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MATLAB SIMULATION OF UNIFIED POWER QUALITY CONDITIONER FOR POWER QUALITY IMPROVEMENT

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ABSTRACT: Aim of this paper is to represents the design and control strategy of UPQC to get the highest benefit in terms of maximum power transfer capability and system stability. The UPQC design and controlling is shown using current source topology. FACTS devices are very effective and capable of increasing the power transfer capability of a line, as thermal limits permit, while maintaining the same degree of stability. With the improvements in current and voltage handling capabilities of the power electronic devices that have allowed for the development of Flexible AC Transmission System (FACTS), the possibility has arisen in using different types of controllers for efficient shunt and series compensation In series compensation, the FACTS Sis connected in series with the power system. It works as a controllable voltage source. Shunt compensation, power system is connected in shunt with FACTS. It works as a controllable current source. The rating of a shunt FACT device is selected in such a way so as to control the voltage equal to sending end voltage at the bus of the shunt FACT device. A series capacitor is placed at the centre to get the maximum power transfer capability and compensation efficiency for the selected rating of the shunt FACTS device.

I. INTRODUCTION

Introduction

The flexible AC transmission system (FACTS) has received much attention in the last 2 decades. It uses high current power electronic devices to control the voltage, power flow, stability, etc. of a transmission system. FACTS technologies can essentially be defined as highly engineered power-electronics-based systems, integrating the control and operation of advanced power semiconductor based converters (or valves) with software based information and control systems, which produce a compensated response to the transmission network that is interconnected via conventional switchgear and transformation equipment. FACTS devices can be connected to a transmission line in various ways, such as in series with the power system (series compensation), in shunt with the power system (shunt compensation), or both in series and shunt. For example, the static VAR compensator (SVC) and static synchronous compensator (STATCOM) are connected in shunt; static synchronous series compensator (SSSC) and Thyristors controlled series capacitor (TCSC) are connected in series; Thyristors controlled phase shifting transformer (TCPST) and unified power flow controller (UPFC) are connected in a series and shunt combination. In series compensation, the FACTS is connected in series with the power system. It works as a controllable voltage source. Series inductance occurs in long transmission lines, and when a large current flow causes a large voltage drop. To compensate, series capacitors are connected. In shunt compensation, power system is connected in shunt with the FACTS. It works as a controllable current source. The pressure associated with economical and environmental constraints has forced the power utilities to meet the future demand by fully utilizing the existing resources of transmission facilities without building new lines. FACTS devices are very effective and capable of increasing the power transfer capability of a line, as thermal limits permit, while maintaining the same degree of stability. Numerous recent applications of FACTS have proven to be cost-effective, long-term solutions. With the improvements in current and voltage handling capabilities of the power electronic devices that have allowed for the development of Flexible AC Transmission System (FACTS), the possibility has arisen in using different types of controllers for efficient shunt and series compensation. Applying FACTS on a broad-scale basis for both local and. Shunt FACTS devices are used for controlling transmission voltage, power flow, reducing reactive losses, and damping of power system oscillations for high power transfer levels.

General

Modern power systems are designed to operate efficiently to supply power on demand to various load centers with high reliability. The generating stations are often located at distant locations for economic, environmental and safety reasons. For example, it may be cheaper to locate a thermal power station at pithead instead of transporting coal to load centers. Hydropower is generally available in remote areas. A nuclear plant may be located at a place away from urban areas. Thus, a grid of transmission lines operating at high or extra high voltages is required to transmit power from the generating stations to the load centers. In addition to transmission lines that carry power from the sources to loads, modern power systems are also highly interconnected for economic reasons. The interconnected systems benefit by (a) exploiting load diversity (b) sharing of generation reserves and (c) economy gained from the use of large efficient units without sacrificing reliability. However, there is also a downside to ac system interconnection the security can be adversely affected as the disturbances initiated in a particular area can spread and propagate over the entire system resulting in major blackouts caused by cascading outages. Conventional power quality mitigation equipment use passive elements and do not always respond correctly as nature of power system condition change. The term active power filter (APF) is a widely used terminology in the area of power quality improvement. One modern solution that deals with both load current and supply voltage imperfections is the UPQC. The UPQC is one of the APF family members. The UPQC is a combination of series and shunt active filters connected in cascade via a common DC link capacitor. The main purpose of a UPQC is to compensate for supply voltage power quality issues such as, sags, swells, unbalance, flicker, harmonics, and for load current power quality problems such as, harmonics, unbalance, reactive current and neutral current. To maintain the controlled power quality regulations, some kind of compensation at all the power levels is becoming a common practice. At the distribution level, UPQC is a most attractive solution to compensate several major power quality problems. It basically consists of two voltage source inverters connected back to back using a common dc bus capacitor. This paper deals with a novel concept of optimal utilization of a UPQC. The voltage sag/swell on the system is one of the most important power quality problems. The voltage sag/swell can be effectively compensated using a dynamic voltage restorer, series active filter, UPQC, etc. Among the available power quality enhancement devices, the UPQC has better sag/swell compensation capability.

II. POWER QUATY AND ROLE OF FACTS DEVICE

DEFINITION OF POWER QUALITY:-

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment.” As appropriate as this description might seem, the limitation of power quality to “sensitive electronic equipment” might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance.

