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Reactive Power Control with Fuzzy Controller Based STATCOM

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ABSTRACT

Flexible AC Transmission Systems (FACTS) play a major role in controlling the load flow in the power system. In this paper, reactive power control is performed with STATCOM based on the fuzzy controller. The purpose of using the fuzzy controller is to improve the STATCOM performance for continuous and fast reactive power control. The performance of the STATCOM based fuzzy controller in a 14-bus test system with simulation is evaluated by MATLAB/SIMULINK software. Also, a control component to limit STATCOM's reactive power at level of nominal power is used to prevent damage. The simulation results will show the optimal performance of the fuzzy controller and the limiter.

Introduction

Reactive power control is one of the most important issues in electrical power systems. The reactive power in the power grid is shifted between the load and generator, causing problems such as increasing power losses, limiting the maximum transmission active power transmitted from transmission lines, reducing the margin of stability, and so on [1]. The reactive power cannot be eliminated from the power system, but it can be generated at the required location and the task of producing and transmitting reactive power is taken over from the power plants and transmission lines, and the capacity of the power plants and transmission lines to carry more active power is increased [2]. Therefore, reactive power control and compensation is of great importance in electric power systems. Reactive power compensators can be passive or active [3]. Reactive compensation is based on the addition of passive components to the grid, such as inductors and capacitors. The active compensation is based on the power semiconductor switches and can act much faster than passive compensation and can improve the rapid changes of voltage, reactive power, harmonics and transient state of the system [1].

Flexible AC Transmission Systems (FACTS) are controllers based on power semiconductor switches that can improve voltage stability, control the load flow and increase the transmission power of the lines by controlling the parameters of the power system such as the voltage, phase angle, and system impedance [4]. The controllers can be connected to the network in series, parallel and series-parallel. Among these controllers, parallel controllers have wider applications due to cost and technical issues. These controllers at the transmission level increase the transmission power [5], improve the voltage profile [6] and transient stability [7] and are used at the distribution level to the voltage regulation [8], reduce the flicker [9] and voltage sag [10] and voltage balancing [11].

Parallel controllers include Static Var Compensator (SVC) and static synchronous compensator (STATCOM). SVCs are compensators based on semiconductor switches and undertake the compensation of reactive power by controlling the connecting the inductor or capacitor to the power system. Therefore, SVCs are not suitable for issues with fast and continuous control of reactive power. STATCOMs are parallel controllers based on power converters with semiconductor switches on and off. They can therefore operate at high switching frequencies and have a faster response to reactive power transient variations [12]. At first, STATCOM was introduced by Gyugyi in 1976, and the first STATCOM with capacity $\pm 100\,MVA$ in 1975 was installed for voltage regulation in the United States [4]. Extensive research has been done on the analysis [13], modeling [14, 15], control and improvement of the STATCOM operation [16, 17].

One of the issues associated with STATCOM is improving the response to dynamic reactive power changes in the power system. In this paper, a fuzzy controller based STATCOM is presented to improve the response to reactive power changes in a 14-bus system. Also, a control section for limiting the reactive power of STATCOM at nominal level is used. In the section 2, the STATCOM operation is provided for reactive power control, and the STATCOM fuzzy controller and its operation is brought in the section 3. The simulation of the STATCOM based on the fuzzy controller performed with MATLAB/SIMULINK software is presented in the section 4 and finally, a conclusion is presented in the section 5.

The Basis of the STATCOM

Basically, the STATCOM system consists of three main parts: A Voltage Source Converter (VSC), a reactor or transformer, and a controller. Figure 1 shows the STATCOM system. STATCOM is connected to the power system at the point of common coupling (PCC). All voltages and currents required are measured and given to the controller. These values are compared with the reference values and the controller uses the feedback control and generates switching signal in its output.

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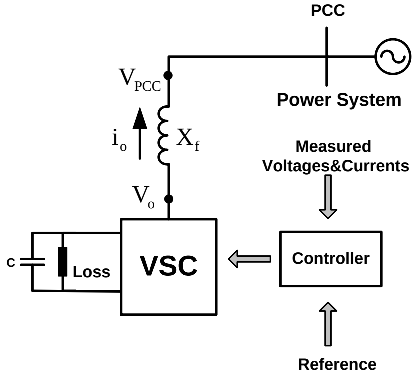

Figure 1. STATCOM system [18].

