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Enhancement Of Voltage Profile Of Transmission Line By Using Static VAR Compensator-An Overview

J. N. Rai, Naimul Hasan*, Rishabh K. Gupta, Rahul Kapoor, Rajesh Garai
Dept. of Electrical Engineering
Delhi Technological University
Dept. of Electrical Engineering
Jamia Millia Islamia, New Delhi, India*

Abstract

One of the main prerequisite of the modern power system is the enhancement and control of voltage from varying from its desired value. For this we used many compensation techniques. In this paper a case study for a particular transmission line has been carried out to enhance and control the voltage profile using compensation. This paper presents the basic aspect of voltage profile enhancement and control without contingency by simple and efficient use of capacitor bank. The effectiveness of proposed experimental result demonstrated on model of 750 kV ,250 km,1000MW EHV lines.

Index terms--compensation, line compensation, series, shunt, static VAR compensation, contingency.

1. Introduction

In a power system, given the insignificant electrical storage, the power generation and load must balance at all times. To some extent, the electrical system is self-regulating. If generation is less than the load, voltage and frequency drop, and thereby reducing the load. However, there is only a few percent margins for such regulation. If voltage is propped up with reactive power support, then the load increase with consequent drop in frequency may result in system collapse. Alternatively, if there is inadequate reactive power, the system may have voltage collapse.

Electrical loads both generate and absorb reactive power. Since the transmitted load varies considerably from one hour to another, the reactive power balance in a grid varies as well. The result can be unacceptable voltage amplitude variations, a voltage depression, or even a voltage collapse. Therefore, transmission line require compensation for this varying reactive power.[4],[6]

2. Load Compensation

Load compensation is the management of the reactive power to improve the power quality i.e. V profile and p.f. Here the reactive power flow is controlled by installing shunt compensation devices (capacitor/reactors) at the load end bringing about power balance between generated and consumed reactive power. This is most effective in improving the power transfer capability of the system and its voltage stability. It is desirable both economically and technically to operate the system near unity power factor. This is why some utilities impose a penalty on low pf loads. Yet another way of improving the system performance is to operate it under near balanced conditions so as to reduce the flow of negative sequence currents thereby increasing the system’s load capability and reducing power loss.

A transmission line has three critical loadings (1) natural loading (2) steady state stability limit and (3) thermal limit loading. For a compensated line the natural loading is the lowest and before the thermal loading limit is reached, steady state stability is arrived.[4]

The three main objectives of load compensation are:

a) Better voltage profile
b) p.f. correction
c) load balancing.[5]

3. Line Compensation

Line compensation can be defined as the use of electrical circuits to modify the electrical characteristics of the line so that the compensated electrical lines can achieved following objectives.

a) Ferranti effect is minimized so that a flat voltage profile is observed on the line during all load conditions.

b) Under excited as well as overexcited operation of line will be avoided and an economical means of reactive power management will be achieved.

c) The power transfer capability of the system will be enhanced and system stability margins increase.

In order to assess the effectiveness a compensated system a performance index in terms of length of line and the power to be transmitted is evaluated. It is very much necessary to fix this criteria as it is not possible to load the longer length line even to their natural loadings without compensation.[5]

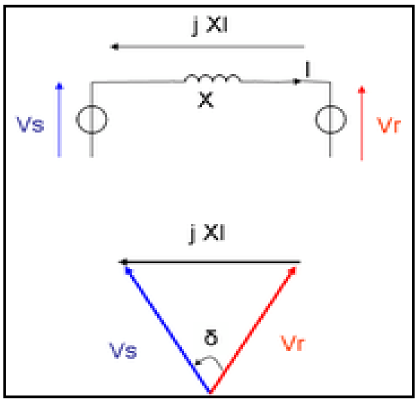


Figure1: Transmission on a no loss line

A. *SERIES COMPENSATION*

In series compensation, the FACTS is connected in series with the power system. It works as a controllable voltage source. Series inductance occurs in long transmission lines, and when a large current flow causes a large voltage drop. To compensate, series capacitors are connected. Series compensation increases transmission capacity, improve system stability, control voltage regulation and ensure proper load division among parallel feeders.[2],[7],[8]