All of these devices and others react adversely to power quality issues, depending on the severity of problems. A simpler and perhaps more concise definition might state: “Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy.” This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms. Along with definitions of the terms, explanations are included in parentheses where necessary. This chapter also attempts to explain how power quality factors interact in an electrical system. The common concerns of power quality are long duration voltage variations (overvoltage, under voltage, and sustained interruptions), short duration voltage variations (interruption, sags (dips), and swells), voltage imbalance, waveform distortion (DC offset, harmonics, inter harmonics, notching and noise), voltage fluctuation (voltage flicker) and power frequency variations. Most reasons of these concerns stems from loads connected to electric supply systems.

There are two types of loads, linear and nonlinear. Motors, heaters and incandescent lamps are examples of linear load produce a current proportional to the voltage. The nonlinear load uses high-speed electronic power switching devices to convert the AC supply voltage to a constant DC voltage used by the internal circuits. During converting, harmonic currents on the power grid are generated. Producing harmonic currents at the point of common coupling (PCC) cause several adverse effects such as a line voltage distortion at PCC, equipment overheating, transformer derating, overheating, failure of sensitive electronic equipment, interference with telecommunication systems due to harmonic noises, flickering of fluorescent lights, erratic operation of circuit breakers and relays, fuse blowing and electronic equipment shutting down, conductor overheating due to Triplen harmonics in 3-phase 4- wire system, increased RMS current. Personal computers, fax machines, printers, UPS, adjustable speed drives, electronic lighting ballasts, ferromagnetic devices, DC motor drives and arcing equipment are examples of nonlinear loads.

Power Quality Issues and Its Consequences:-

Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or malfunctioning of customer equipment. Power quality is a two-pronged issue, with electronic equipment playing both villain and victim. Most new electronic equipment, while more efficient than its mechanical predecessors, consumes electricity differently than traditional mechanical appliances. Power supply quality issues and resulting problems are consequences of the increasing use of solid state switching devices, nonlinear and power electronically switched loads, electronic type loads .the advent and wide spread of high power semiconductor switches at utilization, distribution and transmission leaves have non sinusoidal currents.

Voltage Sag

Voltage sags and momentary power interruptions are probably the most important Power Quality problem affecting industrial and large commercial customers. These events are usually associated with a fault at some location in the supplying power system. Interruptions occur when the fault is on the circuit supplying the customer. But voltage sags occur even if the faults happen to be far away from the customer's site. Voltage sags lasting only 4-5 cycles can cause a wide range of sensitive customer equipment to drop out. To industrial customers, voltage sag and a momentary interruption are equivalent if both shut their process down. A typical example of voltage sag is shown in fig.2.1

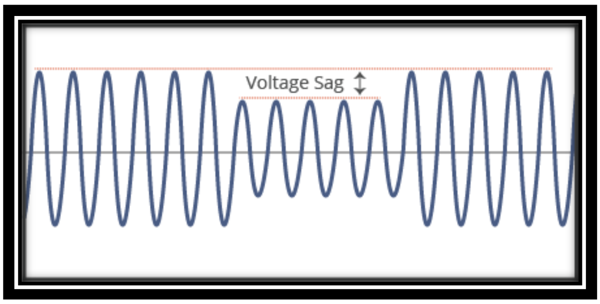

Fig.2.1- Voltage Sag condition

Voltage Swell

A swell is the reverse form of Sag, having an increase in AC Voltage for duration of 0.5 cycles to 1 minute's time. For swells, high-impedance neutral connections, sudden large load reductions, and a single-phase fault on a three phase system are common sources. Swells can cause data errors, light flickering, electrical contact degradation, and semiconductor damage in electronics causing hard server failures. Our power conditioners and UPS Solutions are common solutions for swells.

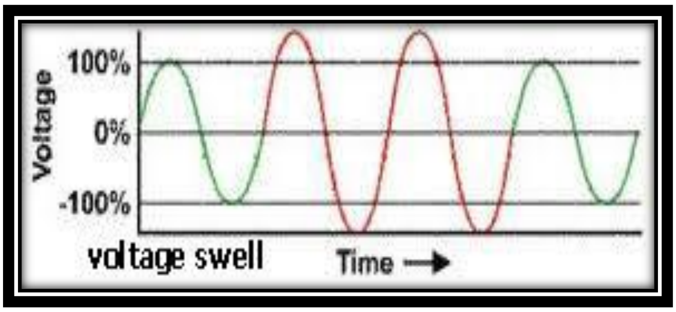

Fig.2.2-Voltage swells condition

It is important to note that, much like sags, swells may not be apparent until results are seen. Having your power quality devices monitoring and logging your incoming power will help measure these events.

Over-voltage

Over-voltages can be the result of long-term problems that create swells. Think of an overvoltage as an extended swell. Over-voltages are also common in areas where supply transformer tap settings are set incorrectly and loads have been reduced. Over-voltage conditions can create high current draw and cause unnecessary tripping of downstream circuit breakers, as well as overheating and putting stress on equipment. Since an overvoltage is a constant swell, the same UPS and Power Conditioners will work for these. Please note however that if the incoming power is constantly in an overvoltage condition, the utility power to your facility may need correction as well. The same symptoms apply to the over-voltages and swells however since the overvoltage is more constant you should expect some excess heat. This excess heat, especially in data center environments, must be monitored. If you are experiencing any of these power quality problems we have solutions ranging from Power Conditioners / Voltage Regulators to traditional UPS Systems and Flywheel UPS Solutions.

