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The Modeling of SVC for the Voltage Control in Power System

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Abstract

One of the major causes of voltage instability in power system is the reactive power limit. Therefore, this paper aims to analyze the effect of Static Var Compensator (SVC) on voltage stability of a power system. There are many ways to control the voltage, but in this paper only focus on the SVC and IEEE-9 buses. The SVC circuit and IEEE-9 buses were designed and modelled in Power World. The Newton Raphson method was applied to compute the load flow solution. Then, the reactive power (Q) was injected to SVC and the effect of SVC on IEEE 9-buses were studied. The analysis of voltage control was considered the conditions of fault occurred at the bus. The simulation results obtained in Power World demonstrate that the improvement voltage in the IEEE 9-buses when the Q was injected into SVC circuit. Besides, the QV curve was plotted to show the sensitivity and variation bus voltages with respect to the Q injection.

Keywords*: Static Var Compensator, Voltage Control, IEEE 9-bus, Power World*

1. Introduction

The Static Var Compensator (SVC) is one of the FACTS devices that widely used in transmission application. The Static Var Compensator (SVC) is one of the FACTS families and the SVC also commonly used to improve the voltage stability in the power system network [1]. SVCs are mainly used to perform voltage or reactive power regulation [2]. It should be installed through transmission line as well as to control the voltage. This is because the SVC is one of the interest applications of the FACTS devices that very effective in enhancing voltage stability and voltage control due to their fast and flexible control. The FACTS controllers like SVC are used today in electrical power network depending upon its application. SVCs have been used for highperformance steady state and transient voltage control compared with classical shunt compensation. SVCs are also used to dampen power swings, improve transient stability, and reduce system losses by optimized reactive power control [3]. Over the last many years ago, the use of the SVC concept has produced significant benefits for the power system network.

Today, the voltage stability plays major role in the power system environment; it is an integral part of the power system stability. The electric power system has grown in size and complexity with a huge number of interconnections to meet the increase in the electric power demand [4]. The voltage drop exists along a transmission line can cause many problems to the consumers [5]. The increasing of load atpower system network can cause to voltage instability due to lack of reactive power support. This is also can cause improper or less-efficient equipment operation and can lead to blackout of the power system network. In addition, the reactive power Q needs to be injected to buses in order to maintain the voltage in the system. Therefore, by applying the SVC to the power system network, it was able to control the voltage and improves the system stability.

Furthermore, the Static Var Compensator (SVC) is one of the FACT devices that have their own benefits to improve or enhance in the power system. The main advantage of SVC over simple mechanically switched compensation schemes is their near instantaneous response to change in the system voltage. For this reason they are often operating at close to their zero-point in order to maximize the reactive power correction [6]. They are in general, cheaper,

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higher capacity, faster, and more reliable than dynamic compensation schemes [7]. Following stated the advantages of the SVC:
1. Improvement in voltage quality and voltage control.
2. Improved system steady-state stability and transient stability.
3. Dynamic reactive power control and damping of power oscillations.
4. Increase in system stability and power transfer capability.
5. Reduced voltage drops in load areas during severe disturbances and transmission losses.
6. Better adjustment of line loadings and load division on parallel circuits.

Table 1 shows the benefits of FACTS devices for different application [8]:

Table 1. Benefit of facts device application

Facts Devices	Load Flow Control	Voltage Control	Transient Stability	Dynamic Stability
SVC	+	+++	+	++
STATCOM	+	+++	++	++
TCSC	++	+	+++	++
UPFC	+++	+++	+++	+++

Good (+), Better (++), Best (+++)

2. Research Method

In this paper, the main focus is to design and model the IEEE 9-bus system together with SVC and analyze the performance of voltage control by inserting the SVC circuit at optimum buses. The SVC circuit was tested with consideration of fault occurred in the system. Then, the Power World software was used to analyze the effects of injecting Q into SVC circuit on IEEE 9–bus. Next, the QV curve was plotted to show the variation of voltage with injected Q.

2.1. Designing IEEE 9-bus

First, the IEEE 9-bus was designed into Power World. All the requirement for this system buses is according to what is needed. The IEEE 9-bus test system consists of 3 generators as a source. There are 9 numbers of buses, 3 transformers, 6 transmission lines and 3 impedance loads.

