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Abstract—In the power grid system, the prime subjects are to transmit power with supreme power factor and high power quality, supreme transient stability, economical and minimum risk of system failure. The constantly growth of electrical power demands and loads, particularly non-linear loads making the power system network become more obscure to operate and the system becomes unstable with large power flows without proper control and operation. The development in power system with time have brings new challenges and sometimes it is tough to operate system in stable condition due to complex system network. Though, on the other side there is vast development been made in power electronics, which helps the power system to continue in stable condition during most horrible condition occurred due to fault. One of the creation of power electronics is FACTS technology. FACTS (Flexible Alternating Current Transmission Systems) devices are created on power electronics and other dynamic controllers that provide control of one or more AC transmission system parameters to enhance controllability and growth power transfer capability. One way to enhance the power system control is by applying FACTS controller such UPFC (Unified Power Flow Controller). UPFC can control voltage, impedance and phase at alike time. The UPFC control scheme for the grid connected power system is simulated by MATLAB/PSAT in power system block set. By means of IEEE 9 bus power system network, the effectiveness of UPFC are tested by applying the 3-phase fault at dissimilar buses and evaluated the performance of FACTS devices in IEEE nine bus power system during fault condition.

Keywords— FACTS, Faults, UPFC.

I. INTRODUCTION

Due to enormous increase in needs of human being, the integrated power generation system surfaces a shortage of main energy sources (fossil fuels) as the demand is growing day by day without an increase in substitute generation resources and transmission line capability. All these ins and outs may have strained the power system to function beyond the capability it is constructed to be handled originally [1]. This carries the chief issue of transient stability of power system in apprehension. If some generators are functioning far-off from the load centers, then the problem of transient stability will prime to a main disturbance which can be a hazard to the supply's security as well as grid operators will find it problematic for the daily operations of power system. Transient stability refers to intense transfer of power through transmission line without dropping stability due to

huge and abrupt variations in the power network environments such as 3-phase fault or damage of huge generating/load units abruptly. Overloaded power system may parade the non-linear performance and the abnormal interaction among several power system units will outcome in different modes of oscillations. If there is no protection taken on time to damp the oscillations, then these oscillations will result the power flow and may even lead to the un-synchronization of generators which can source the total or partial system stoppage. The irregular response of system due to instabilities and the hazard of losing synchronization among generators can be decrease by introducing the FACTS technology to power system. The implication of the application of FACTS devices to the grid will bright to lead to energy efficiency and emission decrease. With the rise of the FACTS systems executing to the grid, power quality and stability of the low to high voltage power transmission system is flattering a major area of concern [2].

The impression of Flexible AC Transmission system was projected in 1995, which is then called as FACTS technology [3]. The main idea on which FACTS devices have been projected to the world is to connect the power electronics devices at the high-voltage transmission and distribution sides of the power grid in demand to mark the overall system controlled electronically. The progress made in high power electronic semiconductor devices and control technology have attained the creation of FACTS devices [4]. During the fault incident in power system, FACTS devices offers active and reactive power rapidly to the system in command to uphold the system stability and lesser the transients of power generators. The power reimbursement provided by FACTS devices possibly will uphold the voltage of the entire power system due to which power flow can be simply controlled.

Normally, FACTS devices can be branded into two generations.

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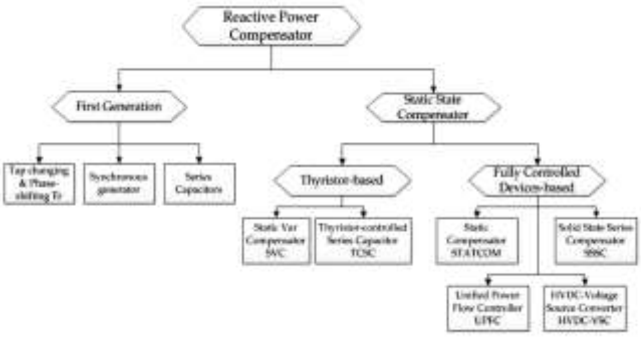

Figure 1: The classification of FACTS devices

1st Generation FACTS devices: Static capacitance as well as dynamic devices are 1st generation of the FACTS technology. These 1st generation FACTS devices comprises of tap changing as well as phase changing transformers, series capacitors and synchronous generators. These are all dynamics devices apart from the series capacitors which are correspondingly called capacitor bank. These devices are commonly operated at the generation side of the power system however their cost is very high due to their tremendously huge size and maintenance. The great drawback of these devices is permanent series capacitors, since such devices are prepared of numerous fixed-capacitance capacitors so these devices are very challenging to control to give the precise not-fixed input capacitance to the grid.

