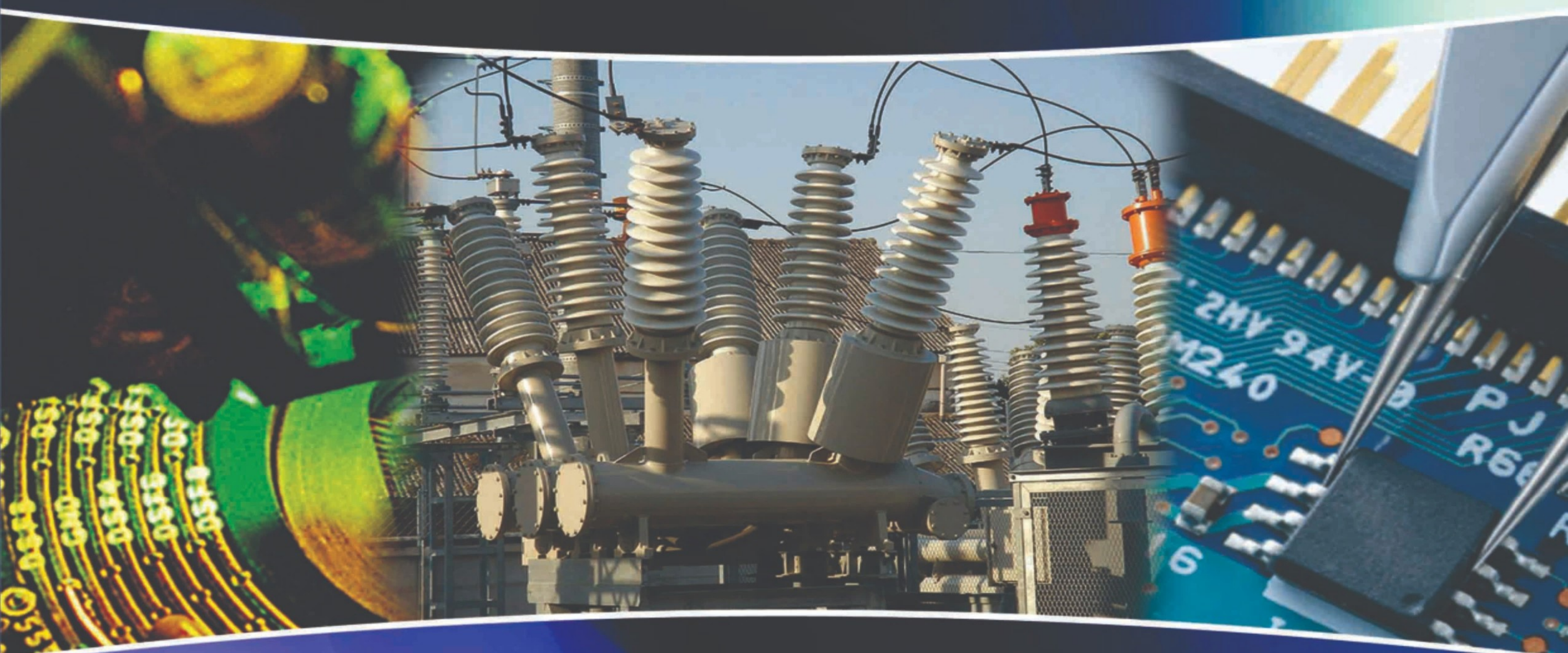

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ENHANCEMENT OF TRANSIENT STABILITY OF MULTI-AREA POWER SYSTEM USING FACTS DEVICES

M.V. Suresh Kumar
Assistant Professor, Department of EEE
Lendi Institute of Engineering and Technology, Vizianagaram, Andhra Pradesh, India.

Bobbadi Jhansi Rani
Student, Department of EEE
Lendi Institute of Engineering and Technology, Vizianagaram, Andhra Pradesh, India.

Kuna Rohith
Student, Department of EEE
Lendi Institute of Engineering and Technology, Vizianagaram, Andhra Pradesh, India.

Kshtriya Vikas Singh
Student, Department of EEE Lendi Institute of Engineering and Technology, Vizianagaram, Andhra Pradesh, India.

Gedela Venkata Harsha Vardhan
Student, Department of EEE
Lendi Institute of Engineering and Technology, Vizianagaram, Andhra Pradesh, India.

ABSTRACT

This paper presents the increasing demand for electrical power and restrictions on expanding transmission networks have led to stressed power systems, raising concerns about stability. One solution to mitigate these issues is the implementation of Flexible AC Transmission System (FACTS) devices, such as Static Synchronous Compensator (STATCOM), Static VAR Compensator (SVC), and Unified Power Flow Controller

(UPFC). These controllers enhance power transmission efficiency by regulating voltage, managing power flow, and improving transient stability without requiring additional transmission lines.

This study focuses on the role of the UPFC in enhancing the transient stability of a multi-machine power system. The UPFC integrates shunt and series compensation to dynamically control power flow and inject reactive power, thereby reducing the risk of system instability following disturbances. By actively damping power oscillations and preventing loss of synchronism, the UPFC plays a critical role in ensuring the reliability of interconnected power systems.

To evaluate its effectiveness, a three-machine, nine-bus Western System Coordinating Council (WSCC) multi- machine power system is analyzed under different fault conditions using MATLAB Simulink. The study examines fault clearing times and the UPFC's impact on transient stability under severe disturbances through simulation models. The MATLAB-based simulation results demonstrate the UPFC's capability to enhance power system stability by improving voltage regulation, damping power oscillations, and increasing transient stability. The findings confirm its role as a valuable asset for modern power networks facing increasing operational challenges.

Keywords: FACTS, UPFC, Transient Stability, Voltage Control, Power Flow Control, WSCC System, MATLAB Simulation, Fault Analysis.

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1. Introduction

The rapid development of power electronics technology has led to the introduction of Flexible AC Transmission System (FACTS) controllers. These controllers have been proposed in recent years to enhance the utilization of existing transmission facilities by improving power flow controllability and power system stability. The implementation of FACTS technology allows for better transient and dynamic stability of power systems.

Over the past decade, various control devices based on FACTS technology have been developed and implemented to improve the performance of power systems. These devices contribute to voltage stability, voltage regulation, damping enhancement, and overall system stability. FACTS devices can be categorized based on their connection in the power system—some operate in series with transmission lines, others in shunt, and some function as a combination of both. Rather than being a single high-power controller, FACTS technology comprises multiple controllers that work together or independently to regulate system parameters such as voltage, current, impedance, phase angle, and oscillation damping.

Static Synchronous Compensator (STATCOM) plays a crucial role in reactive power compensation and voltage support due to its excellent steady-state performance. STATCOM functions as a voltage source inverter (VSI) connected to a DC capacitor to generate AC voltage and provide necessary voltage regulation. Another key FACTS device is the Static Var Compensator (SVC), a shunt- connected system that generates or absorbs reactive power. It dynamically adjusts capacitive or inductive currents to regulate voltage and maintain system stability.

Unlike synchronous condensers, which rely on rotating electrical machines, SVCs operate without significant moving parts.

