Performance of Static VAR Compensator for Changes in Voltage Due to Sag and Swell

M. S. Priyadarshini and M. Sushama

Abstract The deviations that occur in electrical power supplied by utilities to end users result in voltage decrease termed as sag and increase termed as swell. Due to voltage variations, change is evident for a short duration in voltage, current or frequency. In order to maintain constant voltage to the connected load, compensation devices are used based on flexible AC transmission systems (FACTS) technology. Based on an increase or decrease in voltage, suitable correction action can be taken by power electronic-based devices. The performance of static VAR compensator (SVC), which is a shunt connected FACTS device, is analyzed for voltage sag and swell. The SVC controller scheme, reactive power generated or absorbed, firing pulse generation and modes of SVC operation in MATLAB/Simulink environment are explained.

Keywords Sag · Swell · Thyristor controlled reactor · Thyristor switched capacitor · Static VAR compensator

1 Introduction

Power system is defined as an interconnection between generator and load buses through transmission lines. If any generator is disconnected or taken out for service or maintenance, the lines fed by that generator will be disconnected and must be connected to other generator buses. This results in a change in voltage profile at the buses. Sudden increase in load also affects voltage. To achieve the aim of maintaining constant voltage, proper balance must be maintained between active and reactive power. Electric power supplied by utilities must be free of disturbances and

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H. S. Saini et al. (eds.), *Innovations in Electrical and Electronics Engineering*,
Lecture Notes in Electrical Engineering 626,
https://doi.org/10.1007/978-981-15-2256-7_22

supply voltage must be within the range specified. Any violation of these conditions results in erroneous operation of power-consuming equipment. In flexible AC transmission systems (FACTS), control is increased and power transfer capabilities are increased [1]. In order to minimize the impact of changes in supply voltage, the quality of power supplied must be monitored. Static VAR compensator (SVC) is a shunt connected reactive power generator or absorber whose output is adjusted to exchange capacitive or reactive current [1]. It is used with the objective to maintain or control certain quantities which are subjected to a change of the electric power system. Based on requirement, compensation devices have to either absorb or generate reactive power. FACTS are defined by IEEE as AC transmission systems using controllers to increase controllability and power transfer capability. The aim of this paper is to study the performance of FACTS-based static VAR compensator for sag and swell. SVC and its controller operation are explained in Sect. 2 and performance of SVC is explained in Sect. 3 with suitable correction action that is taken and Sect. 4 ends with conclusion.

1.1 Voltage Sag and Swell

If 1 per unit (pu) is taken as reference, sag is a decrease in voltage to between 0.1 per unit (pu) and 0.9 pu for durations from half-cycle to 1 min [2]. Swell is an increase in voltage above 1.1 pu for durations from half-cycle to 1 min [2]. Due to momentary or persistent disturbances in supply voltage, the connected loads in the system can be severely affected. Some of the reasons for the disturbances to occur are load changes, faults, lightning and switching of loads with reactive components [3]. With respect to reference voltage of 1 pu, sag is defined with a decrease in voltage to 0.5 pu and swell with an increase to 1.5 pu out of the considered voltage waveform duration of 0.6 s as shown in Fig. 1.

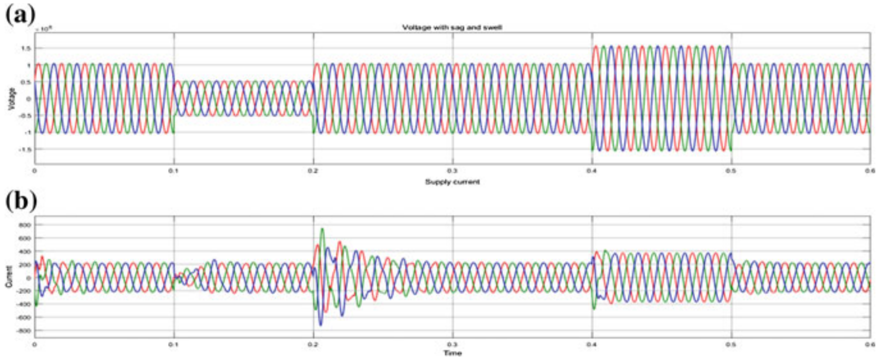


Fig. 1 **a** Three-phase voltage signal with sag and swell **b** current corresponding to voltage with disturbances

