Reactive power management at high voltage long AC transmission line.

A Thesis submitted in partial fulfillment of the requirements for the Degree of Bachelor of Science in Electrical and Electronic Engineering

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CERTIFICATION

This is to certify that this thesis entitled “**Reactive power management at high voltage long AC transmission line.**” is done by the following students under my direct supervision and this work has been carried out by them in the laboratories of the Department of Electrical and Electronic Engineering under the faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering. The presentation of the work was held on October 2020.

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Dedicated to

MY PARENTS
And
TEACHERS
With Love & Respect

DECLARATION

We do hereby declare that this thesis is based on the result found by ourselves. The materials of work found by other researchers are mentioned by reference. This thesis is submitted to Daffodil International University for partial fulfillment of the requirement of the degree of B.Sc. in Electrical and Electronics Engineering. This thesis neither in whole nor in part has been previously submitted for any degree.

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LIST OF ABBREVIATIONS

AC	Alternating current
DC	Direct current
KVA	Kilovolt ampere
KW	Kilowatt
Kvar	Kilovar
SVC	Static var compensator
STATCOM	Static synchronous compensator
FACTS	Flexible AC transmission systems
SSSC	Static synchronous series compensator
TCSC	Thyristor controlled series compensator
TCSR	Thyristor controlled series reactor
TSSC	Thyristor switched series capacitor
VSC	Voltage source converter
GTO	Gate turn off thyristor
IGBT	Insulated gate bipolar transistors
PWM	Pulse width modulation
IPFC	Interline power flow controller
UPFC	Unified power flow controller
AFCI,AFDD	Arc fault circuit interrupter, Arc fault detection device

ABSTRACT

In a high voltage long AC transmission system, the system voltage changes continuously with the changes of load. The reactive power also changes with the changing of load which affects the system voltage for this reason it is important to analyze the power system in order to determine system parameters and its variation under various load conditions. The reactive power can be improved by compensation. Reactive power compensation is defined as the management of reactive power to improve the performance of AC power systems. In general, the problem of reactive power compensation is related to load and voltage support. In load support the objectives are to increase the value of the system power factor, to balance the real power drawn from the AC supply, to enhance voltage regulation, and to eliminate current harmonic components produced by large and fluctuating nonlinear industrial loads. Voltage support is generally required to reduce voltage fluctuation at a given terminal of a transmission line. Reactive power compensation in transmission systems also improves the stability of the AC system by increasing the maximum active power that can be transmitted.

This thesis presents a different section of transmission line with simulation work by using MATLAB. It also presents reactive power compensation by using capacitor banks at different section of transmission line. There is voltage, current and power level shown in table and graph. How the power level decrease by the inductive load without compensation and how much increase the power level by using the capacitor banks compensation are analyzed in this work.

CHAPTER-1

1.1 Introduction

AC transmission lines are used to transfer electrical power from the power generating stations to the distribution grid, which then provides customers with electrical power. AC transmission lines also have to transmit electrical power over long distances, as the power generation stations in an AC power network may be very far from the energy consumption centers. A variety of different systems have been built to minimize or remove the disadvantages of using shunt condenser substations for AC transmission line voltage compensation. These systems are part of the device family of versatile ac transmission systems (commonly shortened as FACTS), one of the most common FACTS devices, the static synchronous compensator (commonly shortened as STATCOM). [1] The high voltage AC long transmission line is shown in fig 1.1

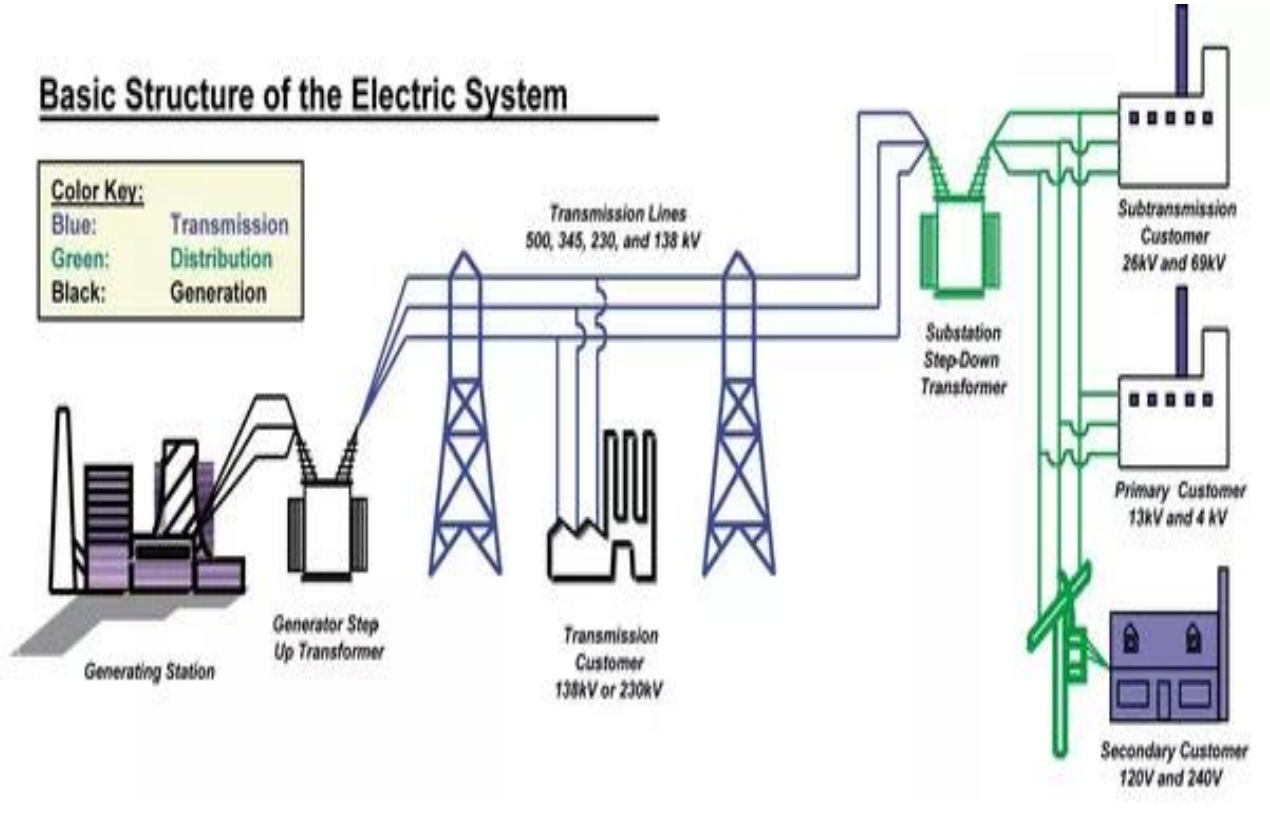

Fig 1.1: High voltage long AC transmission line [2]

1.2 Reactive power

Reactive power is the power that provides electrical energy in reactive components. Power, as we know, consists of two parts, active and reactive power. The entire sum of active and reactive power is named as apparent power.

For most electrical loads like motors, the voltage V is leading the current I by an angle ϕ.

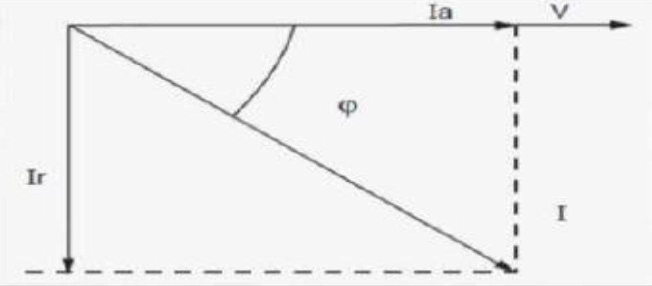

Fig: 1.2 Current vector diagram [3]

- In current vector diagram, the current vector can be divided into two parts:

Ia is called the "**active**" part of the current.

Ir is called the "**reactive**" part of the current.

- The previous figure was drawn up for currents also applies to

Power by multiplying each current by the common voltage V.

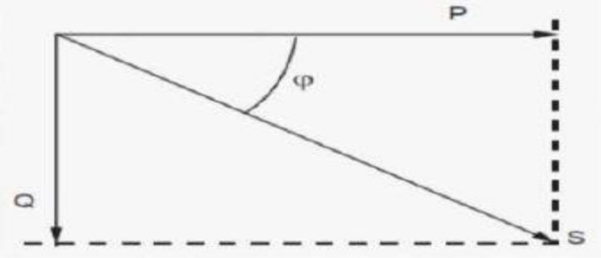

Fig: 1.3 Power vector diagram [3]

Apparent power: S = V x I (kVA)

Active power: P = V x Ia (kW)   (Active part)

Reactive power: Q = V x Ir (kvar)   (Reactive part)[3]

1.3 Analogy to explain the reactive power:

Take a boat on a canal, pulled by a horse

Fig 1.4: Analogy to explain the reactive power [3]

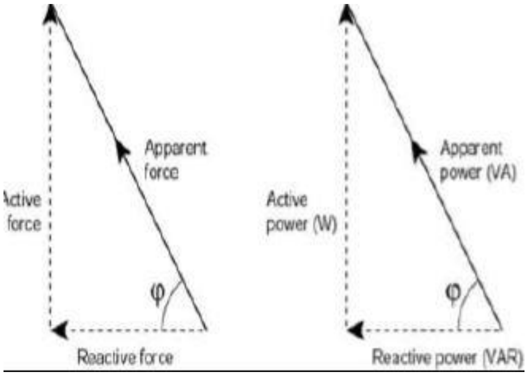

Fig 1.5: reactive power explain [3]

Here the horse is not walking straight in front of the boat.

