Improvement of Voltage Profile in Distribution Line Using "Sen" Transformer

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ABSTRACT

This study presents the problem of improving the voltage quality in distribution lines using "Sen" transformer (ST). The ST is made out of a transformer and tap changers and is capable of regulating the active and the reactive power flow selectively in the electric transmission and distribution line. A power system is having a need to provide good quality of supply which means the voltage should be maintained at some reasonable limits. All the electric devices are designed only to operate for a fixed value of its terminal voltage. The resent electrical power system is more complicated, so, there are many disturbances that occur in the system like voltage sag and swell, fault, unbalance loading, uncontrolled power flow, etc. Voltage sags and swells in the medium and low voltage distribution grid are considered to be the most frequent type of power quality problems based on recent power quality studies. In this paper, the ST has been used to improve quality of voltage in the distribution line with different phase angle of injecting voltage. Usage of ST has improved the voltage profile of the system. In this paper, the ST is simulated in MATLAB/SIMULINK for compensating voltage in distribution line during fault condition for maintaining constant voltage profile of the network. Through the simulation, it was confirmed that the voltage sags and swells in the distribution line are effectively suppressed by ST. The ST is easy to operate for improving voltage profile than other devices like DVR, D-STATCOM etc. The cost is also reduced and the operating reliability is increased compared to other types of devices using power electronic components.

Keywords: Distribution line, Voltage Fluctuation, Facts, "SEN" Transformer, Voltage Compensation

INTRODUCTION

With the development of science and technology, the variety of loads that consume electricity is becoming more diverse, and the quality of power-sensitive loads are increasing. If there is any deviation in the voltage and frequency at which the power is being supplied, then the quality of the power is affected. Equipment's used in the system gets affected which reduces their performance and life. If the disturbance occurs in the power system then the continuity of the power supply is affected. So, the power system switchgear should be designed to operate without any time lag and the faults should be c1eared at a faster rate. Efficiency of distribution line is increased by improving quality of power system. There are many methods to increase the

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efficiency of power system. Quality of power is also improved by improving the voltage stability and power factor of supply. There are many devices available to increase the efficiency and quality in power system. Flexible AC Transmission System (FACTS) devices are mostly used in power system [8]. These devices can be used more efficiently and conveniently in power systems. With help of these devices one can improve the power quality and reliability of the power system.

The FACTS devices provide voltage support at critical buses in the system with shunt connected controllers and regulate power flow in critical lines with series connected controllers. It is also possible to control the voltage fluctuations in the line using the combination of series and shunt controller. The unified power flow controller (UPFC) has the ability to control independently active and reactive power flow by changing voltage and phase angle of voltage. The FACTS devices are quite fast and which enables them to regulate under unstable and faulty condition. The ST is cost-efficient power flow controller that provide the same independent active and reactive power control as of UPFC [2,5]. It is a tap changing device and its working depends on tap changing.

Principle of ST

The ST proposed by K.K. Sen and M.L. Sen [1] is a single core 3-phase transformer with star-connected primary winding and nine-secondary winding. The main circuit diagram of ST is shown in Figure 1. ST is a family of tap changing transformer that has the same independent active and reactive power flow controllability of UPFC with somehow slow response [2, 9]. The compensating voltage Vs's generated from secondary winding of ST that are connected in series with line. The magnitude of the sending end voltage, Vs, and its angle is modified to be useful value of sending end voltage, Vs', by changing the magnitude and the angle of compensating voltage, Vs's, and therefore, the active and reactive power flow in the system are regulated independently.

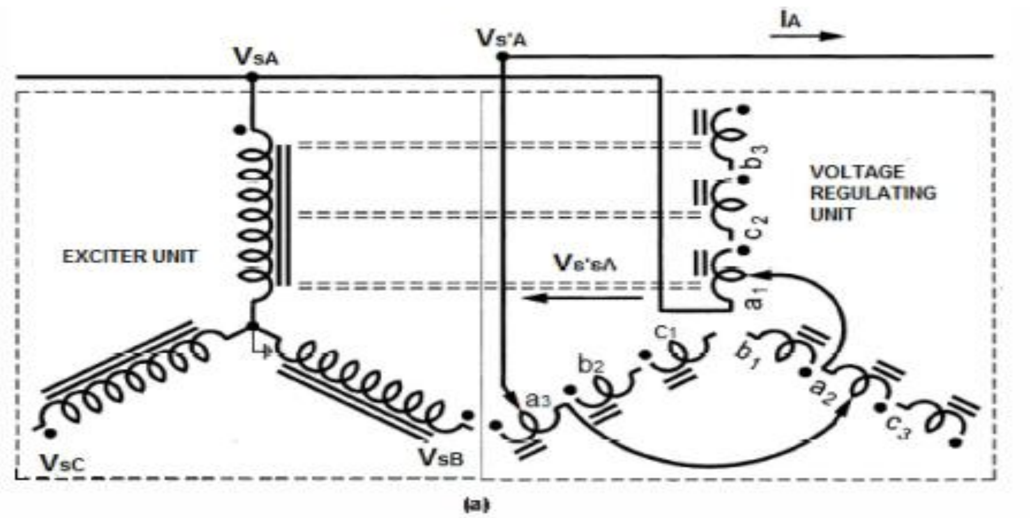

Figure 1. The Main Circuit Diagram of a "SEN" transformer

The ST has mainly composed of two parts [1, 4]. They can be divided into excitation and compensation voltage parts. The exciting part comprises of star-connected shunt primary winding (A phase, B phase, and C phase) and the compensating voltage part comprises of nine-secondary windings, out of which three are located on each limb of the core e.g., al, c2, and b3 on the first limb of the core A; bl, a2, and c3 on the second limb of the

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core B and cl, b2, and a3 on the third limb of the core C. The sending end line voltage (V_A, V_B, and V_C) are supplied in shunt to the exciting mechanism. The induced voltage from three-secondary winding which are located on different limbs are added through series connection to produce the compensating voltage. e.g., al, a2, and a3 for injection in A-phase, bl, b2, and b3 for injection in B-phase, and cl, c2, and c3 for injection in C-phase. The magnitudes and phase angle of the three injecting voltages from the ST which are 120° phase shifted to each other are varied through active turns in the secondary compensating windings, and therefore, the compensating voltage Vs's becomes variable in magnitude and also in phase angle (0° to 360°), as shown in Figure 2.

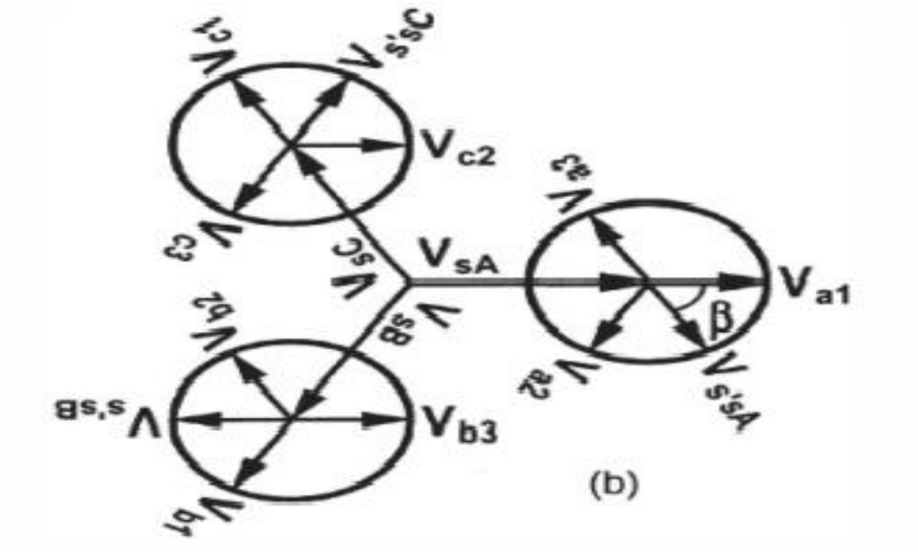

Figure 2. The Phasor Diagram of ST

The compensating voltage can provide in phase, leading phase and lagging phase voltage. Detail operating principle of ST can be found in [4]. ST can provide voltage with any angle to regulate bus voltage.

