ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

Investigation of SVC and STATCOM Devices in terms of Static and Dynamic Voltage Stability

Kadir ABACI, Volkan YAMAÇLI

Associate Professor, Department of Electrical-Electronics Engineering, Mersin University, Mersin, Turkey
Research Assistant, Institute of Electrical-Electronics Engineering, Mersin University, Mersin, Turkey

ABSTRACT: It is desired to enhance performance of devices that are used to improve voltage stability in power systems such as Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) which become increasingly complex and exhibit highly dynamic behavior. In this study, voltage stability analyzes have been performed to improve and compare static and dynamic voltage stability in steady state and transient states of power systems by using dynamic models of (SVC) and (STATCOM) devices. 14-bus standard test system is studied after comparing the performances of the models in a simple two-bus test system. Simulations on both systems were performed in the DiGSiLENT Power Factory environment and the results were compared.

KEY WORDS: Voltage Stability, SVC, STATCOM, DIgSILENT

I.INTRODUCTION

Due to increasing power demand and complexity in operation and structure, utilizing modern electrical power devices becomes much more difficult and formidable. Voltage instability is almost the most studied problem in power systems as one of the major causes of voltage instability in the power system is reactive power limit and increasing reactive load. Providing sufficient reactive power to the appropriate bus enhances voltage instability problems. [1] Shunt capacitor groups and load tap changer transformers which are used to improve voltage stability by supporting reactive power are not able to respond at a short time interval after a disturbance. Thus, static var compensator (SVC) and static synchronous compensator (STATCOM) devices are preferred instead of these slow responding devices. SVC is a well known FACTS device which is generally used in transmission networks due to low cost and good performance with the purpose of improving the voltage stability. There is another compensator device, STATCOM, which is also connected to a desired load bus in shunt. STATCOM device, like SVC, is also an important member of the FACTS family which is preferred to be used especially in long range transmission lines. SVC and STATCOM devices improve the security and quality of power by increasing the margin of system voltage stability and capacity of both active and reactive power transfer. In many studies, researchers have reported that these devices improve reactive power capacity[2,3], increase the system's loadability limit[4-7], improve voltage regulation, and prevent static and dynamic voltage instability and accompanying voltage collapse [8-12]. In [13] Mansour has proposed techniques for voltage stability analysis. Because the voltage instability exhibits a fast developing and dynamic situation, dynamic analysis methods [14, 15] output more effective results than static analysis methods [16]. In [17] Morrison et al. presented a study on analysis methods about dynamic approaches. Modeling of SVC and STATCOM devices is very important in voltage stability analysis studies and many control models have been proposed for these devices in the literature. This paper has compared the performance of controller models recommended for these devices in static and dynamic voltage stability analysis. In this study, it is aimed to evaluate the voltage stability for both dynamic P-V curves and time-domain simulations considering the dynamic control effects of SVC and STATCOM.
This paper proposes and implements SVC and STATCOM models in order to improve control modules in DIgSILENT, which are connected to IEEE 14-bus standard power system, verifying the validity of SVC and STATCOM models while verifying its effect on power system.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

II. VOLTAGE STABILITY

In recent years voltage stability and voltage collapse phenomena have become more and more important issues in power system analysis and control. Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subject to a disturbance from a given initial operating condition. Researchers have suggested techniques for voltage stability analysis considering both static and dynamic aspects.

A. Static Voltage Stability Analysis

The P-V Curve, Q-V Curve, have been widely used to analyze power system behaviors under varying loading conditions. Voltage stability analysis and loadability analysis are examples of the application of these curves in power system analysis.
In power flow studies and to obtain the corresponding P-V curves, the loads are typically represented as constant PQ loads with constant power factor, and increased according to

$$P_d = P_{d0}(1+\lambda) \quad (1)$$
$$Q_d = Q_{d0}(1+\lambda) \quad (2)$$

where P_{d0} and Q_{d0} are the initial real and reactive power respectively and λ is a p.u. loading factor, which represents a slow varying parameter typically used in voltage stability studies [18].

B. Dynamic Voltage Stability Analysis

Voltage stability is a dynamic phenomenon and analysis based on static modeling is not sufficient and usually leads to erroneous results. A common situation that is often encountered is that the system can collapse after a disturbance even if a post disturbance equilibrium point exists. In such cases, detailed dynamic models need to be used to analyze system stability.

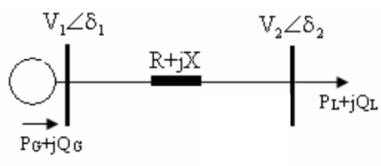


Fig 1: Two bus sample system.

