KLR COLLEGE OF ENGINEERING & TECHNOLOGY
(Affiliated to JNTUH, Approved by AICTE New Delhi, an ISO 9001:2015 Certified)
BCM Road, Paloncha-507115, Bhadradri Kothagudem (Dist.), Telangana.

Lecture Notes

On

POWER QUALITY & FACTS

IV BTECH II SEM (EEE)

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Regulation - R18

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UNIT-I

POWER QUALITY PROBLEMS IN DISTRIBUTION SYSTEM

Introduction:

The electric power supply systems of whole world are interconnected, involving connections inside the utilities, own territories with external to inter-utility, internationals to inter regional and then international connections. This is done for economic reasons, to reduce the cost of electricity and to improve reliability of power supply. We need the interconnections to pool power plants and load centres in order to minimize the total power generation capacity and fuel cost. Transmission lines interconnections enable to supply, electricity to the loads at minimized cost with a required reliability. The FACTS Technology is adopted in the transmissions to enhance grid reliability and to over come the practical difficulties which occur in mechanical devises used as controllers of the transmission network.

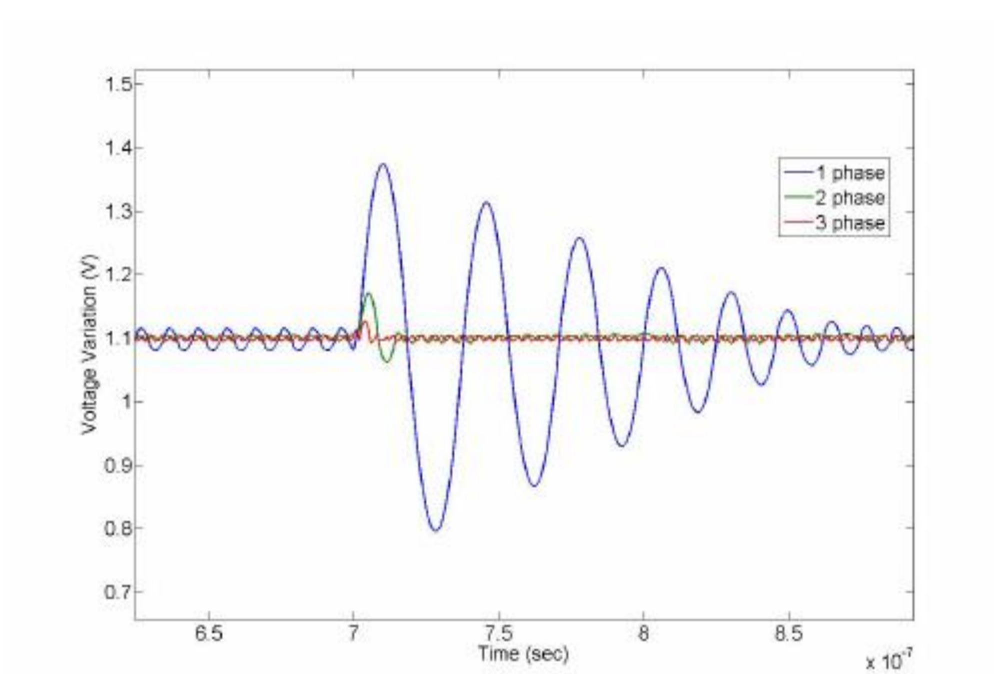
The FACTS Technology has opened a new opportunity to the transmission planner for controlling power and enhancing the useable capacity presently, also to upgrade the transmission lines. The current through the line can be controlled at a reasonable cost which enables a large potential of increasing the capacity of existing lines with large conductors and by the use of FACTS controllers the power flow through the lines is maintained stable. The FACTS controllers control the parameters governing the operation of transmission systems, such as series impedance, shunt impedance, current, voltage, phase angle and damping of oscillations at various frequencies below the rated frequency.

In an A.C power flow, the electrical generation and load must be balanced all the times. Since the electrical system is self regulating, therefore, if one of the generators supplies less power than the load, the voltage and frequency drop, thereby load goes on decreasing to equalize the generatedpower by subtracting the transmission losses. However there is small margin of self-regulating. If voltage is dropped due to reactive power, the load will go up and frequency goes on decreasing and the system will collapse ultimately. Also the system will collapse if there is a large reactive power available in it. In case of high power generation the active power flows from surplus generating area to the deficit area.

TRANSIENT STATE VARIATIONS IN VOLTAGE AND FREQUENCY

TRANSIENT STATE VARIATIONS IN VOLTAGE:-

- "Transients", a term we will use for simplicity here, are actually "Transient Voltages". In terms that are more familiar… "surges" or "spikes".
- Basically, transients are momentary changes in voltage or current that occur over a short period of time.
  This interval is usually described as approximately 1/16 (one sixteenth) of a voltage cycle (in the US, about 1/60th of a second) or about 1 milliseconds (milli = .0 0 1–one thousandths…
- In laymen's terms, .0166 seconds……or really darned quick.). Voltage transients normally last only about 50 microseconds (micro = .0 0 0 0 0 1–one millionth) and current transients last typically 20 microseconds according to the ANSI C62.41-1991 which is the standard for transients in facilities operating under 600 Volts.
- Transient activity is believed to account for 80% of all electrically-related downtime.
- Lightning accounts at least 5% of Insurance claims and costs an average of $13,000 per occurrence.
- Effective transient voltage suppression equipment can double or triple the life of electrical and electronic equipment.
- A systems approach to transient voltage surge suppression can result in dramatic performance in terms of return-on investment.
- Transient Voltage Surge Suppression is the most immediately apparent, and the most cost-effective means of improving your power quality.

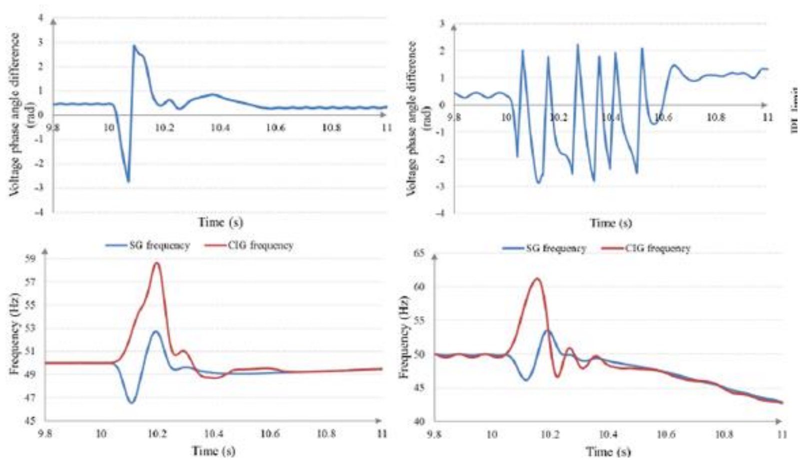


TRANSIENT STATE VARIATIONS IN FREQUENCY:

Transient Stability frequency entails the assessment of a power system following a significant disruption or disturbance. For example, (generators) following a substantial disruption in the synchronous alternator, the load angle changes due to the sudden acceleration of the rotor shaft. Therefore, the main objective of a transient stability study is to determine if the load angle returns to a constant value following the correction of the disturbance.

Also, Dynamic Stability or small-signal stability is the analysis of a power system's ability to remain stable under continuous small disturbances. Furthermore, these minor disruptions occur due to erratic fluctuations in generation levels and loads. Moreover, with interconnected power systems, these arbitrary variations can lead to catastrophic failure.

Finally, with mechanical systems, if you apply a periodic force, it will usually reach a steady state after going through some transient behavior. Furthermore, this mostly occurs in vibrating systems, for example, a clock pendulum. However, this can occur within any semi-stable or stable dynamic system. Also, the amount of time spent in the transient state depends on the initial conditions of the system.



STEADY STATE VARIATIONS IN VOLTAGE AND FREQUENCY;-

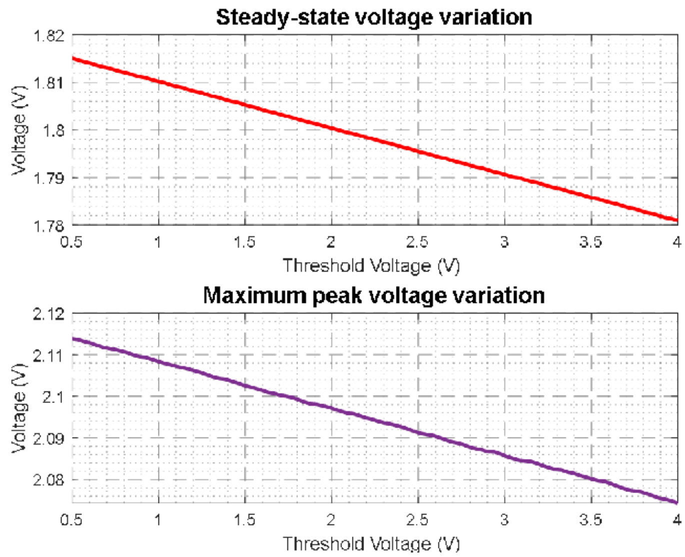
STEADY STATE VARIATIONS IN VOLTAGE:-

Steady state voltage limits are an example of System steady state performance criteria.

Steady state voltage modulation shall not exceed one cycle per second.

Steady state voltage up to 44,000 V is supplied in accordance with the provisions of standard No. CAN3-C235-83 (R2010) in force at the time of application.

Steady state voltage regulation For stable or slowly varying load conditions, the inverter output voltage is regulated to within ±0.5% in amplitude.

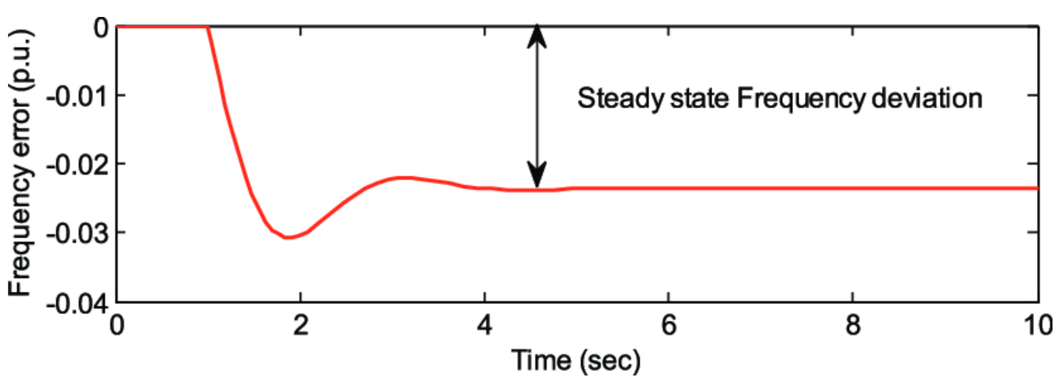


Steady state voltage was examined with the generator off-line and on-line for the different system operating conditions.

