Analysis of Variability of Solar Panels in The Distribution System

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***Abstract*— This paper analyzes effect of variations in the solar panel outputs on the distribution system. This may be due to changing weather conditions. Reactive power controlling devices (SVCs) were implemented at different points along the feeder and the effect of SVCs on the bus voltages were studied.**

***Index Terms*—Distribution feeder, Static VAR Compensator(SVC), solar panel, voltage, reactive power, variability, weather.**

I. Nomenclature

SVC – Static VAR Compensator;
SP – Solar Panel.

II. Introduction

THE years and the evolution of technology made new energy sources more accessible. The hydro, solar and wind power are the most commons renewable energy sources available.

However, with the increase of implementation of solar panels in the distribution system the operation of the grid was affected. This alters the manner in which electricity is being generated, transmitted and managed.

The solar panels, however, do not affect just the design of the power system. The dependence on weather conditions and its variation, affects the voltage across the feeder.

Thus, what is an option to control this voltage, avoiding overvoltage or voltage sags, which can result in flicker and equipment damage? One of the options is to implement reactive power controlling devices along the feeder, such as Static VAR Compensator (SVC). These devices control, inject or absorb, reactive power as needed, being able to control the voltage through the feeder and avoiding any future problem of energy distribution.

The use of SVCs in the distribution feeder is one the options to control the voltage. These devices were utilized because the grid does not have to be designed again.

III. Background

A. Static VAR Compensator

The Static VAR Compensator (SVC) is a device which is used to regulate the voltage of the system at the point of connection. The SVC has a variable reactor and a variable capacitor parallel to each other. The variable reactance is realized by utilizing power electronic switches named thyristors. By controlling the firing angle of the thyristors the reactance of the reactor can be varied.

Similarly, more capacitive reactance can be added to the circuit by controlling the switching of capacitor banks. This switching is also implemented using power electronic switches.

When the system is heavily loaded, the voltage at the bus drops to a low value and the SVC has to inject reactive power to raise the bus voltage. Similarly, when the system is lightly loaded, the SVC has to absorb reactive power and the voltage at the bus is reduced to a safe value.

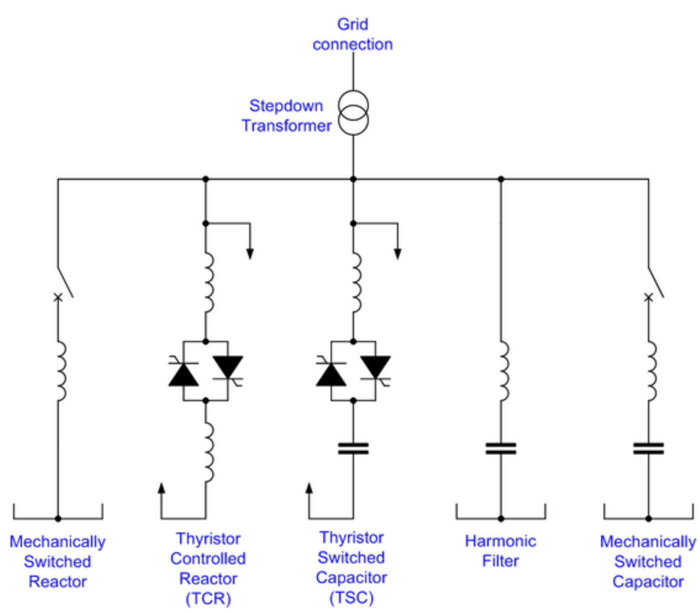

Fig. 1. Example of a SVC.

The SVC characteristics, Figure 2, is seen to have a small slope Ksl. This is because, it is desired to regulate the SVC bus voltage within a band of acceptable values and not strictly at Vref. The voltage at the bus in which the SVC is connected is given by the equation

$$V_{svc} = V_{ref} \pm K_{sl} I_{svc} \quad (1)$$

where, Isvc is the current injected by the SVC and Vsvc is the voltage of the bus at which SVC is connected.