The simple two bus system is shown in figure 1. whose dynamic equations for machine and load are given by:

$$\dot{\omega} = \frac{1}{M}(P_M - P_G - D_G\omega) \quad (3)$$

$$\dot{\delta} = \omega \quad (4)$$

$$\dot{V}_2 = \frac{1}{\tau}(Q_L - Q_D) \quad (5)$$

where the generator inertia and damping constants are represented by M and D_G, and τ stand for the dynamic load voltage time constants respectively [19].

III. SHUNT FACTS DEVICES MODELLING

Shunt Flexible AC Transmission System (FACTS) device such as SVC and STATCOM, when used, play an important role in controlling the reactive power flow to the power network and hence both the system voltage stability and transient stability.

A. Static Var Compensator (SVC)

The SVC has been widely used in power system are well known to improve power system properties such as steady-state stability limits, voltage regulation and var compensation, dynamic over-voltage and under voltage control, and damp power system oscillations for both voltage regulation and dynamic stability enhancement[11]. The main job of a

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 7, Issue 8 , August 2020

SVC is to inject a controlled capacitive or inductive current so as to maintain or control a specific variable, mainly bus voltage [20].

SVC Susceptance model (Type 1).
The SVC controller is modeled as a first order pure integrator [21]. The control system for the SVC controller model type 1 is depicted in figure 2.

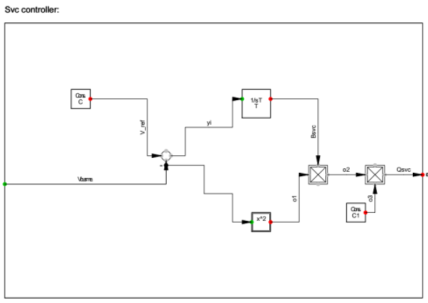


Fig 2: Structure of a SVC control model type 1 in DIgSILENT.

$$\dot{B}_{SVC} = \frac{1}{T_B}(-V_2 + V_{ref}) \tag{6}$$

where B_{SVC} is the equivalent susceptance of the SVC. T_B ve V_{ref} are time constant and reference voltage values of load bus taken as 0.001 s and 1.0 pu, respectively.

SVC Susceptance model (Type 2).
In this session, SVC has been represented by Basic Model [23].

$$\dot{B}_{ref} = \frac{1}{T_R}[-B_{ref} + K_R(V_{ref} - V_2)) \tag{7}$$

$$\dot{B}_{SVC} = \frac{1}{T_B}(-B_{SVC} + B_{ref}) \tag{8}$$

where T_R and K_R are time and gain constants of voltage regulator, and also T_B ve B_{ref} are time constant and reference susceptance values of SVC. The voltage regulator is of the proportional type and the gain is the inverse of the slope- a gain of 100 p.u B_{ref} /pu ΔV on the SVC base means a 1% slope. This model is often used for preliminary studies. The gain, K_R is the reciprocal of the slope setting K_R is usually between 20 perunit (5% slope) and 100 perunit (1%slope) on the SVC base. The time constant, T_R is usually between 20 and 150 miliseconds. The lead-lag terms are often zero. The control system for the SVC controller model type 2 is depicted in figure 3.

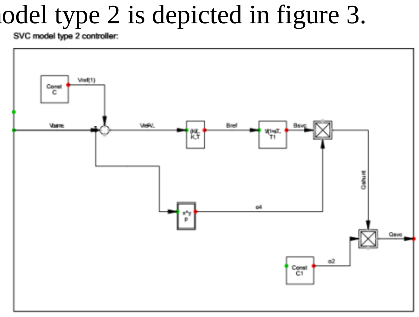


Fig 3: Structure of a SVC control model type 2 in DIgSILENT.

B. STATCOM
The Static Synchronous Compensator (STATCOM), previously referred to as Static Synchronous Condenser (STATCON), produces reactive power in the capacitive and inductive range by using self-commutating converters. It has advantages when compared to the Static Var Compensator (SVC), e.g., current injection independent of system voltage, faster control and less of a space requirement. With the possibility of using proper storage device equipment, it could control active power swings.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

STATCOM CIGRE Model.
The used CIGRE model for modeling STATCOM is presented in figure 4. The control function of STATCOM consist of two parts.

- A power System control contains the necessary circuitry for deriving the required reference reactive power or converter current value. Other possible control modes may be available reactive power control, power factor correction, start-up and shutdown control etc.),
- A converter control where triggering signals are determined for appropriate gating of the power electronic switches in order to obtain the target reactive power or converter current, determined by the power system control [24].