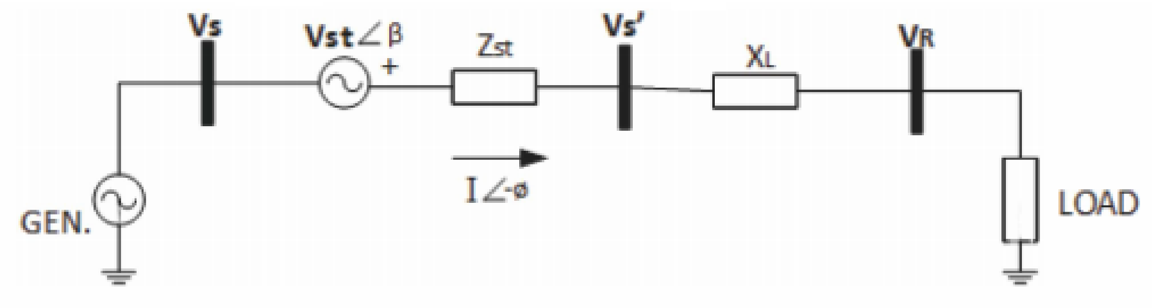

Figure 3. Equivalent Circuit of the distribution Line with the ST.

Let us consider that the control scheme is to normalize the magnitude of the active (V_{stp}) and the reactive (V_{str}) voltage added by the ST. The equivalent circuit of the line with ST is shown in Figure 3.

Let the injected voltage V_{st} be express as,

$$\hat{V}_{st} = V_{st}\angle\beta \qquad (1)$$

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From the circuit diagram of the system is shown in Figure 4, we get the expressions for P_r and Q_r as,

$$P_r + jQ_r = (P_0 + jQ_0) + \frac{VV_{st}}{X_{st} + X_L} e^{j(\frac{\delta}{2}+\beta-\frac{\pi}{2})} \quad (2)$$

where P_0 and Q_0 are the receiving end active and reactive power flow in the absence of the compensating device, which are

$$P_0 = \frac{V^2 \sin\delta}{X_{st} + X_L}, \quad Q_0 = \frac{V^2}{X_{st} + X_L}(1 - \cos\delta) \quad (3)$$

For a continuous value of V_{st} and ß changing over 360°, the locus of (P_r-jQ_r) is the radius $\frac{VV_{st}}{X_{st} + X_L}$ of circle and having centre at (P_0, Q_0). The region of operation is the inside of the circle bound within the maximum radius (V_{st}=V_{stmax}).

For a particular value of δ, P_r is maximum at ß $= \frac{\pi}{2} - \frac{\delta}{2}$, then P_{rmax} is given by,

$$P_{r\max} = P_0 + \frac{VV_{st}}{X_{st} + X_L}$$

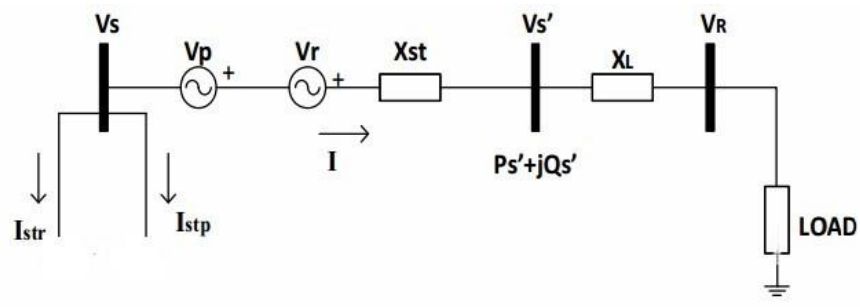

Figure 4. Equivalent Circuit of the ST

The equivalent circuit of the ST is shown in Figure 4. The shunt primary side of the ST draws both active (I_{stp}) and reactive current (I_{str}). The power in the line is to regulate by controlling the injected voltages, V_{stp} and V_{str}. Since, the voltage Vs' is normally unrestrained, the power (Ps'+jQs') need not be a circle for constant magnitude V_{st}.

Simulation of ST in Matlab/ Simulink

The model of the ST has been developed by using MATLAB/Simulink software.

A. Electrical System with the ST

The electrical network with the ST is shown in Figure 2. As can be seen, the feeder loads are fed with three-phase power. And the ST is connected at the supplied side of the distribution line.

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• Electrical Network Model: The ac source at both end of electrical network has same voltage magnitude and no phase difference between sending end voltage and receiving end voltage. The ST is connected at supply end of the system. The distribution line is designed as lumped series impedance.

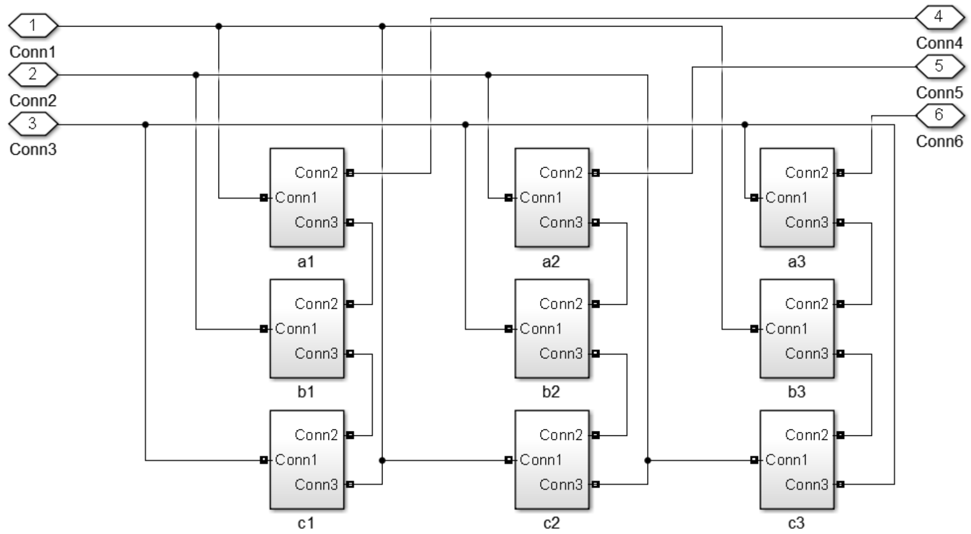


Figure 5. Simulink Model of ST (Connection of nine transformer).