Steady state voltage regulation shall be in accordance with the operating limit values of the performance class specified in the paragraph entitled "Performance Class." a.

STEADY STATE VARIATIONS IN FREQUENCY:-

Maximum steady-state frequency deviation means the maximum expected frequency deviation after the occurrence of an imbalance equal to or less than the reference incident at which the system frequency is designed to be stabilized.

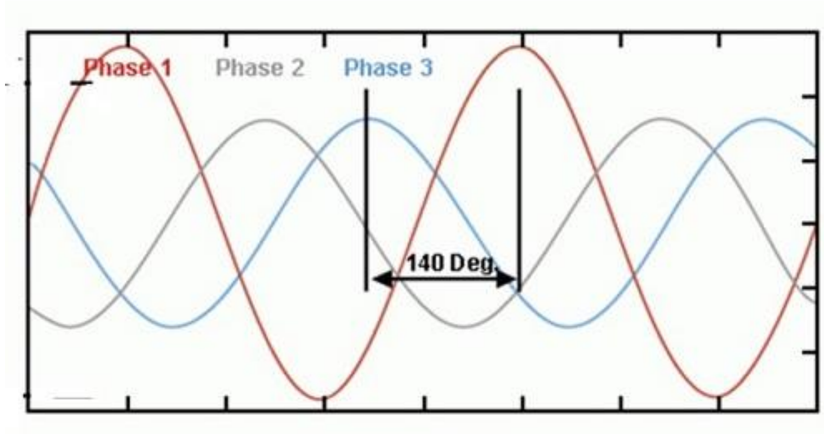


Maximum steady-state frequency deviation means the maximum expected frequency deviation at which the system frequency is designed to be stabilized after the occurrence the Dimensioning Incident.

The default value in the NSA is defined in [8] to be ± 0.5 Hz.

POWER QUALITY UNBALANCE

Unbalance or imbalance is a measurement of the inequality of the phase voltages. Voltage imbalance is the measure of voltage differences between the phases of a three-phase system.



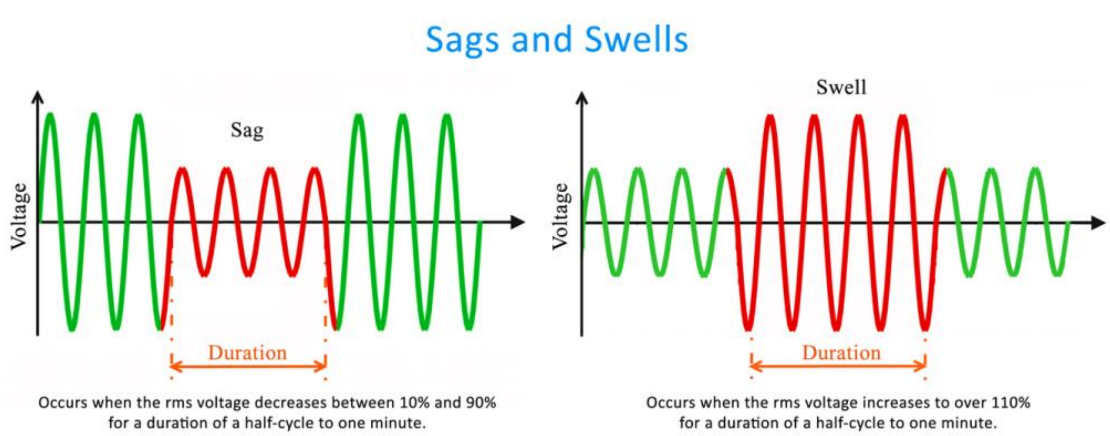
Unbalanced Phases

It degrades the performance and shortens the life of three-phase motors.

The impact of the transients on motors can be severe.

POWER QUALITY SAGS:

A voltage sag is a short duration (i.e., 0.5-60 cycles) decrease in the rms voltage magnitude, usually caused by a fault somewhere on the power system (Figure 1). Voltage sags are the most important power quality problem facing many industrial customers especially those with a process.

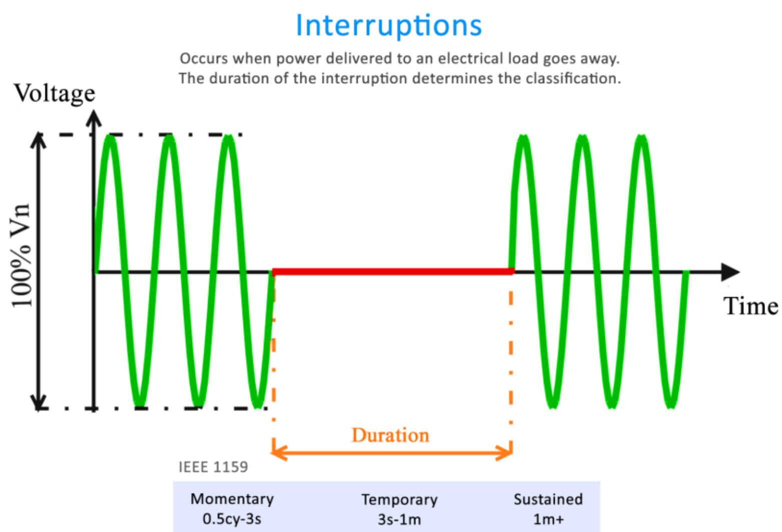


POWER QUALITY SWELLS:-

A voltage swell is a short-duration increase in voltage values. Voltage swells lasting longer than two minutes are classified as overvoltages. Voltage swells and overvoltages are commonly caused by large load changes and power line switching. If swells reach too high of a peak, they can damage electrical equipment.

POWER QUALITY INTERRUPTIONS:-

An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min.



Sources: Interruptions can be the result of power system faults, equipment failures, and control malfunctions.

WAVE FORM DISTORTIONS:-

Waveform distortions are common power problems that cause equipment to malfunction and sources of power to overload. It is an unexpected change in the waveforms of current and voltage as they pass through a device. There are five main types of waveform distortions: DC offset, harmonics, interharmonics, notching and noise.

DC offsets

Instances where direct current (DC) overlaps an alternating current (AC) distribution system. This overlapping of two different types of current can cause overheating in the equipment.

Harmonics

when some loads affect the main waveform of voltage. In this situation, the new loads prevent the waveform from reaching its highest and lowest levels. Harmonics can cause circuit breakers to trip and transformers to overheat.

Fluctuation

It is a condition where a signal affects the main voltage waveform. It can cause display monitors to flicker and equipment to overheat. Interharmonics can also cause communication issues.

Notching

It is an intermittent disturbance that can affect voltage. It normally happens when light dimmers or arc welders are being used. It results in data loss and issues with the transmission of data.

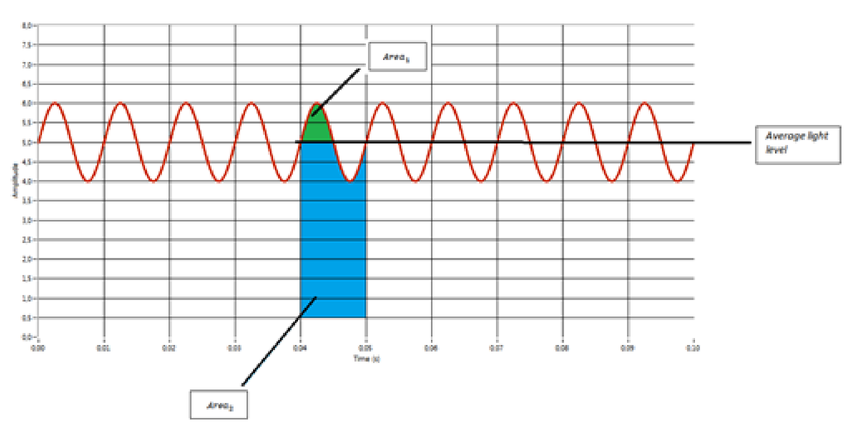
Noise

It is any unnecessary current or voltage affecting the waveform of the main power supply. This waveform distortion can cause data issues and equipment to malfunction.

The effects of waveform distortion can be reduced through the use of an uninterruptible power supply (UPS) and filter equipment. Line conditioners can also be used to minimize the effect of this power problem. Reducing the load used on a transformer can also help reduce waveform distortion. Relocating equipment causing this common power problem can also help prevent it from happening.

FLICKER AND ITS MEASUREMENTS:-

Flicker is defined as short-term voltage fluctuations in the power supply system. This can cause lamps to flicker, as the brightness is proportional to the applied voltage. Other technical devices are also sensitive to voltage fluctuations. Power supplies or TV receivers can have their function disrupted or, in extreme cases, even be destroyed by flicker.



To measure flicker, one always has to take a psychological component into account. This is usually included in the calculation by means of an empirically determined flicker curve. This curve indicates how strongly light fluctuations are perceived on average by a person. The frequency and strength of the voltage fluctuation do also play a role.

To classify the intensity of flicker one often uses so called perceptibility units P. There are three different types of perceptibility units:

- P_inst: current flicker perception.
- P_st: short-term flicker strength. This is the average over a period of 10 minutes.
- P_lt: long-term flicker strength. This is the average over a period of 2 hours.

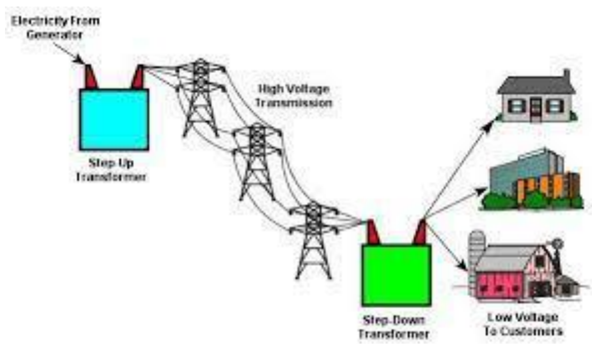
Flicker is a phenomenon that manifests itself in very short voltage fluctuations. Therefore, it also requires high-quality measuring instruments to be able to measure flicker accurately. Also, the measurement should be done in a controlled environment because electrical components can behave differently depending on temperature or load. Nevertheless, the test environment should reflect the actual operating location of the device as well as possible.

