© MAY 2026 | IRE Journals | Volume 9 Issue 11 | ISSN: 2456-8880
DOI: https://doi.org/10.64388/IREV9I11-1717521

Voltage and Reactive Power Control in a Power System

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Abstract- Control of reactive power and voltage is necessary in order to improve the performance of ac power systems. This is known as var compensation - defined as the management of reactive power to improve the performance of ac power systems. Traditional static var compensators (SVCs) employ reactors and capacitors. These standard reactive power elements are controlled to produce or absorb rapid and variable reactive power. Reactive power compensation can be implemented with var generators connected in parallel or in series. In this paper the principle of series reactive power compensation is the focus. There are many SVC configurations. The configuration known as thyristor-controlled series compensator (TCSC) is described, modelled and analyzed. Model equations are derived and used to demonstrate the applicability of this SVC in power system var compensation. Power electronic switching devices like the thyristor etc. are used to control the flow of reactive power. The control variable is the delay angle, of the switches. The paper shows how the application of this SVC raised the power factor of a system to unity, regulate bus voltage and consequently reduced power loss, and increased active power transfer capability of transmission or distribution line.

Keywords – Reactive Power, Static Var Compensators, Power Factor, Voltage Regulation, Power Transmission, Power Loss.

I. INTRODUCTION

Reactive power is the product of voltage and current where the voltage and current are 90o out of phase with one another. Most loads are inductive, and draw lagging reactive power, making electric power system voltage to sag, whereas under light loads, the shunt capacitance of long lines can become dominant and can create excessive leading reactive power, causing the voltage at some locations to rise above the nominal value. The current associated with this reactive power flows through the conductor and cause extra losses. At the distribution level, about 13% of the generated power is lost as ohmic losses [1]. These losses can be reduced by installing SVCs at appropriate locations. The reactive power generated by the ac power source is stored in a capacitor or a reactor during a quarter of a cycle, and in the next quarter cycle is sent back to the power source. In other words, the reactive power oscillates between the ac source and the capacitor or reactor, and also between them, at a frequency equal to two times the rated value (50 or 60 Hz) [2]-[4]. For this reason var generators can be used to control the flow of reactive power so that its oscillation between the load (inductive or capacitive) and the source can be avoided, thereby improving voltage stability of the power system. Var compensation can be implemented either in shunt mode or in series mode. In the shunt mode, the SVC is connected in parallel with and near the load. Supplying reactive power near the load reduces or minimizes the line current, and consequently reduces power losses and improves voltage regulation at the load terminals. In series compensation, SVCs are connected in series with the load. Typical series compensation systems use capacitors to decrease the equivalent reactance of a power line at rated frequency. The connection of a series capacitor generates reactive power that, in a self-regulated manner, balances a fraction of the line's transfer reactance [5]-[6]. This paper is intended to investigate the principles of operation and compensation characteristics of a series compensator known as thyristor-controlled series compensator (TCSC). It addresses the problem of determining the values of the TCSC circuit components to obtain optimum power factor and voltage regulation. The equations which describe the performance of the TCSC are derived, and used to determine the steady-state rating of the main components of the TCSC.

The result of applying this SVC to power system is improved functionality of the power transmission system through: (i) reduction of losses in the system by improving the power factor, (ii) improvement of transient stability by providing voltage support, (iii) enhancement of angular stability of the power corridor by compensating for varying loads, and (iv) enhancement of active power transfer capability of the transmission system [7]-[9].

II. MATERIALS AND METHODS

2.1 Power Transmission

Generating stations are often located far from load centers for economic, environmental, and safety reasons. So, power electronic-based equipment known as flexible AC transmission systems (FACTS) are incorporated in the transmission network to enhance controllability and power system operation flexibility which improves system stability [10]. Fig. 1 is a transmission system without compensation, operating at lagging power factor of . Fig. 2 shows the associated phasor diagram.

