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Using UPFC (Unified Power Flow Controller) to Improve Power System Transient Stability

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Abstract

The transmission of power with a high power factor and high power quality, supreme transient stability, economics, and a low risk of system failure are the primary concerns in the power grid system. The steady growth of electrical power demands and loads, especially non-linear loads, makes the power system network increasingly difficult to manage, and the system becomes unstable with massive power flows if effective control and operation are not implemented. The evolution of the power system has brought new obstacles, and due to the complex system network, it might be difficult to operate the system in a stable state at times. On the other hand, significant progress has been achieved in power electronics, which allows the power system to remain stable even when the worst-case scenario occurs due to a fault. FACTS technology is one of the innovations in power electronics. FACTS (Flexible Alternating Current Transmission Systems) devices are based on power electronics and other dynamic controllers that adjust one or more AC transmission system parameters in order to improve controllability and power transfer capabilities. FACTS controllers, such as UPFC, are one way to improve power system control (Unified Power Flow Controller). At the same time, UPFC can manage voltage, impedance, and phase. In the power system block set, MATLAB/PSAT is used to simulate the UPFC control technique for grid-connected power systems. The effectiveness of UPFC is examined using an IEEE 9 bus power system network by applying a 3-phase fault to dissimilar

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buses and evaluating the performance of FACTS devices in an IEEE 9 bus power system during a fault situation.

Keywords: *FACTS, Faults, UPFC.*

INTRODUCTION

The integrated power generating system suffers a lack of main energy sources (fossil fuels) due to the massive increase in human demands, as demand grows day by day without an expansion in replacement generation resources and transmission line capability. All of these ins and outs may have put a burden on the power system, causing it to perform beyond its original design capacity [1]. This raises concerns about the main issue of power system transient stability. If certain generators are located far from load centres, the problem of transient stability will arise, posing a threat to supply security and making daily operations of the power system difficult for grid managers. The term "transient stability" refers to the ability to transfer a large amount of power along a transmission line without losing stability due to large and abrupt changes in the power network environment, such as a 3-phase fault or the sudden damage of large generating/load units. Overloaded power systems can exhibit nonlinear behaviour, and anomalous interactions among power system elements can result in various oscillation modes. If no action is done in a timely manner to dampen the oscillations, the power flow may be disrupted, and the generators may become unsynchronized, resulting in a whole or partial system shutdown. The risk of losing synchronisation among generators and the erratic response of the system due to instabilities can be reduced by integrating the FACTS technology to the power system. The application of FACTS devices to the grid will have a positive impact on energy efficiency and emissions reduction. Power quality and stability of the low to high voltage power transmission system is also a key area of concern with the advent of FACTS systems operating to the grid [2].

In 1995, the FACTS technology [3], which was then known as Flexible AC Transmission system, was projected. The fundamental concept behind the FACTS devices is to connect power electronics devices to the high-voltage transmission and distribution sides of the power grid in demand to mark the overall system as being regulated electronically. FACTS

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devices were created as a result of advances in high-power electronic semiconductor devices and control technologies [4]. During a power system fault, FACTS devices provide active and reactive power to the system in command quickly to maintain system stability and reduce power generator transients. The power reimbursement offered by FACTS devices may be able to maintain the voltage of the entire power system, allowing for easy regulation of power flow. FACTS devices are usually divided into two generations.

1st Generation FACTS Devices: The 1st generation of FACTS technology includes both static and dynamic capacitance devices. Tap changing and phase changing transformers, series capacitors, and synchronous generators are all part of the first generation of FACTS devices. Apart from the series capacitors, which are referred to as a capacitor bank, these are all dynamics devices. These devices are extensively used on the generation side of the power system, but their costs are quite high due to their enormous size and maintenance requirements. Permanent series capacitors are a major disadvantage of these devices; because they are made up of many fixed-capacitance capacitors, they are difficult to manage in order to provide the precise not-fixed input capacitance to the grid.

