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Analysis of Voltage Magnitude, Real Power and Reactive Power Flow in a Power System with and without Facts Devices

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Abstract: Stability of power system is an important factor in electric power system operation. Development of power generation and transmission, in last ten years, has been inadequate due to limited resources while power demand has increased significantly. So the existing transmission lines are used near thermal stability limits under heavy loads and the system stability becomes a power transfer limiting factor. To overcome this, FACTS technology helps in exploring some new possibilities for flow control and improves the operational capability of existing and new transmission lines also. One of the major causes of voltage instability is the reactive power limit of the system. Improving the system's reactive power handling capacity via Flexible AC transmission System (FACTS) devices is a remedy for prevention of voltage instability.

Here the effect of placing FACTs devises such as Static var compensator(SVC),Static synchronous compensator (STATCOM),Unified power flow controller(UPFC) for the system considered is observed here in terms of voltage magnitude, real and reactive power flows. The results obtained show a positive impact in improving the power system stability and it is observed that the performance of UPFC is superior to that of STATCOM and SVC.

Keywords: MATLAB Software, Static var compensator (SVC), Static synchronous compensator (STATCOM), Unified power flow controller (UPFC),

I. INTRODUCTION

In conventional AC transmission system, the ability to transfer AC power is limited by several factors like thermal limits, transient stability limit, voltage limit, short circuit current limit etc. These limits define the maximum electric power which can be efficiently transmitted through the transmission line without causing any damage to the electrical equipments and the transmission lines. This is normally achieved by bringing changes in the power system layout. However this is not feasible and another way of achieving maximum power transfer capability without any changes in the power system layout. Also with the introduction of variable impedance devices like capacitors and inductors, whole of the energy or power from the source is not transferred to the load, but a part is stored in these devices as reactive power and returned back to the source. Thus the actual amount of power transferred to the load or the active power is always less than the apparent power or the net power. For ideal transmission the active power should be equal to the apparent power. In other words, the power factor (the ratio of active power to apparent power) should be unity. This is where the role of Flexible AC transmission System comes.

A Flexible AC transmission System refers to the system consisting of power electronic devices along with power system devices to enhance the controllability and stability of the transmission system and increase the power transfer capabilities [1]. With the invention of thyristor switch, opened the door for the development of power electronics devices known as Flexible AC transmission systems (FACTS) controllers. Basically the FACT system is used to provide the controllability of high voltage side of the network by incorporating power electronic devices to introduce inductive or capacitive power in the network.

Power System network consist of three kinds of powers, namely, active, reactive and apparent power. Active power is the useful or true power that performs a useful work in the system or load .Reactive power is caused entirely by energy storage components and the losses due to reactive power may be considerable, although reactive power is not consumed by the loads.The presence of reactive power reduces the capability of delivering the active power by the transmission lines. And the apparent power is the combination of active and reactive power. In order to achieve maximum active power transmission, the reactive power must be compensated. This compensation is necessary for

1) Improving the voltage regulation
2) Increasing system stability

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3) Reducing the losses associated with the system
4) Improving the power factor
5) Better utilization of machines connected to the system

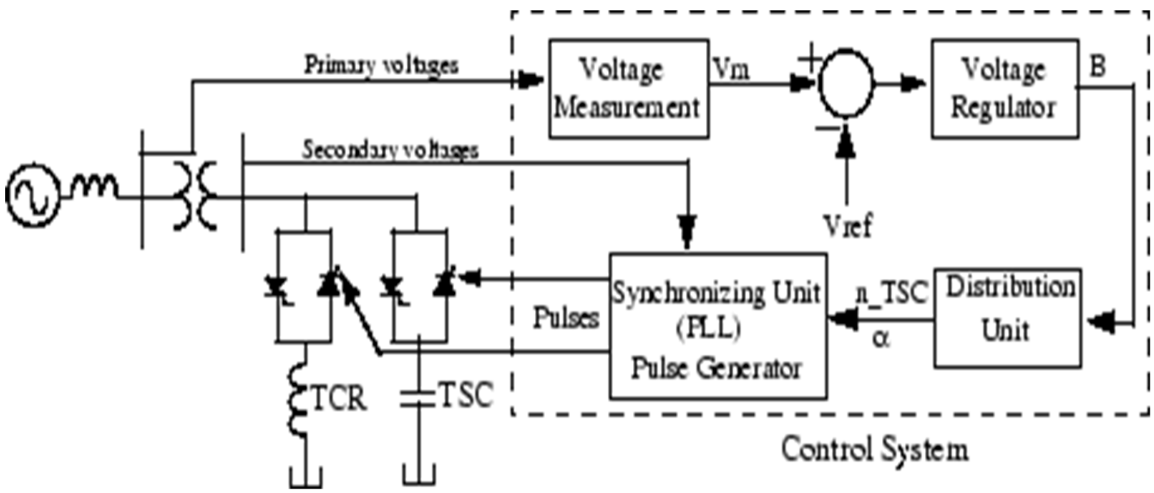
II. CONCEPT OF SVC

A static VAR compensator is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks[7]. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics and stabilizing the system. A static VAR compensator has no significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks.

The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

1) Connected to the power system, to regulate the transmission voltage ("Transmission SVC")
2) Connected near large industrial loads, to improve power quality ("Industrial SVC")

Figure 1 Single Line Diagram of an SVC and its Control System



A. SVC V-I Characteristics

The SVC can be operated in two different modes:

1) In voltage regulation mode (the voltage is regulated within limits as explained below)
2) In var control mode (the SVC susceptance is kept constant)

When the SVC is operated in voltage regulation mode, it implements the following V-I characteristic.

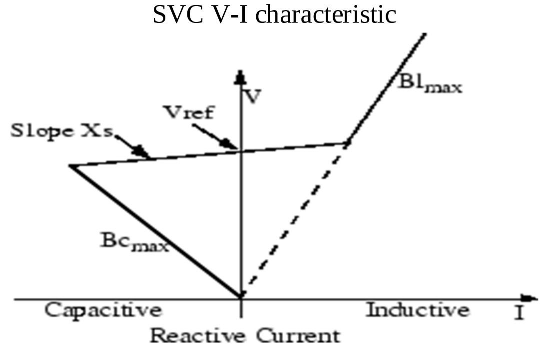


Figure 2 SVC V-I characteristic

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (Bc_{max}) and reactor banks (Bl_{max}), the voltage is regulated at the reference voltage Vref. However, a voltage droop

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is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure.

When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains (proportional gain Kp and integral gain Ki), the droop reactance Xs, and the system strength (short-circuit level).

III. CONCEPT OF STATCOM

The STATCOM has a characteristic similar to the synchronous condenser, but as an electronic device it has no inertia and is superior to the synchronous condenser in several ways, such as better dynamics, a lower investment cost and lower operating and maintenance costs. A STATCOM is build with Thyristors with turn-off capability like GTO or today IGCT or with more and more IGBTs. The static line between the current limitations has a certain steepness determining the control characteristic for the voltage.

The advantage of a STATCOM is that the reactive power provision is independent from the actual voltage on the connection point. This can be seen in the diagram for the maximum currents being independent of the voltage in comparison to the SVC. This means, that even during most severe contingencies, the STATCOM keeps its full capability.

In the distributed energy sector the usage of Voltage Source Converters for grid interconnection is common practice today. The next step in STATCOM development is the combination with energy storages on the DC-side.