Another essential FACTS device is the Static Synchronous Series Compensator (SSSC), which is based on a voltage source converter (VSC). It is connected in series with the transmission line via a transformer and injects a balanced set of voltages to adjust the line's impedance dynamically. The SSSC provides series capacitive or inductive compensation, enhancing power flow control. If equipped with a storage source, it can also exchange real power with the system.

Among all FACTS controllers, the Unified Power Flow Controller (UPFC) is the most advanced multifunctional device. The UPFC integrates the capabilities of STATCOM, SSSC, and a phase shifter to provide comprehensive power system control. It enables simultaneous control over multiple parameters such as voltage, impedance, and phase angle while mitigating oscillations and enhancing system stability. The UPFC consists of two voltage source converters connected back-to-back through a DC capacitor, allowing it to inject AC series voltage into the transmission line and regulate power flow effectively.

Overall, FACTS controllers play a vital role in modern power systems by enhancing controllability, increasing power transfer capability, and ensuring system stability. These controllers can be classified into different categories based on their mode of operation and function within the transmission network.

2. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

2.1 CONTROLLERS

FACTS controllers are essential components in modern power transmission systems, improving stability, controllability, and efficiency. These controllers are designed to regulate various electrical parameters such as voltage, current, impedance, and phase angle. By incorporating power electronics-based technology, FACTS controllers enhance the utilization of existing transmission infrastructure while minimizing losses and improving power quality. They are classified into four main types: Series FACTS Controllers, Shunt FACTS Controllers, Combined Series-Shunt FACTS Controllers, and Combined Series-Series FACTS Controllers. Each type serves a unique purpose in maintaining the reliability and efficiency of power transmission networks.

Series FACTS Controllers are connected in series with the transmission line and primarily influence line impedance to control power flow. These controllers effectively enhance voltage stability and system damping by dynamically adjusting reactance. Some notable examples include the Static Synchronous Series Compensator (SSSC), which injects a series voltage to regulate power flow, and the Thyristor-Controlled Series Capacitor (TCSC), which adjusts line reactance using thyristor-switched capacitors. Another variant, the Thyristor-Switched Series Capacitor (TSSC), provides stepwise impedance control, improving system stability and reducing oscillations.

Shunt FACTS Controllers, on the other hand, are connected in parallel with the transmission system to provide reactive power compensation and voltage regulation. These controllers help maintain a stable voltage profile and enhance power factor correction. Examples include the Static Synchronous Compensator (STATCOM), which rapidly injects or absorbs reactive power using a voltage source inverter (VSC), and the Static Var Compensator (SVC), which employs thyristor- controlled reactors and capacitors for voltage stabilization. The Thyristor-Controlled Reactor (TCR) is another shunt device that absorbs excess reactive power, preventing voltage fluctuations.

Combined Series-Shunt FACTS Controllers integrate the functions of both series and shunt controllers, offering a more comprehensive approach to power system control. The most advanced of these devices is the Unified Power Flow Controller (UPFC), which combines two VSCs—one in series and one in shunt—to simultaneously regulate voltage, impedance, and phase angle. Another example is the Thyristor-Controlled Phase-Shifting Transformer (TCPST), which adjusts the phase angle between sending and receiving ends to optimize power transfer. These controllers provide enhanced flexibility and dynamic response to system disturbances.

Lastly, Combined Series-Series FACTS Controllers manage power flow across multiple transmission lines, improving network performance and stability. The Interline Power Flow Controller (IPFC) is a prime example, consisting of multiple VSC-based controllers that enable power exchange between different transmission lines. This category also includes Multi- Line FACTS Controllers, which coordinate power distribution across multiple circuits, optimizing transmission efficiency and preventing overload conditions.

3. STASTIC VAR COMPENSATOR(SVC)

A Static Var Compensator (SVC) is a shunt- connected device used in power systems to regulate voltage, control reactive power, and improve system stability. It is widely used in transmission networks to mitigate voltage fluctuations and enhance power transfer capability. By dynamically adjusting the amount of reactive power injected or absorbed, an SVC helps maintain a steady voltage profile, reducing the risk of instability and improving overall system efficiency.

The operation of an SVC is based on thyristor- controlled switching of reactors and capacitors. It primarily consists of Thyristor-Controlled Reactors (TCR) and Thyristor-Switched Capacitors (TSC). The TCR adjusts inductive reactance by varying the conduction angle of thyristors, allowing controlled absorption of reactive power. The TSC, on the other hand, provides capacitive reactance by switching capacitor banks in and out as needed. This combination allows the SVC to rapidly respond to voltage fluctuations, ensuring smooth power flow and system reliability.

An SVC is equipped with a voltage measurement and control system that continuously monitors system conditions and dynamically adjusts reactive power compensation. This automated control enhances power factor correction, reduces system losses, and prevents voltage instability. Additionally, SVCs offer faster response times compared to conventional reactive power compensation methods, making them highly effective in damping oscillations and improving transient stability in large-scale power networks.

The advantages of SVCs include improved voltage regulation, enhanced system stability, and reduced transmission losses. Unlike rotating synchronous condensers, SVCs have no moving parts, making them more reliable and requiring less maintenance. Their ability to quickly adjust reactive power also makes them ideal for modern power grids, which experience frequent load variations and increased renewable energy integration.

3.1 Static Synchronous Compensator(STATCOM)

A Static Synchronous Compensator (STATCOM) is a shunt-connected device used in power systems to regulate voltage, provide reactive power compensation, and enhance system stability. It is a type of Flexible AC Transmission System (FACTS) device that utilizes power electronics to dynamically control reactive power injection or absorption. STATCOMs are widely used in transmission networks to stabilize voltage levels, support power factor correction, and improve transient stability in the grid.

STATCOM operates based on a Voltage Source Converter (VSC), which generates a controllable AC voltage from a DC capacitor. By adjusting the magnitude and phase angle of the output voltage, the STATCOM can either supply or absorb reactive power as needed. When the generated voltage is higher than the system voltage, the STATCOM injects reactive power into the network, increasing voltage levels. Conversely, when its voltage is lower, it absorbs reactive power, reducing voltage levels.

This bidirectional capability allows STATCOM to maintain a steady voltage profile, even during fluctuations in load demand.

Unlike traditional reactive power compensation devices such as Static Var Compensators (SVC), STATCOM provides superior performance, especially under low voltage conditions. While the reactive power output of an SVC decreases as system voltage drops, STATCOM can maintain a nearly constant reactive current, making it more effective in stabilizing the grid during voltage sags. Additionally, STATCOM has a faster response time due to its fully electronic operation, allowing it to mitigate voltage fluctuations and dampen power oscillations more efficiently.

STATCOMs offer several advantages, including improved voltage stability, enhanced power transfer capability, and reduced transmission losses. Their compact design and absence of large passive components make them more efficient and reliable compared to conventional reactive power compensators. Furthermore, STATCOMs are highly adaptable to modern power networks, where rapid fluctuations in load demand and renewable energy integration require fast and precise voltage regulation.

STATCOMs are widely used in various applications, including transmission and distribution networks, industrial power systems, and renewable energy integration. In high-voltage transmission systems, they help maintain grid stability by compensating for reactive power imbalances. In industrial settings, STATCOMs are used for power factor correction, ensuring efficient operation of electrical equipment. Additionally, in wind and solar farms, STATCOMs help mitigate voltage variations caused by intermittent power generation, improving the overall stability and reliability of the grid.

