CHAPTER ONE

INTRODUCTION

1.1 General Concepts

Reactive power analysis and compensation have been growing in importance in energy systems over the lasted cade. The main driving factors are the emergence of qualitatively different system elements (distributed generation and controlled power electronic systems as loads) and the legal and economic changes in the form of deregulation. The new system elements are characterized by complex, bi-directional power flows, both in steady state and in frequent transients. The deregulation motivates a precise quantification of not only power flows, but also of compensation efforts. Power Generation and Transmission is a complex process, requiring the working of many components of the power system in tandem to maximize the output. One of the main components to form a major part is the reactive power in the system. It is required to maintain the voltage to deliver the active power through the lines. Loads like motor loads and other loads require reactive power for their operation. To improve the performance of ac power systems, we need to manage this reactive power in an efficient way and this is known as reactive power compensation.

1.1.1Reactive power

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 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.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:

$Q = |V|\,|I| \sin \theta$ (1.1)

Where:

Q = reactive power

V = voltage waveform

I = current waveform

T = Time period

θ = Angle by which the current lags the voltage in phase

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.

1.1.2 Reactive power compensation principles

In a linear circuit, the reactive power is defined as the ac component of the instantaneous power, with a frequency equal to 100 / 120 Hz in a 50 or 60 Hz system. The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. In other words, the reactive power oscillates between the ac source and the capacitor or reactor, and also between them, at a frequency equals to two times the rated value (50 or 60 Hz). For this reason it can be compensated using VAR generators, avoiding its circulation between the load (inductive or capacitive) and the source, and therefore improving voltage stability of the power system. Reactive power compensation can be implemented with VAR generators connected in parallel or in series. The principles of both shunt and series reactive power compensation alternatives, are described in chapter Two.

1.2 Problem Statement

During the past two decades, the increase in electrical energy demand has presented higher requirements from the power industry. More power plants, substations, and transmission lines need to be constructed. However, the most commonly used devices in present power grid are the mechanically-controlled circuit breakers. The long switching periods and discrete operation make them difficult to handle the frequently changed loads smoothly and damp out the transient oscillations quickly. In order to compensate these drawbacks, large operational margins and redundancies are maintained to protect the system from dynamic variation and recover from faults. This not only increases the cost and lowers the efficiency, but also increases the complexity of the system and augments the difficulty of operation and control. Severe black-outs happened recently in power grids worldwide and these have revealed that conventional transmission systems are unable to manage the control requirements of the complicated interconnections and variable power flow.

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).

1.3 Objectives

The aims of this research explain the importance of VAR compensation to improve the performance of ac power systems. The reactive power compensation is viewed from two aspects: load compensation and voltage support. In load compensation the objectives are to increase the value of the system power factor, to balance the real power drawn from the ac supply, compensate voltage regulation and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line. Reactive power compensation in transmission systems also improves the stability of the ac system by increasing the maximum active power that can be transmitted. It also helps to maintain a substantially flat voltage profile at all levels of power transmission, it improves HVDC (High Voltage Direct Current) conversion terminal performance, increase transmission efficiency, controls steady-state and temporary over voltage , and can avoid disastrous blackouts.

1.4 Methodologies

In this project reactive power compensation techniques has been used to solve the problems of low power factor and voltage regulation. Examples obtained from relevant applications describing the use of reactive power compensators implemented with new static VAR technologies are also described. A SIM Power toolbox in MATLAB 2016a is used to carry out simulations of the system under study and detailed results are shown to access the performance of SVC and STATCOM on the voltage of the system.

1.5 Project Layout:

Chapter one include introduction the introduction consist of General Concepts of the research, and Problem of the research, and Objectives of the research, and methodology of the research. In chapter two discuss all reactive power compensation devices and discuss SVC and STATCOM in separate chapter (chapter three) because SVC and STATCOM are the most wildly used in the power grid these years, but we will not expansion on the details of configuration of svc because we had already discusses it chapter two. In chapter four discussed the SVC and STATCOM simulation model which constructed on Matlab/simulink software (R2016a). Chapter five includes conclusion and important recommendation.

CHAPTER TWO

REACTIVE POWER COMPENSATION DEVICES

2.1 Need for Reactive Power Compensation

Main aims of the reactive power compensation are:

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

2.2 Compensation Techniques

There are two techniques use of compensation a) shunt compensation, and b) series compensation,this techniqueis described below:

2.2.1 Shunt compensation:

Figure 1 shows the principles and theoretical effects of shunt reactive power compensation in a basic ac system, which comprises a source V_1, a power line and a typical inductive load. Fig 2.1-a shows the system without compensation, and its associated phasor diagram. In the phasor diagram, the phase angle of the current has been related to the load side, which means that the active current(IP)is in phase with the load voltage V_2. Since the load is assumed inductive, it requires reactive power for proper operation and hence, the source must supply it, increasing the current from the generator and through power lines. If reactive power is supplied near the load, the line current can be reduced or minimized, reducing power losses and improving voltage regulation at the load terminals. This can be done in three ways:

a) With a capacitor.

b) With a voltage source or with a current source. In Fig 2.1-b.

a current source device is being used to compensate the reactive component of the load current (I_Q). As a result, the system voltage regulation is improved and the reactive current component from the source is reduced or almost eliminated. If the load needs leading compensation, then an inductor would be required. Also a current source or a voltage source can be used for inductive shunt compensation. The main advantages of using voltage or current source VAR generators (instead of inductors or capacitors) is that the reactive power generated is independent of the voltage at the point of connection.

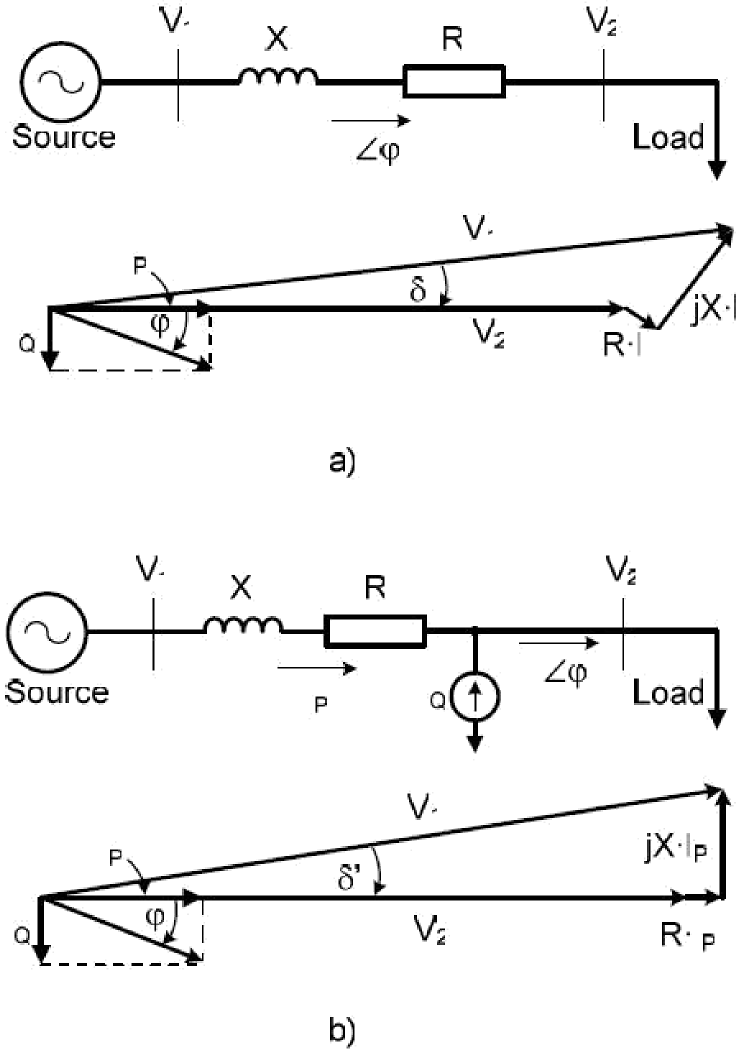


Figure 2.1: Principles of shunt compensation in a radial ac system

a) Without reactive compensation.

b) Shunt compensation with a current source.

2.2.2 Series compensation

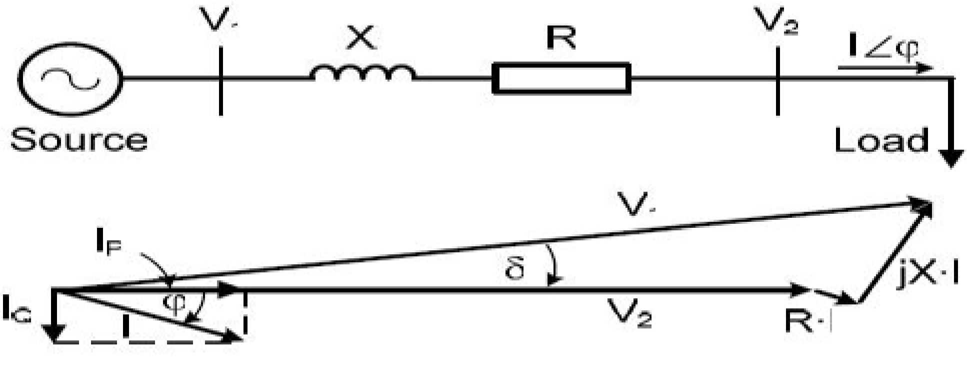
VAR compensation can also be of the series type. Typical series compensation systems use capacitors to decrease the equivalent reactance of a power line at rated frequency. The connection of a series capacitor generates reactive power that, in a self-regulated manner, balances a fraction of the line's transfer reactance. The result is improved functionality of the power transmission system through:

i) Increased angular stability of the power corridor.

ii) Improved voltage stability of the corridor.

iii) Optimized power sharing between parallel circuit

Like shunt compensation, series compensation may also be implemented with current or voltage source devices, as shown in Fig. 2.2. Figure 2.2-a shows the same power system of figure 2.1-a, also with the reference angle in V2, and Fig. 2.2-b the results obtained with the series compensation through a voltage source, which has been adjusted again to have unity power factor operation at V2. However, the compensation strategy is different when compared with shunt compensation. In this case, voltage VCOMP has been added between the line and the load to change the angle of V2’, which is now the voltage at the load side. With the appropriate magnitude adjustment of VCOMP, unity power factor can again be reached at V2. As can be seen from the phasor diagram of Fig. 2.2-b, VCOMP generates a voltage with opposite direction to the voltage drop in the line inductance because it lags the current IP.



a)

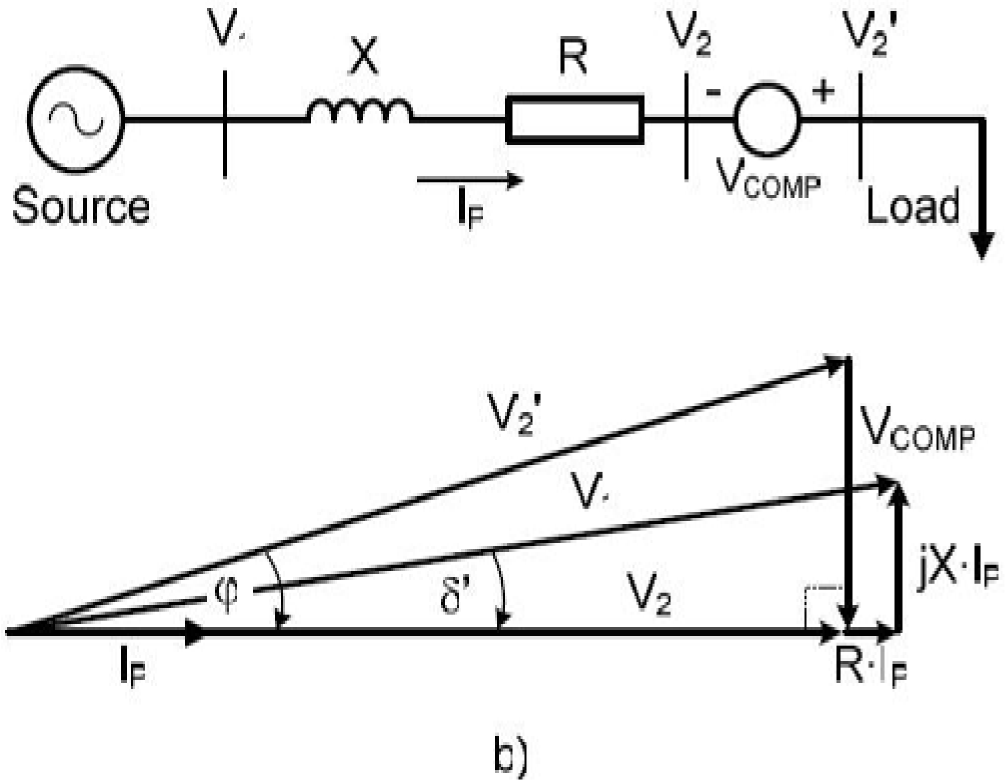


Figure 2.2: Principles of series compensation.

a) Without compensation.

b) Series compensation with a voltage source.

2.3 FACTS Devices

The concept of Flexible AC transmission system has been proposed in 1995, which is called FACTs. The basic idea of FACTs is installing the power electronic devices at the high-voltage side of the power grid to make the whole system electronically controllable.

The advances achieved in high power semiconductor devices and control technology makes the foundation of the development of FACTs. The FACTs devices are able to provide active and reactive power to the power grid rapidly. The power compensation achieved by FACTs devices could adjust the voltage of the whole system and the power flow could be satisfactorily controlled [1].

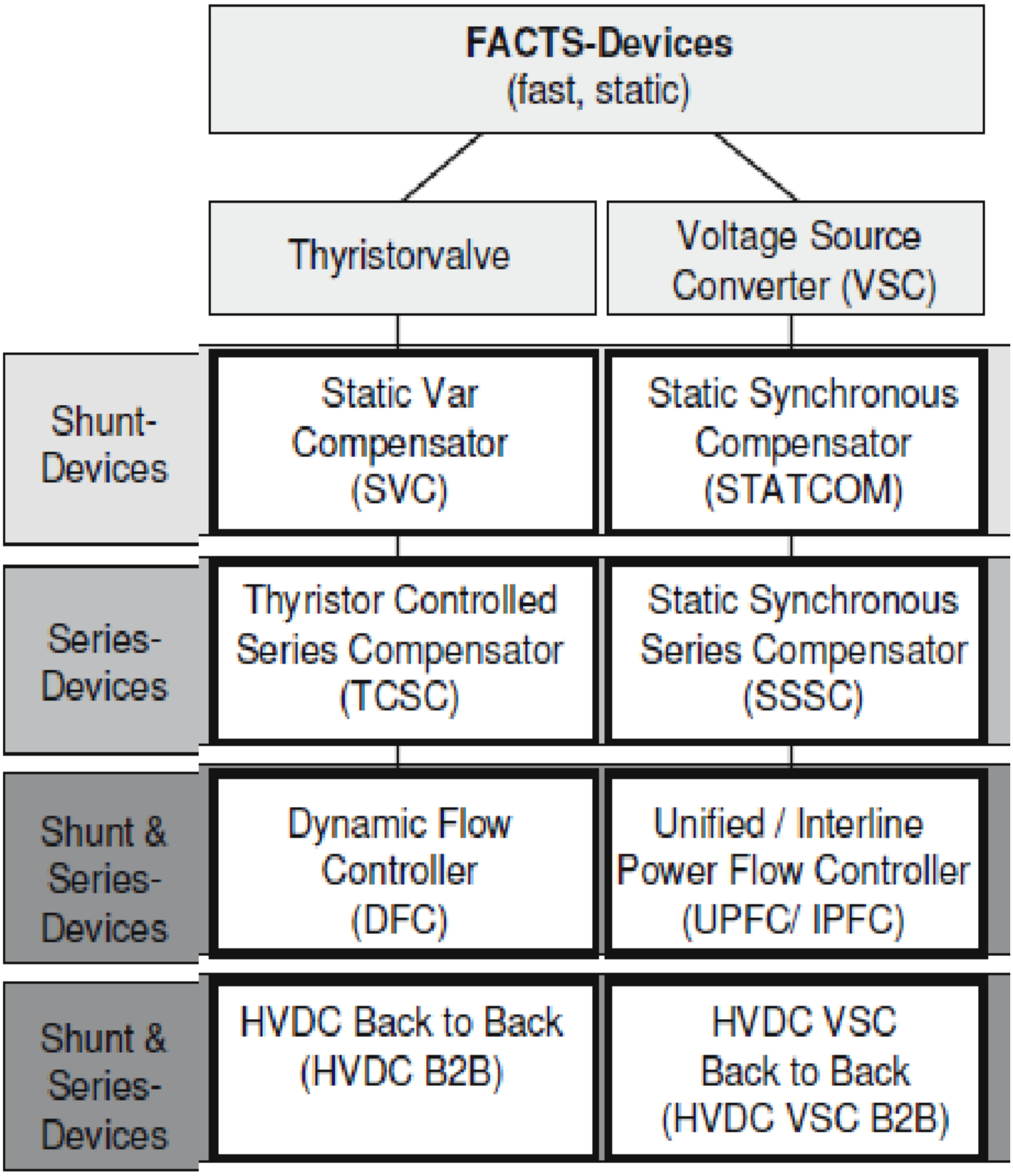


Figure 2.3: Overview of major FACTS-Devices

2.4 Reactive Power Compensation Devices

There are many devices for reactive power compensation. The power capacitors are the biggest group of the devices used in Compensation but In recent years, static VAR compensators like the STATCOM have been developed. These quite satisfactorily do the job of absorbing or generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS). Reactive Power Compensation Devices classification shown in figure below:

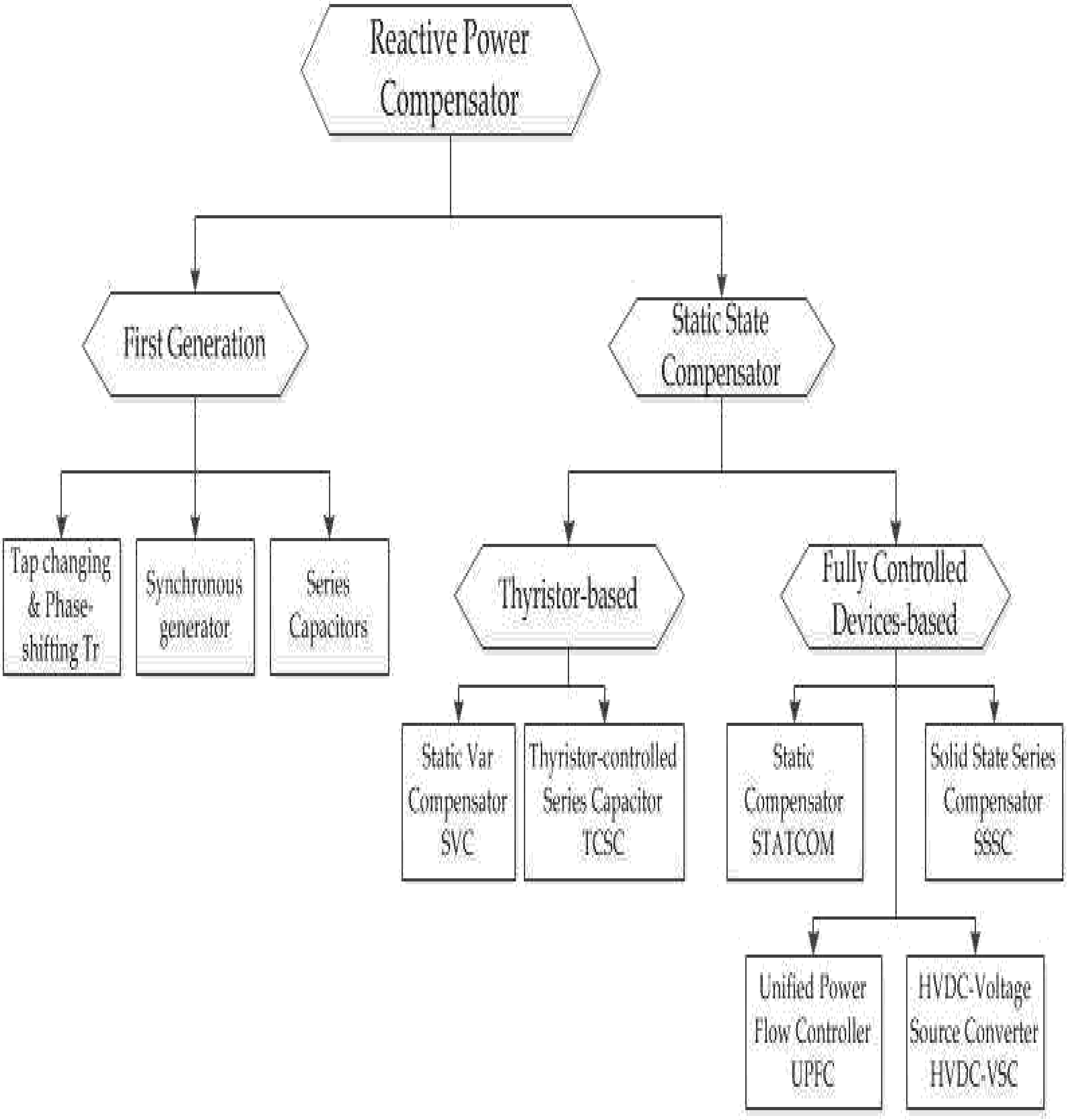


Figure 2.4 the classification of Reactive Power Compensation Devices

2.4.1 Traditional var generators

By definition, capacitors generate and reactors (inductors) absorb reactive power when connected to an ac power source. They have been used with mechanical switches for (coarsely) controlled var generation and absorption since the early days of ac power transmission. Continuously variable var generation or absorption for dynamic system compensation was originally provided by over- or under-excited rotating synchronous machines and, later, by saturating reactors in conjunction with fixed capacitors.

Since the early 1970s high power, line-commutated thyristors in conjunction with capacitors and reactors have been employed in various circuit configurations to produce variable reactive output. These in effect provide a variable shunt impedance by synchronously switching shunt capacitors and/or reactors “in” and “out" of the network. Using appropriate switch control, the var output can be controlled continuously from maximum capacitive to maximum inductive output at a given bus voltage. More recently gate turn-off thyristors and other power semiconductors with internal turn-off capability have been used in switching converter circuits to generate and absorb reactive power without the use of ac capacitors or reactors. These perform as ideal synchronous compensators (condensers), in which the magnitude of the internally generated ac voltage is varied to control the var output.

Eventually VAR generators are classified depending on the technology used in their implementation and the way they are connected to the power system (shunt or series). Rotating and static generators were commonly used to compensate reactive power. In the last decade, a large number of different static VAR generators, using power electronic technologies have been proposed and developed. There are two approaches to the realization of power electronics based VAR compensators, the one that employs thyristor-swicthed capacitors and reactors with tap changing transformers, and the other group that uses self-commutated static converters.

.2.4.1.1 Fixed or mechanically switched capacitors

Shunt capacitors were first employed for power factor correction in the year 1914. The leading current drawn by the shunt capacitors compensates, the lagging current drawn by the load. The selection of shunt capacitors depends on many factors, the most important of which is the amount of lagging reactive power taken by the load. In the case of widely fluctuating loads, the reactive power also varies over a wide range. Thus, a fixed capacitor bank may often lead to either overcompensation or under-compensation. Variable VAR compensation is achieved using switched capacitors Depending on the total

VAR requirement; capacitor banks are switched into or switched out of the system. The smoothness of control is solely dependent on the number of capacitors switching units used. The switching is usually accomplished using relays and circuit breakers. However, these methods based on mechanical switches and relays have the disadvantage of being sluggish and unreliable. Also they generate high inrush currents, and require frequent maintenance**.**

2.4.1.1.1 Installation of capacitor bank

In electrical power system, capacitors are commonly used to provide reactive power compensation in order to reduce power losses, regulate bus voltage and improve the power factor. The capacitor’s size and allocation should be properly considered, if else they can amplify harmonics currents and voltages due to possible resonance at once or several harmonic frequencies. This condition could lead to potentially dangerous magnitudes of harmonic signals, additional stress on equipment insulation, increased capacitor failure and interference with communication system.

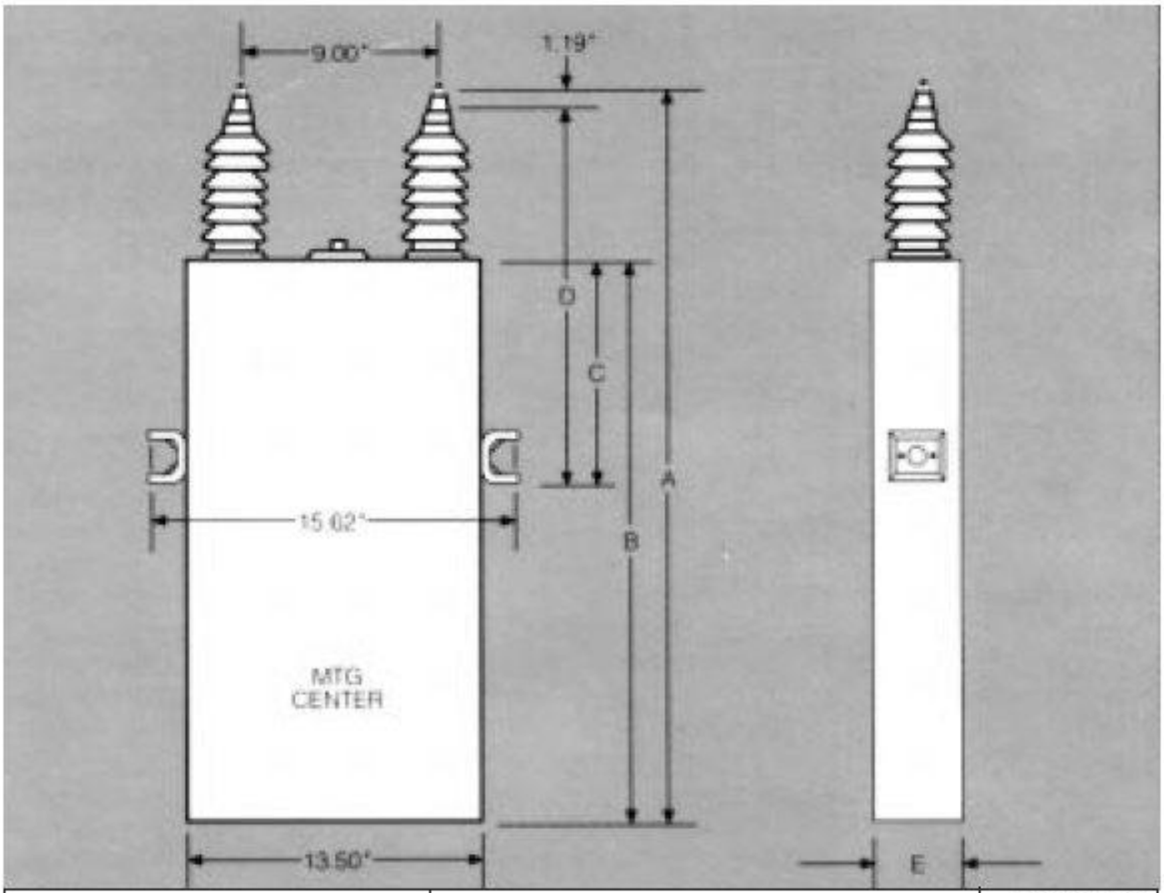
2.4.1.1.2 Capacitor Bank Placement

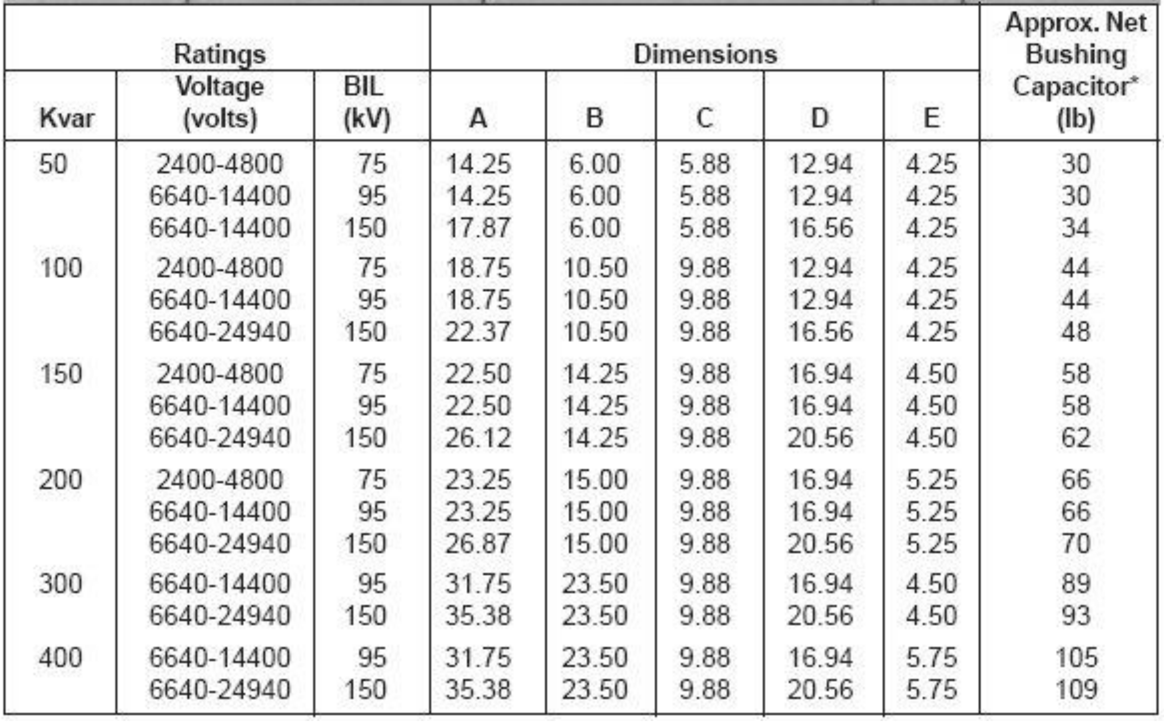
The general problem for capacitor placement is to determine the optimal number, location, sizes and switching times for capacitors to be installed on a distribution feeder to maximize cost savings subjected to operating constraints. The installed sizes for fixed capacitor banks located on distribution lines are based on matching reactive load to available bank sizes as closely as possible.

For capacitor banks installed at substations, the size is chosen to maintain suitable power factor at peak loads, compensate for reactive losses in substation transformers, and release substation capacity. See Figure below for a photograph of an automatically switched, line-mounted capacitor bank and its components. Referring to table 2.1, it’s showed the dimension and weights of capacitors. This example is taken from Cooper Power System Brochure.

Based on this table, noticed that the difference rating of Kvar has their own dimension and weights for capacitors.

Table 2.1: Example of Standard Dimension and Weights of capacitor bank:





Ratings			Dimensions					Approx. Net Bushing Capacitor* (lb)
Kvar	Voltage (volts)	BIL (kV)	A	B	C	D	E	
50	2400-4800	75	14.25	6.00	5.88	12.94	4.25	30
	6640-14400	95	14.25	6.00	5.88	12.94	4.25	30
	6640-14400	150	17.87	6.00	5.88	16.56	4.25	34
100	2400-4800	75	18.75	10.50	9.88	12.94	4.25	44
	6640-14400	95	18.75	10.50	9.88	12.94	4.25	44
	6640-24940	150	22.37	10.50	9.88	16.56	4.25	48
150	2400-4800	75	22.50	14.25	9.88	16.94	4.50	58
	6640-14400	95	22.50	14.25	9.88	16.94	4.50	58
	6640-24940	150	26.12	14.25	9.88	20.56	4.50	62
200	2400-4800	75	23.25	15.00	9.88	16.94	5.25	66
	6640-14400	95	23.25	15.00	9.88	16.94	5.25	66
	6640-24940	150	26.87	15.00	9.88	20.56	5.25	70
300	6640-14400	95	31.75	23.50	9.88	16.94	4.50	89
	6640-24940	150	35.38	23.50	9.88	20.56	4.50	93
400	6640-14400	95	31.75	23.50	9.88	16.94	5.75	105
	6640-24940	150	35.38	23.50	9.88	20.56	5.75	109

The allocation of capacitor banks corresponds to one of the most important problems related to the planning of electrical distribution networks This problem consists of determining, with the smallest possible cost.

2.4.1.2 Synchronous condensers

Synchronous condensers have played a major role in voltage and reactive power control for more than 50 years. Functionally, a synchronous condenser is simply asynchronous machine connected to the power system. After the unit is synchronized, the field current is adjusted to either generate or absorb reactive power as required by the AC system. The machine can provide continuous reactive power control when used with the proper automatic exciter circuit. Synchronous condensers have been used at both distribution and transmission voltage levels to improve stability and to maintain voltages within desired limits under varying load conditions and contingency situations. However, synchronous condensers are rarely used today because they require substantial foundations and a significant amount of starting and protective equipment.

They also contribute to the short circuit current and they cannot be controlled fast enough to compensate for rapid load changes. Moreover, their losses are much higher than those associated with static compensators, and the cost is much higher compared with static compensators. Their advantage lies in their high temporary overload capability [3].

2.4.2 Thyristorized var compensators

As in the case of the synchronous condenser, the aim of achieving fine control over the entire VAR range, has been fulfilled with the development of static compensators but with the advantage of faster response times. Thyristorized VAR compensators consist of standard reactive power shunt elements (reactors and capacitors) which are controlled to provide rapid and variable reactive power. They can be grouped into two basic categories, the thyristor-switched capacitor (TSC) and the thyristor-controlled reactor (TCR).

2.4.2.1 Thyristors switched capacitors (TSCs).

Figure 2.4 shows the basic scheme of a static compensator of the thyristor switched capacitor (TSC) type. First introduced by ASEA in 1971 [16], the shunt capacitor bank is split up into appropriately small steps, which are individually switched in and out using bidirectional thyristor switches. Each single-phase branch consists of two major parts, the capacitor C and the thyristor switches Sw1 and Sw2. In addition, there is a minor component, the inductor L, whose purpose is to limit the rate of rise of the current through the thyristors and to prevent resonance with the network (normally 6% with respect to Xc). The capacitor may be switched with a minimum of transients if the thyristor is turned on at the instant when the capacitor voltage and the network voltage have the same value. Static compensators of the TSC type have the following properties: stepwise control, average delay of one half a cycle (maximum one cycle), and no generation of harmonics since current transient component can be attenuated effectively [16], [17].