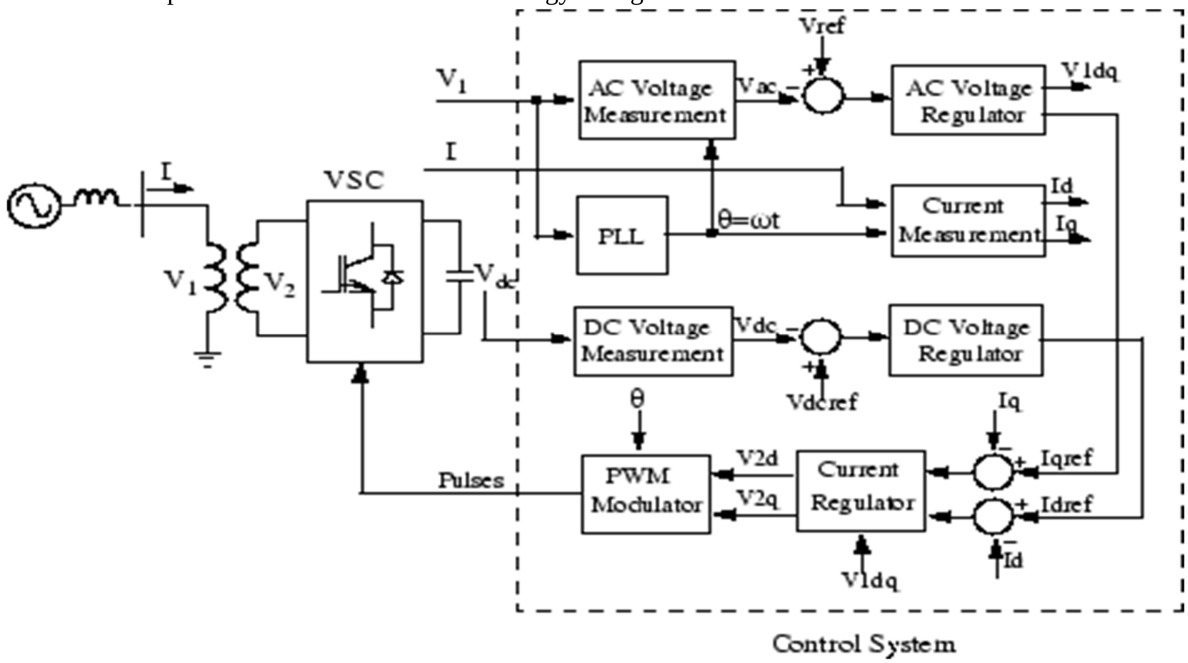


Figure 3 Single Line Diagram of a STATCOM and its Block Diagram

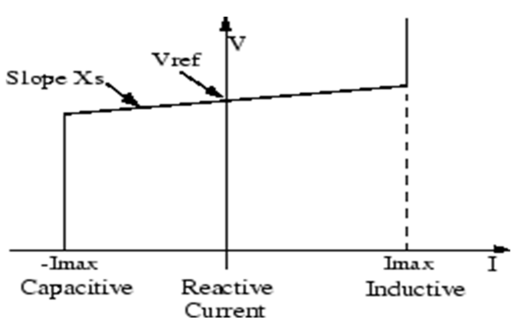
The STATCOM can be operated in two different modes:

1) In voltage regulation mode (the voltage is regulated within limits as explained below)

2) In var control mode (the STATCOM reactive power output is kept constant)

When the STATCOM is operated in voltage regulation mode, it implements the following V-I characteristic.

A. Statcom V-I characteristic



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As long as the reactive current stays within the minimum and minimum current values (-Imax, Imax) imposed by the converter rating, the voltage is regulated at the reference voltage Vref. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure

IV. CONCEPT OF UPFC

The unified power flow controller, which has been recognized as one of the best featured FACTS devices, is capable of providing simultaneous active and reactive power flow control, as well as voltage magnitude control. The UPFC is a combination of static synchronous compensator and static synchronous series compensator which is connected via a common dc link, to allow bi-directional flow of real power between series output terminals of SSSC and the shunt terminals of the STATCOM, and is allowed to provide concurrent real and reactive power compensation[9]. The UPFC comprises of two voltage source inverters, operated from a common dc link provided by a dc storage capacitor. The dc link capacitor should be properly designed so as to substantially reduce the ripple present in the dc voltage . The ratings of this dc link capacitor bank pose a significant impact on the cost and physical size of the UPFC. Besides, this capacitor has shorter life when compared to ac capacitor of same rating. This in turn limits the life and reliability of the voltage source inverter . Therefore efforts have to be taken to eliminate the need of the dc link capacitor and still obtain more or less the same performance. It is in this pretext two different schemes of UPFC without dc link capacitor have been proposed. In the first method the dc link capacitor present in the UPFC is eliminated and suitable modulation techniques are employed in the converter configurations so as to operate the UPFC without degrading its performances.

3) Single Line Diagram Of A Upfc And Phasor Diagram Of Voltage

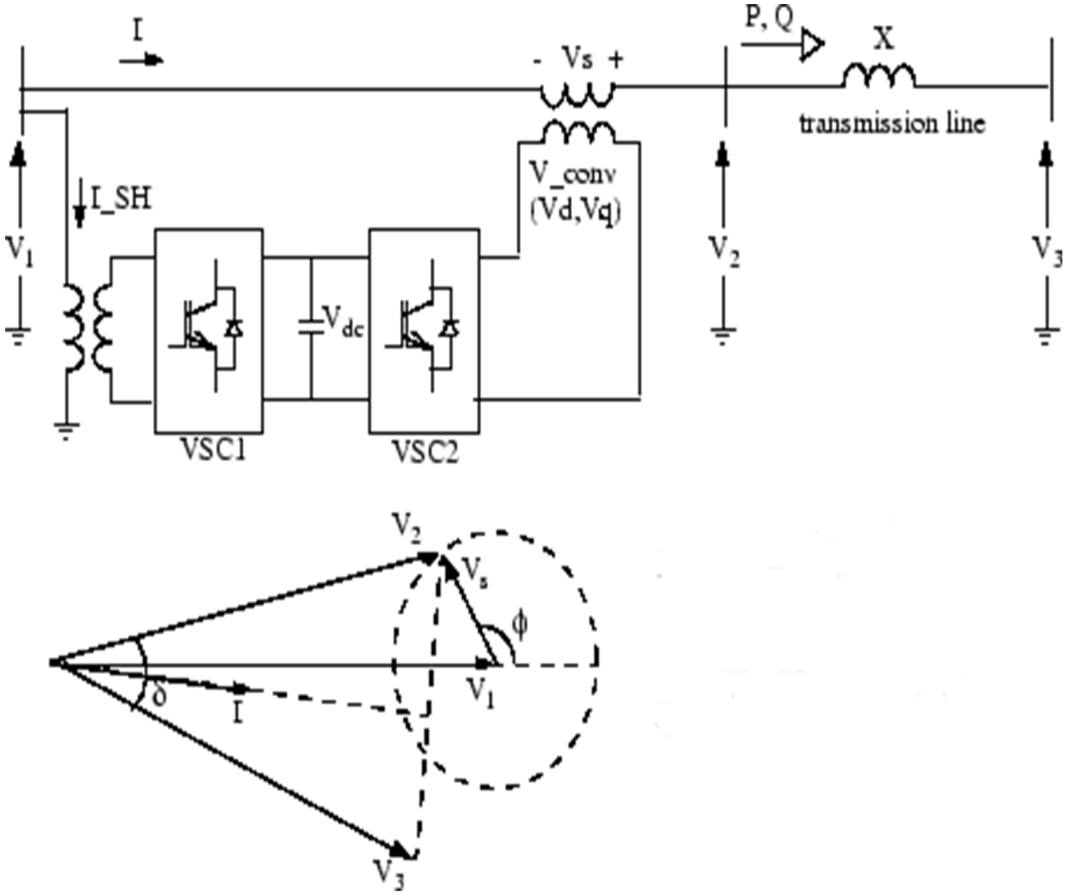

Figure 4: Single-line Diagram of a UPFC and Phasor Diagram of Voltages and Currents

