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Application of the Posicast control method to static shunt compensators

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Abstract

In this paper, the Posicast control method is used for decreasing the reactive power oscillations of static shunt compensators. Shunt compensators such as the static synchronous compensator (STATCOM) and static VAR compensator (SVC) are considered to be FACTS devices. The applied control method decreases the amount of oscillations in the outputs of STATCOM and SVC considerably, with fast damping. In this paper, a PI controller is added to the model to decrease the sensitivity of the Posicast controller to the parameter variations and plant model mismatch. Simplicity and applicability are the main features of this controller. The model is simulated in a MATLAB/Simulink environment.

Key Words: *Static synchronous compensator (STATCOM), static VAR compensator (SVC), Posicast controller*

1. Introduction

Using a suitable shunt compensator for reactive power causes an increase in the transferable power in the steady state condition and allows control of the voltage profile along the power line. The static synchronous compensator (STATCOM) and static VAR compensator (SVC) are 2 of these shunt compensators belonging to the flexible AC transmission system (FACTS) devices family. They control the voltage level by injecting or absorbing the reactive power. A shunt compensator injects the reactive power if the system's voltage is lower than the reference voltage (V_{Ref}). Moreover, the controller absorbs the reactive power if the system's voltage is higher than the V_{Ref} [1].

The Posicast controller was first presented to damp the oscillations of systems that have low damped oscillations. Having accurate information about the system and the natural frequency of the oscillations is necessary for designing a feed-forward compensator to suppress the output's peak in response to step inputs [2]. The Posicast controller has been under study on different systems that have oscillating response with low damp since 1960. In [2] and [3], developed approaches were presented for high degree systems with a variable

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structure. Applying the Posicast controller to nonlinear dynamics that have slow time variations has always been effective.

Some surveys indicated that Posicast is very sensitive to incorrect information in the damp's resonance frequency and this sensitive structure is usually seen in the many feed-forward control methods. The Posicast controller can be quite useful if the sensitivity of the design parameters for this controller is decreased.

In [4] and [5], the sensitivity problem of the parameters was decreased in comparison to the classic Posicast controller by using Posicast in the feedback control.

In recent years, Posicast-based feedback control has been used for boost converters [6], multilevel dynamic voltage restorers (DVRs) [7], Z-source current-type inverters [8], and so on. In [9] and [10], the Posicast controller was applied in exciting the system of the synchronous generator to improve the small signal and transient stability of the generator.

The terminal's voltage of the compensator (SVC/STATCOM) can be regulated by changing its reference signal (V_{Ref}), but this method causes oscillations in the output of the shunt compensator.

In this paper, the Posicast control method is used for designing a feed-forward controller for shunt compensators. It is demonstrated that the performance of the controller in damping the oscillations is increased drastically, even though its design is simple.

2. History of the Posicast controller

The block diagram of the Posicast controller is represented in Figure 1. The transfer function of the Posicast block diagram is introduced as 1 + Po(S), where Po(S) is as follows [11]:

$$Po(s) = \frac{\delta}{1+\delta}\left[-1 + e^{-S(T_d/2)}\right]. \tag{1}$$

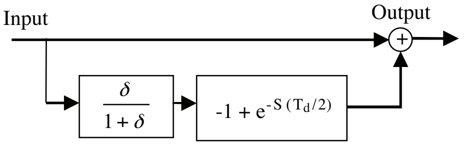


Figure 1. Open-loop half-cycle Posicast.

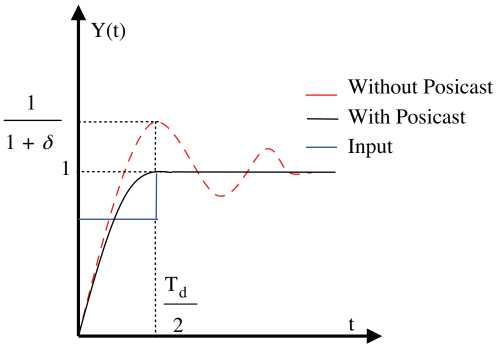


Figure 2. Step response of the system.