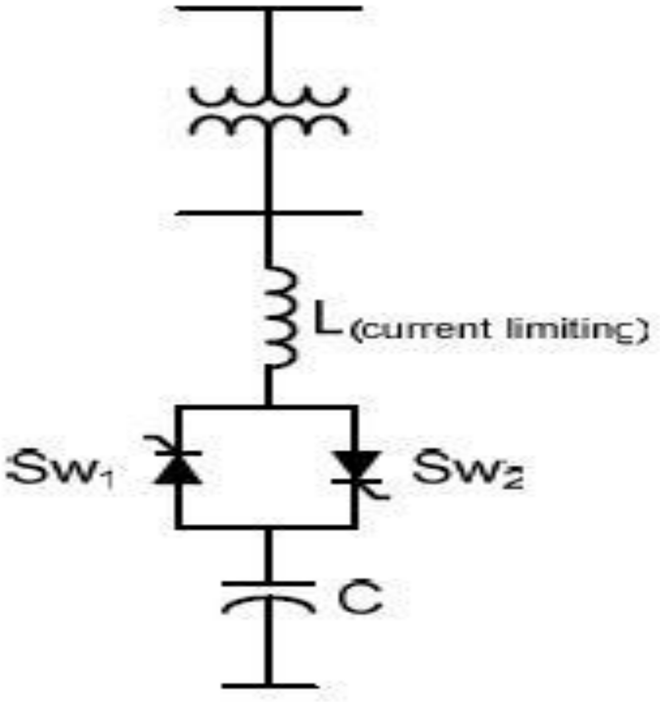


Figure 2.5: The thyristor-switched capacitor configuration.

The current that flows through the capacitor at a given time t, is defined by expression below:

$$i\,(t) = \frac{v_m}{x_c - x_l}\cos(\omega_t + \alpha) - \frac{v_m}{x_c - x_l}\cos(\alpha)\cos(\omega_r t) + \left[\frac{x_c v_m \sin(\alpha)}{\omega_r l(x_c - x_l)} - \frac{v_{co}}{\omega_r l}\right]\sin(\omega_r t) \tag{2.1}$$

where Xc and XL are the compensator capacitive and inductive reactance, Vmthe source maximum instantaneous voltage, the voltage phase-shift angle at which the capacitor is connected, and ꞷr the system resonant frequency (ꞷr= 1/ √LC), Vco capacitor voltage at t = 0. This expression has been obtained assuming that the system equivalent resistance is negligible as compared with the system reactance. This assumption is valid in high voltage transmission lines. If the capacitor is connected at the moment that the source voltage is maximum and Vco is equal to the source voltage peak value, Vm, (α = ± 90º) the current transient component is zero. Despite the attractive theoretical simplicity of the switched capacitor scheme, its popularity has been hindered by a number of practical disadvantages: the VAR compensation is not continuous, each capacitor bank requires a separate thyristor switch and therefore the construction is not economical, the steady state voltage across the non-conducting thyristor switch is twice the peak supply voltage, and the thyristor must be rated for or protected by external means against line voltage transients and fault currents.

2.4.2.2 Thyristor controlled reactor (TCRs)

Fig 2.5 shows the power scheme of a static compensator of the TCR type. In most cases, the compensator also includes a fixed capacitor or a filter for low order harmonics, which is not shown in this figure. Each of the three phase branches includes an inductor L, and the thyristor switches Sw1 and Sw2. Reactors may be both switched and phase-angle controlled [22].

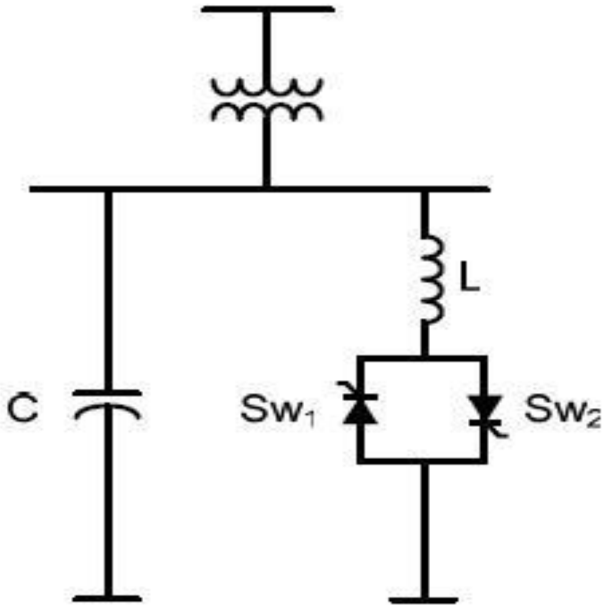


Figure 2.6: The thyristor-controlled reactor configuration.

When phase-angle control is used, a continuous range of reactive power consumption is obtained. It results, however, in the generation of odd harmonic current components during the control process. Full conduction is achieved with a gating angle of 90. Partial conduction is obtained with gating angles between 90 and 180, as shown in Fig 2.6. By increasing the thyristor gating angle, the fundamental component of the current reactor is reduced. This is equivalent to increase the inductance, reducing the reactive power absorbed by the static compensator. However, it should be pointed out that the change in the reactor current may only take place at discrete points of time, which means that adjustments cannot be made quicker than once per half cycle.Static compensators of the TCR type are characterized by the ability to perform continuous control, with maximum delay of one-half cycle and practically no transients. The principal disadvantages of this configuration are the generation of low frequency harmonic current components, and higher losses when working in the inductive region (i.e., absorbing reactive power) [20].

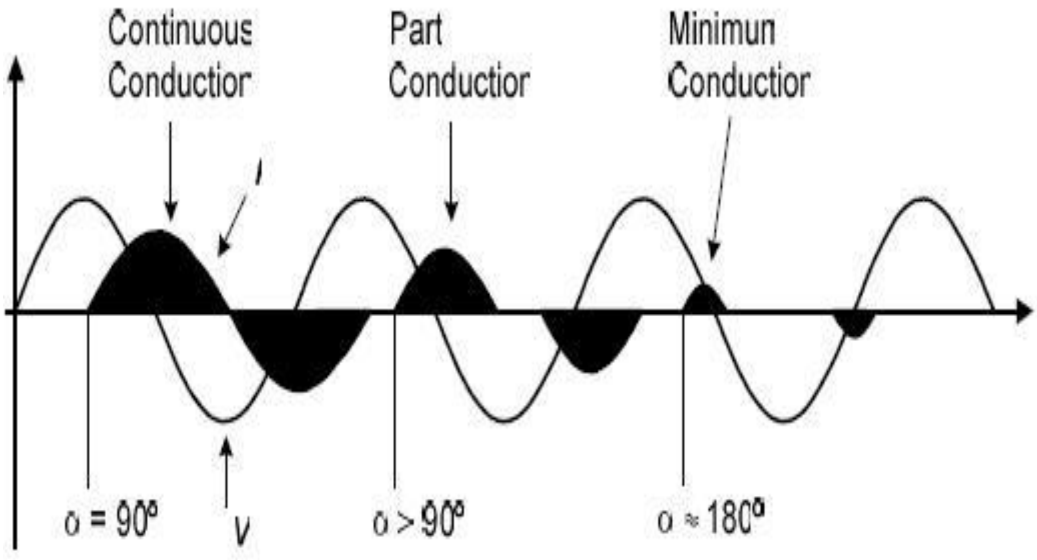


Figure 2.7: Simulated voltage and current waveforms in a TCR for Different thyristor phase-shift angles α.

The relation between the fundamental component of the reactor current and the phase-shift angle a is given by:

$$I_1 = \frac{V_{rms}}{\pi\omega l}(2\pi - 2\alpha + \sin(2\alpha)) \qquad (2.2)$$

2.4.3 Self commutated VAR compensators

With the remarkable progress of gate commutated semiconductor devices, attention has been focused on self-commutated VAR compensators capable of generating or absorbing reactive power without requiring large banks of capacitors or reactors. Several approaches are possible including current-source and voltage-source converters. The current-source approach shown in Fig 2.7 uses a reactor supplied with a regulated dc current, while the Voltage-source inverter, displayed in Fig 2.8, uses a capacitor with a regulated dc voltage.The principal advantages of self-commutated VAR compensators are the significant reduction of size, and the potential reduction from the elimination of a large number of passive components and lower relative capacity requirement for the semiconductor switches [19]. Because of its smaller size, self-commutated VAR compensators are well suited for applications where space is a premium. Self-commutated compensators are used to stabilize transmission systems, improve voltage regulation, correct power factor and also correct load unbalances, [23].Moreover, they can be used for the implementation of shunt and series compensators. This technology has been used to implement more sophisticated compensator equipment such as static synchronous compensator (STATCOM), unified power flow controllers (UPFCs), and interlines power flow controllers (IUPFCs), dynamic voltage restorers (DVRs), the Static Synchronous Series Compensator (SSSC).

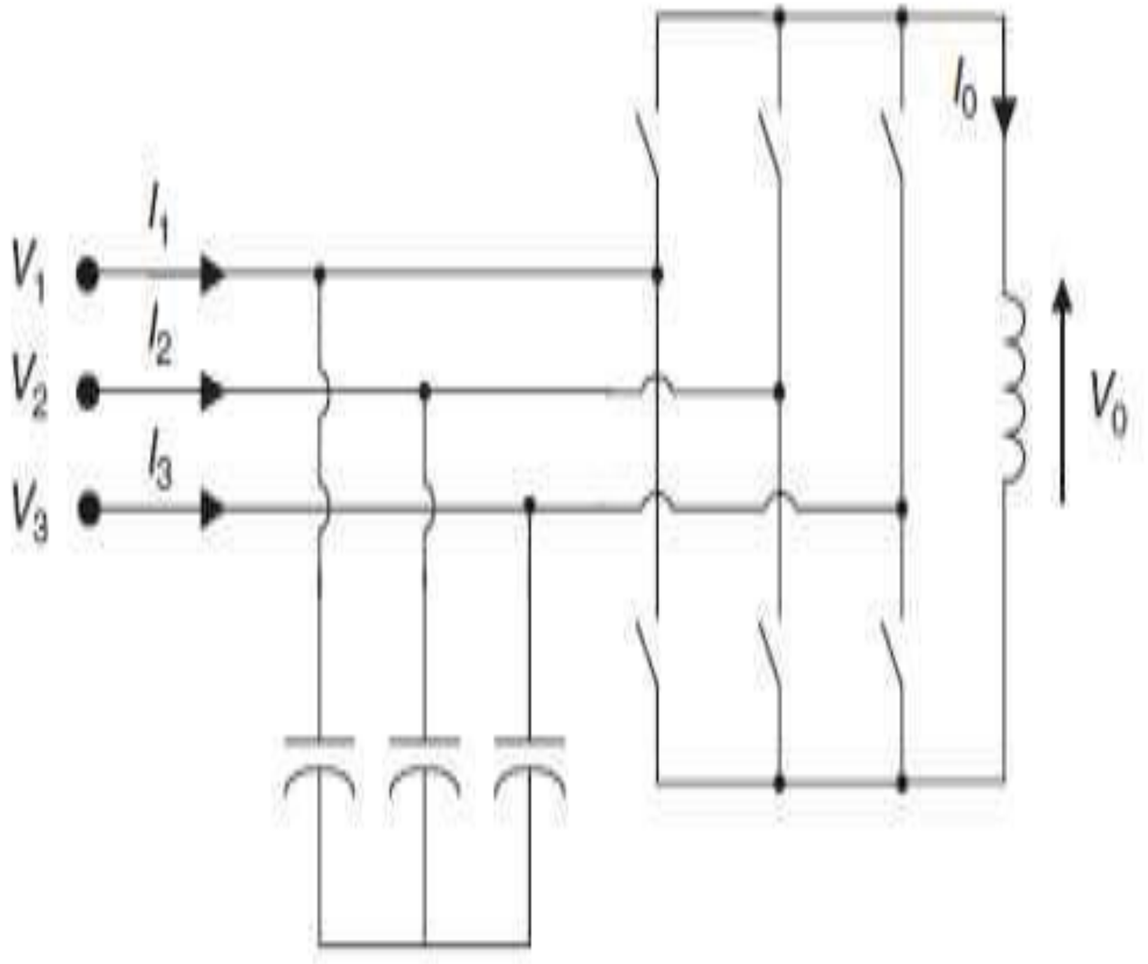


Figure 2.8: A VAR compensator topology implemented with a current-source converter

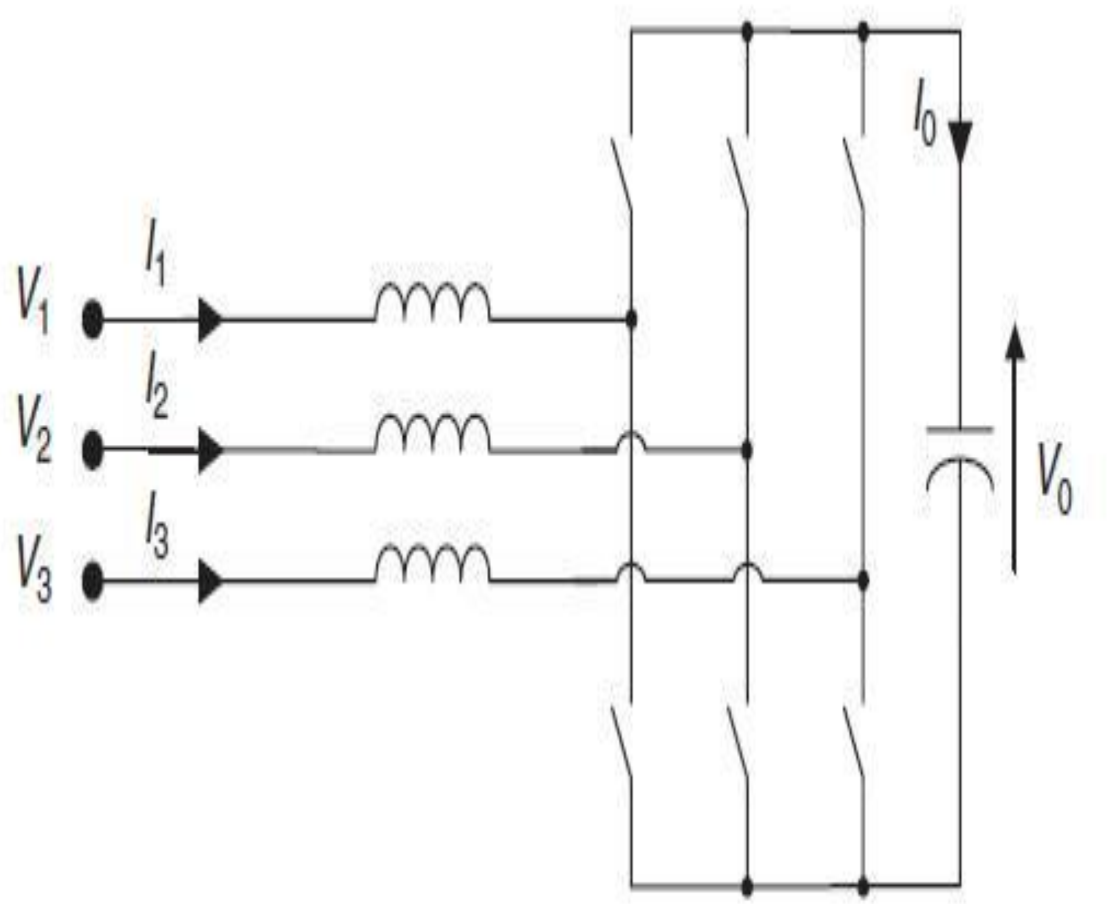


Figure 2.9: A VAR compensator topology implemented with a voltage-source converter.

2.4.3.1 The solid state series compensator (SSSC)

A voltage source converter can also be used as a series compensator as shown in Fig 2.9 The SSSC injects a voltage in series to the line, 90º phase-shifted with the load current, operating as a controllable series capacitor. The basic difference, as compared with series capacitor, is that the voltage injected by an SSSC is not related to the line current and can be independently controlled. [28].