$$P=V^2V^3\sin\delta X, Q=V^2(V^2-V^3\cos\delta)X$$

This FACTS topology provides much more flexibility than the SSSC for controlling the line active and reactive power because active power can now be transferred from the shunt converter to the series converter, through the DC bus. Contrary to the SSSC where the injected voltage Vs is constrained to stay in quadrature with line current I, the injected voltage Vs can now have any angle with respect to line current. If the magnitude of injected voltage Vs is kept constant and if its phase angle ϕ with respect to V1 is varied from 0 degrees to 360 degrees, the locus described by the end of vector V2 (V2=V1+Vs) is a circle as shown on the phasor diagram. As ϕ is varying, the phase shift δ between voltages V2 and V3 at the two line ends also varies. It follows that both the active power P and the reactive power Q transmitted at one line end can be controlled.

V. MATLAB SIMULATON MODEL

We have taken an power system as shown in below figure 5 on which simulation is carried out. The simulation is done on the power system by connecting the different FACT Controllers STATCOM,SVC,UPFC individually to the power system by applying the fault in the system and without fault in the system.

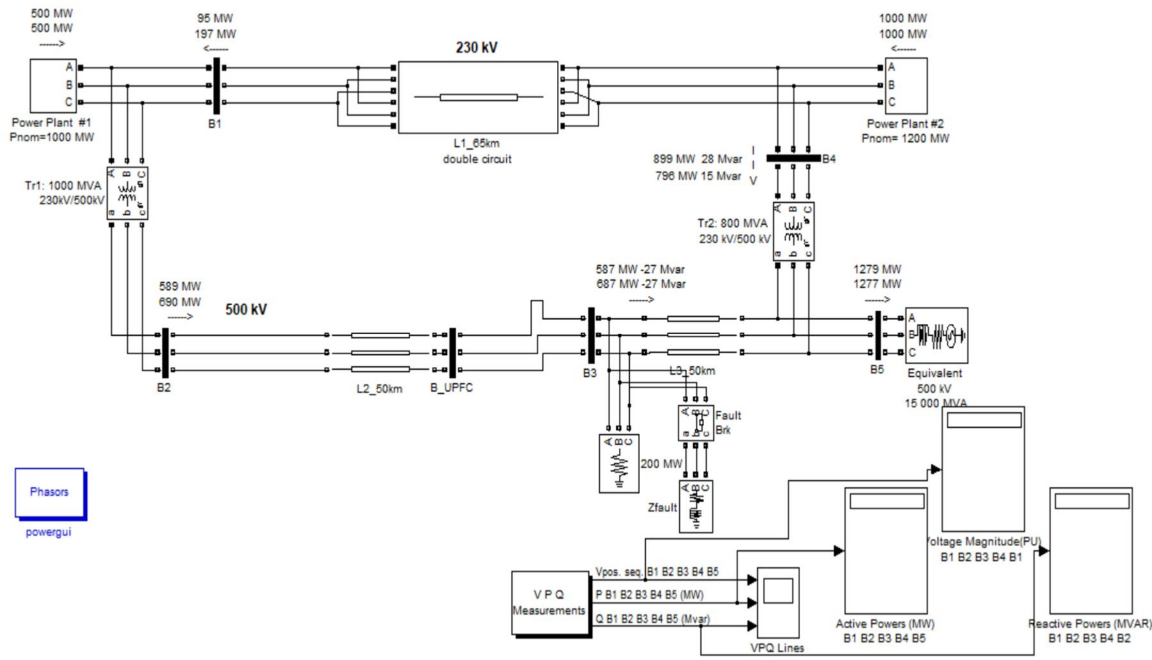

Figure 5: Simulink block diagram of power system

A. Block Diagram Of Power System With Svc

The simulation block diagram of the power system with Fact controller SVC is shown below figure 6.

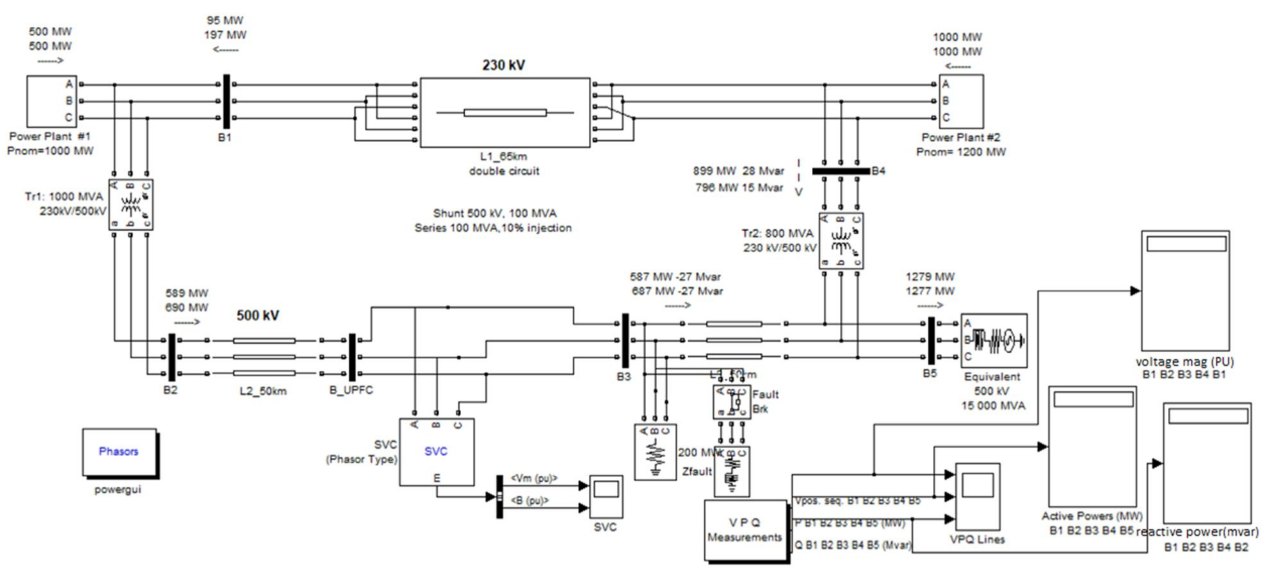

Figure 6: Simulink block diagram of power system with SVC

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B. Block Diagram Of Power System With Statcom

The simulation block diagram of the power system with Fact controller STATCOM is shown below figure 7

