Introduction

Power industry is required to generate both real & reactive power. Reactive power is required to excite the various types of electrical equipment, in addition to energizing the transmission network. Reactive power has been recognized as a significant factor in the design & operation of alternating current systems for a long time.

The Requirement of Reactive Power

The reactive power requirement of the consumers is mainly lagging vars to supply magnetizing current to transformers & induction motors. In the transmission network, requirement is the difference between that absorbed in the series inductance & that produced in the shunt capacitance. There is a level of loading at which the leading vars of charging current balance the lagging vars of the inductive lines, called natural or surge impedance loading of the system. The reactive power compensation of the transmission system depends on the load & its power factor. For long distance transmission of power, the use of HVDC transmission has proved economical in certain cases. The var demand of dc terminals varies usually from 0-60% of the MW rating of the dc lines as power transfer is varied over its full range. When a fault takes place on the nearby ac system, the var demand of the dc link may reach a high value & unless compensated may produce large ac voltage variations.

Reactive Power Generation in Power Plants

The generator can absorb & produce reactive power while supplying the rated power to the load. A reduction of active power load on the generator increases both its reactive absorption & production capability.
Transmission Lines - The efficacy factor

Long transmission lines present a problem of unequal voltage along the length. Once energized shunt capacitance of the line becomes a source of reactive power (var). Under low load conditions the var generation exceeds the var consumption. Without compensation, under light load conditions the endpoint voltage may exceed the upper permissible voltage limit.

This is solved by connection of shunt reactors. Controlled shunt compensation of long lines improve the voltage profile. It also enhances the power transfer capability of a long line by giving voltage support.

Shunt Reactors - The rescue operation

Shunt reactors can be classified as ‘normally in service’ type or ‘switched in, switched off’ type. If the reactor is kept normally in service, during peak load time the excitation of generator can be increased & consequently the stability of the system. Under service fault condition the reactor may be switched off as a further measure to improve the margins of stability. This disconnection momentarily increases the voltage of the network. The use of shunt reactors in normal service may also result in poor voltage levels in the underlying systems & increase system losses.

Under heavy load conditions the voltage may dip below the lower permissible limit. The voltage profile of the line becomes flat at surge impedance load (SIL). In practice, on account of the transient stability considerations the permissible loading of long lines are kept below surge impedance load & therefore problem is to restrict overvoltage along the length of the line.

Switched-in reactor is normally used when system voltages are required to be controlled. The amount of reactance to be switched in at a time must be limited to suitable value otherwise it may result in objectionable voltage fluctuations in the entire system. For switching in & switching off the shunt reactor, protective gears should be more reliable. The switched-in, switched-out type of reactor is sometimes connected to a low voltage tertiary winding of a large transformer. The tertiary connected low voltage reactor is obviously cheaper but, it causes extra losses in the transformer. Its rated voltage must be carefully selected because of the large voltage drop in the series reactance of the transformer between high voltage & tertiary winding. Modern systems normally
neutral points grounded. Neutral earthing reactor is one of the means to ground the neutral. There is no idea in purposely increasing the grounding reactance of the system beyond that required to keep currents within non-destructive range, except of course for the special case of ground fault neutralisers used in resonant grounding. In the transmission systems which require single pole opening & reclosing of the EHV lines from the consideration of transient stability, successful single pole reclosing requires that extinction of secondary arc & the deionization of arc path in faulty phase should occur before reclosure is effected. In this case it may be necessary to reduce secondary arc current & thus may call for compensation of phase to phase & phase to ground capacitance of the line. In EHV system this is achieved by installing a single phase shunt reactor between neutral point of EHV reactor & the earth.

Synchronous Condensers - The technique of yesteryears

Synchronous motors are connected to the system at appropriate places only for the purpose of controlling vars. These machines operate on no-load with adjustable excitation. They are normally used with voltage regulators which operate when the voltage deviates by a certain predetermined percentage of system voltage. These are capable of giving dynamic reactive power compensation i.e. they make available the reactive power within a short time.