Swell causes

As discussed previously, swells are less common than voltage sags, but also usually associated with system fault conditions. A swell can occur due to a single line-to ground fault on the system, which can also result in a temporary voltage rise on the un faulted phases. This is especially true in ungrounded or floating ground delta systems, where the sudden change in ground reference result in a voltage rise on the ungrounded phases. On an ungrounded system, the line-to ground voltages on the ungrounded phases will be 1.73 p.u during a fault condition. Close to the substation on a grounded system, there will be no voltage rise on un faulted phases because the substation transformer is usually connected delta-wye, providing a low impedance path for the fault current. Swells can also be generated by sudden load decreases. The abrupt interruption of current can generate a large voltage, per the formula:-

$v = L\, di/dt$, where L is the inductance of the line, and di/dt is the change in current flow. Switching on a large capacitor bank can also cause a swell, though it more often causes an oscillatory transient.

Cost of poor power quality:-

Poor Power Quality can be described as any event related to the electrical network that ultimately results in a financial loss. Possible consequences of poor Power Quality includes as follows:-

Unexpected power supply failures (breakers tripping, fuses blowing).

- Equipment failure or malfunctioning.
- Equipment overheating (transformers, motors) leading to their lifetime reduction.
- Damage to sensitive equipment (PC's, production line control systems).
- Electronic communication interferences.
- Increase of system losses.
- Need to oversize installations to cope with additional electrical stress with consequential increase of installation and running costs and associated higher carbon footprint.
- Penalties imposed by utilities because the site pollutes the supply network too much.

The following are the main contributors to Low Voltage poor Power Quality can be defined:-

1. Reactive power, as it loads up the supply system unnecessary, Harmonic pollution, as it causes extra stress on the networks and makes installations run less efficiently,
2. Load imbalance, especially in office building applications, as the unbalanced loads may result in excessive voltage imbalance causing stress on other loads connected to the same network, and leading to an increase of neutral current and neutral to earth voltage build-up,
3. Fast voltage variations leading to flicker.

All this phenomena potentially lead to inefficient running of installations, system down time and reduced equipment life and consequently high installation running costs. The solution to improve the power quality at the load side is of great important when the production processes get more complicated and require a bigger liability level, which includes aims like to provide energy without interruption, without harmonic distortion and with tension regulation between very narrow margins. The devices that can fulfil these requirements are the Custom Power; a concept that we could include among the FACTS, but that is different to them because of their final use. In fact the topologies that they employ are identical to the ones in the FACTS devices with little modifications and adaptations to tension levels; therefore they are most oriented to be used in distribution networks of low and medium tension, sometimes replacing the active filters. Recent developments in electrical power systems such as deregulation, open access, and cogeneration are creating Scenarios of transmission congestion and forced outages. Addition of new transmission lines is an almost impossible solution due to environmental and other considerations, and developing new approaches to Power System Operation and Control is the need of the hour for overload relief and efficient .and reliable operation

Compensation in power system:-
Except in a very few special situations, electrical energy is generated, transmitted, distributed, and utilized as alternating current (A.C.). However, alternating current has several distinct disadvantages. One of these is the necessity of reactive power that needs to be supplied along with active power. Reactive Power can be leading or lagging. While it is the active power that contributes to the energy consumed, or transmitted, reactive power does not contribute to the energy. Reactive power is an inherent part of the total power. Reactive power is either generated or consumed in almost every component of the system, generation, transmission, and distribution and eventually by the loads. The impedance of a branch of a circuit in an AC system consists of two components, resistance and reactance. Reactance can be either inductive or capacitive, which contribute to reactive power in the circuit. Most of the loads are inductive, and must be supplied with lagging reactive power. It is economical to supply this reactive power closer to the load in the distribution system. Reactive power compensation in power systems can be either shunt or series. Therefore, investment is necessary for the studies into the security and stability of the power grid, as well as the improved control schemes of the transmission system. Different approaches such as reactive power compensation and phase shifting have been applied to increase the stability and the security of the power systems. The demands of lower power losses, faster response to system parameter change, and higher stability of system have stimulated the development of the Flexible AC Transmission systems (FACTS). Based on the success of research in power electronics switching devices and advanced control technology, FACTS has become the technology of choice in voltage control, reactive/active power flow control, transient and steady-state stabilization that improves the operation and functionality of existing power transmission and distribution system. The achievement of these studies enlarge the efficiency of the existing generator units, reduce the overall generation capacity and fuel consumption, and minimize the operation cost.

Necessity of reactive power compensation
"Reactive power (vars) is required to maintain the voltage to deliver active power (watts) through transmission lines. Motor loads and other loads require reactive power to convert the flow of electrons into useful work. When there is not enough reactive power, the voltage sags down and it is not possible to push the power demanded by loads through the lines". Transformers, transmission lines, and motors require reactive power. Transformers and transmission lines introduce inductance as well as resistance; both oppose the flow of current. It must raise the voltage higher to push the power through the inductance of the lines, unless capacitance has introduced to offset of inductance. The reactive power is require when one waveform leads to other, Phase angle not equal to 0° and Power factor less than unity. The reactive power produced when the current waveform leads voltage waveform (Leading power factor), and consumed when the current waveform lags voltage (lagging power factor).

Introduction to FACTS:-
Flexible AC Transmission Systems, called FACTS, got in the recent years a well known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice.
In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. The basic applications of FACTS-devices are:
• Power flow control,
• Increase of transmission capability,
• Voltage control,
• Reactive power compensation,
• Stability improvement,
• Power quality improvement,
• Power conditioning,
• Flicker mitigation,
• Interconnection of renewable and distributed generation and storages.
Figure-2.3 shows the basic idea of FACTS for transmission systems. The usage of lines for active power transmission should be ideally up to the thermal limits. Voltage and stability limits shall be shifted with the means of the several different FACTS devices. It can be seen that with growing line length, the opportunity for FACTS devices gets more and more important. The influence of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices work electrically as fast current, voltage or impedance controllers. The power electronic allows very short reaction times down to far below one second.