Consequences:

- The fact that the rope is pulling at the flank of the horse and not straight behind it, and limit the horse’s capacity to deliver work.
- The turned rudder leads to extra losses. The vector representation of the force to pull the boat is similar to the vector representation of power in an electric system-Analogy to explain the reactive [3]

1.4 Necessity of reactive power in power system

Necessary to regulate of Voltage and Reactive Power:

Voltage management and reactive power management are two aspects of one activity that each supports reliability and facilitates commercial transactions across transmission networks. On an AC power system, voltage is controlled by managing production and absorption of reactive power. There are 3 reasons why it's necessary to manage reactive power and management voltage. First, each customer and power system instrumentation are designed to control inside a range of voltages, typically within±5% of the nominal voltage. At low voltages, many types of apparatus perform poorly, lightweight bulbs give less illumination, induction motors will overheat and be damaged, and some electronic devices won't operate at high voltage. This high voltage will harm instrumentation and shorten their lifetimes. Second, reactive power consumes transmission and generation resources. To maximize the quantity of real power that may be transferred across a full transmission interface, reactive power flows should be decreased. Similarly, reactive power production will limit a generator's real power capability. Third, moving reactive power on the gear mechanism incurs real power losses. Each capability and energy should be provided to exchange these losses. Voltage management is difficult by 2 extra factors. First, the gear mechanism itself could be a nonlinear client of reactive power, betting on system loading. At flare loading the system generates reactive power that has got to be absorbed, whereas at significant loading the system consumes an outsized quantity of reactive power that has got to get replaced. The system's reactive power needs conjointly depend upon the generation and transmission configuration. Consequently, system reactive needs vary in time as load levels and cargo and generation patterns amendment. The majority power grid consists of the many items of apparatus, anybody of which may fail at any time. Therefore, the system is intended to face up to the loss of any single piece of apparatus and to continue in operation while not impacting any customers. That is, the system is intended to face up to one contingency. The loss of a generator or a serious conductor will have the combination impact of reducing the reactive offer and, at an equivalent time, reconfiguring flows specified the system is intense extra reactive power. A minimum of a little of the reactive offer should be capable of responding quickly to ever-changing reactive power demands and to keep up acceptable voltages throughout the system. Thus, even as AN electrical system needs real power reserves to retort to contingencies, thus too it should maintain reactive-power reserves. Loads can even be each real and reactive. The reactive portion of the load may well be served from the gear mechanism. Reactive loads incur additional fall and reactive losses within the gear mechanism than do similar size (MVA) real loads. System operation has 3 objectives once managing reactive power and voltages. First, it should maintain adequate voltages throughout the transmission and distribution system for each current and contingency condition. Second, it seeks to reduce congestion of real power flows. Third, it seeks to reduce real power losses. [3]

1.5 Thesis objectives:

1. We will observe the impacts of reactive power in a system.
2. We will observe the behaviors of reactive power with different loads.
3. Reactive power falls due to inductive load and the maturing of reactive power with inductive load will be observed.
4. Reactive power reduces due to inductive load. So, we will study how to compensate the reactive power.
5. In this case, we will set the capacitor bank in the different points of a system to figure out the good result comes from which point.
6. We will take a system model for sake of observing the reactive power management. At first, we will develop the circuit model in Simulink at MATLAB program. Then we will observe the overall situation by analyzing the circuit Model.

CHAPTER-2

Reactive power compensation

2.1 Reactive power compensation in power system

Reactive power compensation is defined as the management of reactive power to enhance the performance of alternating-current power systems. Usually the matter of reactive power compensation is related to load and voltage support. In load support the objectives are to enhance the value of the system power factor, to balance the real power drawn from the ac supply, to increase voltage regulation, and to sort out current harmonic parts produced by large and fluctuating nonlinear commercial loads. Generally Voltage support is required to minimize voltage fluctuation at a given terminal of a transmission line. Reactive power compensation in transmission systems also enhances the stability of the ac system by raising the maximum active power that can be transferred. [4]

2.2 Benefits of reactive power compensation:

There are many benefits to compensation of reactive power in power transmisssion line :

-Improvement in voltage level.

-Improves system power facor .

-Higher load capability.

-Reducing KVA demand.

-Reduction in system losses.

-Saves cost to transmit power.[3]

2.3 Compensation technique with power electronics device:

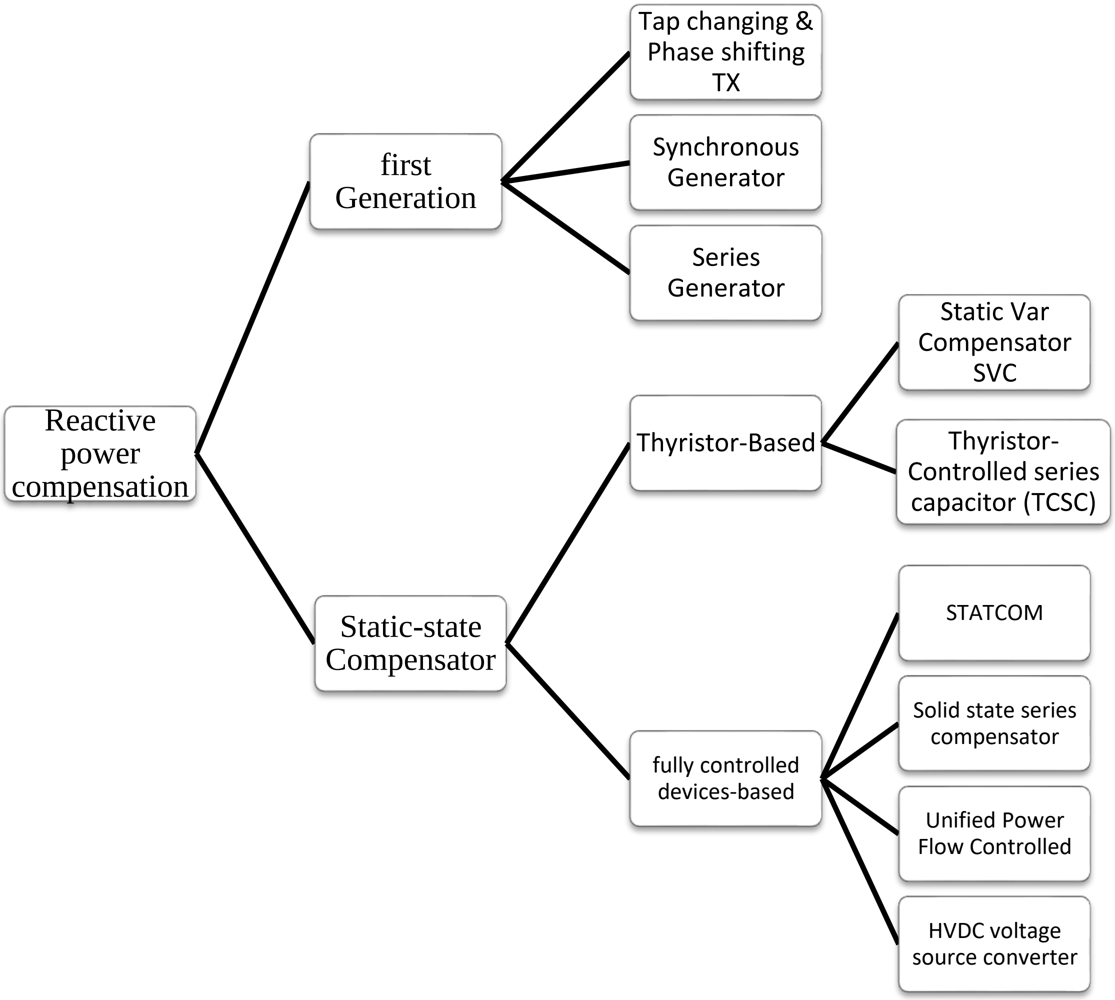

Fig 2.1: Compensation technique with power electronics device [4]

2.4 Types of compensation:

Primarily The reactive power compenation three types ,they are-

1. Capacitor bank
2. Synchronous Condencer
3. FACTS devices

2.4.1 Static Capacitor Bank: The capacitor bank compensation is a most common technique to compensate reactive power management. Let describe about it, here is a capacitor bank compensation technique is given below-

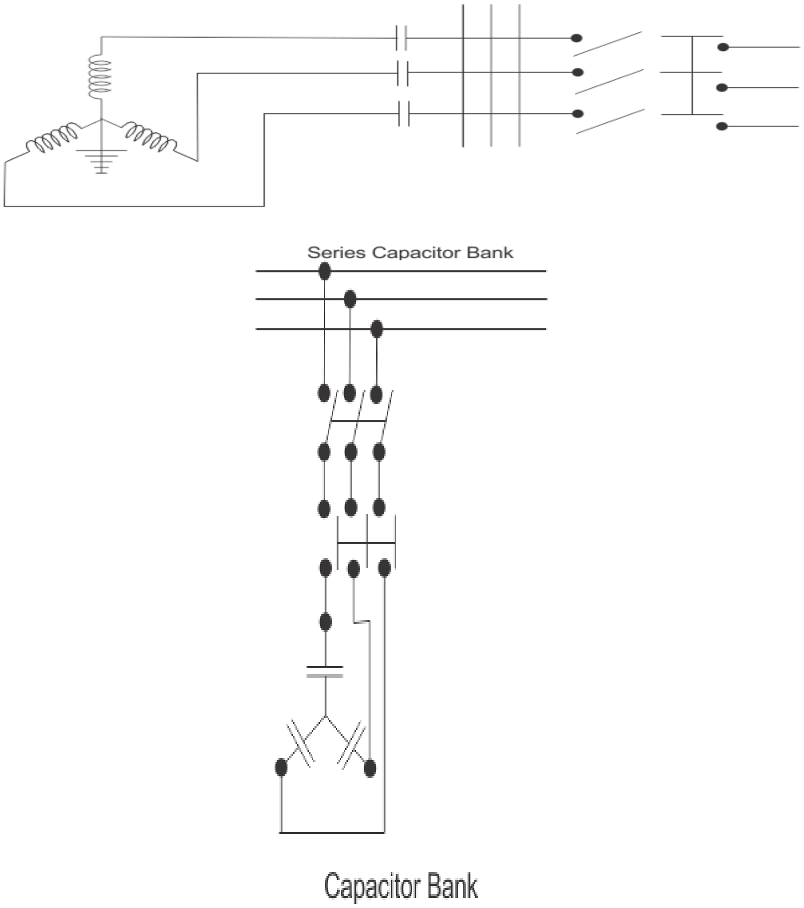

Fig 2.2: Static Capacitor Bank compensation connection in power system [5]

Static capacitors can be define into two categories:

.

1. Shunt capacitor
2. Series capacitor

These categories are principally based on the processes of joining the capacitor bank with the system. Among these two categories, shunt capacitors are more normally used in the power system of all voltage levels.

There are some specific merits of using shunt capacitors,

1. It reduces the line current of the system.

2. It enhances the voltage level of the load.
3. It also diminishes system Losses.
4. It improves the power factor of the source current.
5. It reduces the load of the alternator.
6. It reduces capital investment per MW of the Load.