In Eq. (1), $1 + \delta$ is the response's peak value and T_d is the oscillation period to reach the final value, as shown in Figure 2. According to Figure 1, the Posicast controller has 2 sections. The upper section changes the input and the lower section changes the input value according to the response peak value. The second part of the lower section makes a delay in the changed input that is half of the response's oscillation period. In the half-cycle Posicast, the input is applied to the Posicast controller before being applied to the considered system, G(s), and the output of the controller is an input for G(s). The half-cycle Posicast controller acts like a full-zero filter and leads the system response to reach a final value after half-cycle ($T_d/2$) [2]. 1 + Po(s) is considered equal to 0.

$$1 + Po(s) = 0 \Rightarrow s = \sigma + j\omega \tag{2}$$

Thus, by solving Eq. (2), the following parameters can be obtained:

$$\sigma = \frac{2}{T_d}\ln\delta, \tag{3}$$

$$\omega = \frac{2\pi}{T_d}(2n+1), n = 0, 1, 2, ... \tag{4}$$

As seen above, the first pair of roots suppresses the poles with slow damp. For systems with a feedback controller, the Posicast controller is used in the feedback loop, as shown in Figure 3 [4,5]. Posicast in the feedback loop needs a transfer function, C(s), to decrease the system's sensitivity to the design parameters. C(s) can be an integral function that decreases the system's noise.

$$C(s) = \frac{k}{s} \tag{5}$$

3. SVC and STATCOM modeling

A single-line diagram of the considered system, along with the equivalent circuit of a shunt compensator, is shown in Figure 4. This system has 2 generators that are connected through 2 transmission lines at the length of 300 km and a voltage level of 500 kV. The power system's parameters are listed in the Appendix.

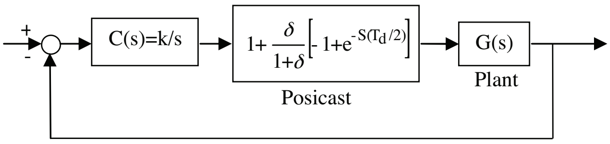


Figure 3. Posicast within a feedback system.

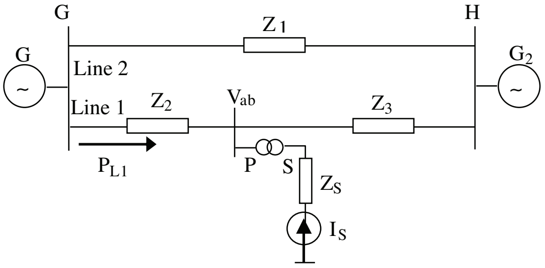
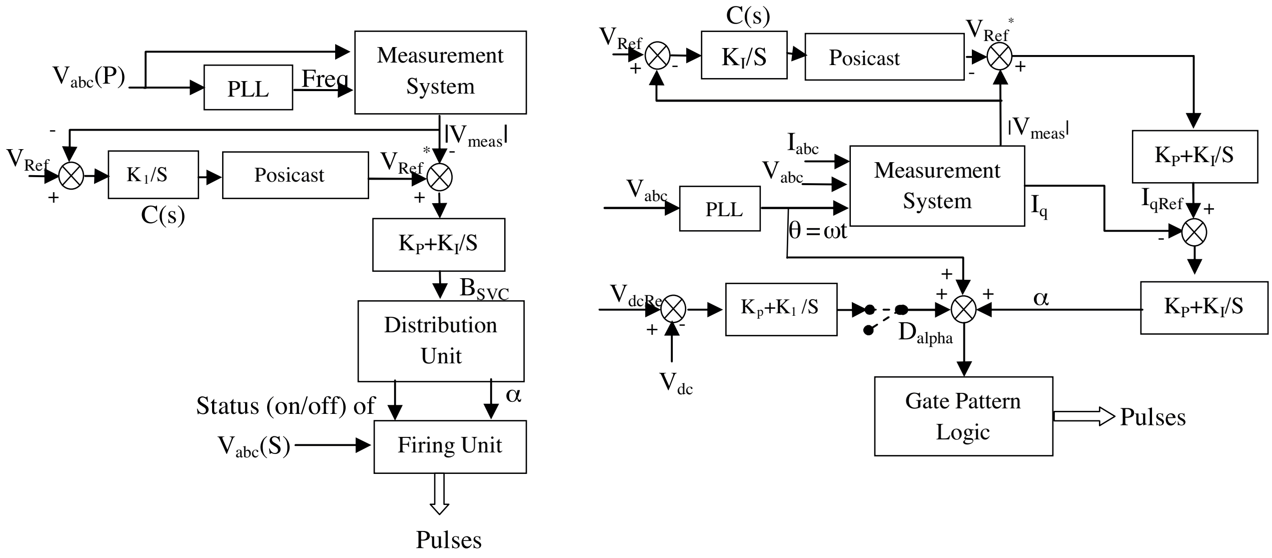


