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Application of Fuzzy Controller for Voltage Stability Enhancement of AC Transmission system by STATCOM

A. AJAMI[1], S.H. HOSSEINI[2]
Electrical & Computer Engineering Faculty
Islamic Azad University _Ahar Branch
I.R. IRAN

Abstract: - In this paper the fuzzy controller is designed for Static Synchronous Compensator (STATCOM) to enhance voltage stability. The transient stability model of a STATCOM is presented first. Then fuzzy controllers are designed for main and supplementary controllers of STATCOM. The main controller is used for regulating of AC bus voltage and the supplementary controller is designed for controlling of DC capacitor voltage. The PSCAD/EMTDC simulation program is used for simulation of test system. In this paper the STATCOM is connected to a typical two machine transmission system. This study demonstrates that STATCOM considerably improves transient stability of power system after occurring fault and load changing.

Key-Words: - FACTS, STATCOM, Transient Stability, Voltage Stability, Fuzzy Logic Controller.

1 Introduction

The static synchronous compensator is one of FACTS devices which resembles in many respects with a rotating synchronous condenser used for voltage control and reactive power compensation. The relatively recent development and use of FACTS controllers in power system has led to many applications of these controllers to improvement the stability of transmission networks [1, 2]. Several FACTS equipments are readily available or still under development based on the thyristor controlled converters or based on the voltage source inverters (with GTO, IGBT or IGCT switches). All these equipment provide controllability to the AC transmission system by adjusting the transmission parameters, i.e. magnitude and phase angle of bus voltage and transmission line impedances [3].

The STATCOM was proposed by several researchers as a shunt device to compensate the reactive current from or to the power system [4, 5, 6]. This function is identical to the synchronous condenser with rotating mass, but its response time is extremely faster than the synchronous condenser. This capability is an effective tool for increasing transient stability, enhancing the voltage profile and damping the low frequency oscillations in power systems [7].

In recent years fuzzy logic control is beginning to receive more attention. The advantages of applying fuzzy logic control in power systems are apparent. Modern power systems are large, complex, geographically widely distributed and highly nonlinear systems. More over, power system operation conditions and topologies are time varying and the disturbances are unforeseeable. These uncertainties make it very difficult to effectively deal with power system stability problems through conventional controller that is based on linearized system model. Therefore the fuzzy logic control approach, as one area of artificial intelligence, has been emerging in recent years as a complement to the conventional approach. The fuzzy controller is intelligent controller and this is the most significant advantage of fuzzy controller. The human knowledge can be coupled with easily through control rules. Also the fuzzy controller is a nonlinear controller and is not sensitive to system topology, parameters and operation condition changes. These features make it very attractive for power systems applications.

In this paper, the fuzzy controller is designed for STATCOM to enhance the transient stability of AC power system. The rule base table method is used in fuzzy controller designing.

2 Mathematical Model of STATCOM

Fig. 1 shows the basic structure of six-pulse STATCOM in a power system where Rp represents the ON state resistance of switches including transformer leakage resistance, Lp is transformer leakage inductance and Rc shows the switching losses. The STATCOM generates a balanced and controlled 3-phase voltage. The voltage control is achieved by firing angle control of the VSI.

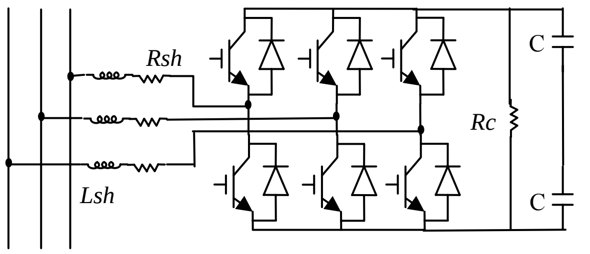
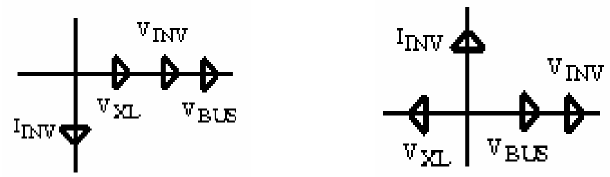


Fig.1. The basic structure of six-pulse STATCOM.

The STATCOM is contains a voltage source inverter, a DC link capacitor, coupling transformer and control system. Fig. 2 shows the phasor diagram of STATCOM for the capacitive and inductive operation mode. From these diagrams is seen that the STATCOM operates as a capacitor if inverter output voltage is greater than the bus voltage and otherwise operates as an inductor.



a) Inductive mode b) Capacitive mode
Fig.2.Phasor diagram of STATCOM.