FACTS devices of the second generation: The 2nd generation of FACTS technology is the static state compensator. It can be classified into two types: thyristor-based technology and fully-controlled compensator-based technology. The thyristor-controlled device is a semi-controlled device since once it is turned on, it cannot be turned off manually until the main power is turned off [5]. This category includes Static Var Compensator (SVC) and Thyristor-Controlled Series Capacitor (TCSC) devices [6]. The completely controlled devices, on the other hand, are made up of Gate Turn-OFF (GTO) Thyristors, which may be physically switched on and off as needed. Fully-controlled devices use the Static Compensator (STATCOM), Solid Static Series Compensator (SSSC), and Unified Power Flow Controller (UPFC). The Unified Power Flow Controller (UPFC) is the most effective and versatile FACT device because it can perform both STATCOM and SSSC functions at the same time and increase transient stability by managing power flow on both sides of the transmission line using shunt and series convertors. In this study project, we will focus on UPFC from now on [7].

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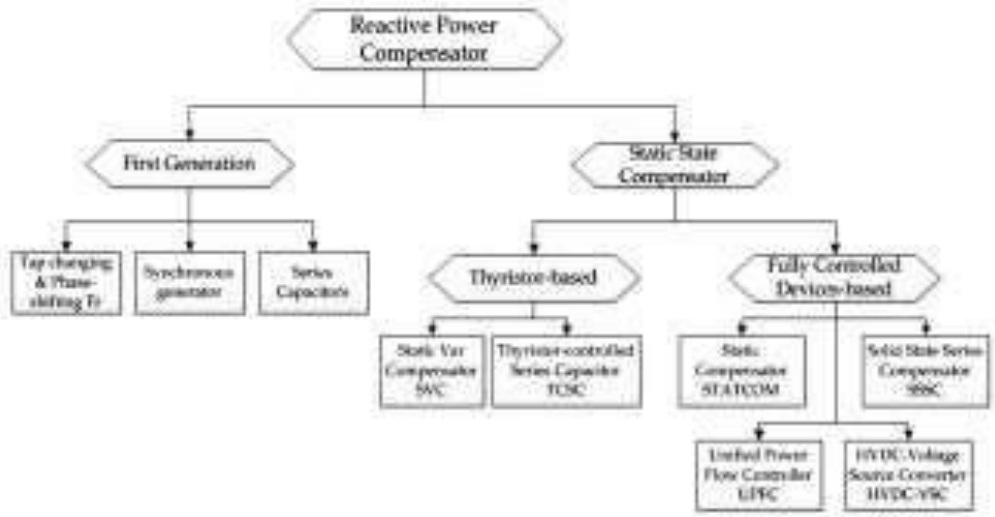


Figure 1: The classification of FACTS devices

FACTS CONTROLLERS

The Flexible AC Transmission System (FACTS) concept is based on power electronics, which proposes the effective regulation of one or more AC transmission parameters in order to improve controllability and power transfer capability. There are three different types of FACTS controllers: series, shunt, and mixed shunt-series controllers.

The shunt kind of FACTS controller is precise and effective in improving the voltage profile of a specific bus, power damping oscillation, and system transient stability for the duration of a disruption. Static VAR Compensator (SVC) and Static Synchronous Compensator are two examples of FACTS controllers in the shunt category (STATCOM).

The FACTS controller's series category is useful for increasing the voltage stability limit, increasing the transient stability margin, and helping to improve the power oscillation damping and sub synchronous oscillation damping of power systems during disturbances. Thyristor Controlled Series Capacitor (TCSC), Thyristor Switch Series Capacitor (TSSC), and Static Series Synchronous Capacitor are examples of series FACTS controllers (SSSC).

The mutual shunt-series type of FACTS controller delivers multifunctional competency at a time when the power industry is facing multiple problems. Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) are two examples of shunt-series FACTS devices [3].

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Various types of FACTS controllers are grounded on a voltage source converter, also known as a voltage source converter (VSC). Every voltage source convertor VSC has an essential building block circuit that is quite similar to a three phase Convertor Bridge. Figure 2 depicts the most collectively known configuration of a three-phase bridge circuit. In the diagram below, the basic three phase bridge convertor has two DC terminals that are represented by the plus "+" and negative "-"signs.

There are three AC terminals that stay connected in the middle of the bridge convertor legs. An arbitrary series of voltage waveforms at the AC terminals can be generated by regulating the varied states of switches linked to the bridge legs. When a voltage source convertor VSC is linked to a transmission system, it must operate at the frequency of the transmission line in order to provide a consistent set of sinusoidal voltage waveforms.

As a result, a VSC connected to a transmission system has just two modes of operation: it can vary the amplitude and phase angle of its output voltage in response to the system voltage [8].