• ST Model: The ST is three phase tap changing transformer, which is designed as multiple tap winding in secondary winding of transformer. This type of transformer is not available in MATLAB. Therefore, A ST is a nine single phase transformer, which has multiple winding for tap changing in secondary side as shown in Figure 5. In this model, transformers 1, 4 and 7 are set-1, 2, 5 and 8 are set-2 and, 3, 6 and 9 are set-3. These transformers are designed with small resistance and leakage reactance. Each single-phase transformer is shunt excited from supply. Output of three transformers (from phase A, B, and C) are injected in series to one of the phases of system. There are nine outputs from the nine single phase transformer which are secondary tap terminal selection depend on magnitude of injected voltage and its phase angle.

B. Control System

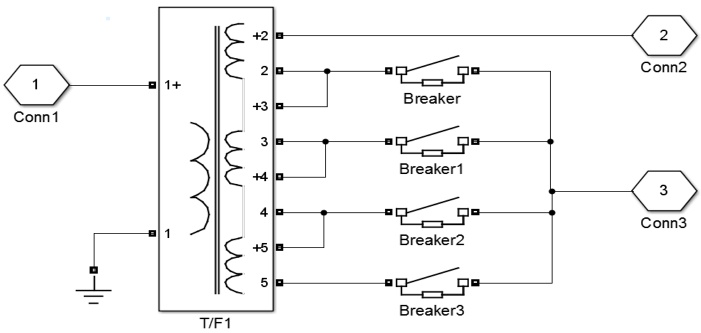


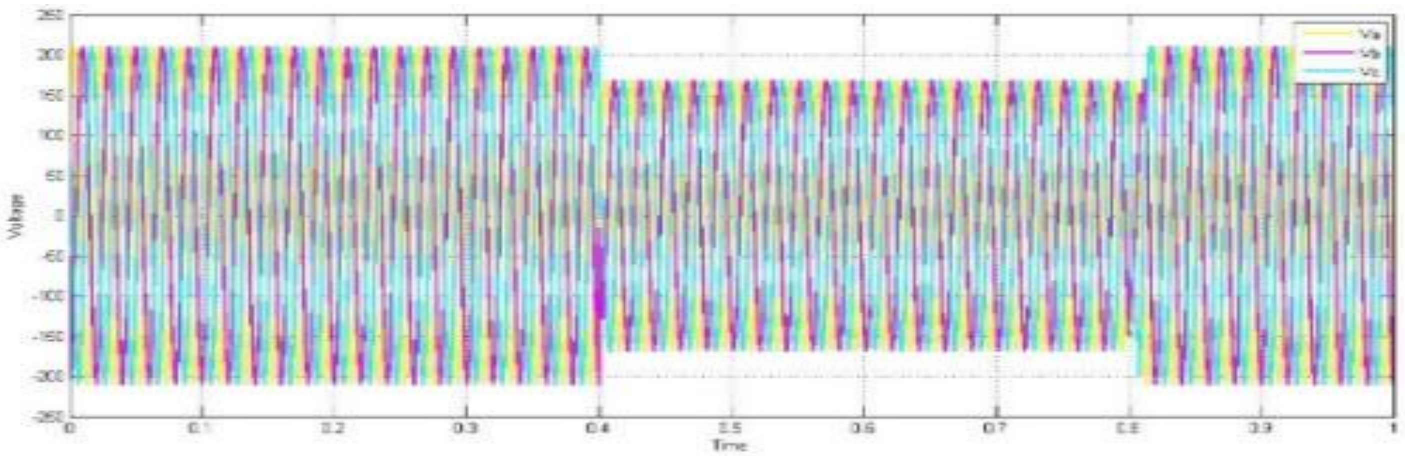
Figure 6. Tap Changing of Transformer

The ST is tap changing transformer which has nine secondary tap winding. These tap terminals are controlled by tap selection algorithm [3]. Tap terminal selection depend on the requirement of injected voltage. In mechanical LTCs, the efficiency is 99.7% and in thyristor-controlled LTCs, the efficiency is 99%.

• Tap Changer Model: The tap changer model of the ST is developed in MATLAB as shown in Figure 6. In these models, the ST with mechanical tap-changing switches takes 2 seconds to change from a tap position to the adjacent tap position and a normally 5% of taps will be provided for the simulation of the ST.

RESULTS AND ANALYSIS

The ST was simulated by using MATLAB simulink. In this model, it is supposed that each transformer is capable of added in series up to 0.5 per unit voltage in the line. Each multi-winding transformers have four taps having different voltage magnitude. These multi tap winding are connected in a phase shifted manner to get both the magnitude and phase angle regulation. The ST connected with a three phases supply system operating with 150V, 50Hz line voltage. The ST is rated at 100VA. The fault is occurring on supply end in duration of 0.4 to 0.8 sec. when fault is occurred in the system then the supply voltage is reduced by 20%. If set-1 is operated then the voltage injected in distribution line is in phase with the supply voltage. There is no phase difference between the input voltage and the output voltage of ST. The resultant waveforms for the simulation results are shown in Figure 7.



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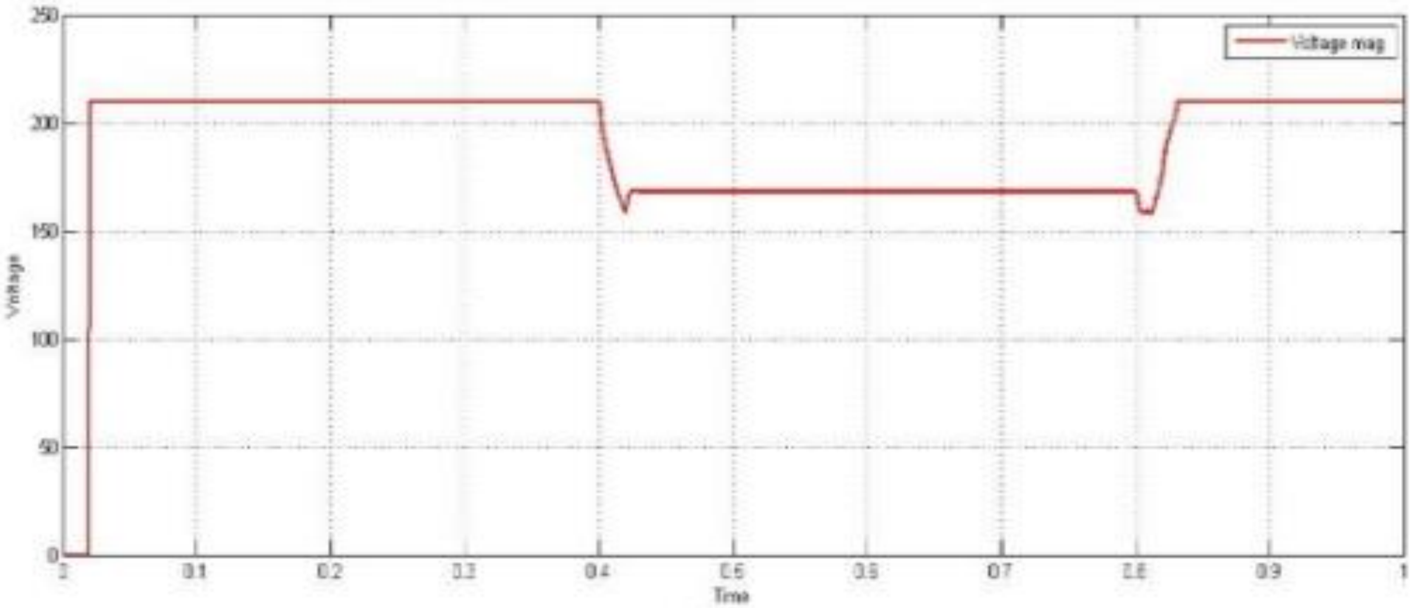