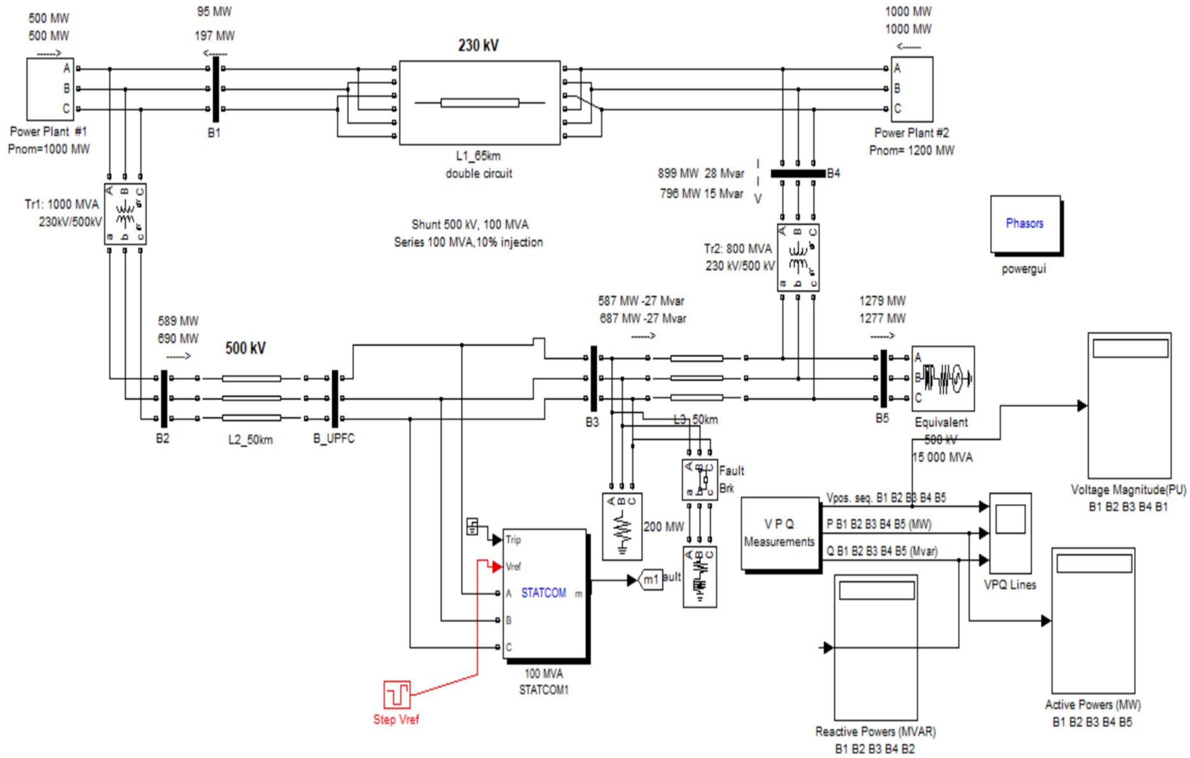

Figure 7: simulink block diagram of power system with STATCOM

C. Block Diagram Of Power System With Upfc

The simulation block diagram of the power system with Fact controller UPFC is shown below figure 8.

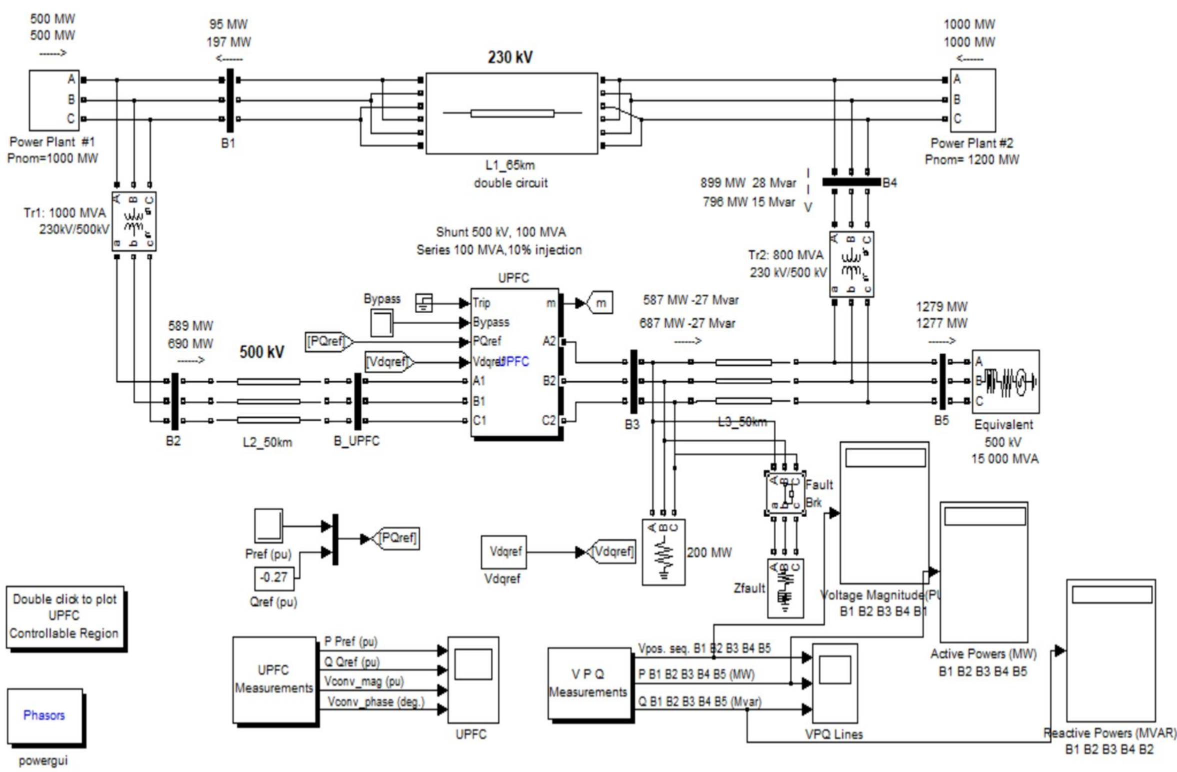

Figure 8: simulink block diagram of power system with UPFC

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VI. RESULTS

Voltage Magnitude, Active power and Reactive power of the power system without any fault

Bus no / parameters	Voltage magnitude(PU)	Real power (MW)	Reactive power (MVAR)
Bus 1	0.9965	95.16	-16.34
Bus 2	0.9993	588.8	-63.27
Bus 3	0.9995	587	-27.79
Bus 4	0.9925	898.7	26.89
Bus 5	0.9977	1279	-106.4

Table 1: Bus parameters of power system

Voltage Magnitude, Active power and Reactive power of the power system with L-G fault

Bus no / Parameters	Voltage magnitude(PU)	Real power (MW)	Reactive power (MVAR)
Bus 1	0.8418	34.6	137
Bus 2	0.6716	502	619.8
Bus 3	0.5729	453.4	307
Bus 4	0.9048	949.3	543.1
Bus 5	0.806	1112	-2013

Table 2: Bus parameters of power system with L-G fault

Voltage Magnitude, Active power and Reactive power of the power system with L-G fault by using SVC