Series Capacitors - The trendsetter

Series capacitors compensate the line reactance in long overhead lines & thus improve the stability limit. By connecting series capacitors into the line, a corresponding capacitive voltage drop is obtained. Since the drop in voltage, both over the series capacitor & the line impedance is proportional to the load current, voltage control is instantaneous & self-regulating.

This means that the voltage can be kept constant even in the case of rapid variations in load. In case of overcurrent, the series capacitor is by-passed, and hence there will be no rise in the short circuit current of the line.

Tap-changing Transformers

Tap changing transformers with variable transformation ratio can cause substantial change in the flow of vars. The tap-changing transformers when used in radial lines maintain voltage at their secondary terminals or at load terminals within limits. When used in tie lines, the tap-changer can regulate vars substantially. In case of weaker tie lines active power may also change to some extent. When two or more transformers of similar impedance are operated in parallel they will each provide an equal share of the load current. In the event of one of these transformers changing to a higher tapping position, a circulating current will flow between this transformer & the remaining units. This circulating current will appear as a lagging current from the unit which has changed taps. It will be equally divided between the other transformers which are in parallel & will appear to these transformers as a leading current. It is possible by judicious connection of current transformers to separate this circulating current from the load current & introduce it into components in the automatic voltage regulating circuit. These are so connected into the AVR circuit such as to provide an additional voltage to the AVR which has tapped up & a subtractive voltage to the remaining AVR’s controlling the parallel-connected transformers. Using this method &

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**Diagram:**

- C - Capacitor bank
- Z - Metal Oxide Varistor (MOV)
- D - Current limiting reactor
- G - Triggered spark-gap
- DOCT - Digital Optical Current Transducer
- B - By-pass switch
carefully adjusted components, transformers can be kept within close tapping positions of each other. Lastly, when used in networks or loops, circulating vars can be controlled by tap-changing transformer. At low loads, the reactive losses in transformers are also low. The surplus generated by the system at such low loads can be absorbed by increased reactive power losses in transformers using tap staggering. If the taps on the transformers are staggered, a quadrature current circulates around the transformers & carries additional reactive losses. With more number of transformers operating, the levels could be increased by this method.

Modern Technique - The Static VAR Compensator

In a power system there is a continuous variation of reactive power with variation in load. Mostly power is reactive lagging & sometimes it is reactive leading. Therefore, an automatic device is required which may sense the reactive power requirement & its automatic control is carried out. Circuit-breakers are not capable for repeated switching during voltage variation. A SVC is a parallel combination of var absorption component (reactor) & var generation component (capacitor).

Static thyristor controlled compensator operate essentially as variable reactances (capacitive & inductive impedances) as per the reactive power demand of the system. Thyristors are used for switching devices for the capacitor & the inductor in place of circuit-breakers. As the thyristor operation is very fast, so compensation can be controlled within a short period of a few milliseconds. During heavy load on transmission line the thyristors of capacitor control supply more current by conducting for a longer period in each cycle. During low loads the thyristors in reactor circuit conduct current for longer period in each cycle. The change in capacitor current & reactor current is brought about by varying the firing angle of thyristors.

Arc Furnace —The troublemaker

For efficient use of electrical power in the steelmaker’s arc furnace, a unique combination of problems must be solved, particularly in voltage stabilization, but also in power factor correction & harmonic filtering. While voltage stabilization is always a benefit to the steelmaker, to the supply utility it may be necessary as a remedy for voltage disturbances caused by the rapid, large & erratic variations in furnace current. Such disturbances might otherwise be a nuisance to neighbouring customers. Methods that have been used for voltage stabilisation include
connection at a higher network voltage, synchronous condensers with buffer reactors and modern high speed thyristor-controlled & saturated-reactor compensator. The rapid response of high speed compensators helps to resolve the conflict between furnace performance & flicker reduction which is met with the synchronous condenser / buffer reactor combination.