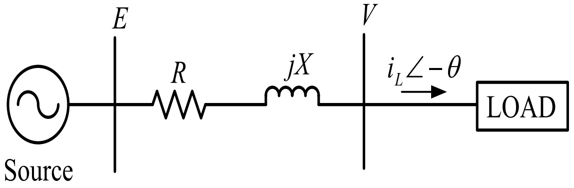

Fig. 1 Transmission system without var compensation

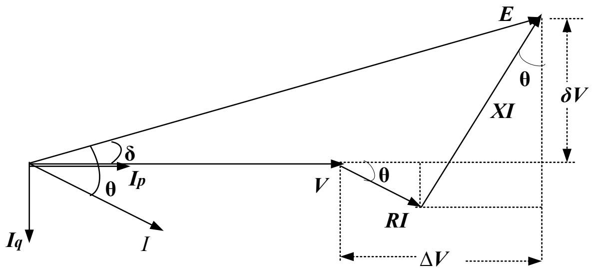

Fig. 2 Phasor diagram of Fig.1.

From the phasor diagram:

$$E^2 = (V+\Delta V)^2 + (\delta V)^2 \quad (1)$$

$$E^2 = \left(V + RI\cos\theta + XI\sin\theta\right)^2 + \left(XI\cos\theta - RI\sin\theta\right)^2 \quad (2)$$

$$E^2 = \left(V + \frac{RP}{V} + \frac{XQ}{V}\right)^2 + \left(\frac{XP}{V} - \frac{RQ}{V}\right)^2 \quad (3)$$

E = source voltage, V = receiving-end voltage, I = line current, θ = power factor angle,
P = active power, Q = reactive power, R = line resistance, X = line reactance.

It can be noticed in Fig. 2 that is usually much less than , $(V+\Delta V)$ so from Equation (3):

$$E \approx \left(V + \frac{RP}{V} + \frac{XQ}{V}\right) \quad (4)$$

Thus, the voltage drop on the line is:

$$\Delta V = E - V = \frac{RP + XQ}{V} \quad (5)$$

And,

$$\delta V = \frac{XP - RQ}{V} \quad (6)$$

From Equation (4)

$$V^2 = VE - RP - XQ \quad (7)$$

If R is neglected (often the resistance of lines is negligible compared with reactance), Equations (5) and (6) become:

$$\Delta V = \frac{XQ}{V} \quad (8)$$

$$\delta V = \frac{XP}{V} \quad (9)$$

The angle of transmission,

$$\delta = \sin^{-1}\left(\frac{\delta V}{E}\right) \quad (10)$$

$$\theta = \tan^{-1}\left(\frac{Q}{P}\right) \quad (11)$$

Power factor = $\cos(\theta)$ (!2)

Thus, Equation (7) shows that the phase voltage, at a node is a function of the active power, P and reactive power, flowing on the line. The higher the reactive power transmitted, the lower the receiving-end voltage. In other words, voltage drop, on the transmission line increases with increase in reactive power as shown by Equations (5) and (8).

Poor power factor in transmission and distribution networks result in poor voltage profile at the receiving-end, and network losses, costing millions of dollars every year [11]. Any modest reduction in transmission losses, by limiting the flow of load reactive current along the transmission lines, means considerable cost savings in both power capacity and energy production [12]. In Electrical Power System, Static VAr Compensators (SVCs) are used to control the flow of reactive power. They generate or absorb reactive power in order to compensate for the reactive power drawn by loads. An SVC is installed at one or more suitable points in the network to regulate the voltage at that point, and compensate for poor power factor, thereby reducing power losses.

2.2. TCSC Configuration

Fig. 3 shows a thyristor-controlled series compensator (TCSC) system connected to the network in order to mitigate the effects of reactive power. In the TCSC, capacitor is inserted directly into the transmission line and Thyristor-Controlled Reactor (TCR) is mounted in parallel with the capacitor. TCR is a shunt-connected thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor. TCR has been in use as one of the economical FACTS controllers [13]. Firing angle of back-to-back thyristors are controlled to control the reactor current. At 180° firing angle TCR, is non- conducting and at 90° firing angle TCR is in full conduction [14].

