Enhancement of Voltage Stability in Electric Power System using Embedded based Compensation Method

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Contents

Chapter 1
Introduction

In the past, transmission systems were conservatively designed with large stability margins and then available dynamic compensators, such as rotating synchronous condensers and more recently saturating reactors were rarely required. The broad variety of FACTS technologies provides reliable solutions to most challenging requirements in power transmission. Advances in high power semiconductors and sophisticated electronic control technologies have made the development of fast, thyristor-controlled Static VAR Compensators. These were originally developed for arc furnace compensation in the early 1970s, and a few years later they were adopted for transmission system compensation.

The analysis of a power system component such as generators, transmission lines and transformers, rely on harmonic voltage and current distortion levels. The harmonic distortion in voltage and current is usually calculated by means of load flow studies with an assumption that power generation and transmission system is perfectly linear. Harmonic voltages and currents as harmonic interaction takes place between the rotor and stator circuit of the generator causes magnetizing spectrum results in repetition of the harmonic conversion process at the synchronous generator of the transformer. Apart from this, any harmonic contribution from any other network component like transmission line, triggers the harmonic interaction between these two nonlinear power system components.

The traditional reactive power regulation methods before the invention of Static VAR Compensator (SVC) are, reconfiguration of system structure, generator excitation regulation, synchronous compensator, change the voltage by transformer tap to adjust the power flow in the grid, series compensation capacitor, switching in or out the shunt reactor or shunt capacitor and magnetic controlled reactor, compared to these traditional reactive power compensation methods, the Static VAR Compensator has extensively gained a significant market, primarily because of its superior performance to supply dynamic reactive power with fast response time and with low-cost maintenance.

Many SVC' spreviously were based on the effect of self-saturation of the iron core of a so-called saturated reactor. Since at the end of the seventies, thyristor controlled Static VAR Compensator have been available on the market and for a few years, it can be able to observe that the development of new Static VAR Compensator technologies wasbased on GTO or IGBT semiconductors.

Voltage stability is a common issue in developing power system. It is mainly affected by reactive power balance in the system. If reactive power is not well planned and managed, there is possibility of occurrence of voltage instability in the system. One solution to prevent voltage instability in the system is by VAR compensation. The aim of this implementation is to improve dynamic performance, flicker control and speed of reactive power regulation as well as the reduction of losses which form a major part of operating costs of such an installation. Regulating the supply voltage within the specified limits, about the desired steady state value under normal operating condition and compensation of the voltage fluctuation caused by the reactive power, demand of large and fluctuating domestic or industrial load compensation of the voltage variation, under unbalanced load has a significant role in electric power system.

Both industry and domestic equipment's are sensitive to voltage changes above or below a given magnitude due to the unbalanced load. Too high voltage may lead to insulation failure, damage to components or mal-operation of electrical equipment's and too low voltage may results in unsatisfactory performance, hence the development of thyristor-valves capable of handling large currents, as well as the technique of using them to switch capacitor in and out and control the current through a reactor improves the reliability of the interconnected power system.

The principle behind Static VAR Compensator is the cyclic process of storing in the passive reactive elements and releasing it to the system. This device employs fixed banks of power factor capacitors controlled with thyristors, which can switch them on and off rapidly. SVC maintains voltage levels, reduce voltage flicker, improvepower factor, correct phase imbalance and improve system stability.

A Static VAR Compensator is an electrical device for providing fast-acting reactive power on high-voltageelectricity transmission networks. Because of its fast response, it can stabilize the bus bar voltage even during fast changes of the load. Usually, a Static VAR Compensator is directly connected to a medium voltage power system. SVCs are a part of the Flexible AC Transmission System (FACTS) device family, which can be used for regulating voltage and stabilizing the system.

The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power 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 variation of reactive power is performed by switching three-phase capacitor banks and inductor banks connected on the secondary side of a coupling transformer. Reactors are either switched on-off (Thyristor Switched Reactor or TSR) or phase-controlled (Thyristor Controlled Reactor or TCR).

The SVC is one of the best device in which, it can contribute to improve the voltages profile in the transient state and therefore, in improving the quality and performance of an electric service or electric power system. SVC is one of the controller, based on Power Electronics known as FACTS (Flexible AC Transmission

Systems) Controller, which can control one or more variables in a power system, wherethyristors are turned on by a suitable control that regulates the magnitude of the current.

In an ideal AC power system, the voltage and frequency at every supply point would be constant and free from harmonics; the power factor would be unity. Three keys' aspects of voltage stability are the load characteristic as seen from bulk power network, the available means for voltage control at generators and in the network, the ability of the network to transfer power, particularly reactive power from the point of production to point of consumption.

In recent years, one problem that received wide attention is voltage instability. Voltage stability is the ability of a power system to maintain adequate voltage magnitude so that when the system nominal load is increased, the actual power transferred to that load will increase. The main cause of voltage instability is the inability of the power system to meet the demand for reactive power. Voltage instability is the cause of system voltage collapse, in which the system voltage decays to a level from which it is unable to recover. Voltage collapse may lead to partial or full power interruption in the system.

There are many reasons for over voltages in power system. The overvoltage causes number of effects in the power system. It may cause malfunction of the equipment's that are incorporated in a power system. Overvoltage can cause damage to the components connected to the power supply and lead to insulation failure, damage to electronic components, heating, flashovers, etc. Over voltages occur in a system when the system voltage rises over 110% of the nominal rated voltage. Overvoltage can be caused by a number of reasons, sudden reduction in loads, switching of transient loads, lightning strikes, failure of control equipment such as voltage regulators, neutral displacement, the causes of power system over voltages are numerous and the waveforms are complex. It is customary to classify the transients on the basis of frequency content of the waveforms.

Providing adequate reactive power support at the appropriate location solves voltage instability problems. There are many reactive compensation devices used by the utilities for this purpose, each of which has its own characteristics and limitations. However, the utility would like to achieve this with the most beneficial compensation device. It is a well-known fact that shunt compensation can be used to provide reactive power compensation. Traditional shunt capacitors or newly introduced FACTS controllers can be used for this purpose. Also, implementation of FACTS controllers is quite expensive.

As the next generation product of SVC, STATCOM has superior performance in response speed, stability of voltage level, reducing system loss, increasing transmission capacity and improving transient voltage limit, reducing harmonics and decreasing occupation area etc. Since 2005, Rongxin Power Electronic Co., Ltd (RXPE), one of the largest SVC manufacturers in the world, has begun to research and develop STATCOM with high-pressure large-capacity. In 2006, the

STATCOM test platform has been completed successfully using DSP TMS320F2812. In 2007, the first STATCOM used for traction substation in China developed by Rongxin Power Electronic Co., Ltd (RXPE).

The functions of FACTS devices are: regulation of power flows in prescribed transmission corridors, secure loading of lines near their thermal limits, prevention of cascading out-ages by contributing to emergency control, damping of oscillations which can threaten security or limit the usable line capacity and improve system stability.

Static Synchronous Compensator (STATCOM) previously known as STATCON or static condenser is converter based VAR compensator, which is an advanced Static VAR Compensator. STATCOM uses voltage source converters with capacitors connected on DC side. STATCOM resembles in many respects a rotating synchronous condenser used for voltage control and reactive power compensation. As compared to conventional SVC, STATCOM does not re-quire expensive large inductors; moreover, it can also operate as reactive power sink or source for wide range of operation, which makes it more attractive. A STATCOM plays an important role in reactive power compensation and voltage support because of its attractive steady state performance and operating characteristics. A number of studies have been performed about the dynamic behavior of STATCOM and its applications to improve the transient performance of power systems.

Installation of SVCs and STATCOMs for application in utility power system supply dynamic reactive power with fast response and with low maintenance. It responds to changes in power system operating conditions fast and continuously. Considering investment cost of SVCs is today substantially low and transient stability is comparatively high lower than of STATCOM.

Chapter 2
Review of Literature

2.1 Flexible Ac Transmission Systems (FACTS)

The term “FACTS” (Flexible AC Transmission Systems) covers several power electronics based systems used for AC power transmission and distribution. It is meant to enhance controllability and increase power transfer capability of the network. It is generally power electronics based system. FACTS are defined by the IEEE as "a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability". FACTS are devices used to control the governing parameters of the transmission line. For the given nature of power electronics equipment, FACTS solutions will be particularly justifiable in applications requiring one or more of the following qualities like rapid dynamic response, ability for frequent variations in output, smoothly adjustable output.

The main purpose of these systems is to supply the network as quickly as possible with inductive or capacitive reactive power that is adapted to its particular requirements, while also improving transmission quality and the efficiency of the power transmission system. Power supplies are increasingly dependent on distributed power plants with higher voltage levels, a greater exchange within meshed systems, and transport to large load centers over what are often long distances. This type of power transmission must be implemented safely and cost effectively with a view to the future.

FACTS provide, fast voltage regulation, increased power transfer over long AC lines, damping of active power oscillations and load flow control in meshed systems, thereby significantly improving the stability and performance of existing and future transmission systems. This means that with FACTS, power companies will be able to better utilize their existing transmission networks, substantially increase the availability and reliability of their line networks, and improve both dynamic and transient network stability while ensuring a better quality of supply. FACTS are a family of devices which can be inserted into power grids in series, in shunt, and in some cases, both in shunt and series. Important application in power transmission and distribution systems that involve devices, such as SVC (Static VAR Compensators), Fixed Series Capacitors (SC) as well as Thyristor-Controlled Series Capacitors (TCSC) and Static synchronous compensator (STATCOM).

FACTS mainly find applications in the following areas like power transmission, power quality, railway grid connection, wind power grid connection, cable systems. With FACTS, the following benefitscan be attained in AC systems are improved power transmission capability, improved system stability and availability, improved power quality, minimized environmental impact, minimized transmission losses.

The main objective of FACTS is to improve the power transferring capacity of the line and to have a control over the power flow in a line. If these objectives are fulfilled, then the power can be transferred in a transmission line with fewer requirements. The major problem in a transmission line is blackouts caused by the reactive power in which FACTS can be implemented to reduce the reactive power in power system.

2.2 Facts and Reactive Power

FACTS have a lot to do with reactive power compensation, and indeed, that used to be the term utilized for the technology in the old days. Reactive power appears in all electric power systems, due to the laws of nature. Contrary to active power, which is what we really want to transmit over our power system, and which performs real work, such as keeping a lamp lit or a motor running, reactive power does not perform any such work.

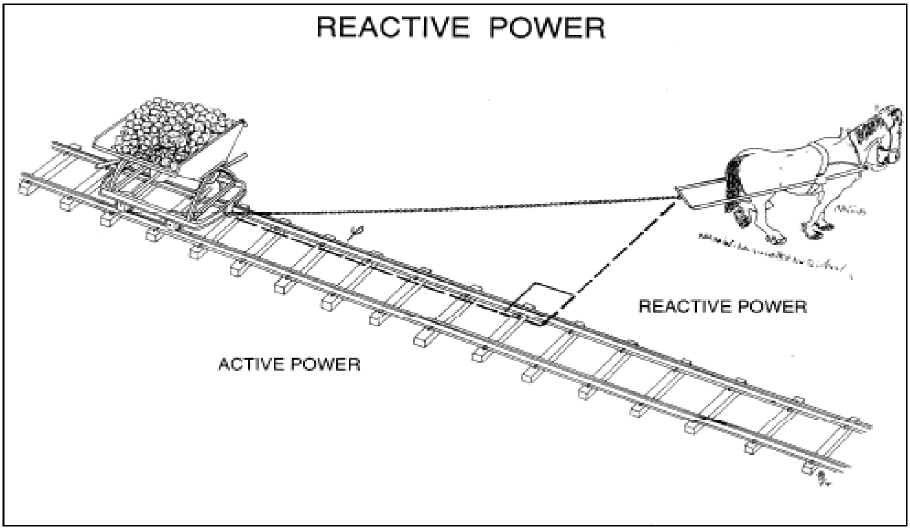


Fig 2.2.1. There is potential for more efficient use of this line

Consequently, the presence of reactive power in a grid makes it heavier for it to perform its task, i.e. transmit power from A to B (Figure 2.2.1), and consequently less efficient than would otherwise be possible. Referring to Lenz´ law, formulated already in the nineteenth century: Every change in an electrical system induces a counter-reaction opposing its origin. So as a consequence, if the flow of reactive power is minimized over the transmission system, the system can construct more efficient and put it to better and more economical use.

In total it cannot be done without reactive power, though, because it is intimately linked with grid voltage (500 kV, 400 kV, 220 kV, etc). To get the correct grid voltage, right amount of reactive power in the system is needed because if there is no enough reactive power, the voltage will sag and vice versa. If there is too much of reactive power, the voltage will be too high. So, to have it in the right amount, at all times and in the right places of the grid, Reactive Power Compensation is highly essential. Also, Reactive power balance is important also from another point of view: it ensures that valuable space in transmission lines and equipment such as transformers is not occupied by “idle” reactive power, but rather available for a maximum of useful, active power (Figure2.2.2).

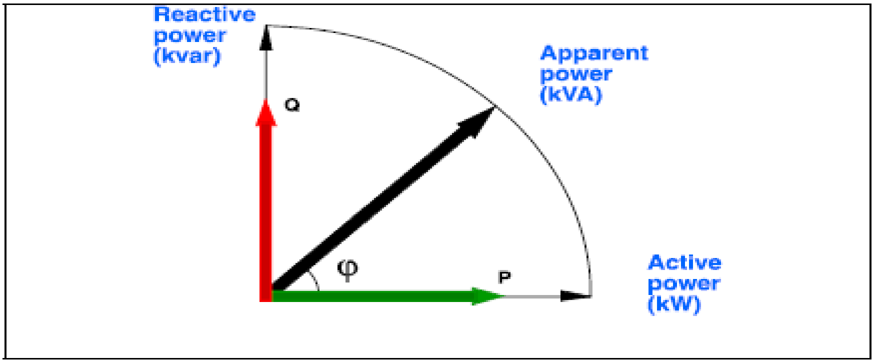


Fig 2.2.2. Reactive power steals precious space in power lines and equipment

Here it should be pointed out that a reactive power compensator needs to be fast, i.e. fast response is a key characteristic of the device. This is particularly crucial in situations where some fault appears in the grid. In such a situation, it will often be a matter of milliseconds for the Reactive Power Compensator, i.e. the FACTS device, to go into action and help to restore the stability, and the voltage of the grid, in order to prevent, or mitigate, a voltage collapse. Quite in general, there is a tendency for a deficit of reactive power close to large, electricity consuming areas, as well as close to large, electricity consuming industry enterprises, such as steel works, petrochemical complexes, and large mine complexes. That means that in such cases, reactive power needs to be added. There is usually a surplus of reactive power at the end of long, lightly loaded transmission lines and cables. Here, reactive power has to be compensated away. In either case, or particularly when the reactive power is fluctuating with time, FACTS is the solution.

2.3 Losses

Maintaining proper balance of reactive power in the grid is important also from another point of view in excess of reactive power flowing in the grid also gives rise to losses. FACTS prevent such losses and it is important that reactive power is not permitted to flow over long distances, because losses grow with the distance that the reactive power is flowing over. Instead, reactive power should be inserted where it is needed. For example, close to large cities and or large industry enterprises etc.

2.4 Voltage Stability Phenomenon in Power System

a) Major reasons for voltage stability problems on power system.

There are some reasons for voltage stability problems in power system as follows:

1) Large load or large disturbance in a heavily stressed power system.
2) Large disturbance between generation and load.
3) Unfavorable load characteristics.
4) More distance between Voltage sources and load centers.
5) The source voltage is too low.
6) In sufficient load reactive compensation.
7) Action of ULTC during low voltage conditions.
8) Poor coordination between various control and protective systems.
9) High reactive power consumption at heavy load.
10) Unsuitable locations of FACTS controllers.

2.5 Voltage Control Methods in Power System

The control of voltage levels is accomplished by controlling the production, absorption, and flow of reactive power at all levels in the system. The devices used for this purpose may be classified as follows,

1) Sources or sinks of reactive power, such as shunt capacitors, shunt reactors, synchronous condensers and Static Var Compensators (SVCs).
2) Line reactance compensators, such as series capacitors.
3) Regulating transformers, such as tap-changing transformers and boosters.