2nd Generation FACTS devices: Static state compensator stands the 2nd generation of FACTS technology. It can be separated into dual categories: thyristor-based technology as well as fully-controlled compensator constructed technology. The thyristor controlled device is semi-controlled device for the reason that once the device is ON then it cannot be moved OFF manually till the chief power is Cut-OFF [5]. Static Var Compensator (SVC) and Thyristor-Controlled Series Capacitor (TCSC) devices fit in to this category [6]. Whereas the fully controlled devices comprise of Gate Turn-OFF (GTO) Thyristor i-e these devices can be physically swapped ON and OFF when required. The Static Compensator (STATCOM), Solid Static Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) fit in to fully-controlled devices. Unified Power Flow Controller (UPFC) is in principle the best effective and multipurpose FACT device as it can execute the function of both STATCOM and SSSC at a time as well as it has transient stability improvement ability by controlling the power flow on together sides of transmission line via shunt and series convertors. Henceforward our concentration drive be on UPFC in this research work [7].

II. FACTS CONTROLLERS

The idea of Flexible AC Transmission System (FACTS) is grounded on power electronics which propose the effective control of single or further AC transmission parameters to increase controllability and enhance the power transfer ability. Here are three types of FACTS devices which exist classified as series, shunt as well as combined shunt-series controllers.

The shunt sort of FACTS controller is precise effectual in enhancing the voltage profile of a definite bus, improve the power damping oscillation and enhance the transient stability of system for the duration of disruption. Some of instances of shunt category of FACTS controllers are Static VAR Compensator (SVC) also Static Synchronous Compensator (STATCOM).

The series category of FACTS controller is valuable in improving the voltage stability limit, increases the transient stability margin, helps in improving the power oscillation damping and sub synchronous oscillation damping of power system throughout disturbance. Instances of series category of FACTS controllers exist are Thyristor Controlled Series Capacitor (TCSC), Thyristor Switch Series Capacitor (TSSC) as well as Static Series Synchronous Capacitor (SSSC).

The mutual shunt-series sort of FACTS controller proposes multifunctional competence at a time due to which numerous complications have overcome fronting by power industry. Some of instance of shunt-series sort of FACTS devices are Unified Power Flow Controller (UPFC) also Interline Power Flow Controller (IPFC) [3].

Entirely types of FACTS controllers grounded on convertor which is well-known as Voltage Source Convertor (VSC). An elementary building block circuit of every voltage source convertor VSC is accurately similar as three phase Convertor Bridge. The utmost collective known configuration of a three phase bridge circuit is presented in Figure 2. The elementary three phase bridge convertor comprises of two DC terminals which are presented by plus '+' and negative '- 'sign in the underneath given figure 2. There are three AC terminals '~' which remain connected at the middle of bridge convertor legs. By regulating the different states of switches connected to the legs of bridge, an arbitrary series of voltage waveforms at the AC terminals can be formed.

While a voltage source convertor VSC is connected to a transmission system at that time it has to use the transmission line frequency for its operation in command to produce a stable set of sinusoidal waveforms of voltage. Therefore, a VSC connected to the transmission system have acquired only two choices of operation, it can fluctuate the magnitude also the phase angle of its output voltage in according to the system voltage [8].

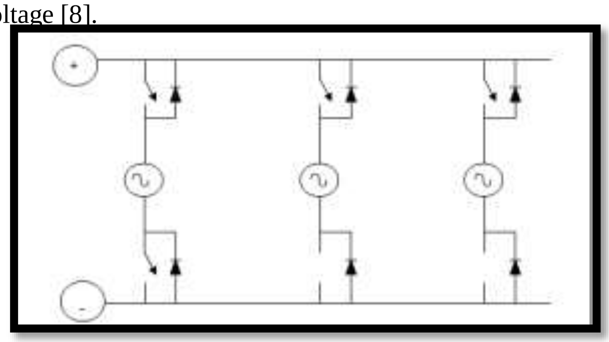

Figure 2.:Phase Convertor Bridge (Basic Building Block of Voltage Source Convertor)

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These two control approaches of choice can be monitored all together to exchange the reactive and active power with the transmission system. Magnitude of reactive power, swapped with transmission system is limited merely due to the current quantity of the convertor switches. Whereas on the other hand active power related to (from) the transmission line has to be delivered from (delivered to) the DC terminals, as characteristically represented in figure3 [8].