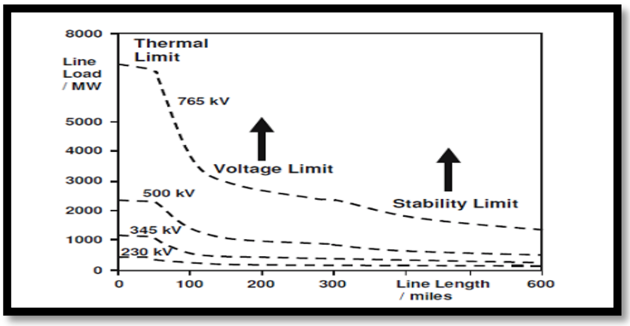

Fig 2.3- Operational limits of transmission lines for different voltage levels

The development of FACTS-devices has started with the growing capabilities of power electronic components. Devices for high power levels have been made available in converters for high and even highest voltage levels. The overall starting points are network elements influencing the reactive power or the impedance of a part of the power system. Figure 2.4 shows a number of basic devices separated into the conventional ones and the FACTS-devices. For the FACTS side the taxonomy in terms of 'dynamic' and 'static' needs some explanation. The term 'dynamic' is used to express the fast controllability of FACTS-devices provided by the power electronics. This is one of the main differentiation factors from the conventional devices. The term 'static' means that the devices have no moving parts like mechanical switches to perform the dynamic controllability. Therefore most of the FACTS-devices can equally be static and dynamic.

Types of facts devices:-

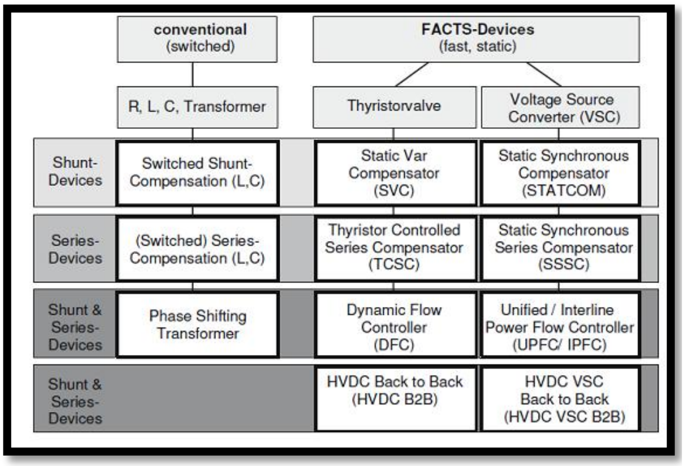

Fig 2.4 Types of FACTS Devices

The left column in Figure-2.4 contains the conventional devices build out of fixed or mechanically switch able components like resistance, inductance or capacitance together with transformers. The FACTS-devices contain these elements as well but use additional power electronic valves or converters to switch the elements in smaller steps or with switching patterns within a cycle of the alternating current. The left column of FACTS-devices uses Thyristor valves or converters. These valves or converters are well known since several years. They have low losses because of their low switching frequency of once a cycle in the converters or the usage of the Thyristors to simply bridge impedances in the valves.

III. UNIFIED POWER QUALITY CONDITIONER (UPQC)

Basic configuration of UPQC

UPQCs consist of combined series and shunt APFs for simultaneous compensation of voltage and current. The series APF inserts a voltage, which is added at the point of common coupling (PCC) such that the load end voltage remains unaffected by any voltage disturbance, whereas, the shunt APF is most suitable to compensate for load reactive power demand and unbalance, to eliminate the harmonics from supply current, and to regulate the common DC link voltage [2].

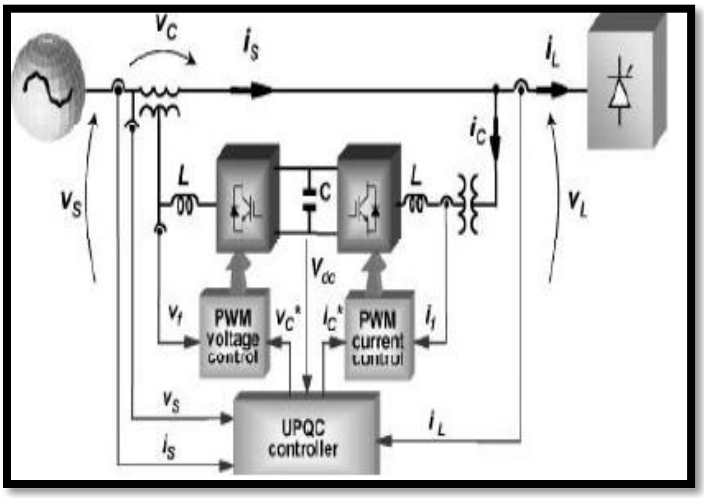

Figure 3.1- Basic configuration of the UPQC [2]

Figure 3.1 shows the basic configuration of the UPQC. The UPQC has two distinct parts:-

- Power circuit formed by series and shunt PWM converters
- UPQC controller

The series PWM converter of the UPQC behaves as a controlled voltage source, that is, it behaves as a series APF, whereas the shunt PWM converter behaves as a controlled current source, as a shunt APF. No power supply is connected at the DC link. It contains only a relatively small DC capacitor as a small energy storage element.