All the previous merits come from the fact, that the impact of the capacitor reduces the reactive current flowing through the entire system. A shunt capacitor draws almost fixed amount of leading current that is superimposed on the load current and consequently reduces reactive parts of the load and therefore improves the power factor of the system. Series capacitors have no control over the flow of current. As these are connected in series with the load, the load current always passes through the series capacitor bank. Actually, the capacitive reactance of the series capacitor neutralizes the inductive reactance of the road. Therefore, it reduces the effective reactance of the road. Thereby, the voltage regulation of the system is improved. But a series capacitor bank has a major disadvantage. During fault conditions, the voltage across the capacitor is also raised up to fifteen times over its rated value. Thus series capacitor must have sophisticated and elaborate protective instrumentation. Due to this, the use of series capacitors is confined within the extra high voltage system only. [5]

2.4.2 Synchronous Condenser:

An over excited synchronous motor (condenser) incorporates a leading power factor. Increasing the condenser's field excitation leads to furnishing reactive power (vars) to the system. Synchronous Condenser Like capacitor bank, we are able to use an excited synchronous motor to enhance the poor power factor of an influence system. The most advantage of using synchronous motor is that the advance of power factor is smooth. When a synchronous motor runs with over-excitation, it attracts leading current from the supply. We tend to use this property of a electric motor for the aim. Suppose because of a reactive load of the power system the system attracts a current IL from the supply at a lagging angle θL in respect of voltage. Currently the motor attracts a IM from a similar supply at a leading a number one. Currently the overall current drawn from the supply is that the resultant of the load current IL and motor current IM. The resultant current I drawn from the supply has an angle θ in respect of voltage. The angle θ is a smaller amount than angle θL. Therefore power factor of the system cosθ is currently over the power the facility of the system before we tend to connect the synchronous condenser to the system. The synchronous condenser is that the additional advanced technique of up power issue than a static condenser bank, however power issue improvement by synchronous condenser below five hundred kVAR isn't economical than that by a static capacitor bank. For land network we tend to use synchronous condensers for the aim, except for relatively lower rated systems we tend to typically use capacitor bank. The benefits of a synchronous condenser area unit that we are able to management the power factor of system smoothly while not stepping as per demand. Just in case of a static capacitor bank, this fine changes of power factor can't be possible rather a capacitor bank improves the power factor stepwise. The short circuit withstand-limit of the coil winding of a synchronous motor is high. Although, synchronous condenser system has some disadvantages. The system isn't silent since the synchronous motor needs to rotate endlessly. A perfect load less synchronous motor attracts leading current at 90° (electrical). [6]

Here, in a three-phase system, we connect one three-phase synchronous motor and run it at no load. Basic scheme of synchronous condenser and power factor improvement diagram shown in figure2.2 and load curve of under excitation and over excitation in figure 2.3.

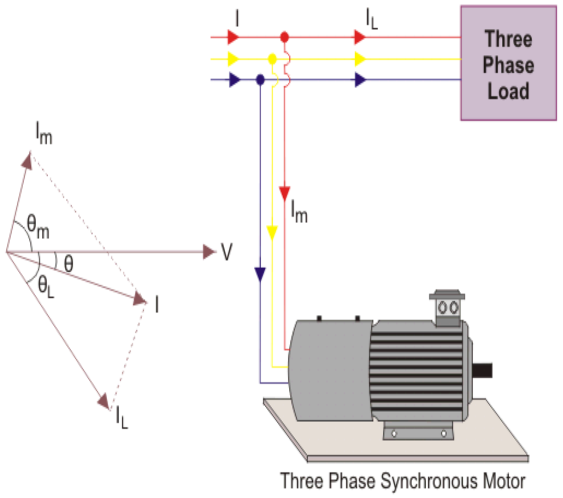

Fig 2.3: Basic scheme of synchronous condenser and power factor improvement diagram .[6]

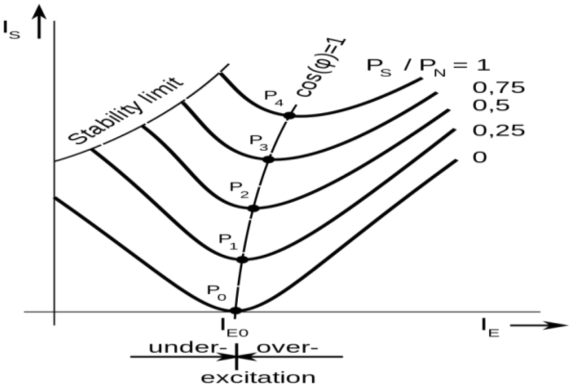

Fig 2.4: load curve of under excitation and over excitation[7]

Chapter-3

FACTS devices

3.1 Flexible AC Transmission Systems (FACTS):

FACTS is that the abbreviation for “Flexible AC Transmission Systems” and refers to a group of resources used to overcome certain limitations within the static and dynamic transmission capability of electrical networks. The IEEE defines FACTS as AC transmission systems incorporating power-electronics based and alternative static controllers to increase control ability and power transfer ability. The main purpose of these systems is to supply the network as soon as possible with inductive or capacitive reactive power that's adapted to its specific requirements, whereas additionally improving transmission quality and the efficiency of the power transmission system. Features of versatile AC Transmission Systems (FACTS):

- 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 power system stability and performance of existing and future transmission systems. That is, with flexible AC Transmission Systems (FACTS), power companies are going to be ready to utilize their existing transmission networks better, considerably increase the availability and reliability of their line networks, and improve each dynamic and transient network stability whereas ensuring a much better quality of supply. [8]

3.2 Reactive Power Compensation in Power Transmission System by using FACTS:

Consumer load needs reactive power that varies continuously and will increase transmission losses whereas affecting voltage within the transmission network. To prevent unacceptably high voltage fluctuations or the Reactive power compensation consumer load needs reactive power that varies continuously and will increase transmission losses whereas affecting voltage within the transmission network. To prevent unacceptably high voltage fluctuations or power failures that may result, this reactive power, should be compensated and kept in balance. The passive elements like reactors or capacitors, as well as mixtures of the two that provide inductive or capacitive reactive power, will perform this function. The more quickly and exactly the reactive power compensation will accomplish, the more efficiently the various transmission characteristics will be controlled. For this reason, fast thyristor-switched and thyristor controlled elements are replacing almost these slow mechanical switched elements. Owner failures that may result, this reactive power should be compensated and kept in balance. [8]

3.3 Types of FACTS devices:

Primarily there are three type of FACTS devices with respect to connection.

- Series compensator
- Shunt compensator
- Series-Series compensator
- Series-Shunt compensator

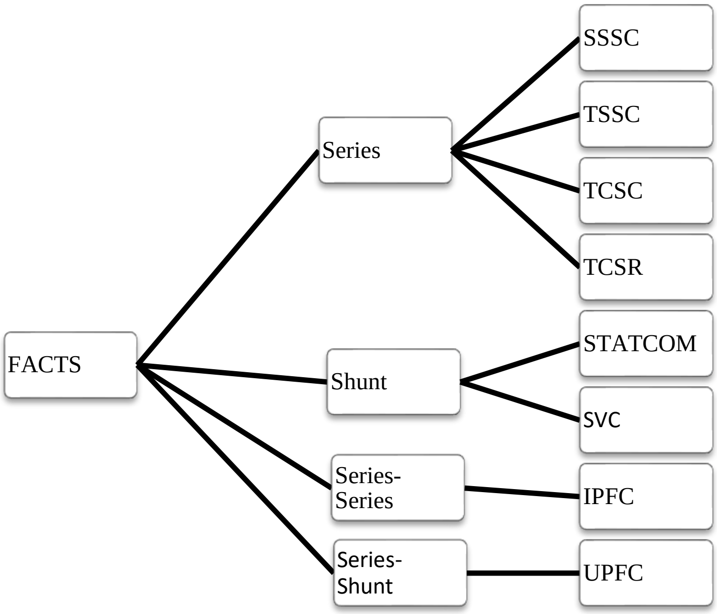

Fig3.1: classification of FACTS devices

3.4 Series compensation:

Series compensation is that the technique of improving the system voltage by connecting a capacitance nonparallel with the line. In different words, in series compensation, reactive power is inserted nonparallel with the line for rising the impedance of the system. It improves the power transfer capability of the road. It's largely employed in extra and ultrahigh voltage line.

FACTS for series compensation modify line impedance: X is decreased thus on increase the transmittable active power. However, additional reactive power should be provided. [9]

$$P = \frac{V^2}{X - Xc} \sin(\delta)$$

$$Q = \frac{V^2}{X - Xc} \sin(1 - \cos\delta)$$

Here P is the real Active Power and Q is Reactive power of the system.

The Series compensator devices are-

- Static synchronous series compensator (SSSC)
- Thyristor-controlled series capacitor (TCSC)
- Thyristor Controlled Series Reactor (TCSR)
- Thyristor Switched Series Capacitor (TSSC)

3.4.1 Static Synchronous series compensator (SSSC):

Static Synchronous Series Compensator (SSSC) could be a modern power quality FACTS device that employs a voltage supply device connected in series to a line through a transformer. The SSSC operates sort of a controllable series capacitance and series inductance. The primary difference is that its injected voltage isn't associated with the transmission line intensity and may be managed separately. These feature permits the SSSC to work satisfactorily with high loads are additionally like lower loads. [10]

The Static Synchronous Series Compensator has 3 basic parts:

a. Voltage Source Converter (VSC) – main part

b. Transformer – couples the SSSC to the transmission line

c. Energy Source – provides voltage across the DC capacitor and compensate for device losses

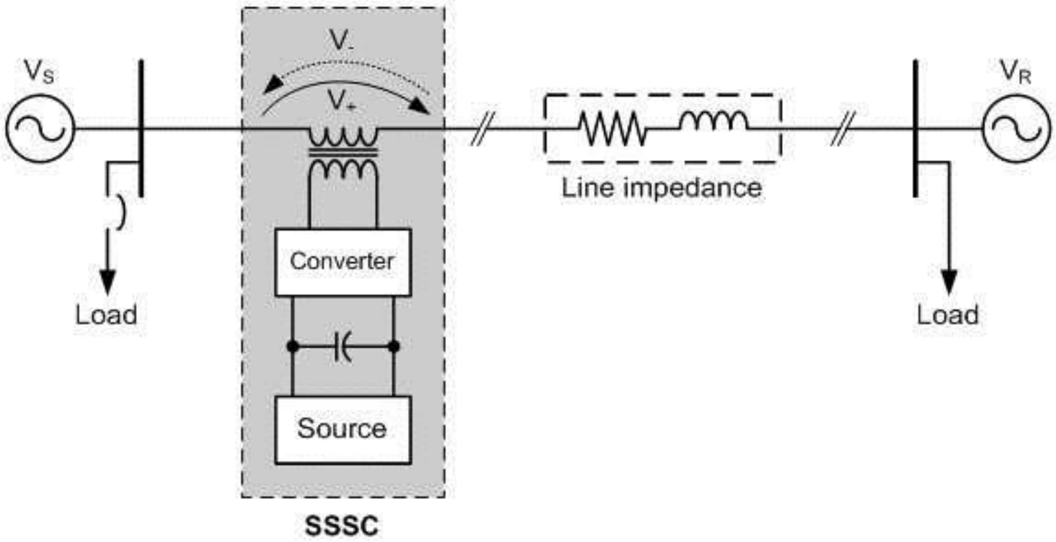

Fig 3.2: Static Synchronous Series Compensator (SSSC) Diagram [10]

Operation and Capabilities:

Static synchronous series compensator works just like the STATCOM, except that it's serially connected instead of shunt. It's able to transfer each active and reactive power to the system, allowing it to compensate for the resistive and reactive voltage drops – maintaining high effective X/R that's independent of the degree of series compensation. However, this is often expensive as a comparatively massive energy supply is needed. On the other hand, if management is restricted to reactive compensation then a smaller supply ought to be enough. During this case only the voltage is manageable because the voltage vector forms 90º with the line intensity. Later the serial injected voltage will advance or delay the line current, meaning, the SSSC will be uniformly controlled in any worth. The SSSC when operated with the proper energy provide will inject a voltage component that is of constant magnitude but opposite in phase angle with the voltage developed across the line. As a result, the impact of the voltage drop on power transmission is offset. Additionally the static synchronous series compensator provides quick control and is inherently neutral to sub-synchronous resonance.