Bus no / parameters	Voltage magnitude(PU)	Real power (MW)	Reactive power (MVAR)
Bus 1	0.9474	86.11	49.18
Bus 2	0.8953	577	316.3
Bus 3	0.8653	568.3	297.2
Bus 4	0.9651	906.7	204
Bus 5	0.9371	1181	-912.1

Table 3: Bus parameters of power system with SVC

Voltage Magnitude, Active power and Reactive power of the power system with L-G fault by using STATCOM

Bus no / Parameters	Voltage magnitude(PU)	Real power (MW)	Reactive power (MVAR)
Bus 1	0.9503	87.77	45.41
Bus 2	0.9013	578.8	294.4
Bus 3	0.8717	569.4	364.7
Bus 4	0.9668	905.1	193.6
Bus 5	0.9407	1176	-865.3

Table 4: Bus parameters of power system with STATCOM

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Voltage Magnitude, Active power and Reactive power of the power system with L-G fault by using UPFC

Bus no / Parameters	Voltage magnitude(PU)	Real power (MW)	Reactive power (MVAR)
Bus 1	0.9746	102.9	-29.29
Bus 2	0.9579	595.4	62.05
Bus 3	0.8437	587	114
Bus 4	0.968	889.9	257.7
Bus 5	0.9492	1194	-1015

Table 5: Bus parameters of power system with UPFC

A. Simulation Result

The colour notation for the buses of simulation result shown in fig 7.6 is common for all the simulation results.

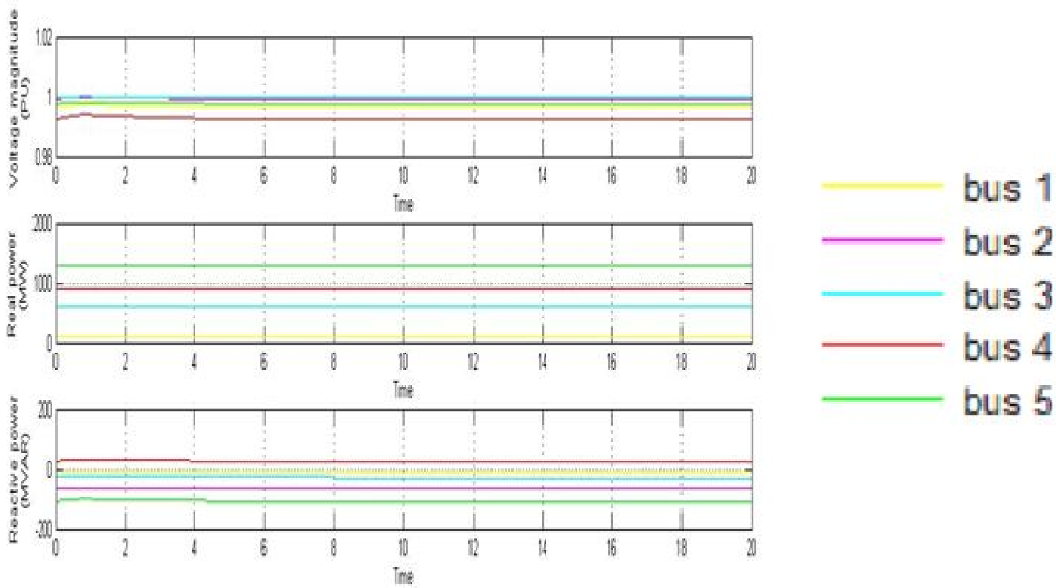

Figure 9: Simulation result of power system without FACT device

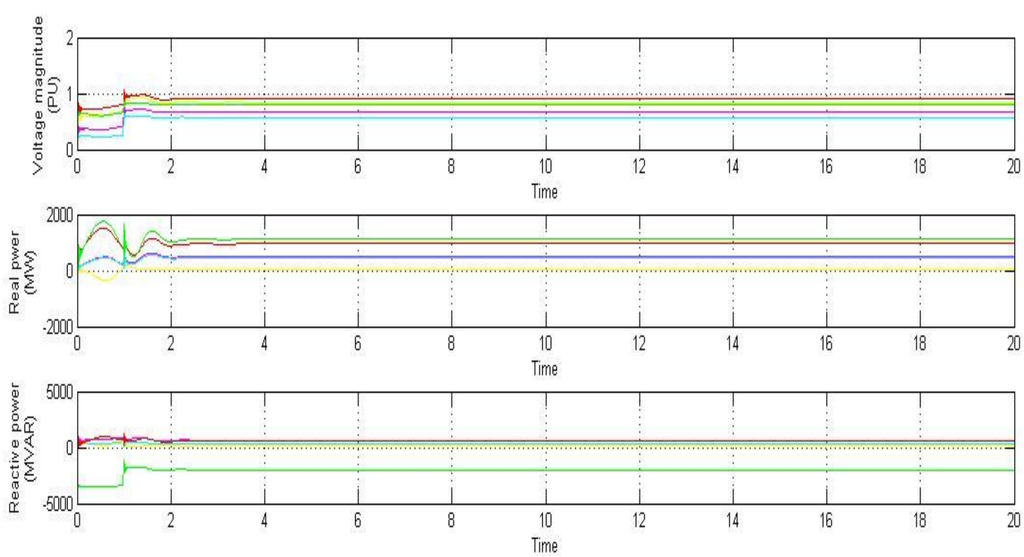

Figure 10: Simulation result of power system without FACT device with L-G fault

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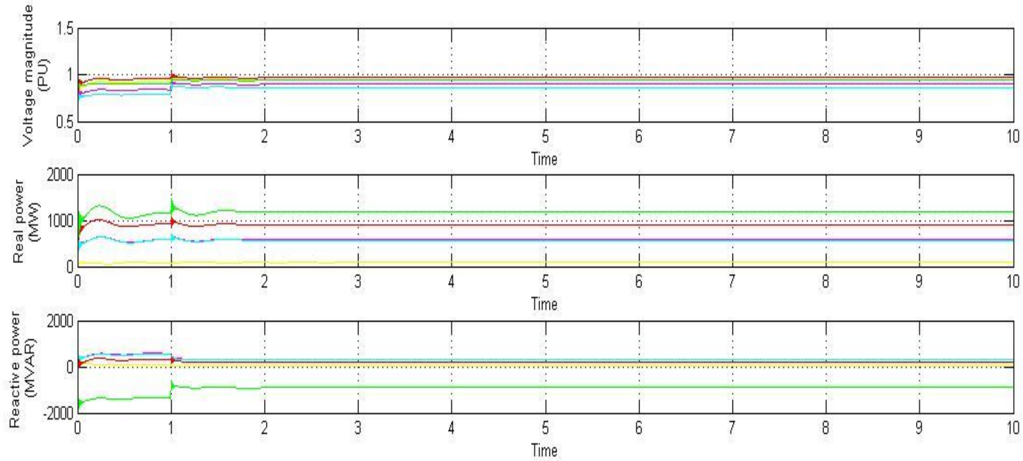

