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MODELLING AND SIMULATION OF STATCOM CONTROL TOPOLOGIES FOR REACTIVE POWER COMPENSATION

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ABSTRACT: In increasing demand of power in recent system it is important to regulate the reactive power and voltage in the system. Due to new technology development in recent years the demand and use of Power electronics devices, Nonlinear Load, Switching & Arcing devices, etc. are increased which affects the Power quality in the system. Due to that kind of issues different types of power quality problems are occurred like voltage sag, swell, Active & Reactive Power unbalancing , Flicker, Transient stability etc. For mitigation these all power quality issues and enhancement of power quality Filter Techniques and FACTS devices are used in the power system. In this proposed work the main focus is on Reactive Power compensation using FACTS devices. For Reactive power compensation SVC and STATCOM compensating devices are used, but compare to SVC operation STATCOM is better for performance as well as large variety of control techniques. In this paper STATCOM device has been implemented using MATLAB-Simulink for Reactive power compensation in three phase system. After that the controlling methods like PI, Hysteresis, etc. will be compared with each other for Result Analysis and controlling methods comparative Analysis.

1. INTRODUCTION

The electric utility industry and consumers of electrical energy are facing new challenges for cutting the electric energy cost, improving energy utilization, enhancing electric energy efficiency, improving supply waveform power quality, reducing any safety hazards to personnel and protecting electronic sensitive computer and automatic data processing networks.

The growing use of nonlinear type electric loads causes a real challenge to any power quality and harmonic mitigation for electric utilities around the world, especially in the existing era of unregulated electricity market where: competition, supply quality, security and reliability are now key issues for any economic survival. Network pollution is characterized by the nonlinear electric load ability to distortion modify and change the voltage and current waveform RMS due to its inherent nonlinearity. The global need for electrical energy sources, energy conservation measures, and rising world energy demand drive exiting power systems and transmission lines toward their crucial stability and thermal limits and grid security, reliability, and voltage stability. This can result in sustained faults, Brownouts, Blackouts, and severe power quality problems.
To reduce system active and reactive power losses and resultant poor power factor problems due to poor power quality, fixed, switched, and modulated capacitor banks have been widely used. Fixed power filters which have low cost and simple robust structure are usually installed particularly in industrial utilization networks to improve power quality and reduce the level of harmonic distortion. Active power filters can be used to fulfil power quality requirements but they are expensive and consume large current rating. Other option is using the switched/modulated family of passive filters and capacitive compensators developed. Advent of Flexible A. C. Transmission System (FACTS) based Switched Capacitor Compensation (SCC) utilized with dynamic control systems for compensation of reactive power and harmonics to system [2]. Switched capacitor compensation is to provide or absorb the required reactive power and harmonic mitigation from power supply system. The capacitors store energy in an electric field, Inductors store energy in a magnetic field. To reduce system active and reactive power losses and resultant poor power factor problems due to poor power quality and waveform distortion due to harmonics due to nonlinear load, the different arrangement of capacitor is used like fixed, switched, and modulated. Active power filters can be used to fulfil power quality requirements but they are expensive and consume large current rating. For this reason I have used switched capacitor compensation with the help of passive filters and capacitive compensators. The switching of capacitor is done by two Insulated Gate Bipolar Transistor. The main objective of this STATCOM scheme is to provide harmonic compensation.

2. LITERATURE SURVEY

Reactive power is the power that supplies the stored energy in reactive elements. Power, as we know, consists of two components, active and reactive power. The total sum of active and reactive power is called as apparent power. In AC circuits, energy is stored temporarily in inductive and capacitive elements, which results in the periodic reversal of the direction of flow of energy between the source and the load.
The average power after the completion of one whole cycle of the AC waveform is the real power, and this is the usable

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energy of the system and is used to do work, whereas the portion of power flow which is temporarily stored in the form of magnetic or electric fields and flows back and forth in the transmission line due to inductive and capacitive network elements is known as reactive power. This is the unused power which the system has to incur in order to transmit power. Inductors (reactors) are said to store or absorb reactive power, because they store energy in the form of a magnetic field. Therefore, when a voltage is initially applied across a coil, a magnetic field builds up, and the current reaches the full value after a certain period of time. This in turn causes the current to lag the voltage in phase.