Figure 4. Single-line diagram of the considered system with the equivalent circuit of a shunt compensator.

3.1. SVC specifications and control system

A 100-Mvar thyristor-controlled reactor (TCR) bank with 3 thyristor-switched capacitor (TSC) banks, each at 100 Mvar, are used for modeling the SVC. A 340-MVA transformer is connected to the middle of the transmission line and all of the TSC and TCR banks are in Δ form to refuse injection of the third harmonic to the network.

The SVC controller, along with the added Posicast controller, can be seen in Figure 5a, where the first component of positive sequence voltage that is related to the primary SVC transformer is calculated by the measurement unit. The calculated value is compared with the output of the Posicast controller or V_{Ref}, and its result after amplification by PI controller is entered into the next section. As described in Section 2, an integral function is also used to decrease the sensitivity of the Posicast to its parameters. A distribution unit determines the firing angle of the TCR thyristors and their on-off states using calculated B_{SVC} values [1,12,13]. The control circuit of the STATCOM is shown in Figure 5b and is discussed below. Modeling of the system under study with the SVC using MATLAB/Simulink is shown in Figure 6, with only one TSC bank shown.



(a) (b)

Figure 5. Control model of the a) SVC and b) STATCOM.

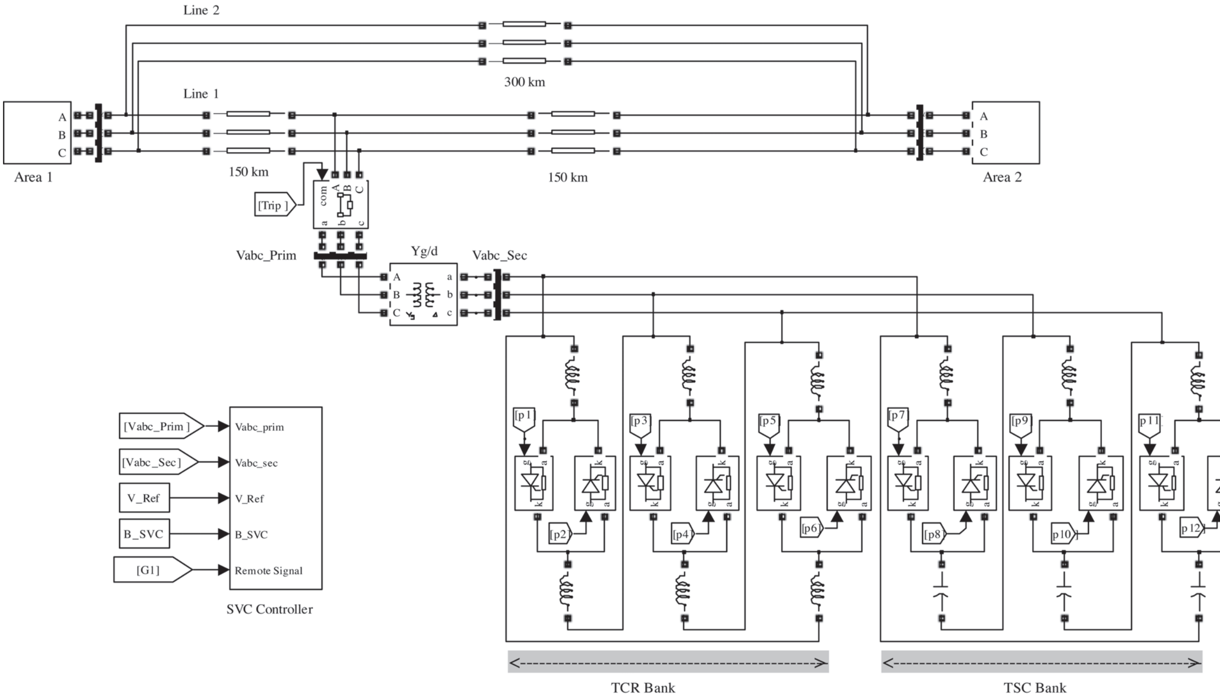