UNIT-II

TRANSMISSION LINES AND SHUNT/SERIES REACTIVE POWER COMPENSATION

BASICS OF AC TRANSMISSION:-

AC transmission lines are a vital element of any ac power network. They are used to transfer electrical power from the power generating stations to the distribution system, which then supplies the electrical power to the consumers.

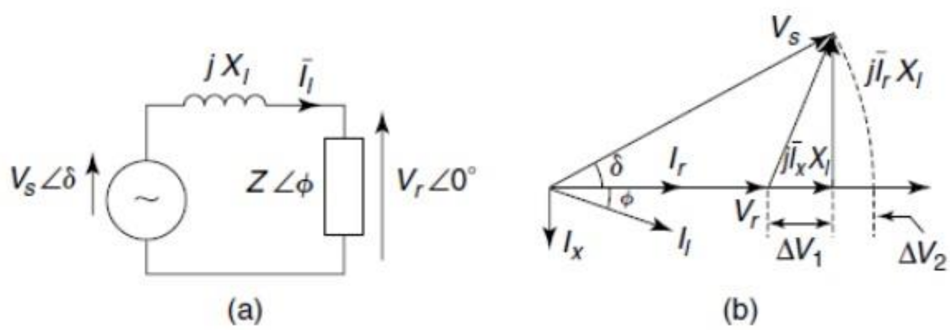


AC transmission lines are a vital element of any ac power network. They are used to transfer electrical power from the power generating stations to the distribution system, which then supplies the electrical power to the consumers. As the power generating stations in an ac power network can be quite distanced from the centers of energy consumption, ac transmission lines often have to transfer electrical power over great distances.

This particularity, coupled with the fact that ac transmission lines are primarily inductive, has many effects on the operation of ac transmission lines. One of the main effects is that a significant voltage drop occurs at the receiver end of ac transmission lines. This voltage drop must be continually compensated in order to maintain the receiver voltage equal to the sender voltage. This is commonly achieved using capacitors connected in parallel to the line. When an ac transmission line is particularly long, substations containing parallel connected (shunt) capacitors must be added at regular intervals along the line.

ANALYSIS OF UNCOMPENSATED AC TRANSMISSION LINES:-

For simplicity let us consider only the inductive reactance



From the above figure it is clear that between he sending and the receiving end voltages and magnitude variation as well as a phase difference is created and the most significant part of the voltage drop in the line reactance is due to the reactive component of the load current and to keep the voltages in the network nearly at the rated value.

Two compensation methods are:

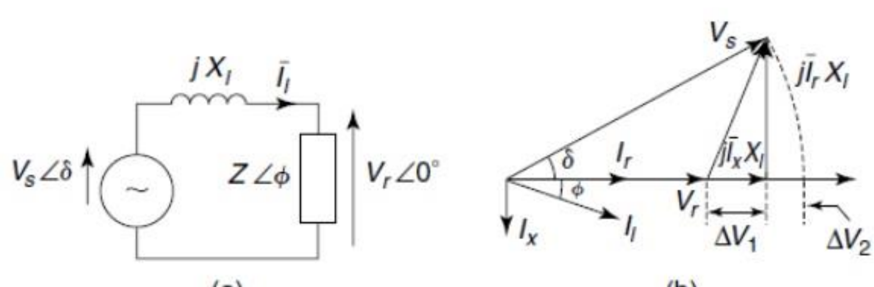
1. Load compensation
2. System compensation

2. Load Compensation

Ø It is possible to compensate for the reactive current of the load by adding a parallel capacitive load so that Ic = Ix and the effective power factor to become unity.

Ø In the figure the absence of Ix eliminates the voltage drop ∆V1 bringing Vr closer in magnitude to Vs, this condition is called load compensation and actually by charging extra for supplying the reactive power a power utility company makes it advantageous for customers to use load compensation on their premises.

Loads compensated to the unity power factor reduce the line drop but do not eliminate it. They still experience a drop of ∆V2 from j IrX1.



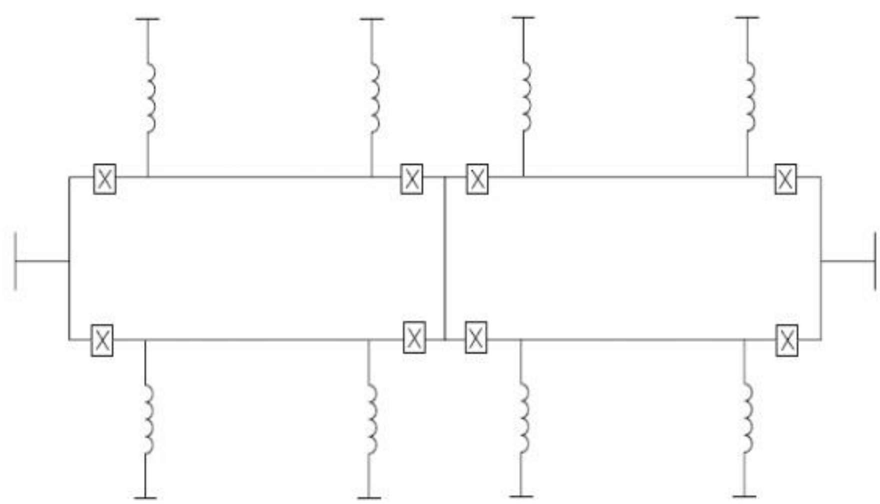
PASSIVE REACTIVE POWER COMPENSATION:-

The reactive-power control for a line is often called reactive-power compensation and external devices or subsystems that control reactive power on transmission lines are known as “compensators”.

A compensator mitigates the undesirable effects of the circuit parameters of a given line and the objectives of line compensation are invariably

1. To increase the power-transmission capacity of the line.

2. To keep the voltage profile of the line along its length within acceptable bounds to ensure the quality of supply to the connected customers, to minimize the line insulation costs.



Types

1. Shunt Compensation

2. Series Compensation

1. Shunt Compensation

- In a weak system voltage control by means of parallel compensation is applied to increase the power quality and improvement of the voltage profile for different system and load conditions when using a Static Var Compensator (SVC) for fast control of shunt connected capacitors and reactors.

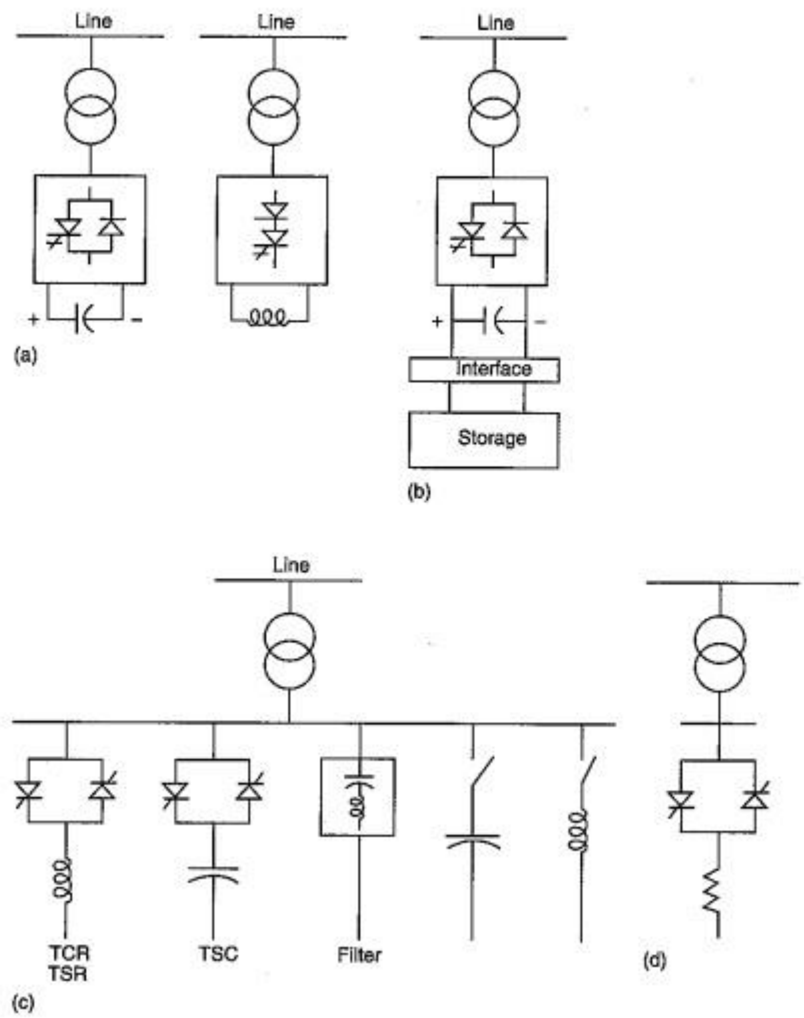
- Shunt compensation can also be employed as a 'local' remedy against voltage collapse which can occur when large induction machines are connected to the system.

  After system faults the machines load the power system heavily with high reactive power consumption and the remedy for such fault is strong capacitive power injection for example by using an either SVC or STATCOM or just switched capacitors.

- The reactive current is injected into the line to maintain voltage magnitude and transmittable active power (P) is increased but more reactive power (Q) is to be provided. g e

$P = (2V2/X)\sin(\delta/2)$

$Q = (2V2/X)[1-\cos(\delta/2)]$



2. Series Compensation

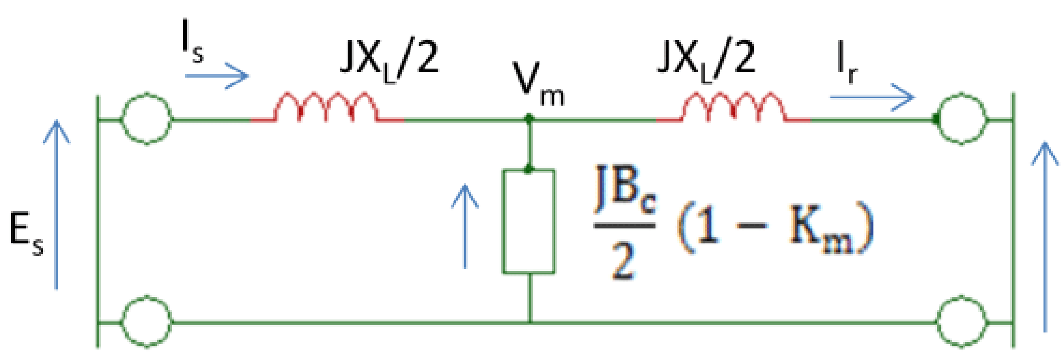
Ø The Series Compensation is a well-established technology that primarily used to transfer reactance’s most notably in bulk transmission corridors.