Capacitors are said to generate reactive power, because they store energy in the form of an electric field. Therefore when current passes through the capacitor, a charge is built up to produce the full voltage difference over a certain period of time. Thus in an AC network the voltage across the capacitor is always charging. Since, the capacitor tends to oppose this change; it causes the voltage to lag behind current in phase.

In an inductive circuit, we know the instantaneous power to be:

$$p = V_{max}I_{max}\cos\omega t\cos(\omega t - \theta)$$

$$p = \frac{VmaxImax}{2}\cos\theta\,(1+\cos 2\omega t) + \frac{VmaxImax}{2}\sin\theta\sin 2\omega t$$

The instantaneous reactive power is given by:

$$\frac{VmaxImax}{2}\sin\theta\sin 2\omega t$$

Where:
p = instantaneous power
Vmax = Peak value of the voltage waveform
Imax = Peak value of the current waveform
ω = Angular frequency
= 2πf where f is the frequency of the waveform.
t = Time period
θ = Angle by which the current lags the voltage in phase

From here, we can conclude that the instantaneous reactive power pulsates at twice the system frequency and its average value is zero and the maximum instantaneous reactive power is given by:

$Q = |V|\,|I|\sin\theta$

The zero average does not necessarily mean that no energy is flowing, but the actual amount that is flowing for half a cycle in one direction, is coming back in the next half cycle.

3. COMPENSATION TECHNIQUES

The principles of both shunt and series reactive power compensation techniques are described below:

SHUNT COMPENSATION

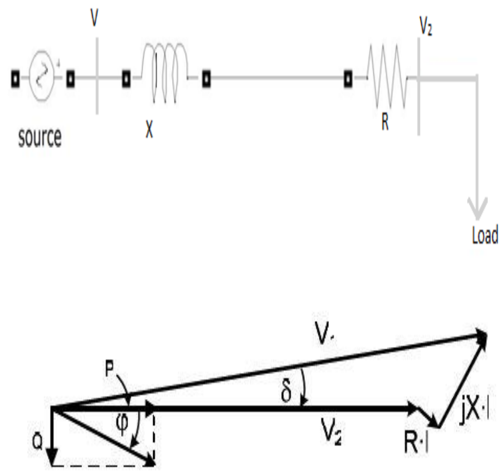
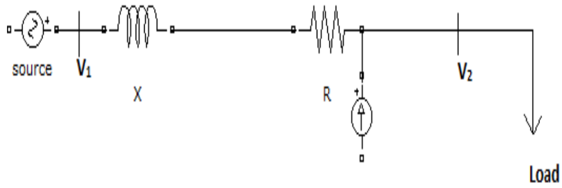


Fig 3.1 Shunt Compensation Concept



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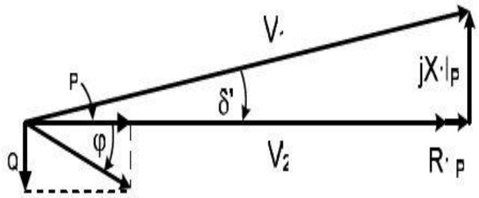

Fig 3.2 Shunt Compensation diagram

The figure 3.1 comprises of a source V1, a power line and an inductive load. The figure 3.1 shows the system without any type of compensation. The phasor diagram of these is also shown above. The active current Ip is in phase with the load voltage V2. Here, the load is inductive and hence it requires reactive power for its proper operation and this has to be supplied by the source, thus increasing the current from the generator and through the power lines. Instead of the lines carrying this, if the reactive power can be supplied near the load, the line current can be minimized, reducing the power losses and improving the voltage regulation at the load terminals. This can be done in three ways: 1) A voltage source. 2) A current source. 3) A capacitor.