Applications and Benefits:

The SSSC is usually applied to correct the voltage during a fault within the grid. However, it also has many benefits during traditional conditions:

Power factor correction through the continuous voltage injection and in combination with a properly structured controller. Load equalization in interconnected distribution networks. It may help to cover the capacitive and reactive power demand. Power flow control Reduces harmonic distortion by active filtering. [10]

3.4.2 Thyristor-controlled series compensation (TCSC):

The TCSC conception is that capacitor is inserted directly in series with the line and the thyristor controlled inductance is mounted directly in parallel with the capacitor. Therefore no interfacing instrumentation like high voltage transformer is needed. So TCSC is more economic than other difficult FACTS technologies. TCSC Thyristor controlled series capacitance is a series FACTS device. TCSC could be a capacitive reactance compensator. It's a more practical and provides appropriate solutions because of flexible management of thyristor. TCSC is connected nonparallel with the transmission line conductors. [11]

The Basic scheme of TCSC:

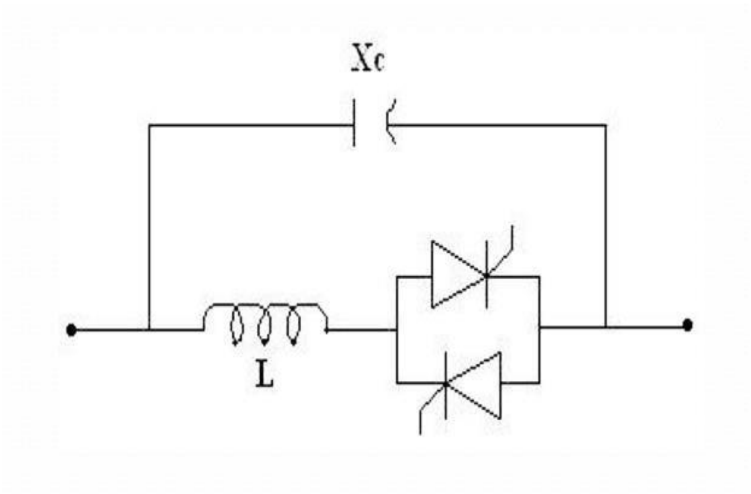

Fig 3.4: The basic scheme of TCSC. [11]

Merits of TCSC:

- Increase power transmission capability.
- Improve system stability.
- Reduce system losses.
- Improve voltage profile of the lines.
- Optimize power flow between parallel lines.
- Damping of the power swings from local and inter area oscillations.

Application of TCSC:

Thyristor-controlled series compensation has a number of important benefits in the application:

- Mitigation of sub-synchronous resonance.
- Damping of active power oscillations.
- Post-contingency stability improvement.
- Dynamic power flow control.
- Accurately regulating the power flow on a transmission line.
- Improving transient stability.

3.4.3 Thyristor Controlled Series Reactor (TCSR):

This is a series compensator that gives a smooth variable inductive reactance. This device is same as TCSC, simply the capacitor is replaced with the reactor. The reactor stops conducting when the firing angle is 180˚ and it starts conducting when the firing angle is below 180˚. The basic diagram of Thyristor Controlled Series Reactor (TCSR) is as shown in the below figure.

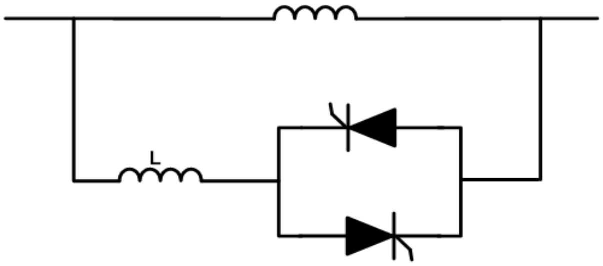

Fig 3.5: Thyristor Controlled Series Reactor (TCSR) [12]

3.4.4 Thyristor Switched Series Capacitor (TSSC):

This Compensation technique is comparable to the TCSR. In TCSR, the power controlled by controlling the firing angle of a thyristor. Hence, it provides stepwise management. However within the case of TSSC, the thyristor will only be on or off. There's no firing angle. So, the capacitor either totally connected or totally disconnected from the line. It'll reduce the cost of the thyristor and reduce the cost of the controller. The fundamental diagram of TSSC is the same as the TCSC. [12]

3.5 Shunt Compensation:

In shunt compensation, power system is connected in shunt (parallel) with the FACTS. It works as a controllable current source. Shunt compensation is of two types. This method is used to improve the power factor. Whenever an inductive load is connected to the transmission line, power factor lags because of lagging load current. To compensate, a shunt capacitor is connected which draws current leading the source voltage. The net result is improvement in power factor. [13]

3.5.1 Shunt capacitive compensation

This technique is used to enhance the power factor. Whenever an inductive load is connected to the line, power factor lags due to lagging load current. To compensate, a shunt capacitor is connected which draws current leading the supply voltage. Net result's improvement in power factor. [13]

3.5.2 Shunt inductive compensation

This technique is used either when charging the transmission line, or, when there's very low load at the receiving end. Because of very low, or no load a very low current flows through the line. Shunt capacitance within the line causes voltage amplification (Ferranti Effect). The receiving end voltage may become double the sending end voltage (generally just in case of very long transmission lines). To compensate, shunt inductors are connected across the transmission line. Examples of FACTS for shunt compensation Reactive current is injected into the line to maintain voltage magnitude. Transmittable active power is enhanced however more reactive power is to be provided. [13]

$$P = \frac{2V^2}{X} \sin\left(\frac{\delta}{2}\right)$$

$$Q = \frac{4V^2}{X} \left[1 - \cos\left(\frac{\delta}{2}\right)\right]$$

Here P is Active power and Q is the reactive power of the system.

3.6 Types of shunt compensator:

Shunt Capacitor basically two type -

- Static VAR Compensator (SVC)
- Static Synchronous Compensator(STATCOM)

3.6.1 Static VAR compensator (SVC):

A static VAR compensator (SVC) 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. A static VAR compensator has no significant moving parts. 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:

- Connected to the power system, to regulate the transmission voltage ("Transmission SVC")
- Connected near large commercial loads, to enhance 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 thyristor 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 thyristor-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 [14]

Principle:

Typically, an SVC contains one or more banks of fixed or switched shunt capacitors or reactors, of which a minimum of one bank is switched by thyristors. The components which can be used to build an SVC generally include:

- Thyristor controlled reactor where the reactor may be air- or iron-cored
- Thyristor switched capacitor
- Harmonic filter(s)
- Mechanically switched capacitors or reactors (switched by a circuit breaker)

By means that of phase angle modulation switched by the thyristors, the reactor is also variably switched into the circuit then give a continuously variable VAR injection (or absorption) to the electrical network. During this configuration, coarse voltage management is provided by the capacitors; the thyristor-controlled reactor is to provide smooth management. This smoother control and more flexibility will be supplied with thyristor-controlled capacitor switching. The thyristors are electronically controlled. Thyristors, like all semiconductors, generate heat and deionized water is usually used to cool them. Chopping reactive load into the circuit during this manner injects undesirable odd-order harmonics then banks of high-powered filters are typically provided to smooth the wave form. Since the filters themselves are capacitive, they also export MVARs to the power system. More complex arrangements are practical wherever precise voltage regulation is needed. Voltage regulation is provided by means that of a closed-loop controller. Remote supervisory control and manual adjustment of the voltage set-point are also common. [14]

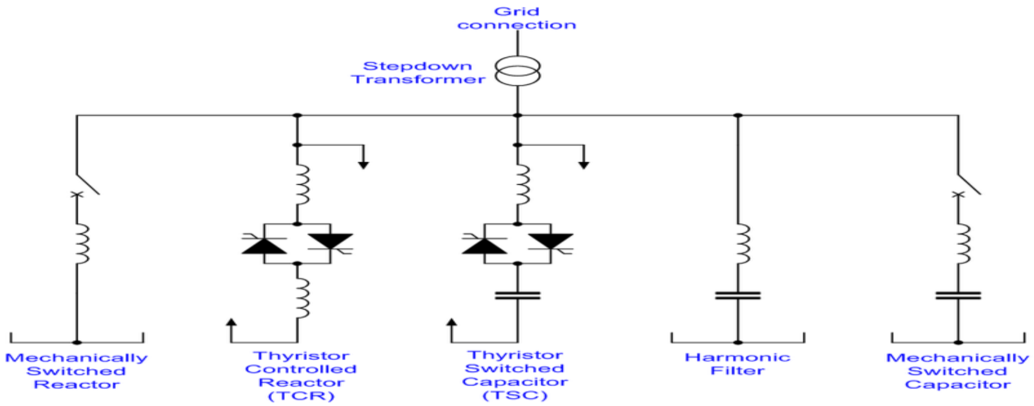

Fig 3.6: One-line diagram of a typical SVC configuration. [14]

Advantages:

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 VAR.[14]

3.6.2 Static synchronous compensator (STATCOM):

STATCOM or Static Synchronous Compensator is a shunt device, that uses force-commutated power electronics (i.e. GTO, IGBT) to regulate power flow and improve transient stability on electric power networks. It's also a member of the so-called flexible AC transmission (FACTS) devices. The STATCOM basically performs as the function because the static var compensators but with some benefits. The term Static Synchronous Compensator is derived from its capabilities and in operation principle, that are almost like those of rotating synchronous compensators (i.e. generators), but with comparatively quicker operation. [15]

Applications:

STATCOMs are usually applied in long distance transmission systems, power substations and heavy industries wherever voltage stability is the primary concern additionally, static synchronous compensators are installed in choose points within the power system to perform the following:

- Voltage support and control
- Voltage fluctuation and flicker mitigation
- Unsymmetrical load balancing
- Power factor correction
- Active harmonics cancellation
- Improve transient stability of the power system

Design:

A STATCOM is composed of the following components:

A. Voltage-Source converter (VSC). The voltage-source device transforms the DC input voltage to an AC output voltage. Two of the most common VSC sorts are represented below.

1. Square-wave Inverters using Gate Turn-Off Thyristors:

Generally, four three-level inverters are used to form a 48-step voltage wave. After, it controls reactive power flow by changing the DC capacitor input voltage, just because the basic element of the converter output voltage is proportional to the DC voltage.