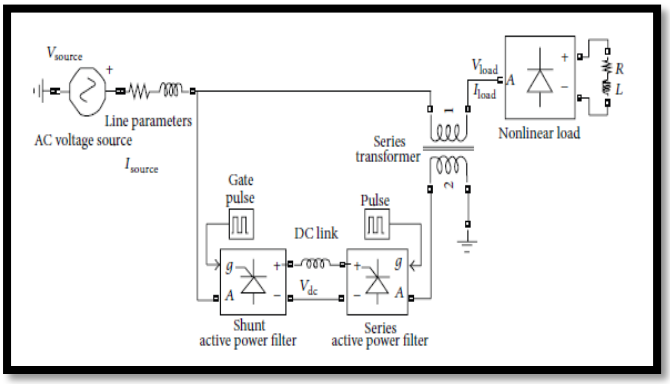

Figure 3.2: The design configuration of UPQC-CSC [3]

In this, the design configuration is right series and left shunt with the current source converter (CSC). In thesis, UPQC-CSC is designed and analysis of the results has been done. Unified power quality conditioner (UPQC) for nonlinear and voltage sensitive load has following facilities.

- It reduces the harmonics in the supply current, so that it can improve utility current quality for nonlinear loads.
- UPQC provides the VAR requirement of the load, so that the supply voltage and current are always in phase; therefore, no additional power factor correction equipment is required.
- UPQC maintains load end voltage at the rated value even in the presence of supply voltage sag.

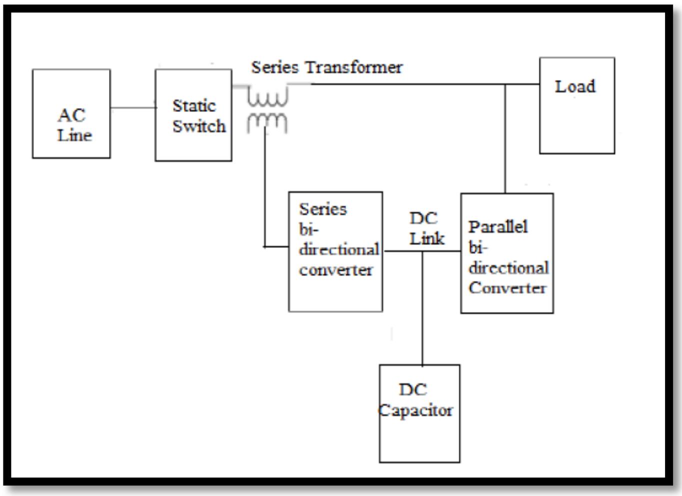

Fig 3.3- Block diagram of a UPQC

Conventional UPQC topology consists of the integration of two active power filters are connected back to back to a common dc-link bus. A simple block diagram of a typical UPQC is shown in Fig.3.3.

It can be configured either with voltage-source converters or current source converters in single phase, three-phase three wire, or three-phase four-wire configurations. The UPQC with the voltage-source converter (VSC) is most common because of its smaller size and low cost. Despite these previously mentioned advantages, the VSI topology has slow control of the converter (LC filter) output voltage and no short-circuit/over current protection. When the active rectifier inside the UPQC is used as a power factor corrector, dc bus voltage oscillations appear which makes the control of the series filter output voltage more difficult. The CSI-based UPQC has advantages of excellent current control capability, easy protection, and high reliability over VSI-based UPQC. The main drawback of the CSI-based UPQC has been so far the lack of proper switching devices and large dc-side filter.

The new insulated-gate bipolar transistors (IGBTs) with reverse blocking capability are being launched in the markets which are suitable for the CSI-based UPQC. With the use of SMES coils, the size and losses can be reduced considerably. A configuration of UPQC using two current-source converters connected back to back through a large dc-link reactor is shown in fig 3.4.

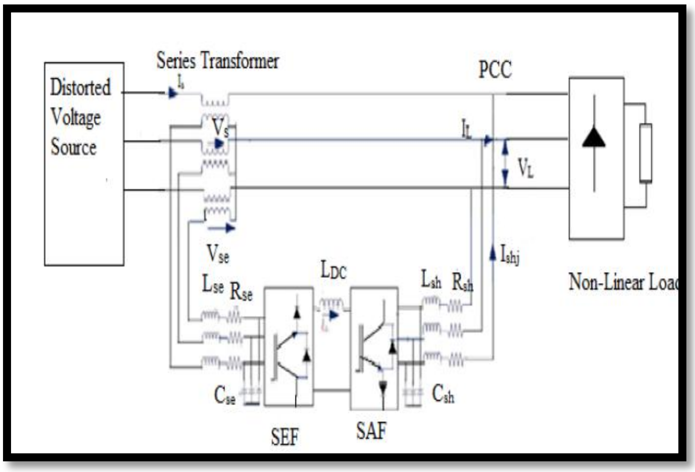

Fig 4.4 UPQC topology using current-source converters

The performance of the UPQC mainly depends on how accurately and quickly the reference signals are derived. After efficient extraction of the distorted signal, a suitable dc-link current regulator is used to derive the actual reference signals. A dc current regulator will serve as power-loss compensation in the filter circuits, which will take place through the activation of a shunt unit. This regulator will maintain dc-link current constant for stable operation of the filter. In the conventional PI controller, the error between the actual dc-link current and a reference value, which is generally slightly greater than the peak of the dc-link value, is fed to the PI controller. The output of the PI controller is added suitably for the generation of a reference template [5].