Ø The result is a significant increase in the transmission system transient and voltage stability and Series Compensation is self-regulating in the sense that its reactive power output follows the variations in transmission line current that makes the series compensation concept extremely straight forward and cost effective.

The thyristor controlled series capacitors adds another controllability dimension as thyristor are used to dynamically modulate the ohms provided by the inserted capacitor and this is primarily used to provide inter-area damping of prospective low frequency electromechanical oscillations but it also makes the whole Series Compensation schema immune to Sub Synchronous Resonance (SSR).

SHUNT AND SERIES COMPENSATION AT THE MID POINT OF AN AC LINE

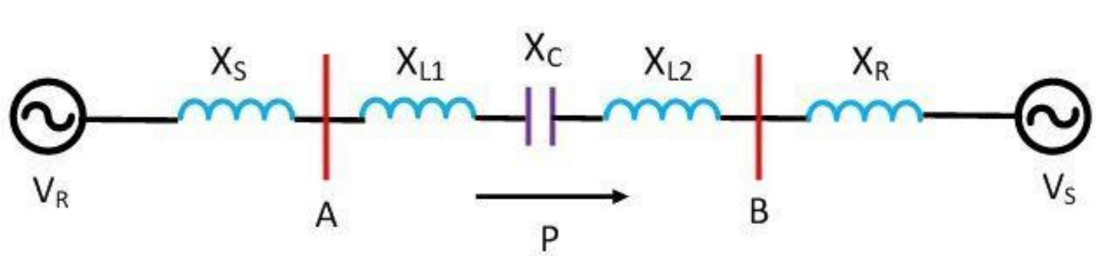
Series compensation reduces the series impedance of the line which causes voltage drop and is the most important factor in finding the maximum power transmission capability of a line A, C and D constants are functions of Z and therefore the also affected by change in the value of Z, but these changes are small in comparison to the change in B as B = Z for the nominal -π and equals Z (sinh γ1/γ1) for the equivalent π.



The voltage drop ΔV due to series compensation is given by

$$\Delta V \approx IR \cos \phi_r + I(X_L - X_C) \sin \phi_r$$

Here XC = capacitive reactance of the series capacitor bank per phase and XL is the total inductive reactance of the line/phase. In practice, XC may be so selected that the factor (XL — XC) sin Φr becomes negative and equals (in magnitude) R cos Φr so that ΔV becomes zero. The ratio XC/XL is called “compensation factor” and when expressed as a percentage is known as the “percentage compensation“.



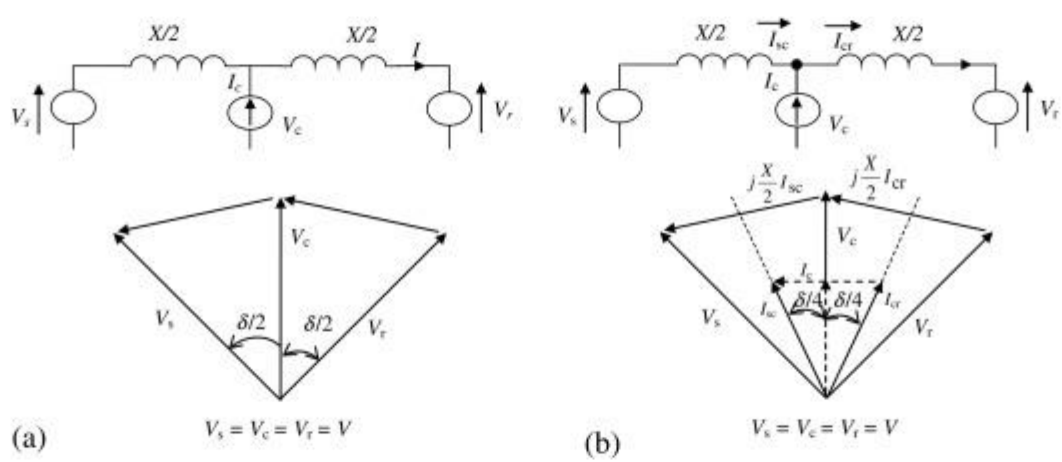
The extent of series and shunt compensation of transmission lines depends on the number, location and circuit arrangements of series capacitor and shunt reactor stations. While planning long-distance lines, besides the average degree of compensation required, it is required to find out the most appropriate location of the reactors and capacitor banks, the optimum connection scheme and the number of intermediate stations. For finding the operating conditions along the line, the ABCD constants of the portions of line on each side of the capacitor bank, and ABCD constants of the. bank may be first found out and then equivalent constants of the series combination of line-capacitor-line can then be arrived at by using the formulae.

Thus, we see that in both series and shunt compensation of transmission lines it is possible to transmit large amounts of power efficiently with a flat voltage profile. Proper type of series and shunt compensation of transmission lines should be provided in proper quantity at appropriate places to achieve the desired Voltage Control Method.

COMPARISON OF SERIES AND SHUNT COMPENSATION:-

SHUNT COMPENSATION;

In shunt compensation, FACTS are connected in parallel with the power system transmission line. It works as a controllable current source. A reactive current is injected into the line to maintain constant voltage magnitude by varying shunt impedance. Therefore, the transmittable active power is increased but at the expense of increasing the reactive power demand. There are two methods of shunt compensations:



(i) Shunt capacitive compensation

This method is used improve the power factor. Whenever an inductive load is connected to the transmission line, power factor lags because of lagging load current. To compensate it, a shunt capacitor is connected, which draws current leading to the source voltage. The net result is improvement in power factor.

(ii) Shunt inductive compensation

This method is used either when charging the transmission line or when there is very low load at the receiving end.

Due to very low or no load, a very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification (Ferranti effect). The receiving end voltage (Vr) may become double the sending end voltage (Vs) (generally in case of very long transmission lines). To compensate it, shunt inductors are connected across the transmission line.

SERIES COMPENSATOR:

Series compensation is the method of improving the system voltage by connecting a capacitor in series with the transmission line. In other words, in series compensation, reactive power is inserted in series with the transmission line for improving the impedance of the system. It improves the power transfer capability of the line. It is mostly used in extra and ultra-high voltage line.

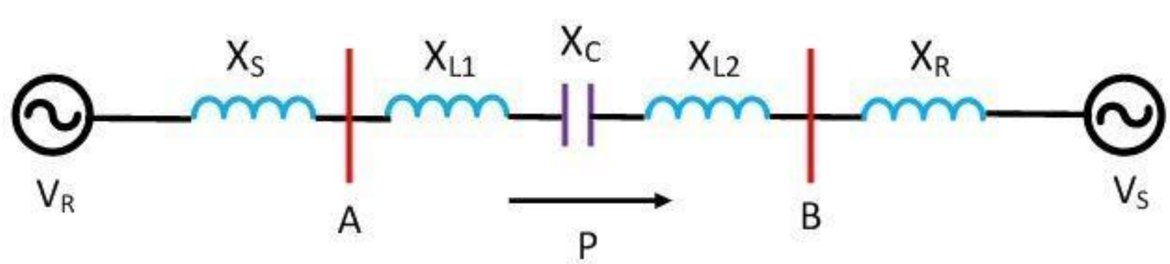
Series compensation has several advantages like it increases transmission capacity, improve system stability, control voltage regulation and ensure proper load division among parallel feeders. These advantages are discussed below.

- Increase in Power Transfer Capability – The power transfer over a line is given by

$$P_1 = \frac{V_s V_R}{X_L} sin\delta$$

Where P1 – power transferred per phase (W)
Vs – sending-end phase voltage (V)
Vr – receiving-end phase voltage
XL – series inductive reactance of the line
δ – phase angle between Vs and Vr

If a capacitor having capacitance reactance Xc is connected in series with the line, the reactance of the line is reduced from XL to (XL– Xc). The power transfer is given by



$$P_2 = \frac{V_s V_R}{X_L - X_C} sin\delta$$

$$\frac{P_1}{P_2} = \frac{X_L}{X_L - X_C} = \frac{1}{1 - \frac{X_C}{X_L}} = \frac{1}{1-k}$$

$$k = \frac{X_C}{X_L}$$

The factor k is known as a degree of compensation or compensation factor. Thus, per unit compensation is given by the equation percentage

$$k = \frac{X_C}{X_L}\ pu$$

compensation is given by the equation

$$k = \frac{X_C}{X_L}\ pu\ \times 100\ \%$$

Where XL = total series inductive reactance of the line per phase

XC = capacitive reactance of the capacitor bank per phase

In practice , k lies between 0.4 and 0.7. For k = 0.5.

UNIT-III

STATIC SHUNT COMPENSATORS

OBJECTIVES OF SHUNT COMPENSATION:-

Shunt compensation is use to improve power factor. In Shunt compensation FACTS are connected in parallel with power system and works like a controllable current source. There are two types of shunt compensation. If the inductive load is connected the lagging load current flows to compensate this shunt capacitor is used. And if the capacitive load is connected the leading load current flows to compensate this shunt inductor is use. If the power system is lightly loaded then fixed or switched shunt reactor is use for maintaining voltage level.

And if the power system is heavily loaded then fixed or switched shunt capacitor is use for maintaining voltage level. The objective of using shunt compensator is to increase the transmittable power, Increase transient stability, Increase system stability, reduce loss. AR compensator is use for voltage regulation, Dynamic voltage control and damp power oscillation. Examples of shunt compensation is STATCOM and SVC.

METHODS OF CONTROLLABLE VAR GENERATION:-

Capacitors generate and inductors (reactors) absorb reactive power when connected to an ac power source. They have been used with mechanical switches for controlled var generation and absorption. Continuously variable var generation or absorption for dynamic system compensation as originally provided by

- over or under-excited rotating synchronous machines
- saturating reactors in conjunction with fixed capacitors Using appropriate switch control, the var output can be controlled continuously from maximum capacitive to maximum inductive output at a given bus voltage. More recently gate turn-off thyristors and other power semiconductors with internal turn off capacity have been use of ac capacitors or reactors.

STATIC VAR COMPENSATOR & CHARACTERISTICS:-

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 (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.