3.2 Static Shunt Compensator

Shunt static compensator is a vital technique used in power systems to regulate voltage, improve power factor, and provide reactive power support. By connecting compensation devices in parallel with the transmission network, shunt compensation dynamically adjusts reactive power levels to stabilize voltage and enhance power system efficiency. This method is particularly effective in heavily loaded power grids and long-distance transmission lines, where voltage drops and reactive power imbalances can lead to instability and reduced power transfer capability.

The primary function of shunt static compensation is to manage reactive power demand by either injecting or absorbing reactive power as needed. When a power system experiences inductive loads, it requires additional reactive power to maintain voltage levels, which is provided by shunt compensators such as the Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM). The SVC uses thyristor-controlled reactors (TCRs) and thyristor-switched capacitors (TSCs) to quickly adjust reactive power flow, while the STATCOM, based on a voltage source converter (VSC), provides even faster and more precise compensation. These devices help maintain voltage stability and prevent fluctuations that could impact power system reliability.

Shunt static compensators offer several advantages, including improved power factor correction, reduced transmission losses, and enhanced voltage stability. Unlike traditional capacitor banks, FACTS-based compensators such as SVC and STATCOM provide dynamic and real-time reactive power support, allowing the system to respond effectively to changing load conditions. Additionally, these devices improve system resilience by damping power oscillations and mitigating voltage instability during disturbances.

As modern power grids integrate more renewable energy sources, shunt static compensation plays a crucial role in ensuring grid stability and maintaining power quality in the face of fluctuating generation patterns.

3.3 Combined shunt and series conpensators

Combined shunt and series compensation is an advanced power system technique that integrates both shunt and series compensators to enhance voltage stability, power flow control, and system reliability. This type of compensation combines the benefits of both series and shunt compensation to provide comprehensive reactive power management and dynamic voltage regulation. By simultaneously controlling transmission line impedance and injecting or absorbing reactive power, combined compensation improves overall system stability and efficiency, making it a crucial solution for modern high- voltage transmission networks.

One of the most widely used combined shunt and series compensators is the Unified Power Flow Controller (UPFC), which consists of two Voltage Source Converters (VSCs)—one connected in shunt and the other in series. The shunt converter injects or absorbs reactive power to maintain voltage stability, while the series converter controls the power flow by adjusting the line impedance and phase angle. This dual-action capability allows the UPFC to provide real-time control over both active and reactive power, reducing transmission losses and improving system efficiency. Unlike separate shunt and series compensators, the UPFC enables more flexible and coordinated power flow management.The advantages of combined shunt and series compensation include improved voltage regulation, enhanced transient stability, and better power transfer capability. By actively controlling power flow and reactive power, these compensators help mitigate voltage fluctuations, prevent system congestion, and increase transmission efficiency. They are particularly beneficial in large interconnected power grids and deregulated electricity markets, where maintaining optimal power flow is essential for operational reliability. As power systems continue to evolve with increasing renewable energy integration, combined shunt and series compensation plays a vital role in ensuring stable and efficient electricity transmission.

3.4 Series compensators

Series compensators are a category of Flexible AC Transmission System (FACTS) devices that are connected in series with transmission lines to regulate line impedance and enhance power transfer capabilities. These devices help in reducing transmission line reactance, improving system stability, and increasing power transfer limits. By controlling the voltage drop across transmission lines, series compensation ensures efficient utilization of transmission assets while mitigating power oscillations and voltage instability.

Series compensators work by injecting voltage in series with the transmission line, effectively modifying the line impedance to regulate power flow. These devices are particularly useful in long-distance transmission networks where inductive reactance can limit power transfer. By reducing the apparent reactance of the line, series compensators increase power transmission capability and enhance the overall stability of the system. They also play a significant role in damping power oscillations, reducing losses, and mitigating sub-synchronous resonance.

Common types of series compensators include Thyristor-Controlled Series Capacitors (TCSC), Thyristor- Switched Series Capacitors (TSSC), and Static Synchronous Series Compensators (SSSC). TCSC utilizes thyristors to control the insertion of a series capacitor, dynamically adjusting the reactance of the line. TSSC works similarly but switches capacitors in discrete steps instead of continuously. The SSSC, based on a voltage source converter (VSC), provides a more flexible approach by generating a controlled voltage to regulate line impedance. By improving power flow control, stability, and transient response, series compensators play a crucial role in modern power transmission systems.

3.5 Unified Power Flow Controller (UPFC)

A Unified Power Flow Controller (UPFC) is the most advanced and versatile FACTS device used for power flow control, voltage regulation, and system stability enhancement in electrical power networks. It is designed to simultaneously control multiple transmission parameters, including voltage, impedance, and phase angle, providing optimal power flow management. The UPFC is widely implemented in modern power systems to improve the efficiency and reliability of electricity transmission.

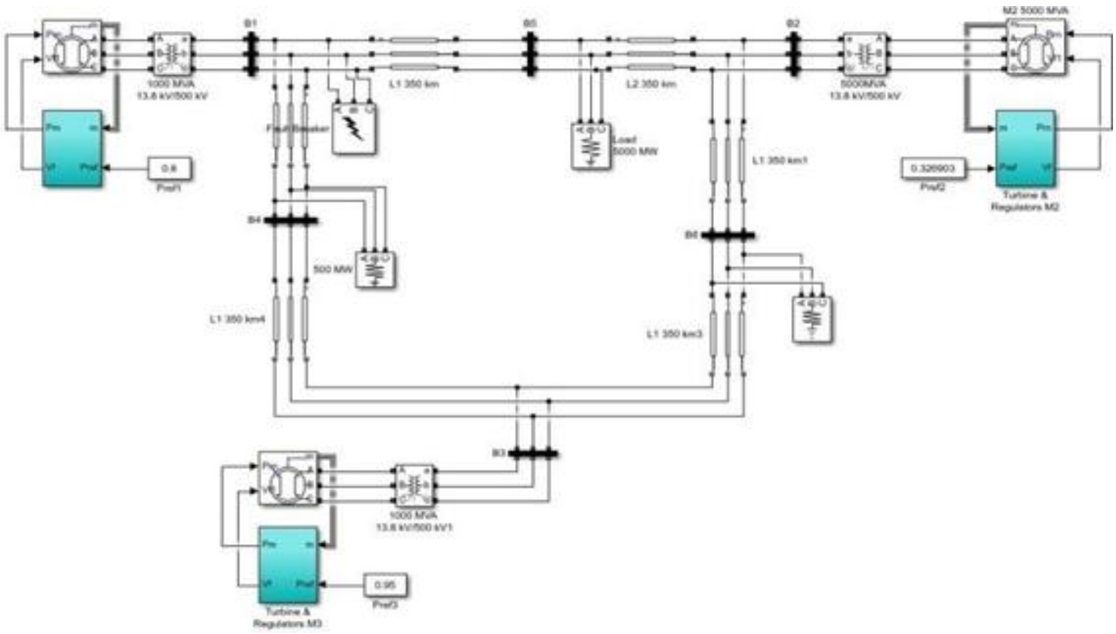
The operation of a UPFC is based on two Voltage Source Converters (VSCs) connected back-to-back through a common DC link. One converter, known as the shunt converter, is connected in parallel with the system and is responsible for regulating voltage and supplying or absorbing reactive power. The second converter, called the series converter, is connected in series with the transmission line and injects a controllable voltage to manage power flow. The combination of these converters allows the UPFC to independently control real and reactive power, unlike other FACTS devices that can only control one parameter at a time.