2.6 Technology Underlying Facts

Power transmission and distribution systems should be able to carry power up to the thermal design limit. However, the power flow is usually constrained to a lower limit owing to reactive power considerations and reliability requirements determined through contingency analysis to ensure security of the grid under varying system conditions. Improved power flow control of power systems can be achieved through the use of various technologies that can be generally categorized as mechanical-based and power electronics-based technologies. Tap-changing or phaseshifting transformers, switched shunt capacitors and inductors, and voltage regulators are mechanical-based technologies that provide a coarse level of control. FACTS devices are power electronics-based technologies and represent a wide range of controllers with different designs and different levels of power flow control capabilities. Reactive power support from FACTS devices can help to increase power transfer capabilities, improve voltage stability, and enhance system stability. Criteria and metrics used for measuring improvements in FACTS devices could include their ability to meet voltage stability criteria (e.g., voltage or power criteria with minimum margins), dynamic voltage criteria (e.g., minimum transient voltage dip/sag criteria [magnitude and duration]), transient stability criteria, and power system oscillation damping.

To provide stable, secure, controlled, high quality electric power on today's environment and to do better utilization of available power system capacities Flexible AC transmission systems (FACTS) controllers are employed to enhance power system stability in addition to its main function of power flow control. The FACTS devices are focused on power flow modulation, control, stability enhancement and oscillation damping. The Power electronic based FACTS devices are added to power transmission and distribution systems at strategic locations to improve system performance. The development of FACTS-devices has started with the growing capability of power electronics components. Devices for high power levels have been made available in converters for higher and even highest voltage levels. FACTS-devices provide a better adaption to varying operational conditions and improve the usage of existing installations.

Applications of FACTS Controllers

1) Control of power flow in a transmission line
2) Increase the loading capability of line to their thermal limit
3) Control of voltage in a line
4) Control of reactive power in a power line
5) Improvement of system stability, security & reliability
6) power quality improvement in a line
7) Provide greater flexibility insisting new generation
8) Upgradation of lines
9) Reduce reactive power flow
10) Increase utilization of lowest cost generation
11) Rapid dynamic response
12) Ability for frequent variation in output

13) Adjustable smooth output
14) Minimized transmission losses

The FACTS device can be classified in to four types:

1. Shunt compensation
2. Series compensation
3. Shunt-series compensation
4. Back to back compensation

2.6.1 Shunt Compensation

In shunt compensation, the controller (variable impedance or variable voltage source or combination of both) is parallel to the system. FACTS work as a controllable current source. Here FACTS act as a reactive power compensator. It has two types namely:

1. Shunt capacitive
2. Shunt inductive

2.6.1.1 Shunt Capacitive Compensation

This method is used to improve the power factor. When there is an inductive circuit there is a lagging current. Due to this, the losses and poor efficiency occur. Hence when a capacitor is added it will produce a leading current compensating the lagging current.

2.6.1.2 Shunt Inductive Compensation

This is used in two cases, when charging the transmission line and when there is very low load at the receiving end. As a result, very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification (Ferranti Effect). The receiving end voltage may become double the sending end voltage. To compensate, shunt inductors are connected across the transmission line.

Advantages of Shunt Compensation

1. Compensate the reactive power and hence reduce the losses

2. Improvement in static and transient stability
3. Improvement in power quality
4. Compensation of thyristor converters

Examples of shunt compensation are SVC, STATCOM. A Static VAR Compensator (SVC) is based on thyristor controlled reactors (TCR), thyristor switched capacitors (TSC), and/or Fixed Capacitors (FC) tuned to Filters. A TCR consists of a fixed reactor in series with a bi-directional thyristor valve. TCR reactors are as a rule of air core type, glass fiber insulated, epoxy resin impregnated.

A TSC consists of a capacitor bank in series with a bi-directional thyristors valve and a damping reactor which also serves to de-tune the circuit to avoid parallel resonance with the network. The thyristors switch acts to connect or disconnect the capacitor bank for an integral number of half-cycles of the applied voltage. A complete SVC based on TCR and TSC may be designed in a variety of ways, to satisfy a number of criteria and requirements in its operation in the grid. Two very common design types, both having each their specific merits, are shown in Figure 2.4.1a and 2.4.1b.

A Static Synchronous Compensator (STATCOM) consists of a voltage source converter, a coupling transformer and controls (Figure. 2.4.1c). In Figure.2.4.1c*Iq*is the converter output current and is perpendicular to the converter voltage *Vi*. The magnitude of the converter voltage and thus the reactive output of the converter (Q) is controllable. If *Voltage, Vi T* is greater, the STATCOM supplies reactive power to the ac system. If *Voltade Vi T* is lesser, the STATCOM absorbs reactive power. State of the art for STATCOM is by the use of IGBT (Insulated Gate Bipolar Transistors). By use of high frequency Pulse Width Modulation (PWM), it has become possible to use a single converter connected to a standard power transformer via air-core phase reactors. The core parts of the plant are located inside a prefabricated building. The outdoor equipment is limited to heat exchangers, phase reactors and the power transformer. For extended range of operation, additional fixed capacitors, thyristors switched capacitors or an assembly of more than one converter may be used.

The semiconductor valves in a STATCOM respond almost instantaneously to a switching order. Therefore, the limiting factor for the compel plant speed of response is determined by the time needed for voltage measurements and the control system data processing. A high gain controller can be used and a response time shorter than a quarter of a cycle is obtained.

The high switching frequency used in the IGBT based STATCOM concept results in an inherent capability to produce voltages at frequencies well above the fundamental one. This property can be used for active filtering of harmonics already present in the network. The STATCOM then injects harmonic currents into the network with proper phase and amplitude to counteract the harmonic voltages.

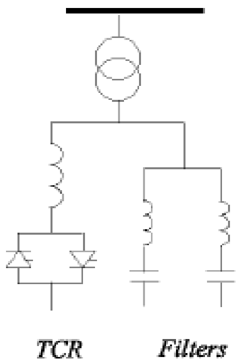


Fig 2.4.1a. TCR / FC configuration

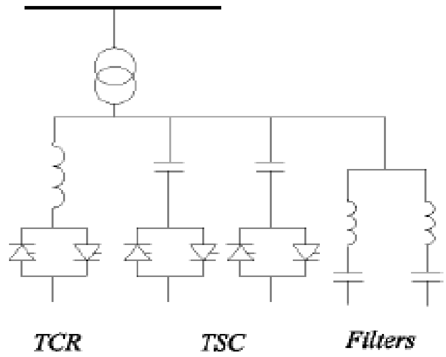


Fig 2.4.1b. TCR / TSC configuration

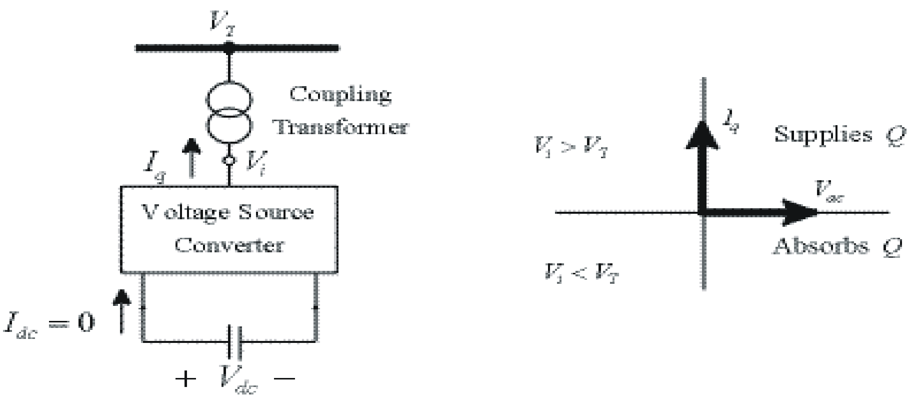


Fig 2.4.1c. STATCOM

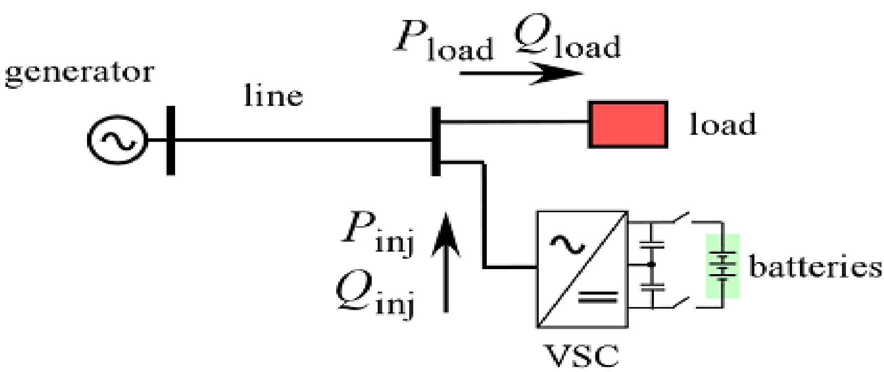


Fig 2.4.1d. STATCOM with energy storage

By adding storage capacity to the DC side of STATCOM, it becomes possible not only to control reactive power, but also active power. As storage facility, various kinds of battery cells can be used, depending on the requirements on the storage facility. The result, STATCOM with energy storage (Figure. 2.4.1 d), is expected to come into use in years to come as dynamic storage facility particularly of renewable energy (wind, solar).

2.6.2 Series Compensation

In series compensation, the controller (variable impedance or variable voltage source or combination of both) is in series to the system. FACTS work 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.

Advantages of series compensation:

1. Reduction of series voltage drop
2. Reduction of voltage fluctuation
3. Improvement of system damping
4. Limitation of short circuit current

Examples of Series Compensation are, a Series Capacitor (SC) is not just a capacitor in series with the line. For proper functioning, series compensation requires control, protection and supervision facilities to enable it to perform as an integrated part of a power system. Also, since the series capacitor is working at the same voltage level as the rest of the system, it needs to be fully insulated to ground.

The main circuit diagram of a state of the art series capacitor is shown in Figure 2.4.2 a. The main protective device is a varistor, usually of metal oxide type, limiting the voltage across the capacitor to safe values in conjunction with system faults giving rise to large short circuit currents flowing through the line. A spark gap is utilized in many cases, to enable by-pass of the series capacitor in situations where the varistor is not sufficient to absorb the excess current during a fault sequence. There are various bypass solutions available today like spark gap, high power plasma switch, power electronic device, etc.

Finally, a circuit breaker is incorporated in the scheme to enable bypassing of the series capacitor for more extended periods of time as need may be. It is also needed for extinguishing the spark gap, or, in the absence of a spark gap, for by-passing the varistor in conjunction with faults close to the series capacitor (so-called internal faults).

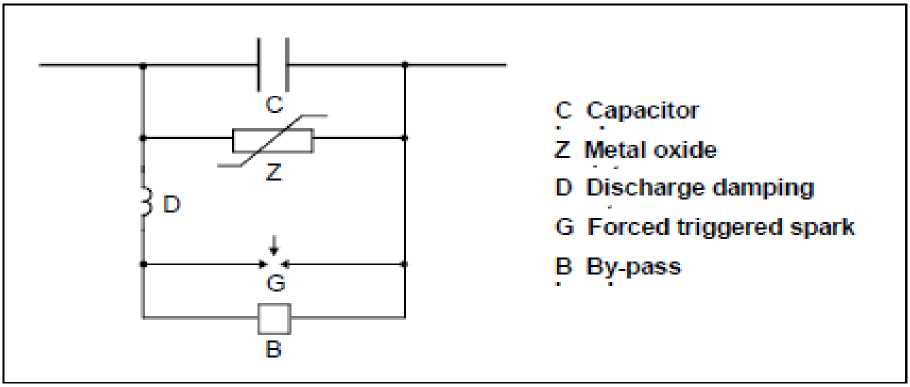


Fig 2.4.2 a. Main configuration of a Series Capacitor

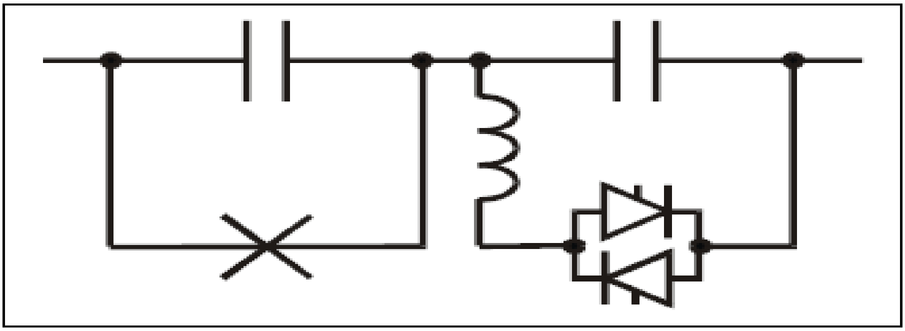


Fig 2.4.2 b. Controllable Series Compensation

The Fig. 2.4.2 b shows the controllable series compensation. Though very useful indeed, conventional series capacitors are still limited in their flexibility due to their fixed ratings. By introducing control of the degree of compensation, additional benefits are gained. The introduction of thyristors technology has enabled strong development of the concept of series compensation. Added benefits are dynamic power flow control, possibility for power oscillation damping, as well as mitigation of sub-synchronous resonance (SSR), should this be an issue.

2.6.3 Series Shunt Controllers

This could be the combination of both shunt and series controllers, which are controlled in a coordinate manner. Combined series and shunt controller would inject current with the shunt part and voltage in series. There is a real power exchange in this system. There is various application of this device.

1. Dynamic Flow Controller (DFC)

2. Unified Power Flow Controller (UPFC)
3. Interline Power Flow controller (IPFC)
4. Generalized Unified Power Flow Controller (GUPFC)

2.6.4 Back-To-Back Devices

A back to back device provides a full power flow controllability and power flow limitation. Overload in these devices are not possible. They can resist cascading outages which occur due to line outages when one line after the other is over loaded.

Uses of back to back device

1. Coupling of electricity mains of different
2. Frequency coupling two networks of the same nominal frequency but no fixed Phase relationship.

2.7 Impact of Facts in Interconnected Networks

The benefits of power system interconnection are well established. It enables the participating parties to share the benefits of large power systems, such as optimization of power generation, utilization of differences in load profiles and pooling of reserve capacity. From this follows not only technical and economic benefits, but also environmental, when for example surplus of clean hydro resources from one region can help to replace polluting fossil-fueled generation in another.For interconnections to serve their purpose, however, available transmission links must be powerful enough to safely transmit the amounts of power intended.

If this is not the case, from a purely technical point of view it can always be remedied by building additional lines in parallel with the existing, or by up rating the existing system(s) to a higher voltage. This, however, is expensive, time-consuming, and calls for elaborate procedures for gaining the necessary permits. Also, in many cases, environmental considerations, popular opinion or other impediments will render the building of new lines as well as up rating to ultra-high system voltages impossible in practice. Hence FACTS are the solution. Examples of successful implementation of FACTS for power system interconnection can be found among others between the Nordic Countries and between Canada and the United States. In such cases, FACTS helps to enable mutually beneficial trade of electric energy between the countries. Other regions in the world where FACTS is emerging as a means for AC bulk power interchange between regions can be found in South Asia as well as in Africa and Latin America. In fact, AC power corridors equipped with SVC and or SC transmitting bulk power over distances of more than 1000 km are a reality today.

Chapter 3
Static VAR Compensator (SVC)

3.1 Introduction

A Static VAR Compensator is a set of electrical devices for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage, power factor, harmonics and stabilizing the system. Unlike a synchronous condenser which is a rotating electrical machine, a static VAR compensator has no significant moving parts (other than internal switchgear). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers or switched capacitor banks. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

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

In transmission applications, the SVC is used to regulate the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use thyristors controlled reactors to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the thyristors-controlled reactor, which is continuously variable, along with a capacitor bank step, the net result is continuously variable leading or lagging power. In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage. SVC could provide the fast acting voltage support necessary to prevent the possibility of voltage instability at the bus bar or in power distribution system.

Typically an SVC comprises one or more banks of fixed or switched shunt capacitors or reactors, of which at least one bank is switched by thyristors. The variable shunt compensation using SVC can be extended to the large rating machines and large interconnected power systems.