2 Static VAR Compensator (SVC) and SVC Controller

SVC comes under the category of variable impedance type FACTS devices. SVC injects or absorbs reactive power to regulate voltage at a given bus. The two operation modes in SVC operation are voltage regulation and VAR control mode. In voltage control mode, the voltage at supply side of SVC is controlled, and in VAR control mode, the SVC susceptance is kept constant.

SVC consists of parallel connection of:

(i) A reactor whose operation is controlled by a thyristor (TCR).
(ii) Three numbers of thyristor switched capacitors (TSC).

In the case of TSC, switch has only ON and OFF possibilities and no control is possible. In the case of TCR, control of impedance is possible by varying firing angle of the pulse generators. Figure 2 shows the block diagram representation of SVC.

In [4], a system is considered for analysis without compensation and with shunt and series compensation provided by SVC and thyristor controlled series compensators (TCSC). Load flow results are obtained and a comparison of apparent impedances of uncompensated case with 100 and 200% loading for SVC and TCSC compensated cases. In [5], advanced SVC and advanced static compensator are proposed and the optimum values of inductor, capacitor and proportional and integral gains are obtained using optimization techniques. IEEE 14 and 30 bus systems are considered in [5] with the variation in magnitude of voltage swell. For an improved and cost-effective operation of grid, distribution static VAR compensator (D-SVC) during internal, peak load and power losses profile is used in [6], considering the effects of total harmonic distortion (THD) on load profile. IEEE 14 bus system is modeled and simulated in [7] with magnitude of active power,

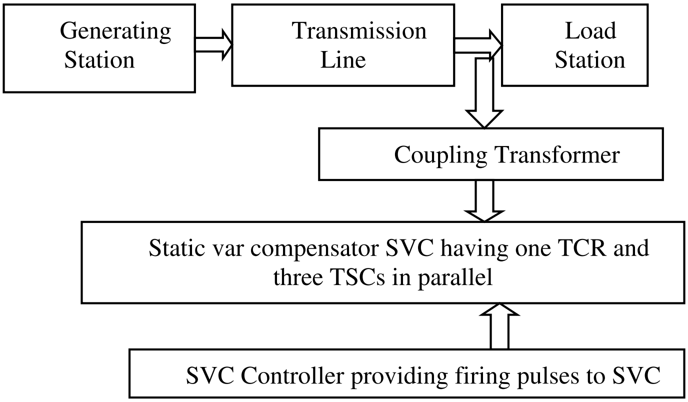


Fig. 2 Block diagram showing interconnection of generators and load through a transmission line along with SVC

reactive power and voltage magnitude with different types of variations in load. The waveforms shown in Fig. 3 depict currents drawn by TCR, three TSCs and resultant sum of currents drawn by TCR and three TSCs. The basic components of SVC controller are: voltage measurement, voltage regulator, distribution unit and firing unit which are all connected in sequence. The input signals for SVC controller are measured voltage and current as shown in Fig. 1 and output is firing angle controlled pulses for TCR and ON/OFF pulses for TSCs.

3 Performance of SVC

When the reference voltage and measured voltages are same, reactive power will be zero. When there is a decrease in voltage for the duration between 0.1 and 0.2 s, reactive power generated is increased from 0 to 96.14 MVAR. During restoration of voltage to normal, the reactive power generated increases to a peak value of 417 MVAR at 0.222 s. Due to fault or overloaded conditions, when swell occurs from 0.4 to 0.5 s reactive power absorption takes place to −200 MVAR and becomes equal to zero when reference and measured voltages are same. The minimum value of reactive power is −224.7 MVAR at 0.461 s. The gate signals of TCR vary from a minimum value of 90° to a maximum value of 180°.