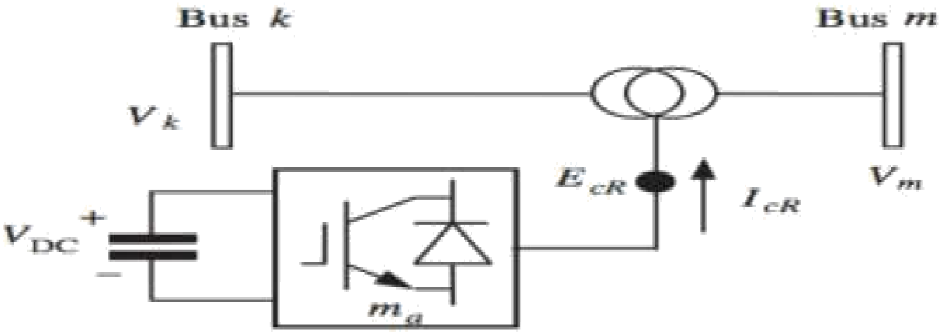


Figure 2.10: Basic structure of SSSC

4.3.2 The unified power flow controller (UPFC)

The unified power flow controller (UPFC), shown in Fig 2.10, consists of two switching converters operated from a common dc link provided by a dc storage capacitor. One connected in series with the line, and the other in parallel [28], [32]. This arrangement functions as an ideal ac to ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate (or absorb) reactive power at its own ac output terminal. The series converter of the UPFC injects via series transformer, an ac voltage with controllable magnitude and phase angle in series with the transmission line. The shunt converter supplies or absorbs the real power demanded by the series converter through the common dc link. The inverter connected in series provides the main function of the UPFC by injecting an ac voltage V_{pq} with controllable magnitude ($0 \leq V_{pq} \leq V_{pqmax}$) and phase angle ρ ($0 \leq \rho \leq 360^{\circ}$), at the power frequency, in series with the line via a transformer. The transmission line current flows through the series voltage source resulting in real and reactive power exchange between it and the ac system. The real power exchanged at the ac terminal, that is the terminal of the coupling transformer, is converted by the inverter into dc power which appears at the dc link as positive or negative real power demand. The reactive power exchanged at the ac terminal is generated internally by the inverter. The basic function of the inverter connected in parallel (inverter 1) is to supply or absorb the real power demanded by the inverter connected in series to the ac system (inverter 2), at the common dc link. Inverter 1 can also generate or absorb controllable reactive power, if it is desired, and thereby it can provide independent shunt reactive compensation for the line. It is important to note that whereas there is a closed “direct” path for the real power negotiated by the action of series voltage injection through inverter 1 and back to the line, the corresponding reactive power exchanged is supplied or absorbed locally by inverter 2 and therefore it does not flow through the line. Thus, inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by inverter 2. This means that there is no continuous reactive power flow through the UPFC.

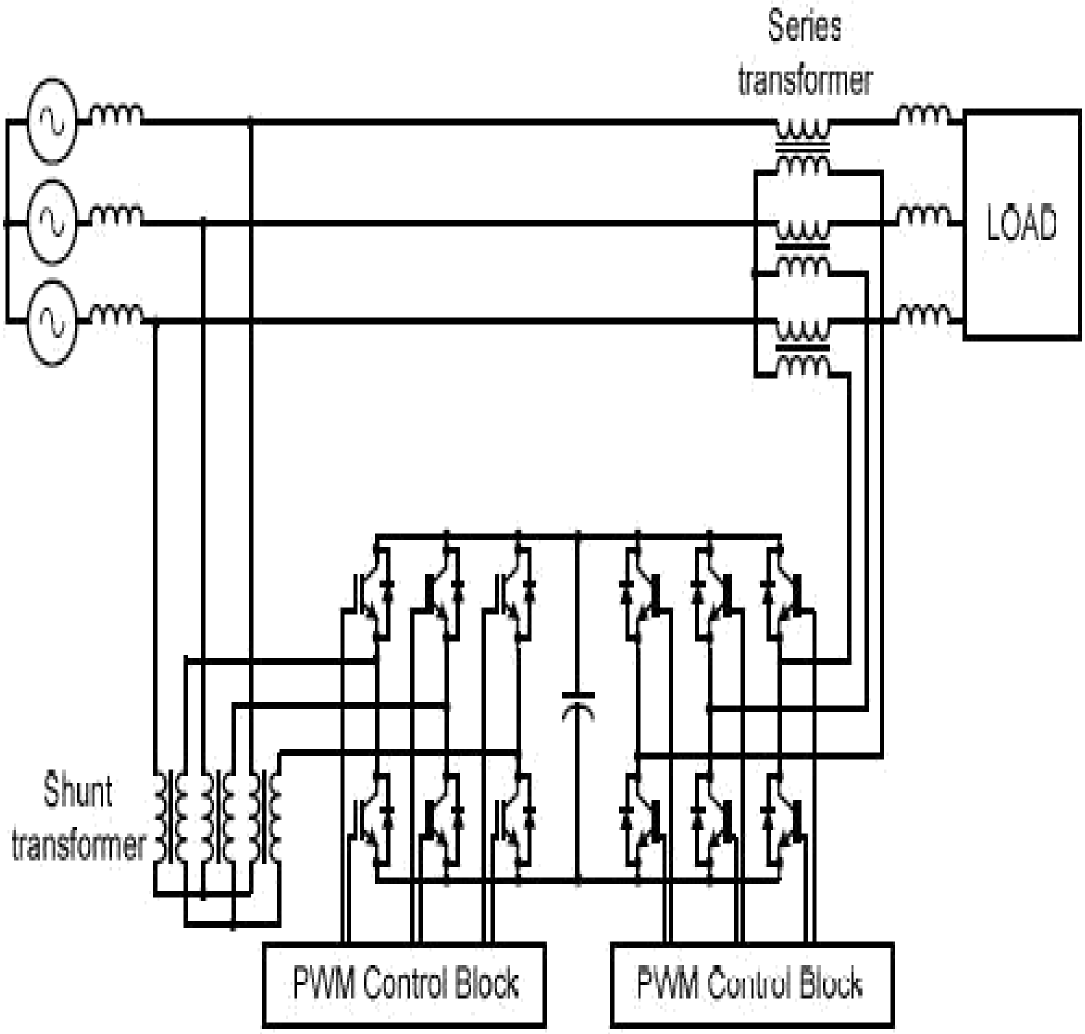


Figure 2.11 UPFC power circuit topology.

2.4.3.3 The unified power flow controller (IPFC)

An Interline Power Flow Controller (IPFC), shown in Fig 2.11 consists of two series VSCs whose DC capacitors are coupled, allowing active power to circulate between different power lines [33]. When operating below its rated capacity, the IPFC is in regulation mode, allowing the regulation of the P and Q flows on one line, and the P flow on the other line. In addition, the net active power generation by the two coupled VSCs is zero, neglecting power losses.

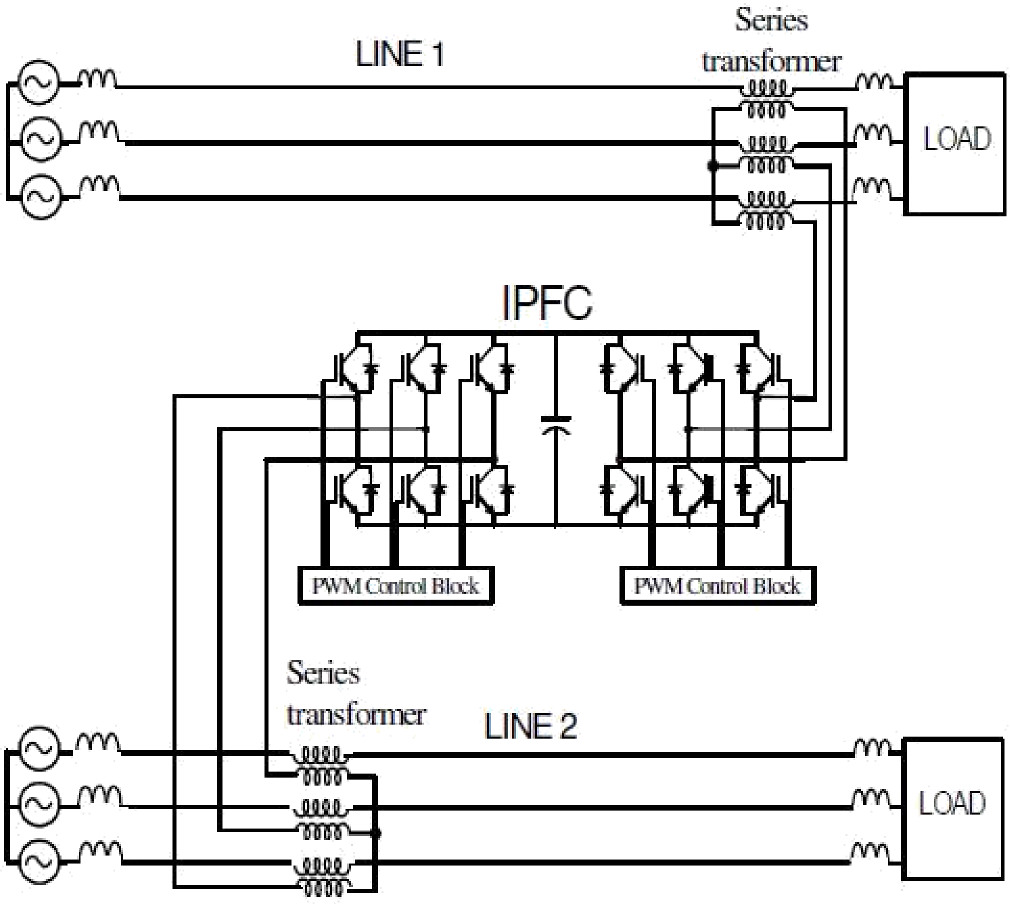


Figure 2.12 IPFC power circuit topology.

2.4.3.4 Dynamic voltage restorer (DVR)

A DVR, shown in Fig 2.12, is a device connected in series with the power system and is used to keep the load voltage constant, independently of the source voltage fluctuations. When voltage sags or swells are present at the load terminals, the DVR responds by injecting three ac voltages in series with the incoming three-phase network voltages, compensating for the difference between faulted and prefault voltages. Each phase of the injected voltages can be controlled separately (i.e., their magnitude and angle). Active and reactive power required for generating these voltages are supplied by the voltage source converter, fed from a DC link. In order to be able to mitigate voltage sag, the DVR must present a fast control response. The key components of the DVR are:

- Energy source Switchgear
- Booster transformer
- Harmonic filter

- IGCT voltage source converter
- DC charging unit
- Control and protection system

, that is, a storage capacitor When power supply conditions remain normal the DVR can operate in low-loss standby mode, with the converter side of the booster transformer shorted. Since no voltage source converter (VSC) modulation takes place, the DVR produces only conduction losses. Use of Integrated Gate Commutated Thyristor (IGCT) technology minimizes these losses.

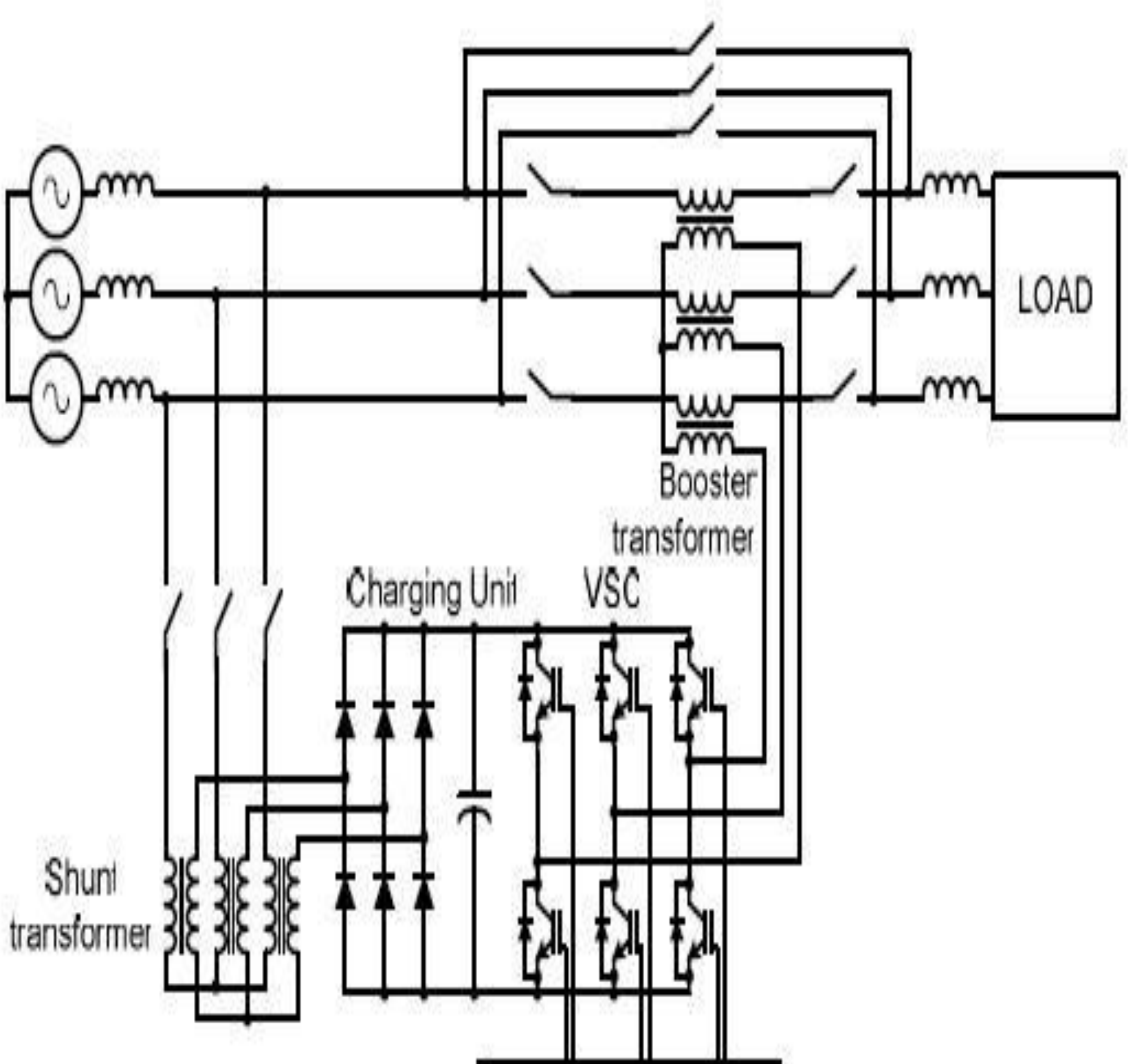


Figure 2.13. Dynamic voltage restorer (DVR)

CHAPTER THREE

STATIC VAR AND STATIC SYNCHRONOUS COMPENSATORS DEVICES

3.1 Introduction

Static var compensators are very popular in controlling reactive power and are currently used in many power transmission networks all over the world with many configurations. However, in general SVCs and STATCOM are shunt connected sinks and/or sources of reactive power and their output may be varied to maintain or control specific parameters of a power system. For example, by generating or absorbing reactive power, an SVC can maintain virtually constant voltage at any particular network node under almost any conditions. Unlike rotating var compensators, static var compensators do not have inertia or any moving components, and are mainly power electronics devices which can act instantly. Since there are no mechanical switching devices or rotating components in SVC& STATCOM, routine or preventive maintenance needed for these devices is minimal. shunt-connected static var compensators (SVCs) are used extensively to control the AC voltage in transmission networks. Power electronic equipment, such as the thyristorcontrolled reactor (TCR) and the thyristor switched capacitor (TSC) have gained a significant market, primarily because of well-proven robustness to supply dynamic reactive power with fast response time and with low maintenance. With the advent of high power gate turn-off thyristors and transistor devices (GTO, IGBT, …) a new generation of power electronic equipment, STATCOM, shows great promise for application in power systems. This research aims to explain the benefits of SVCs and STATCOMs for application in utility power systems. Installation of a large number of SVCs and experience gained from recent STATCOM projects throughout the world motivates us to clarify certain aspects of these devices. The application of SVC & STATCOM as a means of compensating reactive power has demonstrated to be an effective solution.This chapter explains briefly the basic configuration of SVCs and STATCOMs.

3.1.1 Semiconductor devices used for self commutated VAR compensators

Three are the most relevant devices for applications in SVC: thyristors, Insulated Gate Bipolar Transistor (IGBTs) and Integrated Gate Controlled Thyristors (IGCTs). This field of application requires that the semiconductor must be able to block high voltages in the kV range. High voltage IGBTs required to apply self-commutated converters in SVC reach now the level of 6.5 kV, allowing for the construction of circuits with a power of several MW. Also IGCTs are reaching now the level of 6 kV. Perhaps, the most important development in semiconductors for SVC applications is the Light Triggered Thyristor (LTT). This device is the most important for ultrahigh power applications. Recently, LTTs devices have been developed with a capability of up to 13.5 kV and a current of up to 6 kA. These new devices reduce the number of elements in series and in parallel, reducing consequently the number of gate and protection circuits. With these elements, it is possible to reduce cost and increase reactive power in SVC installations of up to several hundreds of MVARs [2].

3.2 Static Var Compensator(SVC)

In general terms, SVC means thyristor-controlled or thyristor-switched reactor, and/or thyristor-switched capacitor combination as shown in Fig 3-1. However, SVC is based on thyristors without the gate turn off capability. Separate equipment is used for leading or lagging vary by having thyristor controlled or thyristor –switched reactor for absorbing vary, and or thyristor –switched capacitor for supplying vars. Thyristor controlled reactor (TCR) consists of shunt connected thyristor controlled inductor whose effective reactance is varied in a continuous manner by a partial conducting of the thyristors. Thyristor–switched reactor (TSR) consists of shunt connected thyristor controlled inductor whose effective reactance is varied in a step wise manner by controlling the on and off turning of thyristors.