IV. MODELLING AND SIMULATION

MATLAB DESIGN OF THREE PHASE COMPENSATED NETWORK WITHOUT UPQC

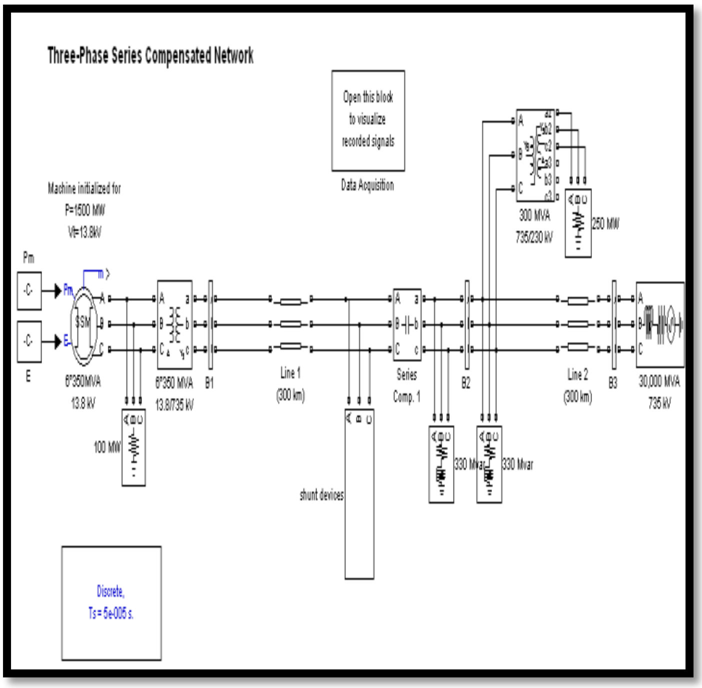

Fig4.1-matlab model of three phase series compensated network

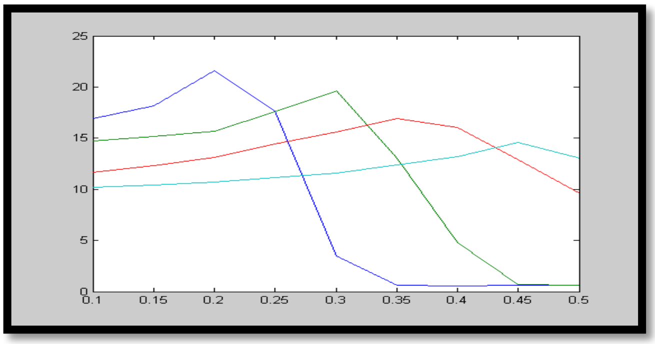

Fig.4.2- Variation in maximum RE power for diff. value of %S

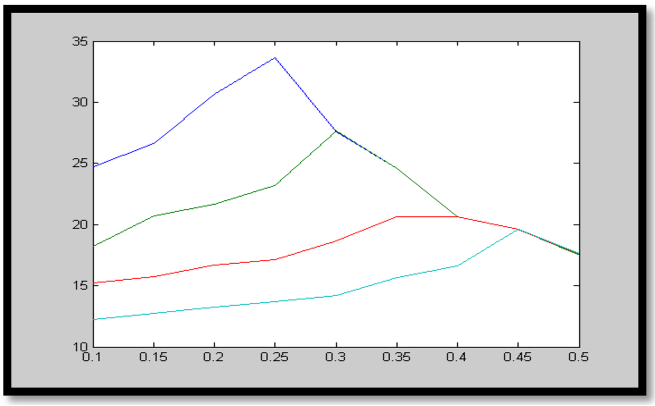

Fig.4.3- Variation in maximum SE power for diff. value of %S

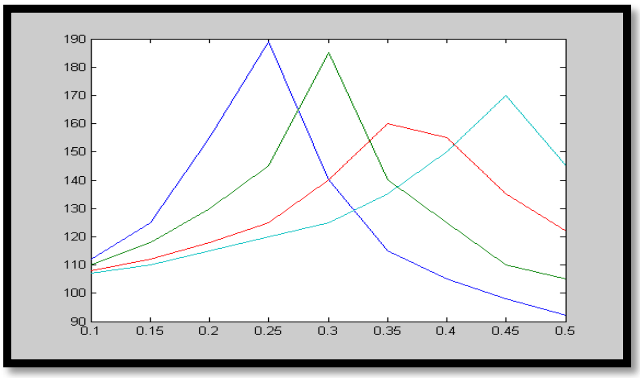

Fig.4.4- Variation in transmission angle at the max. SE power for diff. %S

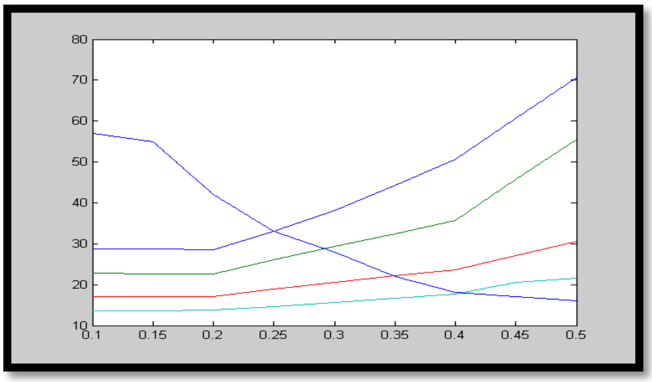

Fig.4.5-Variation in the maximum RE power of section-1 and SE power of section-2 against k for diff. value of %S