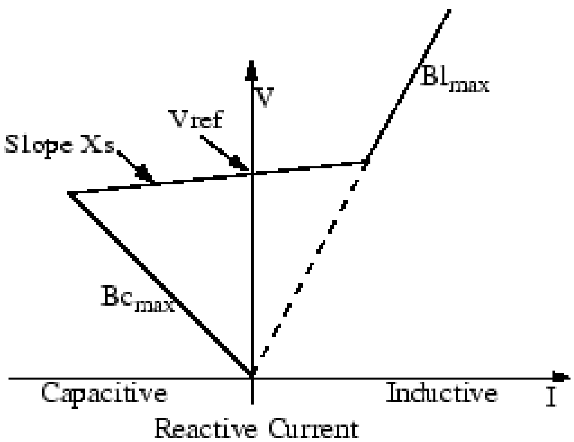

Fig. 2. SVC V-I characteristics.

B. Mathematical Modeling

The block diagram of the system considered with the SVC is shown in figure 3. From the block diagram, we obtain an expression for the voltage V2t as follows:

$$\frac{V_{2t}}{V_{svc}} = \frac{1}{1+sT} \quad (2)$$

$$\dot{V}_{2t} = \frac{(V_{svc} - V_{2t})}{T} \quad (3)$$

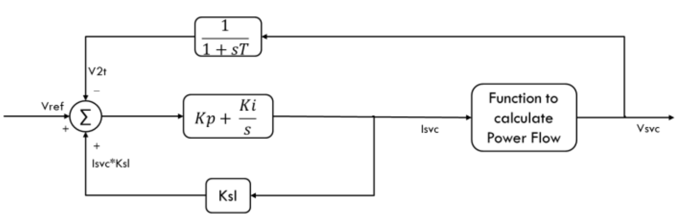

Fig. 3. Block diagram.

An expression for the current injected by the SVC is also obtained from the block diagram as follows:

$$\frac{I_{svc}}{V_{ref} - V_{2t} + I_{svc}K_{sl}} = K_p + \frac{K_i}{s} \quad (4)$$

$$I_{svc} = (V_{ref} - V_{2t} + I_{svc}K_{sl})K_p + (V_{ref} - V_{2t} + I_{svc}K_{sl})\frac{K_i}{s} \quad (5)$$

Let $y = \frac{K_i}{s}(V_{ref} - V_{2t} + I_{svc}K_{sl}) \quad (6)$

Then Equation (5) can be written as

$$I_{svc} = (V_{ref} - V_{2t} + I_{svc}K_{sl})K_p + y \quad (7)$$

From Equation (6),

$$\dot{y} = K_i(V_{ref} - V_{2t} + I_{svc}K_{sl}) \quad (8)$$

Substituting (7) in (8), as expression for $\dot{y}$ is obtained as

$$\dot{y} = \frac{K_i}{1 - K_pK_{sl}}(V_{ref} - V_{2t} + yK_{sl}) \quad (9)$$

Equations (3) and (9) constitute the dynamic equations of the system with SVC.

C. Current Power Flow Technique

The current power flow technique was implemented in this project to calculate the voltages at all the buses in the system. This technique was applied because it is simple and straightforward to implement. The algorithm for this technique is presented below.

1. Assume a flat start for all the bus voltages.
   $V_1 = V_2 = \dots = 1+j0$.

2. Calculate the injected current in each bus.
   $$I_i = \frac{P_i - jQ_i}{V_i^*}$$

3. Calculate the current along the feeder
   $\bar{I}_{01}, \bar{I}_{12}, \bar{I}_{23} \dots$

4. Calculate the bus voltages
   $\overline{V}_1 = \overline{V}_0 - \bar{I}_{01}\overline{Z}_{01}$
   $\overline{V}_2 = \overline{V}_1 - \bar{I}_{12}\overline{Z}_{12}$
   And so on.

5. Check for the convergence if max|V(i+1)-V(i)| < ξ where ξ is a tolerance value, the solution has converged and the procedure is stopped. Else go back to step 2 and repeat it with the new values of voltages calculated in step 4.