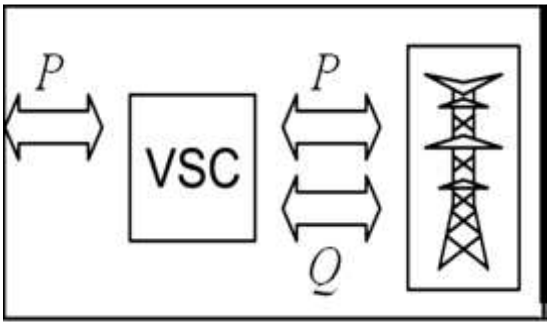

Figure 3: VSC linked to the transmission line- P and Q exchange

III. UPFC

Unified Power Flow Controller (UPFC) is a power electronic built controller which delivers fast and quick reactive power compensation response at high voltage level electric transmission systems during instabilities. The pair of three phase controlled bridges is applied in UPFC which generates an AC current. This AC current is inserted to the transmission line with the aid of series transformer. Succeeding the injection of AC current to transmission line, it can progress the active and reactive power flow in the transmission line. The UPFC includes solid state power electronics devices such as GTO, IGBT etc, which deals multipurpose flexibility to the power system while the conventional control systems is based on thyristors which do not offer such flexibility.

The UPFC idea was developed by L. Gyugyi in 1995. The UPFC is a mutual FACT technology of a static synchronous series compensator (SSS) and a static synchronous compensator (STATCOM) linked through the common DC voltage link (a capacitor).The UPFC accomplishes a secondary but a very important function which is stability control of power system in order to damp the unwanted system oscillations in order to progress transient stability of power system [13, 26].

Unified Power Flow Controller (UPFC) is a multipurpose controller and is well-known for simulating a numerous function at a time, it keeps the power flow level throughout the transmission lines of power system by controlling the voltage magnitude. UPFC can accomplish a principal role in the steady and dynamic operations powers system networks as it can offer several advantages during such operations. With the discovery of UPFC, new challenges have been roused in power electronics and designing of power systems. The core configuration of UPFC comprises of two voltage source convertors (VSC), out of which one convertor is linked in series with transmission line (coupled with SSSC) while the other one is connected in parallel with transmission line (coupled with STATCOM).

The UPFC is planned for the dynamic benefit as well as for the real time control of power flow in AC transmission lines and power systems. It proposes multifunctional flexibility which is required by the power system operators to come up with many problems. With the comparison to the conventional power transmission technology, the UPFC is accomplished to control, either selectively or instantaneously, all those parameters which directly lay effect on power flow in the transmission line (i-e impedance, voltage and phase angle) and this main role marks it unique and powerful than other FACTS devices. It bears the ability of controlling both reactive and active power in the transmission line independently. The UPFC is not only used to play the role of dissimilar controllers and regulators such as STATCOM, TCSC, SSSC, and phase angle shift regulator but also offer other versatile flexibilities by uniting the different functions of these controllers.

Unified Power Flow Controller (UPFC) consist of two voltage source convertors (VSC) along with power electronic switches like GTO's or IGBT's, and these two VSC's share a common DC circuit charged by DC capacitor storage, for their operation. This arrangement makes the convertor to tasks as an ideal ac to ac invertor due to which the real power can run without any restriction in either direction, among the AC terminals of both convertors and each convertor can absorb or produce reactive power at its own AC output terminal [13].

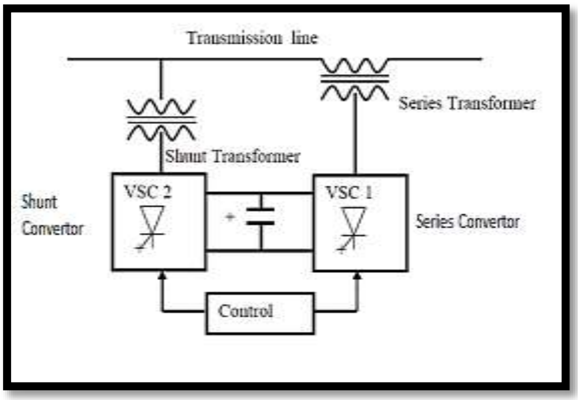

Figure: 4 Simplified Configuration of UPFC

IV. SIMULATION

Results attained for simulation in MATLAB Sim Power System are presented in this chapter. The result as well as the simulation are then followed by discussions and the examination that contains load flow analysis also the Power system performance during fault condition.