One of the key advantages of the UPFC is its ability to provide dynamic and simultaneous control of active and reactive power. By adjusting the magnitude and phase angle of the injected voltage, the UPFC can optimize power flow, mitigate congestion, and improve overall system stability. It also helps in damping power oscillations and enhancing transient stability, making it highly effective in maintaining synchronism between generators during disturbances.

Compared to other FACTS devices such as STATCOM and SVC, the UPFC offers superior flexibility in power system control. While STATCOM and SVC primarily regulate voltage and reactive power, the UPFC can directly influence power transfer by controlling the transmission line's impedance and phase angle. This makes it an ideal solution for complex power networks where multiple control objectives need to be achieved simultaneously.

UPFCs are widely used in transmission networks to enhance grid reliability and efficiency. They help improve voltage stability by compensating for reactive power fluctuations and reducing transmission losses. Additionally, in deregulated power markets, UPFCs play a crucial role in optimizing power flow between different regions, ensuring efficient utilization of available transmission capacity.

4. SIMULATION DIAGRAM OF MULTI AREA SYSTEM:



Bus no	Type	Generation		Load		Voltage	
		P	Q	P	Q	$\|V\|$	θ
1	Slack	0	0	0	0	1	0
2	P-V	0.95	0	0	0	1.086	0
3	P-V	0.95	0	0	0	1.086	0
4	P-Q	0	0	0.5	0	1	0

5	P-Q	0	0	0.5	0	1	0
6	P-Q	0	0	0.5	0	1	0

Input bus data (p.u)

4.1 Transient stability and power stability

Power systems must maintain stability to ensure reliable operation under normal and disturbed conditions. Stability refers to the ability of a power system to return to a steady-state operation after experiencing a disturbance such as a fault, sudden load change, or loss of a generator. Two key aspects of power system stability are transient stability and power stability. These factors play a crucial role in ensuring efficient and secure electricity transmission in modern power networks.

Transient stability refers to a power system's ability to maintain synchronism when subjected to a sudden disturbance, such as a short circuit, a sudden change in load, or the loss of a major generator. When a fault occurs, the system experiences abrupt changes in power flow, causing rotor angle deviations in generators. If the disturbance is severe or not cleared in time, it may result in a loss of synchronism, leading to system instability or a blackout. FACTS controllers such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and Static Synchronous Series Compensator (SSSC) are used to enhance transient stability by dynamically regulating voltage, adjusting impedance, and improving power oscillation damping.

Power stability refers to the ability of a power system to maintain steady voltage and power flow under normal and disturbed operating conditions. It includes aspects such as voltage stability, frequency stability, and small-signal stability. Voltage stability ensures that voltage levels remain within safe limits, while power flow stability ensures that electrical power is efficiently transmitted without excessive losses or oscillations. FACTS controllers play a crucial role in power stability by providing reactive power compensation, improving voltage profiles, and regulating power flow in real time. The integration of shunt and series compensation, such as UPFC, helps mitigate voltage fluctuations, improve power factor correction, and enhance the overall security and efficiency of the transmission system. By improving both transient stability and power system stability, FACTS controllers ensure reliable operation and prevent major disturbances in interconnected power networks.

4.2 Modelling and control scheme for SSSC

The control scheme for the directly controlled Static Synchronous Series Compensator (SSSC) converter is designed to eliminate unwanted output voltage components caused by modulation of the DC capacitor voltage due to sub-synchronous and other line current components. Additionally, it provides both reactive and real (resistive) line compensation, given that the converter is equipped with an appropriate DC power supply or sink. As shown in Figure 3.1, synchronization with the line current is achieved using a Phase-Locked Loop (PLL), similar to the approach used for indirectly controlled converters. However, the direct control structure differs in that it enables continuous and independent control over both the magnitude and angle of the compensating voltage, offering greater flexibility in power system stabilization. The control scheme operates based on three primary reference signals:

Vqref: Specifies the desired magnitude of the series reactive compensating voltage.

Vqref (optional): Defines the desired magnitude of the series real compensating voltage.

Vdcref: Sets the operating voltage of the DC capacitor.

The reactive voltage reference (Vdcref) interacts with the line current to determine the required reactive power exchange for series compensation. Meanwhile, the overall real voltage reference (Vqref + Vdcref), combined with the line current, dictates the real power exchange necessary for optional real power compensation and for maintaining the DC capacitor's operating voltage. These reference values are compared with the corresponding components of the measured compensating voltage (un). The resulting control signals are then used to determine the magnitude (Vn) and angle (theta) of the compensating voltage, which are subsequently used to generate gate drive signals for the converter.

With an appropriately designed closed-loop control system and instantaneous vector-based signal processing, the SSSC maintains a sinusoidal compensating voltage at the system frequency, even in the presence of sub-synchronous line current components and fluctuations in DC capacitor voltage. If resistive line compensation is not applied (Vqref = 0), the angle theta in steady state performs the same function as Aa, maintaining a small, nearly constant angle to ensure energy absorption from the AC system, thereby compensating for converter losses.

4.3 Basic Control Functions of UPFC

Terminal Voltage Regulation: Functions similarly to a transformer tap changer with infinitely small steps. The ΔV0 is injected in phase or anti-phase with V0, ensuring precise voltage control.

Series Capacitive Compensation: The injected voltage Vpq = Vc is in quadrature with the line current, mimicking the effect of a series capacitor or reactor for power flow control.

Transmission Angle Regulation: The injected voltage Vpq = Vσ alters the phase angle of transmission voltage, enabling phase shifting to optimize power transfer.

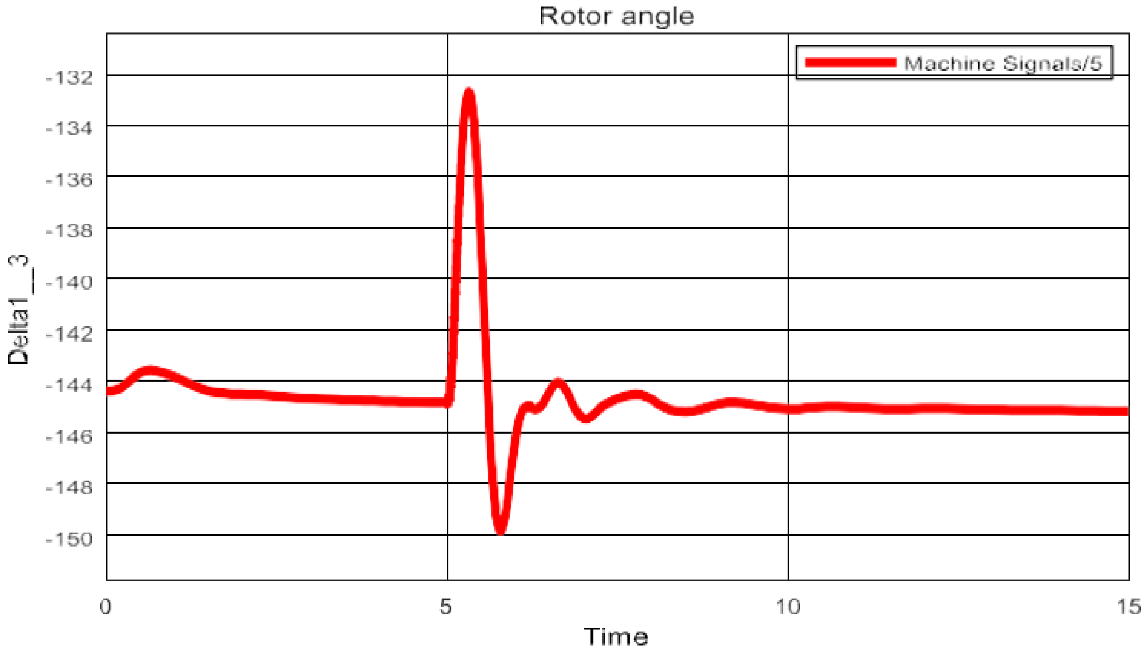
Multi-Function Power Flow Control: This is achieved by a combination of terminal voltage regulation, series capacitive compensation, and phase shifting, making the UPFC a unique and multifunctional FACTS device. The combined effect is represented as Vpq = (ΔV + Vc + Vσ), offering comprehensive control over power system operations.