Fig 3.1 shows a schematic diagram of a static var compensator. The compensator normally includes a thyristor controlled reactor (TCR), thyristor-switched capacitors (TSCs) and harmonic filters. It might also include mechanically switched shunt capacitors (MSCs), and then the term static var system is used.

The harmonic filters (for the TCR-produced harmonics) are capacitive at fundamental frequency. The TCR is typically larger than the TSC blocks so that continuous control is realized. Other possibilities are fixed capacitors (FCs), and thyristor switched reactors (TSRs). Usually a dedicated transformer is used, with the compensator equipment at medium voltage. The transmission side voltage is controlled, and the Mvar ratings are referred to the transmission side [1].

The rating of an SVC can be optimized to meet the required demand. The rating can be symmetric or asymmetric with respect to inductive and capacitive reactive power. As an example, the rating can be 200 Mvar inductive and 200 Mvar capacitive, or 100 Mvar inductive and 200 Mvarcapacitive [4].

3.2.1 Application of SVC

- Power Transmission.
- Distribution System.
- Wind Power Plant.
- Industrial Consumers

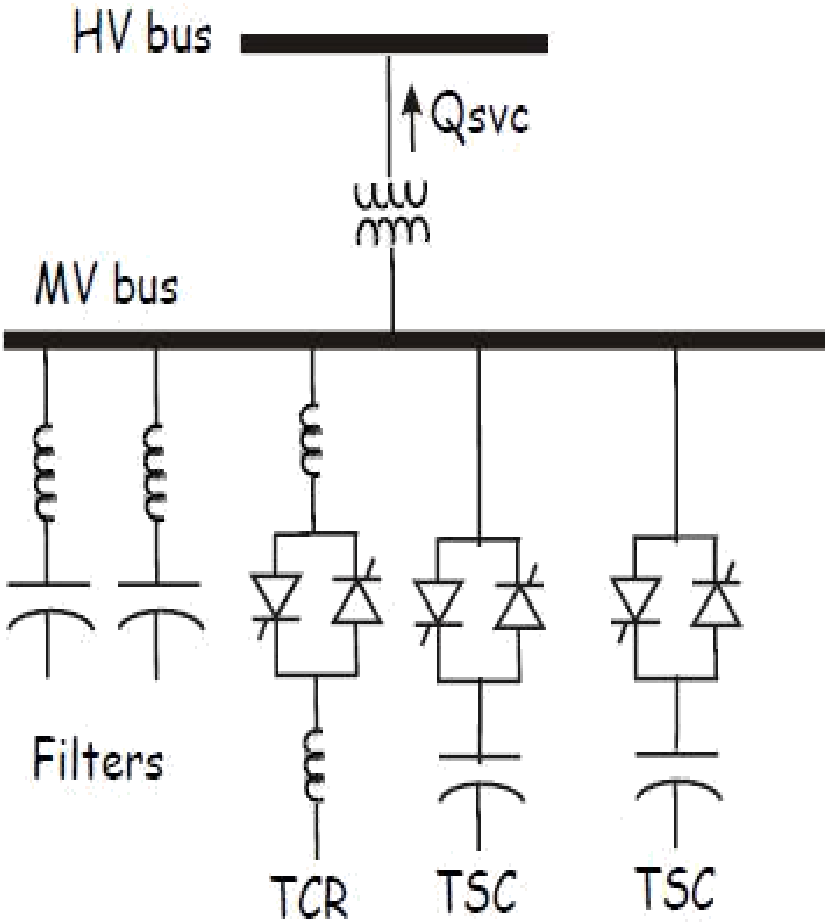


Figure 3.1 Schematic diagram of an SVC

3.2.2 The benefits of SVC to power transmission

- Stabilized voltages in weak systems.
- Reduced transmission losses.
- Increased transmission capacity, to reduce, defer or Eliminate the need for new lines.
- Higher transient stability limit.
- Increased damping of minor disturbances.
- Greater voltage control and stability.
- Power oscillation damping [5].

3.2.3 The benefits of SVC to power distribution

- Stabilized voltage at the receiving end of long lines.

- Increased productivity as stabilized voltage means better utilized capacity.
- Reduced reactive power consumption, which gives lower losses and improved tariffs.
- Balanced asymmetrical loads reduce system losses and enable lower stresses in rotating machinery.
- Enable better use of equipment (particularly transformers and cables).
- Reduced voltage fluctuations and light flicker.
- Decreased harmonic distortion [5].

3.3 Static Synchronous Compensator **(STATCOM)**

In general, STATCOM use to generate or absorb reactive power. One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances

3.3.1 Principles of operation

With the remarkable progress of gate commutated semiconductor devices, attention has been focused on self-commutated FACTS controllers capable of generating or absorbing reactive power without requiring large banks of capacitors or reactors. Several approaches are possible including current-source and voltage-source converters. The current-source approach shown in Fig. 2.7 (previous chapter) uses a reactor supplied with a regulated dc current, while the voltage-source inverter, displayed in Fig. 2.8 (previous chapter) uses a capacitor with a regulated dc voltage.

The principal advantages of self-commutated FACTS controllers are the significant reduction of size and the potential reduction in cost achieved from the elimination of a large number of passive components and lower relative capacity requirement for the semiconductor switches; Because of its smaller size, self-commutated VAR compensators are well suited for applications where space is a premium. Self-commutated compensators are used to stabilize transmission systems, improve voltage regulation, correct power factor, and also correct load unbalances.

Moreover, they can be used for the implementation of shunt and series compensators. Fig 3.6 shows a shunt STATCOM, implemented with a boost type voltage-source converter. Neglecting the internal power losses of the overall converter, the control of the reactive power is done by adjusting the amplitude of the fundamental component of the output voltage V_{MOD} , which can be modified with the PWM pattern as shown in Fig 3.5.

When V_{MOD} is larger than the voltage V_{COMP}, the VAR compensator generates reactive power (Fig . 3.4 b) and when V_{MOD} is smaller than V_{COMP} , the compensator absorb s reactive power (Fig 3.4 c). Its principle of operation is similar to the synchronous machine. The compensation current can be leading or lagging, depending on the relative amplitudes of V_{COMP} and V_{MOD}. The capacitor voltage V_D, connected to the dc link of the converter, is kept equal to a reference value V_{REF} through of a special feedback control loop, which controls the phase-shift angle δ between V_{COMP} and V_{MOD}[9].

3.3.2 Phase angle control

In this case the quantity controlled is the phase angle δ. The modulation index “m” is kept constant and the fundamental voltage component of the STATCOM is controlled by changing the DC link voltage. By further charging of the DC link capacitor, the DC voltage will be increased, which in turn increases the reactive power delivered or the reactive power absorbed by the STATCOM. On the other hand, by discharging the DC link capacitor, the reactive power delivered is decreased in capacitive operation mode or the reactive power absorbed by the STATCOM in an inductive power mode increases.For both capacitive and inductive operations in steady-state, the STATCOM voltage lags behind AC line voltage ($\delta > 0$).

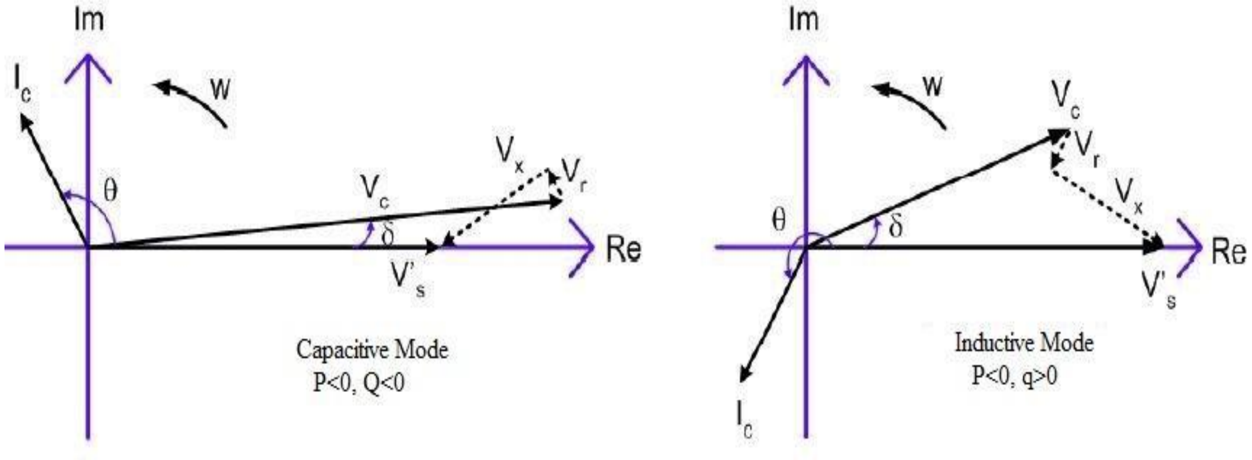


Fig (3.2)Phase Angle Control

By making phase angle δ negative, power can be extracted from DC link.

If the STATCOM becomes lesser than the extracted power, P_c in become negative and STATCOM starts to deliver active power to the source.

During this transient state operation, V_d gradually decreases.The phasor diagrams which illustrating power flow between the DC link in transient state and the ac supply is shown in above Fig 3.2.

For a phase angle 1control system, the open loop response time is determined by the DC link capacitor and the input filter inductance. The inductance is applied to filter out converter harmonics and by using higher values of inductance; the STATCOM current harmonics is minimized.

The reference reactive power (Q_{ref}) is compared with the measured reactive power (Q). The reactive power error is sent as the input to the PI controller and the output of the PI controller determines the phase angle of the STATCOM fundamental voltage with respect to the source voltage.

Fig 3.3 a STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the d.c. side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the a.c supply. The link inductor links this voltage to the a.c supply side. This is the basic principle of operation of STATCOM.

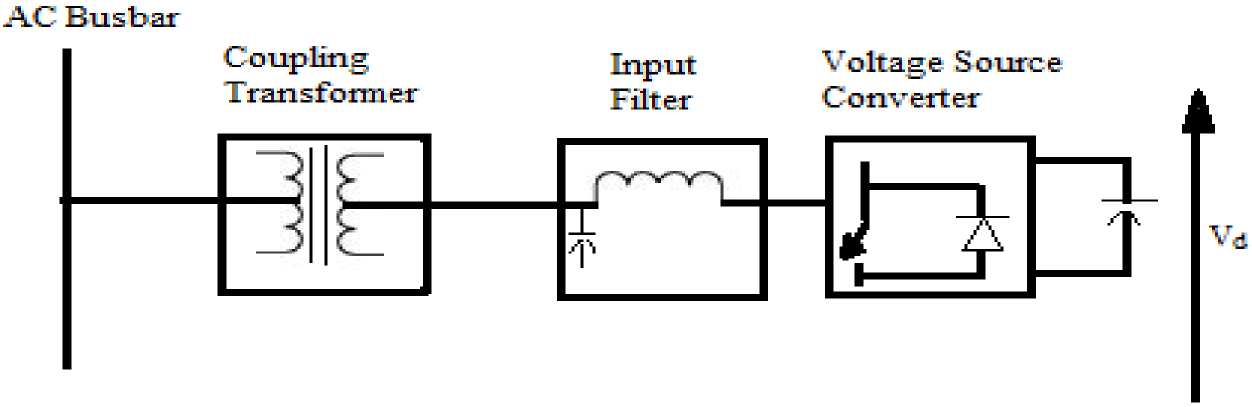


Fig.(3.3) a STATCOM consists of a three phase inverter (generally a PWM inverter).

For two AC sources which have the same frequency and are connected through a series inductance, the active power flows from the leading source to the lagging source and the reactive power flows from the higher voltage magnitude source to the lower voltage magnitude source. The phase angle difference between the sources determines the active power flow and the voltage magnitude difference between the sources determines the reactive power flow. Thus, a STATCOM can be used to regulate the reactive power flow by changing the magnitude of the SVC voltage with respect to source bus voltage.

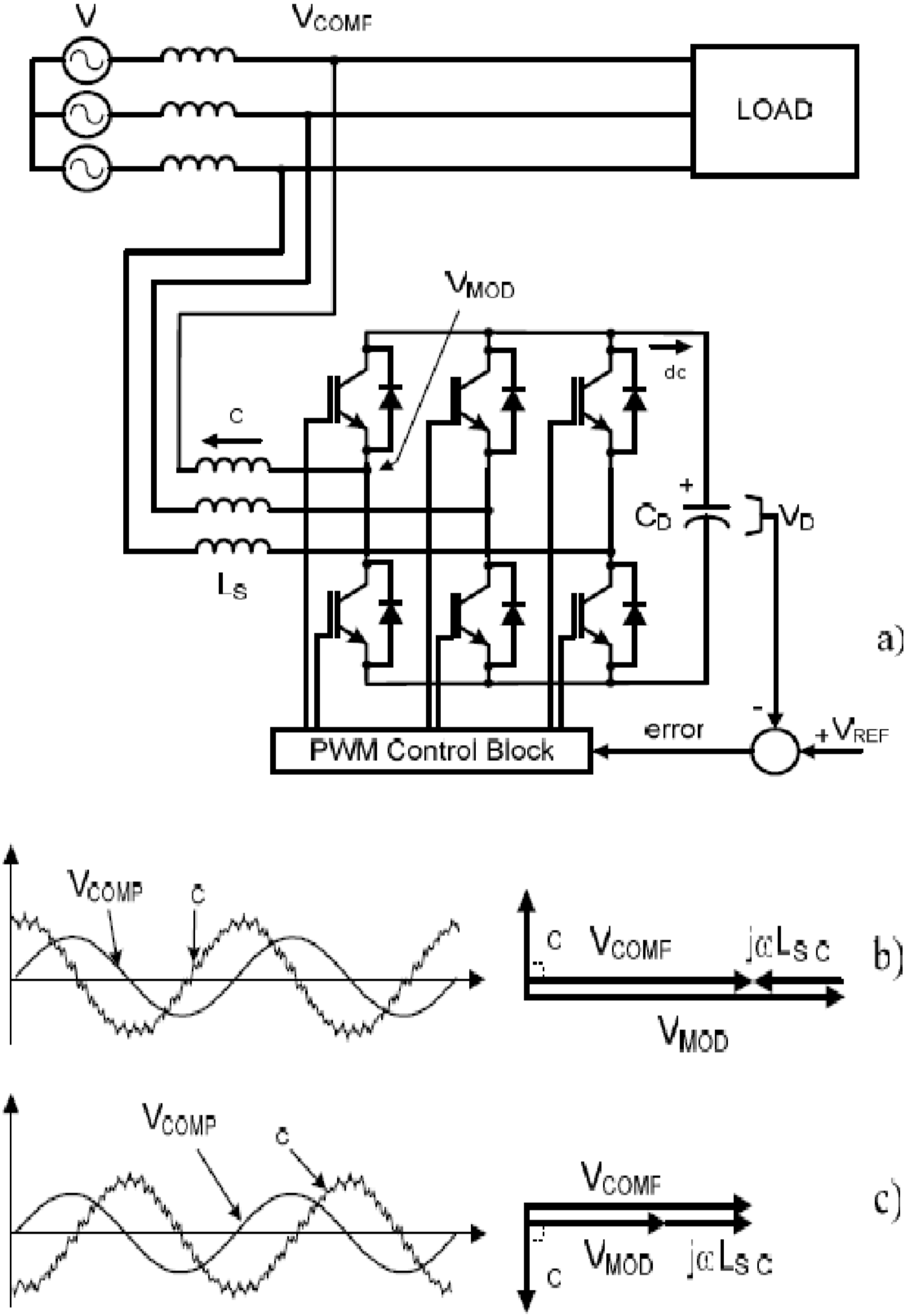


Figure 3.4 Simulated current and voltage waveforms of a voltage-source self-commutated shunt VAR compensator.

(a)STATCOM topology.

(b) Simulated current and voltage waveforms for leading compensation
(VMOD> VCOMP).

(c) Simulated current and voltage waveforms for lagging compensation
(VMOD< VCOMP).

The amplitude of the compensator output voltage (VMOD) can be controlled by changing the switching pattern modulation index (Fig. 3.5), or by changing the amplitude of the converter dc voltage VD. Faster time response is achieved by changing the switching pattern modulation index instead of VD. The converter dc voltage VD, is changed by adjusting the small amount of active power absorbed by the converter and defined by:

$$p = \frac{Vcomb*Vmod}{Xs} sin\delta \qquad (1\text{-}3)$$

XS: converter link reactor.

δ : phase-shift angle between voltages VCOMP and VMOD.