Figure 6. SVC performed in a MATLAB/Simulink environment using the power system block set and Simulink library.

3.2. STATCOM specifications and control system

Four inverters with 3 levels and 12 pulses are used to model a STATCOM with 100 MVA of power that is connected to the middle of the transmission lines through 4 phase shifter transformers. Two capacitors of the 3000 μF series are used to generate variable DC voltage. In total, this unit makes a 48-pulse voltage source converter [14,15].

The control circuit of the STATCOM is shown in Figure 5b, where it can be seen that the required output voltage's magnitude and phase are calculated from the I_{qRef}. The inputs of this controller are: the system's 3-phase voltage, V_{abc} (the STATCOM's location voltage); the STATCOM's output current, I_{abc}; and the reference voltage, V_{Ref}. The STATCOM output current is divided into 2 reactive (I_q) and active (I_d) components. The reactive component of the current (I_q) is compared with the reactive reference current (I_{qRef}) [1,13]. In the STATCOM, similar to the approach used for the SVC, the measured voltage is compared with the output of the Posicast controller, and its result after a suitable amplification using a PI controller determines the value of I_{qref}. Modeling of the system under study with the STATCOM using MATLAB/Simulink is shown in Figure 7.

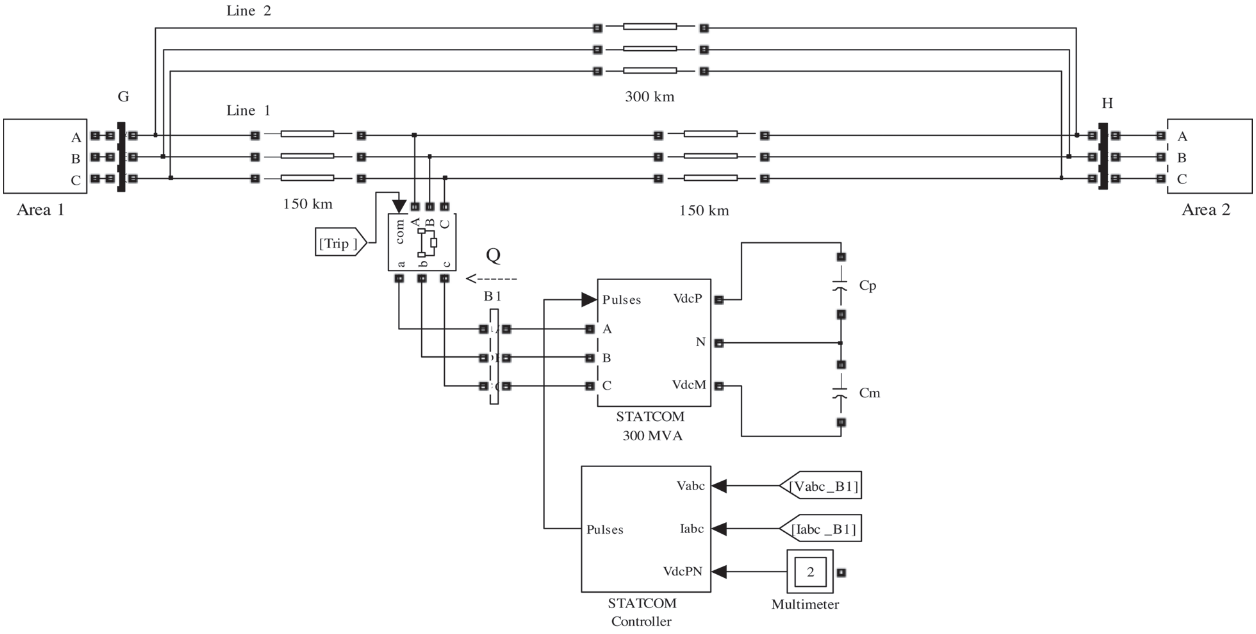


Figure 7. The STATCOM performed in a MATLAB/Simulink environment using the power system block set and Simulink library.