In this case, a current source device is used to compensate Iq, which is the reactive component of the load current. In turn the voltage regulation of the system is improved and the reactive current component from the source is reduced or almost eliminated. This is in case of lagging compensation. For leading compensation, we require an inductor. Therefore we can see that, a current source or a voltage source can be used for both leading and lagging shunt compensation, the main advantages being the reactive power generated is independent of the voltage at the point of connection.

SERIES COMPENSATION

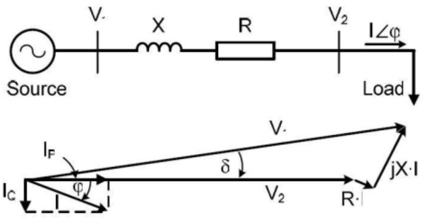

Fig 3.3 Series Compensation Concept

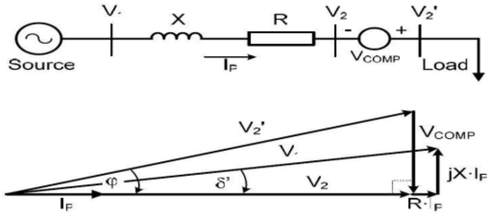

Fig 3.4 Series Compensation diagram

Series compensation can be implemented like shunt compensation, i.e. with a current or a voltage source as shown in figure 3.4. We can see the results which are obtained by series compensation through a voltage source and it is adjusted to have unity power factor at V2. However series compensation techniques are different from shunt compensation techniques, as capacitors are used mostly for series compensation techniques. In this case, the voltage Vcomp has been added between the line and the load to change the angle V2'. Now, this is the voltage at the load side. With proper adjustment of the magnitude of Vcomp, unity power factor can be reached at V2.

FACTS devices used

Flexible AC transmission system or FACTS devices used are:
1) VAR generators.
a) Fixed or mechanically switched capacitors.
b) Synchronous condensers.
c) Thyristorized VAR compensators.
(i) Thyristors switched capacitors (TSCs).
(ii) Thyristor controlled reactor (TCRs).
(iii) Combined TSC and TCR.
(iv) Thyristor controlled series capacitor (TCSC).

2) Self Commutated VAR compensators.
a) Static synchronous compensators (STATCOMs).
b) Static synchronous series compensators (SSSCs).
c) Unified power flow controllers (UPFCs).
d) Dynamic voltage restorers (DVRs).

NEED FOR REACTIVE POWER COMPENSATION

The main reason for reactive power compensation in a system is:

- The voltage regulation;
- Increased system stability;
- Better utilization of machines connected to the system;
- Reducing losses associated with the system; and
- To prevent voltage collapse as well as voltage sag.

The impedance of transmission lines and the need for lagging VAR by most machines in a generating system results in the consumption of reactive power, thus affecting the stability limits of the system as well as transmission lines. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. It is very much required that the lines be relieved of the obligation to carry the reactive power, which is better provided near the generators or the loads. Shunt compensation can be installed near the load, in a distribution substation or transmission substation.

4. STATCOM TECHNOLOGY

This shunt connected static compensator was developed as an advanced static VAR compensator where a voltage source convertor (VSC) is used in- stead of the controllable reactors and switched capacitors. Although VSCs require self-commutated power semiconductor devices such as GTO, IGBT, IGCT, MCT, etc (with higher costs and losses) unlike in the case of variable impedance type SVC which use thyristor devices, there are many technical advantages of a STATCOM over a SVC.

The principal benefit of the STATCOM for transient stability enhancement is direct through rapid bus voltage control. In particular, the STATCOM may be used to enhance power transfer during low-voltage conditions, which typically predominate during faults, decreasing the acceleration of local generators. An additional benefit is the reduction of the demagnetizing effects of faults on local generation. STATCOM behave analogously to synchronous compensators, except that STATCOM have no mechanical inertia and are therefore capable of responding much more rapidly to changing system conditions. When compared to synchronous machines, they do not contribute to short circuit currents and have no moving parts. However, the system has a symmetric lead-lag capability and can theoretically go from full lag to full lead in fraction of cycles.