IV. 4 Bus System

The 4 bus system considered has one substation which distributes power through a feeder which contains 3 sections. A solar panel is implemented in bus 3 and a SVC in bus 2 as shown in the Figure 4. Perturbations were applied to the solar panel outputs at different instances of time and the results are presented below.

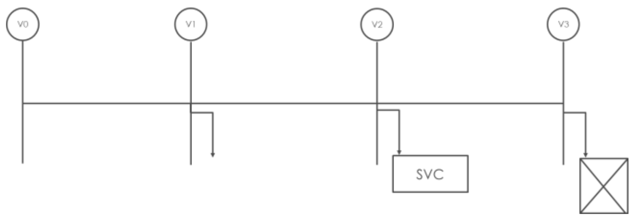

Fig. 4. 4 bus system design.

Figure 5 and 6, show the evolution of the voltage of the bus in which an SVC is connected. It is observed that the voltage of the system is improved when there is a drop in the solar panel output and decreased when the output of the solar panel is increased.

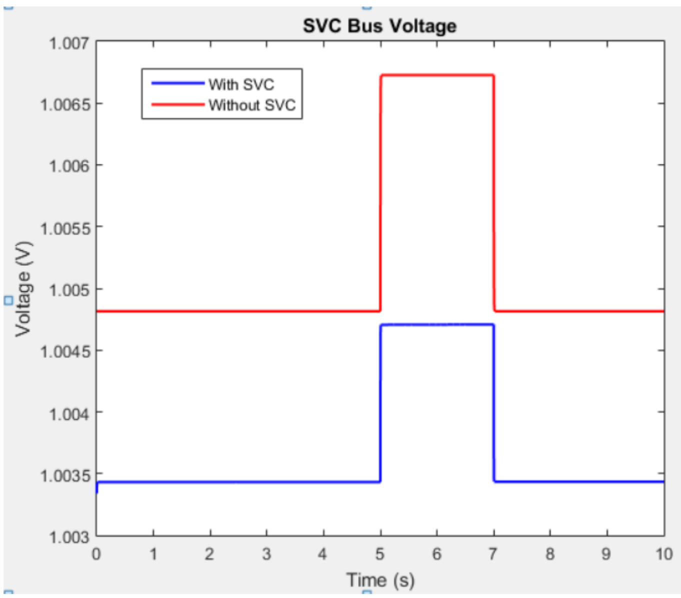

Fig. 5. Voltages in the 4 bus system with power injection of 1p.u. from 0 to 5 seconds, 1.1p.u. from 5 to 7 seconds and 1p.u. from 7 to 10 seconds.

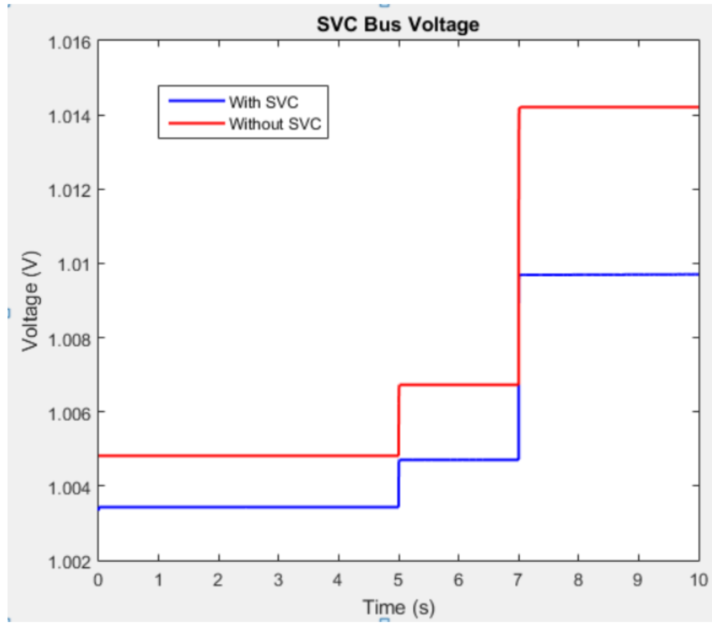

Fig. 6. Voltages in the 4 bus system with power injection of 1p.u. from 0 to 5 seconds, 1.1p.u. from 5 to 7 seconds and 1.5p.u. from 7 to 10 seconds.