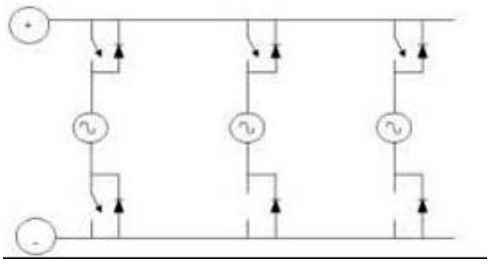


Figure 2. Phase Convertor Bridge (Basic Building Block of Voltage Source Convertor)

To interchange reactive and active power with the transmission system, these two control approaches of choice can be monitored jointly. Due to the current amount of the convertor switches, the magnitude of reactive power switched with transmission system is limited. Active power associated with (from) the transmission line, on the other hand, must be delivered from (delivered to) the DC terminals, as shown in figure 3 [8].

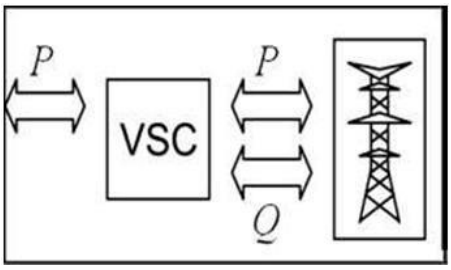


Figure 3: VSC linked to the transmission line- P and Q exchange

UPFC

During instabilities, the Unified Power Flow Controller (UPFC) is a power electronic designed controller that

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provides fast and quick reactive power adjustment reaction at high voltage levels. In UPFC, a pair of three phase regulated bridges is used to generate an AC current. With the help of a series transformer, this AC current is injected into the transmission line. Following the injection of AC current into the transmission line, the active and reactive power flow in the transmission line can be advanced. The UPFC uses solid state power electronics devices like GTOs and IGBTs to provide multipurpose flexibility to the power system, whereas traditional control systems use thyristors, which do not provide this flexibility.

L. Gyugyi came up with the UPFC concept in 1995. The UPFC is a mutual FACT technology that consists of a static synchronous series compensator (SSS) and a static synchronous compensator (STATCOM) that are linked by a shared DC voltage link (a capacitor). The UPFC performs a secondary but critical function: power system stability control, which includes damping undesirable system oscillations and advancing power system transient stability [13, 26].

The Unified Power Flow Controller (UPFC) is a multipurpose controller that is well-known for simulating multiple functions at once. It controls the voltage magnitude to maintain the power flow level throughout the transmission lines of the power system. Because it may provide numerous advantages during such operations, UPFC can play a key role in the steady and dynamic operations that power system networks. With the discovery of UPFC, new difficulties in power electronics and power system design have arisen. The core of the UPFC arrangement is two voltage source convertors (VSC), one of which is connected in series with the transmission line (coupled with SSSC) and the other in parallel with the transmission line (coupled with STATCOM).

The UPFC is designed for both dynamic benefit and real-time power flow regulation in AC transmission lines and power networks. It proposes multifunctional flexibility, which power system operators need to solve a variety of challenges. In comparison to traditional power transmission technology, the UPFC is capable of controlling all those parameters that directly affect power flow in the transmission line (i.e. impedance, voltage, and phase angle) either selectively or instantly, and this main role distinguishes it from other FACTS devices. It has the ability to individually control both reactive and active power in the

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transmission line. The UPFC not only serves as a bridge between multiple controllers and regulators, such as STATCOM, TCSC, SSSC, and phase angle shift regulators, but it also provides additional flexibility by combining the tasks of these controllers.

Unified Power Flow Controller (UPFC) consists of two voltage source convertors (VSC) and power electronic switches such as GTOs or IGBTs, and these two VSCs share a single DC circuit for operation, which is charged by DC capacitor storage. This configuration transforms the convertor into an ideal ac to ac invertor, allowing real power to flow freely in either direction between the AC terminals of both convertors and allowing each convertor to absorb or create reactive power at its own AC output terminal [13].

This section presents the simulation results obtained in MATLAB Sim Power System. The results, as well as the simulation, are then discussed and examined, which includes load flow analysis and the operation of the power system under a fault scenario.

The simulation included a 9-bus Test System without FACTS controllers, which implies that it just analyses the behaviour of the system under fault conditions by applying a three-phase fault to the system, without the FACTS compensating effect. The performance of a system was then assessed using UPFC.