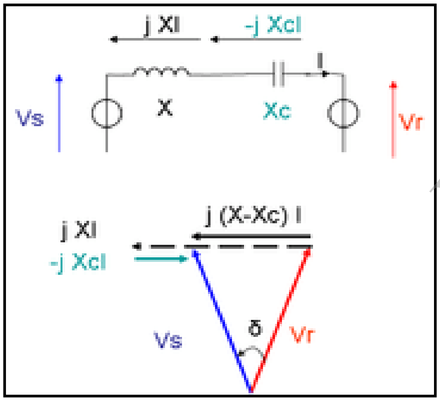


Figure 2: Series Compensation

B. *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 used to influence the natural electrical characteristics of the transmission line to increase the steady state transmittable power and to control the voltage profile of the line. [2],[7],[8]

Shunt compensation is of two types:

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, a shunt capacitor is connected which draws current leading 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 - very low current flows through the transmission line. Shunt capacitance in the transmission line causes voltage amplification (Ferranti Effect). The receiving end voltage may become double the sending end voltage (generally in case of very long transmission lines). To compensate, shunt inductors are connected across the transmission line.[2],[7],[8]

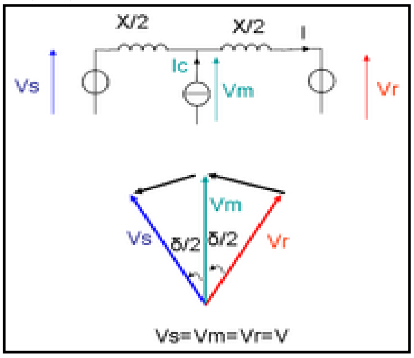


Fig.3: Shunt Compensation [10]

C. *STATIC VAR COMPENSATOR (SVC)*

A static VAR compensator is an electrical device for providing fast active, reactive power compensation on high voltage electricity transmission network. These comprise of three phase static capacitor bank fixed or switched (controlled) or fixed capacitor bank and switched reactor bank in parallel. The term 'static' refers to the fact that SVC has no moving parts. [4],[6]

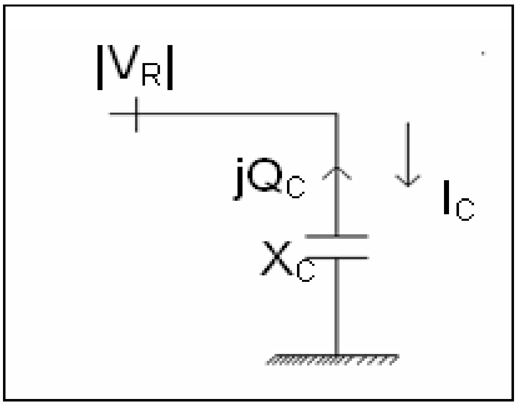


Fig.4: Static Capacitor Bank

A rapidly operating static VAR compensator (SVC) can continuously provide reactive power to control dynamic voltage swings under various system conditions and thereby improve the power system performance. Thus, these compensators draw reactive (leading or lagging) power[†] from the line there by regulating voltage, improve stability (steady state and dynamic), control over voltage and reduce voltage flicker. These also reduce voltage and current imbalances. In HVDC application these compensators provide the required reactive power and damp out sub harmonic oscillations. Since static VAR compensator use switching for VAR control. These are also called static VAR switches or systems. It means that terminology wise

SVC= SVS

and we can use these interchangeably.[4]

†A reactance connected in shunt to line at voltage V draws reactive power V^2/X. It is negative (leading) if reactance is capacitive and positive (lagging) if reactance is inductive.