From reactive power variation, the following are observed:

1. Due to decrease in voltage due to sag, TSCs must be switched into the power system to boost up the voltage and produce leading reactive power. Reactive power generation takes place.
2. Due to increase in voltage due to swell, TCR must be fired into the power system to control the voltage and produce lagging reactive power. Reactive power absorption takes place.

As there is a change in voltage magnitude, corresponding susceptance changes resulting in variation of firing angle pulses. SVC controller provides suitable control action for reactive power generation and absorption based on variations in supply voltage with respect to reference voltage. Equation for amplitude of reactive current shown in Fig. 4c is given by (1). As the operation of TCR depends on firing angle delay α, the current and susceptance will be in terms of α.

$$I_{LF}(\alpha) = VB_L(\alpha) \tag{1}$$

In (1), $B_L(\alpha)$ is the equivalent susceptance given by $\frac{1}{\omega L}\left(1 - \frac{2\alpha}{\pi} - \frac{\sin 2\alpha}{\pi}\right)$.

The primary voltage of transformer is fed to measurement system which converts the three-phase signal to magnitude of positive sequence component of voltage in terms of normalized values. The error signal which is the difference between measured and reference voltages is fed to discrete-time integrator along with droop which is slope measured in pu per 100 MVA. All the components in SVC controller along their sequence of connection are shown in Fig. 5. The input