Fig. 3 shows the detailed model of STATCOM.

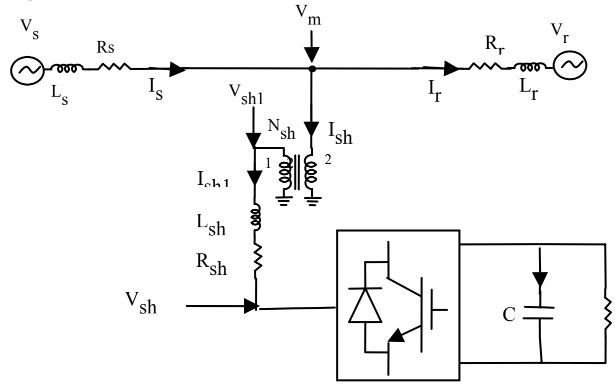


Fig.3. Detailed model of STATCOM.

The dynamic equation of STATCOM is obtained by writing the KVL equation in the shunt branch as bellow:

$$\left(R_{sh} + L_{sh}\frac{d}{dt}\right) i_{sh1} = V_{sh1} - V_{sh} \qquad (1)$$

By applying the Park's transformation [8, 9, 10] to equation 1 the dynamic equation of STATCOM can be obtained as bellow:

$$\begin{bmatrix} V_{shd} \\ V_{shq} \end{bmatrix} = \begin{bmatrix} N_{sh} V_{md} - R_{sh} I_{sh1d} - L_{sh}\frac{d}{dt} I_{sh1d} - \omega L_{sh} I_{sh1d} \\ N_{sh} V_{mq} - R_{sh} I_{sh1q} - L_{sh}\frac{d}{dt} I_{sh1q} + \omega L_{sh} I_{sh1q} \end{bmatrix} \qquad (2)$$

The active power balancing equation between AC system and STATCOM is given in equation 3.

$$\frac{3}{2}\left(V_{md} I_{shd} + V_{mq} I_{shq}\right) = C V_{dc}\frac{dV_{dc}}{dt} + \frac{V_{dc}^2}{R_c} + R_{sh} I_{sh1}^2 \qquad (3)$$

This equation models the dynamic behavior of the DC side capacitor voltage.

3 Conventional Control Scheme of STATCOM

Fig. 4 shows the control system of STATCOM based on conventional controllers. In this control system the DC capacitor voltage and AC bus voltage at the connection point of STATCOM are inputs. The phase angle of α (phase angle between the STATCOM output voltage and AC bus voltage) and m (modulation index) are outputs. α is used for controlling the DC capacitor voltage and m is used for regulating the AC bus voltage.

With noticing to nonlinearity of power system, calculation of parameters control system (parameters of PI controller) is very difficult. Therefore, we are using fuzzy logic controller for over coming to these problems.

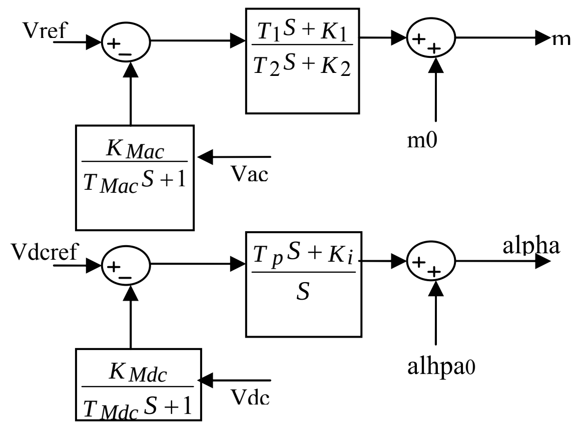


Fig.4. Conventional scheme of STATCOM.

4 Fuzzy Logic Control Scheme of STATCOM

The basic configuration of FLC (fuzzy logic control) used in the STATCOM control system shown in Fig.5 is simply represented by four main parts:

1- The fuzzifier
2-The knowledge base
3- The inference engine and
4- The defuzzifier

The fuzzifier part maps the FLC inputs crisp values, scaled by input gains, into fuzzy variables using normalized membership functions. Then the fuzzy logic engine infers the proper control actions based on the given fuzzy rule base. The fuzzy control action is translated to the proper crisp values that they are scaled by some appropriate output gains through the defuzzifier employing normalized membership functions [11]. In this paper for the defuzzfing of output signals is used the centriod method.