3.3. Design of the Posicast controller

To model the Posicast controller, δ and T_d are required. To obtain δ and T_d, the best and simplest approach is measuring the SVC/STATCOM installed point voltage while changing the V_{Ref}. Therefore, more accurate measuring allows for more accurate parameters of the Posicast. The Posicast parameters obtained are given in Section 4. Modeling of the Posicast using MATLAB/Simulink is shown in Figure 8.

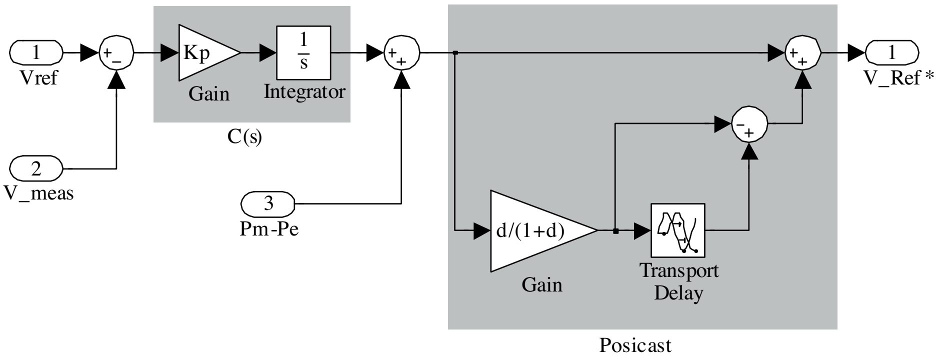


Figure 8. The Posicast controller performed in a MATLAB/Simulink environment using the Simulink library.

3.4. Simulation results

Results of the simulations performed in the MATLAB/Simulink environment are presented in this section. In these simulations, V_{Ref} increased from 0.9611 to 1 at 0.5 s and decreased again to 0.955 at 1.5 s. The V_{Ref}, along with $|V_{abc}|$ for a state without the Posicast controller, is shown in Figure 9. According to Figure 9, $|V_{abc}|$, after some oscillations around the final value, converged to the final value for both states with the SVC and with the STATCOM. It can be seen using a load flow that the $|V_{abc}|$ or voltage in the middle of the transmission line is 0.9611 p.u. without a shunt compensator. Moreover, the performed load flow indicates that 241.3 Mvar of the reactive power needs to be injected into the system in the middle of the transmission line to enable $|V_{abc}|$ to reach 1 p.u., and, similarly, 36.5 Mvar of the reactive power should be absorbed from the middle of line 1 to enable $|V_{abc}|$ to reach 0.955. The reactive power of the shunt compensator is also shown in Figure 10, where it can be seen that the results of the simulation are like the results of the load flow. For example, V_{Ref} is 0.9611 until 1 s; thus, the reactive power of the parallel compensator should be 0 according to the load flow results, such that this is compatible with Figures 9 and 10.

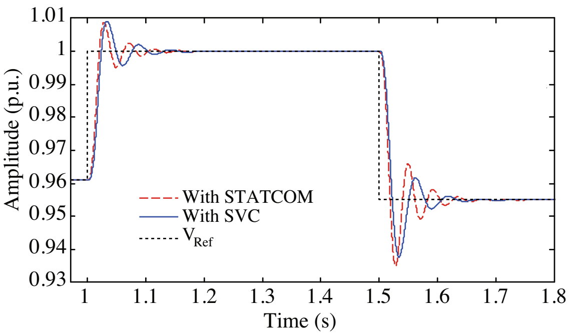


Figure 9. The V_{Ref} along with $|V_{abc}|$ for a state without a Posicast controller.