The voltage controller is usually of proportional-integral type and is used for regulating the magnitude of voltage, improving voltage stability and assistance due voltage recovery after contingencies, as is discussed in [24]. The transfer function of the voltage regulator is the same as the SVC voltage regulator transfer function, with different values for the gains and integral time. The values of the regulator gain and integrator time are chosen, regarding the literature [9]. Higher gain values result in faster response with a small overshoot. The STATCOM model has incorporated a slope X_{SL} characteristic used for adjusted control of the voltage control characteristic (the amount of generated/absorbed reactive power per p.u. voltage deviation). The input signal of the PI voltage regulator is the error signal calculated from the voltage reference V_{ref} the actual value and the STATCOM slope characteristic VSL , given by (9).

$$\Delta V = Vref - V_{SL} - V \qquad (9)$$

The PI voltage regulator output signal Iref represents the required STATCOM reactive current to correct the voltage error signal ΔV [24]. The maximum and minimum limits on the current output Iref are given by I_{max} and I_{min}, respectively (Figure 4). The Measuring circuit represents the delays of the measurement system, from which the actual measured voltage value is derived. A Thyristor Firing Control block represents the converter control part. The Interface block is realized by multiplying the reference value of the current with the voltage to obtain required reactive power generation or absorption. The control system for the STATCOM CIGRE model is depicted in figure 5.

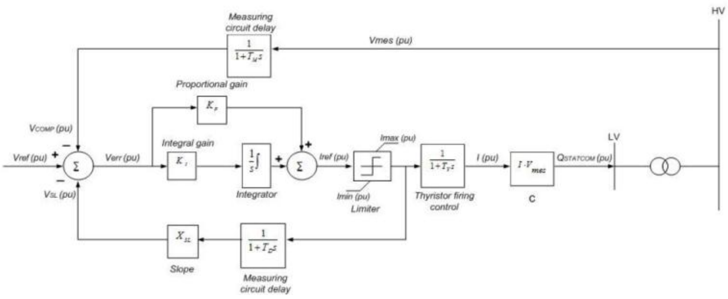


Figure 4. CIGRE model for dynamic modelling of STATCOM

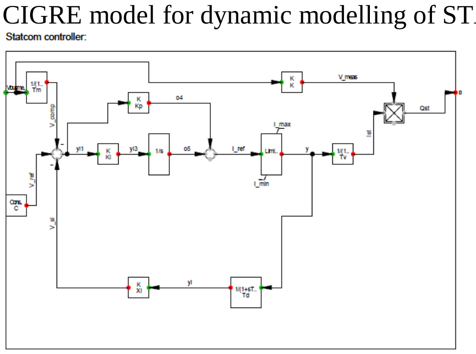


Figure 5: Structure of a STATCOM CIGRE control model in DIgSILENT.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 7, Issue 8 , August 2020

STATCOM Current Injection model.

A simplified STATCOM current injection model has been proposed in [25]. The STATCOM current is always kept in quadrature in relation to the bus voltage so that only reactive power is exchanged between the AC system and the STATCOM. The differential equation and the reactive power injected at the STATCOM node are, respectively:

$$\dot{i}_{sh} = \frac{1}{T_R}[K_R(V_{ref} - V_2) - i_{sh}] \tag{10}$$

where T_R and K_R are time and gain constants of voltage regulator. T_R , V_{ref} and K_R are time constant , reference voltage values of load bus taken as 0.001 s and 1.0 pu and 3000, respectively. The control system for the STATCOM current injection model is depicted in figure 6.

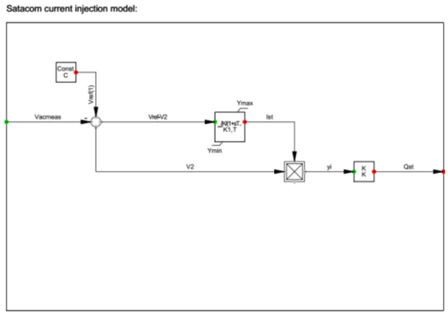


Figure 6: Structure of a STATCOM current injection control model in DIgSILENT.

IV. TOOLS AND METHODOLOGY

In this study, the voltage stability improvement has been investigated effect of SVC and STATCOM devices. In static voltage stability studies, two types SVC Models and STATCOM CIGRE model has been used. In the two buses basic system, the validation of models is showed. Afterwards, at 14 bus test system SVC and is accomplished by obtaining full P-V curves for normal and devices installations conditions. On these P-V curves, Static Load Margins, which are typically the loading levels, is depicted. Also, transient voltage stability analysis is applied to 14-bus test system. In bus 14, three-phase short circuit and line outage between bus 9 and 14 are studied and simulated. SVC and STATCOM devices controller models have been designed by using DIgSILENT Simulation Language (DSL). On the other hand, All P-V curves were obtained using the PowerFactory Version15.0, DIgSILENT software package [22].