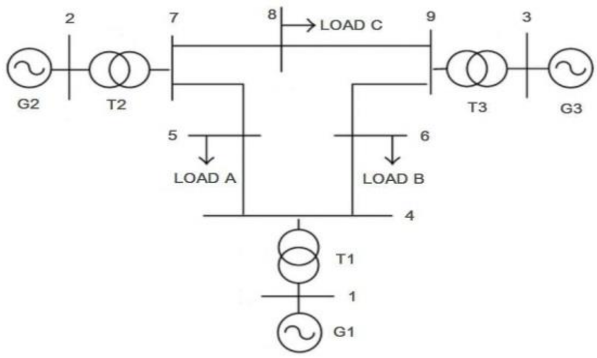

Figure 1. IEEE 9-Bus

2.2. Designing Static Var Compensator (SVC)

Figure 2 shows the basic circuit of SVC used in this project. The SVC circuit applied to IEEE 9-bus consists of 1 bus, 1 transformer, 1 shunt capacitor and 2 shunt reactor. The SVC circuit was tested to different location of bus in order to find the suitable location that contributes to the voltage control.

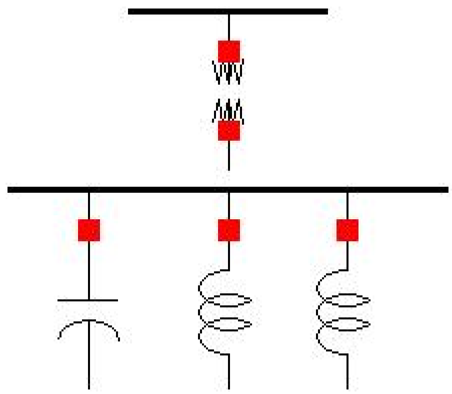

Figure 2. Basic Circuit of Static Var compensator (SVC)

2.3. Block Diagram for Power World Simulator

In this work, it was started by collecting the data from the IEEE 9-bus system. Next, the IEEE 9-bus system was model into Power World. After completing the second steps, the SVC circuit was modelled. The SVC was tested by considering the condition of fault and without fault in order to analyze the effect of SVC to control the voltage. Before placing the SVC into IEEE 9-bus, the load flow solution was computed based on the Newton Raphson method. After that, the SVC was tested to the buses by injecting the Q and the effect of SVC was analyzed.

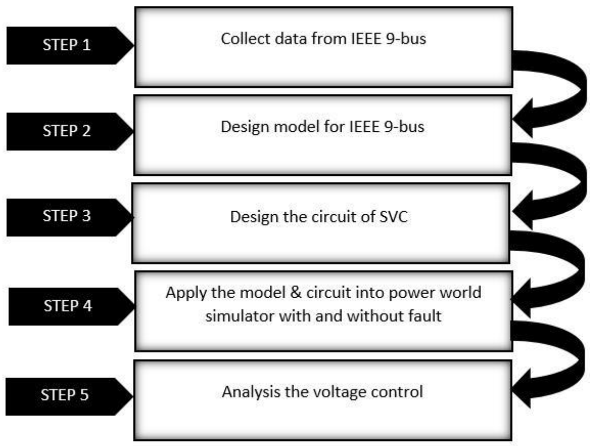

Figure 3. Block Diagram for Power World software

3. Results and Analysis

The SVC is being tested on IEEE 9-bus and the results showed in terms of voltage at the buses, QV curve and an effect of SVC during fault occur. There are data and results shown as follows.

3.1. Voltage Control

The effect on voltage control was determined by placing the SVC circuit at all buses in IEEE 9-bus. The voltage at the buses was expressed in per unit (pu) for all buses. The result shows for condition of SVC and without SVC at each bus and the data were recorded.

In the table 2, it describes the data of voltage (pu) in normal condition and by adding SVC into each bus. The voltage (pu) definitely increased when applying SVC at each bus. Thus, when applying SVC at the bus, it will increase the voltage level of all buses and the highest increment of voltage is at where SVC is placed.