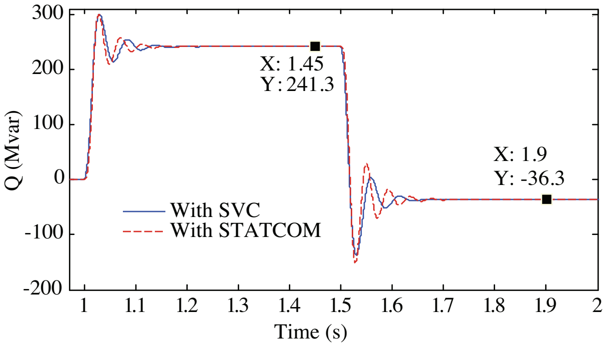
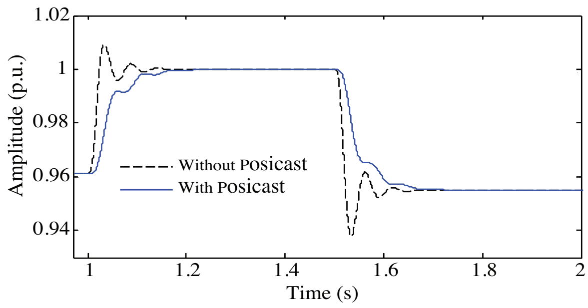


Figure 10. The reactive power of the shunt compensator.

The parameters for the Posicast controller were obtained according to the system's response, which is shown in Figure 9, and they are listed in the Appendix. In this paper, the Posicast controller parameters were obtained from an eigenvalue analysis that had the same results as in the previous approach. The results of the simulation when the Posicast controller is added to the control circuit of the SVC and STATCOM are shown in Figures 11 and 12. According to these results, the Posicast controller causes a decrease in the $|V_{abc}|$ oscillations.



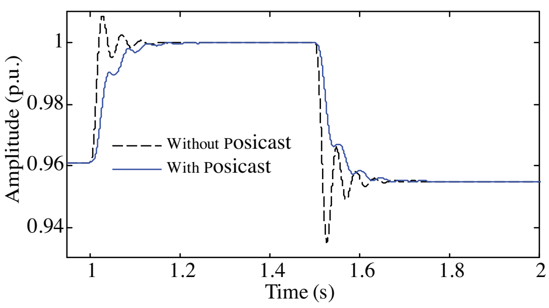
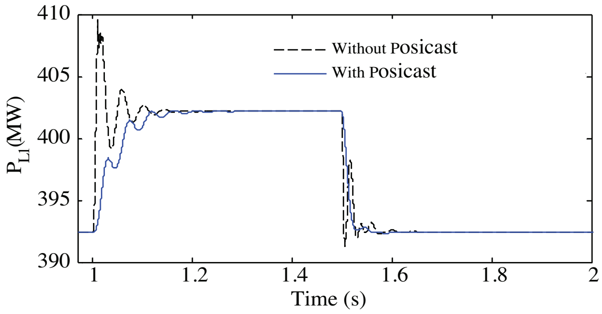


Figure 11. The $|V_{abc}|$ for a state with SVC.

Figure 12. The $|V_{abc}|$ for a state with the STATCOM.

The transferred power from transmission line 1 when the STATCOM is in the middle of the line is presented in Figure 13, showing that a decrease in $|V_{abc}|$ oscillations by the Posicast also decreases the transferred power oscillations. The transferred power of line 1 when the SVC is in the middle of the line is similar to the state with the STATCOM in this location. The simulation results, considering a 20% error in determining the Posicast parameters, are shown in Figures 14 and 15. It can be seen that the existence of the Posicast in the feedback loop decreases its sensitivity to its own parameters and the Posicast is still able to suppress the $|V_{abc}|$ oscillations.



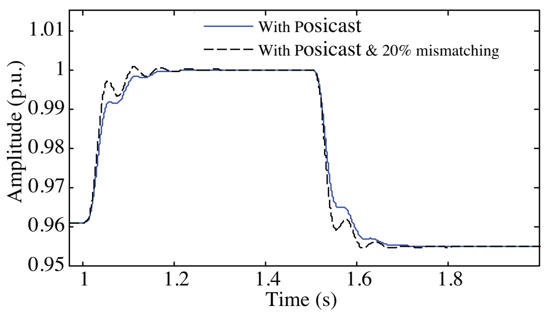


Figure 13. The transferred power from transmission line 1 with the presence of the STATCOM in the middle of the line.