V. SIMULATIONS RESULTS AND DISCUSSION

A. Two bus Test System.

The test system depicted in Fig. 1 is used here to validate the implementation of the devices models into the programs DIgSILENT. The single line diagram of this two bus system modeled in DIgSILENT power factory software 15.0 together with shunt facts devices is shown in Figure 7. Technical values of the power system and controllers have been given at the below tables. All the data and controls required for typical stability studies of the given test system were extracted Tables 1 and 2. Augmentation scenarios are considered as load disturbance that can be seen from Figure 8 . The objective is to fix the voltage magnitude of the bus at 1 p.u. during simulation. Each simulation has duration of 2 s and the loading event started at time of 1s.

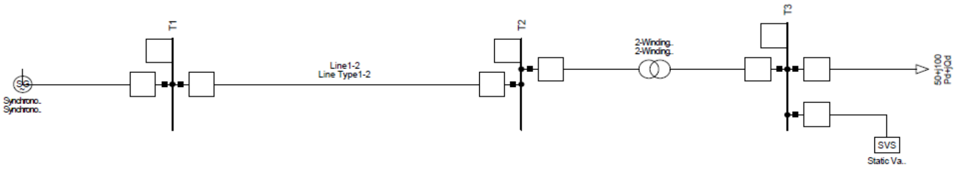


Figure 7: The single line diagram of two-bus system modeled in DIgSILENT

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

Table 1 Test system data

Variable	Value
Generator damping coefficient [D_G]	0.1 p.u
Generator acceleration time constant	10 s
load power factor [k]	2
reactance of transmission line [X]	0.5 p.u
Active demand power[P_d]	0.55 p.u
Reactive demand power [Q_d=k* P_d]	2*0.55 p.u
Transformers tap ratio [a]	1

Table 2 Controller Models data

Devices Model types	T_B	T_d	T_v	T_m	T_R	K_R	K_p	K_i	Xl
SVC Type 1	0.01								
SVC Type 2					0.0016	30000			
STATCOM CIGRE model		0.001	0.001	0.016			10	6000	0.001
STATCOM current injection model					0.001	3000			

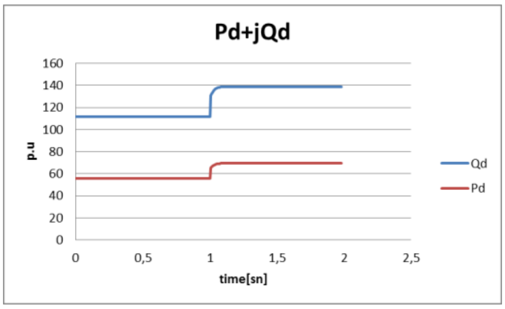


Figure 8: Applied P_d+jQ_d

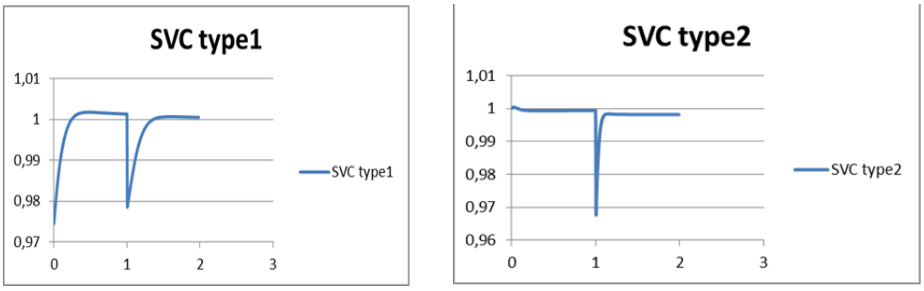
SVC Application. Model type I.

The used suseptance model for modeling SVC is presented in section 3.A Fig. 9 shows the voltage bus against time of the test system. The simulation time is two seconds. As is expected, the voltage magnitude at the load bus decreases to value 0.978 p.u at time t=1.00 s. In It can be seen that SVC controllers achieves good performance in voltage control of load bus (Fig. 9.a).

SVC Application. Model type II.

The used suseptance model for modeling SVC is presented in section 3.A. Fig.9 shows the load bus voltage variation before and after the disturbance. The simulation time is two seconds. Augmentation scenarios are considered as load disturbance. The objective is to fix the voltage magnitude of the bus at 1 p.u. during simulation. As is expected, the voltage magnitude at the load bus decreases to value 0.9678 p.u at time t=1.00 s. In it can be seen that SVC controllers achieves good performance in voltage control of load bus (Fig. 9.b).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020



a) b)

Figure 9: a) In the simple two bus system variation of load bus voltage for SVC Model
b) In the simple two bus system variation of load bus voltage for SVC Model type II.