Elements which may be used to make an SVC typically include:

1. Thyristor controlled reactor (TCR), where the reactor may be air or iron

cored.

2. Thyristor switched capacitor (TSC)
3. Harmonic filter(s)
4. Mechanically switched capacitors or reactors (switched by a circuit breaker)

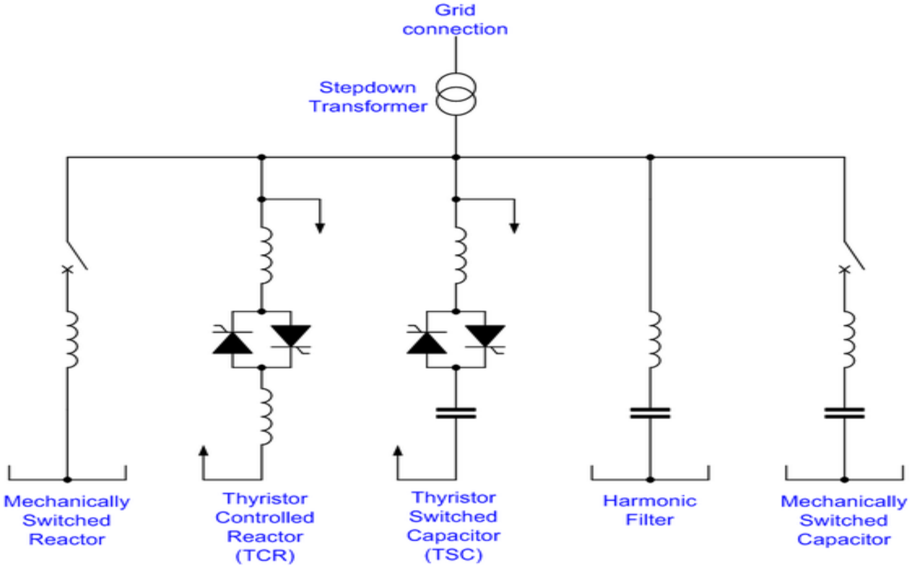


Fig 3.1.1

One-line diagram of a typical SVC configuration here employs a thyristor controlled reactor, a thyristor switched capacitor, a harmonic filter, a mechanically switched capacitor and a mechanically switched reactor. By means of phase angle modulation switched by the thyristor, the reactor may be variably switched into the circuit and so provide a continuously variable MVAR injection (or absorption) to the electrical network.

In this configuration, coarse voltage control is provided by the capacitors; the thyristor-controlled reactor is to provide smooth control. Smoother control and more flexibility can be provided with thyristor-controlled capacitor switching.

Generally, static VAR compensation is not done at line voltage; a bank of transformers steps the transmission voltage (for example, 230 kV) down to a much lower level (for example, 9.0 kV). This reduces the size and number of components needed in the SVC, although the conductors must be very large to handle the high currents associated with the lower voltage. In some static VAR compensators for industrial applications such as electric arc furnaces, where there may be an existing medium-voltage bus bar present (for example at 33kV or 34.5kV), the static VAR compensator may be directly connected in order to save the cost of the transformer.

Another common connection point for SVC is on the delta tertiary winding of Y-connected auto-transformers used to connect one transmission voltage to another voltage. The dynamic nature of the SVC lies in the use of thyristors connected in series and inverse-parallel, forming "thyristors valves"). The disc-shaped semiconductors, usually several inches in diameter, are usually located indoors in a "valve house".

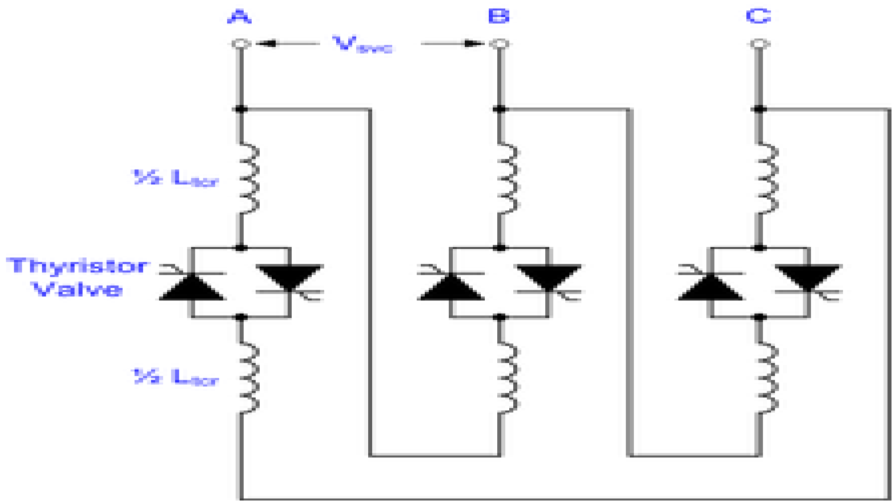


Fig 3.1.2. Thyristor Controlled Reactor (TCR) with Delta connection

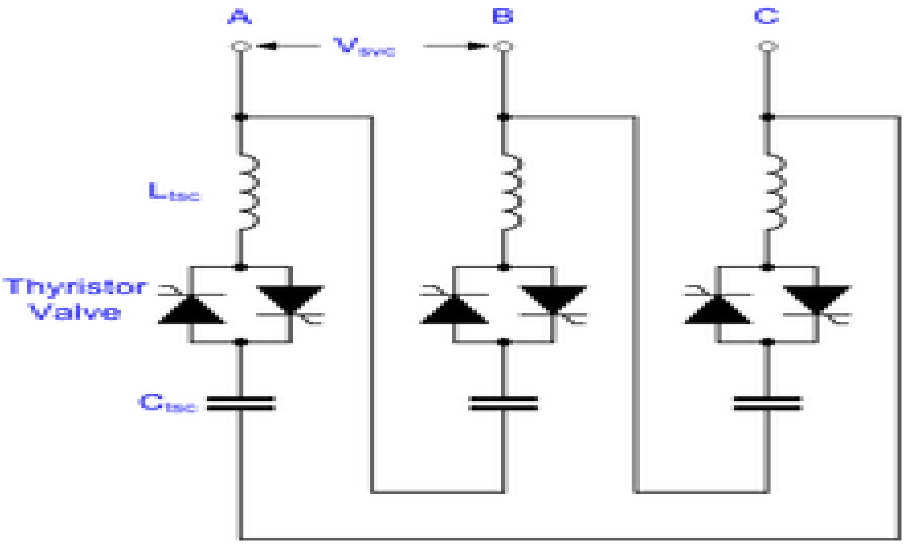


Fig 3.1.3. Thyristor Switched Capacitor (TSC), shown with Delta connection

The main advantage of SVCs over simple mechanically switched compensation schemes is their near-instantaneous response to changes in the system voltage. For this reason, they are often operated at close to their zero-point in order to maximize the reactive power correction they can rapidly provide when required. They are, in general, cheaper, higher-capacity, faster and more reliable than dynamic compensation schemes such as synchronous condensers. However, static VAR compensators are more expensive than mechanically switched capacitors, so many system operators use a combination of the two technologies (sometimes in the same installation), using the static VAR compensator to provide support for fast changes and the mechanically switched capacitors to provide steady-state VARs.

The thyristors are electronically controlled and are semiconductors that can generate heat and deionized water is commonly used to cool them. Chopping reactive load into the circuit in this manner injects undesirable odd-order harmonics and so banks of high-power filters are usually provided to smooth the waveform. Since the filters themselves are capacitive, they also export MVARs to the power system. More complex arrangements are practical where precise voltage regulation is required. Voltage regulation is provided by means of a closed-loop controller. Remote supervisory control and manual adjustment of the voltage set-point are also common.

The FACTS are controllers based on solid states technologies, whose two main objectives are: the increase of the transmission capacity and of the control of the power flow over designated transmission routes. On this way, the controllers FACTS can be classified into four categories: Series Controllers, Shunt Controllers, Combined series-series Controllers, Combined series- shunt Controllers.

The SVC fall into Shunt Controllers category and it function as a fast generator or as a fast absorber of reactive power, with the purpose so as to maintain or control specific parameters of the electric power systems (typically bus voltage). The Static VAR Compensator (SVC) is an early generation of FACTS Controllers and a proven technology for voltage stability and power factor correction.

Static VAR compensators have been building using a wide variety of designs. However, the controllable elements used in most systems are similar. The commonly used controllable elements are:

1. Thyristor-controlled reactor (TCR)
2. Thyristor- switched capacitors (TSC)
3. Thyristor- switched reactor (TSR)
4. Mechanically switched capacitors (MSC)

3.1.1 Thyristor-Controlled Reactor (TCR)

A TCR consists of a fixed reactor in series with a bidirectional thyristor valve. Usually the inductance in each phase is divided such that half of the inductance is on each side of the thyristor valve.

This approach reduces the stresses on the thyristors which is under fault condition. Typically, air-core reactors are used in TCRs. A TCR is used together with a fixed capacitor bank when reactive power generation is required. The characteristics of a TCR/FCs are Continuous control, no transients, Elimination of harmonics by tuning the FCs as filters.

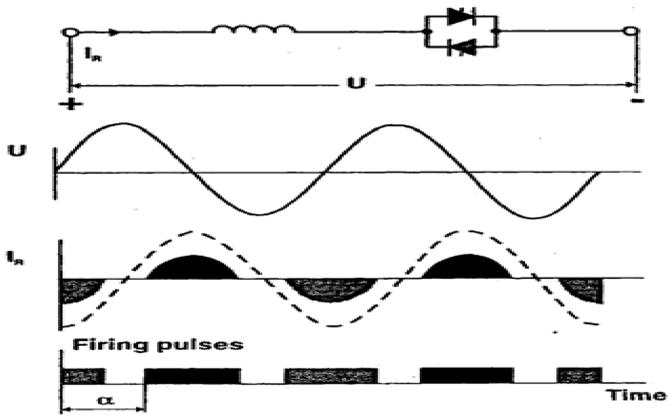


Fig 3.1.4. Operating principle of TCR

3.1.2 Thyristor-Switched Capacitors (Tsc)

A TSC consists of a capacitor in series with a bidirectional thyristor valve and a damping reactor. The thyristor switch acts to connect or disconnect the capacitor for an integral number of half-cycles of the applied voltage. The capacitor is not phase controlled and it is simply on or off. Because of this, a TSC does not produce harmonic distortion.

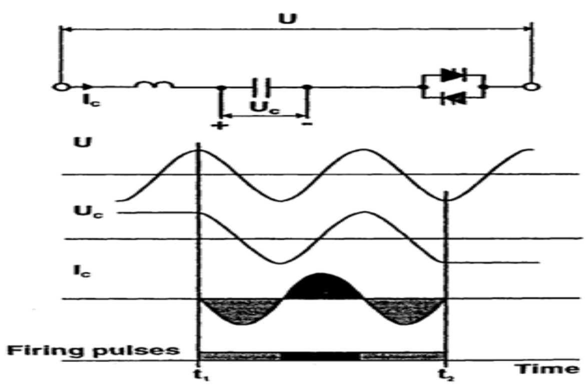


Fig 3.1.5. Operating principle of TSC

The reactor in the TSC circuit serves to limit current under abnormal conditions, as well as to tune the TSC circuit to a desired frequency. The characteristics of a TSC are, Stepped control, No transients and harmonics, Low losses, Redundancy and flexibility.

3.2 Structure and Operation

A Static VAR Compensator (SVC) is a device which compensates for the reactive power of the load connected to a power system. Because of its fast response it can stabilize the bus bar voltage even during fast changes of the load. An SVC is usually directly connected to a medium voltage power system.

Static VAR systems are applied by utilities in transmission applications for several purposes. The primary purpose is usually for rapid control of voltage at weak points in a network. Installations may be at the midpoint of transmission interconnections or at the line ends. Static VAR Compensators are shunt connected static generators / absorbers whose outputs are varied so as to control voltage of the electric power systems. In its simple form, SVC is connected as Fixed Capacitor-Thyristor Controlled Reactor (FC-TCR) configuration as shown in Fig. 3.2.1. The SVC is connected to a coupling transformer that is connected directly to the ac bus whose voltage is to be regulated.

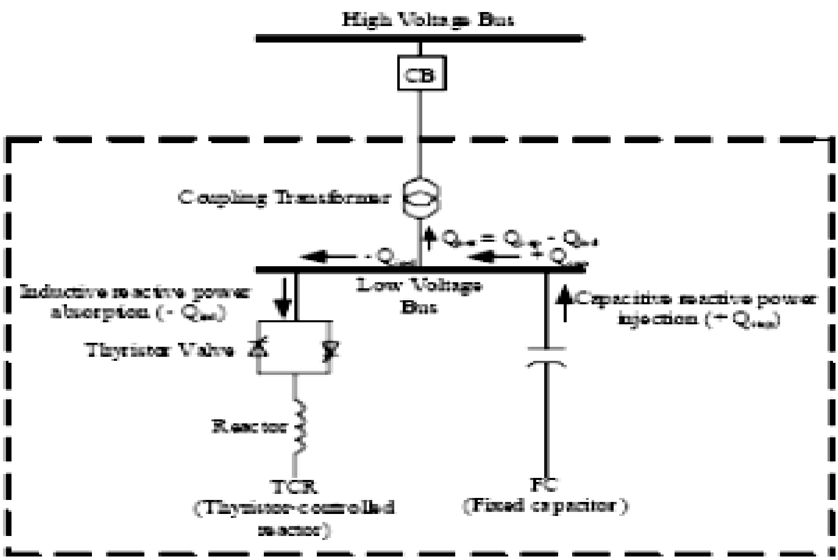


Fig 3.2.1. Configuration of SVC

In Figure3.2.2, a possible structure of a SVC composed of three TSCs and one TCR is given. The combination of TCR and TSCs enable the SVC to operate in the inductive and in the capacitive mode. The maximum current is reached, when the thyristors of the TCR are fully conducting and the TSCs are switched off.

The Static VAR Compensator (SVC) is composed of the capacitor banks/filter banks and air core reactors connected in parallel. The air-core reactors are series connected to thyristors. The current of air-core reactors can be controlled by adjusting the fire angle of thyristors. The SVC can be considered as a dynamic reactive power source. It can supply capacitive reactive power to the grid or consume the spare inductive reactive power from the grid. Normally, the system can receive the reactive power from a capacitor bank, and the spare part can be consumed by an air-core shunt reactor. As mentioned, the current in the air-core reactor is controlled by a thyristor valve. The valve controls the fundamental current by changing the fire angle, ensuring the voltage can be limited to an acceptable range at the injected node (for power system VAR compensation), or the sum of reactive power at the injected node is zero which means the power factor is equal to 1 (for load VAR compensation).

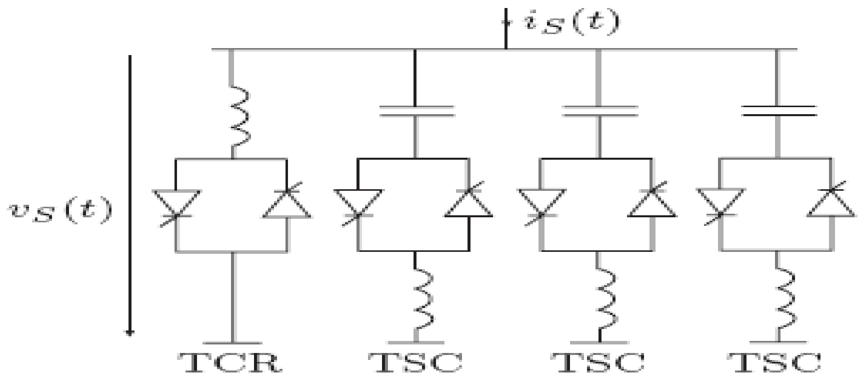


Fig 3.2.2. Possible structure of SVC

Current harmonics are inevitable during the operation of thyristor controlled rectifiers, thus it is essential to have filters in a SVC system to eliminate the harmonics. The filter banks not only absorb the risk harmonics, but also produce the capacitive reactive power. The SVC uses close loop control system to regulate bus bar voltage, reactive power exchange, power factor and three phase voltage balance. The harmonics increases with the increase in the firing angle.