V. 20 Bus System

A 20 bus system, as shown in Figure 7, was considered for study. It has 3 solar panels implemented in buses 3, 8 and 16 and SVCs at buses 4, 10 and 19. Changes were applied to the solar panel outputs and the evolution of the SVC bus voltage with respect to the time was studied.

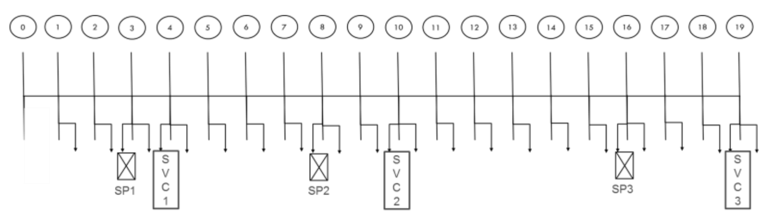

Fig. 7. 4 bus system design

It is observed from Figures 8 to 16 that with the SVC the bus voltage remains almost a constant even though there are changes in the solar panel output and this is not the same as without SVC.

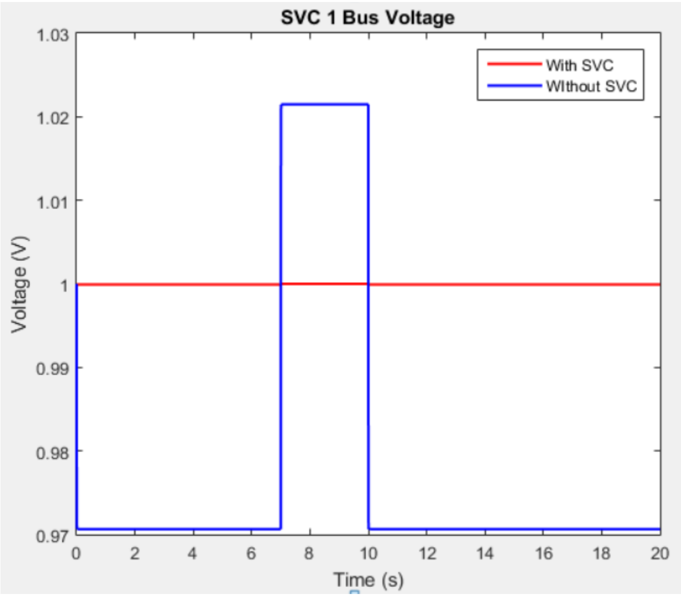

Fig. 8. Voltages in the 20 bus system with power injection of 0.0001p.u. from 0 to 7 seconds, 0.005p.u. from 7 to 10 seconds and 1.5p.u. from 10 to 20 seconds for the SVC1.

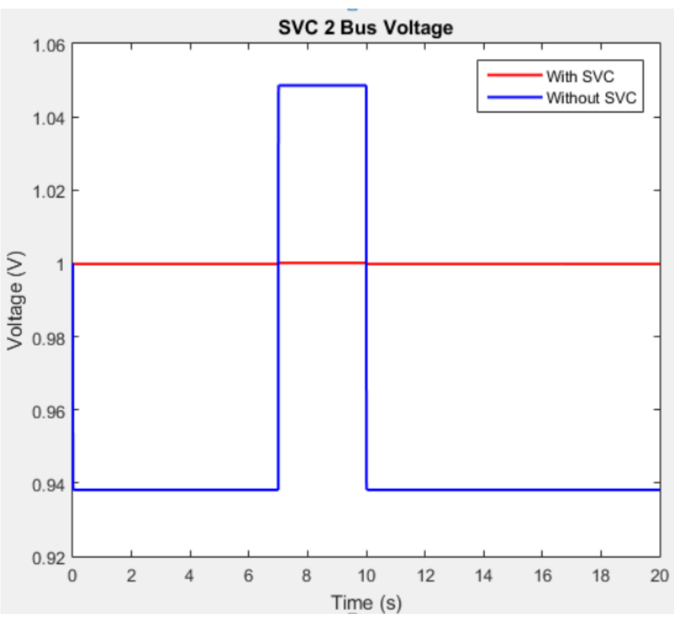

Fig. 9. Voltages in the 20 bus system with power injection of 0.0001p.u. from 0 to 7 seconds, 0.005p.u. from 7 to 10 seconds and 1.5p.u. from 10 to 20 seconds for the SVC2.