Figure 14. The $|V_{abc}|$ for a state with the SVC.

In this paper, droop X_s (p.u./P_{base}) is considered to be ideal (0) for the SVC/STATCOM. As a result, there is no steady-state error in either the Posicast or the classic Posicast. If we consider the nonideal case, both without the Posicast and without the classic Posicast, there will be some steady-state error. This problem can be solved using the Posicast in feedback. The simulation results are shown in the Figure 16 for droop = 0.005 X_s (p.u./P_{base}). It can be seen that the proposed Posicast surpasses the classic Posicast in eliminating steady-state error. This problem for the classic Posicast will be even more important with an increasing droop value.

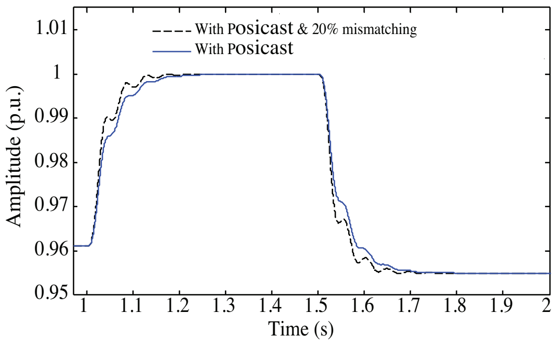


Figure 15. The $|V_{abc}|$ for a state with the STATCOM.

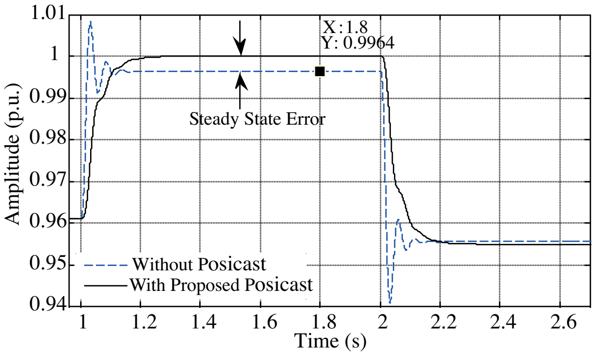


Figure 16. The $|V_{abc}|$ for a state with the SVC.

4. Conclusion

In this paper, the damping of the oscillations caused by changing the shunt compensator reference signal (V_{Ref}) using a Posicast controller was presented. It was shown that using a Posicast controller in the controller of the SVC and STATCOM increased the damping speed of the voltage oscillations in the installed point, and the overshoot of the responses were considerably improved when it was completely removed from the terminal voltage in the shunt compensator. The Posicast controller uses an unsophisticated and easy-to-implement idea to improve system performance. Thus, practical application of this controller can be quite cost-saving.

Appendix

The power system contains 2 transmission lines of 300 km and 500 kV. The positive and negative sequence line impedance is $Z_{1L1} = Z_{1L2} = 0.0255 + j0.3520\ \Omega/\text{km}$, and the zero-sequence transmission line impedance is $Z_{0L1} = Z_{0L2} = 0.3864 + j1.5556\ \Omega/\text{km}$. The short circuit level at G and H = 9000 MVA, system frequency = 60 Hz, load angle between sources = 30°, and ratio between the magnitudes of the source voltages at G and H = 1.072.

The STATCOM rating = ±300 MVA, each of the phase shifting transformers = 125/15 kV and 75 MVA, voltage regulator gains are $K_P = 5$ and $K_I = 3000$, I_q regulator gains are $K_P = 0.3$ and $K_I = 10$.

The considered SVC contains 1 TCR bank of 100 Mvar and 3 TSC banks of 100 Mvar, which are connected to the middle of the transmission line using a coupling transformer = 500/16 kV (Yg/d) and 340 MVA; voltage regulator gains: $K_P = 3$ and $K_I = 2000$.

Parameters of the Posicast controller: $T_d = 0.066$ s and $\delta = 0.01$ p.u.

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