3.3 Characteristics

(i) V-I Characteristics

SVC can be operated in two different modes. In voltage regulation mode and in VAR control mode (the SVC susceptance is kept constant). When the SVC is operated in voltage regulation mode, it implements the following V-I characteristic.

As long as the SVC susceptance B stays within the maximum and minimum susceptance values imposed by the total reactive power of capacitor banks (B cmax) and reactor banks (B lmax), the voltage is regulated at the reference voltage Vref. However, a voltage drop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the Figure.3.3.1.

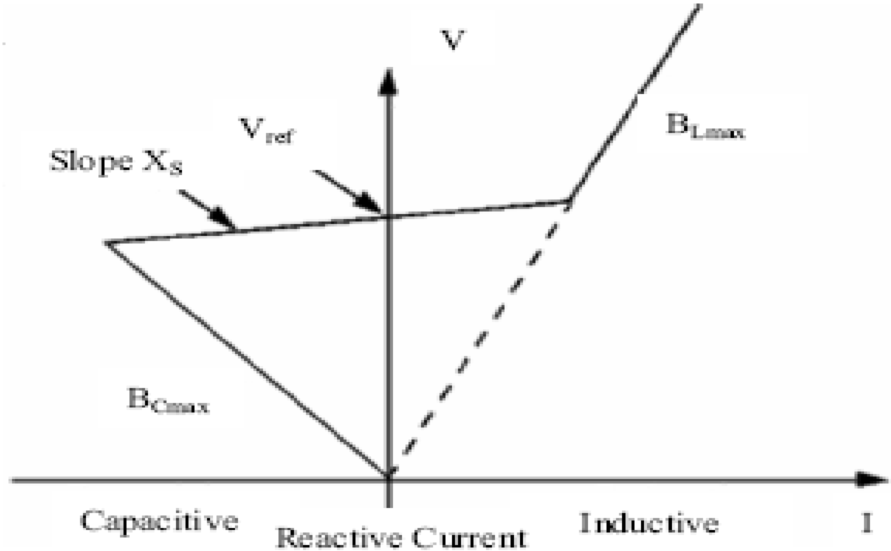


Fig 3.3.1. V–I Characteristic Curve of SVC

The V-I characteristic is described by the following three equations:

SVC is in regulation range ($B_C max < B < B_L max$),

$V = V_{ref} + X_s \cdot I$ ------------ (1)

SVC is fully capacitive ($B = B_{Cmax}$)

$V = \frac{I}{B_{Cmax}}$-------------------------------(2)

SVC is fully inductive ($B = B_{Lmax}$)

$V = \frac{I}{B_{Lmax}}$ ------------------------------(3)

Where,

- V = Positive sequence voltage (p.u.)
- I = Reactive current ($p.u./P_{hase}$) (I > 0 indicates an inductive current)
- X_s = Slope or droop reactance ($p.u./P_{base}$)

- B_{Cmax} = Maximum capacitive susceptance (p.u./P_{base})with all TSCs in service, no TSR or TCR
- B_{Lmax} = Maximum inductive susceptance (p.u./P_{hase}) with all TSRs in service or TCRs at full conduction, no TSC
- P_{base} = Three-phase base power

(a) Speed of response

The TCR has a control in its firing angle α that varies between 90º and 180º. Its speed of response is sufficiently quickly in applications caused by rapidly fluctuating loads. On the other hand, in power system it is important that the control of the TCR is stable and exact.

(b) Independent Phase Control

The Three-Phase TCR used in the SVC, can be independently controlled the three-phase of a power system, so that it can balance any unsymmetrical three-phase load when it is presented. Under unbalance conditions, a TCR can generate more harmonics than under balanced conditions. For this reason, it is necessary, usually, to place passive filter LC, using for that the same compensation capacitors. In this case, the injection of the reactive power of the SVC is due to the filters and the fixed capacitors.

(c) Response to overvoltage and under voltage:

This is one of the most important characteristics of the SVC, because it compensates the voltage when conditions of very high or very low voltage are presented in the bus where the compensator is placed. In that case, it injects the reactive power necessary to restore the normal voltage magnitude.

(ii) Dynamic Response of SVC

When the SVC is operating in voltage regulation mode, its response speed to a change of system voltage depends on the voltage regulator gains (proportional gain Kp and integral gain Ki), the droop reactance Xs, and the system strength (short circuit level). For an integral-type voltage regulator (Kp = 0), if the voltage measurement time constant Tm and the average time delay Td due to valve firing are neglected, the closed-loop system consisting of the SVC and the power system can be approximated by a first-order system having the following closed-loop time constant:

Where, Tc = [1 / Ki – (Xs. Xn)] ----------------------------(4)

Tc = Closed loop time constant.

Ki = Proportional gain of the voltage regulator.

Xs = Slope reactance.

Xn = Equivalent power system reactance.

This equation demonstrates a faster response speed when the gain is increased or when the system short-circuits level decreases (higher Xn values).

(iii)Voltage Stability

The static VAR compensator (SVC) is frequently used to regulate the voltage at dynamic loads. But also it is used to provide a voltage support inside of a power system when it takes place small gradual system changes such as natural increase in system load, or large sudden disturbance such as loss of a generating unit or a heavily loaded line. These events can alter the pattern of the voltage waveform in such a manner that it can damage or lead to mal function of the protection devices.

Generally, there are sufficient reserves and the systems settles to stable voltage level. However, it is possible, that the additional reactive power demands may lead to voltage collapse, causing a major breakdown of part or all system. The SVC can improve and increase significantly the maximum power through the lines. This is achieved, if the SVC is operated an instant after of a disturbance providing the necessary flow of power. Therefore, if the approach of maximum transmitted power is of voltages, it is possible to increase the power flow.

3.4 Merits of Svc Over Other Compensators

The total (or apparent) power required by an inductive device comprises the following, Real power (measured in kilowatts, kW) and Reactive power, the non-working power caused by the magnetizing current required to operate & sustain the magnetism in the device (KVAR). The ratio of active power to the resultant power, called power factor, implies that because of greater demand for reactive power, the percentage of useful utilization of the total generated power starts diminishing. Simply stated, power factor is the percentage of consumed power (KW) versus supplied power (KVA). This is important because a low power factor can waste energy, result in inefficient use of electrical power, and often result in higher energy bills.

More the inductive nature more will be the power factor angle, which consumes more reactive power. This increases the active power range, which demands more current from the source and makes the source to load more than the capacity. Therefore, transformers and cables are forced to carry more useless power than the real demand power, which overrates the capacity of transformer, cables and switchgears. The reactive power not only causes voltage swings, but also displaces transmission capacity, increasing energy losses in the system. It is essential to balance the supply and demand of active and reactive power in an electrical system. The lagging reactive power that makes the power factor poor is compensated by means of VAR Compensators.

The different types of VAR Compensators are:

i) Fixed capacitor banks

ii) Switched capacitors

iii) Synchronous condensers

iv) Self Saturated reactor / Fixed capacitor

v) Static compensators

(i) Fixed capacitor banks

Fixed Shunt capacitors banks were first employed for power factor correction in 1914. The lagging current drawn by the inductive load compensates the leading current drawn by the shunt capacitor.

(ii) Switched Capacitors

For dynamic compensation we are going for switched capacitors. Depending on the VAR requirement, a number of capacitors can be switched into or switched out of the system by means of relays and mechanical switches.

(iii) Synchronous Condensers

All synchronous machines can give continuous variable var compensation. When over excited the machine generates and is operating in a stable condition. When under excited it absorbs vars with a reducing stability down to zero excitation.

(iv) Self-saturated reactor/fixed capacitors

Saturated reactor is a fixed voltage device. It does not pose any stability problem in the system. It consists of a variable reactor and a capacitor by choosing proper values of L and C, we can achieve smooth and steeples control of VAR from lagging and leading.

(v) Static compensators

After the advent of thyristors, fast reactive power compensation is possible. As the response time is very less, static reactive power compensation is becoming increasing popular.

3.5 Applications

A complete set of SVC system can be used to generate constantly varied inductive and capacitive reactive power with fast response time. So far, SVC system has been extensively used in electric power system and industrial field.

3.5.1 Power Transmission

In the case of long-distance AC transmission, due to the influence of Ferranti Effect, the voltage in the middle of transmission lines will raise which will limit the transferred power. Therefore, to reduce the voltage rise and maximally enlarge the transferred power, the SVCs are normally installed in the midpoint or several points in the middle of transmission line. Additionally, a SVC system installed on the AC side of DC converter station can provide sufficient reactive power with fast response and easy maintenance.

The benefits are to regulate the system voltage, increase static stability and transient stability of power system, increase the line transmission capacity, restrain the power oscillation and the sub-synchronous resonance, restrain the transient overvoltage, balance the three-phase voltage, control the voltage in DC converter station and provide reactive power.

3.5.2 Distribution System

The SVC can be connected to the terminal substation in the power distribution system to reduce the reactive power exchange, improve the power factor, decrease the distribution system loss and reduce the damages caused by frequent switch-in of capacitor banks.

The benefits are to reduce the reactive power exchange with system and improve system stability, rapidly and continuously compensate the reactive power, increase the power factor and improve the power quality, reduce the power losses of distribution system, used in combination of stepped-switch over capacitor bank to reduce the damage caused by frequent switching of capacitor bank.

3.5.3 Wind Power Plant

For small hydro-power plant or wind power plant in some remote locations, the connected large power grid is hard to provide enough reactive power, or the excess reactive power may result in a serious voltage drop and large line losses. Installing a SVC system at the connection point can efficiently stabilize the voltage at the connection point to an acceptable level and maximally prevent the harmful impact caused by faults in the power grid.

3.5.4 Industrial Consumers

The electronic rectifiers applied to the electrolysis power supply and mill machine requires large amount of reactive power. The SVC system can not only supply sufficient reactive power, but also eliminate the harmonics generated by rectifiers and prevent the equipment's from the voltage fluctuation. The use of AC arc furnace usually comes with heavy harmonics and large negative sequence current. Large amount of reactive power demand and reactive power variation result in the voltage fluctuation and flicker, which also reduces the operation efficiency.

The main benefits are to increase the power factor by dynamic reactive power compensation, eliminate the voltage distortion caused by harmonics, stabilize the voltage and reduce the voltage fluctuations and flickers, balance the three-phase load current and eliminate the negative sequence current, increase the operation safety of impact loading equipment and its adjacent electrical equipment.

Chapter 4
Implementation Of Embedded in Power System

Introduction to Electric Power System

Electrical energy is very imperative for everyday life and a backbone for all domestic and industrial applications. Electric power systems are constituted by the interconnection of a huge number of different components and also it has to be considered among the most complex systems to be properly designed and safely operated. The power grid forms a bridge between electrical suppliers and consumers through interconnected networks. The electrical power grid consists of three main parts:

i) Generation plant for electric power.

ii) Transmission of the electric power.

iii) Distribution of the electric power.

The definition of electric grid is the networks that can intelligently integrate the behavior and actions of all users connected to the systems such as generators, transmission and consumers. Electric power grid should have the ability to improve safety and efficiency, make better use of existing assets, enhance the reliability and power quality, reduce dependence on imported energy, and minimize costly environmental impact.

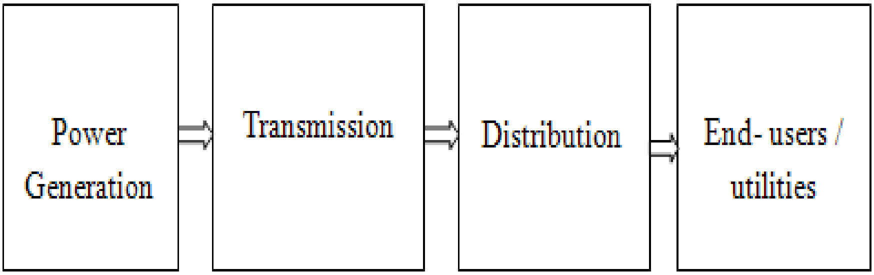


Fig 4.1. Diagram of an electric power transmission system

Electronic power conditioning and control of the production and distribution of electricity are important aspects of the Electric power grid. Roll out of Electric grid technology also implies a fundamental re-engineering of the electricity services industry, although typical using of the term is focused on the technical infrastructure. Numerous contributions to overall improvement of the efficiency of energy infrastructure are anticipated from the deployment of power system technology, in particular including demand-side management, for example turning off air conditioners during short-term spikes in electricity price, reducing the voltage when possible on distribution lines.

Electric power systems can be divided into divided into two sub-systems namely transmission systems and distribution systems. Power is distributed to different customers or utilities from distribution system through service mains, distributors and feeders. Monitoring voltage, current and additionally required parameters at the distribution side can aid in developing both the output generated at the main station and the quality of power being delivered at the utility or customer end.

Enhanced power flow capabilities within the transmission and distribution system will fundamentally change how the grid can be controlled and managed. Greater deployment of power flow controllers can directly alleviate line congestion, increase asset utilization, and optimize generator dispatch for cost savings. Additionally, the enhanced grid flexibility can support increased penetration of variable renewable resources and improve system resiliency.

4.1 Basic Requirements of Electric Power System

Two fundamental requirements for Bulk AC transmission are,

1) Synchronism

The AC transmission is based on the network of synchronous machines interconnected by transmission links, in which all the synchronous machines must remain constantly in synchronism. The stability of the system is its tendency to recover from the disturbances from such as faults or changes of load. Steady state stability limit is a power transmitted between two synchronous machines which can be slowly increased only up to a certain level, beyond this level the synchronous machines fall out of step, i.e. loss synchronism.

A transmission system cannot be operated too close to the steady state stability limit because there must be a margin to allow for disturbances. To determine that the concepts of transient and dynamic stability are useful. Transient stability is concerned with the ability to recover normal operation following specified major disturbances in transmission and distribution systems and dynamic stability is concerned with the ability to recover normal operation following a specified minor disturbance.

2) Voltage profile

Proper voltage level has to be maintained within marginal limits at all stages in the network. Under voltage degrades the performance of loads which leads to over current. Over voltage is dangerous because of the risks of flash over, insulation break down and saturation of transformer. Major voltage changes are caused by variation in load and specifically by reactive components of current flowing in the reactive components of network impedances. Various techniques are used for controlling the voltage profile according to the underlying rate of voltage variation. Disconnection of loads, lines switching operations, faults and lightening causes sudden over voltages, that needs immediate suppression.

4.1.1 Power System in Transmission Line

Transmission line is the long conductor with special design (bundled) to carry bulk amount of generated power at very high voltage from one station to another as per variation of the voltage level.

Types of transmission Line

In transmission line determination of voltage drop, transmission efficiency, line loss etc. are important things to design. These values are affected by line parameter R, L and C of the transmission line. Length wise transmission lines are three types.

Short Transmission Line

- Length is about 50 km.
- Voltage level is up to 20 kV
- Capacitance effect is negligible
- Only resistance and inductance are taken in calculation capacitance is neglected.

Medium Transmission Line

- Length is about 50km to 150km
- Operational voltage level is from 20 kV to 100 kV
- Capacitance effect is present
- Distributed capacitance form is used for calculation purpose.

Long Transmission Line

- Length is more than 150 km
- Voltage level is above 100 kV
- Line constants are considered as distributed over the length of the line.

Transmission Efficiency

Transmission efficiency is defined as the ratio of receiving end power P_R to the sending end power P_S and it is expressed in percentage value. $Cos\theta_s$ is the sending end power factor. $cos\theta_R$ is the receiving end power factor. V_s is the sending end voltage per phase. V_R is the receiving end voltage per phase.

$$\%\eta T = \frac{P_R}{P_S} X\ 100 = \frac{V_R I_R \cos\theta_R}{V_S I_S \cos\theta_S} X\ 100 \qquad \text{---------------- (5)}$$

Transmission Line Voltage Regulation

Voltage regulation of transmission line is defined as the ratio of difference between sending and receiving end voltage to receiving end voltage of a transmission line between conditions of no load and full load. It is also expressed in percentage.

$$\%VR = \frac{V_S - V_R}{V_R} X\ 100 \qquad \text{--------------- (6)}$$

Where V_s is the sending end voltage per phase and V_R is the receiving end voltage per phase.

$$V_S = \sqrt{(V_R \cos\theta_R + IR)^2 + (V_R \sin\theta_R + IX_L)^2} \qquad \text{--------------- (7)}$$

X_L is the reactance per phase. R is the resistance per phase. $Cos\theta_R$ is the receiving end power factor. Effect of load power factor on regulation of transmission line:

1. For lagging load,

$$\%VR = \frac{IR\cos\theta_R + IX_L \sin\theta_R}{V_R} X\ 100 \qquad \text{--------------- (8)}$$

2. For leading load,

$$\%VR = \frac{IR\cos\theta_R - IX_L \sin\theta_R}{V_R} X\ 100 \qquad \text{--------------- (9)}$$

That is,Power factor is lagging or unity, and then VR is increased and goes to be positive.Power factor is leading, and then VR is decreased and goes to be negative.