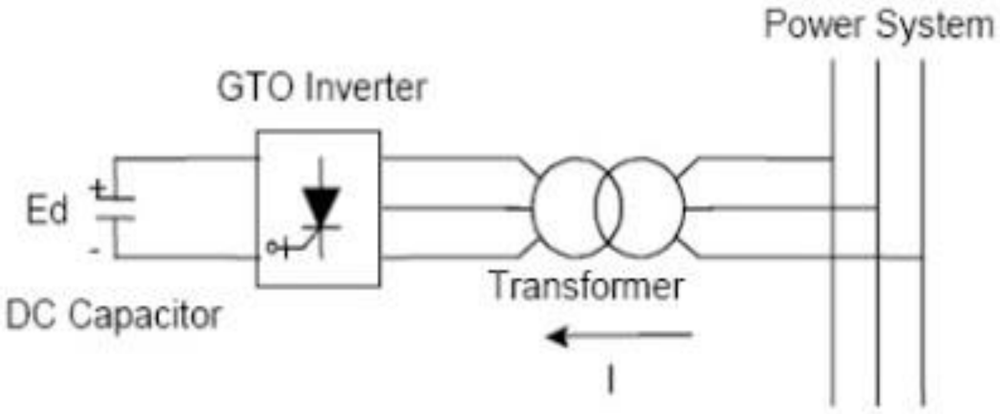

Fig 3.7: GTO-based STATCOM Simple Diagram [15]

Additionally, special interconnection transformers are used to neutralize harmonics contained within the square waves created by individual inverters. In addition, special interconnection transformers are employed to neutralize harmonics contained in the square waves produced by individual inverters.

2. PWM Inverters using Insulated Gate Bipolar Transistors (IGBT)

It uses Pulse-Width Modulation (PWM) technique to make a sinusoidal wave shape from a DC voltage supply with a typical chopping frequency of a few kHz. In contrast to the GTO-based type, the IGBT-based VSC utilizes a set DC voltage and varies its output AC voltage by changing the modulation index of the PWM modulator. Moreover, harmonic voltages are mitigated by installing shunt filters at the AC side of the VSC.

B. DC Capacitor: This component supplies the DC voltage for the inverter.

C. Inductive Reactance (X): It connects the inverter output to the power system. This is commonly the leakage inductance of a coupling transformer.

D. Harmonic Filters: relieve harmonics and other high frequency components due to the inverters.

STATCOM Operation:

In the case of 2 AC sources, that have constant frequency and are connected through a series reactance, the power flows can be:

Active or Real Power flows from the leading source to the lagging source. Reactive Power flows from the upper to the lower voltage magnitude source. Consequently, the phase angle difference between the sources decides the active power flow, whereas the voltage magnitude difference between the sources determines the reactive power flow. Based on this principle, a STATCOM will be used to regulate the reactive power flow by changing the output voltage of the voltage-source converter with reference to the system voltage.

Modes of Operation

The STATCOM can be operated in two different modes:

A. Voltage Regulation

The static synchronous compensator regulates voltage at its connection point by controlling the amount of reactive power that's absorbed from or injected into the power system through a voltage-source converter.

In steady-state operation, the voltage V2 generated by the VSC through the DC capacitor is in phase with the system voltage V1 (δ=0), so only reactive power (Q) is flowing (P=0).

1. When system voltage is high, the STATCOM can absorb reactive power (inductive behavior)
2. When system voltage is low, the STATCOM can generate and inject reactive power into the system (capacitive). [19]

Then, the amount of reactive power flow is given by the equation:

$Q = [V_1(V_1 - V_2)] / X$

B. Var Control

In this mode, the STATCOM reactive power output is kept same independent of other system parameter.

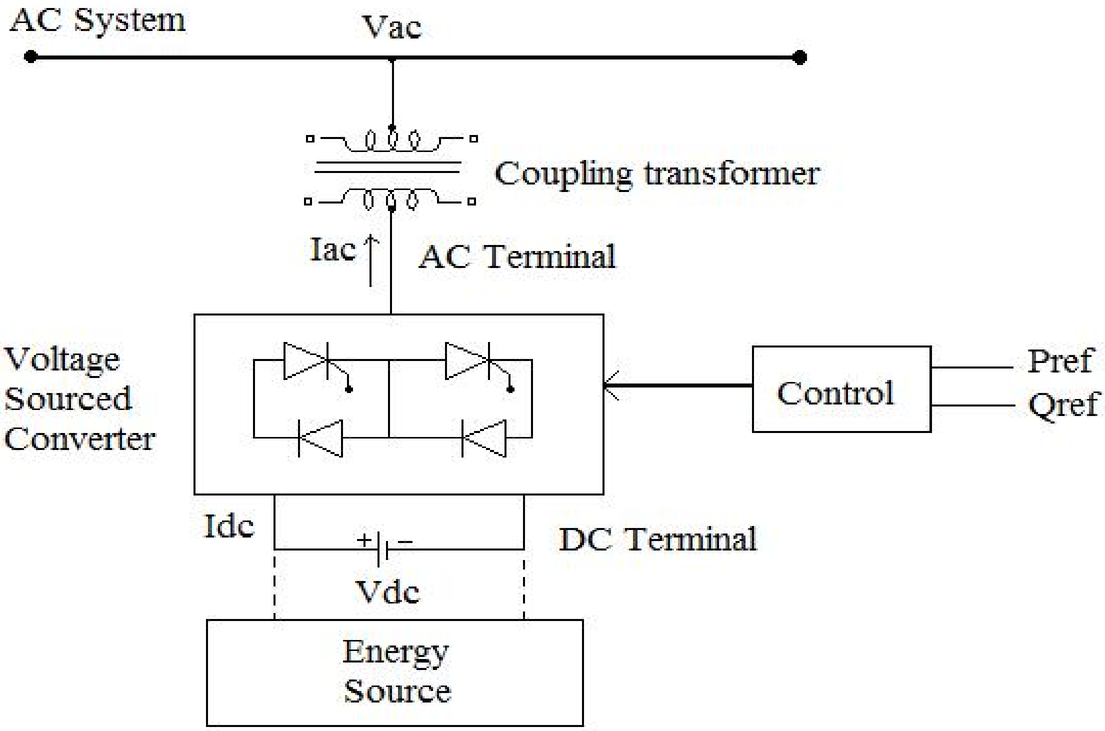

Fig3.8: Functional block diagram of STATCOM [16]

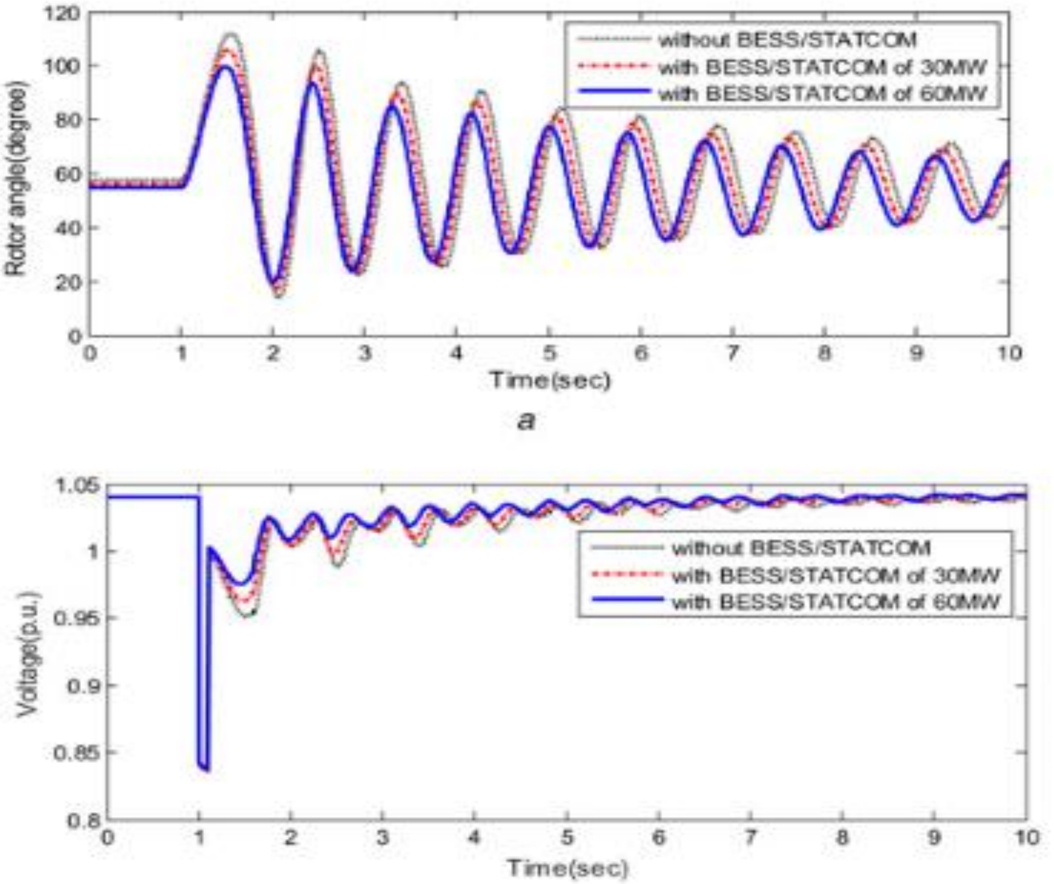

Fig3.9: Influence of BESS/STATCOM capacities on transient stability performance a Rotor angle curves Voltage curves. [17]

STATCOM versus SVC:

The STATCOM has the ability to supply more capacitive reactive power during faults, or when the system voltage drops abnormally, compared to normal static var compensator. This is as a result of the maximum capacitive reactive power generated by a STATCOM decreases linearly with system voltage, whereas that of the SVC is proportional to the square of the voltage. Also, the STATCOM has a quicker response because it has no time delay related to thyristor firing. Yet, these benefits come at a higher worth (about 20% more).

Benefits:

The merits of using STATCOM to compensate Reactive power and voltage control.

1- By using a STATCOM control device both capacitive and inductive modes of operations are shown.

2- STATCOM has several advantages, quick response time, less space requirement and optimum voltage platform.

3- Tighter control of the voltage at the end of the line.

4- Increased line stability during transients due to the superior quickness of the STATCOM response.

5- Enhanced power transfer capability in the power grid.

6- Improved power grid operational reliability.