Simulation were containing 9-bus Test System without concerning FACTS controllers, means to just measures the Systems behavior through fault condition by applying three-phase fault to the system, without the FACTS compensation effect. Then, the performance of a system was measured with UPFC.

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

For the Base Case, the simulation does not include any FACTS controllers, but only inclusive. With two wind generators and an equivalent load. Three-phase fault is applied to bus 08, in order to measure the performance of the system not considering any FACTS controllers. The below figure 5 shows simulated IEEE 9- bus test system.

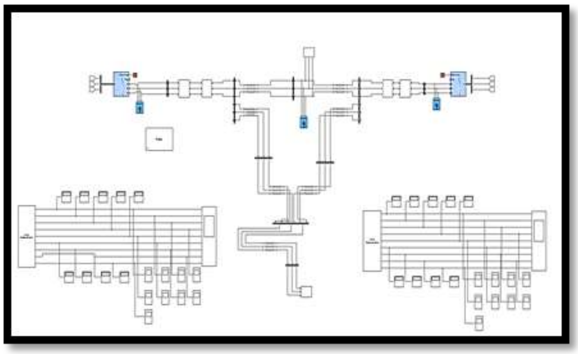

Figure5: IEEE 9-Bus System including 3-phase fault without FACTS Controllers.

The IEEE nine-bus system comprises of the nine buses and 4 Loads. The entire generation also the load of the system is 2000MW and 15500MVA correspondingly. After running simulation for 10 seconds, the voltage and active power profiles of each bus are been plotted, with the help of which we will assess the performance of system during three phase fault condition, applied to bus 08, without using any FACT controller. The voltage and active power profiles resulting from simulation for 10 seconds are shown in figure 6 and figure 7. From these outlines the weakest buses and overloaded buses will be determined with the aid of VPQ measurement blocks.

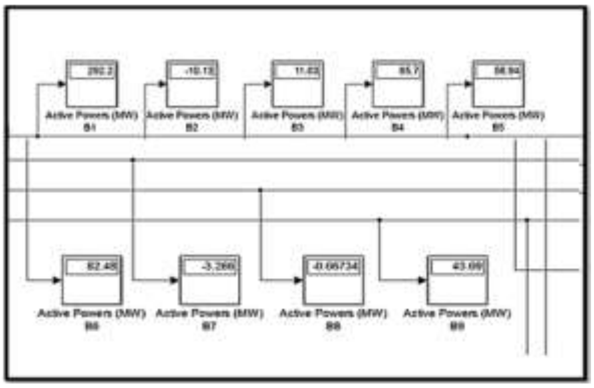

Figure6: Active Power Profiles of nine buses during fault

From above figure 6 active power profiles can be effortlessly evaluated. Due to three phase fault applied on bus 08, the bus 08 is considered to be weakest bus as its active power flow is reduced to -0.06734MW. Other weak buses are Bus 02, bus 05, bus 07 with active power flow of -10.12MW, 56.94MW and -3.266MW correspondingly.

Figure 7 shows the voltage profiles of each bus. Three phase fault has severely effected 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.

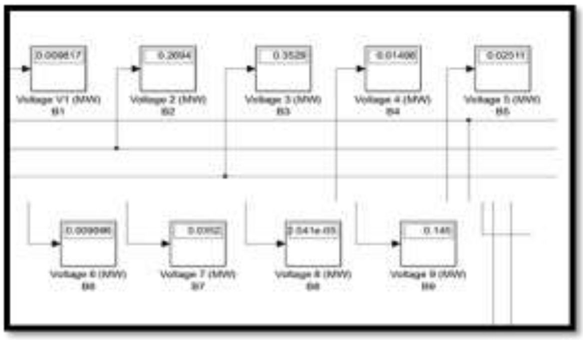

Figure 7: Voltage Profiles of nine buses durilt

B. Analysis of fault effected buses with plots:

The buses that are effected from fault will be assessed by constructing a plots for each bus in MATLAB. From plots the performance and ability of all the effected bus can be determined clearly. The plot of period 10 seconds is constructed for each bus which is sufficient to evaluate the transients produced at bus due to three phase fault.