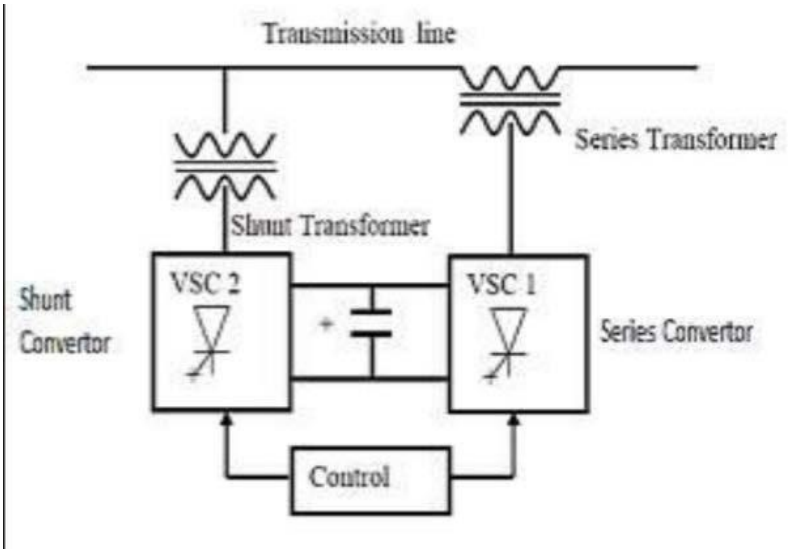


Figure: 4. Simplified Configuration of UPFC

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A. Simulation and Evaluation of IEEE 9-bus System performance During Fault without FACT Controller:

The simulation for the Base Case does not include any FACTS controllers, but it is inclusive. With two wind turbines and a similar load. Bus 08 is subjected to a three-phase fault in order to assess the system's performance without taking into account any FACTS controllers. Figure 5 depicts a simulated IEEE 9-bus test system.

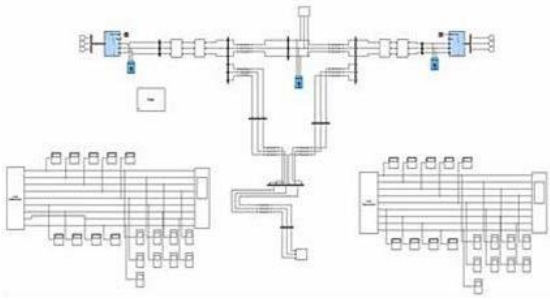


Figure5: IEEE 9-Bus System including 3-phase fault without FACTS Controllers.

There are nine buses and four loads in the IEEE nine-bus system. The system's total 6 active power profiles may be easily analysed using the diagram above. Due to a three-phase malfunction on bus 08, its active power flow has been decreased to -0.06734MW, making it the weakest bus. Buses 02, 05, and 07 are also weak, with active power flows of -10.12MW, 56.94MW, and -3.266MW, respectively.

generation and load are 2000MW and 15500MVA, respectively. After a ten-second simulation, the voltage and active power profiles of each bus are presented, allowing us to evaluate the system's performance under a three-phase fault condition, as applied to bus 08, without the need of a FACT controller. Figures 6 and 7 illustrate the voltage and active power profiles obtained after a 10-second simulation. With the help of VPQ measurement blocks, the weakest and overcrowded buses will be identified from these outlines.

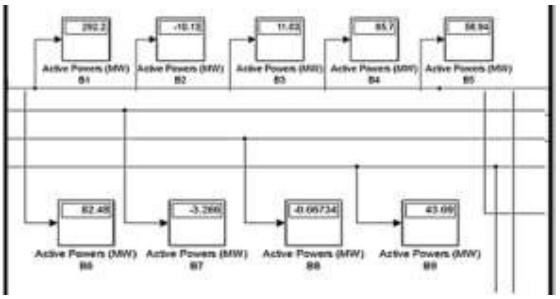


Figure6: Active Power Profiles of nine buses during fault

Figure 7 shows the voltage profiles of each bus. Three phase fault has severely affected the voltage profiles across every bus. The voltage of bus 08 is drives down to 2.041e- 05MW and is considered to be weakest bus. Other buses effected from fault are bus01, bus04, bus05 and bus06 with voltage profile of 0.009871MW,0.0148MW, 0.0251MW and 0.0352MW correspondingly.