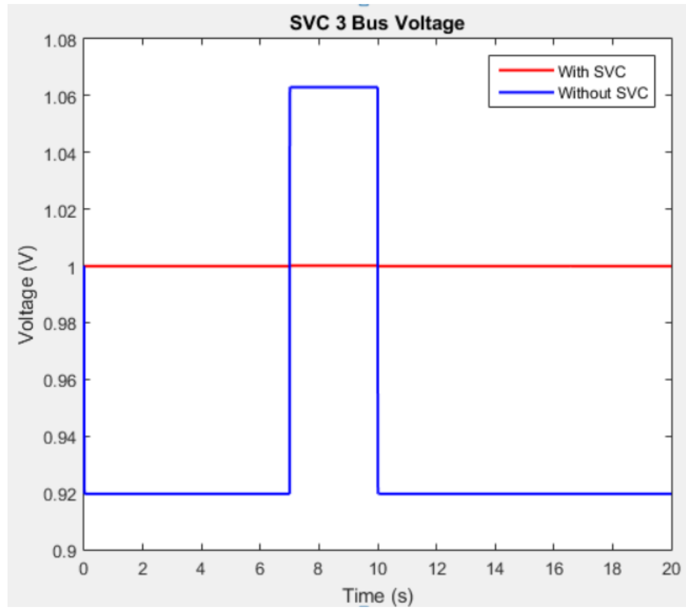

Fig. 10. Voltages in the 20 bus system with power injection of 0.0001p.u. from 0 to 7 seconds, 0.005p.u. from 7 to 10 seconds and 1.5p.u. from 10 to 20 seconds for the SVC3.

The SVC bus voltage rises when the solar panel injection increases and decreases when there is a decrease in the power provided by the solar panel.

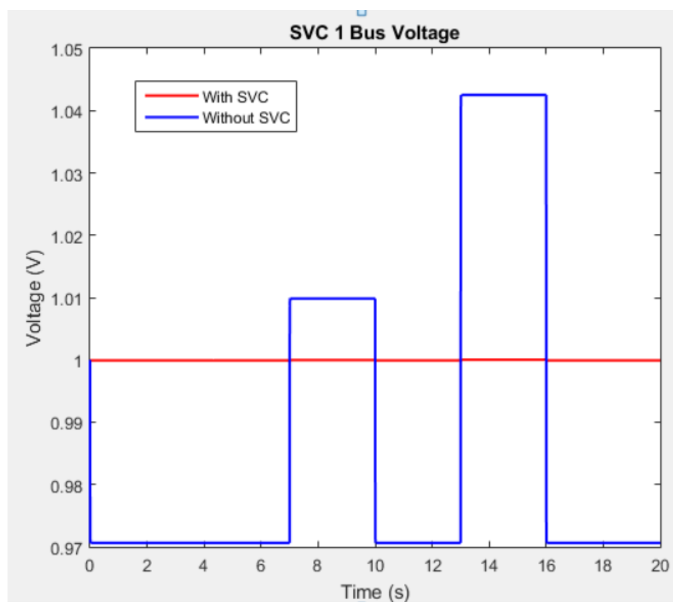

Fig. 11. Voltages in the 20 bus system with power injection of 0.0001p.u. from 0 to 7 seconds, 0.005p.u. from 7 to 10 seconds for the SP2, 0.003p.u. from 7 to 10 seconds for the SP1 and SP3, 0.0001p.u. from 10 to 13 seconds, 0.005p.u. from 13 to 16 seconds for the SP2, 0.009p.u. from 13 to 16 seconds for the SP1 and SP3, and 0.0001p.u. from 16 to 20 seconds for the SVC1.