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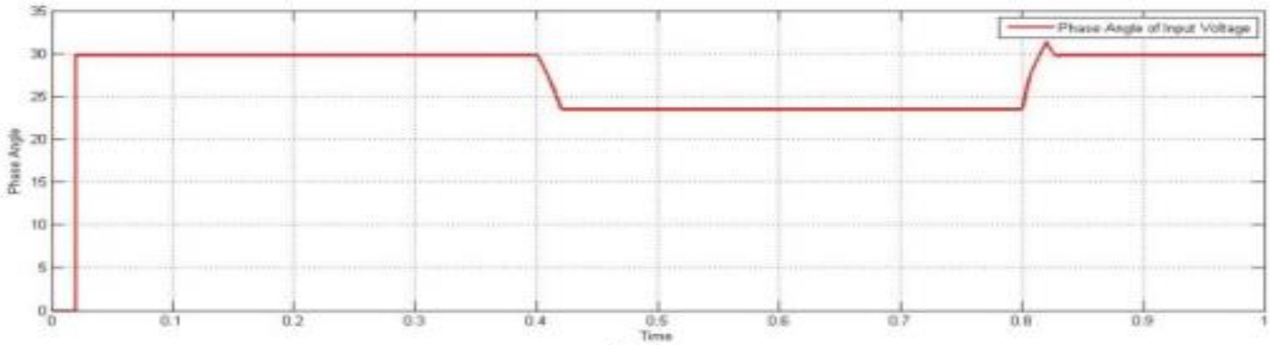

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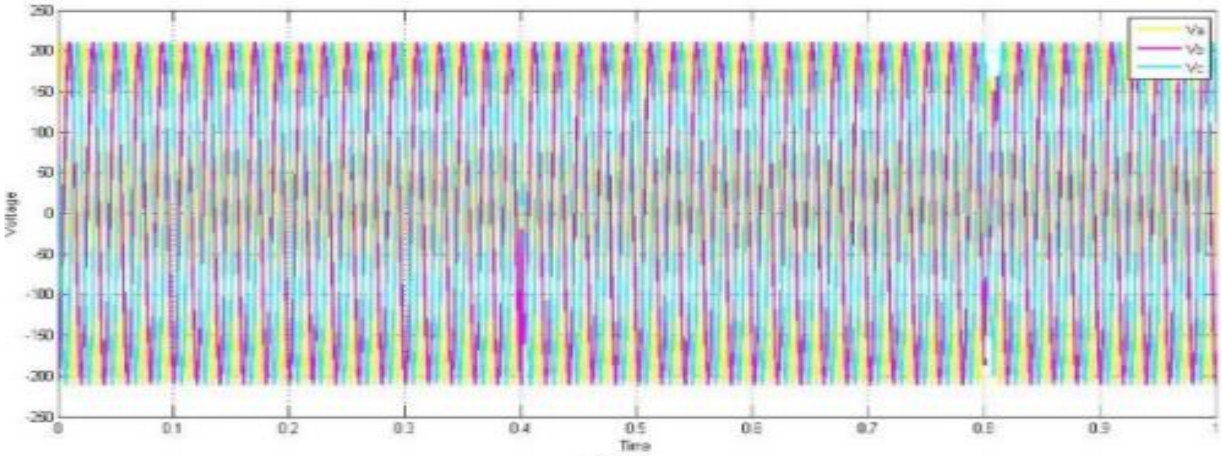

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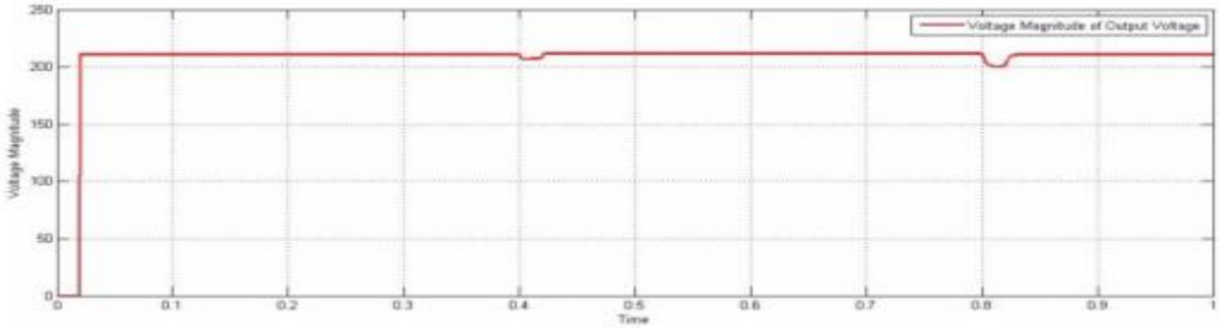

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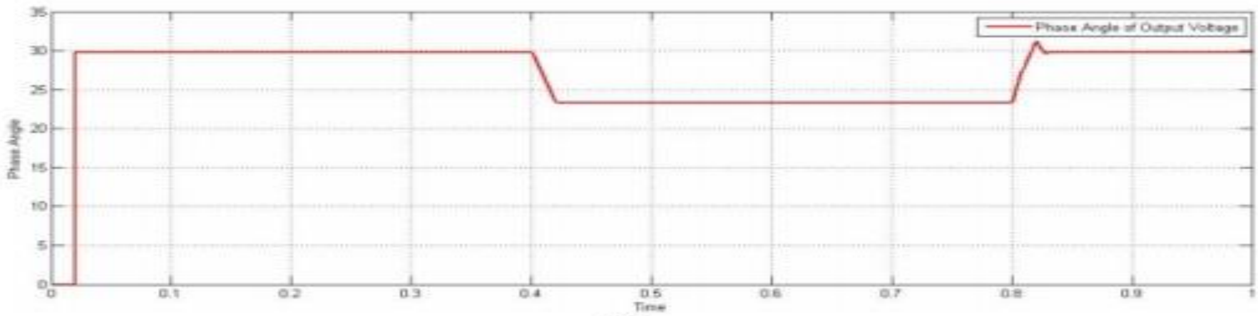

(f)

Figure 7. Resultant Waveform of Simulation, (a) 20% Sag in Distribution Line Voltage, (b) Magnitude of Supply Voltage, (c) Phase Angle of Supply Voltage, (d) Compensated Voltage, (e) Magnitude of Compensated Voltage, (f) Phase Angle of Compensated Voltage.

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If set-2 is operated then the voltage injected in distribution line is 120° out of phase with the supply voltage. There is 80° phase difference between the input and output voltage of ST. The variation curve of phase is shown in Figure 8.