The UPFC's ability to regulate voltage, compensate reactance, and control phase angle simultaneously makes it a highly versatile tool for improving power system stability, efficiency, and controllability. No other single FACTS device provides a similar level of multi- functional power flow control.

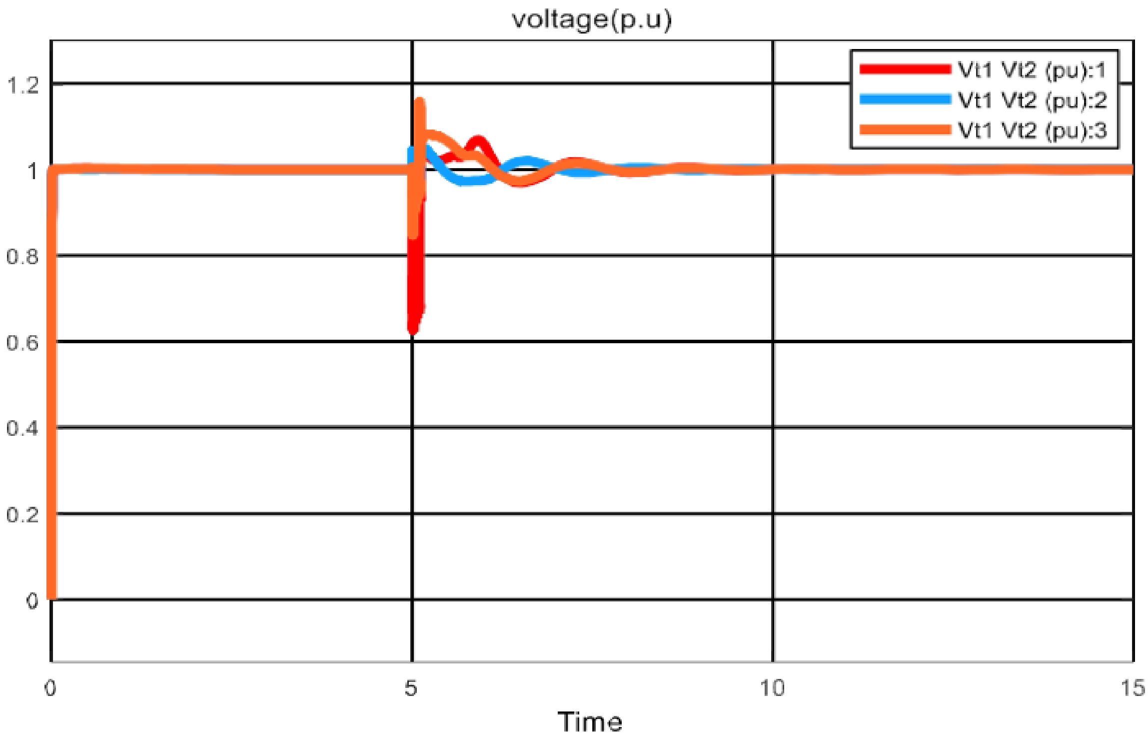
4.4 Simulation results

The transient stability of a six-bus power system is evaluated under a single-phase-to-earth fault scenario. The system is simulated with different fault clearing times to analyze its dynamic behavior. Initially, the system operates under normal pre-fault conditions before a symmetrical fault is introduced at one end of a transmission line. As shown in Figure 4.7, the fault is applied, and the system's response is observed. The simulation is conducted for different fault durations, starting with a fault clearing time (tcl) of 0.1 seconds (six cycles for a 60 Hz system), and then increasing it to 0.15 seconds to analyze the impact of different fault durations on system stability.

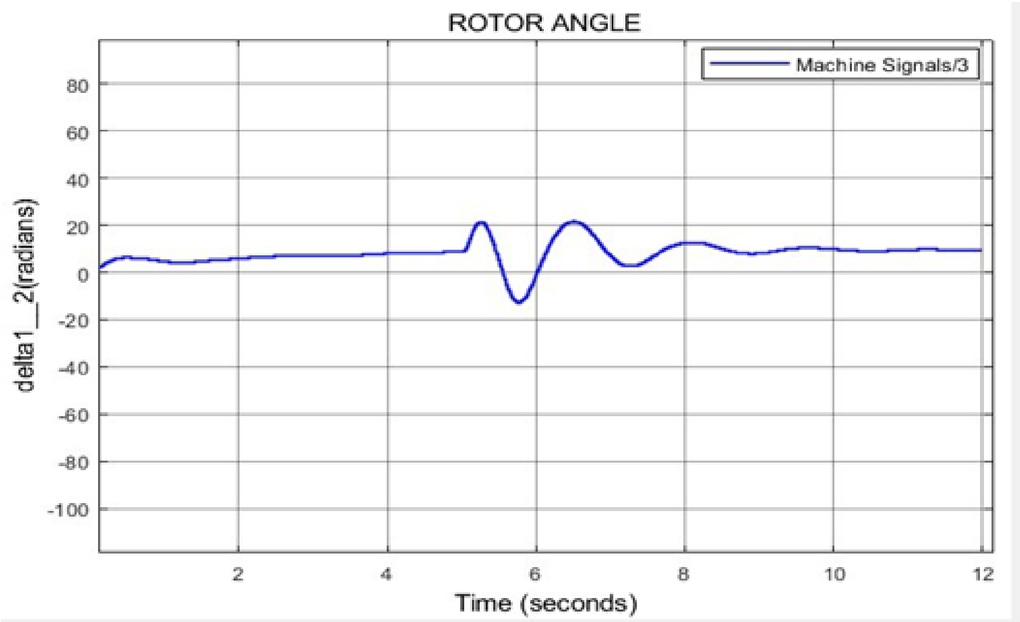
To enhance the system's stability and improve transient response, Static Synchronous Compensator (STATCOM) and Unified Power Flow Controller (UPFC) are integrated into the transmission system. These FACTS controllers are strategically placed at the midpoint of the transmission line to optimize their effectiveness. Their primary function in this scenario is to inject reactive power into the system, ensuring voltage stability and improving power transfer capability. The placement at the midpoint ensures efficient compensation of reactive power demand and mitigates potential system instability caused by fault conditions.