SVC provides fast & accurate control to maintain constant terminal voltage in a substation by supplying required reactive power into the system over a wide range of loading conditions. An electric furnace is a troublesome load for some utilities. The arc furnace current is quite distorted in the early & mid stages of the melt which create lamp flicker & voltage dip. SVC’s are used for rapid change in reactive power compensation & are connected in parallel with the load. The design of these SVC’s are such that compensation of the load occurs in steps of one half cycle or more of the power frequency. When a load is suddenly disconnected due to fault or any other reason a sudden voltage rise is experienced at the receiving end substation. SVC in such condition provides a quick change in reactive power compensation & within a few cycles it regulates the voltage. There is a delicate balance existing between reactive power requirement & reactive power generated by various sources. Any disturbance can upset the balance. If there is no source of reactive power supply nearby to regulate the voltage & maintain reactive balance there is a risk to voltage stability. The SVC provides a reactive power swing in case there is a sudden loss of generation or tripping of a line & saves the system from going to the unstable state.

**FACTS - Technique par excellence**

Flexible Alternating Current Transmission System (FACTS) is an emerging technology for better management of power system world over. High powered electronic controllers based on a variety of thyristor devices constitute the control technology of FACTS in which power flow is controlled in transmission circuits, allowing secure loading of transmission lines to their full thermal capacity. Technical advances in electric power transmission during the past three decades made it possible to transmit large blocks of electric energy over long distances. The rapid increase in extra high voltage (EHV) transmission capability met not only the increasing load requirements but also helped reliability of bulk power supply. Key FACTS controllers are ‘Thyristor Controlled Series & Shunt Capacitors’, ‘Static var Compensator with Thyristor Controlled Reactors & Thyristor Switched Capacitors’. The system basically has controllable series compensation & controllable shunt compensation located at intermediate substations. By rapid control of series compensation the power flow is rapidly controlled. By rapid control of shunt compensation voltage profile is rapidly controlled. By using both series & shunt compensation judiciously, both voltage & dynamic stability are improved.

*Superconducting Magnetic Energy Storage*
FLEXIBLE AC TRANSMISSION SYSTEM (FACTS) BLOCK DIAGRAM

Power Flow Equation

\[ P = \frac{V_1 V_2}{X} \sin(\delta_1 - \delta_2) \]

Static Synchronous Compensator (STATCOM)

Static Synchronous Series Compensator (SSC)

Converter-Based Voltage Regulator

Converter-Based Phase Angle Regulator
## COMPARISON OF REACTIVE POWER SUPPLY SYSTEMS

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### POWER EQUATION

\[ P = \left(\frac{V_1 \cdot V_2}{X}\right) \sin \delta \]

### SUPPLY SYSTEM

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### FACTS EQUIPMENT

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<td>very effective</td>
<td>effective</td>
<td>effective</td>
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<tr>
<td>HSPS</td>
<td>-</td>
<td>very effective</td>
<td>-</td>
<td>very effective</td>
</tr>
<tr>
<td>FWG / SMES</td>
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<td>very effective</td>
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<tr>
<td>SVC</td>
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<td>effective</td>
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<td>-</td>
</tr>
<tr>
<td>BTB (HVDC)</td>
<td>very effective</td>
<td>very effective</td>
<td>effective</td>
<td>-</td>
</tr>
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### FACTS EQUIPMENTS

- FWG — ADJUSTABLE SPEED ROTARY CONDENSOR
- SDR — SYSTEM DAMPING RESISTOR
- SVC — STATIC VAR COMPENSATOR
- TCSC — THYRISTOR CONTROLLED SERIES CAPACITOR
- HSPS — HIGH SPEED PHASE SHIFTER
- SMES — SUPERCONDUCTING MAGNETIC ENERGY STORAGE
- BTB — BACK TO BACK (HVDC SYSTEMS)