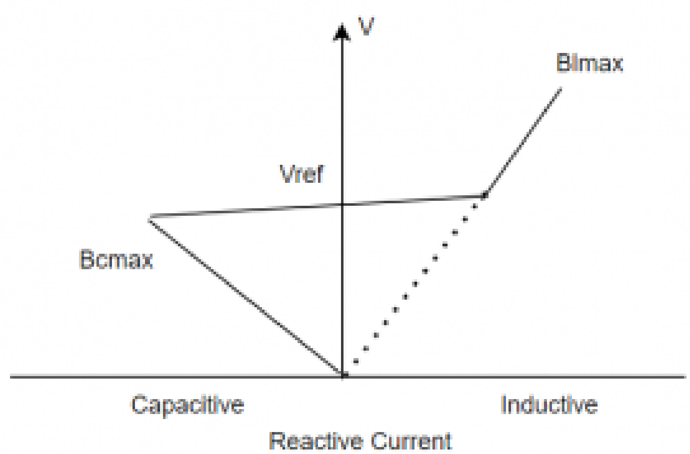
The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. SVCs are used in two main situations:

- Connected to the power system, to regulate the transmission voltage ("transmission SVC")
- 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 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.

CHARACTERISTICS:-

- As voltage controlling mode where there is regulation for voltage within the threshold values.
- As var regulation mode which means susceptance value of the device is maintained at a constant level.



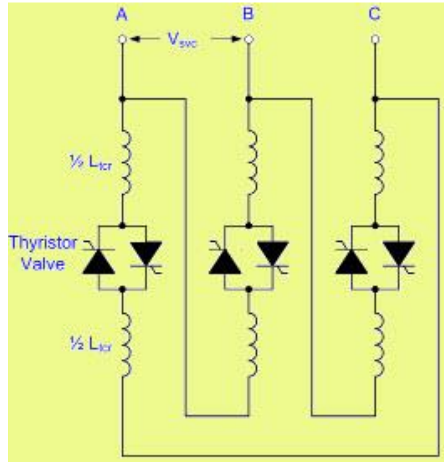
THYRISTOR CONTROLLED RECTIFIER CONFIGURATION:-

The TCR is a three-phase assembly and generally connected in a delta arrangement to give the partial cancellation of harmonics.
The TCR reactor is divided into two halves, with the thyristor valves are connected between the two halves.
Hence it will protect the vulnerable thyristor valve from the high voltage electrical short circuit which is made through the air and exposed conductors.

Operation of TCR

When the current flow through the thyristor controlled resistance it will differ from the maximum to zero by varying the firing delay angle, α. The α is denoted as a delay angle point at which the voltage will become positive and the thyristor will become on & there will be current flow. When α is at 900 then the current is at maximum level and the TCR is known as the full condition & the RMS value is calculated by the equation below.

I TCR – max = V svc / 2ΠfL TCR

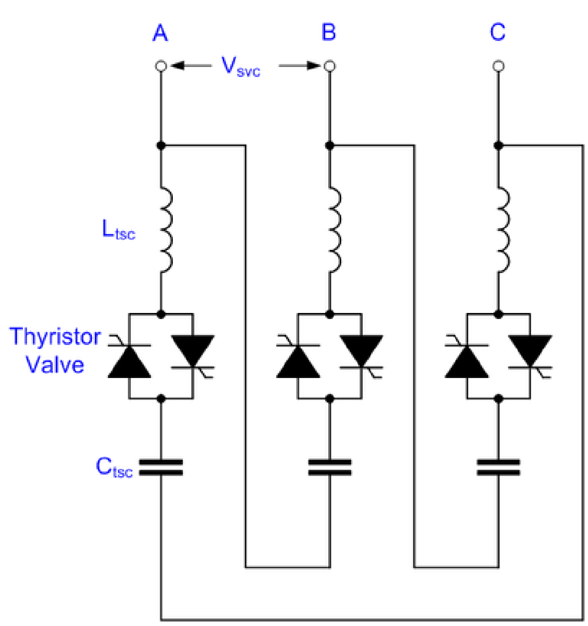


Circuit Explanation of TCR

THYRISTOR SWITCHED CAPACITOR:-

A thyristor-switched capacitor (TSC) is a type of equipment used for compensating reactive power in electrical power systems. It consists of a power capacitor connected in series with a bidirectional thyristor valve and, usually, a current limiting reactor (inductor). The thyristor switched capacitor is an important component of a Static VAR Compensator (SVC), where it is often used in conjunction with a thyristor controlled reactor (TCR). Static VAR compensators are a member of the Flexible AC transmission system (FACTS) family.

A TSC is usually a three-phase assembly, connected either in a delta or a star arrangement. Unlike the TCR, a TSC generates no harmonics and so requires no filtering. For this reason, some SVCs have been built with only TSCs . This can lead to a relatively cost-effective solution where the SVC only requires capacitive reactive power, although a disadvantage is that the reactive power output can only be varied in steps. Continuously variable reactive power output is only possible where the SVC contains a TCR or another variable element such as a STATCOM.



Unlike the TCR, the TSC is only ever operated fully on or fully off. An attempt to operate a TSC in ‘’phase control’’ would result in the generation of very large amplitude resonant currents, leading to overheating of the capacitor bank and thyristor valve, and harmonic distortion in the AC system to which the SVC is connected.

FC-TCR CONFIGURATION:-

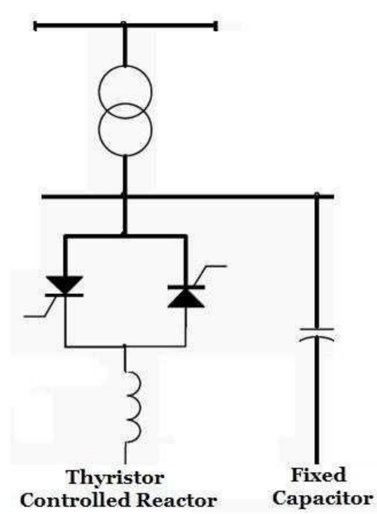
Simple FC-TCR type SVC configuration is shown in figure 1. In FC-TCR, a capacitor is placed in parallel with a thyristor controlled reactor.

Is, Ir and Ic are system current, reactor current and capacitor current respectively which flows through the FC-TCR circuit.

Fixed capacitor- Thyristor controlled reactor (FC-TCR) can provide continuous lagging and leading VARS to the system .

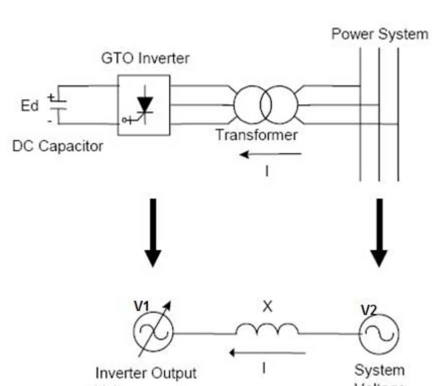
Circulating current through the reactor (Ir) is controlled by controlling the firing angle of back-back thyristor valves connected in series with the reactor.

Leading var to the system is supplied by the capacitor. For supplying lagging vars to the system, TCR is generally rated larger than the capacitor.



STATCOM:-

A Static synchronous Compensator (STATCOM) is a fast-acting device capable of providing or absorbing reactive current and thereby regulating the voltage at the point of connection to a power grid.



BASIC PRINCIPLE OPERATION:-

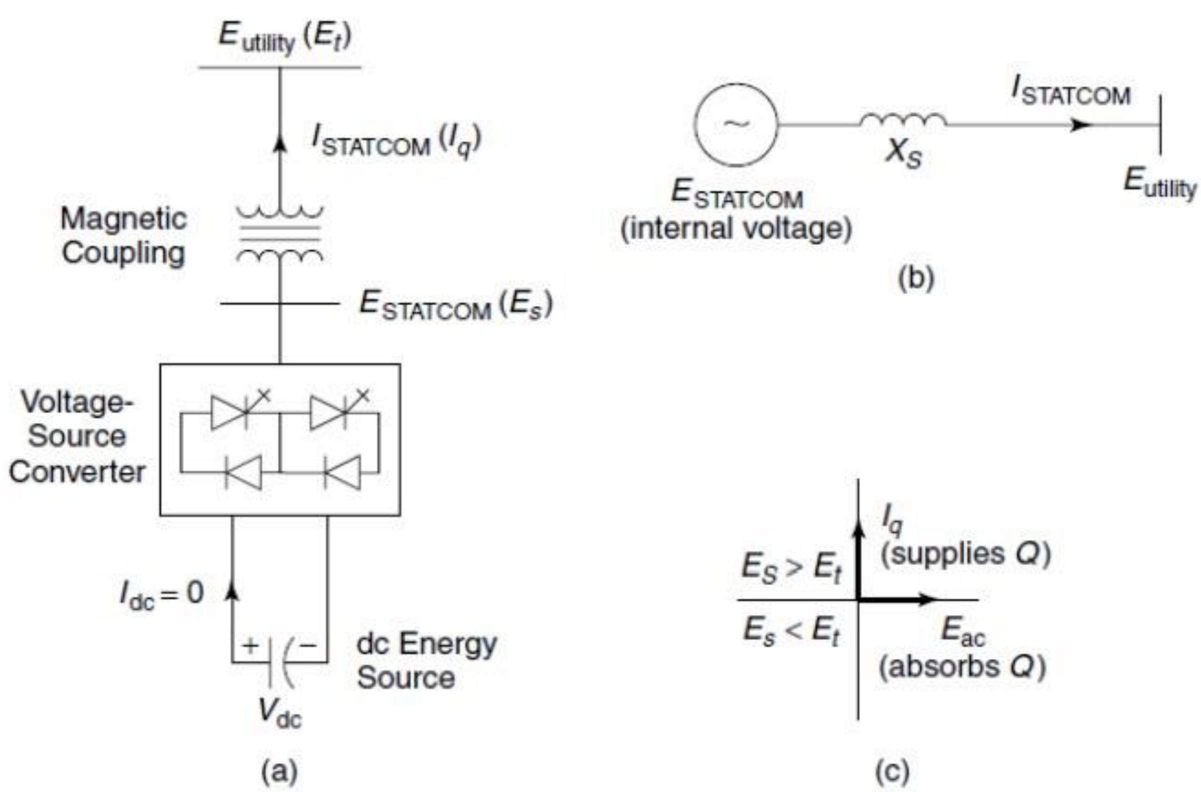
A STATCOM is a controlled reactive-power source. It provides the desired reactive-power generation and absorption entirely by means of electronic processing of the voltage and current waveforms in a voltage-source converter (VSC).