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

Figure 8 shows that plot for bus 01 during fault. It can be noticeably detected that the oscillations produced due to fault are very high and need to be damped. These high oscillations lead to the generation of transients in system due to which system's performance can seriously effected. Here bus 01 is found to be overloaded.

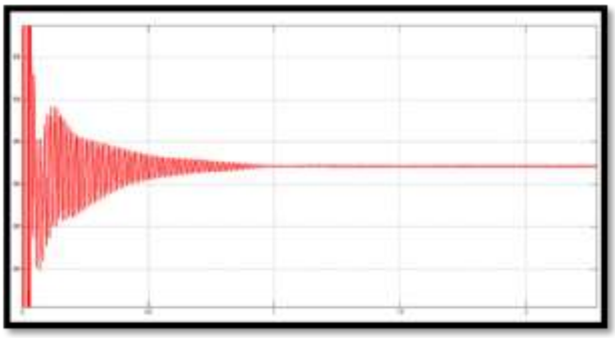

Figure 8: Bus01 Plot during Fault without FACT

Figure 9 shows the bus 02 plot. It shows that the power flow is flowing in negative direction over bus 02 due to fault. If the present situation remains for a long time, then it can affect the operation of generation plant due to opposite direction of power flow.

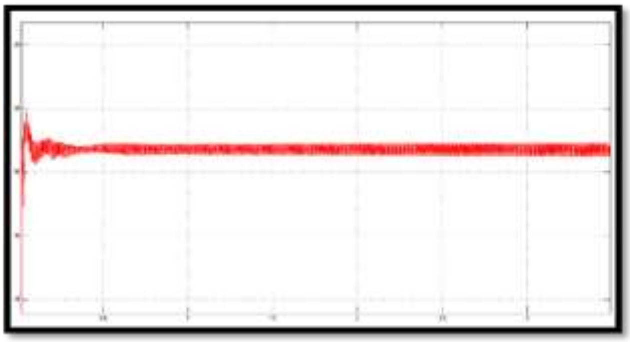

Figure 9: Bus02 Plot during Fault without FACTS

Figure 10 shows that the oscillations that arisen in bus 05 due to fault. Though the level of power flow over bus 05 is highly considerable but the oscillations produced due to fault are continuous and essential to be damped before they effect on power system.

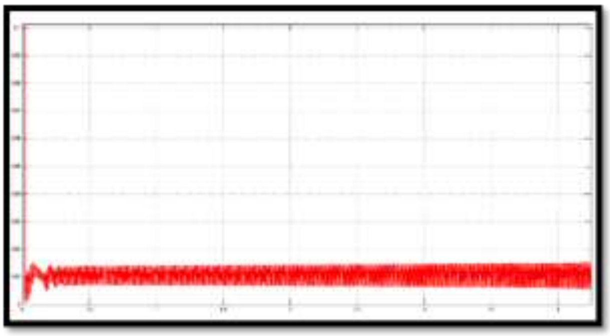

Figure 10: Bus05 Plot during Fault without FACTS

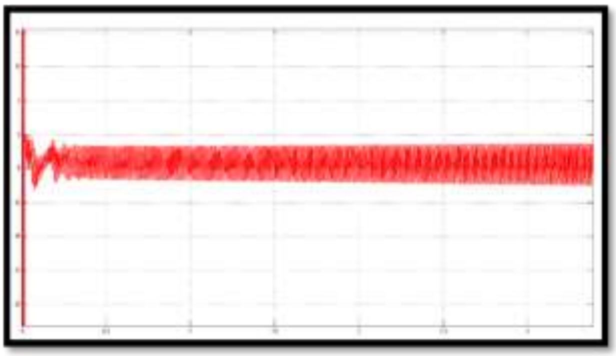

Figure 11 Bus07 Plot during Fault without FACTS

As the fault is applied at bus 08, its power flow level drives down nearly to zero and it becomes under-loaded. The oscillations produced on bus 08 for very small period of time, are very high and leave the bus with almost non-operational condition. Figure 12 demonstrates the power flow profile of bus 08. The power flow of bus 08 also flows in reverse direction after the occurrence of disorder

