FACTS & HVDC   Prof - V.P. More

Unit : 02

Static Shunt Compensator ①

Content :

Objectives of the shunt compensation, method of controller VAR generation, static VAR compensators : SVC & STATCOM, comparison betn STATCOM & SVC.

— Objectives of shunt compensation :

i) To increase the steady state transmittable power & voltage profile along the line controlled by appropriate reactive shunt compensation.

ii) To change the natural electrical characteristics of the transmission line to make it more compatible with the load demand.

iii) To improve the stability of the system.

iv) To minimize the overvoltage under light load conditions by shunt connected, fixed or mechanically switched reactors.

v) To maintain voltage levels under heavy load conditions, by shunt connected, fixed or mechanically switched capacitors.

vi) Shunt VAR compensation is thus used for voltage regulation at the midpoint (or some intermediate) to segment the transmission line & at the end of the line to prevent voltage instability, as well as for dynamic voltage control to increase transient stability & damp power oscillations.

— Midpoint voltage regulation for line segmentation :

The shunt compensator is represented by a sinusoidal AC voltage source in-phase with the midpoint voltage V_m, and with an amplitude of the sending & receiving end voltages ($V_m = V_s = V_r = V$)

Consider the simple two-machine transmission model in which an ideal VAR compensator is shunt connected at the midpoint of transmission line as shown in fig ⓐ below. For simplicity, the line is represented by series line inductance.

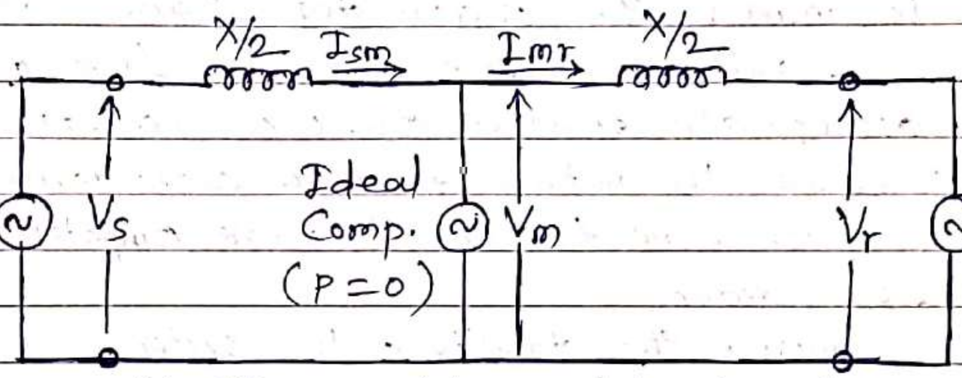
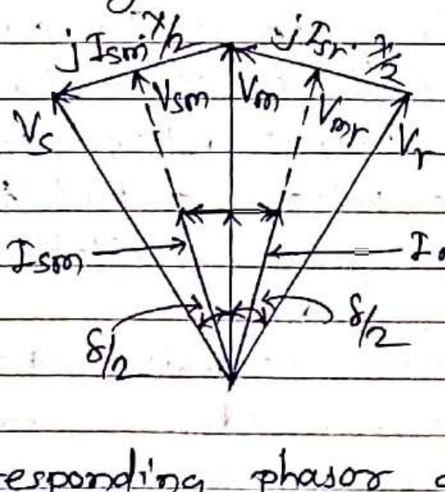


fig ⓐ Two machine model with shunt compensator.

The midpoint compensator in effect segments the transmission line into two independent parts: the first segment, with an impedance of $X/2$, carries power from sending end to midpoint, and the second segment, also with an impedance of $X/2$, carries power from midpoint to receiving end.



$|V_s| = |V_r| = |V_m| = V$

fig. ⓑ Corresponding phasor diagm.

The relationship between voltages V_s, V_r, V_m, V_{sm}, V_{mr} & line segments currents I_{sm} & I_{mr} is shown by the phasor diagram (fig. (b)).

V_{sm} & V_{mr} are voltage at respective reactance.