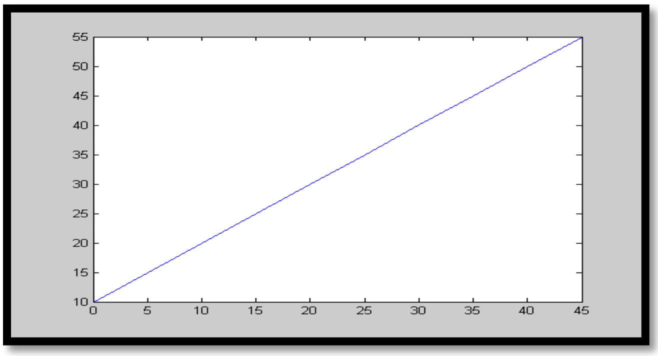

Fig.4.6- Variation in the optimal off-center location of shunt FACTS device against degree of compensation of line (%S)

Simulation Results

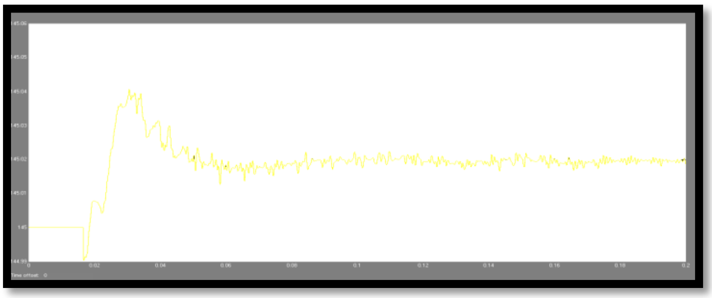

Fig 4.7- Simulation Results of 3-phase voltage Vabc

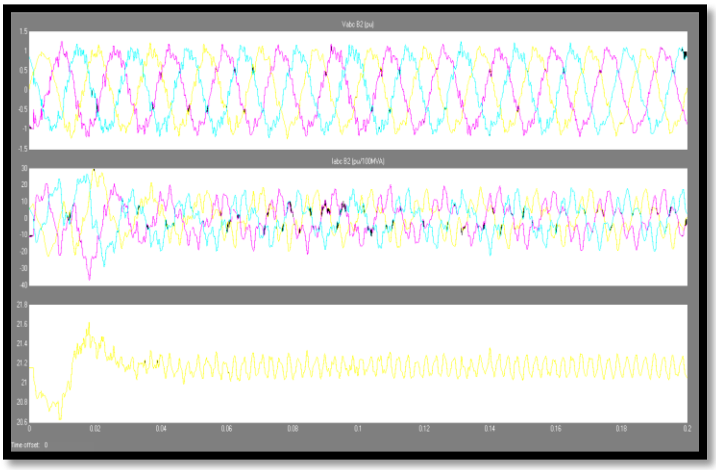

Fig 4.8 -Vabc, Iabc, Real and Reactive power

V. MATLAB DESIGN OF UPQC AND CONNECTION WITH THREE PHASE SYSTEM

From the above simulation results we can say that the three phase system without UPQC device generates distorted voltage, current and power. The value of these output quantities does not remains constant. So we have to interconnect the UPQC device with this three phase compensated network as shown in the fig below. As shown in the fig below the UPQC device is connected between source side and load side. The design of UPQC includes the VSC at input side and one VSC at output side. After the interconnection of UPQC system with three phase compensated network the output value of voltage, current and power becomes constant and pure sinusoidal.

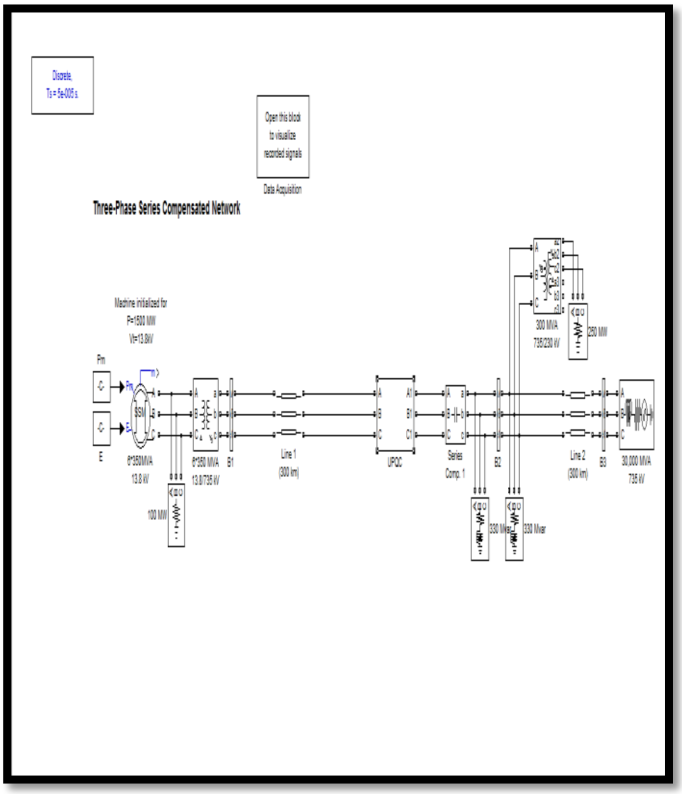

Fig 4.9- Three phase compensated network connect with UPQC system

Now the Subsystem of UPQC is shown in the fig below with their design configuration. As shown in the fig below design of UPQC includes two VSC at input and output side, which is connected through common D.C. link capacitor. The fig design configuration also includes the control circuit of gate triggering circuit for the VSC Thyristors triggering for the constant and pure sinusoidal output.