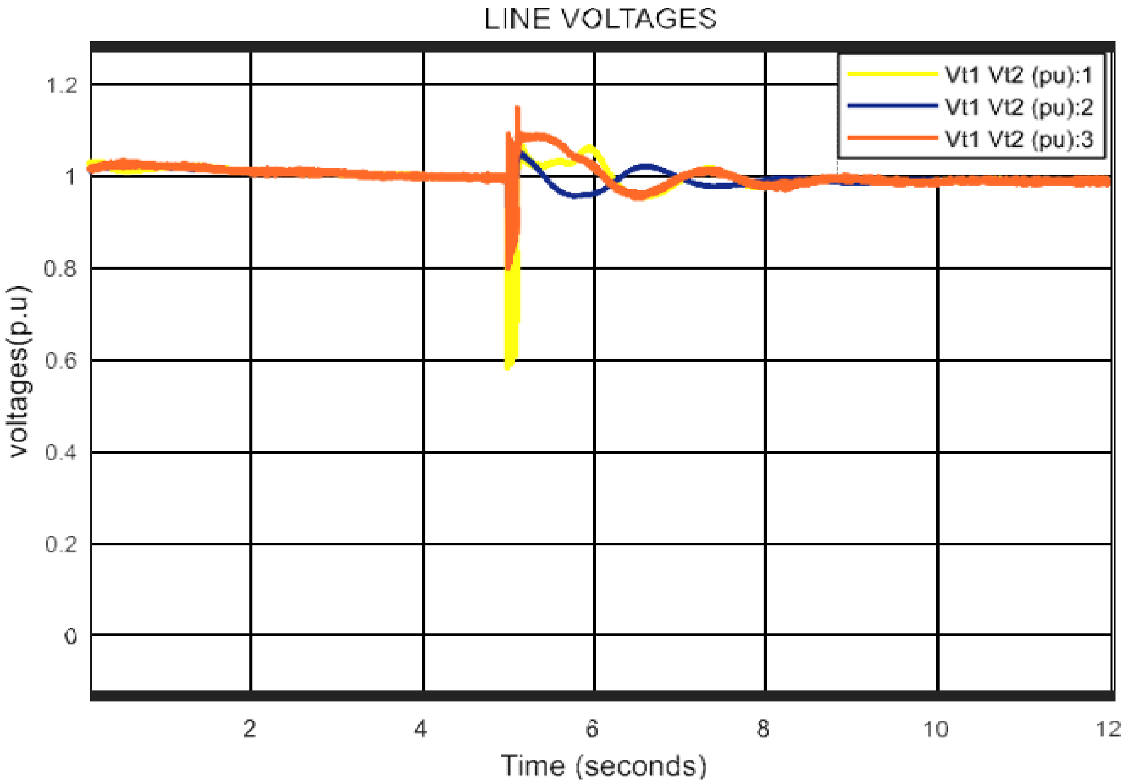
Response of relative machine angles delta1-2for fault at bus1 with only PSS



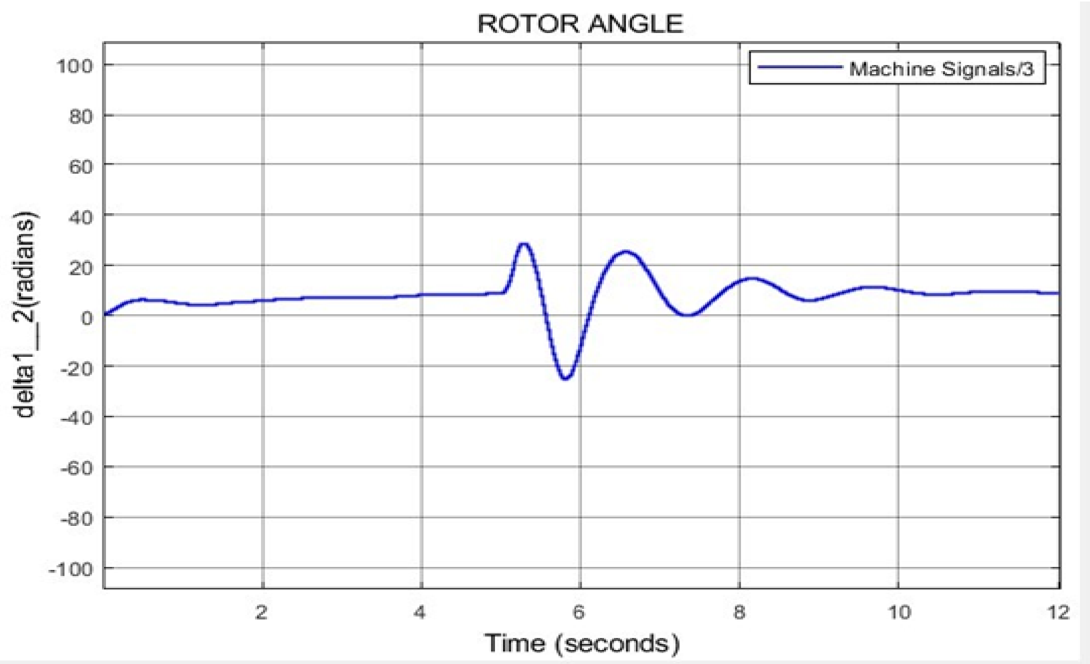
Response of voltages for fault at bus 1with only PSS



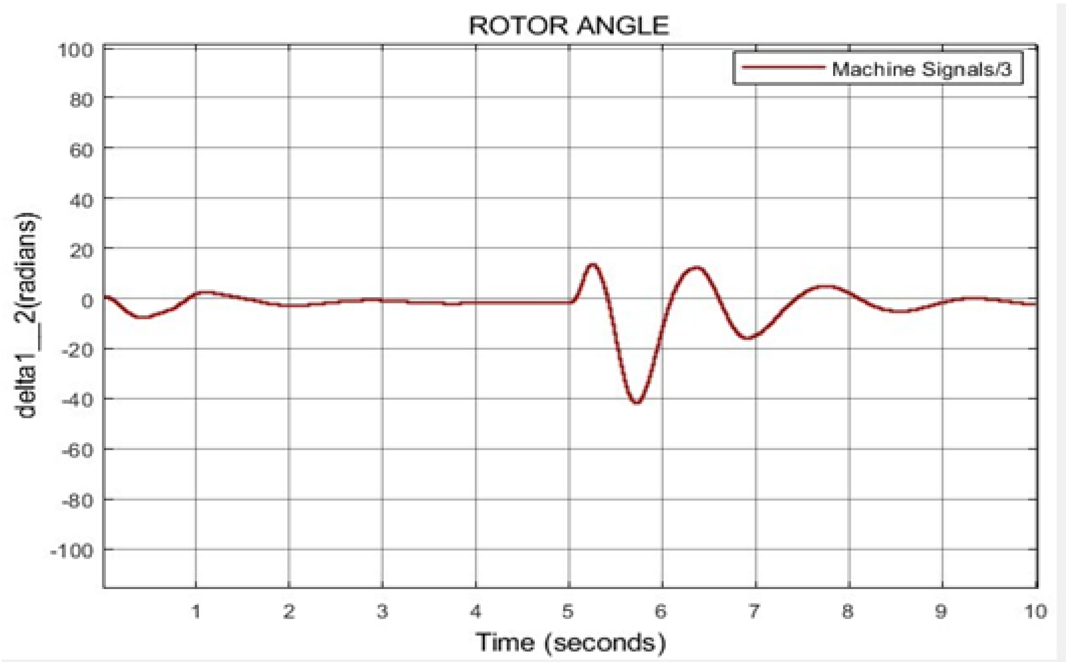
Response of relative machine angles delta1-2 for fault time of 0.1sec at bus 1with PSS and STATCOM