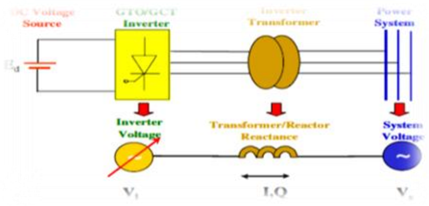

Fig. 4.1 STATCOM arrangement in power system

A STATCOM, connected in shunt, with the system is capable of improving transient stability by compensating the reactive power at the point of common connection. The ultimate objective of applying reactive shunt compensation in a transmission system is to increase the transmittable power during transients. This is achieved by increasing (decreasing) the power transfer capability when the machine angle increases (decreases). The key benefits of Statcom

- Faster response
- Requires less space as bulky passive components (such as reactors) are eliminated
- Inherently modular and relocatable
- It can be interfaced with real power sources such as battery, fuel cell or SMES (superconducting magnetic energy storage)
- A STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit of capacitive susceptance).
- It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload. In a SVC, the maximum reactive current is determined by the rating of the passive components – reactors and capacitors.

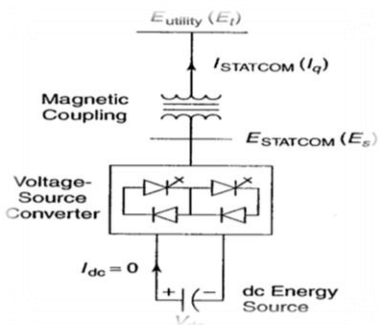

Fig. 4.2 Single Line Diagram of STATCOM

Figure 4.2 shows the single line diagram of a STATCOM. In this configuration the VSC is connected with utility system through magnetic coupling. By controlling the converter output voltage E_s, the reactive power exchange from converter to ac system can achieve easily. That is if the amplitude of output voltage is increased above that of the utility bus voltage, E_t, then a current flows through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system.

If the amplitude of the output voltage is decreased below the utility bus voltage, then the current flows from the ac system to the converter and the converter absorbs inductive-reactive power from the ac system. If the output voltage equals the ac system voltage, the reactive-power exchange becomes zero, in which case the STATCOM is said to be in a floating state. If the DC capacitor voltage, V_{dc}, is increased from its nominal value, the STATCOM is "overexcited" (capacitive mode) and generates reactive power. If the voltage of the DC capacitor bank is decreased below the nominal value, the STATCOM is "under excited" (inductive mode) and absorbs reactive power from the system. This is completely analogous to increasing or decreasing the field voltage of a synchronous compensator.