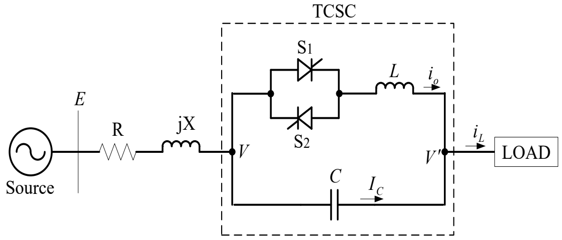

Fig. 3 TCSC Configuration.

The TCSC provides a capacitive reactance, and changes the system apparent impedance (as seen by the line current). Both these objectives are achieved with the TCSC, using controls that function on the thyristor circuit, which is in parallel to the main capacitor bank (C). Thus, the TCSC is a capacitive reactance compensator, which consists of a series capacitor bank shunted by a thyristor-switched reactor to provide a stepwise control of series capacitive reactance. The capacitor acts like a variable capacitor at fundamental frequency [15]-[16].

III. RESULTS AND DISCUSSION

Equation (7) is plotted as shown in Fig. 4, where E = 33kV, P=5MW, R = 10Ω, X = 30Ω. Fig. 4 shows that the voltage, at the receiving-end is in inverse proportion to the reactive power, flowing on the line.

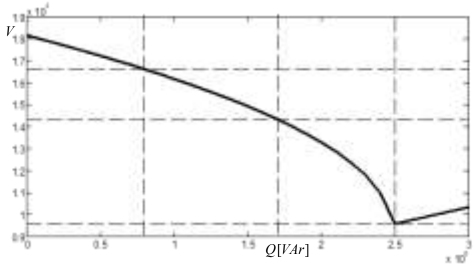

Fig. 4 Plot of reactive power versus receiving-end voltage

The dashed vertical and horizontal lines show reactive powers and the corresponding voltages as (0.8MVAr, 16603V), (1.7MVAr, 14331V), (2.5MVAr, 9574V). Fig.5 is the plot of Equation (5), where it is shown that the voltage drop on the line increases with increase in reactive power. The corresponding voltage drops with Fig. 4 are 2449V, 4722V, 9478V respectively.

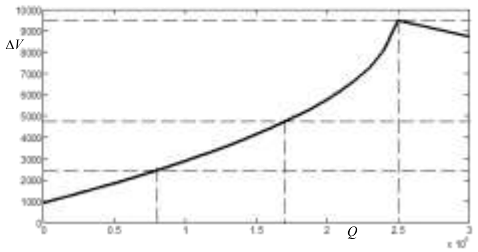

Fig. 5 Reactive power versus voltage drop

The reactive power versus power factor is plotted as in Fig. 6, which shows, like Fig. 4, that power factor decreases with increase in reactive power transmitted, and leads to poor performance of the transmission lines. The dashed vertical and horizontal lines show reactive powers and corresponding power factors as (0.8MVAr, 0.9), (1.7MVAr, 0.7), (2.5MVAr, 0.56).

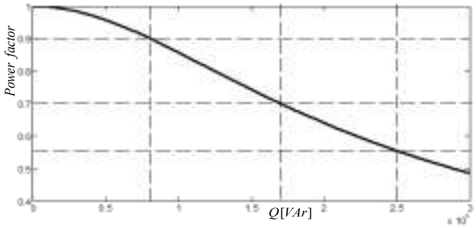

Fig. 6 Plot of reactive power versus power factor

Fig. 7 shows the reactive power, active power, and voltage relationship.