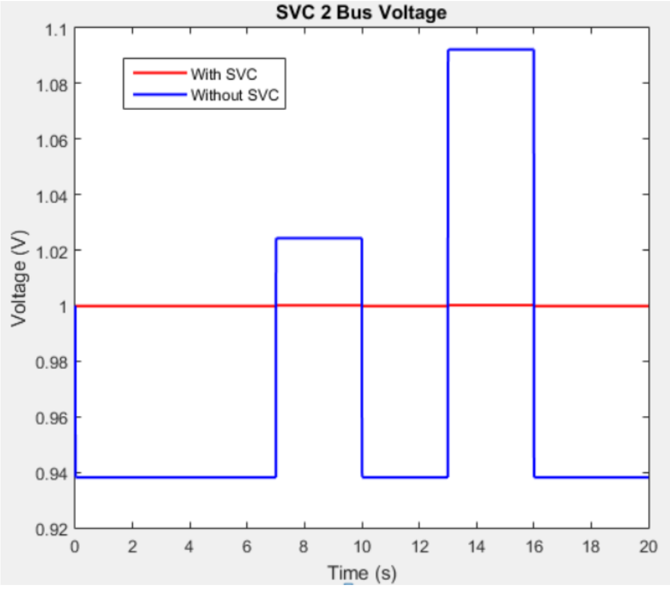

Fig. 12. Voltages in the 20 bus system with power injection of 0.0001p.u. from 0 to 7 seconds, 0.005p.u. from 7 to 10 seconds for the SP2, 0.003p.u. from 7 to 10 seconds for the SP1 and SP3, 0.0001p.u. from 10 to 13 seconds, 0.005p.u. from 13 to 16 seconds for the SP2, 0.009p.u. from 13 to 16 seconds for the SP1 and SP3, and 0.0001p.u. from 16 to 20 seconds for the SVC2.

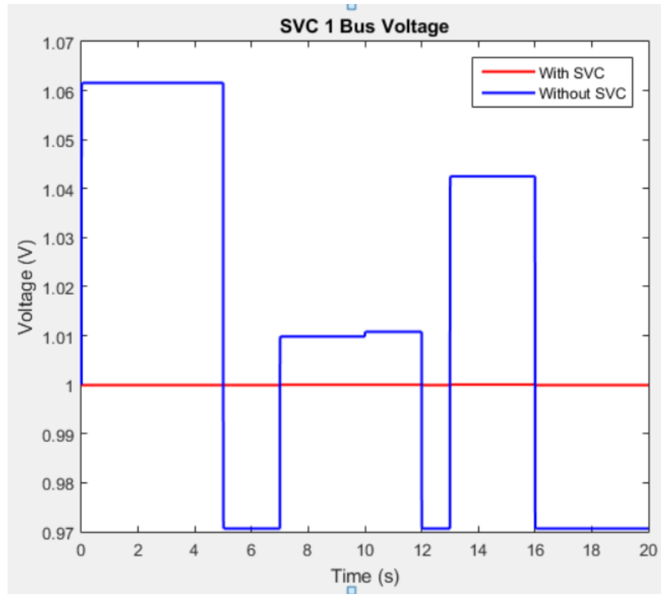

Fig. 14. Voltages in the 20 bus system with power injection of 0.01p.u. from 0 to 5 seconds, 0.0001p.u. from 5 to 7 seconds, 0.005p.u. from 7 to 10 seconds for the SP2, 0.003p.u. from 7 to 10 seconds for the SP1 and SP3, 0.007p.u. from 10 to 12 seconds for the SP2, 0.002p.u. from 10 to 12 seconds for the SP1 and SP3, 0.0001p.u. from 12 to 13 seconds, 0.005p.u. from 13 to 16 seconds for the SP2, 0.009p.u. from 13 to 16 seconds for the SP1 and SP3, and 0.0001p.u. from 16 to 20 seconds for the SVC1.