5. MODELLING AND SIMULATION

MATLAB SIMULATION OF STATCOM FOR REACTIVE POWER COMPENSATION

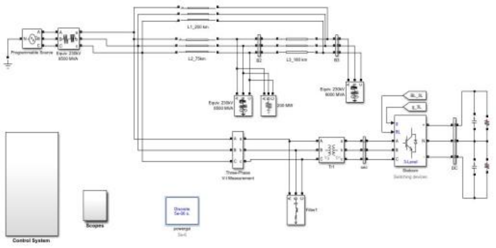

Fig 5.1- Reactive Power Compensation using STATCOM Matlab system

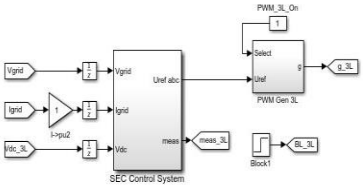

Fig 5.2- STATCOM controlling system

SIMULATION RESULTS

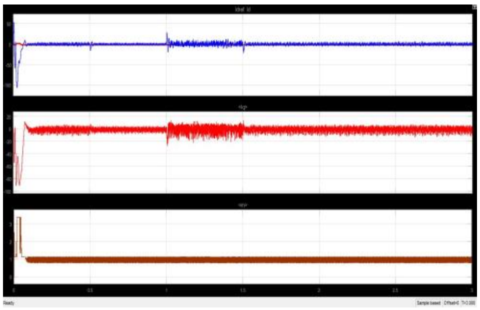

Fig 5.3- Vd, Vq Reference controlling output parameters

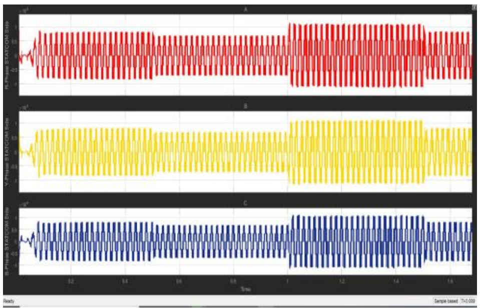

Fig 5.4- STATCOM side three phase output voltage

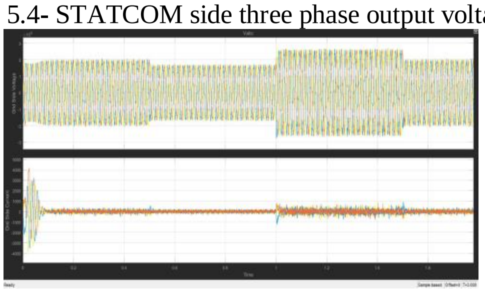

Fig 5.5- Grid Side A.C output voltage and current

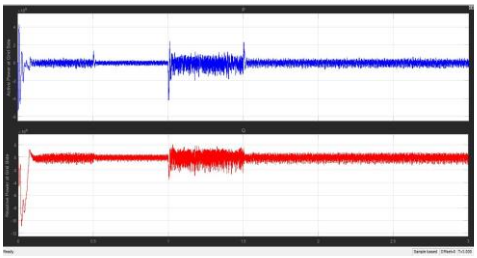

Fig 5.6- Active and Reactive Power variation at Grid Side using STATCOM

6. PROPOSED STATCOM SYSTEM WITH PLL AND PI CONTROL

The rectifier and the inverter which are gate-pulse based IGBT converters connected in series. The converters are interconnected through a 75-km line and smoothing reactors as shown in Fig 5.7. The converter transformers (Wye grounded/Wye/Delta) are modelled with Three Phase Transformer (Three-Winding) blocks. The Matlab simulation of GRID NETWORK system with VSC control is shown in fig 5.7 below.