Ø A single-line STATCOM power circuit is shown in Fig.(a),where a VSC is connected to a utility bus through magnetic coupling.

Ø In Fig. (b), a STATCOM is seen as an adjustable voltage source behind a reactance meaning that capacitor banks and shunt reactors are not needed for reactive-power generation and absorption, thereby giving a STATCOM a compact design, or small footprint, as well as low noise and low magnetic impact.

The exchange of reactive power between the converter and the ac system can be controlled by varying the amplitude of the 3-phase output voltage, Es, of the converter, as illustrated.

If the amplitude of the output voltage is increased above that of the utility bus voltage, Et, then a current flows through the reactance from the converter to the ac system and the converter generates capacitive-reactive power for the ac system.



The STATCOM principle diagram: (a) a power circuit;(b) an equivalent circuit;(c) a power exchange

CONTROL APPROACHES & CHARACTERISTICS:-

CONTROL APPROACHES:-

Controlling is determining what is being accomplished that is evaluating the performance and, if necessary, applying corrected measures so that the performance takes place according to plans." In Terry's view, controlling helps in proper implementing of plans. If the plans are not progressing at a proper pace than necessary measures are taken to set the things right. Controlling is a channel through which plans may be properly implemented.

CHARACTERISTICS:-

- Managerial Function
- Forward Looking
- Continuous Activity
- Control is Related to Planning
- Essence of Control is Action
- Basis for Future Action
- Facilitates Decision-making
- Facilitates Decentralization

UNIT-IV

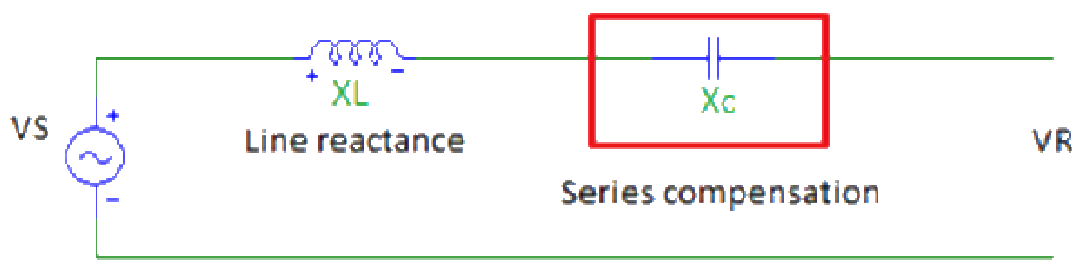
STATIC SERIES COMPENSATOR

OBJECTIVES OF SERIES COMPENSATOR:-

The transmittable power rapidly increases with the degree of series compensation k.

Similarly, the reactive power supplied by the series capacitor also increases sharply with k and varies with angle ş in a similar manner as the line reactive power.

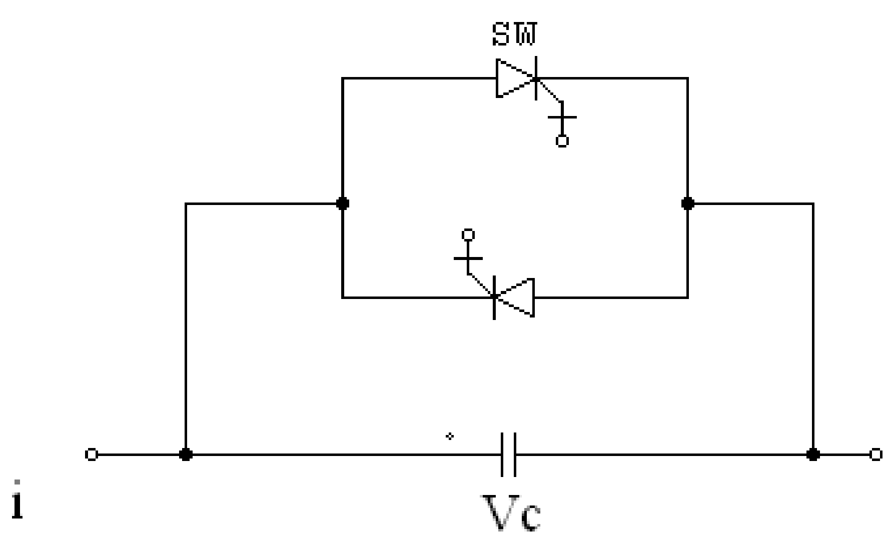
Series capacitive compensation method is very well known and it has been widely applied on transmission grids; the basic principle is capacitive compensation of portion of the inductive reactance of the electrical transmission, which will result in increased power transfer capability of the compensated transmissible.



VARIABLE IMPEDANCE TYPE OF SERIES COMPENSATORS:-

An SSSC is an example of a FACTS device that has its primary function to change the characteristic impedance of the transmission line and thus change the power flow.

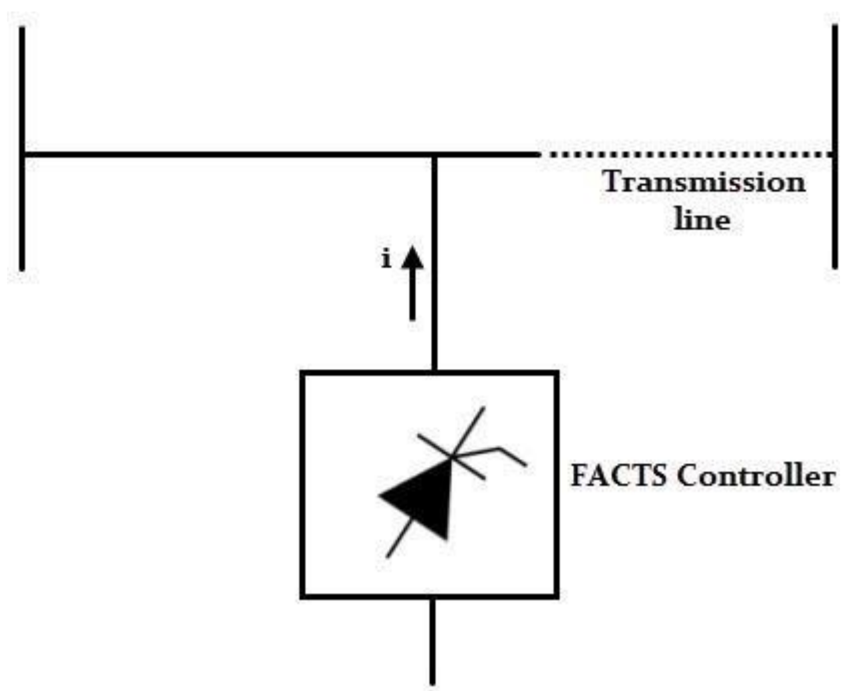
Reactive power is inserted in series with the transmission line for improving the impedance of the system.



Shunt connected controllers

These controllers inject a current into the system at the point of connection. If this current is in phase quadrature with the line voltage, a shunt controller consumes or supplies variable reactive power to the network.

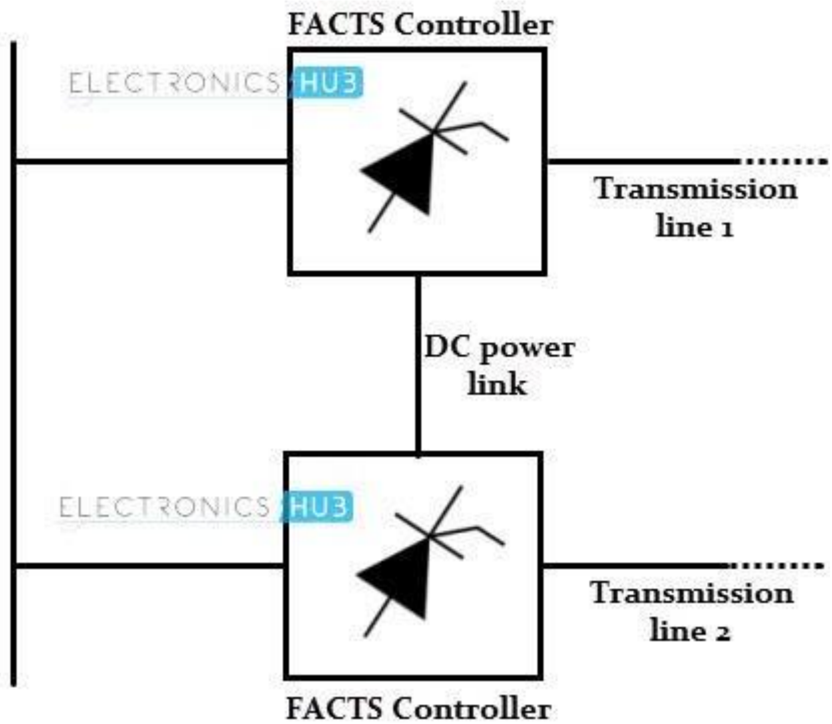
Similar to the series connected controllers, these controllers could be a variable reactor or capacitor or a power electronic based variable source. Examples of the shunt controllers include TCR, STATCOM, TSR, TCBR and TSC.



Combined series-series controllers

These controllers are the combination of individual series controllers that are controlled in a coordinated manner in multiple power transmission systems. Or these could be a unified controllers in which separate series controllers are employed in each line for series reactive power compensation and also to transfer the real power among the lines via proper link.