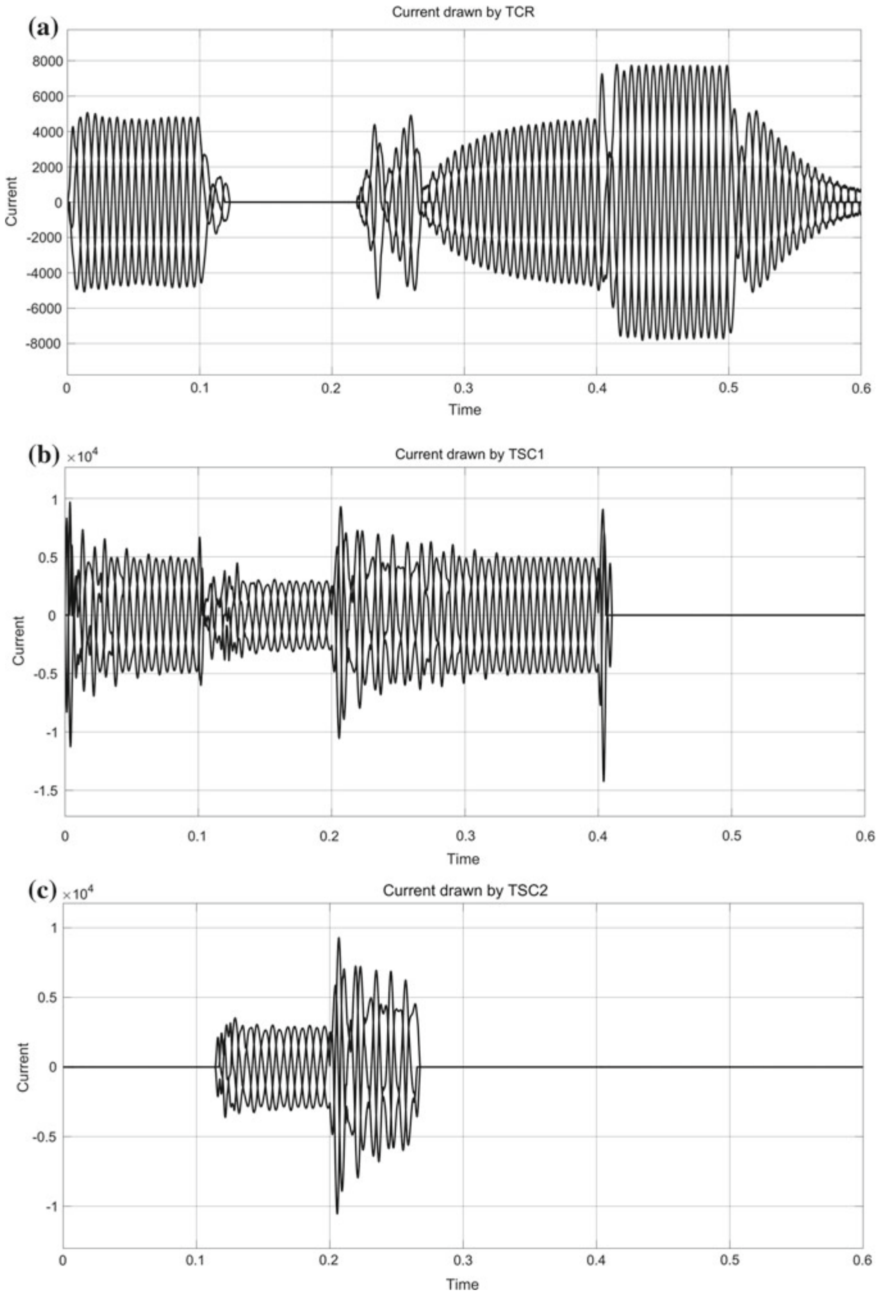


Fig. 3 Currents drawn by **a** TCR, **b** TSC1, **c** TSC2, **d** TSC3, **e** total current drawn by SVC which is the resultant sum of currents of TCR and the three TSCs

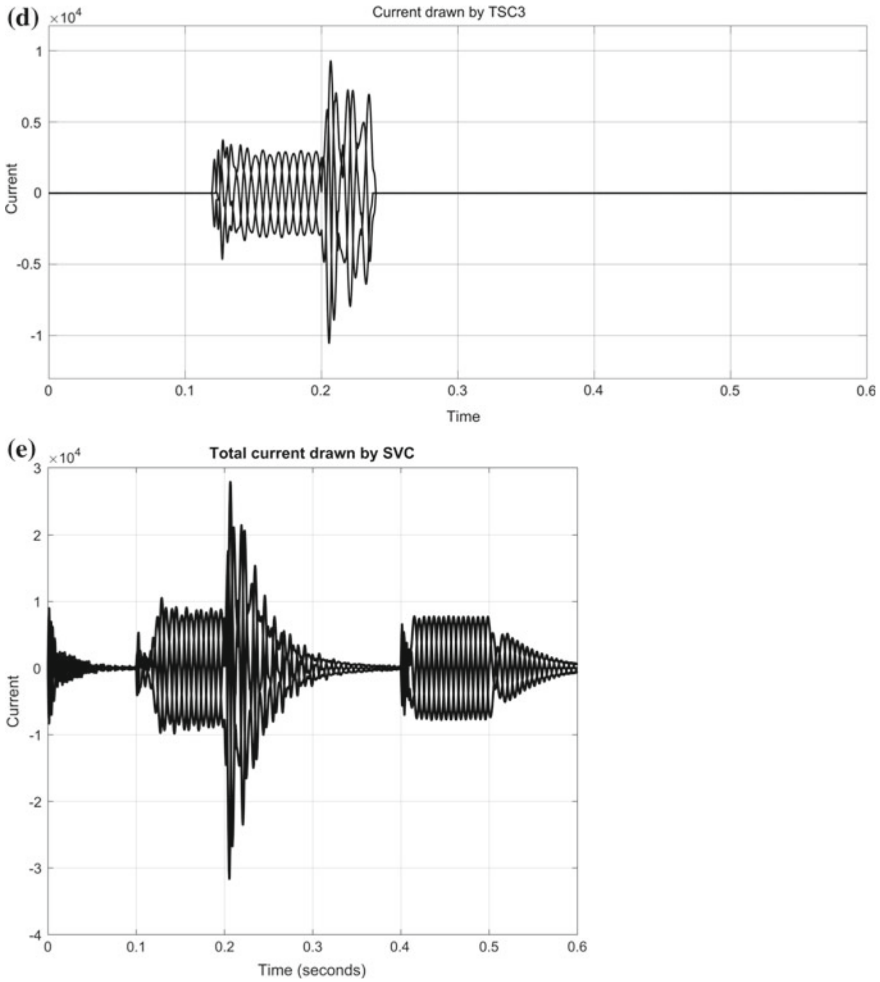
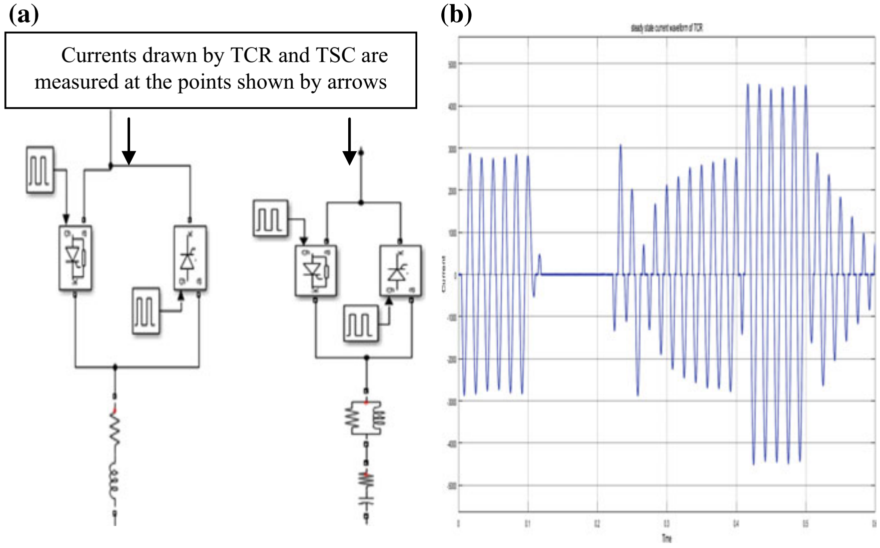