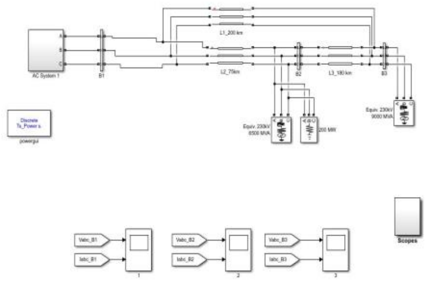

Figure 5.7: Simulink Model of Grid Network without STATCOM

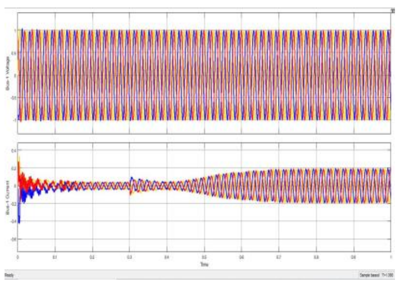

Fig 5.8- Bus-1 Voltage and Current without STATCOM

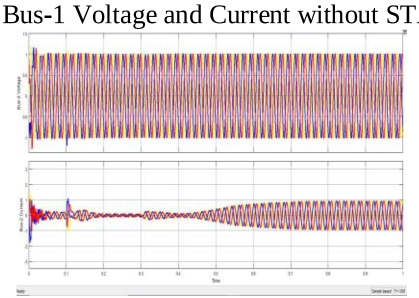

Fig 5.9- Bus-2 Voltage and Current without STATCOM

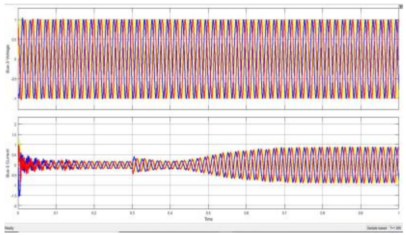

Fig 5.10- Bus-3 Voltage and Current without STATCOM

The firing-angle control system is configured using pulse generator in series, one of which is operated as a modified Converter bridge configuration. The Grid network power converters with thyristor valves will be assembled in a converter bridge of twelve pulse configuration. This is accomplished by star-star connection and star-delta connection. Reduction of harmonic effects is another factor of investigation.

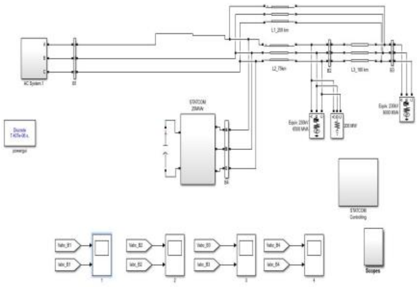

Fig 5.11- Simulink Model of Grid Network with STATCOM

Here, MATLAB/SIMULINK program is used as the simulation tool. The firing angles are always maintained at almost constant or as low as possible so that the voltage control can be carried out. Three level IGBT bridges are the best way to control the DC voltage. Other bridges or convertors are not preferable of series due to the increase in harmonic content. The control of power can be achieved by two ways i.e., by controlling the current or by controlling the voltage.

It is crucial to maintain the voltage in the DC link constant and only adjust the current to minimize the power loss. The rectifier station is responsible for current control and inverter is used to regulate the DC voltage. Firing angle at rectifier station and extinction angle at inverter station are varied to examine the system performance and the characteristics of the grid network system. The voltage and current waveform are shown in figure. The output is get with STATCOM in grid network system.

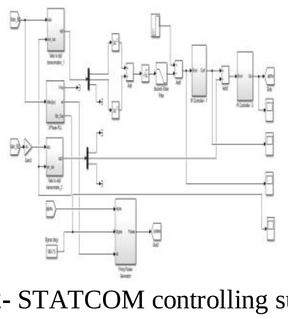

Fig 5.12- STATCOM controlling subsystem

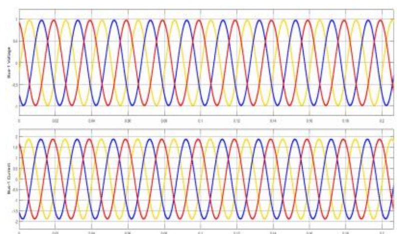

Fig 5.13- Bus-1 Voltage and Current with STATCOM (Zoom Scale)

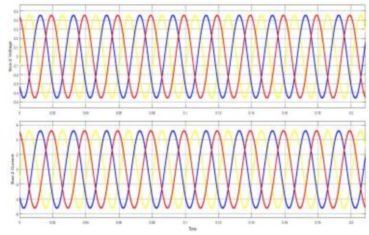

Fig 5.14- Bus-2 Voltage and Current with STATCOM (Zoom Scale)

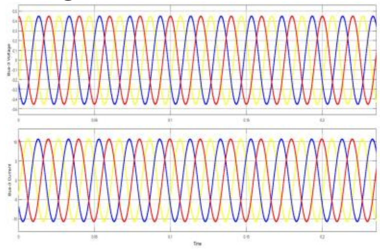

Fig 5.15- Bus-3 Voltage and Current with STATCOM (Zoom Scale)

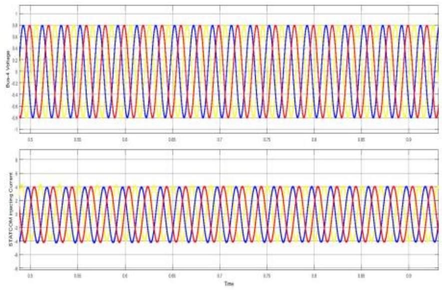

Fig 5.16- Voltage and Current across STATCOM at Bus-4

7. SIMULATION RESULTS FOR REACTIVE POWER COMPENSATION

In the below section we have develop the Matlab simulation of grid network with STATCOM for different Reactive Power Compensation condition analysis. In this different conditions the effect is available on the bus-2 and bus-4 across STATCOM. While the voltage and current of Bus-1 and Bus-3 will remain normal shown in the simulation results below.