Table 2. Data of placement of SVC at each bus

BUS NAME	TYPE OF BUS	VOLTAGE (pu)						
		WITHOUT SVC (normal condition)	WITH SVC					
			BUS 4	BUS 5	BUS 6	BUS 7	BUS 8	BUS 9
BUS 1	SLACK BUS	1.04	1.04	1.04	1.04	1.04	1.04	1.04
BUS 2	PV BUS	1.025	1.025	1.025	1.025	1.025	1.025	1.025
BUS 3	PV BUS	1.025	1.025	1.025	1.025	1.025	1.025	1.025
BUS 4	-	1.02531	**1.04549**	1.04134	1.04056	1.03003	1.02991	1.02951
BUS 5	PQ BUS	0.99972	1.01602	**1.03710**	1.01259	1.00957	1.00790	1.00463
BUS 6	PQ BUS	1.01225	1.02752	1.02492	**1.05505**	1.01756	1.01937	1.02224
BUS 7	-	1.02683	1.03135	1.03611	1.03188	**1.04681**	1.04179	1.03238
BUS 8	PQ BUS	1.01727	1.02172	1.02506	1.02413	1.03241	**1.04823**	1.02807
BUS 9	-	1.03269	1.03672	1.03728	1.04227	1.03825	1.04340	**1.05200**

Table 3 shows the result of inserting the SVC circuit into different types of buses. Based on respective table, it shows by placing the SVC to load bus (PQ) was contributing to high value of voltage difference compared with placed the SVC to slack or PV buses.

Table 3. Data for different placement of SVC at each bus

BUS NAME	TYPE OF BUS	DIFFERENT VOLTAGE (pu)						
		WITHOUT SVC (normal condition)	WITH SVC					
			BUS 4	BUS 5	BUS 6	BUS 7	BUS 8	BUS 9
BUS 1	SLACK BUS	1.04	0	0	0	0	0	0
BUS 2	PV BUS	1.025	0	0	0	0	0	0
BUS 3	PV BUS	1.025	0	0	0	0	0	0
BUS 4	-	1.02531	**0.02018**	0.01603	0.01525	0.00472	0.0046	0.0042
BUS 5	PQ BUS	0.99972	0.0163	**0.03738**	0.1287	0.00985	0.00818	0.00491
BUS 6	PQ BUS	1.01225	0.01527	0.01267	**0.0428**	0.00531	0.00712	0.00999
BUS 7	-	1.02683	0.00452	0.00928	0.00505	**0.01998**	0.01496	0.00555
BUS 8	PQ BUS	1.01727	0.00445	0.00779	0.00686	0.01514	**0.03096**	0.0108
BUS 9	-	1.03269	0.00403	0.00459	0.00958	0.00556	0.01071	**0.01931**

Table 4 shows the extension of data from Table II and Table III where the voltage (pu) in normal condition compared to voltage (pu) by adding SVC with the injecting value of Q (MVar) for each bus and their differences. The SVC are consist of 3 switched shunt (ID 1, ID 2, ID 3) that are needed to inject of value of Q (MVar) followed by required value at the buses.

Table 4. Data of injecting Q (MVar) at each bus

BUS	SVC			VOLTAGE (pu) (normal condition)	VOLTAGE (pu) (with SVC)	DIFFERENT VOLTAGE (pu)
	ID 1	ID 2	ID 3			
BUS 4	97.663	-11.91	-35.73	1.02531	1.04549	0.02018
BUS 5	96.101	-11.72	-35.159	0.99972	1.03710	0.03738
BUS 6	99.455	-12.129	-36.386	1.01225	1.05505	0.0428
BUS 7	97.908	-11.94	-35.82	1.02683	1.04681	0.01998
BUS 8	98.173	-11.972	-35.917	1.01727	1.04823	0.03096
BUS 9	98.88	-12.059	-36.176	1.03269	1.05200	0.01931

From all the table, the SVC will totally increase the bus voltage by injecting the value of Q itself and it also improve the voltage control on the power system. Therefore, based on the results obtained, the optimal location of SVC should be added at load bus (PQ). In this project, the SVC is being tested in bus 5 due to this load bus have a higher load and weakest of voltage (pu).