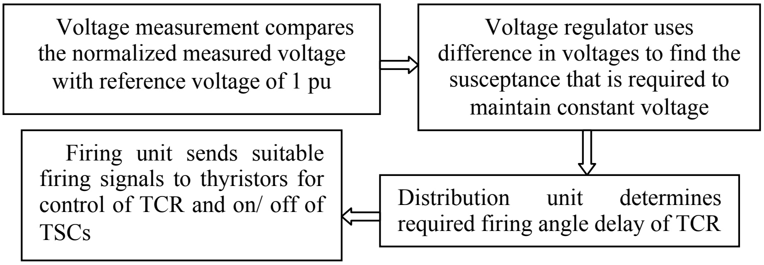
Fig. 3 (continued)

for distribution unit connected to firing unit is susceptance and output is firing angle of TCR and ON/OFF control for TSCs. Distribution unit gives firing angle delay to TCR and pulses to TCS as shown in Fig. 3. Actual voltage is converted to pu and is compared with reference voltage 1 pu. Error signal is fed to voltage regulator which takes into consideration droop value and the susceptance required to provide necessary voltage is calculated. Droop is the slope of voltage–current characteristics of SVC. The three inputs of voltage regulator are measured voltage, reference voltage and reference value of susceptance B_{ref}. This B_{ref} value is taken to be equal to zero. Figure 6a–c shows reactive power generated or absorbed, measured and reference voltages and number of TSC's that are switched on based on variations in voltage.



Currents drawn by TCR and TSC are measured at the points shown by arrows

Fig. 4 **a** A portion of TCR bank, **b** a portion of one of the three TSC bank, **c** steady-state current waveform of TCR



Voltage measurement compares the normalized measured voltage with reference voltage of 1 pu

Voltage regulator uses difference in voltages to find the susceptance that is required to maintain constant voltage

Distribution unit determines required firing angle delay of TCR

Firing unit sends suitable firing signals to thyristors for control of TCR and on/ off of TSCs

Fig. 5 SVC controller with the functions of its various components

By suitable switching operation and gain multiplication, the voltage regulator produces susceptance as shown in Fig. 6d. Firing angle delay control of TCR which consists of delta connected antiparallel thyristors in series with an inductor is shown in Fig. 6e. TSC is also delta connected antiparallel connected thyristor bank in series with a capacitor. During voltage sag, three capacitors are connected, and during swell conditions, no capacitor is switched on as shown in Fig. 6c.