Power at middle, $P_p = V_{sm} \cdot I_{sm}$ —— (1)

from phasor diagram,

$$\cos\left(\delta/4\right) = \frac{V_{sm}}{V}$$

$$\therefore V_{sm} = V\cos\left(\delta/4\right) \text{ —— (2)}$$

$$\sin\left(\delta/4\right) = j I_{sm}\left(\frac{X}{4}\right)/V$$

$$\therefore I_{sm} = \frac{4V\sin\left(\delta/4\right)}{X} \text{ —— (3)}$$

from eqn (1)

$$P_p = V\cdot\cos\left(\delta/4\right) \times \frac{4V\sin\left(\delta/4\right)}{X}$$

$$= \frac{4V^2 \cdot \sin\left(\delta/4\right)\cdot\cos\left(\delta/4\right)}{X}$$

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

$$\left\{\because \sin A\cos B = \frac{1}{2}\left[\sin(A-B)+\sin(A+B)\right]\right\}$$

$$= \frac{2V^2}{X}\cdot\sin\left(\frac{\delta}{2}\right) \text{ —— (4)}$$

So, eqn (4) represents transmitted power due to shunt compensator, so we can write, by using shunt compensator, we can increase the transmittable power to its double.

Similarly, the reactive power is given by,

$$Q = \frac{4V^2}{X}\left(1 - \cos\frac{\delta}{2}\right) \quad \text{--- (5)}$$

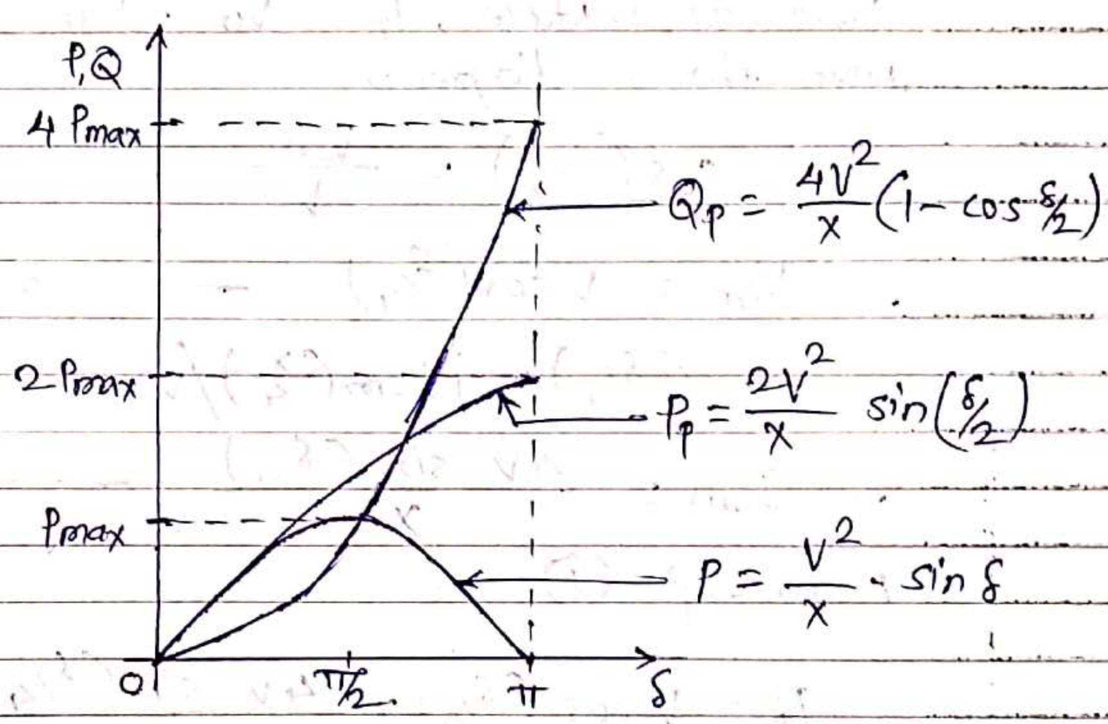


Fig. (c) Power transmission vs. angle characteristics

The relationship betn real power P, reactive power Q & angle δ for the case of ideal shunt compensation is shown in fig. (c).