7- STATCOM installation is small in size but is more expensive. [15]

3.7 Interline Power Flow Controller (IPFC):

Recent developments of FACTS analysis have crystal rectifier to a innovative device: the Interline Power Flow Controller (IPFC).This part consists two (or more) series voltage provide converter-based devices (SSSCs) place in in 2 (or more) lines and connected at their DC terminals. Thus, in addition to serially compensate the reactive power, each SSSC can provide real power to the common DC link from its own line. The IPFC provides them the chance to unravel the matter of dominant fully different transmission lines at a determined station. In fact, the under-utilized lines produce offered a surplus power which could be used by different lines for real power management. This capability makes it possible to equalize each real and reactive power flow between the lines, to transfer power demand from full to under loaded lines, to compensate against resistive line voltage drops and thus the corresponding reactive line power, and to increase the effectiveness of a compensating system for dynamic disturbances (transient stability and power oscillation damping).Therefore, the IPFC provides a very effective theme for power transmission at a multi-line station. The IPFC is also a multi-line FACTS device. AN Interline Power Flow Controller (IPFC) consists of a set of converters that area unit connected asynchronous with fully different transmission lines. [18]

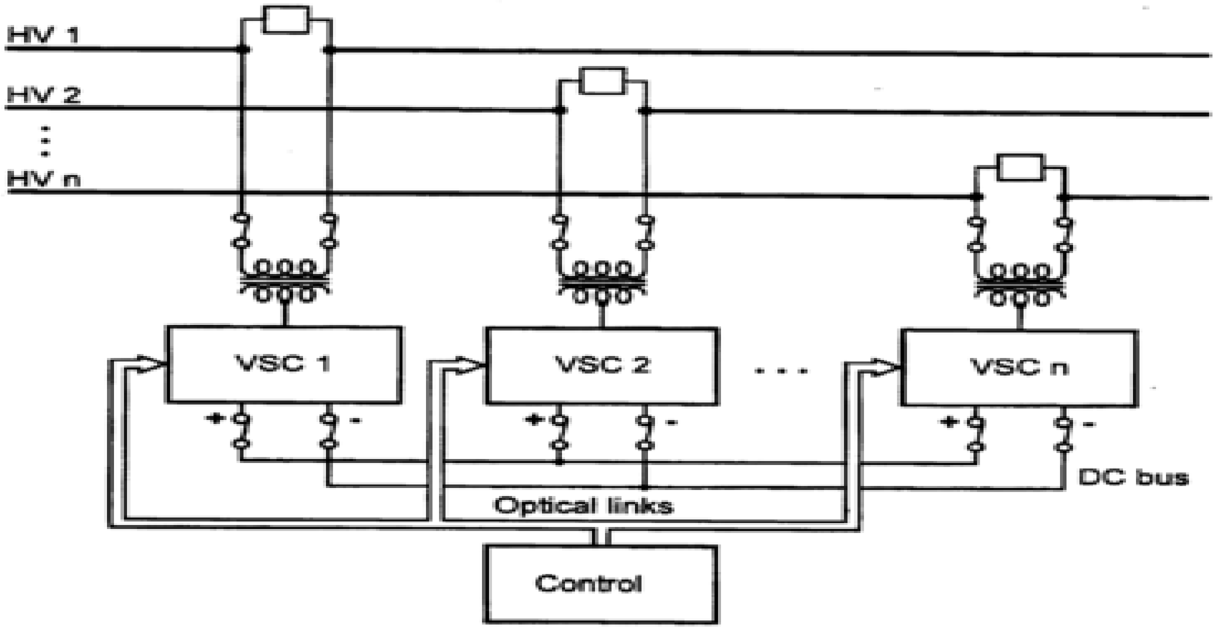

Fig 3.10: The schematic diagram of IPFC [18]

. In addition to those series converters, it's about to in addition embrace a shunt convertor that's connected between a line and thus the ground. The converters area unit connected through a typical DC link to exchange active power. Each series convertor can provide freelance reactive compensation of own line. If a shunt convertor is concerned within the system, the series converters will provide freelance active compensation; otherwise not all the series converters can provide freelance active compensation for his or her own line. Compared to the Unified Power Flow Controller (UPFC), the IPFC provides a relatively economical declare multiple line power flow management, since only one shunt convertor is concerned. The IPFC in addition gains a lot of management capability than the Static Synchronous Series Compensator (SSSC), that's similar to the IPFC but whereas not a typical DC link, From probabilistic purpose of read, the performance of the IPFC are higher once a lot of series convertor involves in to the IPFC system. However, as a results of the converters area unit connected through the common DC link, the converters need to be physically close to each other. The common DC link will become a location constrain for the IPFC and limits its industrial application within the future network. [18]

3.8 Unified power flow controller:

A unified power flow controller (UPFC**)** is an electrical device for providing fast-acting reactive power compensation on high-voltage electricity transmission networks. It uses a pair of three-phase controllable bridges to produce current that is injected into a transmission line using a series transformer. The controller can control active and reactive power flows in a transmission line. Unified Power Flow Controller (UPFC), as a representative of the third generation of FACTS devices, is by far the most comprehensive FACTS device, in power system steady-state it can implement power flow regulation, reasonably controlling line active power and reactive power, improving the transmission capacity of power system, and in power system transient state it can realize fast-acting reactive power compensation, dynamically supporting the voltage at the access point and improving system voltage stability, moreover, it can improve the damping of the system and power angle stability. The UPFC uses solid state devices, which provide functional flexibility, generally not attainable by conventional thyristor controlled systems. The UPFC is a combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) coupled via a common DC voltage link.[24] The main advantage of the UPFC is to control the active and reactive power flows in the transmission line. If there are any disturbances or faults in the source side, the UPFC will not work. The UPFC operates only under balanced sine wave source. The controllable parameters of the UPFC are reactance in the line, phase angle and voltage. The UPFC concept was described in 1995 by L. Gyugyi of Westinghouse.[25] The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system.

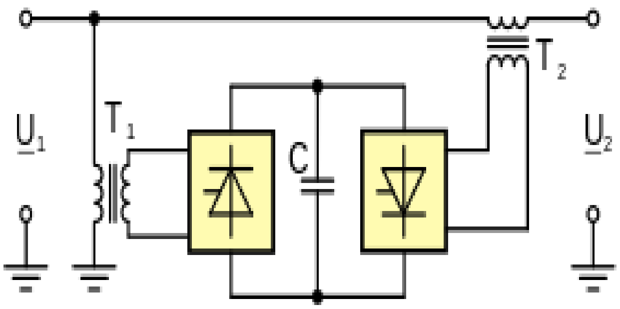

Fig 3.11: Schematic of a Unified Power Flow Controller [19]

Power flow controller for direct current:

A counterpart for unified power flow controller which will be used in direct current systems was proposed to be used in high-voltage direct current grids [27] and for low-voltage direct current micro grids. It uses a high-frequency isolated dc-dc converter cascaded with a manageable full-bridge inverter that makes a small bipolar voltage in series with the line. The controller will control the power and compensate for accumulated voltage drop during a distribution line.

The main advantage of the solution is that the ability to manage the bulk power flow within the line whereas actively process only a small fraction of the bulk power. The partial power process leads to raised system efficiency and use of lower rated elements. The use of lower rated elements results in tiny and cost-effective designs.

Chapter-4

Analysis reactive power Application

The previous study represented that there are various types of reactive power compensation. Each compensation have some merits and limitations also. Now we are going to analyze reactive power compensation by using capacitor banks at different section of transmission line.

4.1 Circuit model of MATLAB (Simulink):

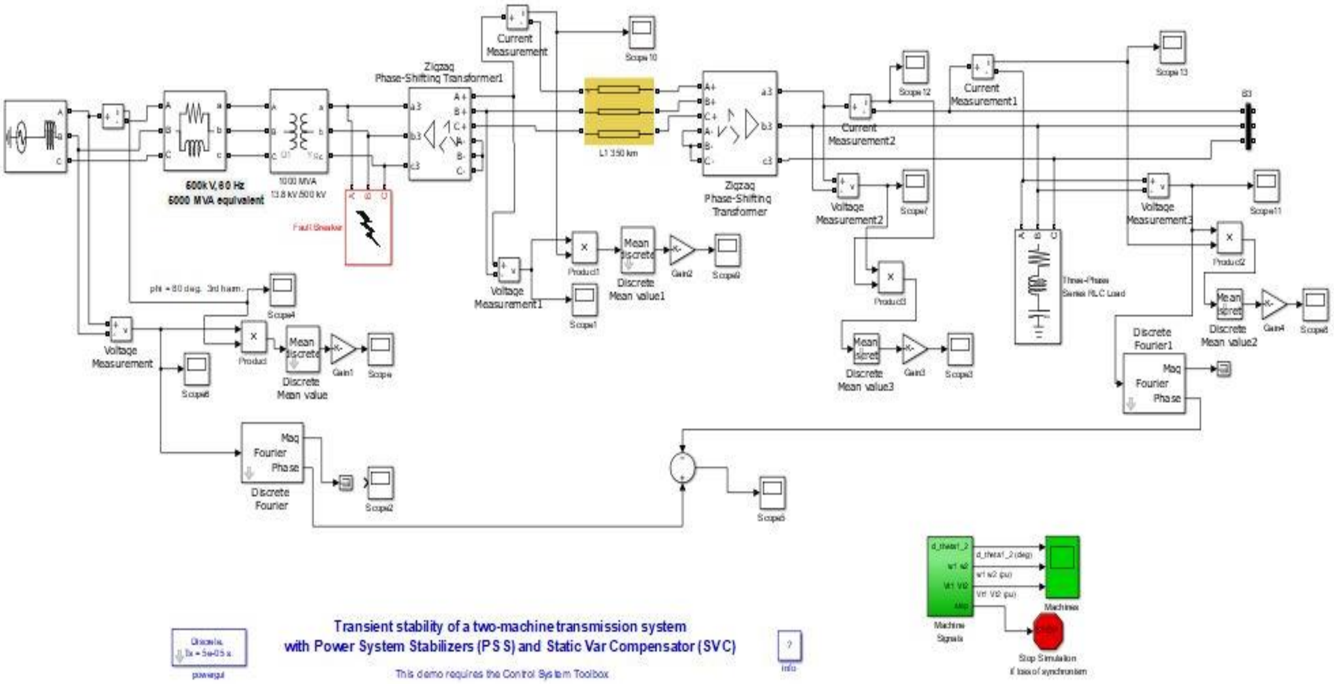

Fig 4.1: Analyzing circuit model of MATLAB (Simulink).

This presented circuit model shows that how the power flow occurs at each branch of transmission line from the power generator end to load end. In this modal appropriately used power generator, the parallel RLC branch, a three phase transformer, a fault breaker, a primary zigzag transformer, a secondary zigzag transformer, Resistive-inductive-capacitive load at load end, a bus bar and 350 km long transmitting line. The discussion of different section of transmission line is given bellow-

4.1.1 Generator:

A generator is often running by the natural fuel that is installed with prime mover and it's coupled to an generator for the production of electrical power. The prime mover converts energy from some natural material into mechanical energy. The generator converts mechanical energy of the prime mover into electrical energy. The electricity produced by the generating station is transmitted and distributed with the help of conductors to various kind of consumers. It's going to be emphasised here that apart from prime mover-alternator combination, a modern generating station employs many electrical equipment and instruments to confirm low-cost, reliable and continuous service.

Depending upon the form of energy converted into electrical energy, the generating stations are classified as:

(i) Steam power stations (ii) Hydroelectric power stations

(iii) Diesel power stations (iv) Nuclear power stations

4.1.2 Zigzag Transformer:

Zigzag transformer is also known as the interconnected star connection. Zigzag transformer is a special purpose electrical device. It's used in power grid, zigzag connection has a number of the features of the star(Y) and delta(Δ) connections.

Zigzag transformer has six coils in which 3 are outer coils and 3 are inner coils. The zig winding of 1 phase is connected nonparallel with the zag winding of another phase thus it's known as interconnected star winding.

The primary coil on each core is connected in opposite direction to the secondary winding on following core. If you need a neutral for grounding or for supplying single-phase line to neutral loads. This transformer operating with a 3-wire, ungrounded power grid. A zigzag connection may be the solution.