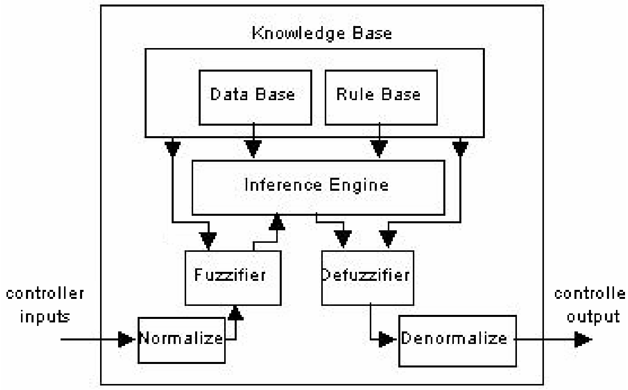


Fig.5.Schematic diagram of the FLC building blocks.

Fig. 6 shows fuzzy logic control system of STATCOM. The control system has two control loops. The first control loop is named main controller and controls output voltage magnitude of STATCOM by adjusting of modulation index.

This control loop has two inputs. Voltage error (ev) and its time derivative (Δev) are inputs of main fuzzy controller. The output of main controller is modulation index. The second control loop is named supplementary controller and controls DC link capacitor voltage by adjusting of phase angle of STATCOM output voltage. This controller has two inputs (evdc, Δevdc) and phase angle of STATCOM output voltage (α) is its output. We have:

$$e_v = V_{ref} - V \quad (4)$$

$$\Delta e_v = [e(kh) - e((k-1)h)]/h \quad (5)$$

$$e_{vdc} = V_{dcref} - V_{dc} \quad (6)$$

$$\Delta e_{vdc} = [e_{vdc}(kh) - e_{vdc}((k-1)h)]/h \quad (7)$$

The function of main controller is regulating of AC bus voltage in the load changing and fault conditions. Also, the supplementary controller is regulating the DC link capacitor voltage at the steady state and transient conditions.

In this paper, we apply the rules table method for designing the FLC. Based on expert knowledge, bus voltage error (ev) and its time derivative (Δev) are taken as the input signals where Δev is approximately calculated from equation 5.

The main fuzzy controller is similar to a nonlinear PID controller. Seven fuzzy sets or logistic variables are defined for ev, Δev and output signal (m) with corresponding membership functions shown in Fig. 7. The main control rule base table for out put signal (m) is given in the table 1.

The inputs and output signals (evdc, Δevdc, α) membership functions of supplementary control system is similar to main controller membership functions. The rule base table for its output signal (α) is shown in table 2.

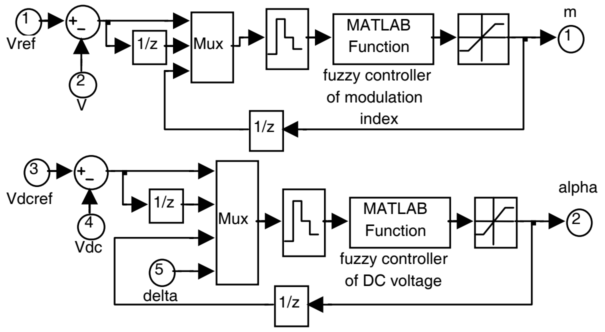


Fig.6. Fuzzy logic control system for STATCOM.

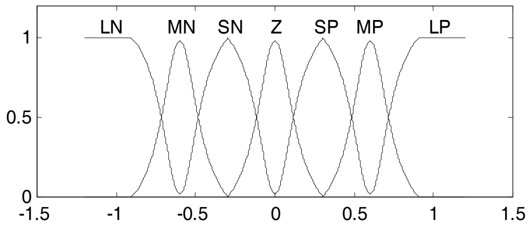


Fig.7a. Membership functions for input signals.

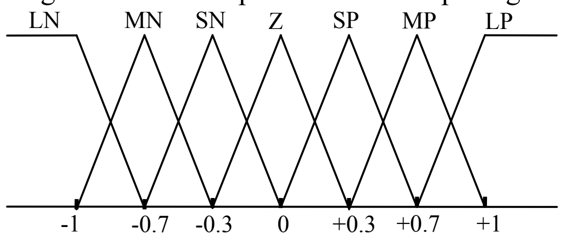


Fig.7b. Membership functions for output signals.