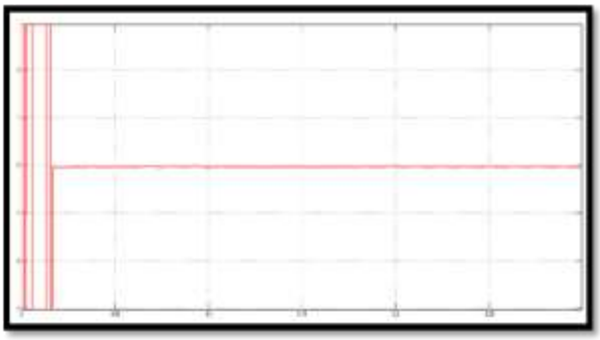

Figure 12: Bus08 Plot during Fault without FAC

D. Analysis of voltage profiles of fault affected buses:

With the disruption in flow of active power through the system, voltage profiles are also being affected due to three phase fault. Figure 13 shows the effect of bus 01 situation during fault condition. Its voltage is drop down to almost zero. The transients and oscillation can visibly be observed.

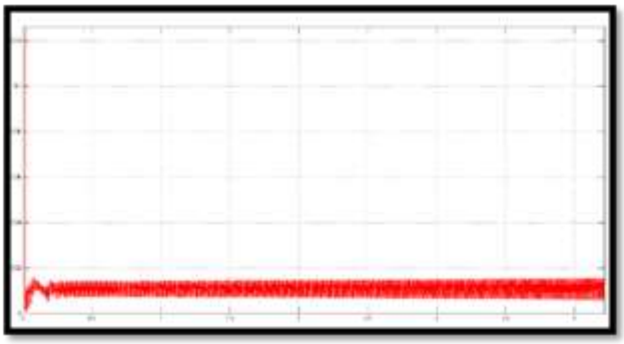

Figure 13: Bus01 Voltage Plot during Fault without FACTS

The voltage Profiles of bus 04, bus 05 and bus 06 are shown in the figure 14, 15 and 16 correspondingly. The voltages of these buses are fallen to a very low level due to fault occurrence in the system. In spite of voltage drop in buses, high transients and oscillations also produces on the buses which lead the power system to instability.

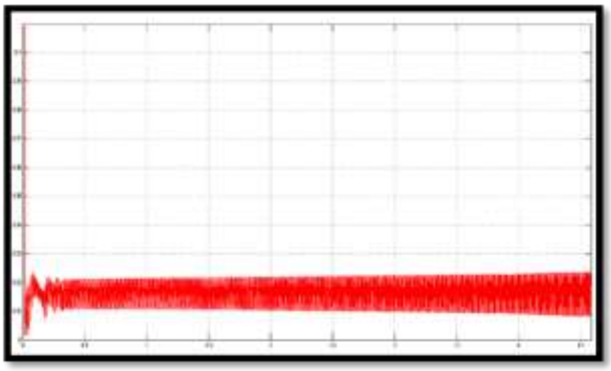

Figure 14: Bus05 Voltage Plot during Fault without FACTS

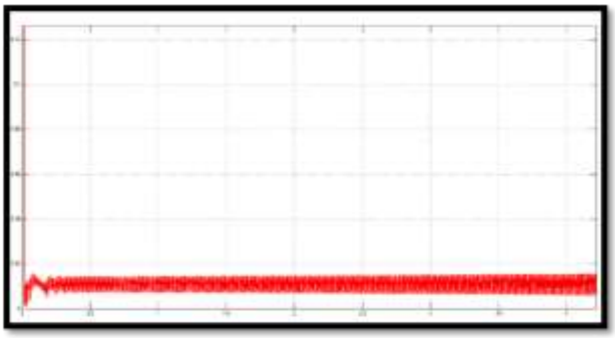

Figure 15: Bus06 Voltage Plot during Fault without FACTS

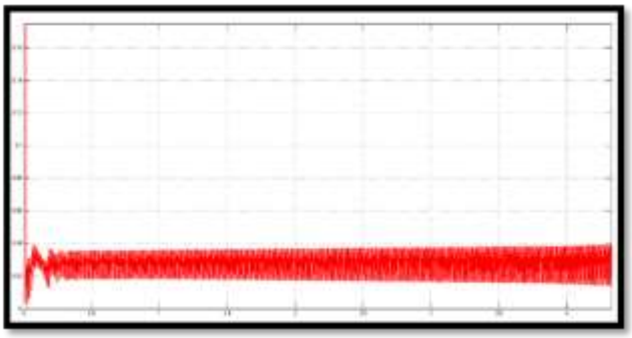

Figure 16: Bus04 Voltage Plot during Fault without FACTS

The three phase fault is applied on bus 08, its voltage is fallen sharply to a very small value of MW which can be seen as a straight red line in figure 17. This bus is severely distorted due to fault and mandatory to return to its original condition else the system will remain unstable for a long period of time and its equipment can be damaged.