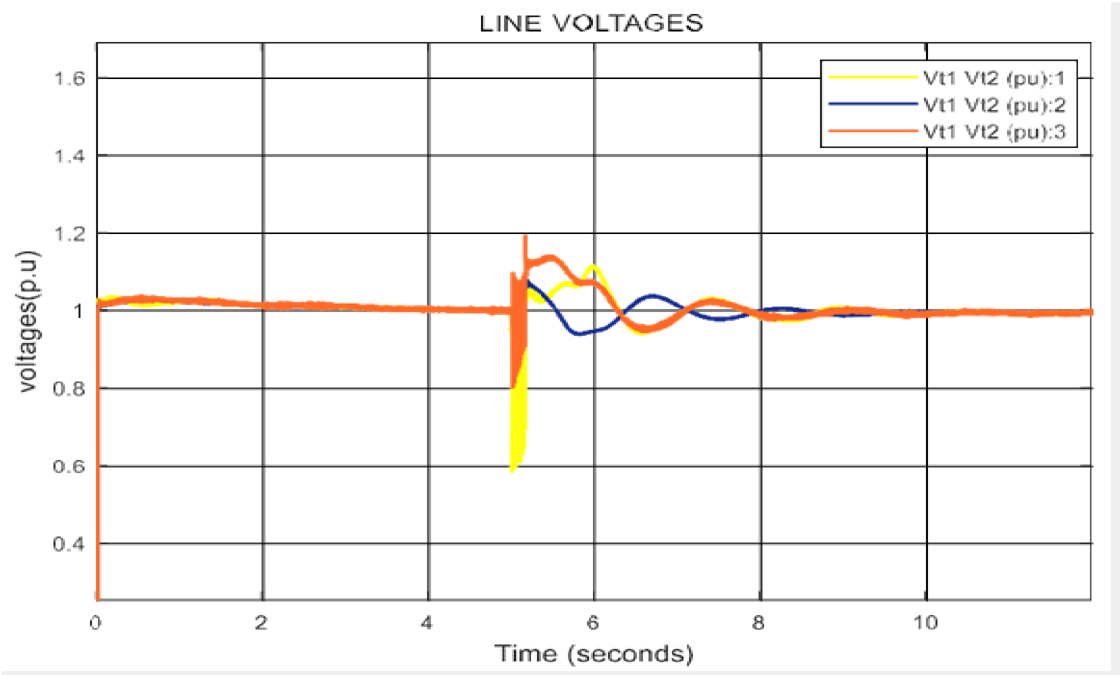
Response of line voltage for fault time of 0.1sec at bus 1 with PSS and STATCOM



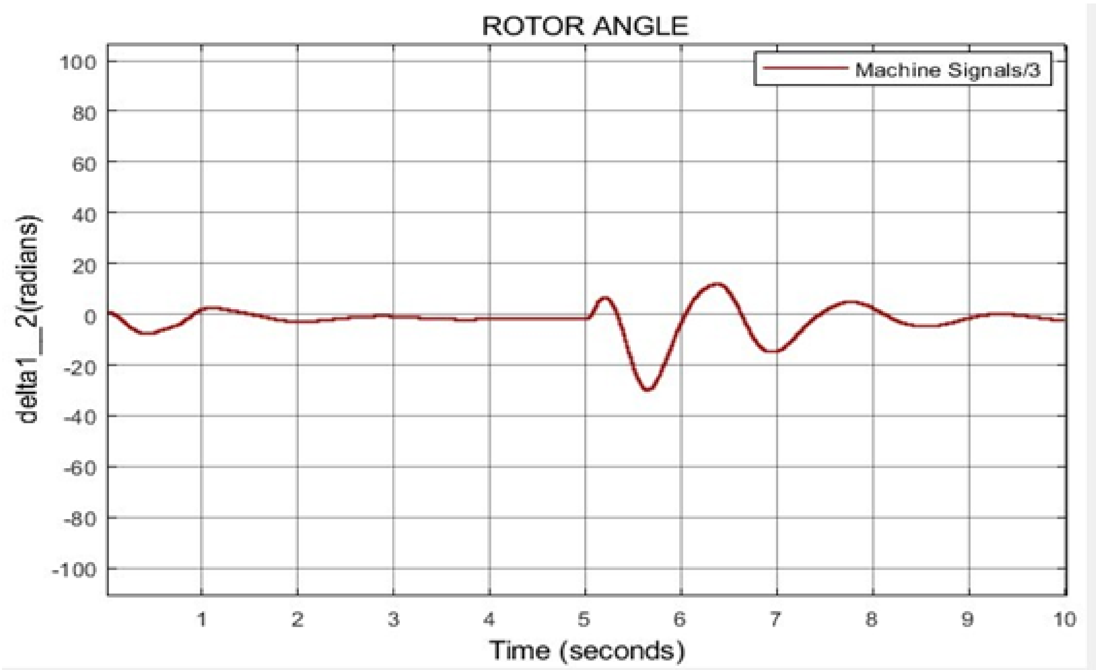
Response of relative machine angles delta1-2 for fault time of 0.15sec at bus 1with PSS and STATCOM



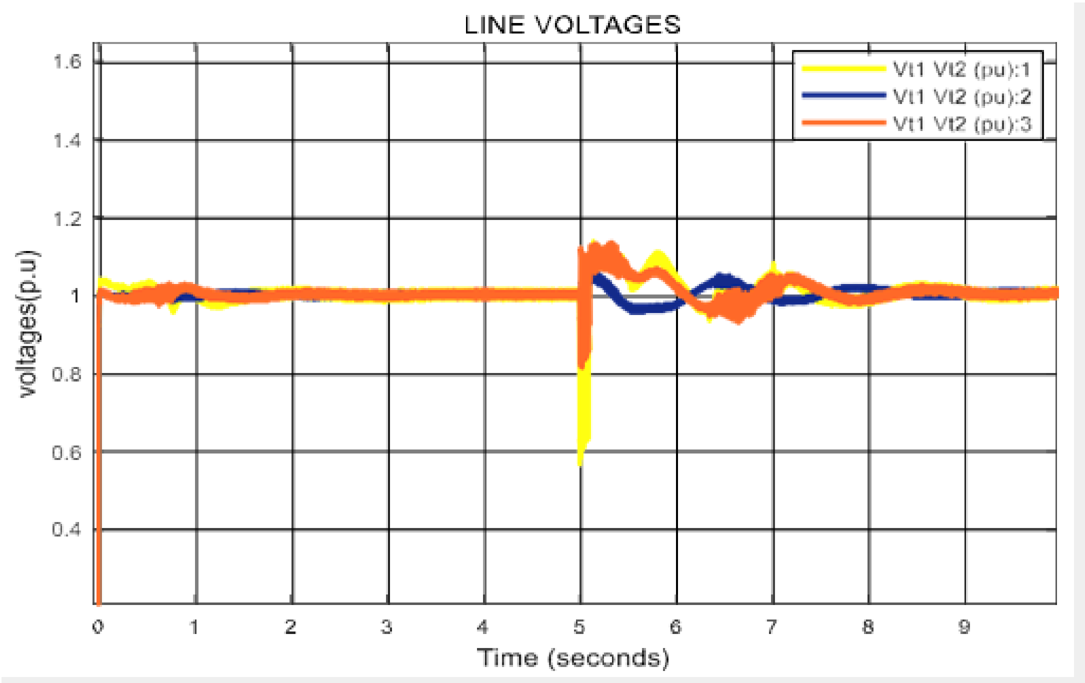
Response of relative machine angles delta 1-2 for fault timeof 0.15sec at bus1with PSS and UPFC