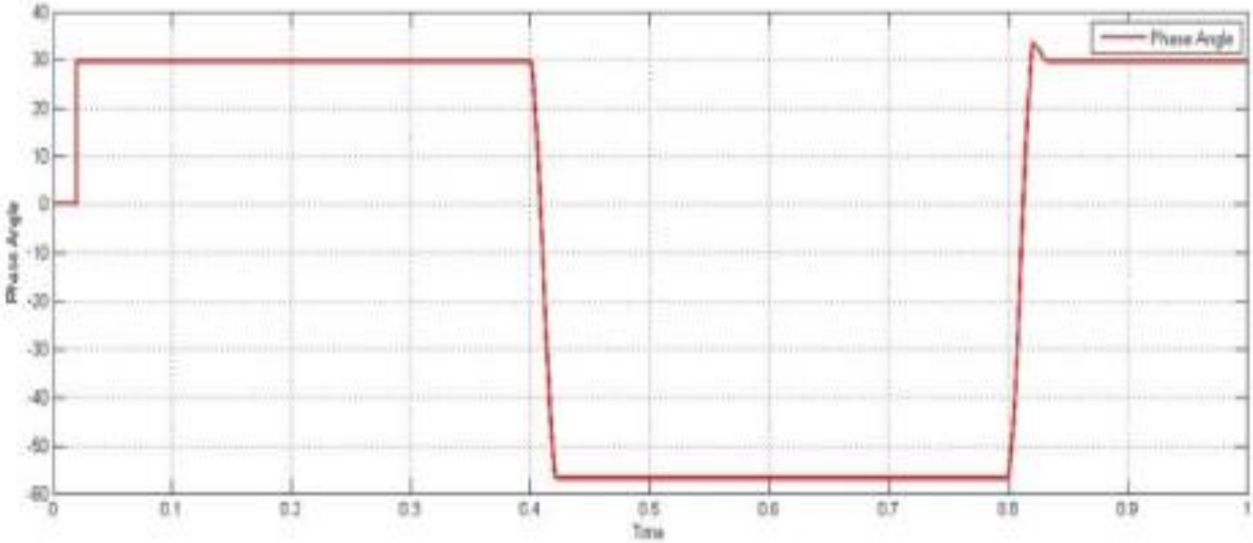

Figure 8. Phase Angle Variation Curve of Compensated Voltage when Voltage Injected is 120° out of Phase with Line Voltage

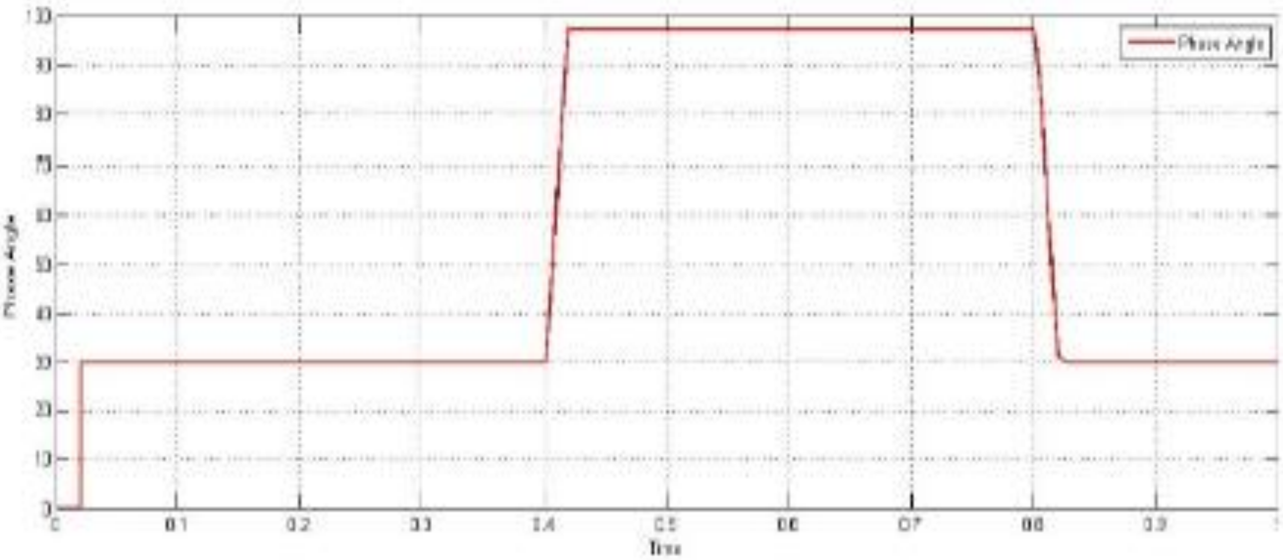

Figure 9. Phase Angle Variation Curve of Compensated Voltage when Voltage Injected is -120° out of Phase with Line Voltage

If set-3 is operated then the voltage injected in line is -120° out of phase with the supply voltage. There is 120° phase difference between the input and output voltage of ST. The resultant waveform of phase is shown in Figure 9.

Next, we consider the operation of ST in case of voltage rise in the distribution line. When some load is suddenly disconnected from the system, the voltage of distribution line is increases. In this case, if the voltage

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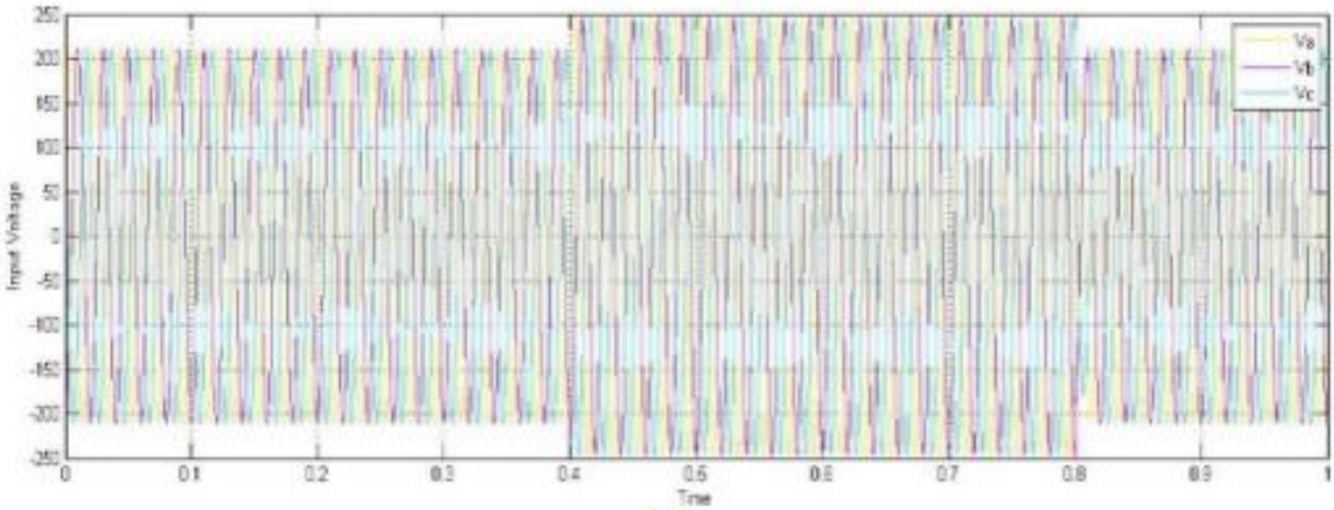
variation of 20% (swell) is assumed, the ST changes its taping and compensating the voltage. If set-2 is operated then the voltage injected in line is 120° out of phase with the supply voltage. There is 30.5° phase difference between the input and output voltage of ST. The resultant waveforms are shown in Figure 10.