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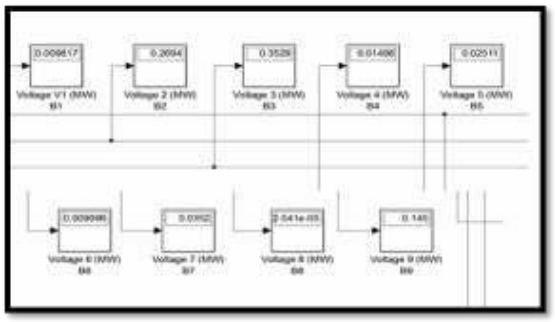


Figure 7: Voltage Profiles of nine buses durilt

A. Analysis of fault effected buses with plots:

The buses that are affected by the malfunction will be evaluated using MATLAB to create graphs for each bus. The performance and capability of all the afflicted buses may be easily determined from plots. For each bus, a plot with a period of 10 seconds is created, which is sufficient to evaluate the transients produced at the bus due to a three-phase defect.

B. Analysis of Active Power Flow of fault effected buses:

The plot for bus 01 during the fault is shown in Figure 8. It can be seen that the oscillations caused by the fault are extremely high and need to be dampened. These high oscillations cause transients in the system, which can have a significant impact on the system's performance. Bus 01 is reported to be overcrowded here.

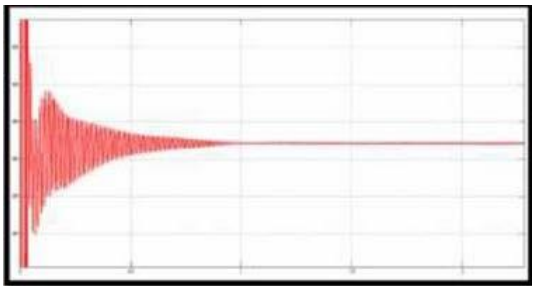


Figure 8: Bus01 Plot during Fault without FACT

Figure 9 illustrates the bus 02 plot. The power flow over bus 02 is in the negative direction due to the problem. The opposite direction of power flow will have an impact on the operation of the generation plant if the current scenario persists for a long time.

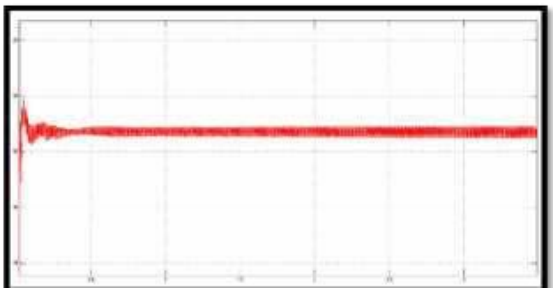


Figure 9: Bus02 Plot during Fault without FACTS

Figure 10 depicts the oscillations that occurred in bus 05 as a result of the failure. Though the amount of power flowing via bus 05 is significant, the oscillations caused by the fault are constant and must be dampened before they have an impact on the power system.

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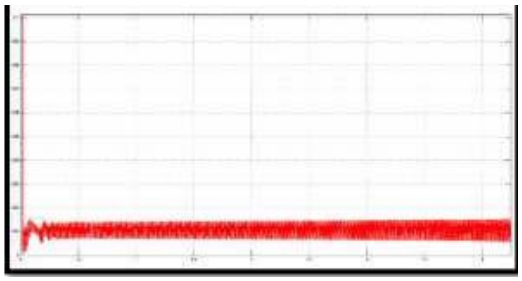


Figure 10: Bus05 Plot during Fault without FACTS

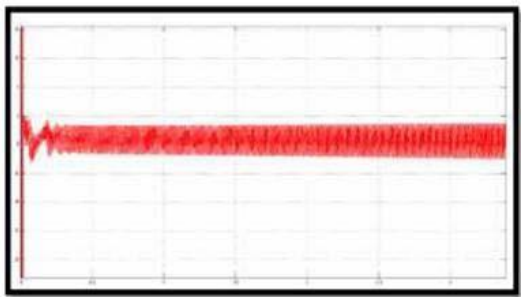


Figure 11 Bus07 Plot during Fault without FACTS

When a fault is applied to bus 08, the power flow level drops to practically nothing, and the bus becomes under-loaded. The vibrations produced on bus 08 for such a short amount of time are quite high, rendering the bus nearly non-operational.