3.2. QV Curve

In QV curve, it can explain the variation in reactive power (Q) affect the voltage (V) in the system. In addition, the QV relationship shows the sensitivity and variety of bus voltage with respect to injections or absorptions of reactive power. Figure 5 indicates the QV curve, which were tested with adding SVC circuit at bus 5. The data were recorded clearly of variant of value Q and that affect the voltage level. The increasing of reactive power value can cause the square of voltage increase.

Based on the data from QV curve shown, it proves the relationship of mathematical expression as follows [9, 10]:

$$Q_{SVC} = -B_{SVC} \times V^2 \qquad (1)$$

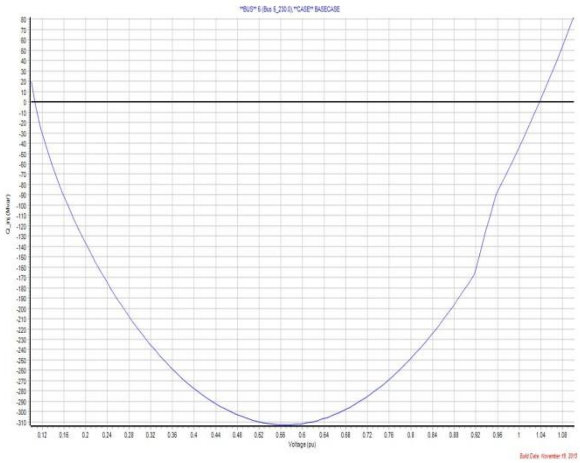

Figure 5. Graph of QV curve at bus 5

3.3. Fault

In this part, the results were shown for the impact of fault occurred. Different types of fault have been observed such as symmetrical and unsymmetrical fault. Bus 5 was selected to observe the effect of fault in voltage with conditions of SVC and without SVC in the IEEE 9-bus system. The results for each type of fault was recorded as follows.

3.3.1. Single Line to Ground

Table 5 shows the voltage (pu) in normal condition and will be compared by placing SVC with and without fault. During single line to ground fault occur, the phase volt A is considered as a fault that means the voltage at bus 5 is equal to 0. From table 5, it shows there is no variation of bus voltage before and after the fault has been selected.

Table 5. Data of single line to ground fault

BUS	VOLTAGE (pu)					
	WITHOUT SVC (NORMAL CON)	WITH SVC	FAULT			WITH SVC (FAULT CON)
			PHASE VOLT A	PHASE VOLT B	PHASE VOLT C	
BUS 1	1.04	1.04	0.91987	0.54780	0.32113	1.04
BUS 2	1.025	1.025	0.70223	0.61167	1.20348	1.025
BUS 3	1.025	1.025	0.72758	0.62015	1.20666	1.025
BUS 4	1.02531	1.04134	0.27665	0.96533	2.57799	1.04134
BUS 5	**0.99972**	**1.03710**	**0**	**0.90826**	**2.49021**	**1.03710**
BUS 6	1.0225	1.02492	0.49585	1.06957	2.66319	1.02492
BUS 7	1.02683	1.03611	0.64446	0.96585	2.65511	1.03611
BUS 8	1.01727	1.02506	0.70915	1.03961	2.69344	1.02506
BUS 9	1.03269	1.03728	0.77513	1.05591	2.73906	1.03728

3.3.2. Line to Line

Table 6 shows the voltage (pu) in normal condition and will be compared by placing SVC with and without fault. In line to line fault, the phase volt B and C are considered. Therefore, when fault is occur, the phase volt of B & C will produces the same voltages. But still there is no variation of bus voltage when adding SVC circuit to the bus 5.