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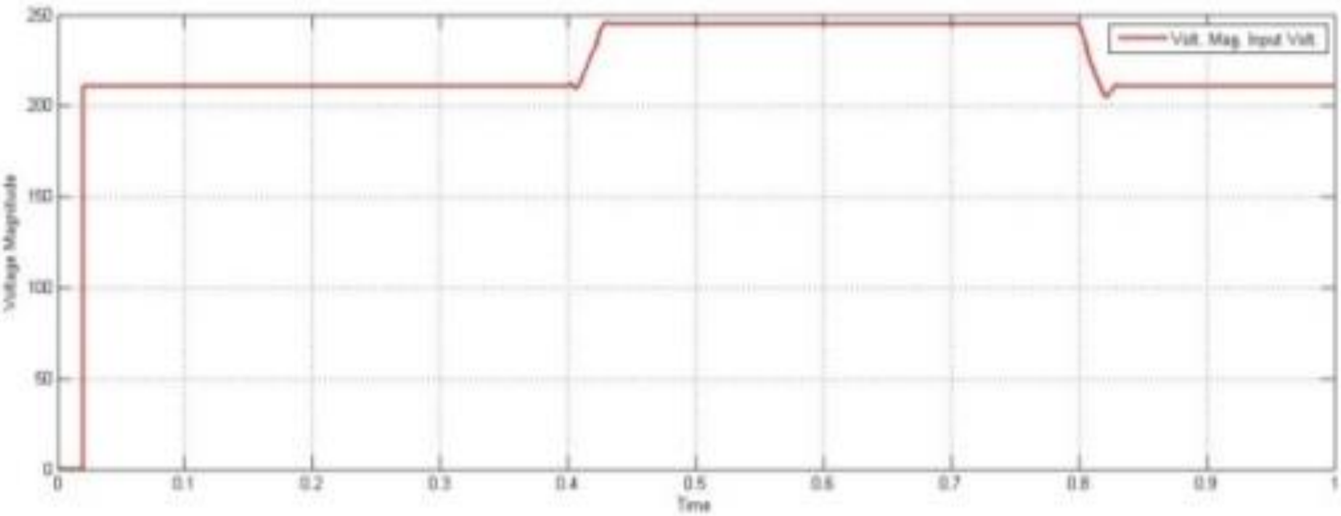

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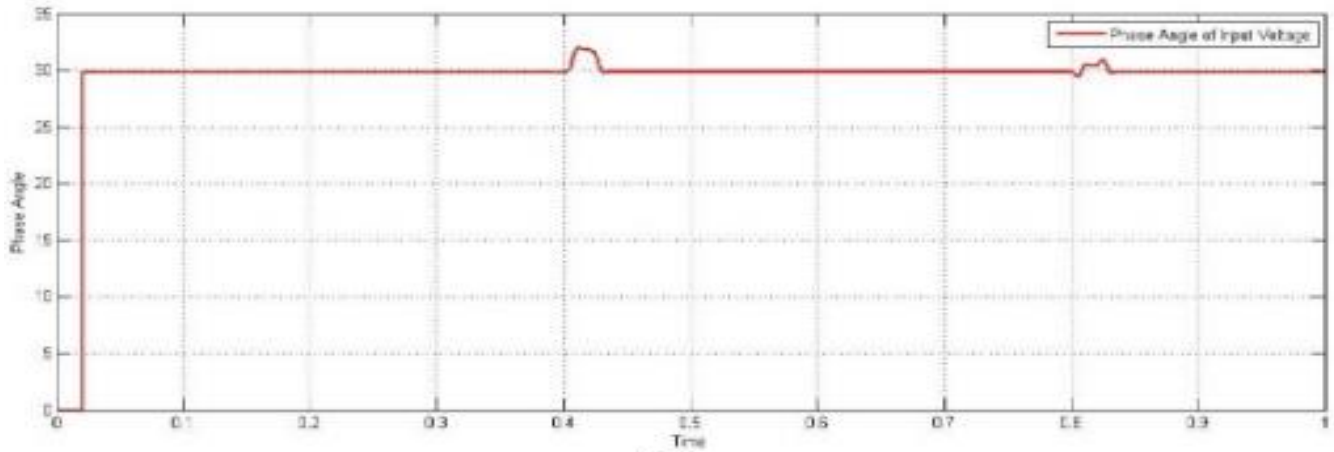

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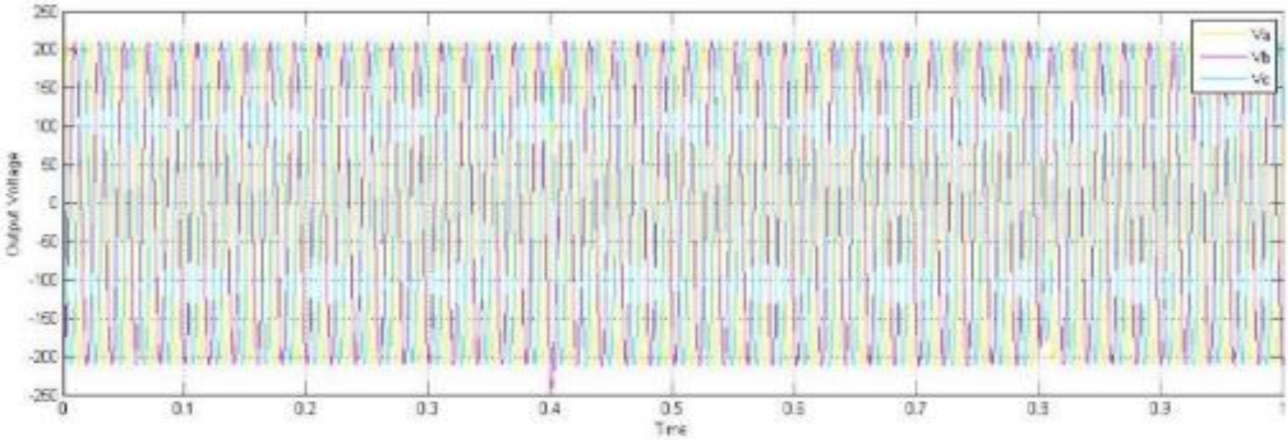

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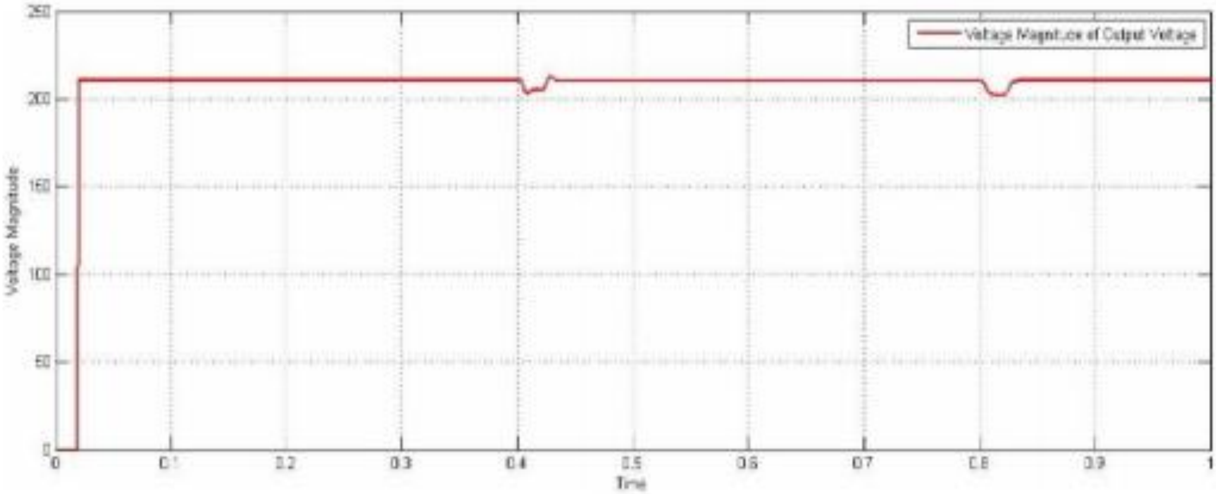