Figure 11: Simulation result of power system with FACT device SVC

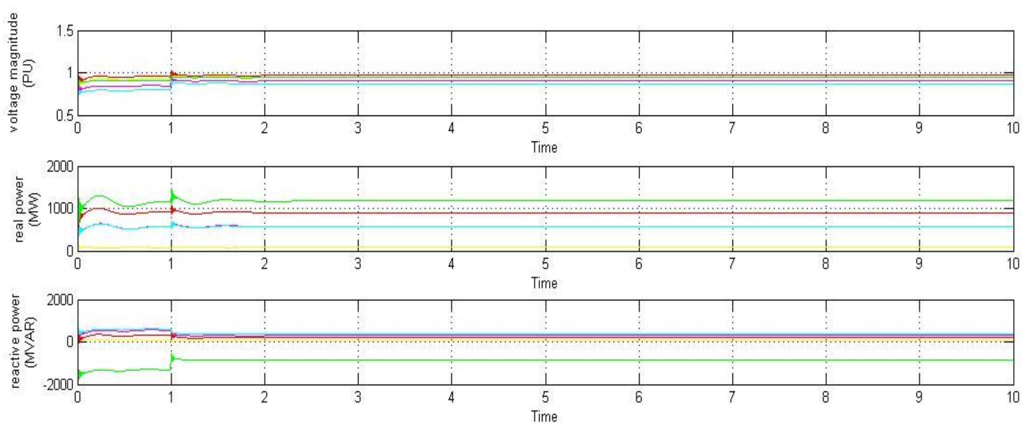

Figure 12: Simulation result of power system with FACT device STATCOM

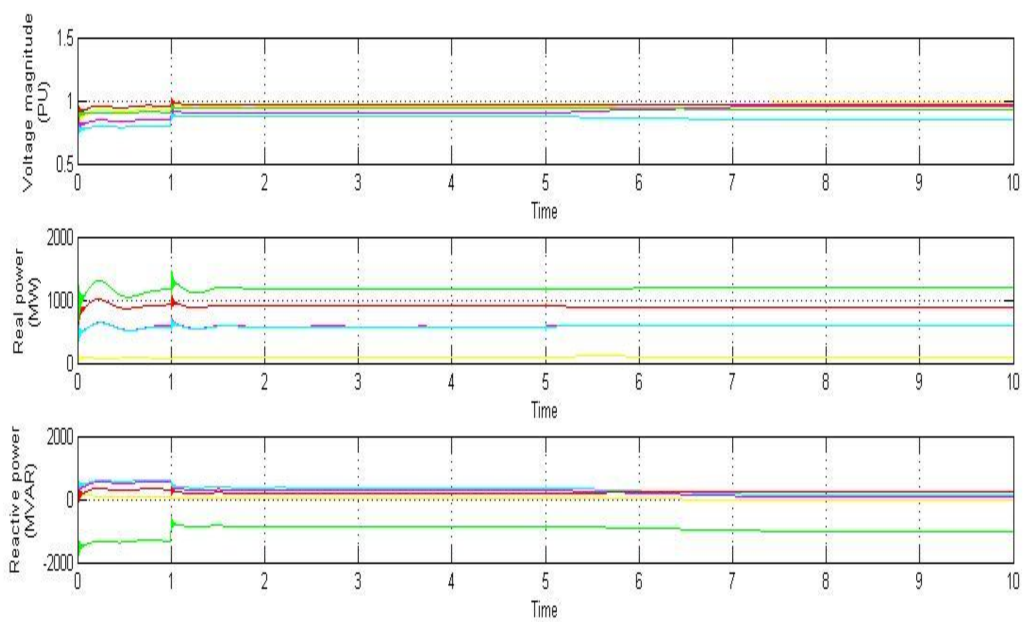

Figure 13: Simulation result of power system with FACT device UPFC

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VII. COMPARATIVE STUDY

A comparative study on voltage magnitude, real and reactive power of a power system with and without FACT controllers was analysed.

A. Abbreviations

Following abbreviations were used for the bar graph representation

SVC	Static VAR Compensator
STATCOM	Static Synchronous compensator
UPFC	Unified Power Flow Controller
WOFLWOF	Without Fault Without FACT Device
WFLWOF	With Fault Without FACT Device