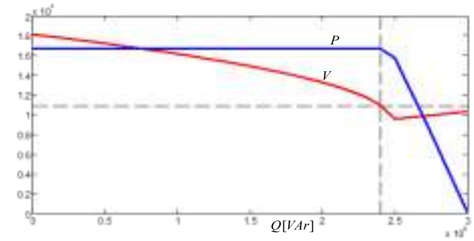

Fig. 7 Plot of reactive power versus voltage and active power

It can be noticed in Fig. 7 that the active power P begins to drop significantly when the reactive power transmitted is 2.4MVAr, and the corresponding receiving-end voltage is 10970V. This corresponds to power factor of 0.57 in Fig. 6. This is the minimum operating power factor of the line. In other words, below the power factor of 0.57, the line can no longer support up to 5MW. The voltage 10970V is known as the critical voltage. Below this voltage, asynchronous loads like induction motors may become unstable and stall. This is voltage instability. The system voltage and the line current are shown in Fig. 8 for operating power factor of 0.7 and power factor angle.

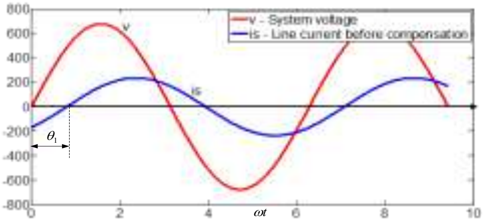

Fig. 8 The system voltage and the line current before compensation

From Fig. 3, The inductor voltage can be expressed in Fourier series as:

$$v_o = \frac{a_o}{2} + \sum_{n=1}^{\infty}\left(a_n \cos n\omega t + b_n \sin n\omega t\right) \qquad (13)$$

Where

$$a_o = \frac{1}{2\pi}\int V_m \sin \omega t \, d(\omega t) = \frac{2V_m}{\pi}\cos\alpha \qquad (14)$$

$$a_n = \frac{2V_m}{\pi}\left[\frac{\cos(n+1)\alpha}{n+1} - \frac{\cos(n-1)\alpha}{n-1}\right] \qquad (15)$$

$$b_n = \frac{2V_m}{\pi}\left[\frac{\sin(n+1)\alpha}{n+1} - \frac{\sin(n-1)\alpha}{n-1}\right] \qquad (16)$$

The inductor voltage is shown in Fig. 9

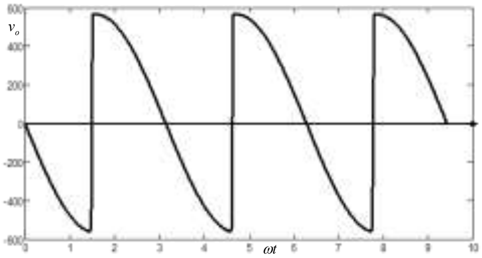

Fig. 9 Inductor voltage

The inductor current is given from Equation (13) as:

$$i_o = I_o + \sum_{n=2,4,6,\ldots}^{\infty}\left(\frac{a_n}{z_n}\cos(n\omega t - \theta_n) + \frac{b_n}{z_n}\sin(n\omega t - \theta_n)\right)$$

(17)

$$Z_n = \sqrt{R^2 + (n\omega L)^2} \qquad \theta_n = \tan^{-1}\left(\frac{n\omega L}{R}\right)$$

$$I_o = \frac{V_o}{R} \qquad (18)$$

The inductor current in shown in Fig. 10

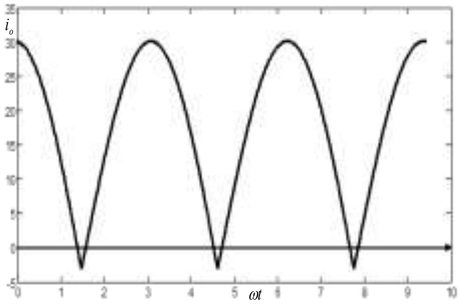

Fig. 10 Inductor current

Fig. 11 is the capacitor current given by:

$$i_C = \frac{V_m}{X_c}\sin\left(\omega t + \frac{\pi}{2}\right) \tag{19}$$

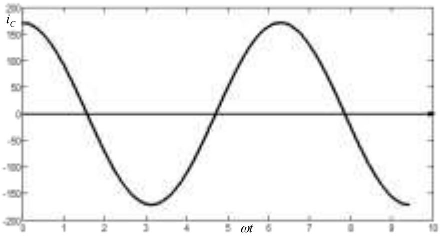

Fig. 11 Capacitor current

The inductor current (i_o) combine with the capacitor current (i_C) to give the compensator current (i_{com}), shown in Fig. 12