Table1. Rule base table of main controller.

e_v \ Δe_v	LN	MN	SN	Z	SP	MP	LP
LN	LN	LN	MN	SN	Z	Z	Z
MN	LN	MN	SN	Z	Z	Z	Z
SN	MN	SN	Z	Z	Z	Z	Z
Z	SN	Z	Z	Z	Z	Z	SP
SP	Z	Z	Z	Z	Z	SP	MP
MP	Z	Z	Z	Z	SP	MP	LP
LP	Z	Z	Z	SP	MP	LP	LP

Table2. Rule base table of supplementary controller.

e_{vdc} \ Δe_{vdc}	LN	MN	SN	Z	SP	MP	LP
LN	LN	LN	MN	MN	SN	Z	Z
MN	LN	MN	MN	SN	Z	Z	SP
SN	MN	MN	SN	Z	Z	SP	MP
Z	MN	SN	Z	Z	SP	MP	MP
SP	SN	Z	Z	SP	MP	MP	MP
MP	Z	Z	SP	MP	MP	MP	LP
LP	Z	SP	MP	MP	MP	LP	LP

In these tables the linguistic variables are as bellow:
LN: Large Negative, MN: Medium Negative
SN: Small Negative, Z: Zero
SP: Small Positive, MP: Medium Positive
LP: Large Positive

5 Simulation Results

The test system depicted in Fig.8 is used for showing validate and effectiveness of presented model and control system of STATCOM. This system is a two machine AC transmission system. The generators with output voltages of 13.8 KV are connected to the transmission line through a 3-phase step up transformers. The output voltage of transformers is 230 KV.

The power system of STATCOM is consists of a six pulse voltage source inverter, 3-phase coupling transformer and a DC capacitor. The inverter is modeled by Integrated Gate Commutated Thyristor (IGCT) [12] switches with reverse diodes and snubbers. In this paper, we are using the SPWM technique for decreasing the output voltage harmonics of STATCOM. All the test system parameters are given in appendix A. A transient stability analysis was performed for the case of connecting the STATCOM in the transmission system. The objective of this simulation is to verify the improvement effect of transient stability with a fuzzy control system described in Fig.6.

The following cases are considered for simulating of test system.

1- Load changing

2- A 3-phase fault

Fig.9 shows the simulation results at the load changing case when the STATCOM is not installed. Fig.9a shows the voltage of bus 2 and its reference value. Fig. 9b shows the reactive power of load and generator 1.

Fig.10 describes the simulation results at the load changing case when the STATCOM is installed. In this case the STATCOM starts to operate at t=0.1 sec. Also at t=0 sec the supplied load by system is 200 MW & 250 MVAR at bus 4. The load2 is increased to 100 MW, 60 MVAR and 200 MW, 200 MVAR at t=1sec and 2 sec respectively.

Fig.10a shows the voltage of bus 2 and its reference value. It can be seen from this figure that the STATCOM with presented FLC regulate the AC bus voltage after load changing. Fig. 10b shows the reactive power of load and generator 1. These figures show that the STATCOM compensates the reactive power of source side.

In the second simulation a 3-phase fault suddenly occurs at t =1.5 sec at bus 4 and cleared by opening the breaker 3-4 after 0.0833 sec.

Fig.11 describes the simulation results at the fault occurring case when the STATCOM is not installed. It can be seen from this figure that the AC bus voltage is not regulated.

Fig.12 describes the simulation results at the fault occurring case when the STATCOM is installed. With considering figures 11 and 12, it can be seen that STATCOM with presented fuzzy logic control system is capable to enhancing the voltage stability after transient conditions.

Fig. 13 shows the DC link capacitor voltage in the load changing and fault occurring cases. These figures reveal that the presented control system is keeping up the capacitor voltage as constant in the steady and transient states.

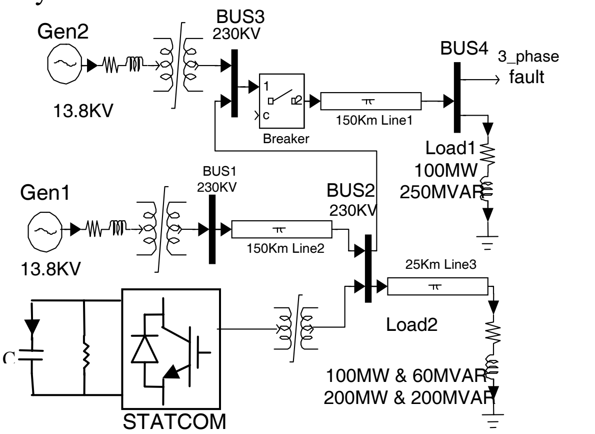


Fig.8. Single line diagram of test system.