The STATCOM single line diagram is shown in Fig. 2. The exchange of reactive and active power between STATCOM and the power system can be done by adjusting the amplitude and phase of the output voltage of the converter. In the case of a lossless power converter, the output voltage of the converter is the same phase with the voltage of the power system, and no active power is exchanged between the STATCOM and the power system. To operate STATCOM in capacitive mode or reactive power generation (+Q), the output voltage range of the converter should be greater than the voltage at PCC. Conversely, if the output voltage range of the converter is lower than the voltage at the PCC, STATCOM will absorb reactive power or STATCOM operate in inductive mode (-Q).

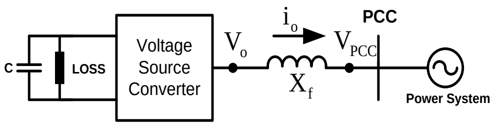

Figure 2. Single line diagram of STATCOM [18].

In practice, power converters have internal power losses, which are because of non-ideal switches and passive components of the converter. Consequently, without any suitable capacitor control to compensate for internal losses, the capacitor is discharged and the capacitor voltage decreases steadily and The STATCOM is been out of its performance. To stabilize the capacitor voltage, a small phase difference δ is established between the voltage of the converter and the voltage of the power system. If voltage of the converter is lagging from voltage at PCC, active power is flowed from power system to STATCOM and conversely, the active power transfer from STATCOM to the power system can be carried out when voltage of the converter is leading from voltage at PCC. Figure 3 shows the phasor diagram of voltages at PCC, converter and output current of converter in PQ coordinate.

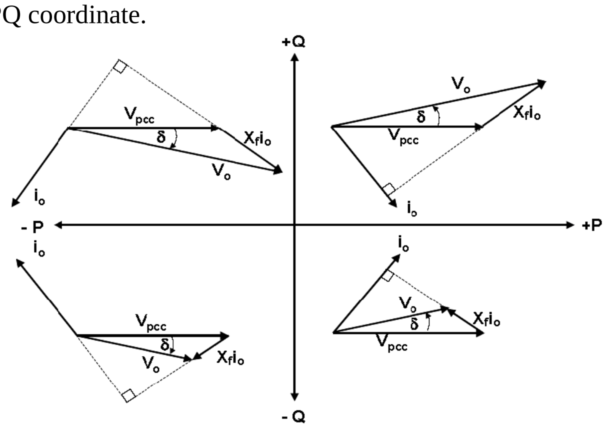

Figure 3. The phasor diagram of voltages at PCC, converter and output current of converter in PQ coordinate.

The Fuzzy Controller of STATCOM

In this section, the STATCOM fuzzy controller is provided for reactive power control of a 14-bus test system. Figure 4 shows the test system and Table 1 shows specifications of it. The system has 14 bus, two generators, 10 PQ buses, one slack bus and STATCOM is connected to bus 7.

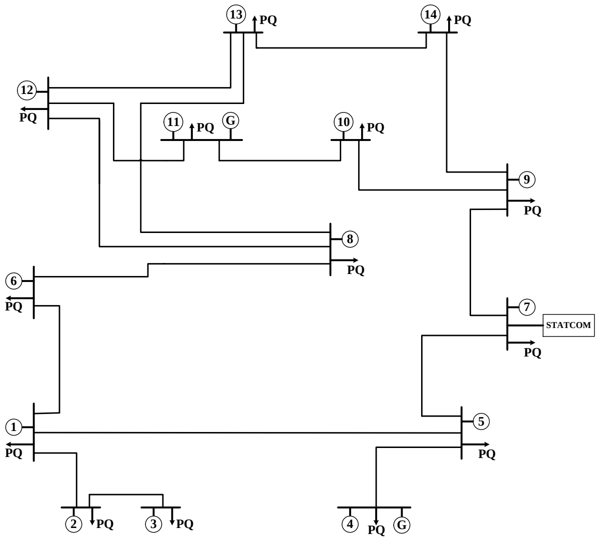

Figure 4. 14-bus test system.