There exists a relationship between Figs. 4c and 6e. For highest and constant value of firing angle, steady current remains zero. There is no variation in current for minimum value of firing angle.

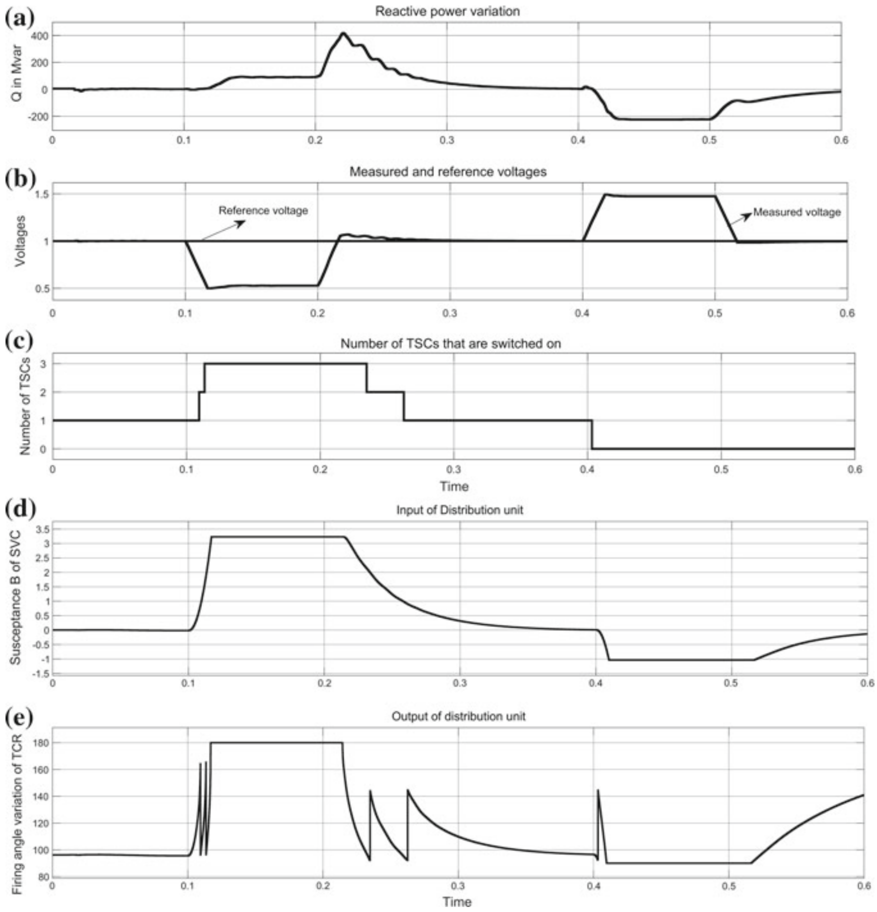


Fig. 6 **a** Reactive power variation, **b** measured and reference voltages, **c** number of TSC's that are switched on based on variations in voltage, **d** input and of distribution unit, i.e., susceptance, **e** firing angle delay control of TCR

4 Conclusion

SVC injects reactive power in the line by thyristor switched capacitor. SVC absorbs reactive power from the line by thyristor controlled reactor. The supply or absorption of reactive power is done to regulate voltage against changes in voltage. An important benefit of using power electronic-based equipment is manifested in the form of increase in power transfer capability. As by switching ON or OFF capacitors, capacitive admittance can be directly connected or disconnected based on reactive power variation. SVC controller calculates the susceptance required to make voltage equal to reference voltage. The TSC components or banks which are made ON/OFF are decided and the delay angle provided by reactor is calculated.

When voltage becomes as a reduced value than reference voltage, TSCs are turned on and when voltage is greater than reference voltage TCR operation is controlled by variation in firing angle. Corresponding to the variation in magnitude of supply voltage, necessary action is taken by reactive power absorption or generation.

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