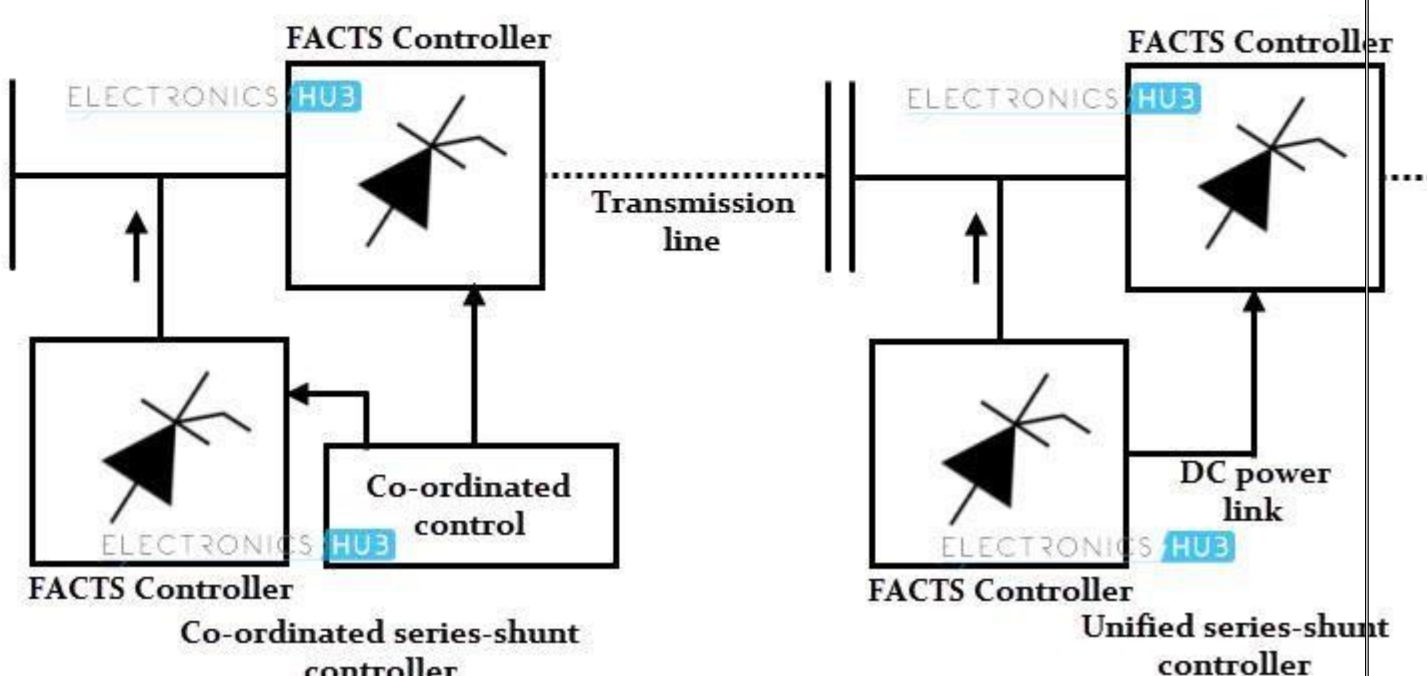
Example of this controller is IPFC that balances the real and reactive power flow in the lines in order to maximize the power transmission.



Combined series-shunt controllers

These are the combination of separate series and shunt controllers that are controlled in a coordinate manner or a unified power flow controller (UPFC) with series and shunt elements.

These combined controllers inject current into the system with series part of the controller and voltage in series in the line with shunt part of the controller. Examples of these controllers include TCPST, UPFC and TCPAR.

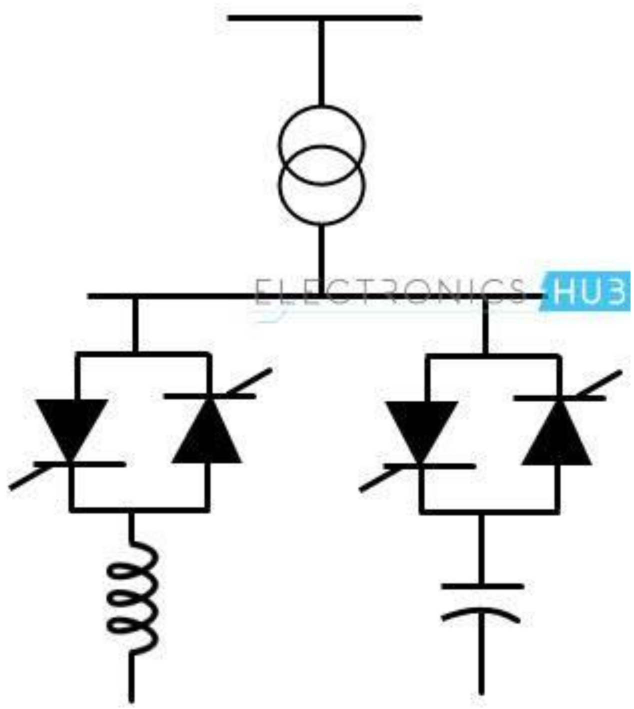


Overview of 10 FACTS Devices or Controllers

In this section we will discuss above mentioned controllers in brief.

Static Var Compensator

It is a shunt type controller which controls the power flow in transmission system and improves the transient stability of power grids. This controller regulates the voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system.

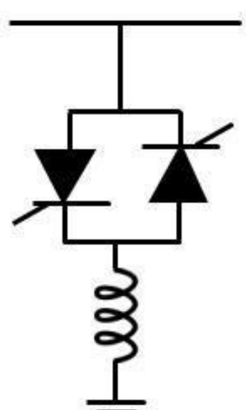


When the system voltage is low, SVC generates the reactive power and when the voltage is high it absorbs the reactive power. The reactive power is varied by switching the three phase inductor and capacitor banks. SVCs are basically thyristor controlled reactive power devices and common types of SVC are given below.

Thyristor controlled Reactor (TCR)

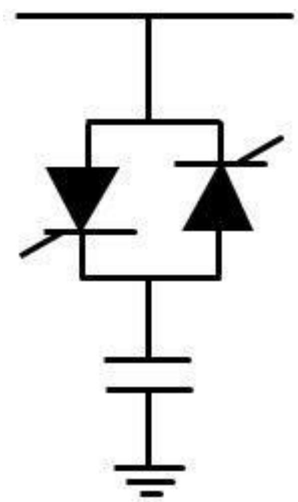
It is a shunt connected static var absorber or generator. It consists of a fixed reactor in series with bidirectional thyristor switches. The impedance of this device varied in a continuous manner by varying the conduction angles of thyristors.

The output of this device is adjusted to exchange either inductive or capacitive current. It maintains and controls the parameters (typically a bus voltage) of the power system. It is an alternative to STATCOM in terms of cost.



Thyristor Switched Capacitor (TSC)

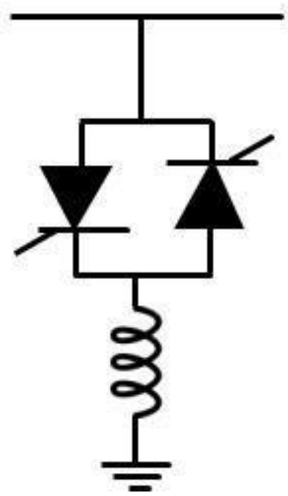
It consists of a shunt connected capacitor which is connected in series with bidirectional thyristor switches. The impedance or reactance of this device is varied in a stepwise manner by controlling the thyristors either in a zero or full conduction operation. This controller offers no harmonics, no transients, and low losses.



Thyristor Switched Reactor (TSR)

It is a special case of a TCR where phase control of the current is not exercised, instead the reactor is switched such that thyristors are either fully ON or OFF as in case of TSC. The advantage of TSR over TCR is that no harmonics current generation. Also, this controller use thyristors without firing control and hence lower cost and losses.

The reactive compensation control in electric power system use the above stated SVC types in different configuration, such as combination of TCR and TSC, combination of TCR and TSC with filter circuit and TCR with filter circuit as shown in figure.



Static Series Synchronous Compensator (SSSC)

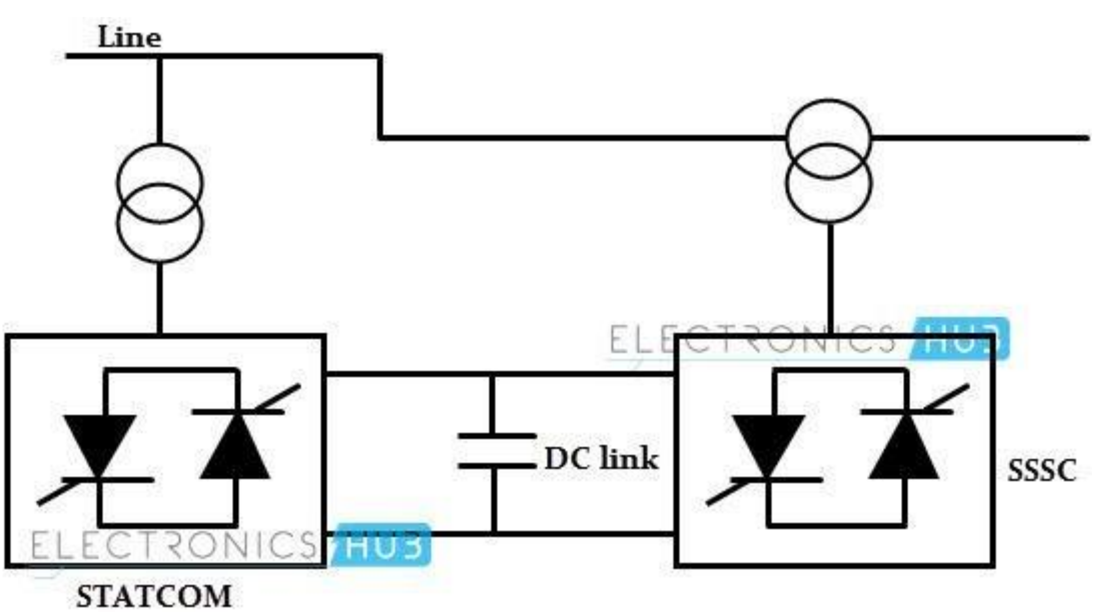
It is a series version of STATCOM and it is an advanced kind of control series compensation. It produces the output voltage in quadrature with the line current such that the overall reactive voltagedrop across the line is increased or decreased.

Although it is like a STATCOM, the output voltage is in series with the line and hence it controls thevoltage across the line, so its impendence. It has a capability to induce both inductive and capacitive voltage in series with the line and hence the power control.

Unified Power Flow Controller (UPFC)

UPFC is the combination of STATCOM and SSSC which are coupled by via a common DC link. It canexhibit the characteristics of both SSSC with series voltage injection and STATCOM with shunt currentinjection, with added features.

It has a unique ability to perform independent control of real and reactive power flow. Also, these canbe controlled to provide concurrent reactive and real power series line compensation without use of anexternal energy source.



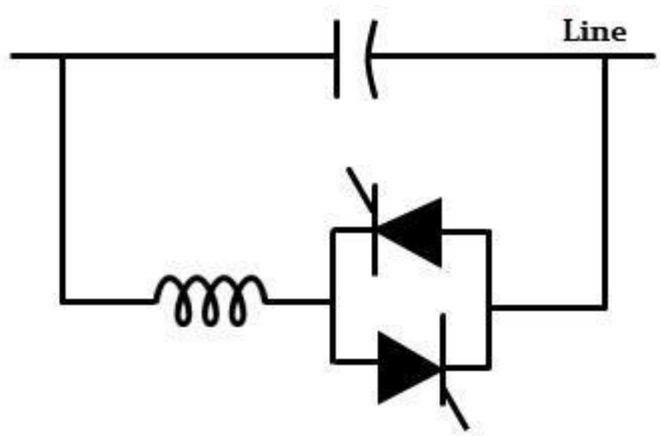
In the above UPFC, SSSC (or converter-2) injects a voltage with controllable magnitude and phase angle in series with the line though a series transformer. The function of STATCOM (or converter-1) isto absorb or supply the reactive power demanded by SSSC at the common DC link.