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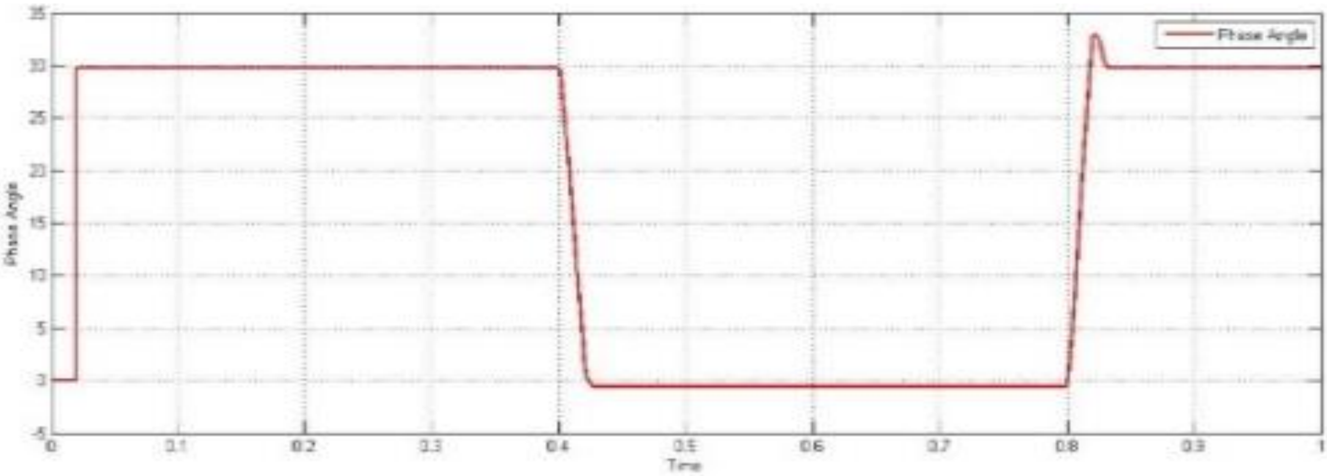

(f)

Figure 10. Resultant Waveform of Simulation, (a) 20% Swell in Line Voltage, (b) Magnitude of Supply Voltage, (c) Phase angle of Supply Voltage, (d) Compensated Voltage, (e)Magnitude of Compensated Voltage, (f) Phase angle of Compensated Voltage

If set-2 and set-3 is operated with same taping then the voltage injected in line is in phase with the supply voltage. There is no phase difference between the input and output voltage of ST. The resuItant waveform of phase is shown in Figure 11.

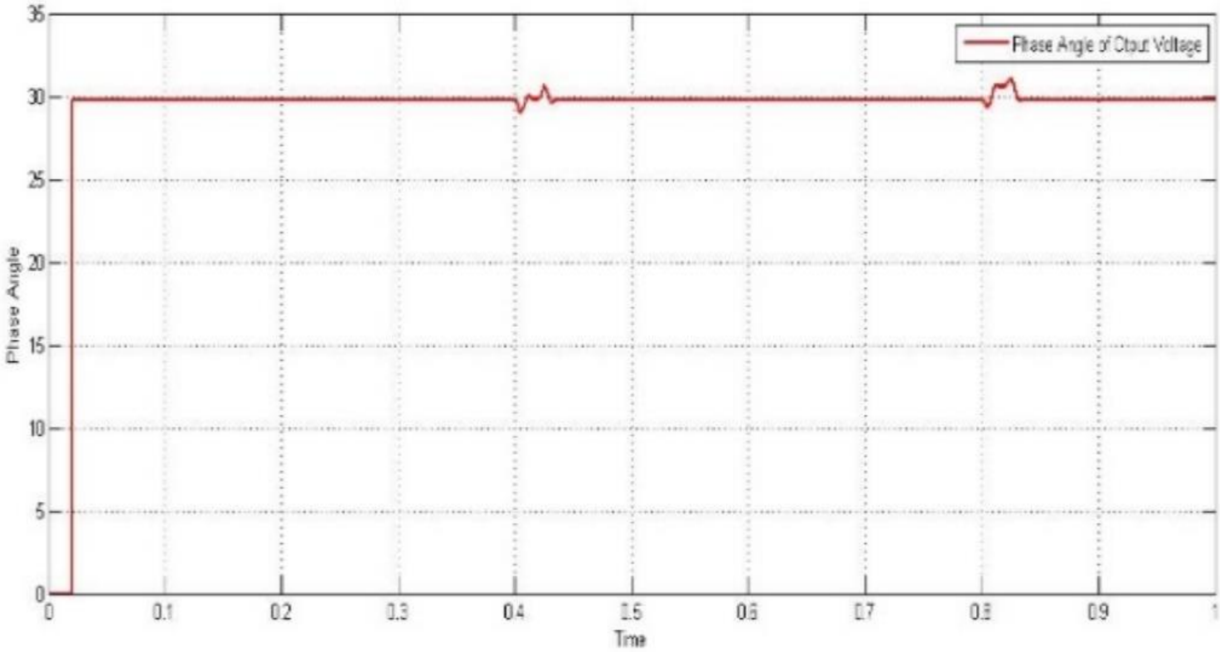

Figure 11. Phase angle Variation curve of Compensated Voltage when Compensated Voltage is in Phase with Supply Voltage

If set-3 is operated then the voltage injected in line is -120° out of phase with the supply voltage. There is 29.54° phase difference between the input and output voltage of ST. The resultant waveform of phase is shown in Figure 12.