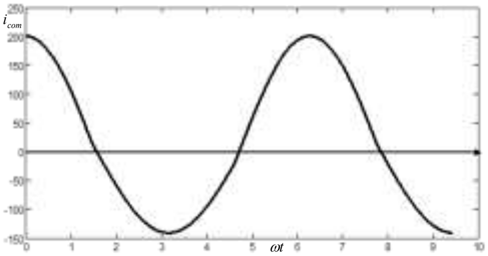

Fig. 12 Compensating current

The inductor current (Equation (17), and consequently the compensating current, can be controlled by adjusting the firing angle, of the active switches in Fig. 3.

The compensator current (i_{com}), superimposed on the line current (i_s) produces the resultant line current (i_a) as shown in Fig. 13.

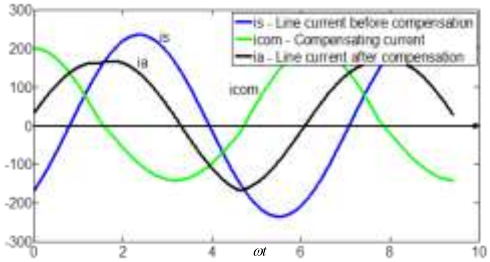

Fig. 13. The system currents.

The rms values of the line current before and after compensation are 166.12A and 118.22A respectively.

Thus,
The active power loss before compensation is $3xRx166.12^2 = 276$ kW
The active power loss after compensation is $3xRx118.22^2 = 139.77$ kW
Power loss reduction (power saved) = 136.18kW
Percentage reduction in power loss = 49.35%

All the system variables are shown in Fig. 14: system voltage (v), the compensating current (i_{com}), line current before compensation (i_s), line current after compensation (i_a). It can be observed, in Fig. 14, that the system is now operating at almost unity power factor (0.98). That is the line current after compensation (i_a) is $\theta_2\,(10.8^{\circ})$ out of phase with the system voltage (v).

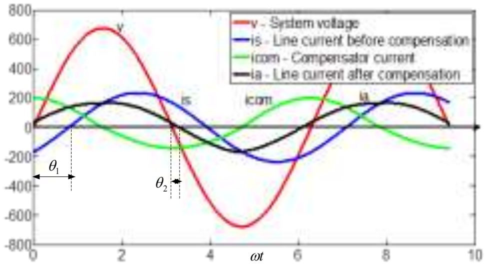

Fig. 14 All the system variables

With unity power factor achieved, Equation (2) can be written as:

$$E^2 = (V + R I_P)^2 + (X I_P)^2 \qquad (20)$$

The phasor diagram becomes as shown in Fig. 15:

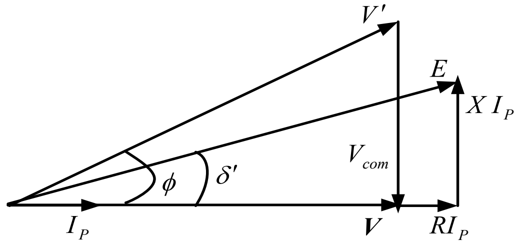

Fig. 15 Phasor diagram after compensation

Equation (20) and Fig. 15 show that the voltage drop has decreased drastically, and the receiving-end voltage (V) is a little less than the sending-end voltage (E).

IV. CONCLUSION

In this paper, it has been shown how an SVC configuration known as TCSC can be used to mitigate the adverse effects of reactive power flow on transmission/distribution lines. By varying the firing angle, of the TCSC switches, this SVC was able to regulate the load voltage, raise the system power factor from 0.7 to 1.0, and reduced the power loss on the line by 49.35%. Consequently, the active power transfer capability of the transmission system was improved.