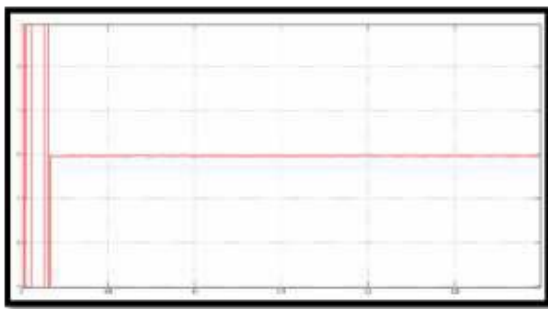


Figure 12: Bus08 Plot during Fault without FAC

The power flow profile of bus 08 is depicted in Figure 12. After the development of disorder, the power flow of bus 08 also runs in the other way.

C. Analysis of voltage profiles of fault affected buses:

Voltage profiles are also altered by the breakdown in active power flow across the system caused by the three phase fault. Figure 13 depicts the impact of the bus 01 situation during a malfunction. Its voltage has dropped to nearly nothing. The transients and oscillations are clearly visible.

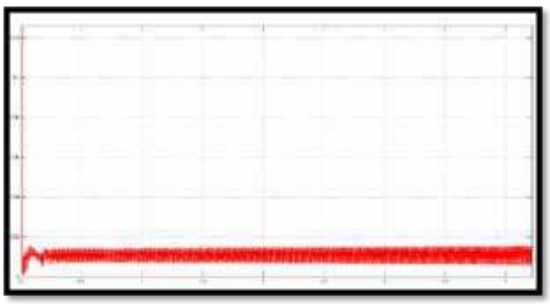


Figure 13: Bus01 Voltage Plot during Fault without FACTS

Figures 14, 15, and 16 depict the voltage profiles of buses 04, 05, and 06, respectively. Due to a failure in the system, the voltages of certain buses have dropped to dangerously low levels. Despite the voltage decrease in buses, high transients

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and oscillations occur, causing the power system to become unstable.

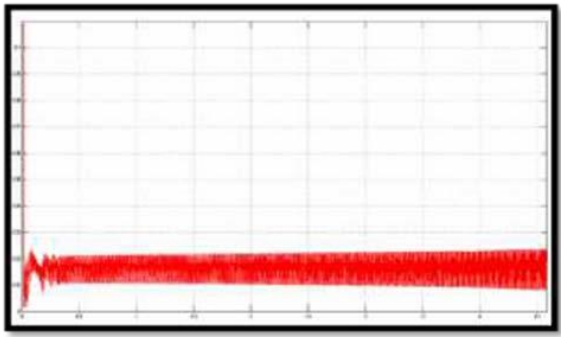


Figure 14: Bus05 Voltage Plot during Fault without FACTS

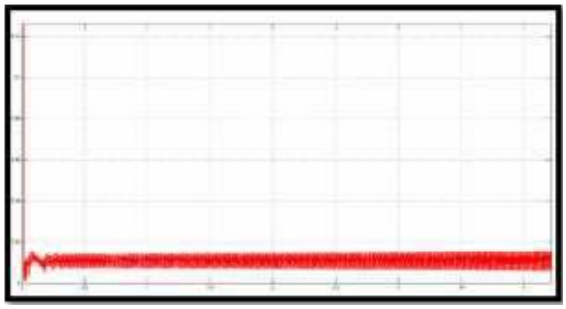


Figure 15: Bus06 Voltage Plot during Fault without FACTS

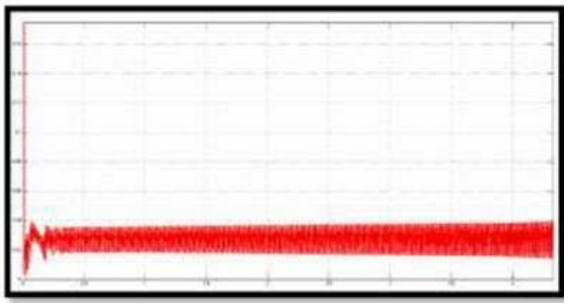


Figure 16: Bus04 Voltage Plot during Fault without FACTS

The three phase fault is applied to bus 08, and its voltage drops abruptly to an extremely low value of MW, which may be seen in figure 17 as a straight red line. Due to a problem, this bus is significantly warped and must be restored to its previous condition; otherwise, the system will stay unstable for an extended period of time, and its equipment may be harmed.