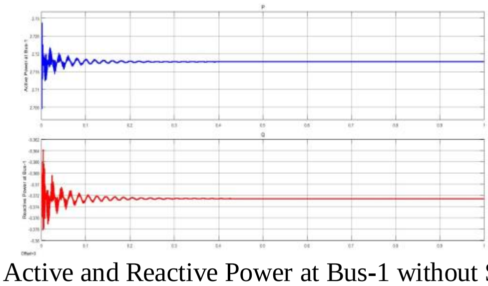

Fig 5.17- Active and Reactive Power at Bus-1 without STATCOM

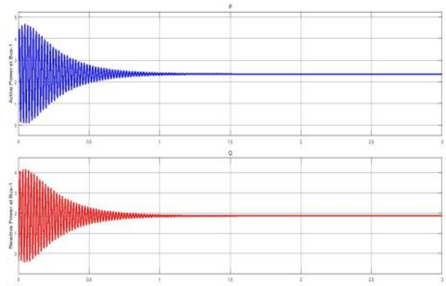

Fig 5.18- Active and Reactive Power at Bus-1 with STATCOM

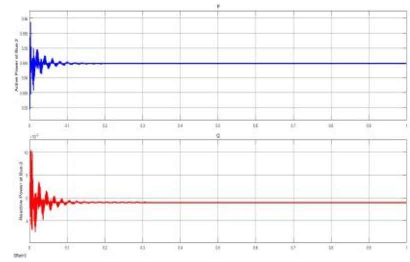

Fig 5.19- Active and Reactive Power at Bus-2 without STATCOM

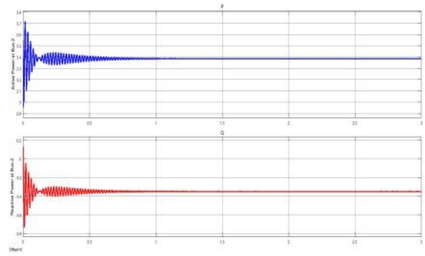

Fig 5.20- Active and Reactive Power at Bus-2 with STATCOM

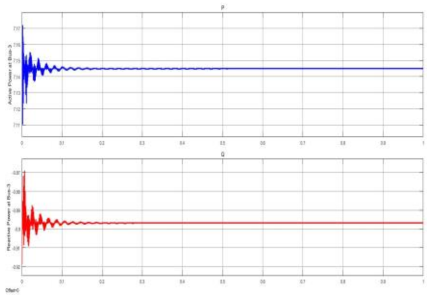

Fig 5.21- Active and Reactive Power at Bus-3 without STATCOM

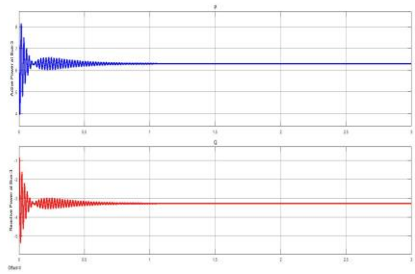

Fig 5.22- Active and Reactive Power at Bus-3 with STATCOM

8. CONCLUSION

The study of the basic principles of the STATCOM is carried out as well as the basics of reactive power compensation using a STATCOM. A power flow model of the STATCOM is attempted and it is seen that the modified load flow equations help the system in better performance. The bus system shows improved plots and the thus we can conclude that the addition of a STATCOM controls the output of a bus in a robust manner.

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