Effect of Load Power Factor on Efficiency of Transmission Line

Efficiency of transmission line is

$$\%\eta T = \frac{P_R}{P_S} X\ 100 = \frac{V_R I_R \cos\theta_R}{V_S I_S \cos\theta_S} X\ 100 \qquad \text{-------------- (10)}$$

Now, for short transmission line, $I_R = I_S = I$ So, considering three phase short transmission line, $P_R = 3V_R I\ cos\theta_R$ -------------- (11)

$$\text{So, } I = \frac{P_R}{3V_R \cos\theta_R} \qquad \text{-------------- (12)}$$

Now, it is clear that to transmit given amount of power, the load current is inversely proportional to receiving end power factor. Again in case of medium and long transmission line,

$$\% \, transmission \ efficiency = \frac{Power \ delivered/phase}{Power \ delivered/phase + Losses/phase} \ X \ 100$$

$$= \frac{V_R I_R \cos\theta_R}{V_R I_R \cos\theta_{R+} I_S^2 R} \ X \ 100 \qquad \text{-------------- (13)}$$

Therefore, here it is clear that transmission efficiency depends on the receiving end power factor.

4.1.2 Ferranti Effect in Transmission line

In all electrical systems current flows from the region of higher potential to the region of lower potential, to compensate for the electrical potential difference that exists in the system. Ferranti effect is an increase in voltage occurring at the receiving end of a long transmission line, above the voltage at the sending end. This occurs when the line is energized, but there is a very light load or the load is disconnected. It occurs when current drawn by the distributed capacitance of the line itself is greater than the current associated with the load at the receiving end of the line (during light or no load).This capacitor charging current leads to voltage drop across the line inductor of the transmission system which is in phase with the sending end voltages. This voltage drop keeps on increasing additively as we move towards the load end of the line and subsequently the receiving end voltage tends to get larger than applied voltage leading to the phenomena called Ferranti effect in power system.

In all practical cases the sending end voltage is higher than the receiving end due to line losses, so current flows from the source or the supply end to the load. But Sir S.Z. Ferranti, in the year 1890, came up with an astonishing theory about medium distance transmission line or long distance transmission lines suggesting that in case of light loading or no load operation of transmission system, the receiving end voltage often increases beyond the sending end voltage, leading to a phenomena known as Ferranti effect in power system.

A long transmission line can be considered to be having considerably high amount of capacitance and inductance distributed across the entire length of the transmission line.Ferranti effect due to rise in voltage at the receiving end is directly proportional to the square of the transmission line length, and hence in case of a long transmission line it keeps increasing with length and even goes beyond the applied sending end voltage. Both the capacitance and inductance effect of transmission lineare equally responsible for this phenomena to occur and hence Ferranti effect is negligible in case of a short transmission lines as the inductance of such a line is practically considered to be nearing zero.

For analysis of Ferranti effect, consider the phasor diagram as depicted below. Here consider $V_{r,}$ to be the reference phasor, which is represented by OA.

$$Thus\ V_r = V_r(1 + j0)$$
$$Capacitance\ current,\ I_c = j\omega CV_r$$
$$Now\ sending\ end\ voltage\ V_s = V_r + resistive + reactive\ drop.$$
$$= V_r + I_cR + jI_cX$$
$$= V_r + I_c(R + jX)$$
$$= V_r + j\omega CV_r(R + j\omega L)[\ Since\ X = \omega L\ ]$$
$$Now\ V_s = V_r - \omega^2 CLV_r + j\omega CRV_r$$

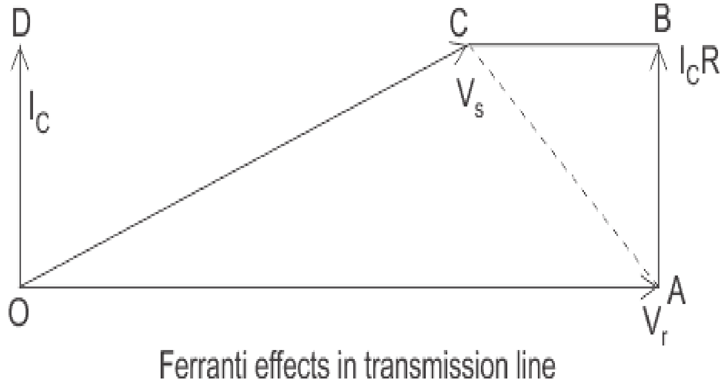


Figure 1. This is represented by the phasor OC.

Power Quality Problems

Power quality problems can be subdivided into two categories:

1. Supply system quality problems.
2. Installation and load related problems.

Supply System Quality Problems:

1. Supply interruption
2. Transient interruption
3. Transients
4. Under voltage/over voltage
5. Voltage dip/voltage surge

6. Voltage imbalance
7. Flicker
8. Harmonic distortion

Transients can originate internally or externally on utility power lines that usually represents about 12 to 15% of all power line problems. These Disturbances can cause damage to the electronic lighting systems, sensitive equipment shutdown, immediate or latent damage to digital equipment's which are connected with the power system.

Installation and Load Related Problems:

The major problems in this category can be classified in either of the three following groups:

1. Harmonic currents
2. Earth (Ground) leakage currents
3. Voltage dips and transients

4.2 Over Voltage And Flickers In Power System

Over voltages or surges on power systems occurs due to various conditions. Voltage stress due to over voltages is very dangerous and even cause damage to both the lines as well as the connected equipment. A temporary overvoltage is an oscillatory phase to ground or phase to phase over voltage that is relatively long duration and is undamped or only weakly damped. Temporary over voltages usually originate from faults, sudden charge of load, Ferranti effect, linear resonance, Ferro resonance, open conductor, induced resonance from coupled circuits and so forth. Hence, protective measures have to be taken into consideration. Over voltages in power systems is classified into two categories.

External over voltage

External Over voltages take the form of a unidirectional impulse or surge whose maximum possible amplitude has no direct relationship with the operating voltage of the system. These voltages originate from atmospheric disturbances mainly due to lightning.

Table 1. Power System Over Voltages

Power frequency overvoltage	Description	Causes
Power frequency overvoltage	Temporary over voltages dominated by the power frequency component.	* Electric faults * Sudden changes of load *Ferro resonance
Switching over voltage	Temporary over voltages resulting from a switching operation.	*Energization of lines *De-energization of capacitor banks * Fault interruption * High speed reclosing *Energization or De-energization of transformers
Lightening over voltage	Temporary over voltages resulting from a lightening stroke terminating at a phase conductor, any other part of power system or a nearby object.	*Lightening – cloud – to – ground flashes

Internal over voltage

Internal over voltages are due to changes in the operating conditions of the network, which can be categorized into two types (Table 1).

(i) Switching over voltages (or transient over voltages of high frequency)

Switching over voltages is due to variation in state of network caused by switching operation or fault condition. Normally it takes the form of a damped sinusoid ranging from a few hundred Hz to a few kHz that is governed by the inherent capacitances and inductances of the circuit.

(ii)Temporary Over voltages (or steady-state over voltages of power frequency)

Temporary over voltages and flickers are due to disconnection of load, particularly in case of long transmission lines. The examination of over voltages on the power system includes a study of their shapes, duration, magnitudes and frequency of occurrence. It is essential to know the causes and effects of over voltages and flickers along the transmission network through which the surges may travel, so that suitable protective measures can be taken.

4.3 Overview of Electric Energy Losses

The quality of electrical power may be described as a set of values of parameters, such as:

1) Continuity of service
2) Variation in voltage magnitude
3) Transient voltages and currents
4) Harmonic content in the waveforms etc.

Demand response support allows generators and loads to interact in an automated fashion in real time, coordinating demand to flatten spikes. Eliminating the fraction of demand that occurs in these spikes eliminates the cost of adding reserve generators, cuts wear and tear and extends the life of equipment, and allows users to cut their energy bills by telling low priority devices to use energy only when it is cheapest. Currently, power grid systems have varying degrees of communication within control systems for their high-value assets, such as in generating plants, transmission lines, substations and major energy users. In general information flows one way, from the users and the loads they control back to the utilities. The utilities attempt to meet the demand and succeed or fail to varying degrees (brownout, rolling blackout, uncontrolled blackout). The total amount of power demand by the users can have a very wide probability distribution which requires spare generating plants in standby mode to respond to the rapidly changing power usage. Demand response can be provided by commercial, residential loads, and industrial loads.

Line faults may be caused due to over current or earth fault. Over current fault occurs. If there is a connection between two phase lines. Earth fault is due to the earthing of phase line through cross arm or any other way. Transmitting electricity at high voltage reduces the fraction of energy loss to resistance, which varies depending on the specific conductors, the current flow, and the length of the transmission line. For a given amount of power, a higher voltage reduces the current and thus the resistive losses in the conductor. In general, losses are estimated from the discrepancy between power produced and power consumed; the difference between what is produced and what is consumed constitute transmission and distribution losses, assuming no theft of utility occurs. The total quantity of electricity loss in transmission, substation and distribution with a given period in an electric supply area or power grid is called electricity line loss or line loss.

The percentage of the electricity line loss in the electric supply is called the line loss rate, and its calculation formula is as follows:

$$\text{Line loss rate (\%)} = \frac{(\textbf{\textit{Electric Supply}} - \textbf{\textit{Power Sales Quantity}})}{\textbf{\textit{Electric Supply}}} \text{ x } 100\ \% \text{ ---- } (14)$$

Calculation of Electric Energy Loss:

Electric Energy Loss ΔA (kW.h) is the integral of active power loss to time within a period,

$$\Delta \mathbf{A} = \int_0^T \Delta \mathbf{P}(\mathbf{t})\mathbf{dt} * \mathbf{10^{-3}} \qquad \text{--------- (15)}$$

For resistance heat loss, the above equation can be rewritten as

$$\Delta \mathbf{A} = \int_0^T \mathbf{I^2}(\mathbf{t})\mathbf{R}(\mathbf{t})\mathbf{dt} * \mathbf{10^{-3}} \qquad \text{--------- (16)}$$

Factors that affect the resistance and thus loss of conductors used in transmission and distribution lines include temperature, spiraling, and the skin effect. The resistance of a conductor increases with its temperature. Temperature changes in electric power lines can have a significant effect on power losses in the line. Spiraling, which refers to the increase in conductor resistance due to the way stranded conductors spiral about the center, also contributes to increases in conductor resistance.

The skin effect causes the effective resistance of a conductor to increase at higher alternating current frequencies. Under excess load conditions, the system can be designed to fail gracefully rather than all at once. Brownouts occur when the supply power drops below the demand. Blackouts occur when the supply fails completely. Rolling blackouts (also called load shedding) are intentionally engineered electrical power outages, used to distribute insufficient power when the demand for electricity exceeds the supply.

A lack of electrical energy storage facilities in transmission systems leads to a key limitation. Electrical energy must be generated at the same rate which it is consumed. A sophisticated control system is required to ensure that power generation very closely matches demand. If the demand for power exceeds supply, the imbalance can cause generation plant(s) and transmission equipment to automatically disconnect and/or shut down to prevent damage.

Electric transmission networks are interconnected into regional, national, and even continent wide networks to reduce the risk of such a failure by providing multiple redundant, alternative routes for power to flow should such shut downs occur. Transmission and distribution companies determine the Maximum reliable capacity of each line (ordinarily less than its physical or thermal limit) to ensure that spare capacity is available in the event of a failure in another part of the network.

Electricity is transmitted at high voltages to reduce the energy loss which occurs in long-distance transmission. Power is usually transmitted through overhead power lines. Underground power transmission has a significantly higher installation cost and greater operational limitations, but reduced maintenance costs. Underground transmission is sometimes used in urban areas or environmentally sensitive locations.

4.3.1 Transmission and Distribution Line Losses

Electrical distribution systems are incurring large losses as the loads are wide spread, inadequate reactive power compensation facilities and their improper control. The amount of energy loss in electrical distribution system is one of the key measures of distribution system performance as it has a direct impact on the utility's bottom line. Distribution system's losses can be attributed to technical and non-technical. Non-technical losses are those associated with inadequate or missing revenue metering, with problems with billing or collection systems, etc. Technical losses in the system are inherently influenced by component and system designs. Since losses represent a considerable amount of operating cost, accurate estimation of electrical losses enables to determine with greater accuracy the operating costs for maintaining supply to consumers. This in turn enables a more accurate estimate of system lifetime costs, over the expected life of the installation. It is also critical to know if the expected target of technical losses is indeed technical, whether it is possible for reduction without changing the components and system design. Lower technical losses will provide for cheaper electricity and lower production costs, with a positive influence on economic growth.

Various studies have been conducted over the years to calculate energy losses in distribution network. Typically, in technical loss estimation studies, the technical loss level is estimate during simulations of the network. However, these studies would require complete set of data to estimate the technical loss level. Technical losses in distribution transformers are estimated based on empirical formulas of no load and full load loss scaled by capacity factors. For low voltage network, its technical losses level is primarily influenced by its percentage loading, besides load factor and network type (overhead or underground).

The term "distribution line losses" refers to the difference between the amount of energy delivered to the distribution system and the amount of energy customers is billed. It is important to know the magnitude and causality factors for line losses because the cost of energy lost is recovered from customers. Between 30 and40 % of total investments in the electrical sector goes to distribution systems, but nevertheless, they have not received the technological impact in the same manner as the generation and transmission systems. Calculations of losses in power systems have been attempted since long. Earlier efforts concentrated on energy loss estimation on a yearly basis and power loss estimations for maximum load situations. The estimated losses were important data when calculating the energy losses and planning electric grid system. There is no difference between a transmission line and a distribution line except for the voltage level and power handling capability.

Transmission lines are usually capable of transmitting large quantities of electric energy over great distances. Normally they operate at high voltages. Distribution lines carry limited quantities of power over shorter distances. Voltage drops in line are in relation to the resistance and reactance of line, length and the current drawn. For the same quantity of power handled, lower the voltage, higher the current drawn and higher the voltage drop. The current drawn is inversely proportional to the voltage level for the same quantity of power handled.

The power loss in line is proportional to resistance and square of current. (I.e.

Power loss = I^2R). Higher voltage transmission and distribution thus would help to minimize line voltage drop in the ratio of voltages, and the line power loss in the ratio of square of voltages. The primary function of transmission and distribution equipment is to transfer power economically and reliably from one location to another. Conductors in the form of wires and cables strung on towers and poles carry the high voltage, AC electric current.

A large number of copper or aluminum conductors are used to form the transmission path. The resistance of the long-distance transmission conductors is to be minimized. Energy loss in transmission lines is wasted in the form of $I^2 R$ losses.

4.3.1.1 Voltage instability

Voltage instability in the system, generally, occurs in the form of a progressive decay in voltage magnitude at some of the buses. A possible outcome of voltage instability is loss of load in an area, or tripping of transmission lines and other elements by their protective systems leading to cascaded outages and voltage collapse in the system. Voltage collapse is the process by which the sequence of events, accompanying voltage instability, leads to a blackout or abnormally low voltages in a significant part of a power system.

4.3.1.2Transmission System Voltage Control

In practical operation of transmission systems, the voltage needs to be continuously monitored and controlled to compensate for the daily changes in load, generation and network structure. In fact, the control of voltage is a major issue in power system operation. It identifies the main objectives of voltage control as: Voltage at the terminals of all equipment in the system should be kept within acceptable limits, to avoid malfunction and damage to the equipment and hence the whole system. Thus keeping voltages close to the values for which stabilizing controls are designed to enhance system stability and allow maximal utilization of the transmission system is quite essential to minimize reactive power flow to reduce active as well as reactive power losses. But distribution systems as a rule are operated in radial configuration, consequently more sophisticated control schemes than those used in distribution systems are necessary.