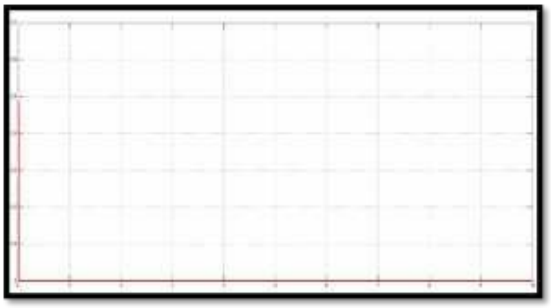


Figure 17: Bus08 Voltage Plot during Fault without FACTS

Following the discussion and investigation of multiple buses that have been significantly impacted by three phase faults across various plots, it is necessary to improve the performance of those buses in order to avoid system instability. FACTS controllers will be used in the IEEE 9 bus system to boost the system's performance and reliability by allowing the system to run nonstop and stable during faults. Bus 05 is where one of the FACT controllers will be used for testing and analysis of FACTS devices. The outcome of the power system with FACTS controllers during the occurrence of a fault at bus 08.will be examined using three

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testing methodologies. The following are the three testing methods:

- Evaluation of IEEE 9-bus system performance in fault with STATCOM is also simulated.
- Evaluation of IEEE 9-bus system performance in fault with SSSC is also simulated.
- Performance of IEEE 9-bus system in failure using UPFC simulation and evaluation

Simulation and Evaluation of IEEE 9-bus system performance during fault with UPFC:

Figure 19 shows how UPFC is connected to the power system's bus 05.

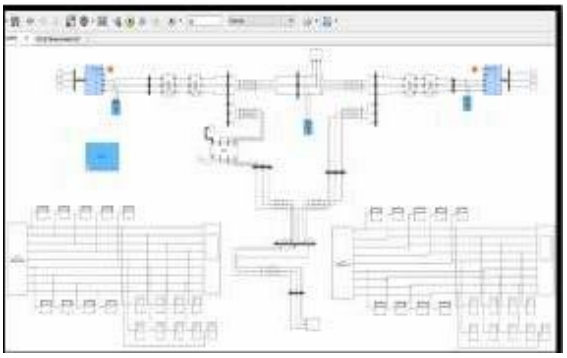


Figure 19: IEEE 9-Bus System including 3-phase fault with UPFC

Because UPFC has both SSSC and STATCOM convertors, it may enhance both active power and voltage profiles at the same time, as well as completely eliminate damps and transients from the system. In terms of system rating, both convertors' ratings are kept at 100MW. While the capacitance rating is kept at 750e-06, it is used to supply power to the UPFC during operation. Underneath charts of active power flow and voltage, the performance of UPFC is evaluated in depth.

Analysis of Buses Active Power Flow Profiles during fault in the presence of UPFC:

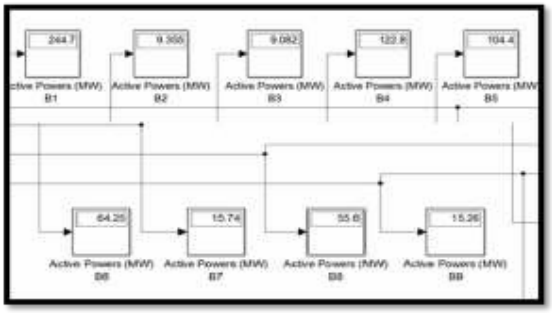


Figure 20: Active Power Flow measurements of nine buses with UPFC

Figure 20 shows the active power flow profiles that exist in UPFC via digital metres. The active power flow on all nine buses has been significantly increased, and the oscillations and transients on all nine buses have been completely eradicated and damped, making the system very stable to run during fault conditions. The most significant benefit of UPFC is that it completely eliminates transients from the system, which was the focus of study in order to make the system's operation

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completely stable and consistent. The plots and waveforms of a few of the buses built under the UPFC programme are shown here.

Figure 21 depicts the active power flow of bus No. 1. UPFC has effectively controlled active power on all buses and increased the active power flow rate on each bus to a significant level. The electricity flow at bus 01 is 244.7 MW (with UPFC), down from 292 MW previously.