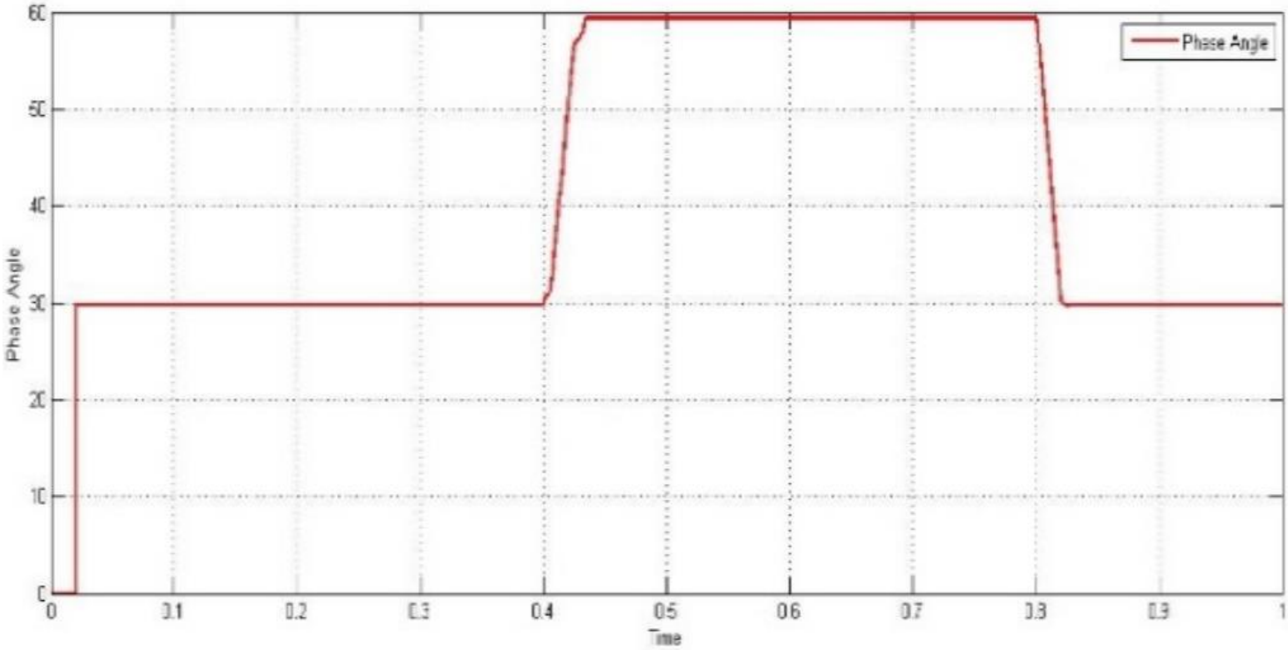

Figure 12. Magnitude Variation curve of Compensated Voltage when Compensated Voltage is 30° Phase with Supply Voltage

An analysis was also carried out to evaluate the harmonic generation in the line using ST. The results of FFT analysis after the line voltage is changed by the compensation voltage are shown in Figure 13. As can be seen from the figure, there are only 0.20% THD after compensating the line voltage.

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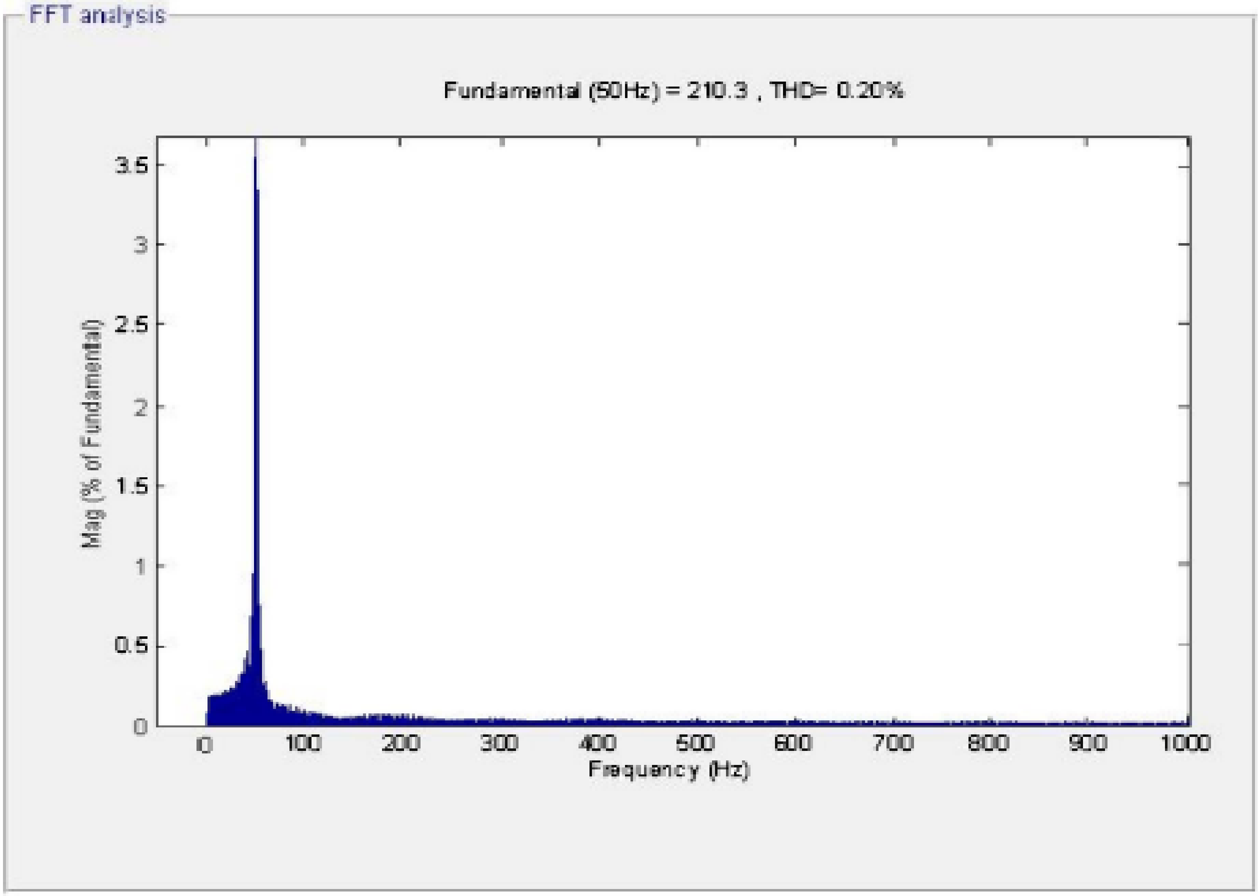

Figure 13. FFT Analysis of Compensated Voltage.

SUMMARY

In distribution lines, three-phase voltage asymmetry may occur due to various faults or load configurations. As can be seen from the phasor diagram in Fig. 2, the compensation voltages in each phase can be obtained differently by different tap switching states of ST. Thus, ST can be used effectively in order to provide the line voltage symmetry.

The advantages of ST over devices using power electronic components can be listed as follows.

• High reliability with the lowest number of components
• Impedance control feature using a shunt-series topology
• Lowest installation cost
• Lowest operating cost with minimum maintenance and losses
• Minimum equipment rating and minimum footprint so that it can be relocated easily when the system needs change
• Free from component obsolescence (note that power electronic systems become outdated every 10-15 years)
• Interoperability so that components from various suppliers can be used, resulting in a global manufacturing standard, ease of maintenance, and ultimately lower cost to consumers.

On the other hand, the drawback of ST is that the response is slow and the magnitude of the injection voltage changes step by step. However, in most applications, these problems may not be highlighted.

CONCLUSION

The ST was used for improving voltage profile by injecting voltage with different phase angle. The ST is easy to operate for improving voltage profile than other devices like DSTATCOM, DVR, etc. As the main equipment is a transformer, the cost is reduced and the operating reliability is increased compared to other types of devices using power electronic components. The ST is also used to control the active and reactive power flow in the distribution line independently like UPFC. In this paper, usage of ST has improved the voltage profile of the system. An important advantage of ST is that no harmonics are generated which are unfavorable for the operation of electrical equipment. However, it has slow response than other devices with power electronic components because it working depends on the response time of taping in secondary winding of transformer. This is a subject of further investigation.

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