Table 1. specifications of 14-bus test system

Bus 1	Slack: V = 238 KV – 50 Hz
Bus 2	PQ: 80 MW – 60 MVAR
Bus 3	PQ: 60 MW – 40 MVAR
Bus 4	PV: -50MVAR<Q<50MVAR
Bus 5	PQ: 120 MW – 85 MVAR
Bus 6	PQ: 35 MW – 35 MVAR
Bus 7	STATCOM: -120MVAR < Q < 120MVAR
Bus 8	PQ: 25 MW – 20 MVAR
Bus 9	PQ: 120 MW – 85 MVAR
Bus 10	PQ: 20 MW – 16 MVAR
Bus 11	PV: -50MVAR<Q<50MVAR
Bus 12	PQ: 20 MW – 16 MVAR
Bus 13	PQ: 25 MW – 15 MVAR
Bus 14	PQ: 25 MW – 15 MVAR

Reactive Current Control System

Figure 5 shows the reactive current control system of STATCOM. Since STATCOM is connected to bus 7, and the 5th and 9th bus are the largest consumer of reactive power and the closest bus to bus 7, STATCOM has the most impact on these two bass. Therefore, the reactive power of these two buses is given to the fuzzy logic controller. The output of fuzzy logic controller determines the amount of reactive current that the STATCOM needs to inject into the power system.

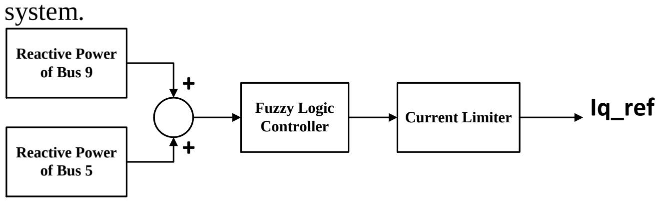

Figure 5. The reactive current control system of STATCOM.

To ensure safe operation of the system, a current limiter is used in the output of the reactive current control system, which is intended to limit the controller output value between ± 400. This does not result in a large output even if the control system fails. The output of this control system is the reference reactive current of STATCOM circuit.

Fuzzy Logic Controller

The fuzzy logic controller has an input that changes in ranges ± 150. The input and output membership function for controller is shown in Figs. 6 and 7. The fuzzy logic controller rules are defined as follows:

$$\begin{cases} If \quad (input \quad is \quad mf1) \quad then \quad (output \quad is \quad mf3) \\ If \quad (input \quad is \quad mf3) \quad then \quad (output \quad is \quad mf1) \\ If \quad (input \quad is \quad mf2) \quad then \quad (output \quad is \quad mf2) \end{cases} \qquad (1)$$

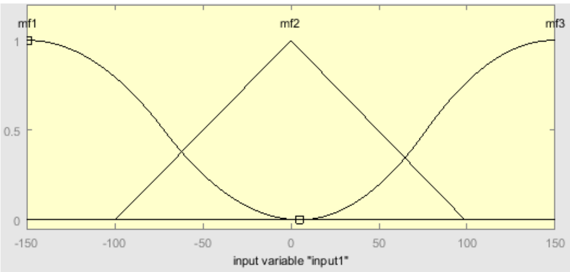

Figure 6. Input membership function.

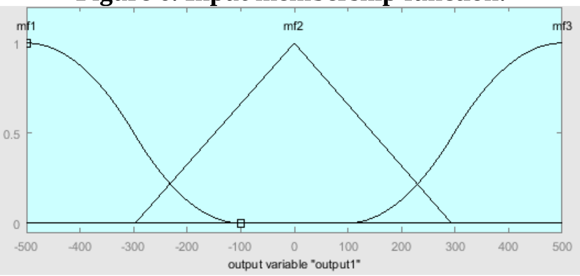

Figure 7. Output membership function.

In this case, the relationship between input and output of the fuzzy logic controller are in Fig. 8. The horizontal axis in this Figure is the reactive power of the 5 and 9 buses as the input of the controller and the vertical axis is the reference reactive value for the STATCOM.