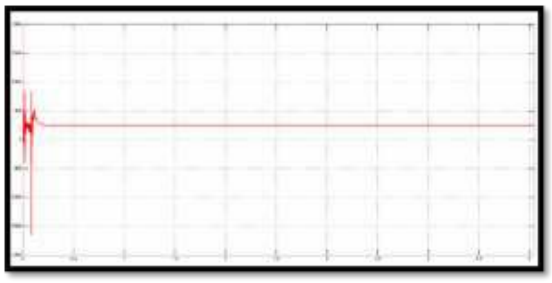


Figure 21: Bus01 Active Power Plot during Fault with UPFC

(Without UPFC), this demostrate that UPFC has relief the bus 01 from over flow of power throughout fault and more significant the transients and oscillations are absolutely vanished from the bus.

The UPFC is inserted to bus 05. The power flow of bus 05 is also amplified to 104.4MW from 55MW, presented in figure 22, which is the major inrease in power flow improvemet at bus 05 and more significantly oscillations have been reduced and vanished from the bus which could be dangerous for system operation.

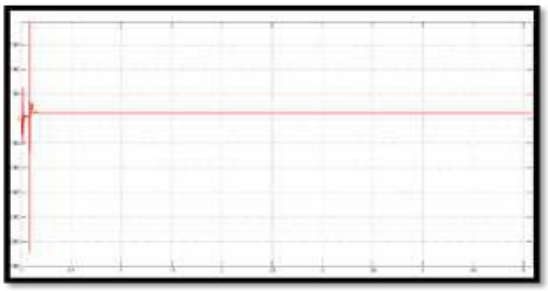


Figure 22: Bus05 Active Power Plot during Fault with UPFC

The performance of fault affected bus 08 is presented in figure 23, in operation of UPFC. As fault has seriously affected the bus active power flow and produces a very high transients and oscillations over the bus. UPFC has considerably performed its operation and not only enhanced the active power but also damps the oscillations and transients absolutely.

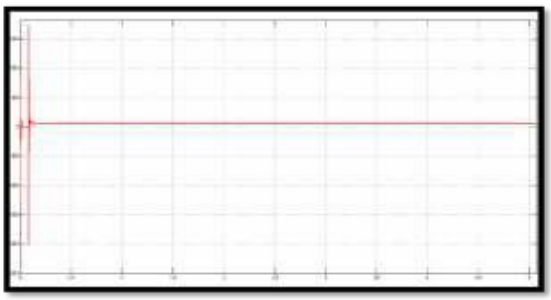


Figure 23: Bus08 Active Power Plot during Fault with UPFC

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The active power flow waveforms of all 9 buses of power system in operation of UPFC are presented in figure 24. The active power flow profiles of all 9 buses are enhanced considerably during disturbance when the UPFC is introduced to the proposed system. UPFC has enhanced both the magnitude and transients very well.

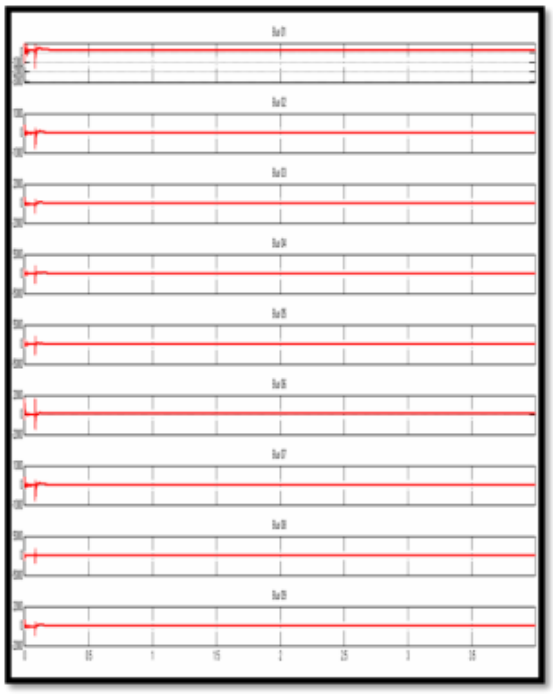


Figure 24: Active Power Flow Plots of all nine buses during fault with UPFC

CONCLUSION

FACTS (Flexible Alternating Current Transmission Systems) devices are based on power electronics and other dynamic controllers. They adjust one or more AC transmission system parameters to improve controllability and power transfer capabilities. Unified Power Flow Controller (UPFC) can manage voltage, impedance, and phase.

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