It can be observed that the midpoint shunt compensation can significantly increase the transmittable power (doubling its max. value) as shown by curve P_p.

— Methods of controllable VAR generation :-

Capacitors generates reactive power while reactors absorb. Mechanical switches with bulky capacitors or reactors are used for VAR generation and absorption. Rotating synchronous machines were used for VAR compensation under dynamic condition. SCRs with bulky capacitors or reactors are used to provide variable reactive power compensation by synchronsly switching them. Static VAR compensators based on power electronics switches are modern FACTS controllers. There are two methods of controllable VAR generation.

1. Variable impedance ~~type~~ static VAR generators :
2. Switching converter ~~type~~ VAR generators.

1. Variable impedance type static VAR generators :-

The performance & operating characteristics of impedance type VAR generators are determined by their major thyristor controlled constituents: the thyristor controlled reactor & thyristor switched capacitor.

i) Thyristor controlled Reactor & Thyristor switched Reactor (TCR & TSR) :

- Thyristor Controlled Reactor : (TCR)

A shunt connected thyristor controlled inductor whose effective reactance is varied in a continuous manner by partial conduction control of thyristor switch.

TCR is a subset of SVC in which conduction time & hence, current in a shunt reactor is controlled by thyristor based AC switch with firing angle control.

- Thyristor Switched Reactor: (TSR)

A shunt connected, thyristor switched inductor whose effective reactance is varied in a stepwise manner by full or zero conduction operation of the ~~th~~ thyristor switch.

TSR is another a subset of SVC. TSR is made up of several shunt connected inductors which are switched in & out by thyristor switches without any firing angle controls. In order to achieve the required step changes in the reactive power consumed from the system. Use of thyristor switches without ~~firing~~ angle control results in lower cost & losses, but without a continuous control.