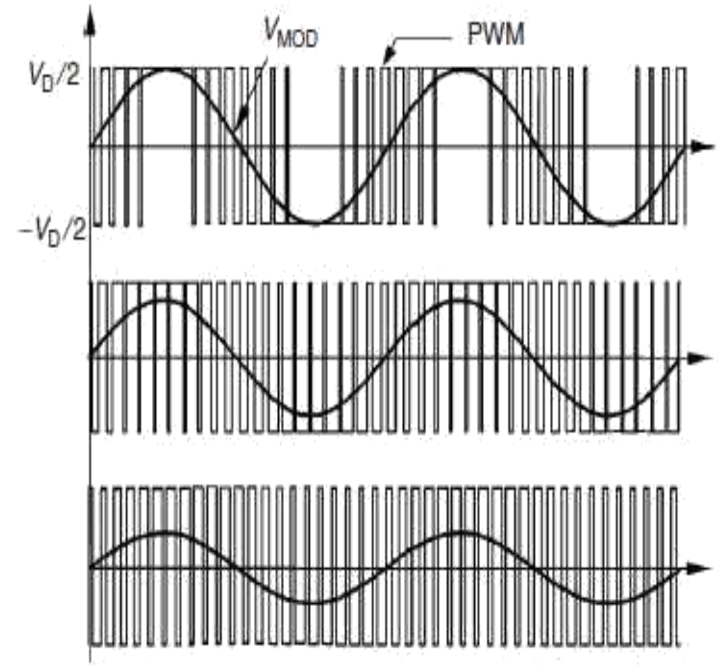


Figure 3.5 Simulated compensator output voltage waveform for different modulation index (amplitude of the fundamental voltage component).

To increase the amplitude of VD a small positive average value of current must circulate through the dc capacitor so that VD will increase until it reaches the required value. In the same way, if it is necessary to decrease the amplitude of VD then a small negative average value of current must flow through the dc capacitor.

The active power flow of the converter is defined by d. If d is positive the converter absorbs active power (increasing VD), and if d is negative the converter generates active power, and therefore VD decreases. One of the major problems that must be solved when self-commutated converters are used in high voltage systems is the limited capacity of the gate-controlled semiconductors available in the market (IGBTs and IGCTs). Actual semiconductors can handle a few thousands of amperes and 6 to 10 kV reverse voltage blocking capabilities, which is clearly not enough for high-voltage applications [9].

3.3.2 Multi-level compensators

Multilevel converters are being investigated and some topologies are used today as static VAR compensators. The main advantages of multilevel converters are less harmonic generation and higher voltage capability because of serial connection of bridges or semiconductors. The most popular arrangement today is the three-level neutral point clamped topology [9].

3.3.2.1 Three-level compensators

Figure 3.6 shows a shunt VAR compensator implemented with a three-level neutral-point clamped (NPC) converter. Three-level converters [24] are becoming the standard topology for medium voltage converter applications, such as machine drives and active front-end rectifiers. The advantage of three-level converters is that they can reduce the generated harmonic content, since they produce a voltage waveform with more levels than the conventional two-level topology. Another advantage is that they can reduce the semiconductors voltage rating and the associated switching frequency.

Three-level converters consist of 12 self-commutated semiconductors such as IGBTs or IGCTs, each of them shunted by a reverse parallel connected power diode, and six diode branches connected between the midpoint of the dc link bus and the midpoint of each pair of switches as shown in Fig 3.6 By connecting the dc source sequentially to the output terminals, the converter can produce a set of PWM signals in which the frequency, amplitude and phase of the ac voltage can be modified with adequate control signals[9].

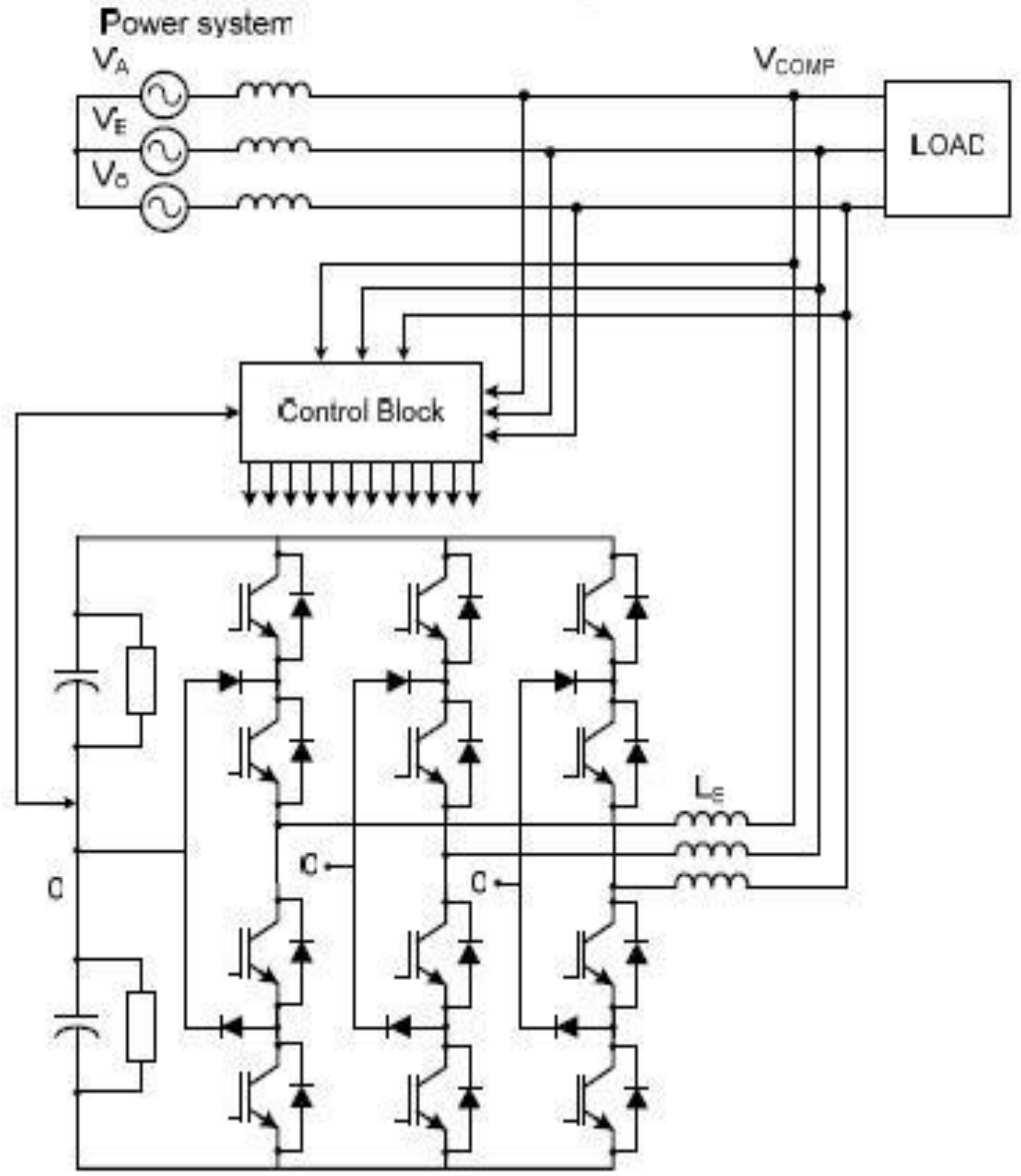
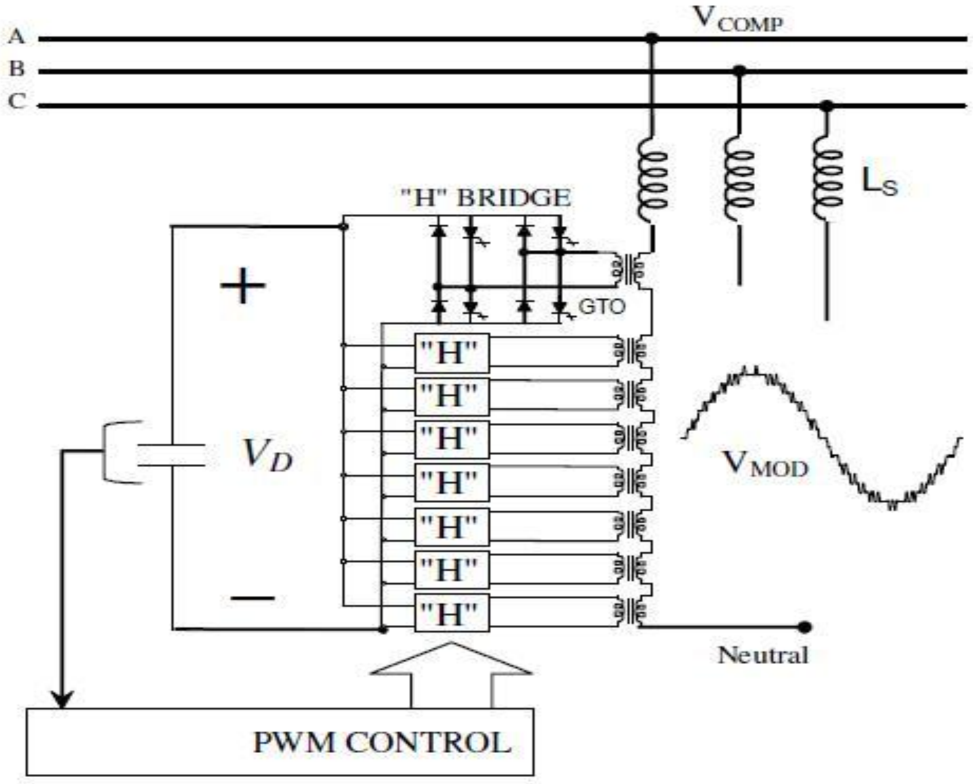


Figure 3.6 Shunt VAR compensator implemented with a three level NPC inverter.

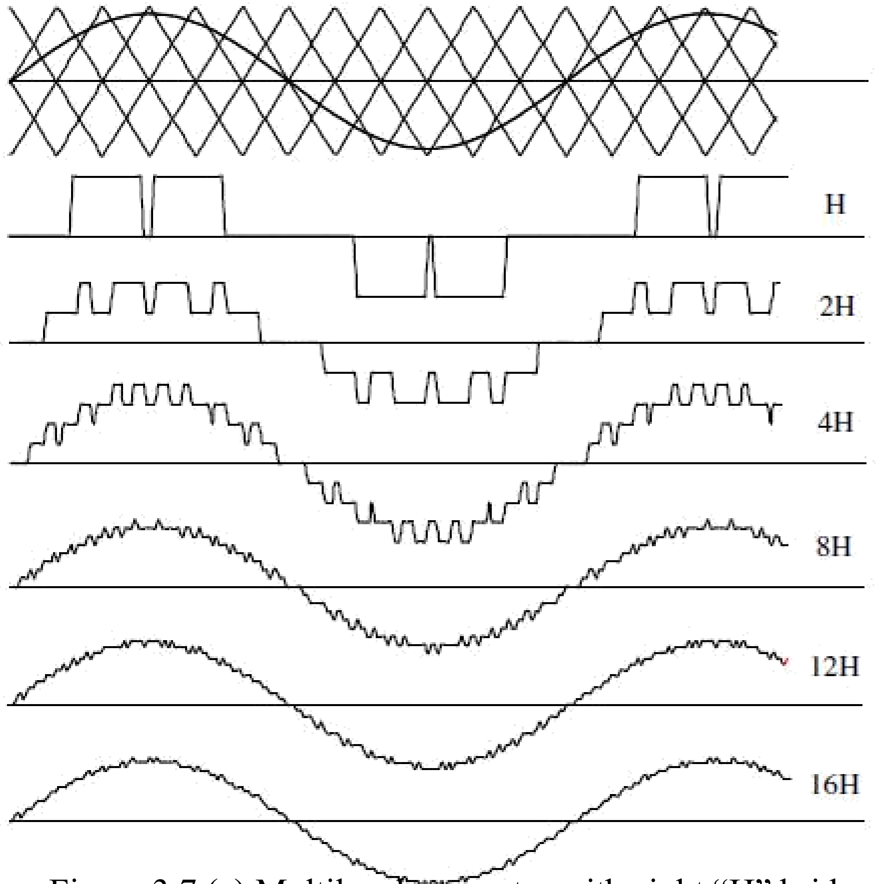
3.3.2.2 Multi-level converters with carriers shifted

Another exciting technology that has been successfully proven uses basic “H” bridges as shown in Fig 3.7, connected to line through power transformers. These transformers are connected in parallel at the converter side, and in series at the line side. The system uses SPWM (Sinusoidal Pulse Width Modulation) with triangular carriers shifted and depending on the number of converters connected in the chain of bridges, the voltage waveform becomes more and more sinusoidal. Fig 3.7 a, shows one phase of this topology implemented with eight “H” bridges and Fig. 3.7 b, shows the voltage waveforms obtained as a function of number of “H” bridges.

An interesting result with this converter is that the *ac* voltages become modulated by pulse width and by amplitude (PWM and AM). This is because when the pulse modulation changes, the steps of the amplitude also change. The maximum number of steps of the resultant voltage is equal to two times the number of converters plus the zero level. Then, four bridges will result in a nine-level converter per phase [9].



a)



(b)

Figure 3.7 (a) Multilevel converter with eight “H” bridges and triangular carriers shifted; (b) voltage quality as a function of number of bridges.

Figure 3.8 shows the AM operation. When the voltage decreases , some steps disappear, and then the amplitude modulation becomes a discrete function.

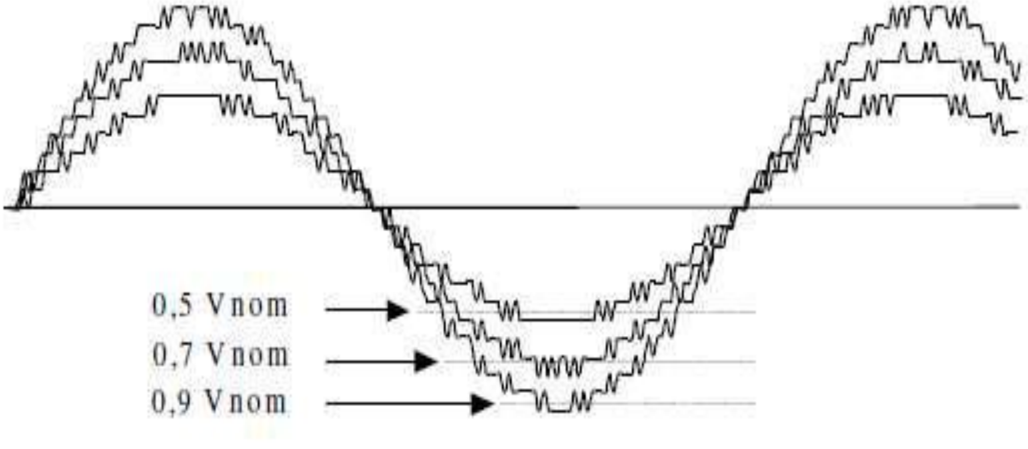
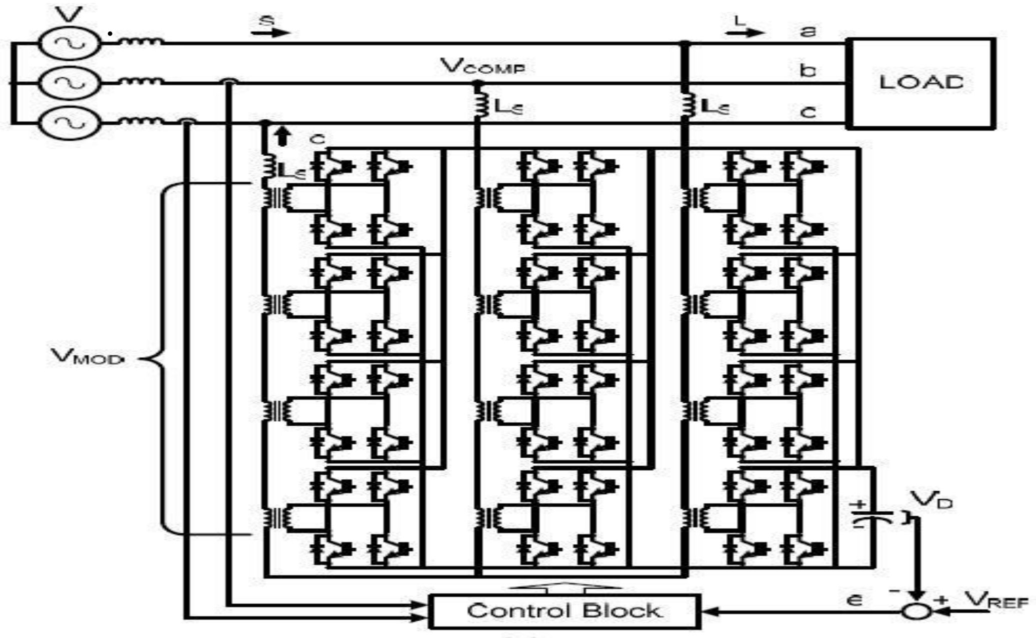


Figure 3.8 Amplitude modulation in topology of Fig 3.9 a.