Due to its design, a zigzag transformer is more practical for grounding purpose. As a result of it has less internal winding impedance reaching to the ground than once using a star type transformer. We can use the zigzag transformer in 2 winding electrical device applications. Wherever we obtain voltage transformation and isolation with the zigzag feature.

The connected zigzag transformer up above MATLAB circuit design for diminish harmonic current and voltage, to provides low impedance to zero sequence currents, to detection phase displacement between primary and secondary winding with this connection, it give additionally excellent isolation between ground and instrumentation. Therefore the zigzag transformer will reduce several losses. The sending end transformer absorbed 33kv line to line voltage and supply 500kv to line. [20]

4.1.3 Fault breaker: An arc-fault circuit interrupter (AFCI) also called an arc-fault detection device (AFDD) is a circuit breaker that breaks the circuit once it detects an electrical arc within the circuit. It protects to stop electrical fires. An AFCI by selection distinguishes between a harmless arc (incidental to normal operation of switches, plugs, and brushed motors), and a probably dangerous arc (that will occur, as an example, in a lamp cord that has a broken conductor). [21]

4.1.4 Long Transmission line:

If the transmission ling length more than 150km and transmission voltage higher than 100kv then the transmission line is named long transmission line. In a long transmission line the line constants are uniformly distributed over the whole length of line. This is often as a result of the effective circuit length is much higher than what it was for the former models (long and medium line) and thus we can't build the subsequent approximations:

1. Ignoring the shunt admittance of the network, like in an exceedingly little conductor model.
2. Considering the circuit impedance and admittance to be lumped and focused at a point as was the case for the medium line model. [22]

4.1.5 RLC loads:

Three basic kinds of loads exist in circuits: capacitive loads, inductive loads and resistive loads. These differ in however they consume power in an AC setup. Capacitive, inductive and resistive load types correspond loosely to lighting, mechanical and heating loads. Some scholars and engineers ask "linear" and "nonlinear" loads, however these terms aren't as useful.

Resistive loads

Loads consisting of any heating element are classified as resistive loads. These include incandescent lights, toasters, ovens, space heaters and coffee manufacturers. A load that draws current during a sinusoidal waxing-and-waning pattern together with a sinusoidal variation in voltage – that's, the most, minimum and nil points of the voltage and current values over time line up – is a purely resistive one and includes no other parts.

Inductive loads

Basically inductive loads are those loads which consume reactive power. These are found during a variety of home items and devices with moving components, including fans, vacuum cleaners, dishwashers, laundry machines and the compressors in refrigerators and air conditioners. In contrast to resistive loads, in a purely inductive load, current follows a sinusoidal pattern that peaks when the voltage wave peaks, so the maximum, minimum and nil points are out of phase.

Capacitive Loads

In a capacitive load, current and voltage are out of phase like an inductive load. The difference is that within the case of a capacitive load, the current reaches its maximum value before the voltage does. The current wave shape leads the voltage wave shape, however in an inductive load, the current wave shape lags it.

In engineering, capacitive loads don't exist during a complete format. No devices are classified as capacitive within the way light bulbs are classified as resistive, and air conditioners are labeled inductive. Capacitors in large circuits are useful, however, in controlling power use. They're usually included at electrical substations to enhance the overall "power factor" of the system. Inductive loads increase the cost of a given power system and reduce the amount of power that is converted to another form of energy. [23]

4.1.6 Bus-Bar

An electrical bus bar is defined as a conductor or a group of conductor used for collection electric power from the incoming feeders and distributes them to the outgoing feeders. The bus bar system consists the isolator and the breaker. On the occurrence of a fault, the breaker is tripped off and also the faulty section of the bus-bar is definitely disconnected from the circuit. The electrical bus bar is available in rectangular, cross-sectional, round and many different shapes. The rectangular bus bar is usually used in the power system. The copper and aluminium are used for the producing of the electrical bus bar. The selection of the bus bar is depended on the various factor likes reliability, flexibility, cost etc. The subsequent are the electrical issues governing the selection of anybody particular arrangement. [24]

- The bus bar arrangement is easy and simple in maintenance.
- The maintenance of the system did not affect their continuity.
- The installation of the bus bar is affordable.

4.2 Analysis 1:

How to decreases the power level while we connecting the inductive load without compensation.

Table 4.1: Inductive load (.5k to 5k) variation with different branch decreases power.

Capacitive load with (+5000 VAR)	Generator voltage (line to line)	Generator line current	Generator power	Primary Tx voltage (line to line)	Primary Tx line current	Primary Tx power	Secondary TX Voltage (line to line)	Secondary TX line current	Secondary TX power	Load voltage (line to line)	Load current	Load power	Load Angle
0.5k	34.19k	7.625kA	391MW	490kV	527A	385MW	188.5k	1185A	210MW	190.5k	1185A	210MW	-14.65
1k	34.20k	7.9kA	405MW	490kv	547A	398MW	190kv	1185A	210MW	190.5k	1185A	210MW	-14.65
1.5k	34.22k	8.175kA	420MW	490kV	567A	412MW	193kV	1180A	222.5M	193kV	1180	222.5M	-14.4
2k	34.24k	8.45kA	434MW	490.5k	585A	427MW	195kv	1175A	236MW	195kv	1175A	236MW	-14
2.5k	34.27k	8.76k	449MW	491.4K	608A	442MW	197.2k	1173A	250MW	197.2k	1173A	250MW	-13.8
3k	34.28k	9.1k	465MW	492.1k	630A	457MW	199.5k	1175A	264MW	199.5k	1175A	264MW	-13.5
3.5K	34.3k	9.4k	480MW	493kv	652A	473MW	202kv	1180A	280MW	202kv	1180A	280MW	-13.2
4k	34.32k	9.7k	497MW	493.7k	675A	489MW	204.3k	1185A	295MW	204.3k	1185A	295MW	-12.9
4.5k	34.35k	10k	515MW	494.5k	700A	505MW	206.6k	1195A	311MW	206.6k	1195A	311MW	-12.4
5k	34.37	10.42k	532MW	495.2k	725A	523MW	209.2k	1210A	328MW	209.2k	1210A	328MW	-12.3

The power of different section in AC transmission line by us with different value of Inductive load is shown in figure 4.2.

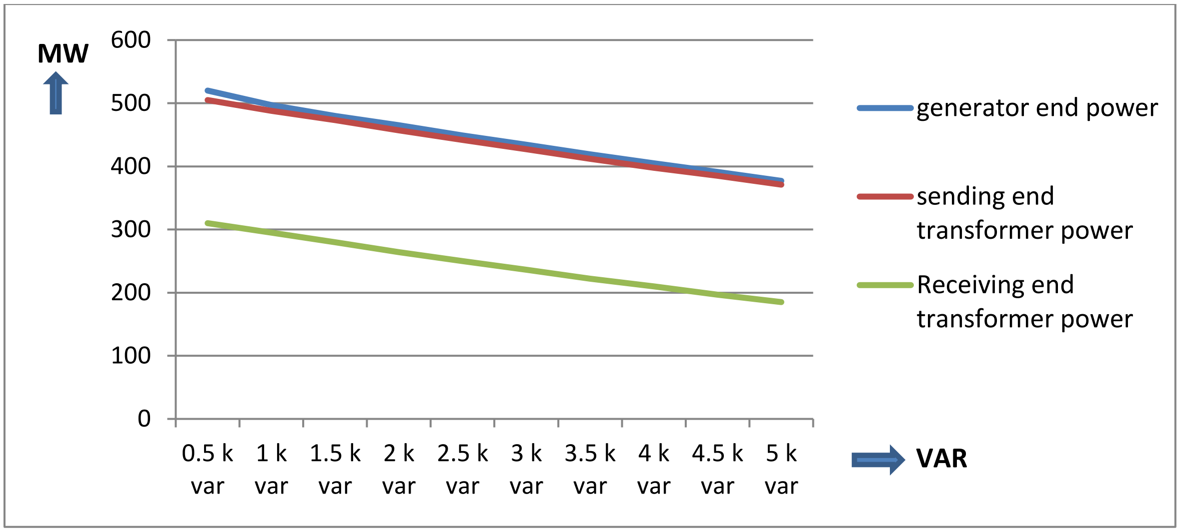

Fig 4.2 : Power level decreasing with varying Inductive load without compensation

Here it is seen that the different section of power decreases with varying inductive load. Firstly generator end power and sending end transformer power are high. And both of power decreases with varying inductive load. The receiving end transformer power is very low and this power also decreases with varying inductive load.

4.3 Analysis 2(compensation at Generator end):

Table 2: Capacitive load (.5k to 5k) at Generator end with 5k inductive load

Capacitive load with (+500 VAR)	Generator voltage (line to line)	Generator line current	Generator power	Primary Tx voltage (line to line)	Primary Tx line current	Primary Tx power	Secondary TX Voltage (line to line)	Secondary TX line current	Secondary TX power	Load voltage (line to line)	Load current	Load power	Load Angle
.5k	34.17k	7.365 kA	377.9 MW	487.74kv	509 A	371.5MW	186.5k	1204 A	185MW	186.5k	1204A	185 MW	-15
1k	34.17k	7.37kA	378 MW	487.77kv	509 A	371.5MW	186.5k	1205 A	185MW	186.5k	1205A	185.5MW	-15
1.5k	34.177k	7.38kA	378.4 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	1205A	185 MW	-15
2k	34.179k	7.38kA	378.7 MW	487.8k	509 A	371.5MW	186.5	1205 A	185MW	186.5	186.5K	185 MW	-15
2.5k	34.18k	7..39 kA	379 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
3k	34.18k	7.39kA	379.4 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
3.5k	34.182k	7.4kA	379.8 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
4k	34.183k	7.4kA	380 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
10k	34.2k	7.465 kA	383 MW	488kv	500 A	372 MW	187kv	1200 A	185Mw	187kv	1200A	185 Mw	-15.2
5k	34.185k	7.413 kA	380 MW	487.8kv	509 A	571.5	186.5k	1205 A	185Mw	186.5k	1205A	185 Mw	-15

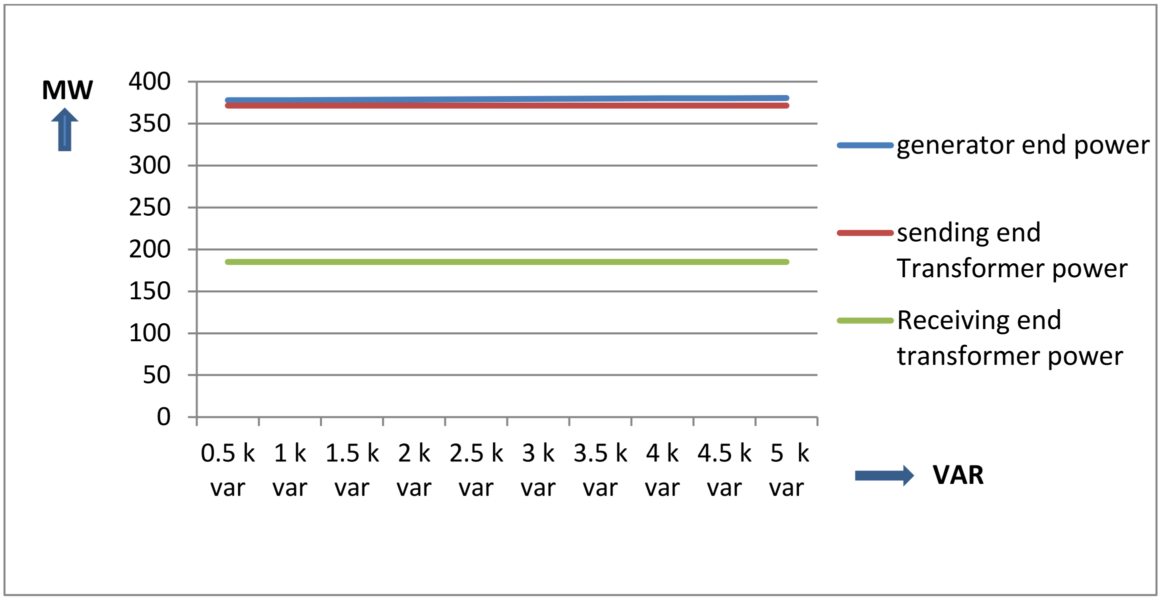

Fig 4.3: power level changing with varying capacitive load at generator end

Figure shows that there is minimum change of power in this system. There is very small change of power with varying capacitor. So we should not use the capacitor bank at the generator end.