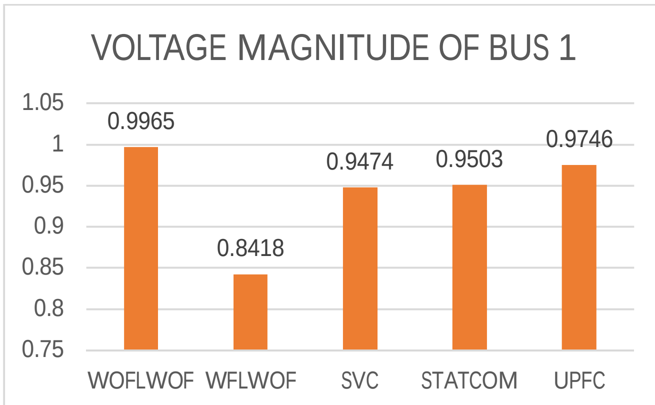

Figure 14 :Voltage Magnitude of bus 1

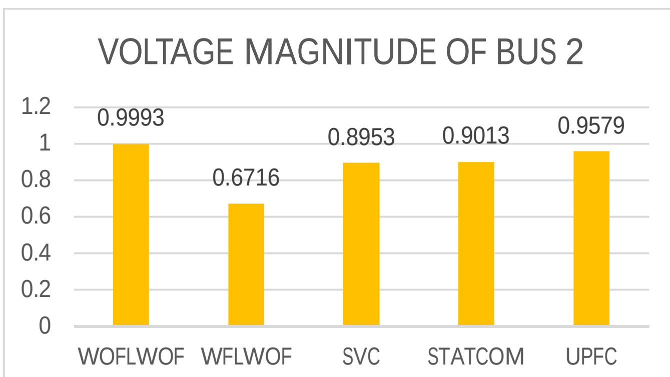

Figure 15: Voltage Magnitude of bus 2

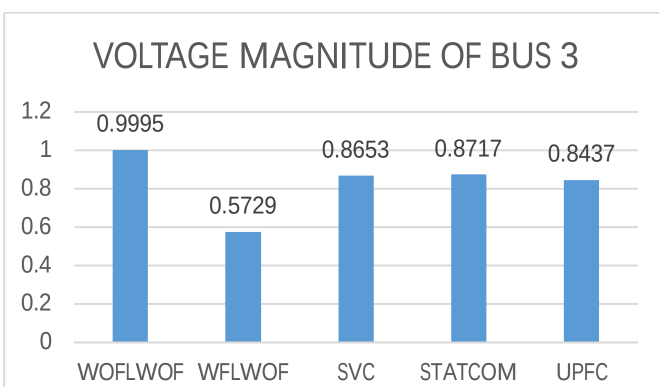

Figure 16: Voltage Magnitude of bus 3

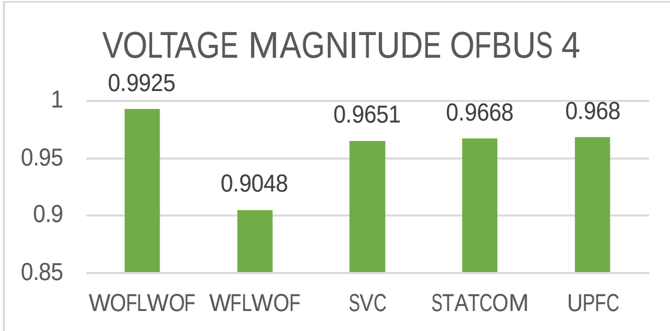

Figure 17: Voltage Magnitude of bus 4

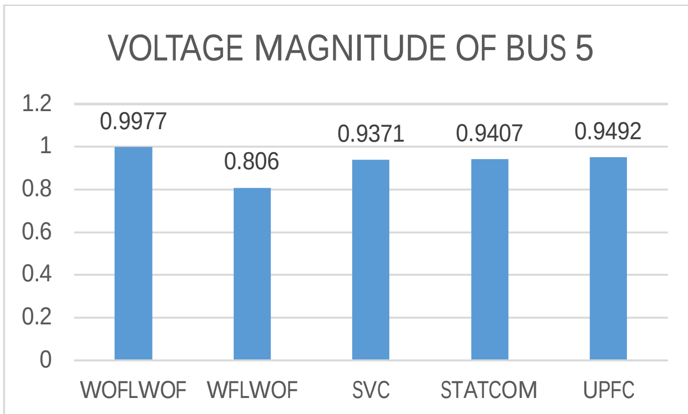

Figure 18: Voltage Magnitude of bus 5

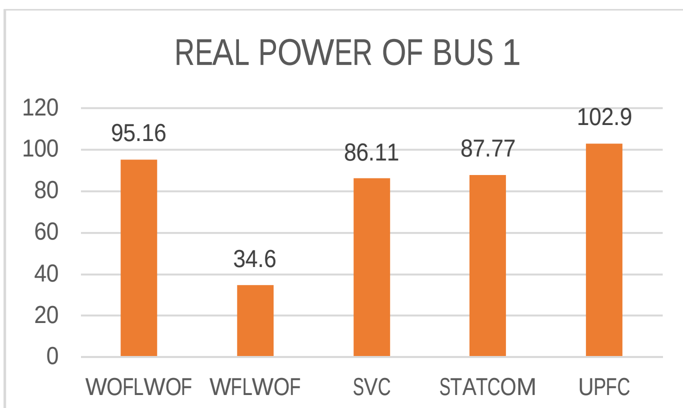

Figure 19: Real Power of bus 1

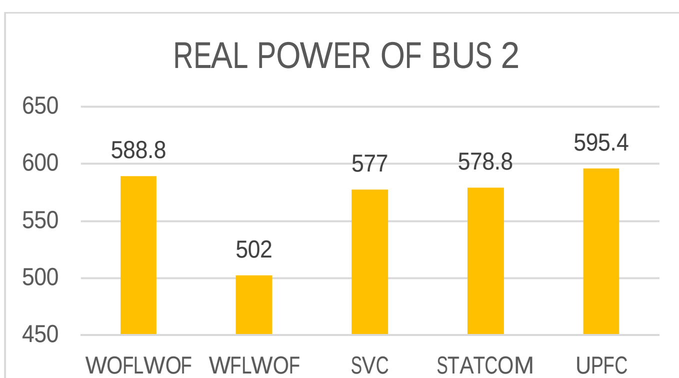

Figure 20: Real Power of bus 2

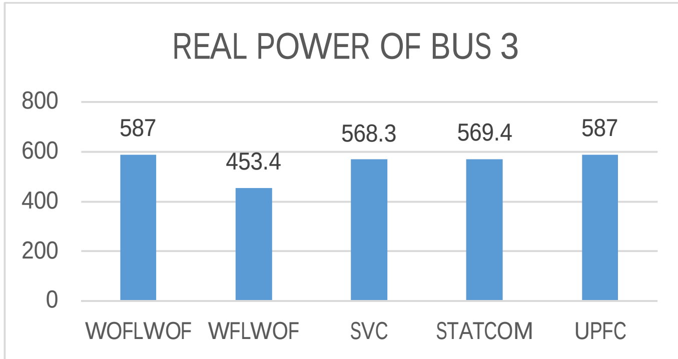

Figure 21: Real Power of bus 3

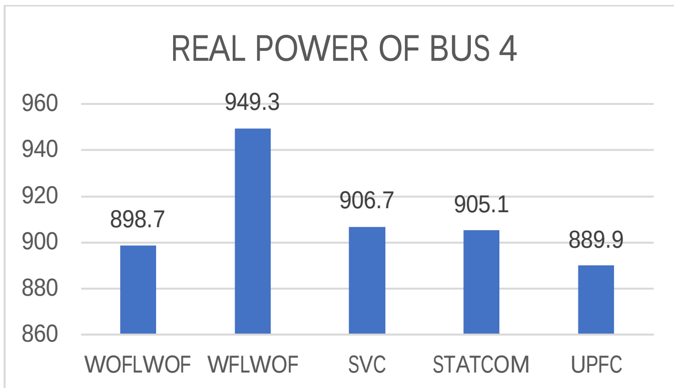

Figure 22: Real Power of bus 4

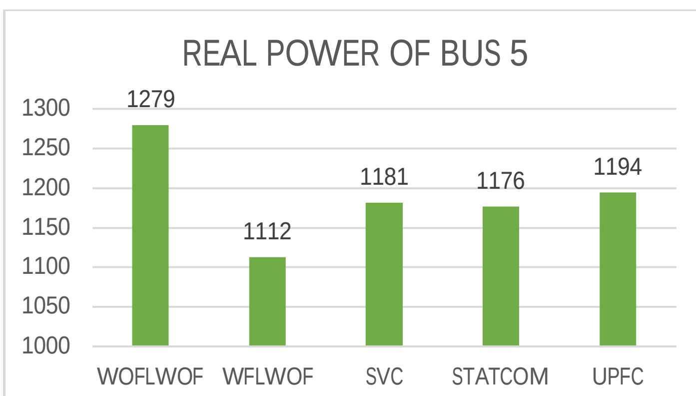

Figure 23: Real Power of bus 5

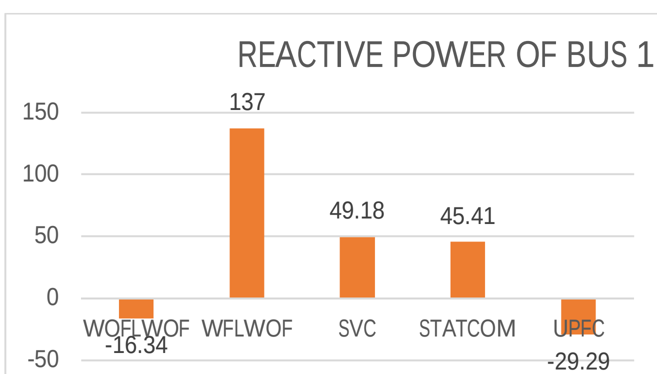

Figure 24: Reactive Power of bus 1

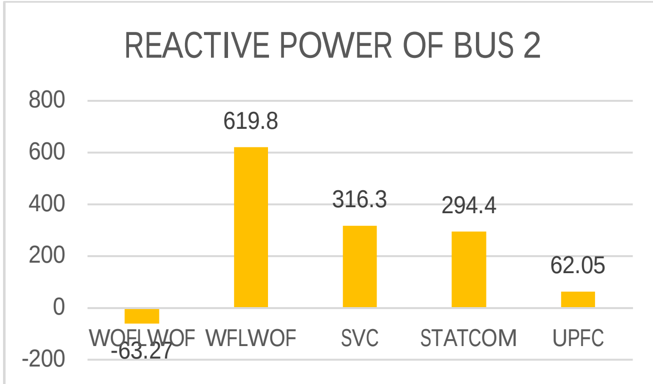

Figure 25: Reactive Power of bus 2

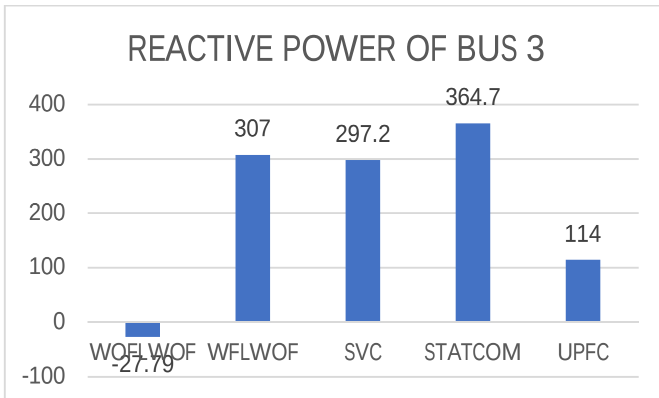

Figure 26: Reactive Power of bus 3

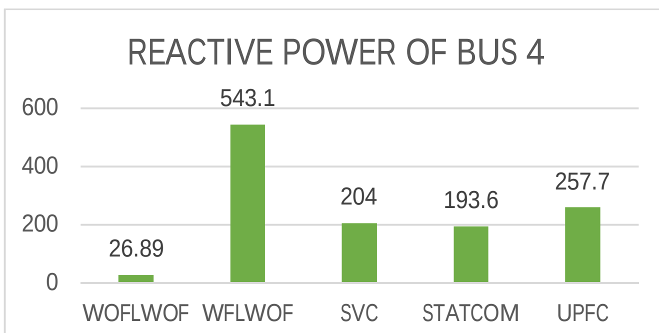

Figure 27: Reactive Power of bus 4

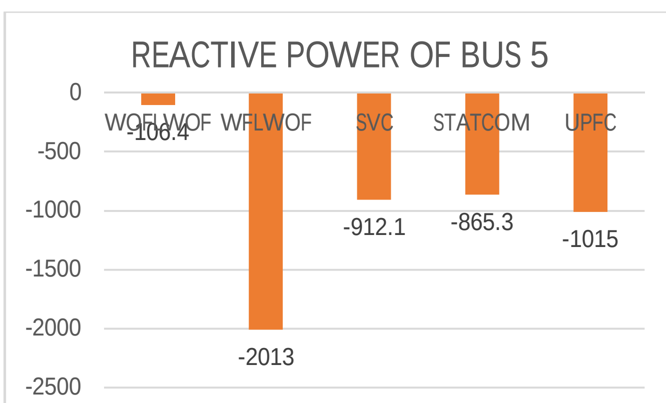

Figure 28: Reactive Power of bus

VIII. CONCLUSION