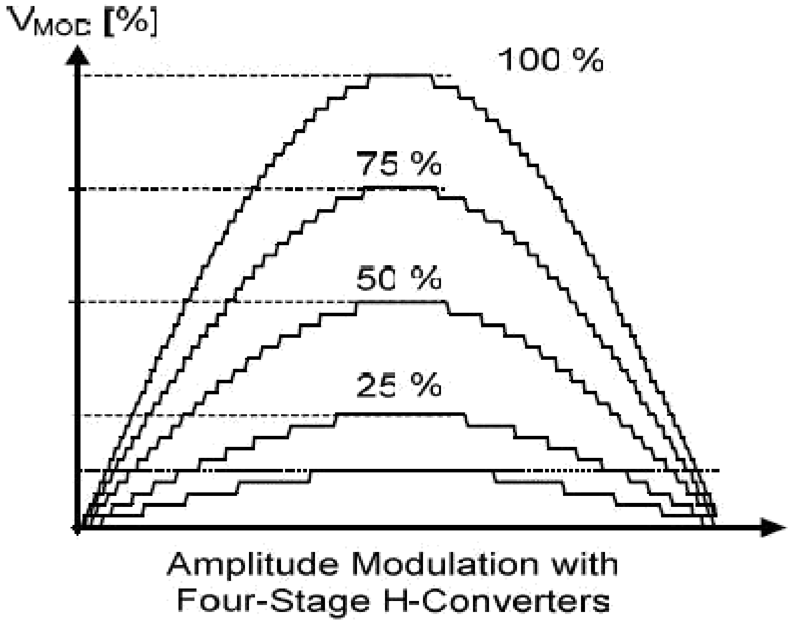
3.3.2.3 Optimized multi-level converter

The number of levels can increase rapidly with few converters when voltage escalation is applied. In a similar way of converter in Fig. 3.10-a), the topology of Fig. 3.9-a) has a common dc link with voltage isolation through output transformers, connected in series at the line side. However, the voltages at the line side are scaled in power of three. By using this strategy, the number of voltage steps is maximized and few converters are required to obtain almost sinusoidal voltage waveforms. In the example of Fig 3.9, Amplitude Modulation with 81 levels of voltage is obtained using only four “H” converters per phase (four stage inverter). In this way, VAR compensators with “harmonic-free” characteristics can be implemented.

It is important to remark that the bridge with the higher voltage is being commutated at the line frequency, which is a major advantage of this topology for high power applications. Another interesting characteristic of this converter, compared with the multilevel strategy with carriers shifted, is that only four “H” bridges per phase are required to get 81 levels of voltage. In the previous multilevel converter with carriers shifted, forty “H” bridges instead of four are required. For high power applications, probably a less complicated three-stage (three “H” bridges per phase) is enough. In this case, 27-levels or steps of voltage are obtained, which will provide good enough voltage and current waveforms for high quality operation[2].



(a)



(b)

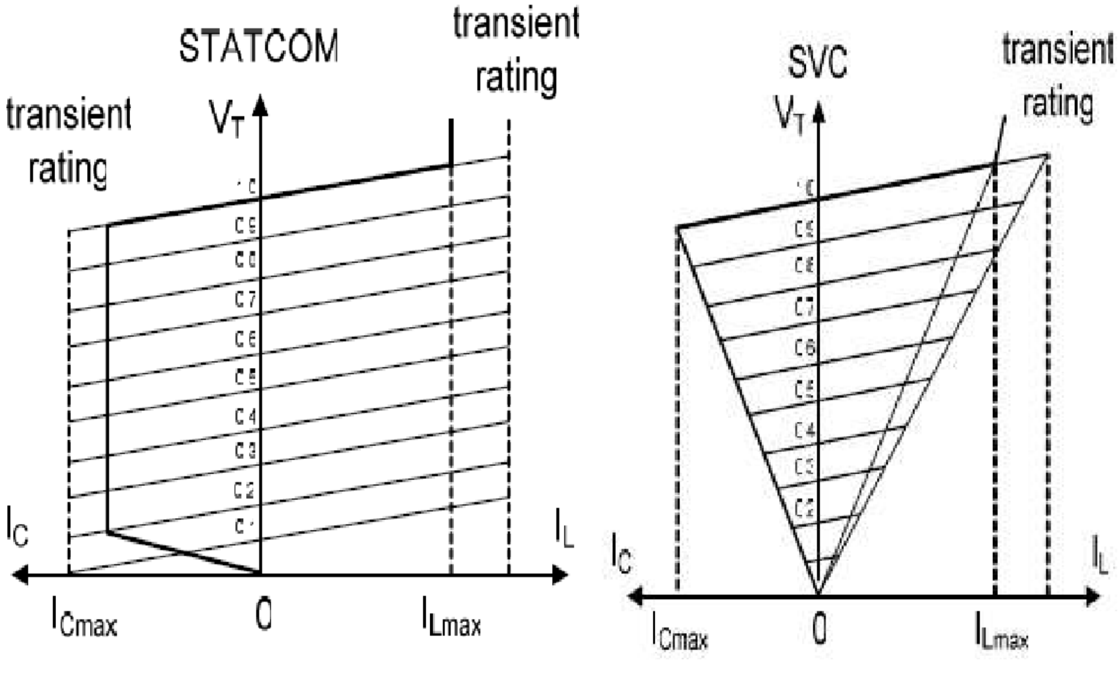
Figure 3.9 (a) Four-stage, 81-level VAR compensator, using “H” bridges scaled in power of three; (b) Converter output using amplitude modulation

3.4 Comparison between Thyristorized and Self-Commutated Compensators

Thyristorized and self-commutated FACTS controllers are very similar in their functional compensation capability, but the basic operating principles, as shown, are fundamentally different. A STATCOM functions as a shunt-connected synchronous voltage source whereas a thyristorized compensator operates as a shunt-connected, controlled reactive admittance. This difference accounts for STATCOM’s superior functional characteristics, better performance, and greater application flexibility.

In the linear operating range of the V–I characteristic, the functional compensation capability of the STATCOM and Static VAR Compensator (SVC) is similar. Concerning the nonlinear operating range, the STATCOM is able to control its output current over the rated maximum capacitive or inductive range independently of the ac system voltage, whereas the maximum attainable compensating current of the SVC decreases linearly with ac voltage. Thus, the STATCOM is more effective than the SVC in providing voltage support under large system disturbances during which the voltage excursions would be well outside of the linear operating range of the compensator. The ability of the STATCOM to maintain full capacitive output current at low system voltage also makes it more effective than the SVC in improving the transient stability limit. The attainable response time and the bandwidth of the closed voltage regulation loop of the STATCOM are also significantly better than those of the SVC [9].

Figure 3.10 shows the voltage / current characteristic of a self-commutated VAR compensator compared with that of thyristor controlled SVC. This figure illustrates that the self-commutated compensator offers better voltage support and improved transient stability margin by providing more reactive power at lower voltages. Because no large capacitors and reactors are used to generate reactive power, the self-commutated compensator provides faster time response and better stability to variations in system impedances.



(a) (b)

figure 3.10. Voltage – Current characteristics of shunt VAR compensators.

(a) Compensator implemented with self-commutated converter (STATCOM).

(b) Compensator implemented with back to back thyristors

Table 3.1 summarizes the comparative merits of the main types of shunt FACTS compensation. The significant advantages of self-commutated compensators make them an interesting alternative to improve compensation characteristics and also to increase the performance of ac power systems [2].

Table 3-Summarizes the comparison

	Synchronous Condenser	**Static Compensator**		**Self-commutated Compensator**
		TCR (with shunt capacitors if necessary)	**TSC (with TCR if necessary)**	
Accuracy of Compensation	Good	Very good	Good, very good with TCR	Excellent
Reactive Power Capability	Leading/ lagging	Lagging/leading Indirect	Leading/lagging indirect	Leading/lagging
Control	Continuous	Continuous	Discontinuous (cont. with TCR)	Continuous
Response Time	Slow Fast, 0.5 to 2	cycles Fast, 0.5 to 2 Cycles	cycles Fast, 0.5 to 2 cycles	Very fast but depends on the control system and switching frequency
Harmonics	Very Good	Very high (large size filters are needed)	Good, filters are necessary with TCR	Good, but depends on switching pattern
Losses	Moderate	Good, but increasing lagging Mode	Good, but increase in leading mode	Very good, but increase with switching frequency
Phase Balancing Ability	Limited	Good	Limited	Very good with 1-units, limited with3-units
Cost	High	Moderate	Moderate	Low to moderate

CHPTER FOUR

SIMULATION RESULTS AND DISCUSSION

4.1 Introduction

In the past, equipment used to control industrial process was mechanical in nature, which was rather tolerant of voltage disturbances. Nowadays, modern system equipment typically uses a large amount of electronic components, such as program logic control (PLCs), adjustable speed drives and optical devices, which can be very sensitive to such voltage disturbances. The amount of reactive power could be control by change firing angle of the thyristor or the DC value.

This chapter investigates in, the performance of the SVC & STATCOM verified when supplying transmission line. The aim of this work is to study SVC & STATCOM modules and studies the compensation impact on the transmission line of these modules**.**

4.2 Static Var Compensators:

In order to analyze the characteristics of the Static Synchronous Compensator, Using Sim Power Systems Toolbox. So we use Simulink toolbox of MATLAB R2010a to carry out the simulation analysis.

4.2.1 Modelling and simulation

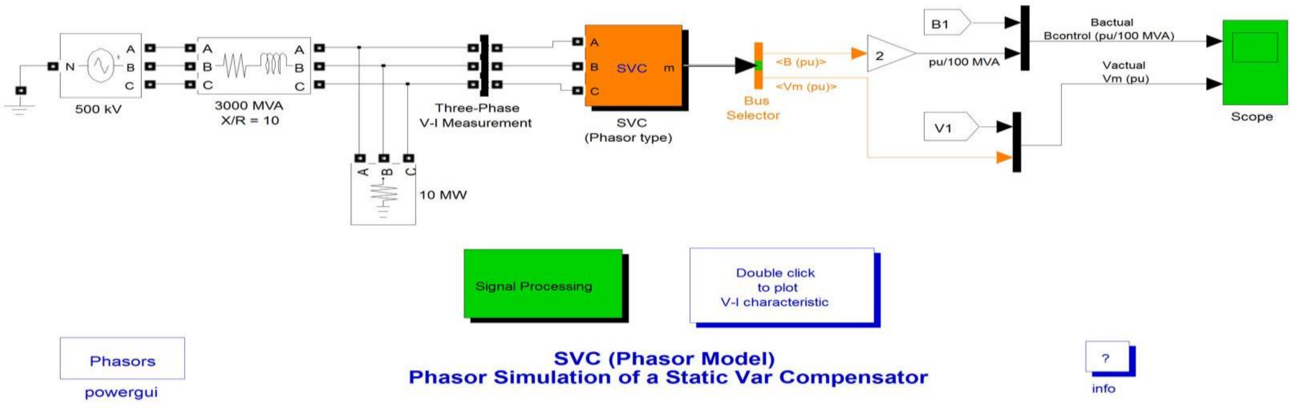


Figure 4.1: Simulation model of static VAR compensator.

4.2.2 Simulation parameters :

A static VAR compensator (SVC) is used to regulate voltage on a 500 kV, 3000 MVA system. When system voltage is low the SVC generates reactive power (SVC capacitive). When system voltage is high it absorbs reactive power (SVC inductive). The SVC is rated +200 MVAR capacitive and 100 MVAR inductive. The Static Var Compensator block is aa phasor model representing the SVC static and dynamic characteristics at the system fundamental frequency. To see the SVC control parameters, open the SVC dialog box and select "Display Control parameters". The SVC is set in voltage regulation mode with a reference voltage Vref=1.0 pu. The voltage droop is 0.03 pu/ 200MVA, so that the voltage varies from 0.97 pu to 1.015 pu when the SVC current goes from fully capacitive to fully inductive.

4.2.3 Simulation and results analysis

Simulation analysis of the Static Var Compensator in the normal working. Remarkable the suceptance of SVC is controlled by thyristor valve. SVC is used to bring the power factor closer to unity and gives instantaneous response to changes in the system. SVC is more reliable than dynamic compensation scheme like synchronous condenser. We had Run the simulation and observed waveforms on the Static Var Compensator scope block which found in another block, the simulation waveforms for the Static Var Compensator is shown below:

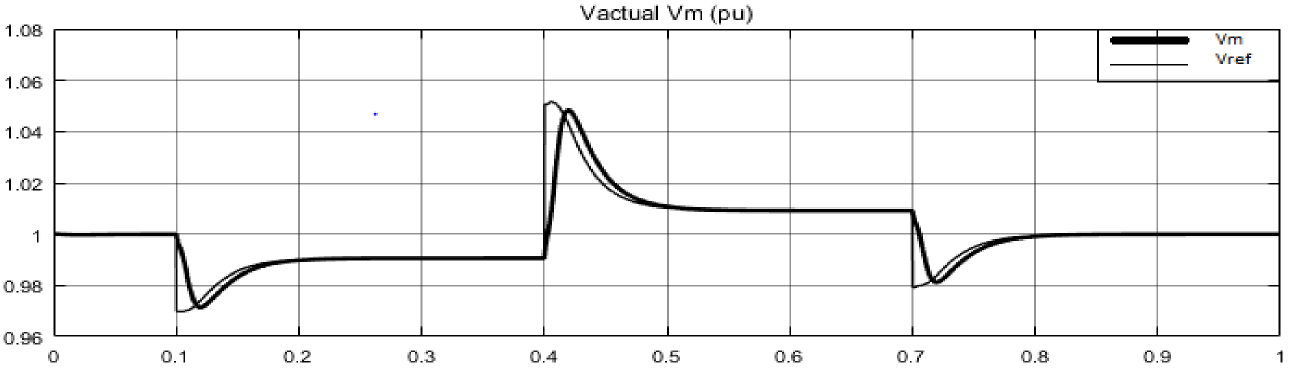


Figure 4.2:svc susceptance output of the voltage (pu).

4.3 Static Synchronous Compensator :

In order to analyze the characteristics of the Static Synchronous Compensator, Using Sim Power Systems Toolbox. So we use Simulink toolbox of MATLAB R2016a to carry out the simulation analysis.

4.3.1 Modelling and simulation

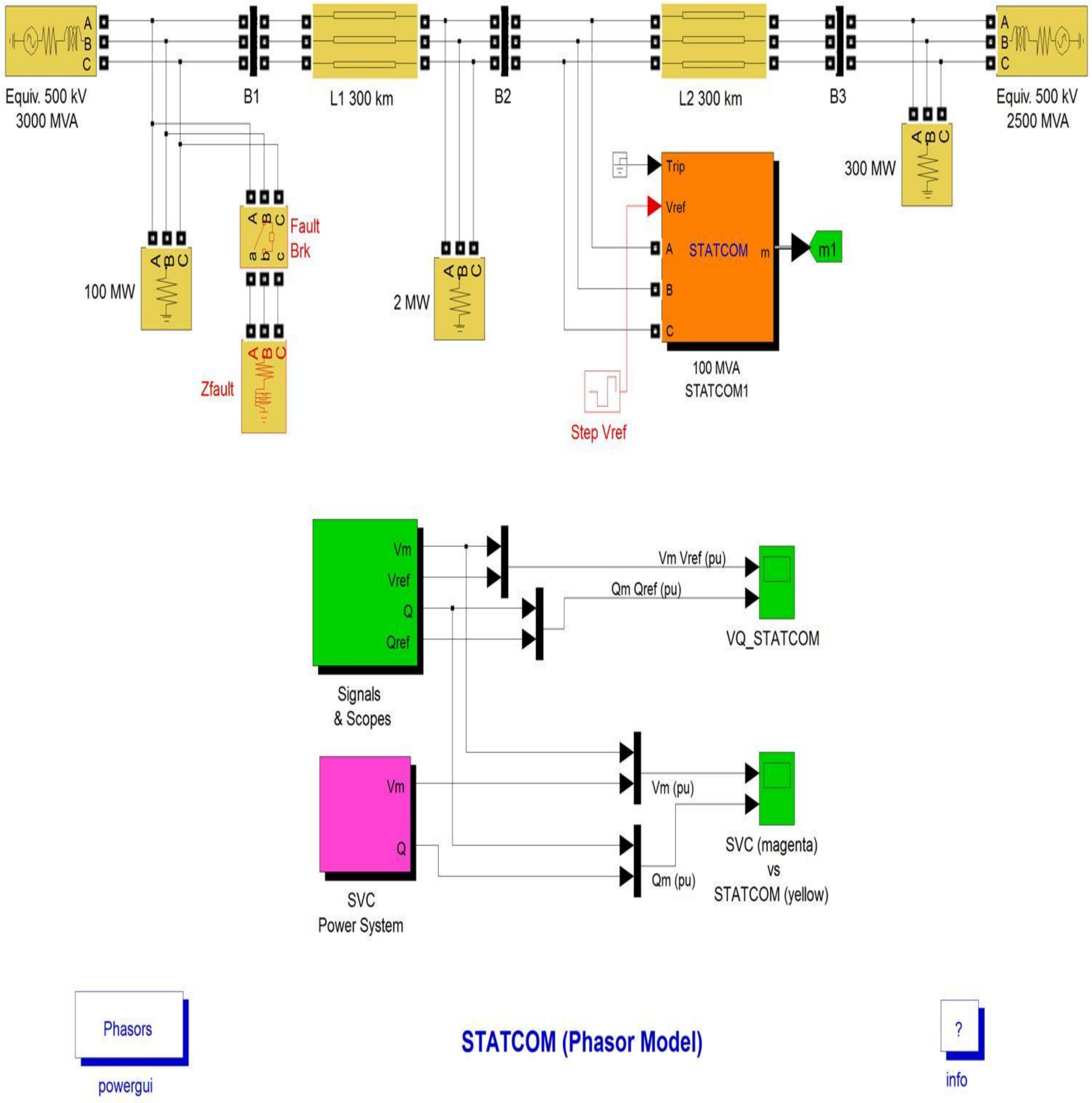


Figure (4.3) : Simulation model of Static Synchronous Compensator

4.3.2 Simulation parameters

The Static Synchronous Compensator (STATCOM) is one of the key FACTS devices. Based on a voltage-sourced converter, the STATCOM regulates system voltage by absorbing or generating reactive power. Contrary to a thyristor-based Static Var Compensator (SVC), STATCOM output current (inductive or capacitive) can be controlled independent of the AC system voltage.