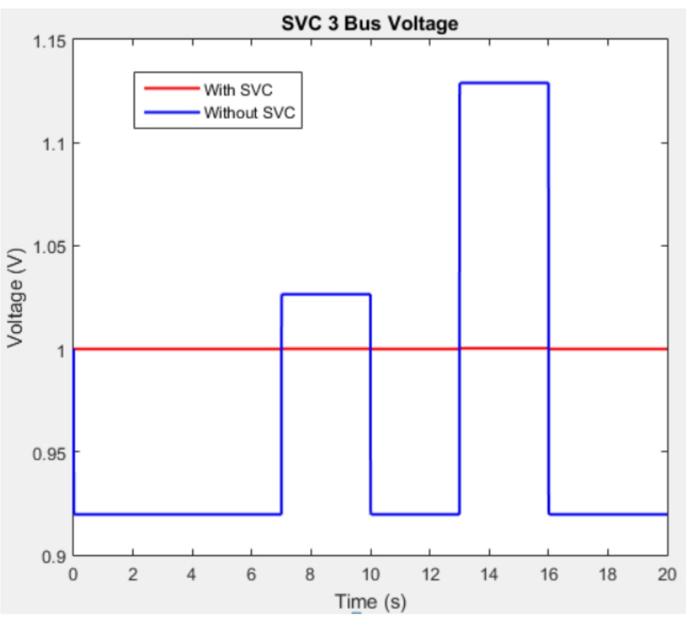

Fig. 13. Voltages in the 20 bus system with power injection of 0.0001p.u. from 0 to 7 seconds, 0.005p.u. from 7 to 10 seconds for the SP2, 0.003p.u. from 7 to 10 seconds for the SP1 and SP3, 0.0001p.u. from 10 to 13 seconds, 0.005p.u. from 13 to 16 seconds for the SP2, 0.009p.u. from 13 to 16 seconds for the SP1 and SP3, and 0.0001p.u. from 16 to 20 seconds for the SVC3.

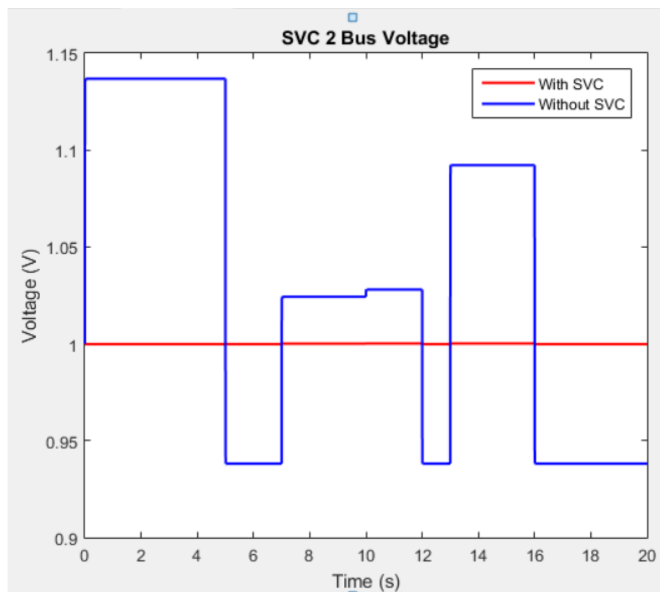

Fig. 15. Voltages in the 20 bus system with power injection of 0.01p.u. from 0 to 5 seconds, 0.0001p.u. from 5 to 7 seconds, 0.005p.u. from 7 to 10 seconds for the SP2, 0.003p.u. from 7 to 10 seconds for the SP1 and SP3, 0.007p.u. from 10 to 12 seconds for the SP2, 0.002p.u. from 10 to 12 seconds for the first and third solar panels, 0.0001p.u. from 12 to 13 seconds, 0.005p.u. from 13 to 16 seconds for the SP2, 0.009p.u. from 13 to 16 seconds for the SP1 and SP2, and 0.0001p.u. from 16 to 20 seconds for the SVC2.