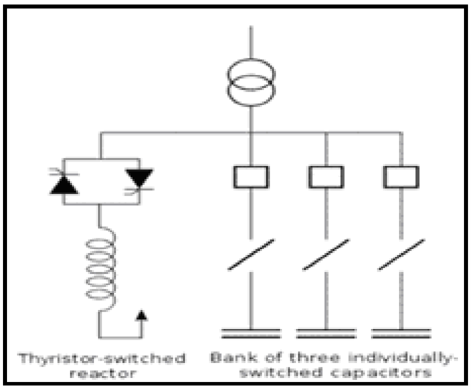


Fig.5: Typical one line diagram of a SVC

PRINCIPAL OF OPERATION

In the case of a no-loss line, voltage magnitude at receiving end is the same as voltage magnitude at sending end: $V_s = V_r = V$. Transmission results in a phase lag δ that depends on line reactance X.

$$\underline{V_s} = V\cos\left(\frac{\delta}{2}\right) + jV\sin\left(\frac{\delta}{2}\right)$$

$$\underline{V_r} = V\cos\left(\frac{\delta}{2}\right) - jV\sin\left(\frac{\delta}{2}\right)$$

$$\underline{I} = \frac{\underline{V_s} - \underline{V_r}}{jX} = \frac{2V\sin\frac{\delta}{2}}{X}$$

As it is a no-loss line, active power P is the same at any point of the line.

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

Reactive power at sending end is the opposite of reactive power at receiving end:

$$Q_s = -Q_r = Q = V\sin\left(\frac{\delta}{2}\right)\cdot\frac{2V\sin\frac{\delta}{2}}{X} = \frac{V^2}{X}(1-\cos\delta)$$

As δ is very small, active power mainly depends on δ whereas reactive power mainly depends on voltage magnitude.[10]

A. SERIES COMPENSATION

FACTS for series compensation modify line impedance: X is decreased so as to increase the transmittable active power. However, more reactive power must be provided.[10]

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

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

B. SHUNT COMPENSATION

Reactive current is injected into the line to maintain voltage magnitude. Transmittable active power is increased but more reactive power is to be provided.[10]

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

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

C. SVC TECHNOLOGY

If $|V_R|$ is in line KV and X_C is the per phase capacitive reactance of the capacitor bank on an equivalent star basis, the expression for the VARs fed into the line can be derived as under:-

$$\boldsymbol{I_C = j\frac{|V_R|}{\sqrt{3}X_C}\ \ \text{KA}}$$

$$\boldsymbol{jQ_C\ \text{(3-phase)} = 3\frac{|V_R|}{\sqrt{3}}(-I_C^*)}$$

$$\boldsymbol{= 3\frac{|V_R|}{\sqrt{3}}\times\frac{|V_R|}{\sqrt{3}}\ \text{MVA}}$$

$$\boldsymbol{Q_C\ \text{(3-phase)} = \frac{|V_R|^2}{X_C}\ \ \text{MVAr}}$$

If inductors are employed instead, VARs fed into the line are:

$$\boldsymbol{Q_C\ \text{(3-phase)} = -\frac{|V_R|^2}{X_L}\ \ \text{MVAr}}$$

Under heavy load conditions, when positive VARs are needed, capacitors are employed; while under light load conditions, negative VARs are needed, inductor banks are needed.[4]

II.EXPERIMENTAL SET UP‡

We can experimentally check the influence of capacitor bank on the voltage profile by making the given set up.

a) Make connection as shown in figure (6).

b) Switch on the power supply, keeping switch 2 and 3 in open position. Adjust sending end voltage V_S and hence V_R at about 100V by adjusting variac across supply. I_{Line} is almost zero , the switch S_2 is closed because of high impedance of voltmeter V_R.

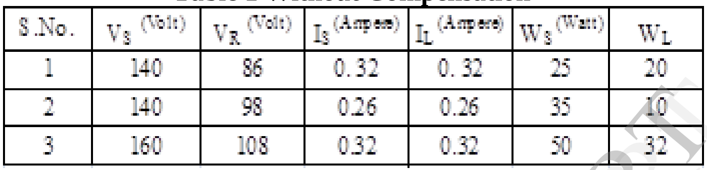
c) Switch on load by closing S_3. I_{Load} should not exceed rated wattmeter current which may otherwise get damaged. Note down V_R,V_S, I_L.

d) Close switch 3. Observe the V_R rises. Adjust capacitance values (by making parallel or series compensation) so that $V_R = V_S$ (full 100% compensation). Note V_S,V_R, I_{Line}, I_{Load} , I_C, W_S.

e) Repeat step 2 and 3 for different load voltages.