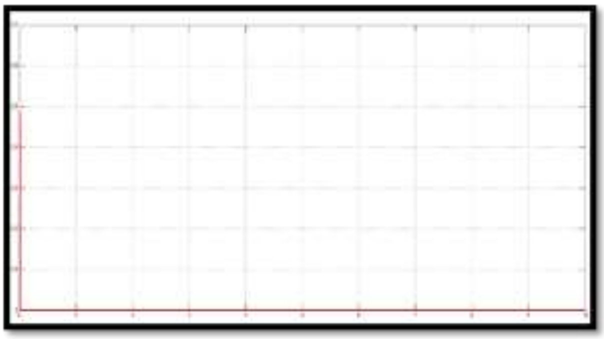

Figure 17: Bus08 Voltage Plot during Fault without FACTS

From above discussion and examination of numerous buses which are much effected from three phase fault, over different plots, it is then required to improve the performance of those buses in order to avoid the system lead to instability. So to make the system's operation nonstop and stable during fault, FACTS controllers will be applied in IEEE 9 bus system to increase the performance and reliability of system. For testing and examination of FACTS devices, bus 05 is considered where one of FACT controller will be applied. Three testing methods will be used to examine the outcome of power system with FACTS controllers during occurrence of fault at bus 08. The three methods of testing are given below:

- Simulation also Evaluation of IEEE 9-bus system performance in fault with STATCOM.
- Simulation also Evaluation of IEEE 9-bus system performance in fault with SSSC
- Simulation as well as Evaluation of IEEE 9-bus system performance in fault with UPFC.

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

UPFC is linked to bus 05 of power system, presented in figure 19. As UPFC comprises of both SSSC and STATCOM convertors, so it has the ability to increase both active power and voltage profiles concurrently as well as can remove the damps and transients from the system absolutely. The ratings of both convertors are retained at 100MW as related to system rating. While the capacitance rating is retained at 750e-06, which is used to source power to UPFC while its operation. The performance of UPFC is assessed in detail in beneath plots of active power flow and voltage.

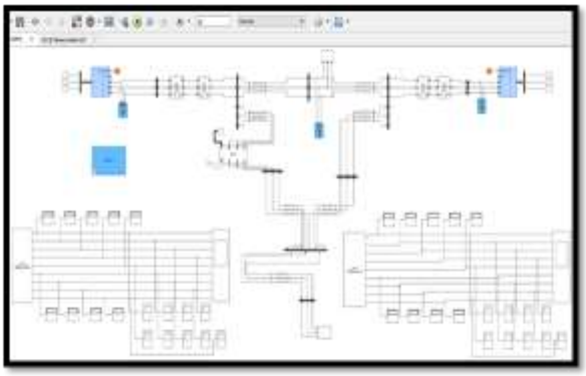

Figure 19: IEEE 9-Bus System including 3-phase fault with UPFC

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

The active power flow profiles in existence of UPFC is presented in figure 4.27, via digital meters. UPFC has considerably enhanced the active power flow on all nine buses as well as totally removed and damped the oscillations and transients from all the buses which make the system very stable to operate during fault condition. The foremost advantage of UPFC is that it has totally eliminate the transients from system which is focus of research to make the system's operation fully stable and constant. The plots and waveforms of selected buses constructed under UPFC are presented below.

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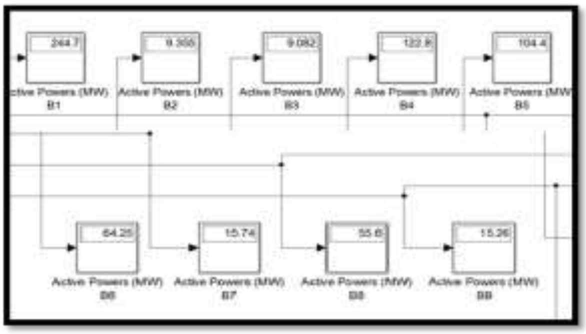

Figure 20: Active Power Flow measurements of nine buses with UPFC

The active power flow of bus 01 is presented in figure 21. UPFC has considerably controlled the active power at all buses and take the active power flow level at each bus to a considerable level of flow. The power flow at bus 01 is 244.7 MW (with UPFC) which is decreased from 292MW.