It can also supply or absorb the controllable reactive power to the transmission line to provideindependent shunt reactive compensation.

Thyristor Controlled Series Capacitor (TCSC)

It is a capacitive reactance compensator. It consists of a series capacitor bank which connected in parallel with a thyristor controlled reactor that provides a smooth variable series capacitive reactance.

The total impedance of the system can be varied by changing the conduction angle of the thyristors andhence the circuit becomes either inductive or capacitive. If the total circuit impedance is inductive, the fault current is limited by this controller. A simple model of TCSC is shown in figure below.



Simple model of
TCSC and TSSC

Thyristor Switched Series Capacitor (TSSC)

Similar to TCSC, it is also a capacitive reactance compensator consisting of thyristor switched reactor inparallel with a series capacitor. It provides the stepwise control of series capacitive reactance.

Instead of controlling in continuous manner, it switches the reactor such that the thyristors are fired at900 and 1800. This controller can be implemented without firing angle control to reduce the cost and losses.

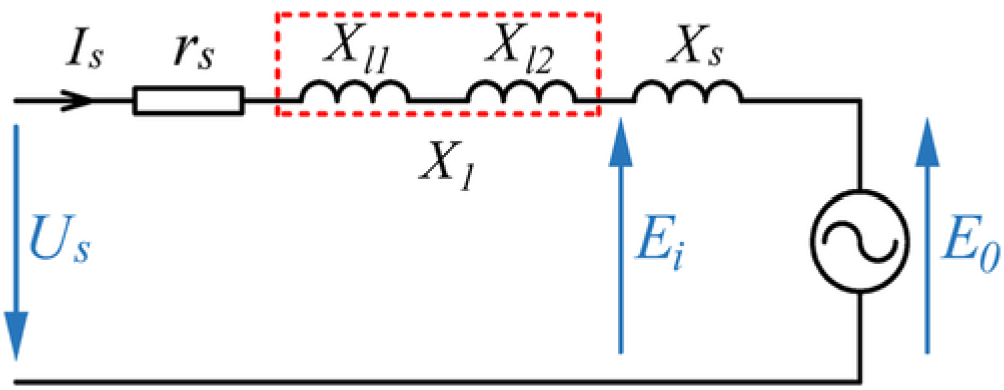
Thyristor Controlled Series Reactor (TCSR)

It is an inductive reactance compensator which consists of a series reactor in parallel with thyristorswitched reactor. This controller provides a smooth variable inductive reactance.

When the thyristors firing angle is 180^0, the reactor stops conducting and hence the uncontrolled reactoronly is in series with the line that acts as a fault current limiter. If the firing angle is below 180^0, the net (or overall) inductance decreases, thereby voltage is controlled in the network.

POWER ANGLE CHARACTERISTICS:-

The power-angle characteristic is the relationship between the thrust and the power angle. Similar to other motors, the PMLSM can be represented by an equivalent circuit, and its phase equivalent circuit.



Here, Us, Is, Xs, Ei, E0, rs, Xl1, Xl2, and X1 are the voltage applied to the armature winding, the armature current, the armature reactance, the internal potential, the external potential, the coil resistance, the slot leakage reactance, the end leakage reactance, and the armature leakage reactance, respectively. Additionally, X1 = Xl1 + Xl2.
According to the positive direction specified in Fig. 3, the voltage balance equation of the PMLSM is as follows.

$$U_s = -E_0 + I_s r_s + \mathrm{j}I_s X_1 + \mathrm{j}I_s X_s \quad (1)$$

With

$$X_T = X_1 + X_s \quad (2)$$

the armature current can be calculated as follows.\

$$I_s = \frac{\left[U_s - (-E_0)\right]}{(r_s + \mathrm{j}X_T)} = I_p + \mathrm{j}I_q \quad (3)$$

Here, Ip and Iq are the active and reactive components of the armature current, respectively.
With

$$Z = \sqrt{r_s^2 + X_T^2} \quad (4)$$

the electromagnetic power can be calculated as follows.

$$P_m = 3E_0 I_p = \frac{3[(E_0 U_s \cos\theta - E_0^2) r_s + X_T E_0 U_s \sin\theta]}{Z^2} \quad (5)$$

Here, Z is impedance. Normally, for permanent magnet rotating motors, rs ≪ XT. For the PMLSM, when the resistance is ignored and Pm = Fxvs is substituted into (5), the mathematical relationship between the thrust and the power angle of the PMLSM is as follows.

$$F_x = 3\frac{E_0 U_s}{v_s X_T}\sin\theta$$

CONTROL RANGE AND VAR RATING

CONTROL RANGE:

Range Control. Means of expanding the pattern obtained on the CRT so that any portion of the total distance being tested can be presented.

Range safety duties vary from installation0level program management (RSO assigned to the installation/wing) to on-site safety oversight performed by the RSO, Range Control Officer (RCO) or activity manager during execution.

Work schedule changes that include additional shifts require 7 days notice.Accommodate military traffic, personnel and recreational users as directed by Range Control.

VAR RATING:

In electric power transmission and distribution, volt-ampere reactive (var) is a unit of measurement of reactive power.

Reactive power exists in an AC circuit when the current and voltage are not in phase. The term var was proposed by the Romanian electrical engineer Constantin Budeanu and introduced in 1930 by the IEC in Stockholm, which has adopted it as the unit for reactive power.

Where a reactive (capacitive or inductive) component is present in the load, the apparent power is greater than the real power as voltage and current are no longer in phase. In the limiting case of a purely reactive load, current is drawn but no power is dissipated in the load.

CAPABILITY TO PROVIDE REACTIVE POWER COMPENSATION

- Reactive power is an essential component of an electric power systems: without it, rotating machines could not rotate, and transmission lines could not transmit active power.

- The ability to control or compensate reactive power has many benefits.

- Reactive compensation is the process of adding or injecting positive and/or negative VAr's to a power system to essentially attain voltage control.
- Depending upon the application, reactive compensation can be achieved passively with capacitors and reactors or actively with power electronic solutions such as STATCOMS.

EXTERNAL CONTROL

- An external control is any sort of influence from outside of an organization that affects how it operates.
- External controls specifically focus on regulating on a company's governance policies, such as hiring policies and safety procedures.
- They include direct rules, such as government regulations, and indirect pressure, such as scrutiny from the media.
- An external control can change a business's internal policies, encourage an organization to comply with industry practices or influence the relationship between a company and its business partners.
- External controls are also important for anyone who works in a compliance role, because compliance professionals need to understand all relevant laws and regulations when determining if their team, department or project meets all necessary requirements.

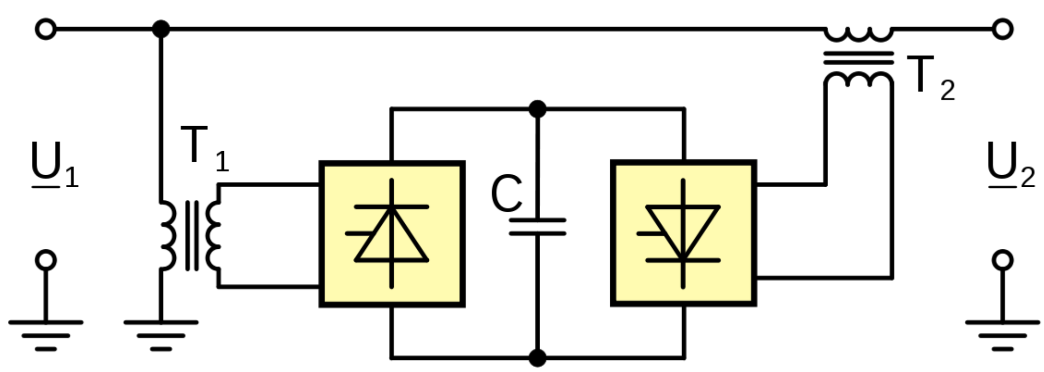
UNIT-V

COMBINED COMPENSATORS

INTRODUCTION TO UNIFIED POWER FLOW CONTROLLER

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.

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 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. The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system.

BASIC OPERATING PRINCIPLES:-

The UPFC is the most versatile FACTS controller developed so far, with all encompassing capabilities of voltage regulation, series compensation, and phase shifting.

It can independently and very rapidly control both real- and reactive power flows in a transmission.

It is configured as shown in Fig. and comprises two VSCs coupled through a common dc terminal.

The implementation of the UPFC using two “back – to –back” VSCs with a common DC-terminal capacitor

One VSC converter 1 is connected in shunt with the line through a coupling transformer; the other VSC converter 2 is inserted in series with the transmission line through an interface transformer.

CONVENTIONAL CONTROL CAPABILITIES:-

- The UPFC is the mostly common and complex power electronic equipment used to control the power flow through transmission systems.
- This paper presents the application of this technology to control the power flow in a part of the Libyan 220 kv ring around Tripoli centre and specifically to reduce the loading of a highly loaded transmission line.
- Capability is the ability of the process to produce output that meets specifications.
- A process is said to be capable if nearly 100% of the output from the process is within the specifications. A process can be in control, yet fail to meet specification requirements.

INDEPENDENT CONTROL OF REAL & REACTIVE POWER

INDEPENDENT CONTROL OF REAL POWER:-

Real power: The real power in a power system is being controlled by controlling the driving torque of the individual turbines of the system.

Real power is the one which converts the electrical energy into other forms of energy. Apparent power provides the total power i.e. active power as well as reactive power in the circuit.

Real power is affected by the power factor of the circuit or load. Apparent power is independent of the circuit power factor.

electrical devices that only consume real power are electric stoves, hairdryers, electric water heaters, and toasters.

INDEPENDENT CONTROL OF REACTIVE POWER:-

Reactive power is the part of complex power that corresponds to storage and retrieval of energy rather than consumption.
On an AC power system, there are two kinds of power - real power that actually does work, and reactive power that enables transformers to transform, generators to generate, and motors to rotate.

Capacitors can be used to intercept the reactive power from inductive motors, and return it to the source on the next cycle.

Reactive power is the part of complex power that corresponds to storage and retrieval of energy rather than consumption.