Table 6. Data of line to line fault

BUS	VOLTAGE (pu)					
	WITHOUT SVC (NORMAL CON)	WITH SVC	FAULT			WITH SVC (FAULT CON)
			PHASE VOLT A	PHASE VOLT B	PHASE VOLT C	
BUS 1	1.04	1.04	1.04	0.45674	0.61621	1.04
BUS 2	1.025	1.025	1.025	0.37172	0.75720	1.025
BUS 3	1.025	1.025	1.025	0.41053	0.73219	1.025
BUS 4	1.02531	1.04134	1.04134	0.47232	0.58277	1.04134
BUS 5	**0.99972**	**1.03710**	**1.03710**	**0.51855**	**0.51822**	**1.03710**
BUS 6	1.0225	1.02492	1.02492	0.43683	0.61722	1.02492
BUS 7	1.02683	1.03611	1.03611	0.39908	0.69520	1.03611
BUS 8	1.01727	1.02506	1.02506	0.40047	0.69520	1.02506
BUS 9	1.03269	1.03728	1.03728	0.41498	0.70632	1.03728

3.3.3. Double Line to Ground Fault

Table 7 shows the double line to ground fault thatoccur at bus 5. The phase volt B & C are considered for this fault that will be zero when it happen. In this situation, when applying SVC at bus 5 that are fault occur at the same time, the voltage (pu) also still same.

Table 7. Data of double line to ground fault

BUS	VOLTAGE (pu)					
	WITHOUT SVC (NORMAL CON)	WITH SVC	FAULT			WITH SVC (FAULT CON)
			PHASE VOLT A	PHASE VOLT B	PHASE VOLT C	
BUS 1	1.04	1.04	1.13925	0.47233	0.68802	1.04
BUS 2	1.025	1.025	1.06741	0.32251	0.80739	1.025
BUS 3	1.025	1.025	1.07294	0.36594	0.80739	1.025
BUS 4	1.02531	1.04134	1.82452	0.36594	0.78804	1.04134
BUS 5	**0.99972**	**1.03710**	**1.77781**	**0**	**0**	**1.03710**
BUS 6	1.0225	1.02492	1.86445	0.33327	0.08117	1.02492
BUS 7	1.02683	1.03611	1.84885	0.46621	0.02249	1.03611
BUS 8	1.01727	1.02506	1.86971	0.49879	0.03704	1.02506
BUS 9	1.03269	1.03728	1.89729	0.54453	0.04222	1.03728

3.3.4. Three Phase Balance Fault

Table 8 shows the three phase balance fault which is all the phases are considered when fault happen. So that all the phases of fault will become to zero. The data are shown when applying the SVC, the voltage (pu) has no change after fault occurs at bus 5.

Based on the data recorded for each type of fault, it shows that by adding the SVC to the bus, does not effects the voltage level at each bus. It only shows the value of phase voltage for each fault. This is because the major benefit of SVC is to improve the voltage control and stability.

Table 8. Data of 3 phase balance fault

BUS	VOLTAGE (pu)					
	WITHOUT SVC (NORMAL CON)	WITH SVC	FAULT			WITH SVC (FAULT CON)
			PHASE VOLT A	PHASE VOLT B	PHASE VOLT C	
BUS 1	1.04	1.04	0.178	0.178	0.178	1.04
BUS 2	1.025	1.025	0.35234	0.35234	0.35234	1.025
BUS 3	1.025	1.025	0.34576	0.34576	0.34576	1.025
BUS 4	1.02531	1.04134	0.11696	0.11696	0.11696	1.04134
BUS 5	**0.99972**	**1.03710**	**0**	**0**	**0**	**1.03710**
BUS 6	1.0225	1.02492	0.17618	0.17618	0.17618	1.02492
BUS 7	1.02683	1.03611	0.26559	0.26559	0.26559	1.03611
BUS 8	1.01727	1.02506	0.27372	0.27372	0.27372	1.02506
BUS 9	1.03269	1.03728	0.29790	0.29790	0.29790	1.03728

4. Conclusion

In this paper, the SVC circuit has been modelled on Power World for IEEE 9-bus. From the obtained results, it shows that the weakest bus voltage is occurring at load bus (PQ). Therefore, the optimal placement of SVC is at bus 5. Besides, based on the obtained results from the QV curve, it shows the relationship of voltage is directly proportional with a reactive power Q injection. Hence, this proves that the SVC is greatly suitable to apply to analyze the voltage control in power system. Unfortunately, for analyzing the effect of faults occurred, the SVC can be replaced with other FACTS devices due to SVC does not work very well to analyze the transient.

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