The control of voltage is often divided into the normal, preventive and emergency state control. A brief overview of the strategies used in the different operating states are as follows:

(a) Primary Control

Primary voltage controllers are used in all power systems to keep the terminal voltages of the generators close to reference values given by the operator or generated by a secondary controller. An automatic voltage regulator (AVR) acts on the exciter of a synchronous machine, which supplies the field voltage and consequently the current in the field winding of the machine and can thereby regulate its terminal voltage. The response time of the primary controller is short, typically fractions of a second for generators with modern excitation systems. Furthermore, many generators use a so-called power system stabilizer (PSS) to modulate the terminal voltage of the machine based on a local frequency measurement to contribute to damping of electromechanical oscillations. Although the power system stabilizer in most cases is integrated in the AVR, it only introduces fast oscillations around the mean value given by the AVR as long as the generator remains synchronized with the rest of the network.

(b) Secondary Control

Secondary voltage control acts on a time-scale of seconds to a minute and within regions of the network. The aim of secondary voltage control is to keep an appropriate voltage profile in a region of the system and to minimize circulating reactive power flows and maximize reactive reserves. Normally, the network is divided in a number of geographic regions. One or a few so-called pilot nodes, which are assumed to be representative of the voltage situation in the region, are selected for voltage regulation by the secondary controller.

The main actuators are the set point voltages of the primary controllers of the generators within a region, although the French implementation also uses static compensation devices such as capacitor banks and reactors. The set point values are calculated by an optimization procedure using a liberalized static network model to make each generator in the region contribute to the control of the pilot node voltage(s).

(c) Tertiary Control

Tertiary voltage control acts system-wide on a time scale of about ten to thirty minutes. The traditional method of tertiary control is so-called reactive power optimal power flow (OPF). The desired operating conditions are specified in the form of a cost function, which is minimized using nonlinear optimization techniques. Usually, the main goal is to minimize losses and to keep voltages close to rated values. A secondary goal may be to maximize and distribute reactive reserves.

The main control variables are voltage set points for the generators, or pilot nodes if secondary control is used, and switching orders to compensation devices such as shunt capacitors and reactors. The power flow equations are specified as equality constraints in the optimization whereas operational limits such as transfer limits, limits on reactive reserves and voltages are specified as inequality constraints.

4.3.2 Classifications of voltage stability

The voltage stability may be broadly classified into two categories:

1. Large disturbance voltage stability

It is defined as the ability of the power system to maintain stable voltages for large disturbances such as such as system faults, loss of load, or loss of generation etc. Large disturbance voltage stability may be further subdivided into two types.

a) Transient stability

b) Long term stability

2. Small disturbance (Small signal) voltage stability

It is concerned with a system's ability to control voltages following small perturbations, such as gradual change in load, this types of stability can be studied with steady-state approaches that use linearization of the system dynamic equations at a given operating point.

4.3.3 Preventive and Emergency State Voltage Control

The operation of power systems can be divided into the states normal, alert or emergency. The system normally operates in the normal state, but enters the alert state if the system cannot be expected to be robust to the contingencies that have been considered in the design of the system. Such situations may occur for example due to unexpected load increase or outage of some component, such that a single contingency may force the system into the emergency state. The system enters the emergency state if a severe enough contingency occurs, so that the system will experience instability or exceeds operational limits unless emergency control actions are taken. However, the system is still synchronized in the emergency state.

Elements of the System, that Produces and absorbs Reactive Power Loads- a typical load bus supplied by a power system is composed of a large number of devices. The composition changes depending on the day, season and weather conditions. The composite characteristics are normally such that a load bus absorbs reactive power. Both active and reactive powers of the composite loads vary due to voltage magnitudes. Loads at low-lagging power factors because excessive voltage drops in the transmission network. Industrial consumers are charged for reactive power and this convinces them to improve the load power factor. Underground cables- they are always loaded below their natural loads, and hence generate reactive power under all operating conditions Overhead lines- depending on the load current either absorb or supply reactive power. At loads below the natural load, the lines produce net reactive power; on the contrary, at loads above natural load lines absorb reactive power.

4.3.4 Methods to improve Voltage Stability

Voltage stability problems provides information for power system planning, operation and control. Ways of Improving Voltage Stability and Control Reactive power compensation is often most effective way to improve both power transfer capability and voltage stability of an electric power system. The control of voltage levels is accomplished by controlling the production, absorption and flow of reactive power. The generating units provide the basic means of voltage control, because the automatic voltage regulators control field excitation to maintain scheduled voltage level at the terminals of the generators. To control voltage throughout the system we have to use addition devices to compensate reactive power. Reactive compensation can be divided into series and shunt compensation. It can be also divided into active and passive compensation. But mostly consideration will be focused on shunt capacitor banks, static var compensator (SVC) and Static Synchronous Compensators (STATCOM), which are the part of group of active compensators called Flexible AC Transmission Systems (FACTS).

The devices used for these purposes may be classified as follows:

1. Shunt capacitors
2. Series capacitors
3. Shunt reactors
4. Synchronous condensers
5. SVC

STATCOM

Shunt Capacitors Shunt capacitors and reactors and series capacitors provide passive compensation. They are either permanently connected to the transmission and distribution system or switched. They contribute to voltage control by modifying the network characteristics. Synchronous condensers, SVC and STATCOM provide active compensation. The voltages of the buses to which they are connected. Together with the generating units, they establish voltages at specific points in the system. Voltages at other locations in the system are determined by active and reactive power flows through various elements, including the passive compensating devices. The primary purposes of transmission system shunt compensation near load areas are voltage control and load stabilization. Mechanically switched shunt capacitor banks are installed at major substations in load areas for producing reactive power and keeping voltage within required limits. For voltage stability shunt capacitor banks are very useful in allowing nearby generators to operate near unity power factor. This maximizes fast acting reactive reserve. Compared to SVCs, mechanically switched capacitor banks have the advantage of much lower cost. Switching speeds can be quite fast.

Current limiting reactors are used to minimize switching transients. There are several disadvantages to mechanically switched capacitors. For voltage emergencies the shortcoming of shunt capacitor banks is that the reactive power output drops with the voltage squared. For transient voltage instability the switching may not be fast enough to prevent induction motor stalling. Precise and rapid control of voltage is not possible. Like inductors, capacitor banks are discrete devices, but they are often configured with several steps to provide a limited amount of variable control. If voltage collapse results in a system, the stable parts of the system may experience damaging over voltages immediately following separation. Shunt capacitors banks are always connected to the bus rather than to the line. They are connected either directly to the high voltage bus or to the tertiary winding of the main transformer. Shunt capacitor banks are breaker-switched either automatically by a voltage relays or manually.

4.3.5 Concepts of Reactive Power Control and Voltage Stability Methods in Power System Network

The primary purpose of transmission system shunt compensation near load areas is voltage control and load stabilization. In other words, shunt capacitors are used to compensate for the losses in transmission system and to ensure satisfactory voltage levels during heavy load conditions. Shunt capacitors are used in power system for power factor correction. The objective of power factor correction is to provide reactive power close to point where it is being consumed, rather than supply it from remote sources.

Switched shunt capacitors are also used for feeder voltage control. They are installed at appropriate location along the length of the feeder to ensure that voltages at all points remain the allowable minimum or maximum limits as the loads vary. For voltage stability, shunt capacitor banks are very useful on allowing nearby generators to operate near unity power factor. This maximizes fast acting reactive reserve. The biggest disadvantage of shunt capacitors is that the reactive power output drops with the voltage squared. Thus, during the severe voltage decays these devices are not efficient enough. Compared to static var compensators, mechanically switched capacitor banks have the advantage of much lower cost.

Switching speeds can be quite fast. Following a transmission line outage, capacitor bank energization should be delayed to allow time for line reclosing. However, capacitor switching should be before significant amounts of load are restored by transformer tap changers or distribution voltage regulators. Despite of many advantages of mechanically switched capacitors, there is couple of disadvantages as well. Firstly, for transient voltage instability, the switching may not be fast enough to prevent induction motor stalling. If voltage collapse results in system breakdown, the stable parts of the system may experience damaging over voltages immediately following separation. Over voltages would be aggravated by energizing of shunt capacitors during the period of voltage decay.

4.3.6 Shunt reactors

Shunt reactors are mainly used to keep the voltage down, by absorbing the reactive power, in the case of light load and load rejection, and to compensate the capacitive load of the line. Other equipment can be involved in the provision of reactive power and energy, such as:

- Unified Power Flow Controllers (UPFC) and other advanced FACTS (flexible ac transmission system) devices.
- Tap staggering of transformers connected in parallel.
- Disconnection of transmission lines.
- Load shedding.

4.3.7 Synchronous condensers

Every synchronous machine (motor or generator) has the reactive power capabilities the same as synchronous generators. Synchronous machines that are designed exclusively to provide reactive support are called synchronous condensers. Synchronous condensers have all of the response speed and controllability advantages of generators without the need to construct the rest of the power plant (e.g., fuel-handling equipment and boilers). Because they are rotating machines with moving parts and auxiliary systems, they require significantly more maintenance than static compensators. They also consume real power equal to about 3% of the machines reactive-power rating. Synchronous condensers are used in transmission systems at the receiving end of long transmissions, in important substations and in conjunction with HVDC converter stations.

Small synchronous condensers have also been used in high-power industrial networks to increase the short circuit power. T

The reactive power output is continuously controllable. The response time with closed-loop voltage control is from a few seconds and up, depending on different factors. In recent years the synchronous condensers have been practically ruled out by the. Thyristor controlled static VAR compensators, because those are much cheaper and have regulating characteristics similar to synchronous condensers.

4.3.8 Static VAR Compensators

An SVC combines conventional capacitors and inductors with fast switching capability. Switching takes place in the sub cycle time frame (i.e. in less than 1/50 of a second), providing a continuous range of control. The range can be designed to span from absorbing to generating reactive power. Advantages include fast, precise regulation of voltage and unrestricted, largely transient-free, capacitor bank switching.

Voltage is regulated according to a slope (droop) characteristic. Static VAR compensator could be made up from: TCR (thyristor controlled reactor); TSC (thyristor switched capacitor); TSR (thyristor switched reactor); FC (fixed capacitor); Because SVCs use capacitors they suffer from the same degradation in reactive capability as voltage drops. They also do not have the short-term overload capability of generators and synchronous condensers. SVC applications usually require harmonic filters to reduce the amount of harmonics injected into the power system by the thyristor switching. SVCs provide direct control of voltage (C.W. Taylor, 1994); this is very valuable when there is little generation in the load area. The remaining capacitive capability of an SVC is a good indication of proximity to voltage instability.

SVCs provide rapid control of temporary over voltages. But on the other hand SVCs have limited overload capability, because SVC is a Capacitor bank at its boost limit. The critical or collapse voltage becomes the SVC regulated voltage and instability usually occurs once an SVC reaches its boost limit. SVCs are expensive; shunt capacitor banks should first be used to allow unity power factor operation of nearby generators.

4.3.9 Static synchronous compensator (STATCOM)

The STATCOM is a solid-state shunt device that generates or absorbs reactive power and is one member of a family of devices known as flexible AC transmission system (FACTS) devices. The STATCOM is similar to the SVC in response speed, control capabilities, and the use of power electronics. Rather than using conventional capacitors and inductors combined with thyristors, the STATCOM uses self-commutated power electronics to synthesize the reactive power output. Consequently, output capability is generally symmetric, providing as much capability for production as absorption. The solid-state nature of the STATCOM means that, similar to the SVC, the controls can be designed to provide very fast and effective voltage control (B. Kirby, 1997). While not having the short-term overload capability of generators and synchronous condensers, STATCOM capacity does not suffer as seriously as SVCs and capacitors do from degraded voltage. STATCOMs are current limited so their MVAR capability responds linearly to voltage as opposed to the voltage-squared relationship of SVCs and capacitors. This attribute greatly increases the usefulness of STATCOMs in preventing voltage collapse.

Series capacitors and reactors Series capacitors compensation is usually applied for long transmission lines and transient stability improvement. Series compensation reduces net transmission line inductive reactance. Series capacitor reactive generation increases with the current squared, thus generating reactive power when it is most needed. This is a self-regulating nature of series capacitors. At light loads series capacitors have little effect.

Power Capacitor Based Compensating Devices Power factor correction method based on power capacitors is the biggest group of the devices used in the industry and by the private users, mainly from economic reasons. On the hand, they may be a reason of unwanted distortions at the spot of operation. That is why they should be carefully selected, in accordance with actual standards. In terms of rated voltage of capacitors, we can distinguish two groups of capacitor banks:

4.3.10 Reactive power capability dependence on real power production for a synchronous generator

Like most electric equipment, generators are limited by their current-carrying capability. Reactive power production is depended on the field heating limit and absorption on the core end-heating limit of the generator. Active power output limit is limited by armature heating. Control over the reactive output and the terminal voltage of the generator is provided by adjusting the DC current in the generators rotating field. Control can be automatic, continuous, and fast. The inherent characteristics of the generator help maintain system voltage. At any given field setting, the generator has a specific terminal voltage it is attempting to hold. If the system voltage declines, the generator will inject reactive power in to the power system, tending to raise system voltage. If the system voltage rises, the reactive output of the generator will drop, and ultimately reactive power will flow into the generator, tending to lower system voltage. The voltage regulator will accentuate this behavior by driving the field current in the appropriate direction to obtain the desired system voltage.

4.4 Reactive Power in Operation

Reactive power affects power system operation in numerous ways:

1. Loads consume reactive power, so this must be provided by some source.
2. The delivery system (transmission lines and transformers) consumes reactive power, power). However, that all transmission lines do provide some reactive power from so this must be provided by some source (even if the loads do not consume reactive their shunt line charging which offsets their consumption of reactive power in their series line losses.
3. The flow of reactive power from the supplies to the sinks causes additional heating of the lines and voltage drops in the network.
4. The generation of reactive power can limit the generation of real power.

One primary dilemma with reactive power is that a sufficient quantity of it is needed to provide the loads and losses in the network, but having too much reactive power flowing around in the network causes excess heating and undesirable voltage drops. The normal solution to this dilemma is to provide reactive power sources exactly at the location where the reactive power is consumed. And, since strictly speaking it does not take any "fuel" to provide reactive power, it should be possible to distribute reactive power sources (such as capacitors) all around the network to avoid the problem of heating the conductors and causing voltage drops. Unfortunately, this is not practical in the extreme since there are literally millions of lines and loads connected to the grid and so this would require millions of reactive power sources - all controlled to provide exactly the right amount of reactive power at the right time - every second of every day.

The best way to we can do in most cases is work with some type of aggregation of load (say at the feeder leaving a substation) and at terminals of major lines and transformers. This also brings up the issue of the difference between power factor control (trying to exactly provide the right amount of reactive power needed to equal that which is consumed) and voltage control (trying to keep voltage levels at exactly theright level no matter how much reactive power it takes). Reactive power is both the problem and the solution to network voltage control.

4.5 Power System Stability

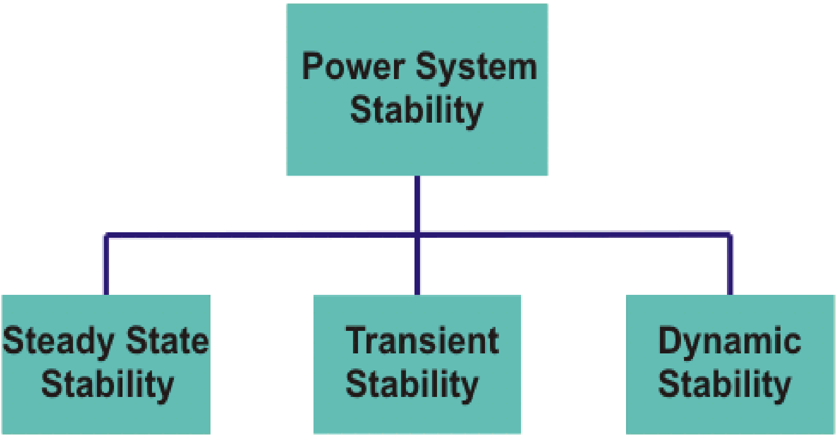
Power system engineering forms a vast and major portion of electrical engineering studies. It is mainly concerned with the production of electrical power and its transmission from the sending end to the receiving end as per consumer requirements, incurring minimum amount of losses. The power at the consumer end is often subjected to changes due to the variation of load or due to disturbances induced within the length of transmission line. “Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact”.