STATCOM Application. CIGRE Model

The used CIGRE model for modeling STATCOM is presented in section 3.B. Fig.10 shows the load bus voltage variation before and after the disturbance. Augmentation scenarios are considered as load disturbance. The objective is to fix the voltage magnitude of the bus at 1 p.u. during simulation. As is expected, the voltage magnitude at the load bus decreases to value 0.9812 p.u at time t=1.00 s. In It can be seen that SVC controllers achieves good performance in voltage control of load bus (Fig. 10).

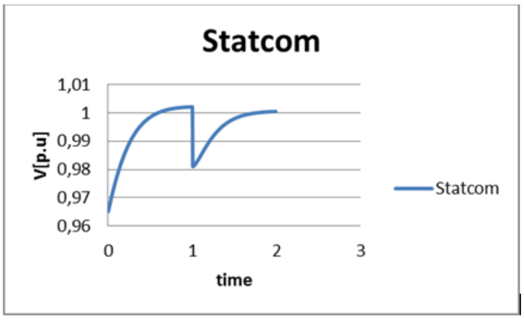


Figure 10: In the simple two bus system variation of load bus voltage for STATCOM CIGRE Model.

In order to make comparison, bus voltage variations related to controllers has been plotted Fig. 11. It is seen from Fig. 11 controllers caught the reference signal with a small delay.

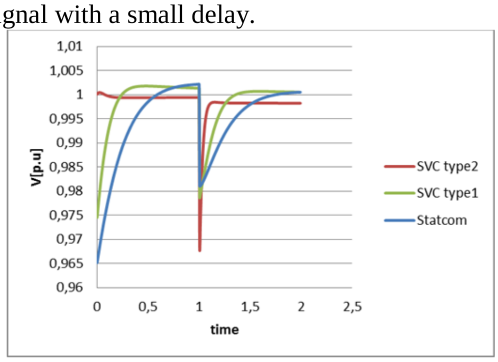


Figure 11: In the simple two bus system variation of load bus voltage compare all controllers model.

B. Very Large Test System Performance

For the IEEE 14-bus system, the P-V curves for various cases, with and without different FACTS controllers, were obtained. In these curves, loadability points are also depicted. The vertical line shown represents the load level in the system, assuming that almost all loads were modeled as constant PQ loads [13], as these are the type of loads that create the most stress in the system (only 14 was modeled as a constant impedance loads due to constraints associated with modeling FACTS controllers in the simulation program DIgSILENT).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

Static Voltage Stability Analysis

A SVC was added to the system to improve voltage stability. This progressive loading scenario will drive the power system from normal operating to voltage instability or collapse. The effect of SVC controller models has been investigated. In Figure 3.8 this effect can be seen. In this case, the loadability margin(λ) is increased from 3.693 to 9.757. It is seen from Fig. 12 controller models caught the reference signal with a small error. It can be seen that the SVC controller models achieves good performance in voltage control of load bus.

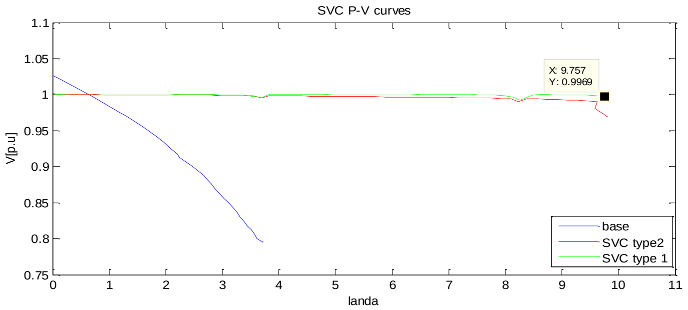


Figure 12: P-V curves at bus 14 of the two types SVC controller models

A STATCOM was added to the system to improve voltage stability. This progressive loading scenario will drive the power system from normal operating to voltage instability or collapse. The effect of STATCOM controller model has been investigated. In Figure 13 this effect can be seen. In this case, the load ability margin (λ) is increased from 3.693 to 9.661. It is seen from Fig. 13 controller model caught the reference signal with a small error.

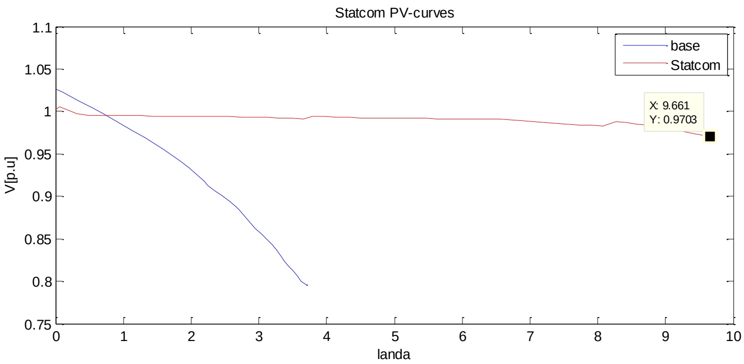


Figure 13: P-V curves at bus 14 of STATCOM controller models

From the above results, we see that voltage stability can be improved by the SVC and STATCOM controllers. SVC Model type 1 provides +285.5 Mvar reactive power support. On the other hand, SVC Model type 2 provides +268.847 Mvar and STATCOM CIGRE model +248.888 Mvar reactive power support. Table 3.3 illustrates the loadability margins the base case and after devices installed.