REFERENCES

[1] Nojavan, S., Jalali M. and Zare K. " Optimal Allocation of Capacitors in Radial/Mesh Distribution Systems using Mixed Integer Nonlinear Programming Approach," Electric Power System Research, Vol. 107, No.11, 2014, pp. 119-124.

[2] Dixon J., Morán L., Rodríguez J., and Domke R, "Reactive Power Compensation Technologies: State-of-the-Art Review," Proceedings of the IEEE, Vol. 93, No. 12, December 2005, pp. 2144-2164

[3] Edris A., "FACTS technology development: An update," IEEE Power Eng. Rev., vol. 20, no. 3, Mar. 2000, pp. 4–9.

[4] Grünbaum R., Halonen M., and Rudin S., "Power factor, ABB static var compensator stabilizes Namibian grid voltage," ABB Rev., Feb. 2003, pp. 43–48.

[5] Grünbaum R., Petersson Å., and Thorvaldsson B., "FACTS improving the performance of electrical grids," ABB Rev. (Special Report on Power Technologies), 2003, pp. 13–18.

[6] Rahul S., Manish K.,"A Review of Enhancement of Transient Stability byFACTS Devices," International Journal of Emerging Technologies in Sciences and Engineering, Vol.5, No.3, March 2012, pp.168-176

[7] Chano S.R., Elneweihi A., Alesi L.H. and Bilodeau H., "Static var compensator protection," IEEE Transaction on Power Delivery, Vol., 10, No. 3, July 1995, p. 1224-1231

[8] Welflen R. N. S., Edison R. C. S., Cursino B. J., Eisenhawer M. F., Alexandre C. O., Rafael R. M., Dalton F. G. F., Otacilio M. A., and Patryckson M. S., "The Transformerless Single-phase Universal Active Power Filter for harmonic and Reactive Power Compensation," IEEE Transactions on Power Electronics, Vol. 29, No.7, July, 2014, pp. 3563-3571

[9] Almoataz Y.A., Ehab S.A. and Sahar M.A., "Flower Pollination Algorithm for Optimal Capacitor Placement and Sizing in Distribution Systems," Electric Power Components and Systems, Vol. 44, No.5, 2016, pp. 544-555.

[10] Rahul D., Subhransu R.S., Bijay K.P. and Vijendran G.V., "Extreme Learning Machine Based Adaptive Distance Relaying Scheme for Static Synchronous Series Compensator Based Transmission Lines," Electric Power Components and Systems, 44(2), 2016, pp. 219-232.

[11] Kantaria R. A., Joshi S. K., and SiddhapurK. R. a, "Novel hysteresis control technique of VSI based STATCOM," Proceedings of the IEEE India international conference on power electronics 2011, pp. 231-239

[12] Hammad A.E., “Comparing the Voltage Control Capabilities of Present and Future Var Compensating Techniques in Transmission Systems,” IEEE Transactions on Power Delivery, Vol. 11, No.1, January, 1996, pp. 475-483.

[13] Santosh G., Tushar G., Boksha p and Surani R. “Comparison of FACT Devices to Control Reactive Power in Long Distance High Voltage Transmission Line,” International Journal of Engineering Research & Technology (IJERT), Vol. 2 Issue 12, December – 2013, pp. 3236-3244

[14] Jalali S., Dobson I., Lasseter R. H., Venkataramanan G., “Fundamental Theory and Applications,” IEEE Transactions on Circuits andSystems-I: 43(3), (1996), pp. 209-217..

[15] Jin H., Goós G., and Lopes L., “An efficient switched-reactor based static var compensator,” IEEE Trans. Ind. Appl., vol. 30, no.4, Jul./Aug. 1994, pp. 997–1005,

[16] Pavlos S. G. and Peter G. V. “Flexible AC Transmission System Controllers: An Evaluation,” Materials Science Forum, Trans Tech Publications, Switzerland, Vol. 670 (2011) pp 399-406.