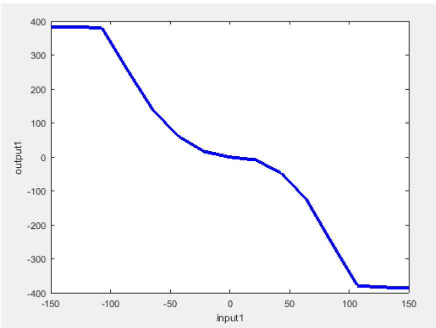

Figure 8. The relationship between input and output of the fuzzy logic controller

Active Current Control System

An active current control system is used to keep constant the DC voltage capacitor of STATCOM. Figure 9 shows the active current control system. In this system, the measured capacitor dc voltage is compared with the reference value and is given to a PI controller. The output of the PI controller is assigned to a single-pole system to reduce overall bandwidth. The reason for using a single-pole system is the removal of high-frequency harmonic currents and the reduction of the effect of noise from the switching of the converter.

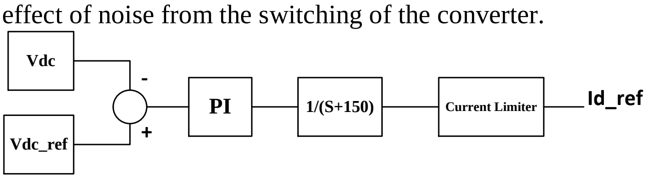

Figure 9. The active current control system of STATCOM

After reactive and active reference currents are obtained, these reference values are converted to reference phase currents by using Park transformation matrix to generate gate signals of the switches. Figure 10 shows the STATCOM voltage source converter (VSC). The current hysteresis control method has been used to generate gate signals. Figure 11 shows the current hysteresis control method. With reference currents and the measurement of the STATCOM output currents, the gate signals of the STATCOM converter switches are generated.

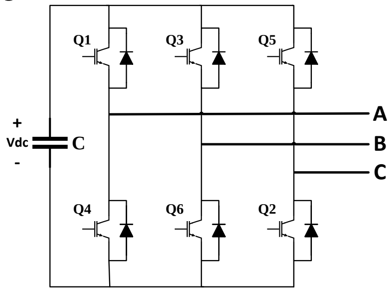

Figure 10. The voltage source converter (VSC) of STATCOM.

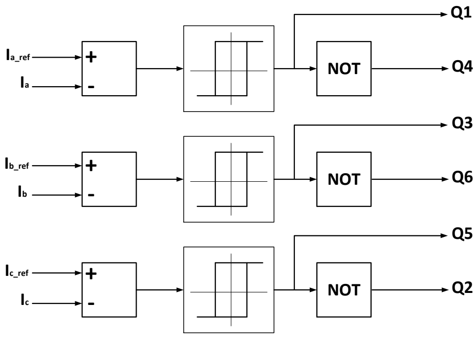

Figure 11. The current hysteresis control method

Simulation and Results.

MATLAB/SIMULINK software is used to simulate the test system and STATCOM. The bus load 5 in 0.4 seconds and the bus load 9 in 0.6 seconds are connected to the system. Figure 12 shows the active and reactive power of Slack bus. When the bus 5 enters, a mutation occurs in active and reactive power in 0.4 seconds that its reactive power decreases to 2MVAR after about 0.05 seconds which is due to the optimal and fast operation of STATCOM in compensation of reactive power. But when bus 9 enters in the 0.6 second, the reactive power of the slack bus reaches a constant value of 35MVAR. This is due to the fact that STATCOM has produced a reactive power to its nominal value in this case.

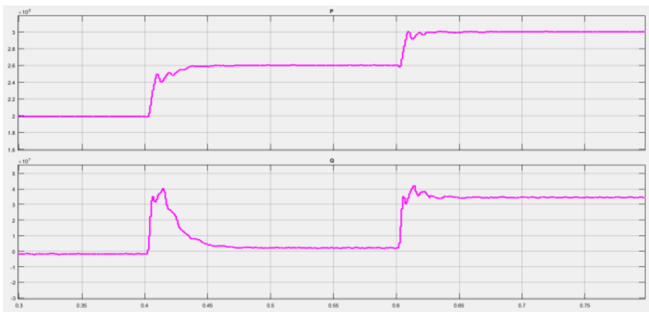

Figure 12. Active and reactive of slack bus.

Figures 13 and 14 show, respectively, the output voltage and current and active and reactive power of the STATCOM. It is known that, before 0.4 seconds, the STATCOM output current is roughly zero and does not play a role in load flow. But after 0.4 seconds, the STATCOM will compensate for the voltage drops due to the load on the bus 5 and quickly inject the reactive current. When the bus 9 enters the circuit in 0.6 seconds, the STATCOM output current is increased to 420 amps. But since this is the maximum STATCOM's nominal current, the control system limits the STATCOM’s current in the same value. In this case, the reactive power output of STATCOM reaches 118MVAR.