Table 3. 3 Loading Margins and reactive power support values for base test system

Device Models	Loading Margin	V	Q
Base Case	3.693	0.796u	
SVC Model Type I	9.757	0.9969	2.855
SVC Model Type II	9.621	0.9905	2.688
STATCOM CIGRE Model	9.961	0.9703	2.489

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 7, Issue 8 , August 2020

Dynamic Voltage Stability analysis

In order to compare the transient voltage stability improvement performances of SVC and STATCOM devices, two scenarios are considered in a 14-bus test system. In the first scenario, a three-phase short circuit fault that occurs in the bus 14 while in the second scenario, the line outage case that occurs between bus 9 and bus 14 are studied. In both scenarios, the load of bus 14 was increased by 50% and 100% while the performances of SVC and STATCOM devices were compared. The control model of SVC is chosen Type 1 model explained in Section 3.A, as for STATCOM the current injection model is used.

Three-Phase Short Circuit at Bus 14

In this section, it is assumed that the three-phase short circuit fault occurring at bus 14 in the 5^{th} second of simulation is cleared after 0.1s while simulation lasts for 10 seconds. In Fig. 14. The comparative simulation results of base system and system including SVC and STATCOM are given for bus 14 voltage. Reference voltage values of the STATCOM and SVC devices are adjusted according to 1.03 p.u value. This value is the bus voltage value of the bus 14 in the basic loading condition. If Fig. 14. is examined, it is seen that SVC and STATCOM devices bring bus voltage to 1.03 pu for basic, 50% and 100% loading conditions of the bus 14. The STATCOM controller behaves faster than the SVC control, bringing bus voltage to the desired value in a very short time. In addition, in the base system where SVC and STATCOM devices are not used in the case of 100% load, the bus voltage is decreased to 1.009 pu which is lower than desired value of 1.03 pu.

Line outage

In this section, a scenario is considered where the transmission line between bus 9 and bus 14 breaks in the 5^{th} second that no power transfer occurs from this transmission line until the end of the simulation which lasts for 10 seconds.

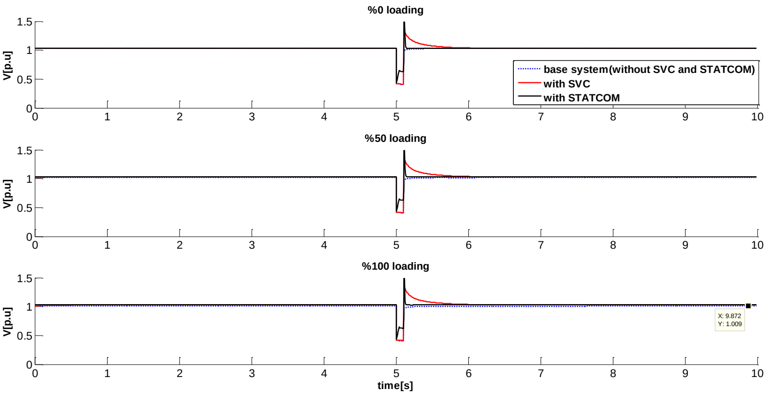


Figure 14: Voltage performances of SVC and STATCOM for 3-phase short circuit at bus 14

SVC and STATCOM devices are installed on bus 14, voltage values of bus 9 and 14 are given in Fig. 15 comparatively. It has been observed that the voltage of bus 9, which the broken line is connected, has increased to very high values due to the effect of SVC or STATCOM. The post-fault voltage value of 1.064 p.u in the basic system increased to 1.07 pu when SVC or STATCOM was installed on the bus 14. In order to prevent this situation, the fixed shunt capacitor of 19 MVAR at bus 9 has been removed. As a result of the simulation, the voltage value after failure in the basic system is 1.037 pu, which is increased to 1.043 pu when SVC or STATCOM is installed on the bus 14 as shown in Fig

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 7, Issue 8 , August 2020

15.