Power system stability has been recognized as an important problem for its secure operation since 1920s. Result of the first laboratory tests on miniature systems were reported in 1924, the first field tests on the stability on a practical power system were conducted in 1925. Traditionally, the problem of stability has been one of maintaining the synchronous operation of generators operating in parallel, known as rotor angle stability.

With continuous increase in power demand, and due to limited expansion of transmission systems, modern power system networks are being operated under highly stressed conditions. This has been imposed the threat of maintaining the required bus voltage and thus the systems have been facing voltage instability problem.For this reason, the term power system stability is of utmost importance in this field, and is used to define the ability of the of the system to bring back its operation to steady state condition within minimum possible time after having undergone some sort of transience or disturbance in the line. Ever since the 20th century, till the recent times all major power generating stations over the globe has mainly relied on AC distribution system as the most effective and economical option for the transmission of electrical power. This has resulted into the difficulty in meeting reactive power requirement, especially under contingencies, and hence maintaining the bus voltage within acceptable limits.

4.5.1 Synchronous Stability of a Power System

In the power plants, synchronous generators with different voltage ratings are connected to the bus terminals having the same frequency and phase sequence as the generators, while the consumer ends are feeded directly from those bus terminals. And therefore for stable operation it is important for the bus to be well synchronized with the generators over the entire duration of transmission, and for this reason the power system stability is also referred to as synchronous stability and is defined as the ability of the system to return to synchronism after having undergone some disturbance due to switching on and off of load or due to line transience.



The stability limit defines the maximum power permissible to flow through a particular point or a part of the system during which it is subjected to line disturbances or faulty flow of power. Having understood these terminologies related to power system stability let us now look into the different types of stability.

The synchronous stability of a power system can be of several types depending upon the nature of disturbance, and on the basis of system analysis, it can be classified into the following three types:

1. Steady state stability
2. Transient stability
3. Dynamic stability

Steady State Stability of a Power System

The steady state stability of a power system is defined as the ability of the system to bring itself back to its stable configuration following a small disturbance in the network. It can only be considered only during a very gradual and infinitesimally small power change. In case the power flow through the circuit exceeds the maximum power permissible, then there are chances that a particular machine or a group of machines will cease to operate in synchronism, and result in yet more disturbances. In such a situation, steady state stability limit of a system refers to the maximum amount of power that is permissible through the system without loss of its steady state stability.

Transient Stability of a Power System

It refers to the ability of a synchronous power system to return to stable condition and maintain its synchronism following a relatively large disturbance arising from very general situations like switching 'on' and 'off' of circuit elements, or clearing of faults etc. is referred to as the transient stability in power system.

Dynamic Stability of a Power System

Dynamic stability of a system denotes the artificial stability given to an inherently unstable system by automatic controlled means. It is generally concerned to small disturbances lasting for about 10 to 30 seconds.

4.6 Role of Embedded in Electric Power System

Power quality is basically determined by the voltage magnitude and frequency in a system. To provide more efficient capability in Electric power grid, it needs to have the combination of several technology including communications, power electronics, Embedded Systems and control system. It provides good automated regulation without consuming much power. With the advancement of technology has given the edge to use the latest trends such as microprocessors, microcontrollers, embedded systems which are used as one of the requirement for the protection of electric power system that provides fast response, better isolation and accurate detection of power loss.

Normally, in power transmission and distribution system losses get reduces, if the generated energy is nearly equal to the consumed energy. Power loss can be reduced in Electric Grid system where the quality of transmission lines has to be improved. An exposure to the characteristics of the grid together with technologies required to build an electric power grid will provide an efficient transmission and distribution system with low power loss. By coming years, Smart grid will be an outcome of an evolutionary development of the existing electricity networks with an optimized and sustainable energy system.

Power systems are designed to function at any frequency which is 50 Hz are prone to unsatisfactory operation and at times failure when subjected to voltages and currents that contains substantial harmonic frequency elements. Very often the operation of electrical equipment may seem normal but under a certain combination of conditions the impact of harmonics is enhanced with damaging results. To avoid this, for example Voltage stabilizers are used for many appliances in home, offices and industries to reduce the variation on end utilities. The mains supply suffers from large voltage drops due to losses on the distribution lines. A voltage stabilizer maintains the voltage to the appliances at the nominal value of around 220volts, even if the inputs main fluctuates over a wide range. The circuit of an automatic voltage stabilizer with embedded Ic in it can be adapted to any power rating. Its intelligence lays in the program on low cost Embedded Ic that is readily available. Hence the circuit, when used with any appliances, will maintain the voltage at around 220V even if the input mains voltage varies between 180V and 250V for domestic application.

It can respond within 100ms to produce a smoothly varying output whenever inputs mains voltages changes. The embedded IC is generally having RISC (Reduced Instruction Set Computer) and hence program development with it is rather tough, but there are good support programs and more reliable too. It can provide an efficient technique to regulate voltage at utility end as it makes use of intelligence of embedded system for its functioning and makes the system completely automated circuit with least user intervention for its functioning.

An Embedded IC can be considered a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes. Mixed signal microcontrollers are common, integrating analog components needed to control non-digital electronic systems.

Some microcontrollers may use four-bit words and operate at clock rate frequencies as low as 4 kHz, for low power consumption (mill watts or microwatts). They will generally have the ability to retain functionality while waiting for an event such as a button press or other interrupt; power consumption while sleeping (CPU clock and most peripherals off) may be just nano watts, making many of them well suited for long lasting battery applications. Other microcontrollers may serve performance-critical roles, where they may need to act more like a digital signal processor (DSP), with higher clock speeds and power consumption.

Chapter 5
SYSTEM DESIGN AND ANALYSIS

5.1 System Design

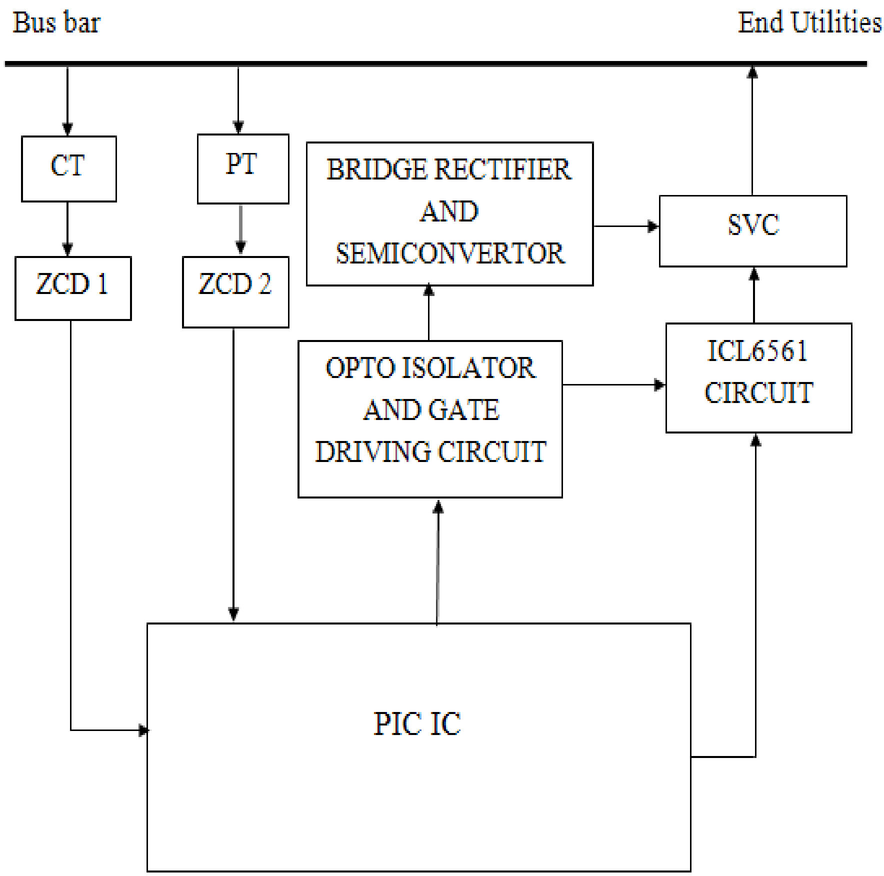


Fig 5.1. Structure of System Design

5.2 Circuit Description

The given block diagram depicts the proposed system for optimal placement of SVC with least losses and to increase power flow and healthy voltage profile in power transmission or distribution system. PIC Microcontroller IC will be the heart of the system, it decides and directs the compensation block to inject the required reactive power into the transmission or distribution systems before delivering to the end utilities in power systems.

A potential and current transformer is used to measure the voltage and current signals in power transmission or distribution system (bus bar). The outputs of these two transformers are the fundamental complex waveforms of the supplied voltage and current respectively. PIC can only detect the digital signal input, or known as ‘pulse’ and hence the two complex sinusoidal waveforms are being changed to square wave or pulses through two zero-crossing detectors (ZCD 1 and ZCD 2) and given to PIC IC as two inputs.

The Synchronizing circuit produces a pulse at each zero-crossing of the supplied sine wave voltage. The rising edge of the synchronizing circuit output pulse is synchronized with the zero-crossing of the input sine wave voltage. The output pulses obtained from the synchronizing circuit are then applied to the input of microcontroller as a reference in order to trigger SVC.

The pulse signal from the Microcontroller drives the gates of the two back-to-back thyristors or TRIAC and for a thyristor, so as to control the reactor current. The phase angle, φm between the fundamental components of the supplied voltage and current (V and I respectively) is measured by the microcontroller. The measured phase angle φm is then compared with a reference value φr that gives the required reactive power. These changes should be in the direction that reduces the difference between φm and φr to a certain acceptable tolerance value, to stabilize the voltage variation in power system.

The PIC Microcontroller IC is used, to select any three pins from any one of the I/O ports, which has eight pins for example, PIN0, PIN1, PIN2 are used to operate as input pins, in which PIN1 represents voltage, PIN2 represents current and PIN0 representing synchronizing pulse. Meanwhile, the pin PIN3 and PIN4 operates as an output pins.

In the first stage, the system is initialized, and the thyristor triggering angle, α is set to the chosen initial value. The value of α is loaded into one general purpose file register in the Microcontroller that read the values of voltage, current and synchronization pulse and generates the output accordingly. It continuously monitors or checks for synchronization, until the signals in the system to bein synchronized state. After attaining synchronized condition it goes for checking the of voltage level in the system. The SVC can do a much better job, improving voltage stability while keeping the voltage magnitude in the acceptable region. When the maximum limit is reached, the SVC behaves exactly like a fixed shunt capacitor, so close attention has to be given in selecting the correct size.

If voltage variation occurs, PIN3 will be high and SVC which will mitigate the voltage variation in the bus bar. The Opto-isolator and gate driver circuit provides proper isolation for the control circuitry and sufficient current boosting. In Bridge rectifier and Semi Convertor Circuits two MOSFET's are connected in parallel that functions for both positive and negative half cycles respectively. It provides controlled output voltage with reference to firing angle. ICL6561 controls the SVC with reference signal from Controller IC.

5.3 System Flow Diagram

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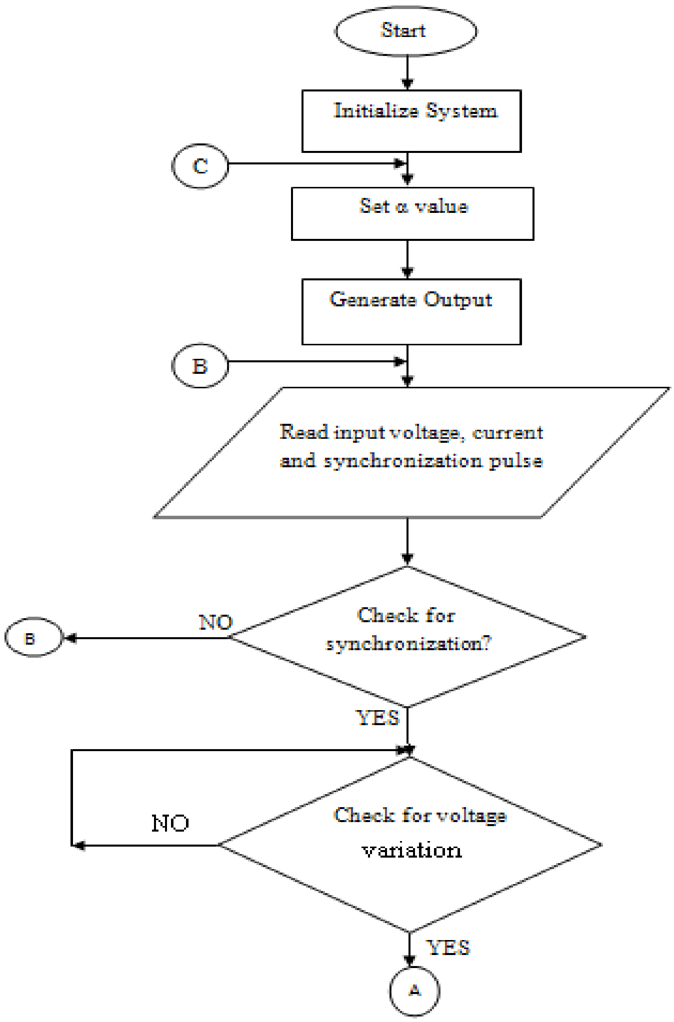

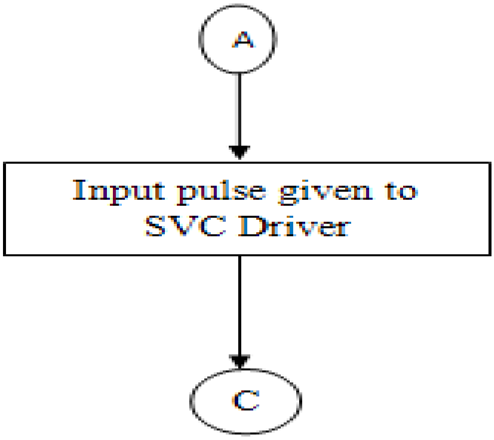

5.4 Advantages

1. Performance level is highly increased.
2. Reduction in power loss.
3. Maintenance free-only 1-2 man-days of maintenance with a minimum of equipment is expected as an annual average.
4. Enhancement in voltage stability.
5. Low power consumption.

Chapter 6
Electric Utility Applications of Compensators

6.1 Introduction

Shunt connected Static VAR Compensators (SVCs) are used extensively to control the AC voltage in transmission networks. Power electronic equipment, such as the thyristor controlled 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 thyristor and transistor devices (GTO, IGBT, …) a new generation of power electronic equipment, STATCOM, shows great promise for application in power systems. Installation of a large number of SVCs and experience gained from recent STATCOM throughout the world motivates to clarify certain aspects of these devices.

In Static VAR Compensator (SVC) it 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 varsystemis 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.

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 Mvar capacitive.

The Voltage-Sourced Converter (VSC) is the basic electronic part of a Static Synchronous Compensators (STATCOM), which converts the dc voltage into a three-phase set of output voltages with desired amplitude, frequency, and phase.There are different methods to realize a voltage-sourced converter for power utility application. Based on harmonics and loss considerations, pulse width modulation (PWM) or multiple converters are used.

STATCOMs have a symmetrical rating with respect to inductive and capacitive reactive power. For example, the rating can be 100 Mvar inductive and 100

Mvar capacitive. For asymmetric rating, STATCOMs need a complementary reactive power source. This can be realized for example with MSCs.

6.2 Dynamic Studies

An SVC is in principle a controlled shunt susceptance. The voltage measurement converts the fundamental three phase waveforms to a RMS value. The conversion and filtering can be represented by an analog lag with around 10 ms time constant.

Today, the controls are digital so that various strategies can be implemented. For example, the “other signals” inputs to summing junction could be damping control. The slope is defined as the ratio between the change of voltage and the change of the SVC current over the whole control range. It determines the steady-state operating point and is normally set between 2–5%.