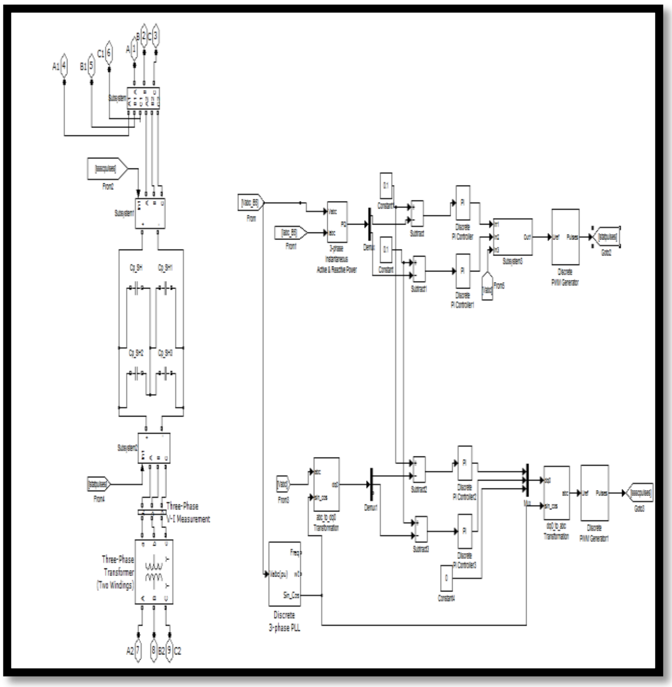

Fig 4.10-Configuration of UPQC System

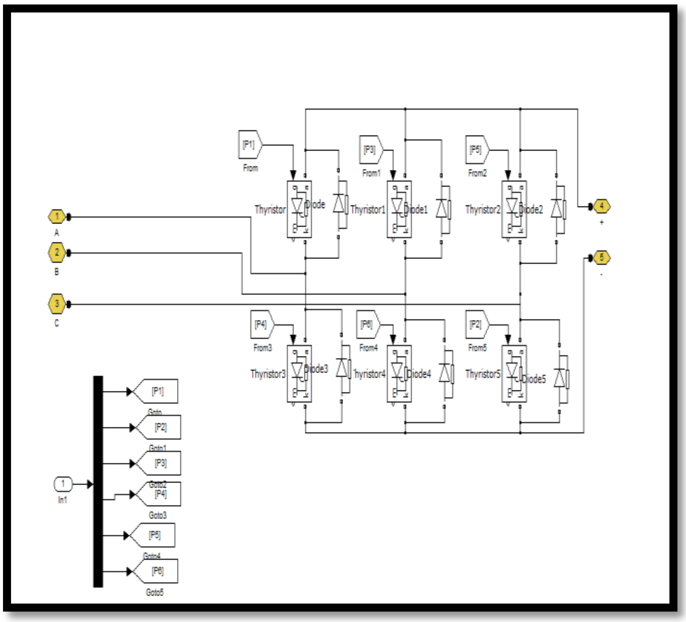

Fig 4.11- VSC configuration in UPQC design

Simulation Results:-

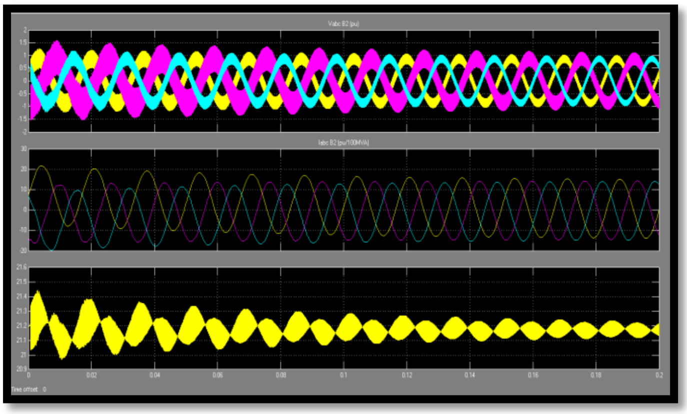

Fig 4.13-Voltage, Current & Power at Input Side

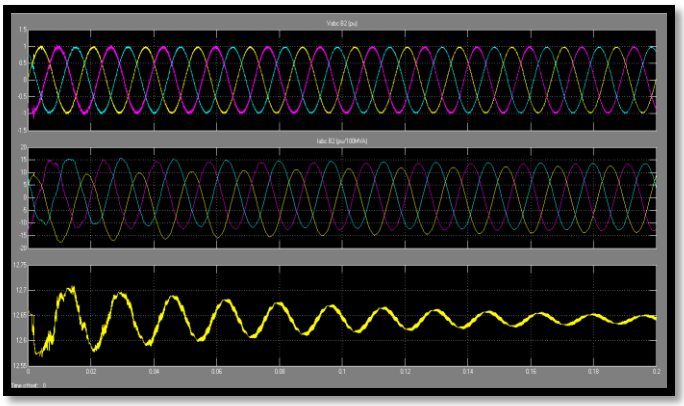

Fig 4.14-Voltage, Current & Power at Load Side

VI. CONCLUSION

- From the simulation results we can say that after the application of UPQC in three phase system the distortion in voltage, current and power has been reduced.

- The power quality is improved using the control strategy of UPQC in three phase compensated system.

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