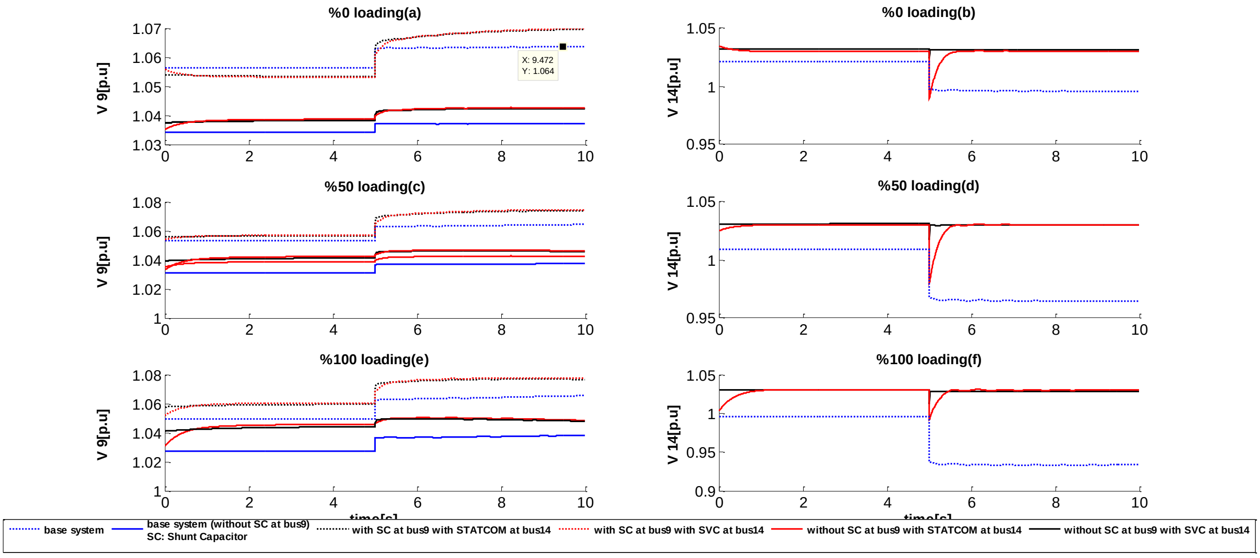


Figure 14: Voltage performances of SVC and STATCOM for line between bus 9 and bus 14

VI. CONCLUSION AND FUTURE WORK

In this study, as a suggested solution both transient voltage stability improving and to increase stability margin of the system, shunt FACTS controller that are SVC an STATCOM controllers are added, modeled in DIgSILENT, tested and compared to show the effect of these controllers on the different stability margins under loading conditions .

The IEEE 14 bus was studied using the DIgSILENT program to obtain the system P-V curves and perform time domain to study the general performance of the system. SVC, STATCOM controllers were also added to the system. The results of the study show that SVC and STATCOM are more helpful in voltage recovery when small and large disturbances of step load increasing and such as heavy loading. Some points resulting from this paper could be the basis for future studies;

The STATCOM CIGRE model and has not been affected. Studying more effectively STATCOM controller model. It is clear that used of optimization algorithms in determining the coefficients of PI parameters will better results as performance of controllers.

REFERENCES

[1] S. M. Padmajag. Tulasiram Das, “Analysis on Static Voltage Stability Using SVC, STATCOM, TCSC & UPFC, International Conference on Power Electronics and Instrumentation Engineering,(PEIE 2010): Power Electronics and Instrumentation Engineering, pp 46-52

[2] K. Dipesh, S. P. Shukla, “Improvement of Voltage Stability of Distributed Generation by Using SVC and STATCOM through Reactive Power Compensation”, Journal of Advanced Research in Dynamical and Control Systems 11(2):241-248 ,January 2019

[3] T.Vignesh, K.Dhivya, R.Chinnaiyan, “Modeling and Simulation of a DSTATCOM for Improvement of Voltage Stability in Microgrid using SPWM Technique”,International Journal of Advanced Research in Science, Engineering and Technology Vol. 2, Issue 11 , November 2015

[4] Bhavin. M.Patel, “Enhancement of steady state voltage stability using SVC and TCSC” National Conference on Recent Trends in Engineering and Technology, BVM Engineering College, Gujarat, India,13-14 May 2011.

[5] S. Musunuri, G.Dehnavi, “Comparison STATCOM, SVC, SSSC and TCSC devices for voltage stability improvement”, North American Power Symposium (NAPS-2010), 26-28 Sept 2010

[6] M.Ahmad, M.Alinezhad, “Comparison of SVC and STATCOM in Static Volatage Stability Margin Enhancement”, Proceedings of world Academy of sciences, Engineering and Technology, Vol. 38, Feb. 2009.