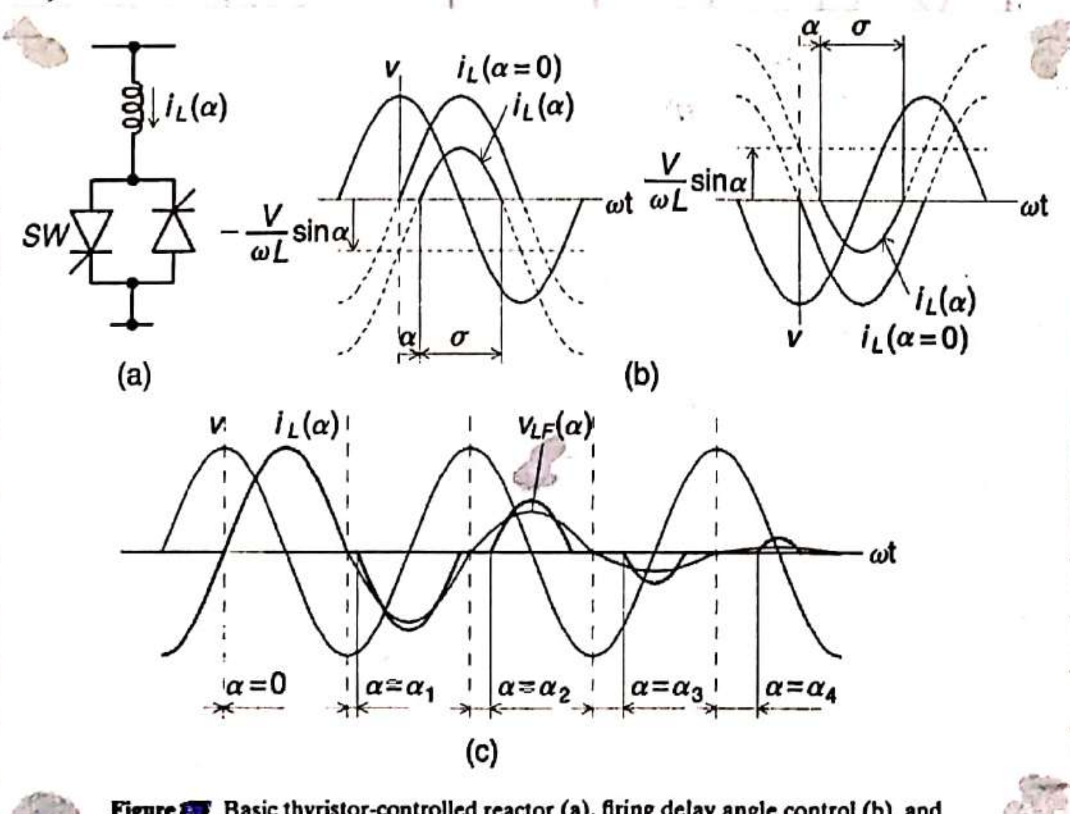


Figure Basic thyristor-controlled reactor (a), firing delay angle control (b), and operating waveforms (c).

Thyristor controlled reactor (TCR) is consist of a fixed (usually air core) reactor of inductance L, and a bidirectional thyristor switch. (fig. a)

TCR used to absorb the excess reactive power in the system.

Currently available thyristors have 4 KV to 10 KV voltage rating & current rating is 3 KA to 6 KA. To meet the required blocking voltage & current in real power system, the series & parallel connection of thyristors are used.

Reactive power absorbed by TCR is proportional to the current flowing through inductor ($i_L(\alpha)$).

The current in the reactor can be controlled from max. (thyristor switched closed) to zero (thyristor switch open) by the method of firing delay angle control.

Firing angle of TCR is varying from $0^\circ \le \alpha \le 90^\circ$. It can't able to varing from 0° to 180°, unlike AC voltage regulator.

This method of current control is illustrated separately for the positive & negative current half cycles in fig. b

When $\alpha = 0$, the switch closes at the peak of applied voltage & evidently the resulting current in the reactor will be the same as that obtained in steady state with a permanently closed switch.

Magnitude of current in reactor can be varied continuously from max. to zero as shown in fig. c

When thyristor firing is delayed by an angle, α, ($0 \le \alpha \le 90^\circ$) with respect to peak of supply voltage, the current in the reactor can be expressed with,

$$v(t) = V \cos \omega t$$

$$\therefore i_L(t) = \frac{1}{L}\int_{\alpha}^{\omega t} v(t) \cdot dt$$

$$= \frac{1}{L}\int_{\alpha}^{\omega t} V \cos \omega t \cdot dt$$

$$\therefore i_L(t) = \frac{V}{\omega L}(\sin \omega t - \sin \alpha)$$

This eq^n is valid for the interval of ($\alpha \leq \omega t \leq \pi - \alpha$).

Fundamental reactor current & susceptance:

The fundamental reactor current $I_{LF}(\alpha)$ can be expressed as a function of angle α.

$$I_{LF}(\alpha) = \frac{V}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

The susceptance, as a function of angle α, can be written as,

$$B_L(\alpha) = \frac{1}{\omega L}\left(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin 2\alpha\right)$$