An SVC might include an undervoltage strategy which forces the susceptance to the lowest level to prevent contribution of the SVC to overvoltage following fault clearing. A current limiter is normally provided to reduce the TCR current within a predefined time (T4 is about 1 second).

STATCOM model is for transient stability studies. STATCOM is in principle a controlled voltage source. In a real installation, the magnitude of the source voltage is controlled through dc voltage across the capacitor. Since this loop is very fast, the dc capacitor does not need to be modeled for dynamic stability studies. The regulator keeps the STATCOM current within the current limit (I_{MAX}).

Voltage Regulation

SVCs and STATCOMs respond to changes in power system operating conditions fast and continuously. Normally, the size of the reactive compensators (SQ) is decided by the network short circuit capacity (SSC). A ratio of 5% (SQ/SSC) is normally selected. This section demonstrates the impact of SVCs and STATCOMs on the bus voltage for deviation of the network strength from the nominal point.

Case I: Under voltage

SVCs work as a shunt capacitor and STATCOMs work as a constant current source. It is seen that if the SSC decreases to one-third of the nominal value (for example, outage of parallel lines), STATCOMs contribute to the voltage regulation more than SVCs by a factor about 1.7%.

Case II: Over voltage

The same network in used to illustrate the influence of SVCs and STATCOMs on reducing overvoltage.

The explanation of the impact of SVCs and STATCOMs on the system voltage during an overvoltage is as follows:

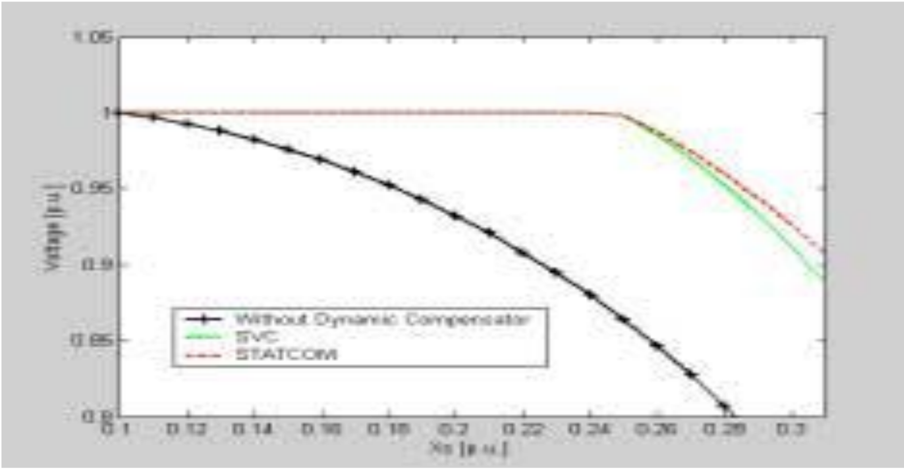

Fig 6.3.1: Voltage variation with change in source reactance

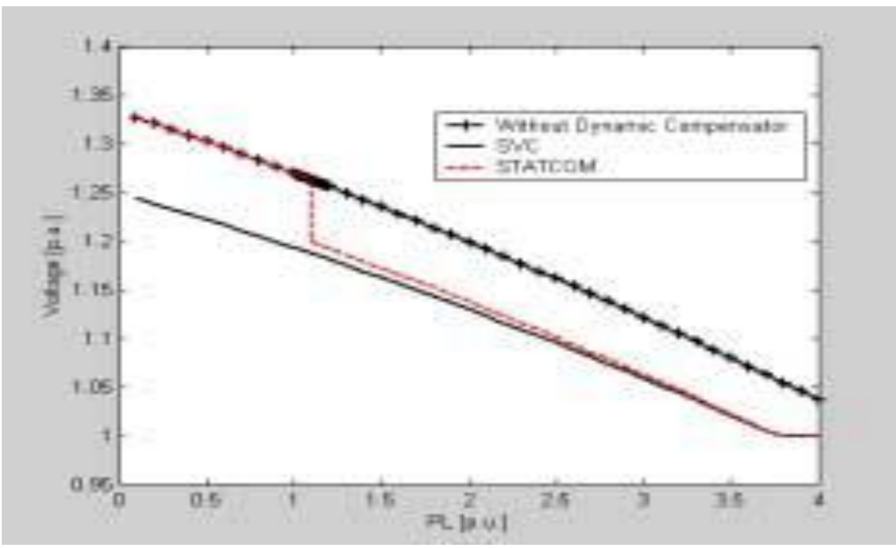

Fig 6.3.2: Illustration of overvoltage for the simple power system

In SVC, at a sudden voltage rise up to less than 1.3 p.u., the TCR current is allowed to increase as determined by the TCR reactance. A limiting function having a time constant of 1.0 second will then reduce the current down to the allowable maximum continuous current, i.e., the current at 1.1 p.u. voltage. At a sudden voltage rise exceeding 1.3 p.u., the TCR current will increase as determined by the reactor impedance. In this case, no current limitation is possible, resulting in disconnection of the SVC after 1 second.

STATCOMs absorb reactive current to reduce the voltage. When the voltage goes higher than a certain value (say 1.2 p.u.), the VSC voltage amplitude must increase to limit the current to the maximum value. For a typical STATCOM with reactance of 10% and with a maximum voltage of ES equivalent to 1.1 p.u., the maximum allowable net voltage will be about 1.2 p.u. If the voltage rises beyond this limit, the STATCOM should be disconnected to protect the valves.

The above examples show that with the same reactive power rating, STATCOMs contribute to voltage regulation more effectively than SVCs during undervoltage situations, while SVCs contribute to voltage regulation more effectively than STATCOMs during overvoltage situations. STATCOM solution allows faster voltage recovery compared to a conventional SVC.

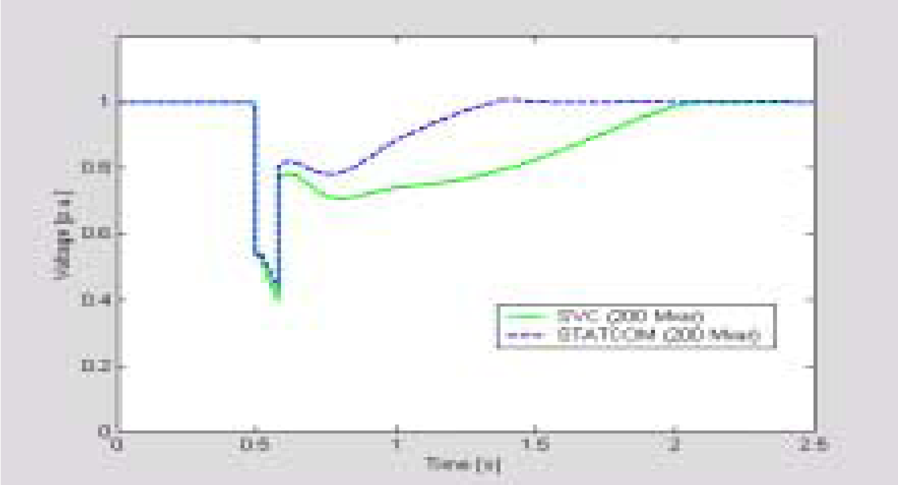

Fig 6.3.3. Voltage variation with SVC and STATCOM

Thus SVCs serve the purpose of continuously maintaining a smooth voltage, piloting the MSC switching. If the task is to support a system limited by post contingency voltage instability or unacceptable voltage levels, a large amount of quickly controllable reactive power is needed for short time duration. An SVC with additional TSCs is an excellent choice. Post recovery voltage support may also be necessary, this is then preferably provided by MSCs governed by the SVC.

For temporary over voltages, large inductive reactive power is needed for a short period of time. The standard TCR has some short-time overcurrent capability. This capacity can easily be extended by lowering its steady state operating temperature and by “under sizing” the reactors.

The SVC characteristic at depressed voltage can be efficiently improved by adding an extra TSC. This branch is intended to operate only during undervoltage conditions. It can be added without introducing additional cost in other parts of the SVC. Most important is that the current rating or the voltage capability of the power transformer does not need to be increased. Power transformers allow large over current during limited time. In many cases three times overload in current for 10 seconds is available. The additional TSC rating is typically in the range of 50 to 100% of the SVC rating.

Both SVCs and STATCOMs generate harmonics. The TCR of an SVC is a harmonic current source. Network harmonic voltages distortion occurs as a result of the currents entering the power system. The STATCOM is a harmonic voltage source. Network voltage harmonic distortion occurs as a result of voltage division between the STATCOM phase impedance and the network impedance.

The major harmonic generation in SVCs is at low frequencies; above the 15th harmonic the contribution is normally small. At lower frequencies the generation is large and filters are needed. SVCs normally have at least 5th and 7^{th} harmonic filters. The filter rating is in the range of 25–50% of the TCR size.

STATCOMs with PWM operation have their major harmonic generation at higher frequencies. The major contributions are at odd multiples of the PWM switch frequency; at even multiples the levels are lower. The harmonic generation decays with increasing frequency. STATCOMs might also generate harmonics in the same spectra as the conventional SVCs. The magnitudes depend on converter topology and the modulation and switching. STATCOMs provides improved performance, it will be the choice in the cases where this can be justified, such as flicker compensation at large electrical arc furnaces or in combination with active power transfer (back-to-back DC schemes). The two different concepts cannot be compared on a subsystem basis but it is clear that the cost of the turn-off semiconductor devices used in VSC schemes must come down significantly for the overall cost to favor the STATCOM.

In other industries using high power semiconductors, like electrical traction and drives, the mainstream transition to VSC technology is since long completed and it is reasonable to believe that transmission applications, benefiting from traction and drive developments, will follow. Although the semiconductor volumes in these fields are relatively small, there is potential for the cost of STATCOMs to come down."

Apart from the losses, the life cycle cost for STATCOM and SVCs will be driven by the efforts required for operation and maintenance. Both technologies can be considered maintenance free—only 1–2 man-days of maintenance with a minimum of equipment is expected as an annual average. The maintenance is primarily needed for auxiliary systems such as the converter cooling and building systems. In all, the difference in the cost for these efforts, when comparing STATCOM and SVC, will be negligible.

The primary losses in SVCs are in the “step-down” transformers, the thyristor controlled air core reactors and the thyristor valves. For STATCOMs the losses in the converter bridges dominate. For both technologies the long-term losses will depend on the specific operation of each installation. The evaluation of investments in transmission has also increasingly included the costs during the entire life cycle, not only the initial investment. Losses will then be increasingly important.

Most utilities to operate their facilities close to zero Mvar output, in order to have SVCs or STATCOMs available for dynamic voltage support. In these cases, both technologies will operate with well below 0.5% losses (based on “step-down” transformer rating). However, the losses will typically increase quite rapidly should the operating point be offset from zero. This is valid for both SVCs and STATCOMs. SVCs will frequently operate with both switched capacitors and controlled reactors at the same time, while converter losses of STATCOMs will increase rapidly with output current. The losses of STATCOMs at rated output will be higher than for comparable SVCs.

The performance of SVCs and STATCOMs in electric power systems is already examined. Both devices significantly improve the transient voltage behavior of power systems. Though, SVC’s and STATCOM’s work on different principles, their impact on increasing power system transmission capacity can be comparable. Specifically, we describe “enhanced” SVCs with voltage recovery performance similar to STATCOMs.

7. Result

The security of Electric grid systems is under threat as a consequence of sophisticated intrusion and imperceptible faults. In the proposed system, the results are analyzed for the better performance of bus barby improving the voltage profile, incase of voltage variations, which gives the solution for the major problems that may rise such as power factor, fluctuations, flickers in dynamic condition. The presence of compensator is one of the best device or solution that can contribute to improve the voltage profile in the transient state and therefore, it enhances the quality performance of an electric service. The shunt compensation is mostly preferred to provide reactive power compensation, which supports in mitigation of variation in voltage level.

This work describes that the proposed system has the ability to compensate the voltage variations in power system. The proposed work is modeled after the familiarization of Static VAR Compensator (SVC), an early FACTS device. FACTS represent a new era for the transmission of electric power. The system compensates the change in voltage by comparing the voltage level with the reference value. The compensator branches consist of capacitors and a fine-tuning inductor that is controlled continuously using a firing angle. This system can be incorporate to both industrial customers and utilities, as well as becoming increasingly important to small commercial and residential consumers.

The system flow diagram explains the working of the proposed system, which will be very effective for the bus bar in electric power system having linear and non-linear loads, while comparing with other existing compensator model system this system will give a better result in all the critical conditions.

The power industry has a large interest in the reduction of harmonics because of the ever-increasing usage of consumer electronic devices. The proposed system significantly improves the transient voltage behavior of electric power system. Also SVCs and STATCOMs work on different principles, but their impact on increasing power system transmission capacity can be comparable. SVCs and STATCOMs can continuously respond to variations in power system operating condition with faster response time. The results show a reduction of peak short-circuit currents, low operating losses and the optimum operation with interconnected bus bars. The implemented system not only prevents economic losses due to the destruction or shortening of useful life of the equipment, but also increases the quality of energy supply to the customers or end utilities and thus it is found that the results were satisfactory to fulfill the requirement for an efficient electric power system. By considering economical point of view in this system SVC's are implemented for reducing power variation in transmission or distribution system as compared to STATCOMs that enhances the efficiency of whole power system.

8. Conclusion

The dissertation presents a concept of reducing the rate of voltage variation problem in transmission and distribution of an electric grid system, the elucidation is given commencing the compensators. The analysis of a power system component such as generators, transmission lines and transformers, rely on harmonic voltage and current distortion levels. The harmonic distortion in voltage and current is usually calculated by means of load flow studies with an assumption that power generation and transmission system is perfectly linear. In practice however, the transformer magnetizing current harmonics will produce harmonic voltages and currents as harmonic interaction takes place between the rotor and stator circuit of the generator. The process of harmonic conversion changes the waveform of the transformer flux which produces distortion. Apart from this, any harmonic contribution from any other network component like transmission line, triggers the harmonic interaction between these two nonlinear power system components.

It is hard to analyze the effect of harmonic cross coupling within conventional frame of references. The dynamic analysis of the power system components often needs a detailed model for a certain part of the network, while the rest of the network can be considered to be an equivalent circuit. In this way the computation efforts required for explanation of the whole network is considerably reduced and simplified to provide an efficient power flow system.

The power semiconductor device considered here is the SVC (Static VAR Compensator) for improving the performance and effectively regulate the system oscillatory disturbances and hence the voltage regulation of the whole power system. SVC can provide fast acting voltage support to take care off voltage reduction at the bus. Static VAR Compensators (SVCs)can be used primarily in power system for voltage control or also a means of achieving other objectives, such as system stabilization. The performance of SVC voltage control is critically dependent on several factors, including the influence of network resonances, transformer saturation, geomagnetic effects, and voltage distortion.

By installing Static VAR Compensators which intend to improve the power transmission quality and by controlling dynamic power, wastages or losses of reactive power can be reduced and indeed increases the efficiency of power system. Hence as efficiency is increased, production of the plant also gets increased. By this voltage stability of electric power system can be improved and enhances the efficient power transmission and distribution capability in electric grid system.

The importance of selecting SVC compensators is to increase the static voltage stability margin and power transfer capability, however, SVC will provide a better behavior, in terms of loss reduction and voltage profile. Overall, SVC offers a better performance than a simple shunt capacitor; however, these controllers are quite expensive as compared to shunt capacitor. But the stability of power system is improved by the compensation of reactive power.

Suggestions for future scope is, in earlier the voltage variation mitigation were done through Microprocessors for each process separately in difficult production environments. But with the advent of Embedded IC's, now Microprocessors are replaced by PIC or Embedded IC that reduces hardware complexity and ensures secure operation. Next to this, the future scope depends on using or implementing simulation software which is upcoming fast where we can also do automatic monitoring of parameters in power systems and to troubleshoot it, for enhancing the voltage stability and to reduce other problems or variations from reference level or range, of entire processes in power system.

With the advent of MOSFET's Static VAR Compensators using MOSFET's are slowly taking over the conventional SVC's. The SVC's ensures stable operation of power systems with no transients, with efficient protection against line disturbances and abnormal conditions, reduction in size, less cost, etc.

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