[7] A. Sode, Y. Adarajah Mithulananthan and Kwang Y. Lee, “Static Voltage Stability Margin Enhancement Using STATCOM, TCSC and SSSC,” IEEE/PES Transmission and Distribution Conference & Exhibition, Asia and pacific, Dalian Chine, 2005

[8]M. Osman Hassan, A. Ishag Idrees, M. E. Hassan “Static voltage Stability Assessment of Sudan National Electric Grid (SNEG) Through Optimal Placement of SVC” ,International Journal of Advanced Research in Science, Engineering and Technology Vol. 6, Issue 7 , July 2019

[9]S., M., Hoseinpoor, Y., Mosadeghardabili, P., and Pirzadeh, T ,“Analysis and simulation of a STATCOM for Midpoint Voltage regulation of transmission Lines”, Australian Journal of Basic and Applied Sciences, 5: 1157-1163.,(2011),

[10] C. A. Canlzares, Z. T. Faur, "Analysis SVC and TCSC Controllers in Voltage Collapse," IEEE Trans. Power Systems, Vol. 14, No. I, pp. 158-165, February 1999.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 7, Issue 8 , August 2020

[11] Baiyat, S. A., "Design of a Robust SVC Damping Controller Using Nonlinear H∞Technique", Arabian Journal for Science and Engineering, Vol. 30. No. 1B, (2005), pp. 65-80.
[12] V Chayapathi , Sharath B , G S Anitha, "Voltage Collapse Miigation by Reactive Power Compensation at the load Side" , International Journal of Research in Engineering and Technology Volume: 02 Issue: 09 pp. 251 -257, Sep-2013.
[13] Mansour Y. et all, "Suggested techniques for voltage stability analysis", Tech. Rep. IEEE pub. 93TH0620-5-PWR, IEEE Power Engineering Society,1993.
[14] Uyaroğlu Y., "Elektrik Güç Sistemlerinde Çatallaşma Analizi İle Kaotik Olayların İncelenmesi", Phd Thesis, SAU Natural sciences Institues, June 2002.
[15] Kose, E., Abaci, K., Aksoy, S., yalcin, M.A., "The Comparasion of the Improving Effects of ULTC and SVC on Dynamical Voltage Stability Using Neural Networks", Modern Electric Power Systems (MEPS) Proceedings of the International Symposium, Wrocklaw Poland. (2010).
[16]V. Ajjarapu and C. Christy, "The continuation power flow: A tool for steady state voltage stability analysis," IEEE Trans. on Power Systems, vol. 7, no. 1, pp.426-423, Feb. 1992.
[17]G.K. Morison B. Gao, Member IEEE P. Kundur,"Voltage Stability Analysis Using Static and Dynamic Approaches", IEEE Transactions on Power Systems, Vol. 8, No. 3, August 1993
[18] Kodsi, Sameh M.K., Canizares, A.C., "Modeling and Simulation of IEEE 14 Bus System with FACTS Controllers", Technical Report, 2003-3.
[19] "Voltage stability assesment: Concepts, practices and tools", IEEE/PES Power system stability Subcommittee Special Publication, product no. Sp 101 PSS, Final document, August 2002.
[20] IEEE FACTS working group 15.05.15, "FACTS Application", December 1995.
[21] W. Gu, F. Milano, P. Jang, G. Tang, "Hopf Bifurcations Induced by SVC Controllers: A Didactic Example",Electric Power Systems Research, Vol. 77, No. 3-4: 234-240, March 2007.
[22] Version 15.0 PowerFactory, User's manual,Gomaringen,Germany:DIgSILENT, 2013,vol.1.
[23] IEEE Special Stability Controls Working Grouph, "Static Var compensator models TSE 2478, (1976). for power flow and dynamic performance simulation", IEEE Trans. on Power Systems, Vol.9, 1: 229-239, Feb., 1994.
[24] Erinmez, I.A., Foss, A.M., "Static Synchronous Compensator (Statcom)", 14.19, Report 144. Cigré (1999).
[25] M.H. Hague, "Improvement of Firt Swing Stability Limit by Utilizing Full Benefit of shunt FACTS Devices", IEEE Trans. On Power Systems, vol.19.4, pp.1894-190, 2004.

AUTHOR'S BIOGRAPHY

Kadir ABACI is Associate Prof. of Department of Electrical and Electronics Engineering at Mersin University. He obtained his B. Sc., M.Sc. and Ph.D. in Electrical and Electronics Engineering in 2007 from Istanbul Technical University, and Sakarya University, respectively. He has done academic work in the Mersin University. His research is mostly in the field of voltage stability of the power systems and its control applications.

Volkan YAMACLI is Research Assistant in Department of Electrical and Electronics Engineering at Mersin University. He obtained his B. Sc. and M.Sc. in Electrical and Electronics Engineering in 2011 and 2014 from Mersin University, respectively. He has done academic work in the Mersin University. His research is mostly in the field of power system optimization, artificial neural networks, artificial intelligence and voltage stability improvement.