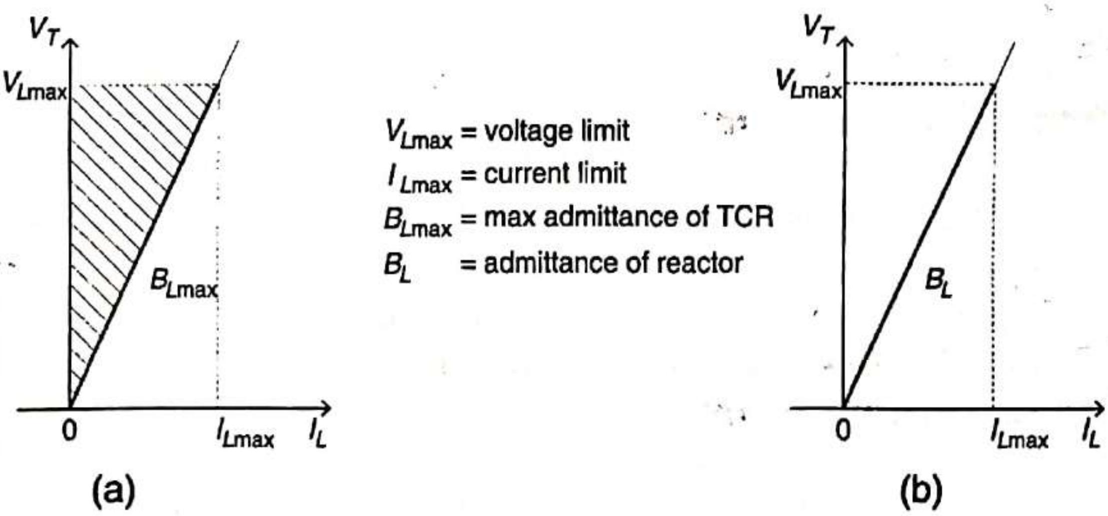


Figure Operating *V-I* area of the TCR (a) and of the TSR (b).

The practical TCR can be operated anywhere in a defined V-I area; the boundaries of which are determined by its max. attainable admittance, voltage, & current rating as shown in fig. (a) above.

If the TCR switching is restricted to a fixed delay angle, usually $\alpha = 0$, then it becomes a TSR. The TSR provides a fixed inductive admittance & thus, when connected to the AC system, the reactive current in it will be proportional to the applied voltage as the V-I plot in fig. (b).

ii) Thyristor Switched Capacitor (TSC) :-

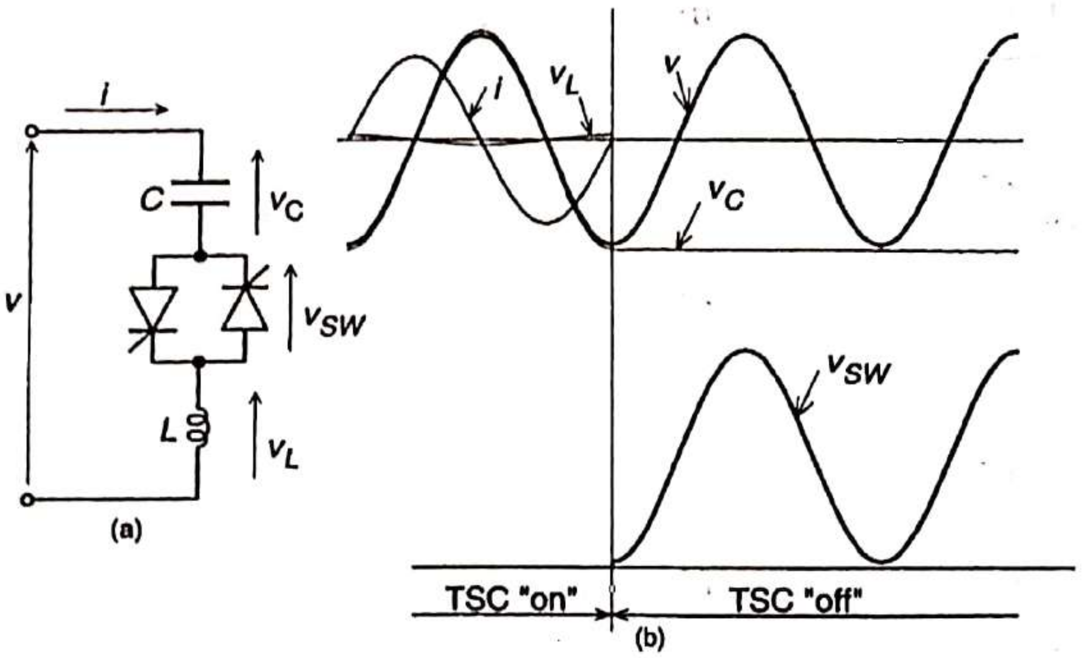


Figure [redacted] Basic thyristor-switched capacitor (a) and associated waveforms (b).

- A Thyristor Switched Capacitor (TSC) consists of a capacitor, ~~(TSC)~~ a bidirectional thyristor switch, & a relatively small surge current limiting reactor.