The power grid consists of two 500-kV equivalents (respectively 3000 MVA and 2500 MVA) connected by a 600-km transmission line. In our lay out, the STATCOM is located at the midpoint of the line (bus B2) and has a rating of +/- 100MVA. This STATCOM is a typical three-level PWM STATCOM. a STATCOM having a DC link nominal voltage of 40 kV with an equivalent capacitance of 375 uF. On the AC side, its total equivalent impedance is 0.22 pu on 100 MVA. This impedance represents the transformer leakage reactance and the phase reactor of the IGBT bridge of an actual PWM STATCOM.

4.3.3 Simulation and results analysis

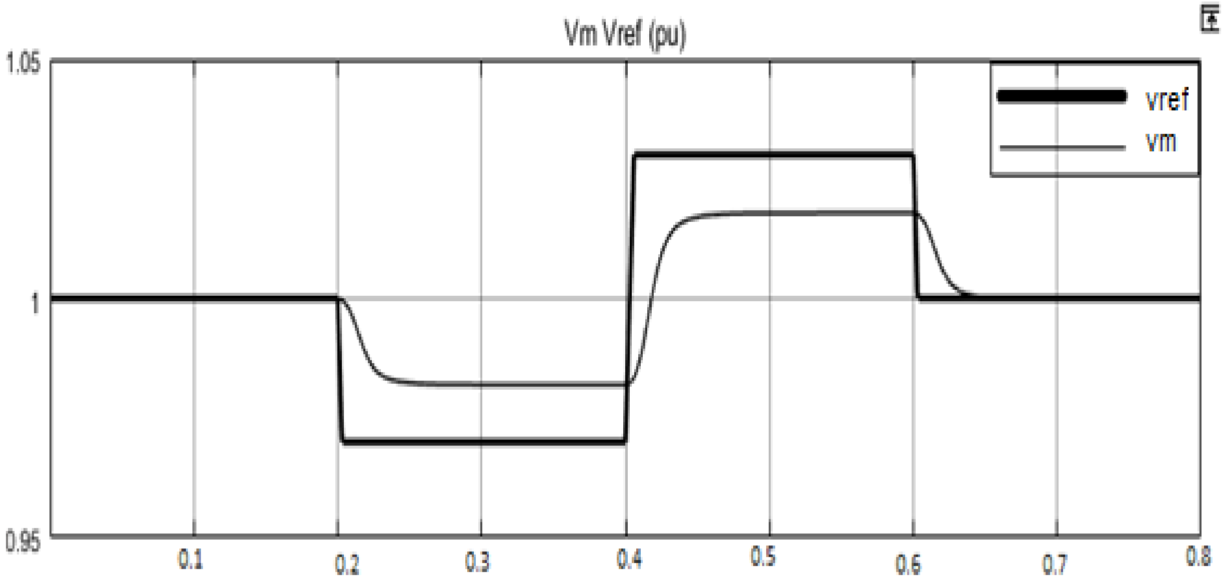


Figure 4.4 STATCOM susceptance output of the voltage regulator (pu)

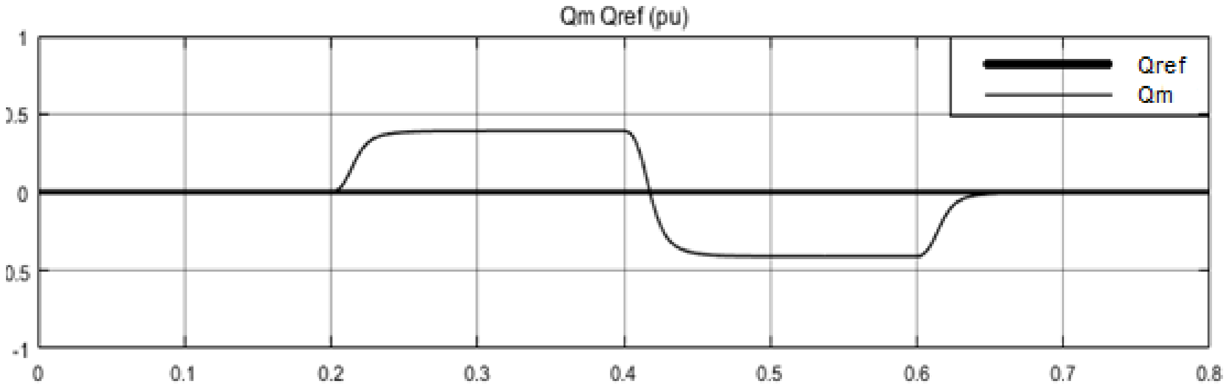


Figure (4.5) : STATCOM reactive power output (pu)

4.3.4 Bends and results analysis

Run the simulation and look at the "VQ_STATCOM" scope. The first graph displays the Vref signal along with the measured positive-sequence voltage Vm at the STATCOM bus . The second graph displays the reactive power Qm (reactive power measured) absorbed (positive value) or generated (negative value) by the STATCOM. The signal Qref (reactive power reference) is not relevant to our simulation because the STATCOM is in "Voltage regulation" and not in "Var Control".

This block should be programmed to modify the reference voltage Vref as follows: Initially Vref is set to 1 pu; at t=0.2 s, Vref(voltage reference) is decreased to 0.97 pu; then at t=0.4 s, Vref is increased to 1.03; and finally at 0.6 s, Vref is set back to 1 pu. and Remarkably:

- -Very fast increased damping of minor disturbances.
    - Increased productivity as stabilized voltage means better utilized capacity.
    - Reduced reactive power consumption, which gives lower losses and improved tariffs.
    - Balanced asymmetrical loads reduce system losses and enable lower stresses in rotating machinery.

- Enables better use of equipment (particularly transformers and cables).
- Good Reduced voltage fluctuations and light flicker.
- More Decreasing harmonic distortion.

4.4 STATCOM Compared to a SVC Under Fault Condition

In order to study the characteristics of Static Var Compensator, this section constructed a kind of Static Var Compensator system that includes Thyristor Switched Capacitor and Thyristor Controlled Reactor sections though Simulink toolbox of MATLABR2016a.

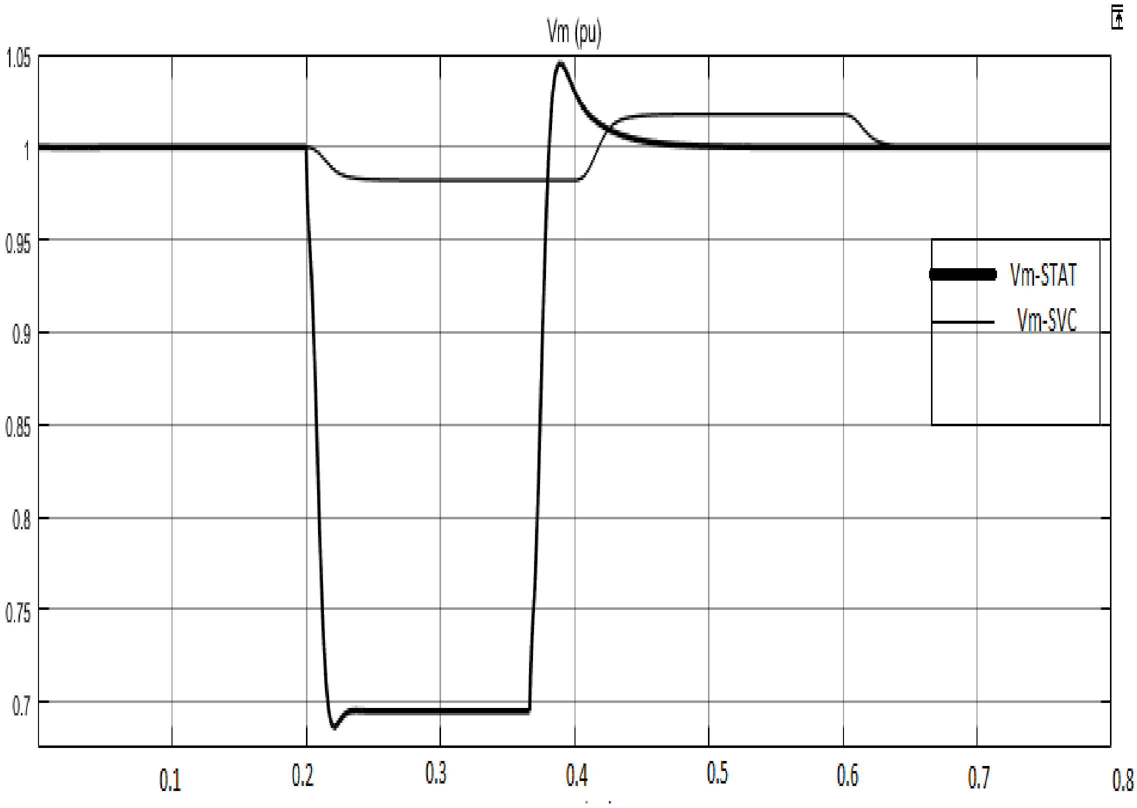


Fig (4.5) : SVC & STATCOM susceptance output of the voltage regulator (pu)

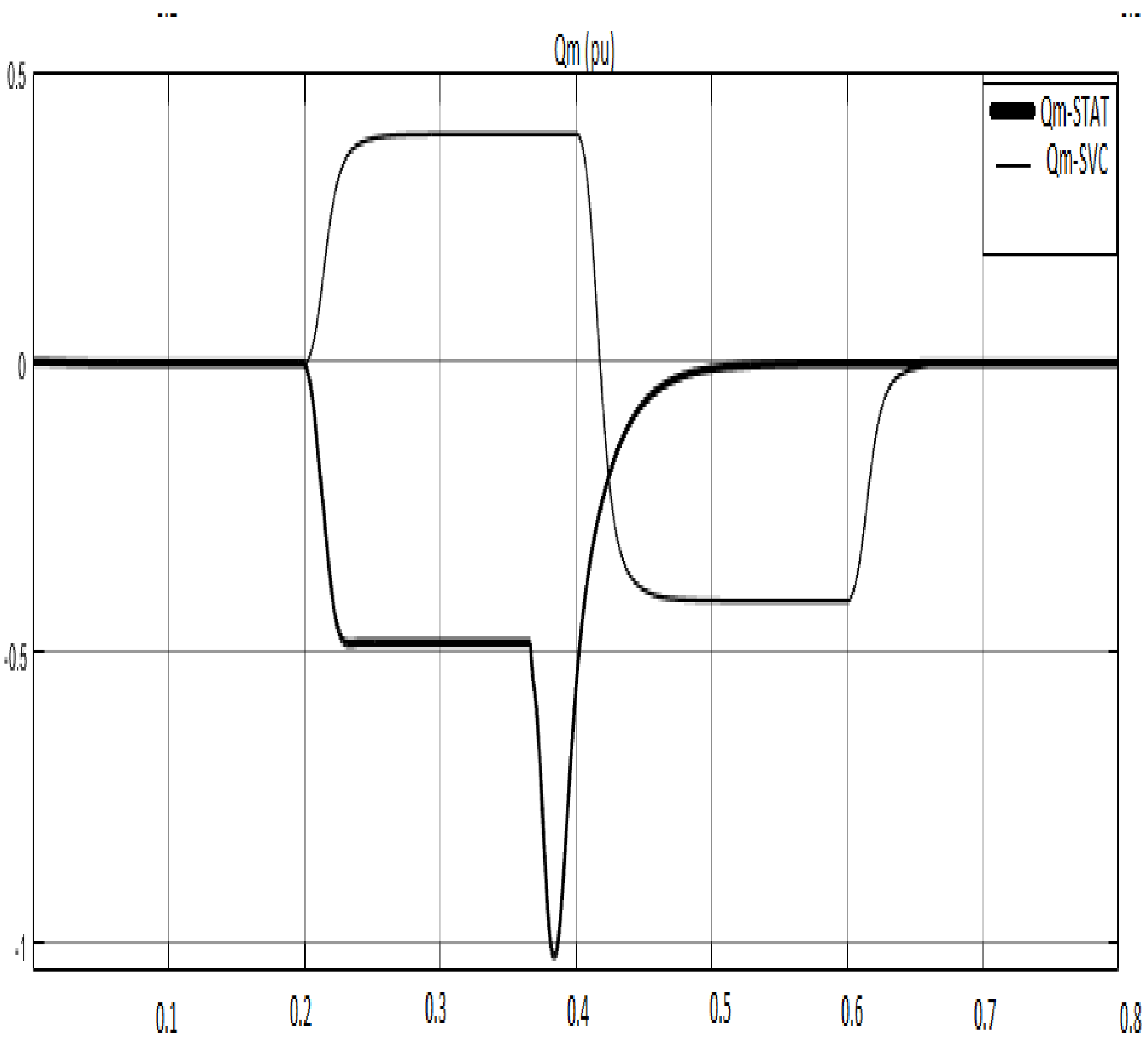


Fig (4.6) : SVC AND STATCOM reactive power output (pu)

4.4.1 Bends and results analysis

Run the simulation and look at the "SVC vs STATCOM" scope. The first graph displays the measured voltage Vm on both systems (magenta trace for the SVC). The second graph displays the measured reactive power Qm generated by the SVC (magenta trace) and the STATCOM (yellow trace). During the 10-cycle fault, a key difference between the SVC and the STATCOM can be observed. The reactive power generated by the SVC is -0.48 pu and the reactive power generated by the STATCOM is -0.71 pu. We can then see that the maximum capacitive power generated by a SVC is proportional to the square of the system voltage (constant susceptance) while the maximum capacitive power generated by a STATCOM decreases linearly with voltage decrease (constant current). This ability to provide more capacitive power during a fault is one important advantage of the STATCOM over the SVC. In addition, the STATCOM will normally exhibits a faster response than the SVC because with the voltage-sourced converter, the STATCOM has no delay associated with the thyristor firing (in the order of 4 ms for a SVC).and Remarkably the table (4-1) comparison between STATCOM and SVC

STATCOM	SVC
Faster	Slower than STATCOM
Cost is high	Cost losses
Higher losses	Less losses
Better characteristics	Not good as STATCOM
Constant current characteristics	Capacitive reactive current drops linearly
Interfaced with real power sources like battery ,fuel cell or SMES	Not interfaced with real power sources like battery ,fuel cell or SMES
Smaller in size	Larger in size
Controllable voltage source	Dynamically controlled reactance
More Decreasing harmonic distortion	Less Decreasing harmonic distortion
Complex construction and expensive	Simple construction and cheaper
Greater voltage control and stability	Lower voltage control and stability

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 The conclusions

Voltage and Reactive power compensation is an important issue in electric power systems, involving operational, economical and quality of service aspects consumer loads (residential, industrial, service sector, etc.) impose active and reactive power demand, depending on their characteristics. Active power is converted into “useful” energy, such as light or heat. Reactive power must be compensated to guarantee an efficient delivery of active power to loads, thus releasing system capacity, reducing system losses, and improving system power factor and bus voltage profile. The achievement of these aims based on the sizing and allocation of shunt capacitors (sources of reactive power).

In this research we studied reactive power compensation techniques; beginning from traditional methods like capacitor bank and synchronous condenser and going through modern methods like SVC and STATCOM. In this research we focused on modern reactive power compensation techniques - SVC and STATCOM - because we found out that it's very important elements in the power system grid. According to the simulation results we knew that Static VAR compensators have a large effect on the power system grid, it's important role that it can solve reactive power problems in the power system, so it improved electrical energy quality.

Specially SVC and STATCOM plays a very important role in transmission systems by controlling system voltage in order to increase the system stability which means better power delivery to the consumers. It also reduced power losses on the power system and improved voltage regulation and transient stability. it also reduced the damping characteristics of low frequency oscillation and governing harmonic in the power system.

It can be used as an important device which will be are widely used in power grid in the future, which is an advanced, economic, energy-efficient technology.

5.2 Recommendations

1- As we know that Sudanese electricity transmission company applied SVC system in some transmission stations, so we recommend the Sudanese electricity transmission company to make the SVC system widely used in all transmission station all over Sudan.

2- We also recommend Sudanese electricity transmission company if it had possibilities to apply the STATCOM system because it better than SVC.

3- In this research we focused on SVC and STATCOM compensation techniques, so we recommend the specialists to do a massive study about other compensation techniques in order to find out more advanced methods.

4 -Recommended to extensive study in the effective of reactive compensation devices stability of power system grid.

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APPENDIX

A. Compensation Devices:

Figure A. 1 Line Mounted Capacitor Bank

Figure A. 2 Capacitor bank (externally fused)

Figure A. 3 Photograph of a synchronous condenser

Figure A. 4 SVC Units

Figure A. 5 Directly connected SVC