In this project on analysing the voltage magnitude, Active and Reactive power of the five buses in power system the stability of the power system has been improved when the power system is equipped with the FACT devices. Stability of the system is obtained by controlling the voltage magnitude, active and reactive power of the power system. Simulation results of the considered model power system when connected with FACT devices are showing positive response in terms of improved voltage stability of the power system. UPFC with series converter controls the power flow in five buses of the power system when the power system is subjected to with fault (L-G) and without fault. Similarly Shunt compensator of UPFC may be operated in voltage regulation or VAR control mode. SVC and STATCOM improves system voltage stability. Voltage regulation mode of SVC and STATCOM is successfully simulated in MATLAB. Simulations carried out showed that SVC and STATCOM provides good voltage regulation, active power and reactive power regulation capabilities, yet it is observed that UPFC providing better results than SVC and STATCOM.

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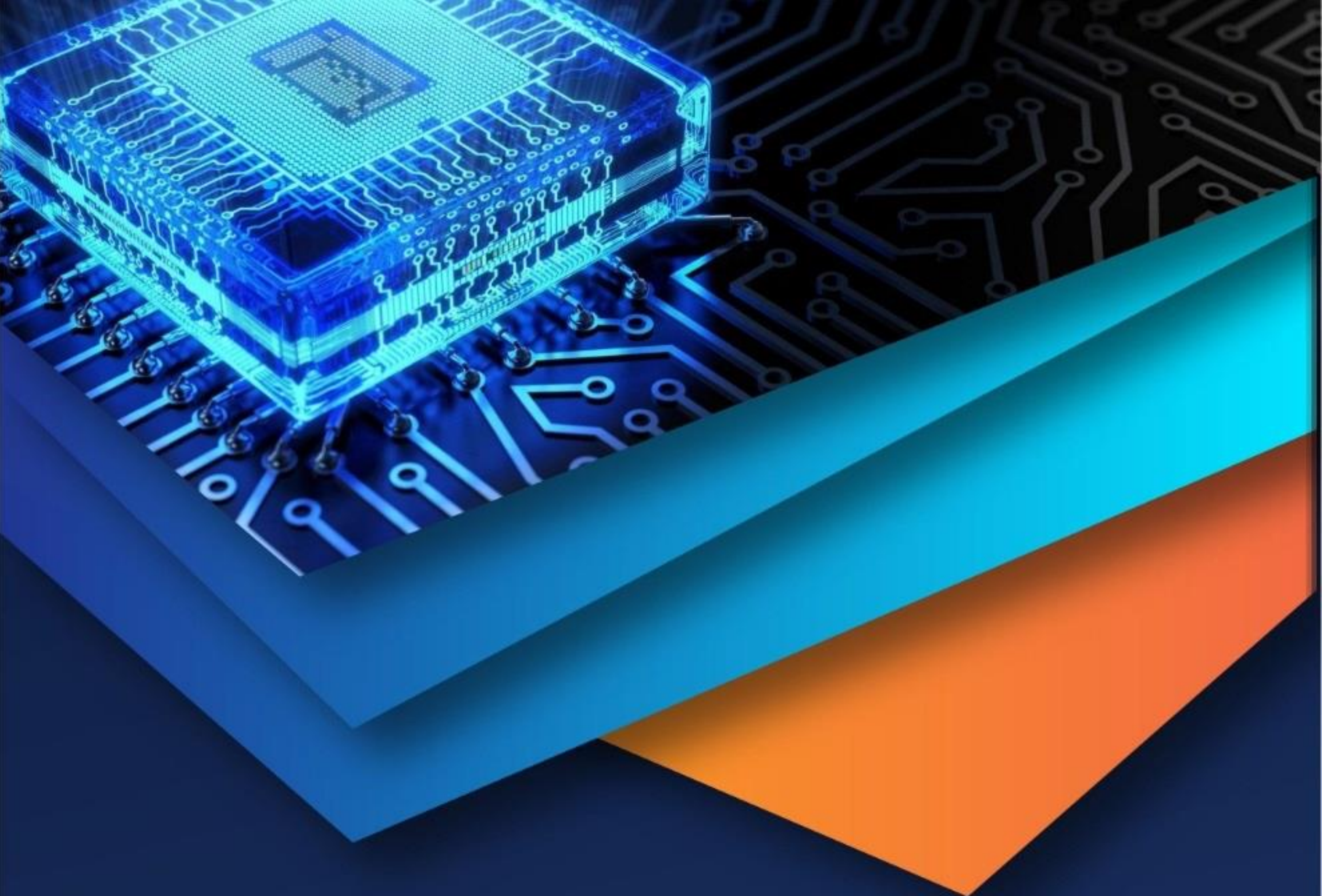

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