4.4 Analysis 3(Compensation at sending end Transformer):

Table 3: Capacitive load (.5k to 5k) at sending end transformer with 5k inductive load

Capacitive load with (+500 VAR)	Generator voltage (line to line)	Generator line current	Generator power	Primary Tx voltage (line to line)	Primary Tx line current	Primary Tx power	Secondary TX Voltage (line to line)	Secondary TX line current	Secondary TX power	Load voltage (line to line)	Load current	Load power	Load Angle
.5 k var	34.3k	8.76k	444 MW	495kv	600 A	436 MW	189.4 kv	1225 A	191 MW	189.4kv	1225A	191 MW	-14.6
1 k var	34.45k	10.5k	515 MW	503kv	730 A	505 MW	192.5 kv	1240 A	198 MW	192.5kv	1240A	198 MW	-13.95
1.5 k var	34.56k	12.37k	590 MW	511kv	870 A	578 MW	195.5 kv	1260 A	204 MW	195.5kv	1260A	204 MW	-13.3
2k var	34.7k	14.45k	670 MW	520kv	1010A	655 MW	198.6 kv	1280 A	210 MW	198.6kv	1280A	210 MW	-12.65
2.5 k var	34.9k	16.65k	757 MW	528kv	1165A	737 MW	202kv	1300 A	217 MW	202 kv	1300A	217 MW	-12
3k	35k	19k	848 MW	537kv	1327A	824 MW	205.1 kv	1325 A	224.5 MW	205.1kv	1325A	224.5MW	-11.3
3.5k	35.18k	21.43k	945 MW	545.5kv	1497A	915 MW	208.5 kv	1346 A	232 MW	208.5kv	1346A	232 MW	-10.6
4k	35.35 kv	23.97 ka	1049 MW	554kv	1675A	1012 MW	212kv	1368 A	240 MW	212 kv	1368A	240 MW	-9.9
4.5k	35.5kv	26.5KA	1160 MW	563.5kv	1860A	1115 MW	215.5 Kv	1490.4A	247.5 MW	215.5Kv	1490.4 A	247.5MW	-9.15
5k	35.68 kv	29.35 kA	1277 MW	572.85kv	2050A	1223 MW	219kv	1414 A	256 MW	219 kv	1414A	256 MW	-8.4

Fig 4.4: Power level changing with varying capacitive load at sending end transformer.

From above figure, we can say that when we are connecting a capacitor bank at sending end transformer then the generator end power and sending end transformer power are increasing very high. But receiving end transformer power are increasing very small. So we never get desired power at the load end. For that reason we should never use the capacitor bank at the sending end transformer.

4.5 Analysis 4(Compensation at receiving end Transformer):

Table 4: Capacitive load at receiving end transformer or load end with 5k inductive load

Capacitive load with (+500 VAR)	Generator voltage (line to line)	Generator line current	Generator power	Primary Tx voltage (line to line)	Primary Tx line current	Primary Tx power	Secondary TX Voltage (line to line)	Secondary TX line current	Secondary TX power	Load voltage (line to line)	Load current	Load power	Load Angle
.5k	34.17k	7.365 kA	377.9 MW	487.74kv	509 A	371.5MW	186.5k	1204 A	185MW	186.5k	1204A	185 MW	-15
1k	34.17k	7.37kA	378 MW	487.77kv	509 A	371.5MW	186.5k	1205 A	185MW	186.5k	1205A	185.5MW	-15
1.5k	34.177k	7.38kA	378.4 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	1205A	185 MW	-15
2k	34.179k	7.38kA	378.7 MW	487.8k	509 A	371.5MW	186.5	1205 A	185MW	186.5	186.5K	185 MW	-15
2.5k	34.18k	7..39 kA	379 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
3k	34.18k	7.39kA	379.4 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
3.5k	34.182k	7.4kA	379.8 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
4k	34.183k	7.4kA	380 MW	487.8k	509 A	371.5MW	186.5K	1205 A	185MW	186.5K	186.5K	185 MW	15
10k	34.2k	7.465 kA	383 MW	488kv	500 A	372 MW	187kv	1200 A	185Mw	187 kv	1200A	185 Mw	-15.2
5k	34.185k	7.413 kA	380 MW	487.8kv	509 A	571.5	186.5k	1205 A	185Mw	186.5k	1205A	185 Mw	-15

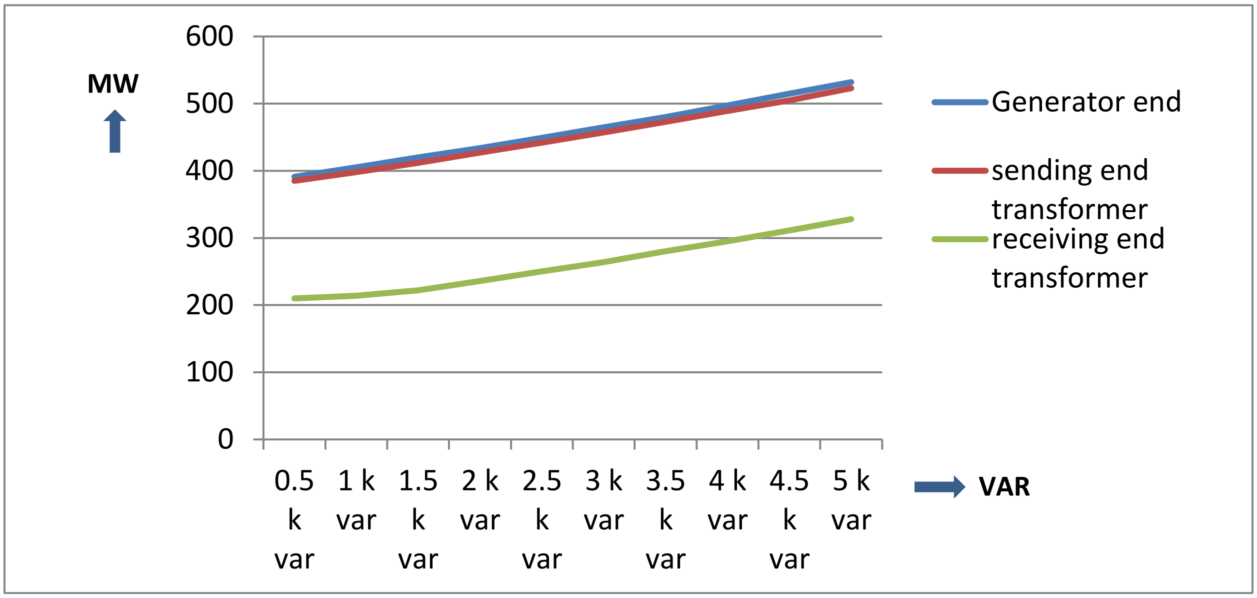

Fig 4.5: Power level changing with variation capacitive load at receiving end transformer or load end.

From above figure, it is seen that the power levels are increasing each section of the transmission line and also increasing the power flow after receiving end TX or load end. So we can use the capacitor bank at receiving end transformer or sub-station. Then we can get desired power at load end.

Chapter-5

Conclusion

How the reactive power can be controlled at high voltage long transmission line by using capacitor banks are analyzed in this thesis. It is observed that the power level increases or decreases by the connecting capacitor banks at different sections of the transmission line. When capacitor banks connect at the generator, there is no change of power level in graph. While the capacitor banks are connected at sending end transformer, the generator end power and sending end transformer power increase very high and the receiving end power(load end power) increases very low. These are not desired power at load end. Finally while capacitor banks are connected at receiving end transformer, the different sections of power of the transmission line increase at optimum value. In this case, the desired power can be obtained.

REFERENCE

[1] https://www.slideshare.net/HussainAli94/reactive-power-management-and-voltage-control-by-using-statcom.

[2] https://www.slideserve.com/jerom/why-an-analogy

[3] https://electricalnotes.wordpress.com/2011/03/21/importance-of-reactive-power-for-system/

[4] https://www.electrical4u.com/capacitor-bank-reactive-power-compensation/

[5]. https://www.quora.com/What-is-a-static-capacitor-Why-is-it-named-so

[6] https://www.electrical4u.com/synchronous-condenser/

[7]https://en.wikipedia.org/wiki/Synchronous_motor#/media/File:V_curve_synchronous_motor.svg

[8] https://www.electrical4u.com/facts-on-facts-theory-and-applications/

[9] https://circuitglobe.com/series-compensation.html/

[10] http://www.powerqualityworld.com/2012/05/sssc-static-synchronous-series.html

[11] https://www.slideshare.net/PrabhuR9/tcsc-ppt

[12] https://www.electricaltechnology.org/2020/06/facts-flexible-ac-transmission-system.html

[13] https://www.sciencedirect.com/topics/engineering/shunt-compensation

[14] https://en.wikipedia.org/wiki/Static_VAR_compensator#cite_note-4

[15] http://www.powerqualityworld.com/2011/09/statcom-static-synchronous-compensator.html

[16]https://www.researchgate.net/figure/Functional-Block-diagram-of-STATCOM_fig1_288937058.

[17] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8311245

[18] https://top10electrical.blogspot.com/2015/11/interline-power-flow-controller-ipfc.html

[19] https://en.wikipedia.org/wiki/Unified_power_flow_controller

[20] http://www.electricalidea.com/what-is-zigzag-transformer/

[21] https://en.wikipedia.org/wiki/Arc-fault_circuit_interrupter

[22] https://www.electrical4u.com/long-transmission-line/

[23] https://sciencing.com/types-electrical-loads-8367034.html

[24] https://circuitglobe.com/electrical-bus-bar-and-its-types.html