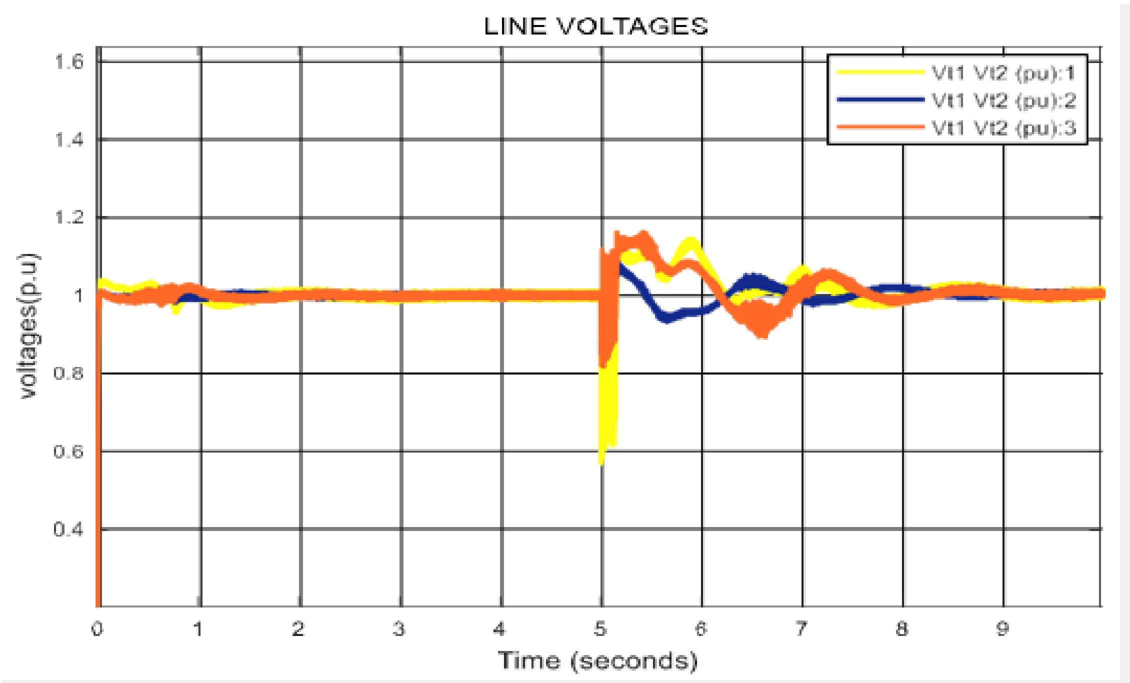
Response of line voltage for fault time of 0.15sec at bus 1 with PSS and STATCOM



Response of relative machine angles delta 1-2 for fault time of 0.1 sec at bus1with PSS and UPFC



Response of line voltage for fault time of0.1sec at bus 1 with PSS and UPFC



Response of line voltage for fault time of 0.15 sec at bus 1 with PSS and UPFC

The simulation results highlight the effectiveness of STATCOM and UPFC in enhancing the system's transient stability and damping power oscillations. By dynamically injecting reactive power, these devices help restore voltage levels more rapidly after disturbances, reducing the likelihood of system instability and power outages. The comparative analysis of different fault clearing times shows that faster fault clearance leads to improved system recovery, while FACTS controllers significantly enhance transient stability and overall system reliability. These findings confirm the crucial role of STATCOM and UPFC in maintaining a stable and efficient power transmission network, making them essential components in modern power system applications.

ROTORANGLE	PSS FAULT CLEARING TIME(SEC)
	Ft=0.1SEC
Delta1-2	4
Delta1-3	4
Delta2-3	5

Fault clearing time of rotor angle using PSS

ROTORANGLE	PSS FAULT CLEARING TIME(SEC)	
	Ft=0.1sec	Tf=0.15sec
Delta1-2	4	4.5
Delta1-3	2	2.5
Delta2-3	4	4.5

Fault clearing time of rotor angle using PSS and STATCOM

ROTORANGLE	UPFC FAULT CLEARING TIME (SEC)	
	Ft=0.1sec	Tf=0.15sec
Delta1-2	3.5	4

Delta1-3	2	2
Delta2-3	3	3.5

Fault clearing time of rotor angle using PSS and UPFC

DEVICE	VOLTAGESTABILITYTIME AFTER FAULT
PSS	5
STATCOM	4
UPFC	3

Voltage stability time by each device

DEVICE	SETTLINGTIME
PSS	4.5
STATCOM	4.2
UPFC	3.5

Settling time of each device

5. Conclusion and future scope

This study investigates the impact of the Unified Power Flow Controller (UPFC) on enhancing transient stability in a multi-machine power system. The UPFC plays a crucial role in improving power system stability by dynamically controlling power flow and injecting reactive power during transient conditions. The MATLAB Simulink simulation results confirm that UPFC significantly enhances transient stability by effectively damping power oscillations and regulating system voltage. Moreover, the study highlights that the optimal placement of the UPFC for transient stability enhancement in the nine-bus system is not fixed but varies depending on the fault location, emphasizing the importance of strategic placement for maximizing its effectiveness.

Before integrating FACTS devices for transient stability improvement, it is crucial to analyze the system's stability under different fault conditions, fault clearing times, and compensation levels. This assessment helps in determining the optimal placement and operation of the UPFC and other FACTS controllers to ensure maximum stability enhancement. The transient stability improvement of the multi-machine power system under various fault conditions has been thoroughly analyzed in this research, demonstrating the UPFC's effectiveness in mitigating disturbances and maintaining system synchronism.

For future work, the transient stability enhancement can be further explored using other FACTS devices, such as the Thyristor-Controlled Series Capacitor (TCSC), to assess its impact on stability under different fault conditions. Additionally, a hybrid compensation strategy utilizing both UPFC and TCSC can be investigated to achieve enhanced power system stability and improved power flow control. Integrating advanced control strategies and optimization techniques for the coordinated operation of UPFC and TCSC could further enhance the power system's efficiency and reliability, making it more resilient to disturbances and dynamic operating conditions.

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