The following observations have been made as according to the table(s):

Table 1 Without Compensation



S.No.	V_S (Volt)	V_R (Volt)	I_S (Ampere)	I_L (Ampere)	W_S (Watt)	W_L
1	140	86	0. 32	0. 32	25	20
2	140	98	0.26	0.26	35	10
3	160	108	0.32	0.32	50	32

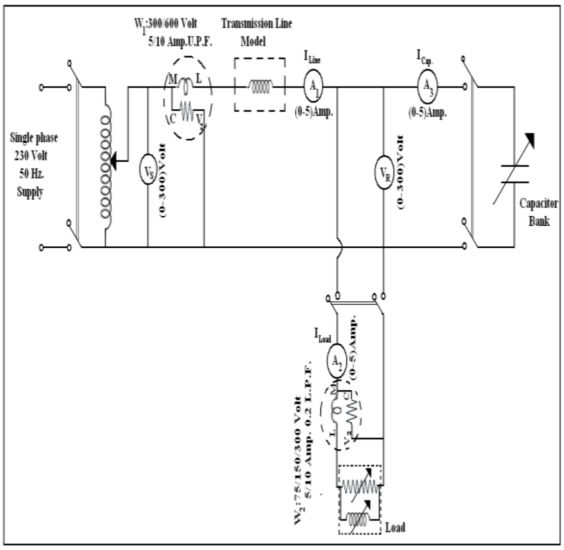


Figure 6. Model of a Transmission line with compensation

Table II: With Compensation

S.No.	V_S (Volt)	V_R (Volt)	I_S (Amp.)	I_L (Amp.)	I_C (Amp.)	W_S (Watt)	W_L (Watt)	KVARby Cap.	VARsby C*
1.	**140**	**138**	**1.58**	**0.54**	**1.54**	**120**	**70**	**1/3**	**137.16**
2.	**140**	**140**	**1.22**	**0.74**	**1.44**	**100**	**56**	**1/3**	**134.99**
3.	**160**	**164**	**1.74**	**0.52**	**1.78**	**135**	**79**	**1/3**	**185.22**

*written after calculations.

Calculations

Set 1:

Sending end VAR = $\sqrt{(V_S * I_S)^2 + (W_S)^2}$

$= \sqrt{(140*1.58)^2 + (120)^2}$

=185.82 VAR

VAR supplied by Capacitor = $1/3*1000(V_R/V_C)^2$
= $1/3*1000(138/220)^2$

=131.16 VAR

Load VAR $= \sqrt{(V_R * I_L)^2 + (W_L)^2}$

$= \sqrt{(138*0.54)^2 + (70)^2}$ = 25.56 VAR

Set 2:

Sending end VAR = $\sqrt{(140*1.22)^2 + (100)^2}$

=138.46 VAR

VAR supplied by Capacitor = $1/3*1000(140/220)^2$ = 134.16 VAR

Load VAR = $\sqrt{(140*0.74)^2 + (56)^2}$

= 87.16 VAR

Set 3:

Sending end VAR = $\sqrt{(160*1.74)^2 + (135)^2}$

= 243.40 VAR

VAR supplied by Capacitor = $1/3*1000(164/220)^2$ = 185.24 VAR

Load VAR = $\sqrt{(164*0.52)^2 + (79)^2}$

= 32.20 VAR

4. CONCLUSION & DISCUSSION

This paper described an efficient and practical method to enhance the voltage profile and control for the particular rating of transmission line. Thus we see within experimental limitations reactive power consumed by the load is equal to the reactive VAR supplied by the capacitor for 100% compensation. Since Q_C is proportional to the square of terminal voltage, for a given capacitor bank, their effectiveness tends to decrease as the voltage sags under full load conditions. Capacitor acts as short circuit when switched on. We should also take the precautions of a possibility of series resonance with the line inductance particularly at harmonic frequencies. Step less (smooth) VAR can be achieved using SCR (silicon controlled rectifier circuitry) as with them we can switch capacitor and inductor in steps.

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