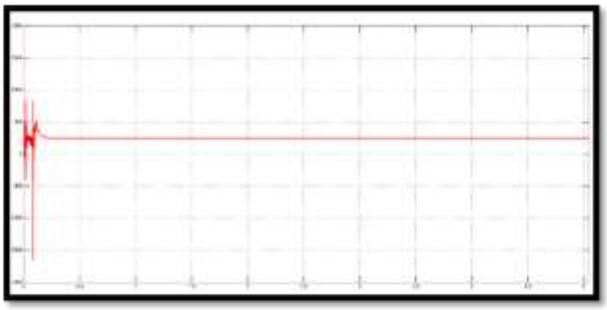

Figure 21: Bus01 Active Power Plot during Fault with UPFC

(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.

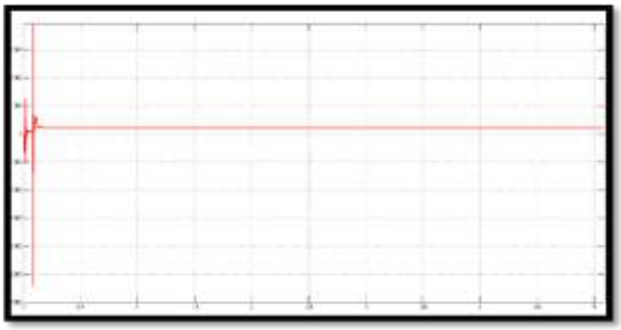

Figure 22: Bus05 Active Power Plot during Fault with UPFC

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.

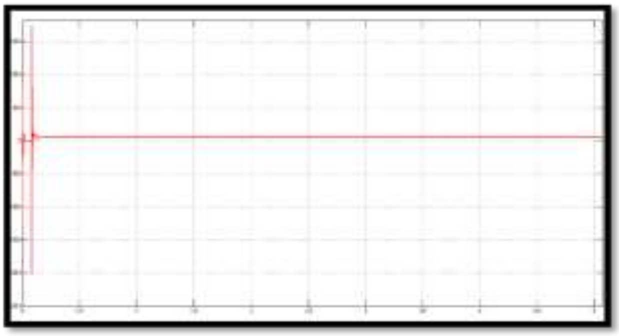

Figure 23: Bus08 Active Power Plot during Fault with UPFC

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.

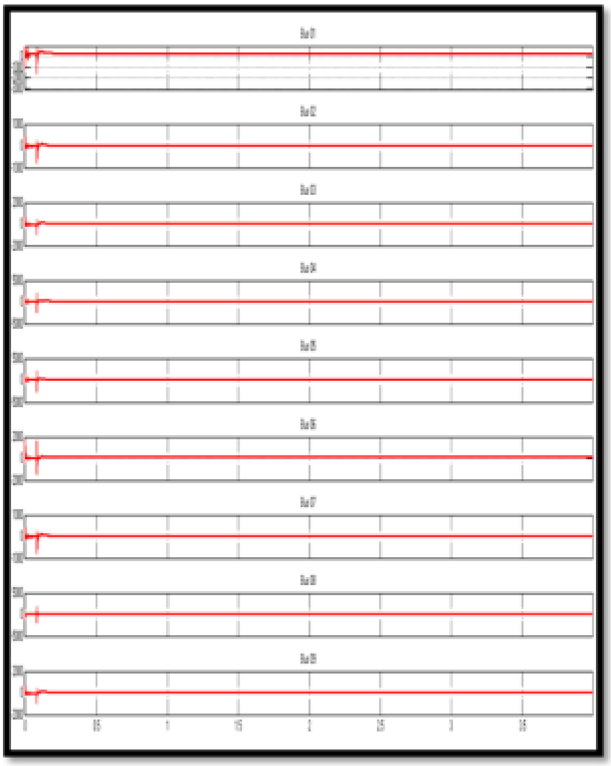

Figure 24: Active Power Flow Plots of all nine buses during fault with UPFC

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