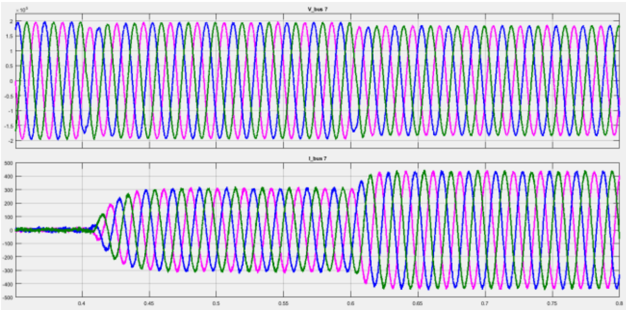

Figure 13. Output voltage and current of the STATCOM.

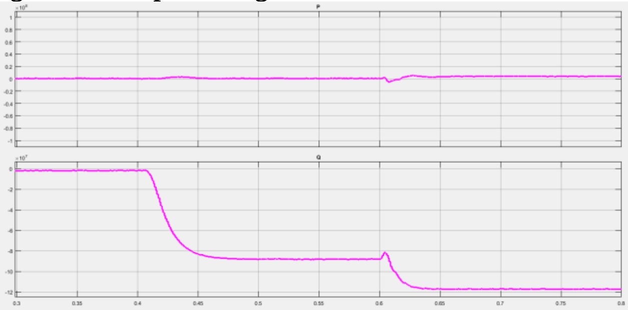

Figure 14. Active and reactive of the STATCOM.

Figures 15 and 16 show the active and reactive power of the PV buses, i.e. buses 4 and 11. As can be seen, STATCOM alone has been able to provide all the reactive power of the system until 0.6 seconds, and the reactive power of both buses is almost zero. But due to the limited STATCOM injection capacity in the nominal value, each PV generator generates approximately 10MVAR reactive power from 0.6 seconds later.

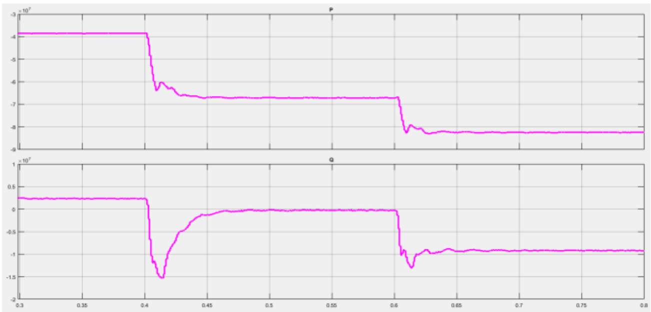

Figure 15. Active and reactive of the bus 4

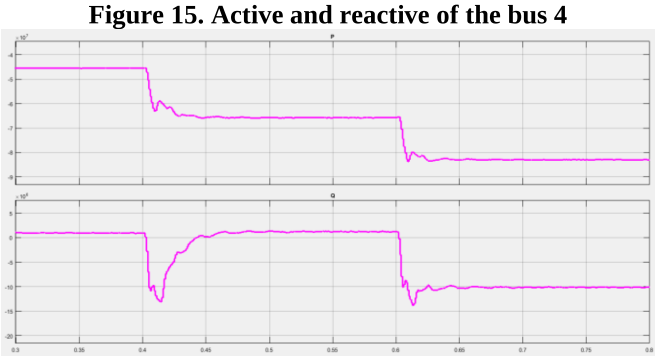

Figure 16. Active and reactive of the bus 11

Conclusion

In this paper, a fuzzy controller based STATCOM was designed to control reactive power. The goal of using the fuzzy controller for STATCOM was the steady and rapid control of reactive power. The controller performance was evaluated on a 14-bus test system.

In this test system, STATCOM was installed around the main bus of reactive power consumer and its performance was simulated using MATLAB/SIMULINK software. The simulation results show the optimal performance of the fuzzy controller in the rapid and continuous control of reactive power and the limiting of injected reactive power at the nominal level, and contributes significantly to power plants and transmission lines for the generation and transmission of reactive power.

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