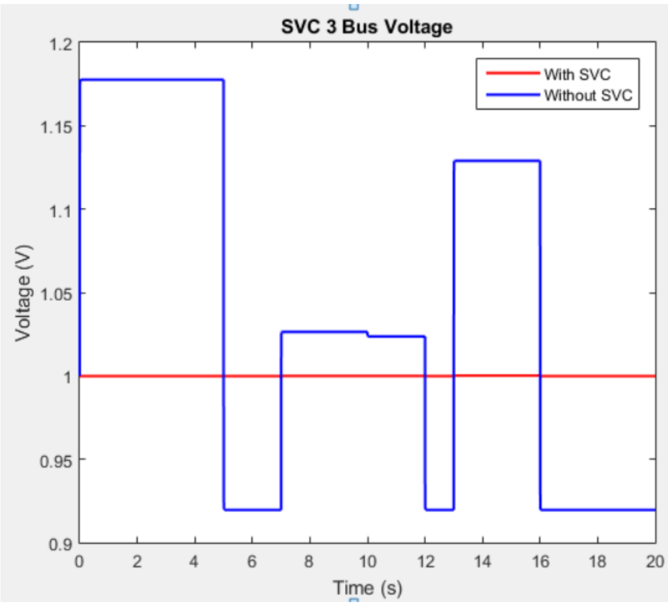

Fig. 16. Voltages in the 20 bus system with power injection of 0.01p.u. from 0 to 5 seconds, 0.0001p.u. from 5 to 7 seconds, 0.005p.u. from 7 to 10 seconds for the SP2, 0.003p.u. from 7 to 10 seconds for the SP1 and SP2, 0.007p.u. from 10 to 12 seconds for the SP2, 0.002p.u. from 10 to 12 seconds for the SP1 and SP2, 0.0001p.u. from 12 to 13 seconds, 0.005p.u. from 13 to 16 seconds for the SP2, 0.009p.u. from 13 to 16 seconds for the SP1 and SP2, and 0.0001p.u. from 16 to 20 seconds for the SVC3.

Figure 17 shows the voltage profile along the feeder at steady state with and without the implementation of SVCs. It can be seen that for the case without SVC the voltages decrease when moved away from the substation bus (bus 0) but with SVC, the entire voltage profile of the system is found to be improved.

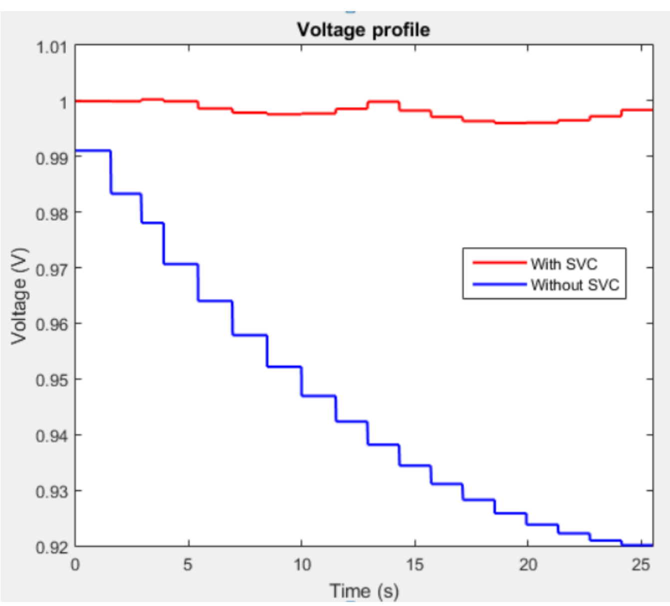

Fig. 17. Voltage profile along the feeder.

VI. Conclusion

SVC absorbs or supplies reactive power at the point of connection and based on this, the voltage at that SVC bus is maintained within an acceptable band. Introduction of more solar panels into the system causes variations in the bus voltages, but with the implementation of SVC the bus voltages are ensured to be within an acceptable range.

VII. Future Work

Future work would be test the implementation of SVC devices in longer distribution line, with more variability in the solar panel outputs, more loads and solar panels connected to the system. Also, studies for optimal location of SVCs can also be carried out.

VIII. Acknowledgement

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