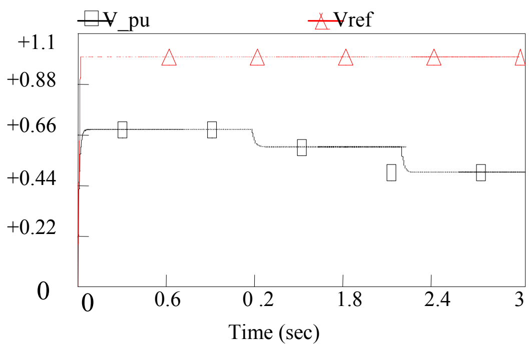


Fig. 9a. Voltage of bus 2 and its reference value when load is changed and STATCOM is not installed.

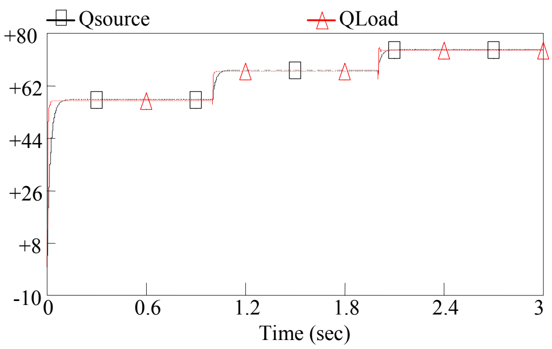


Fig. 9b. Reactive power of load and generator1 when load is changed and STATCOM is not installed.

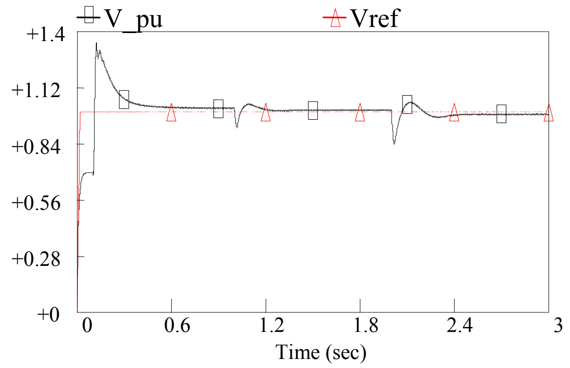


Fig. 10a. Voltage of bus 2 and its reference value when load is changed and STATCOM is installed.

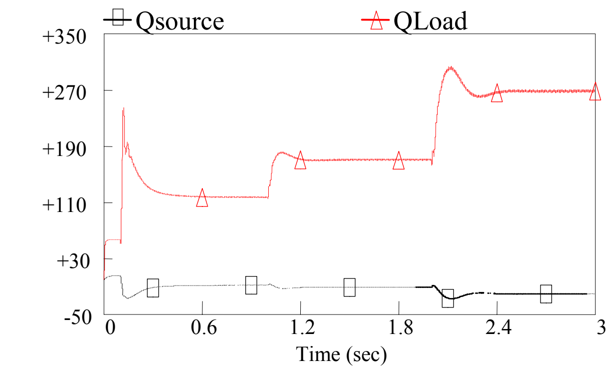


Fig. 10b. Reactive power of load and generator1 when load is changed and STATCOM is installed.

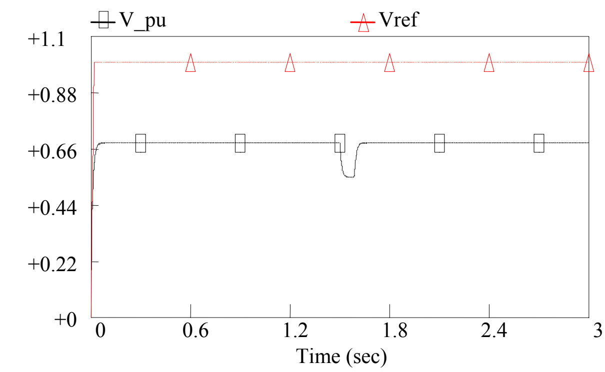


Fig. 11a. Voltage of bus 2 and its reference value when a 3 phase fault is occurred and STATCOM is not installed.

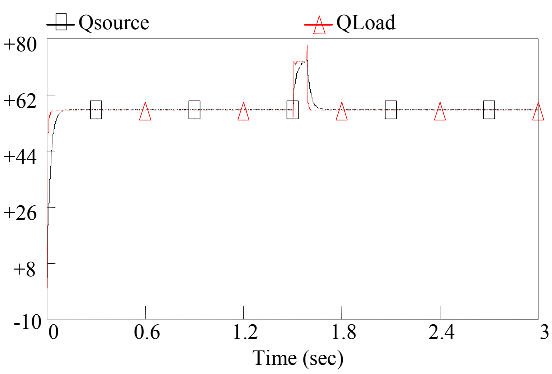


Fig. 11b. Reactive power of load and genrator1 when a 3 phase fault is occurred and STATCOM is not installed.

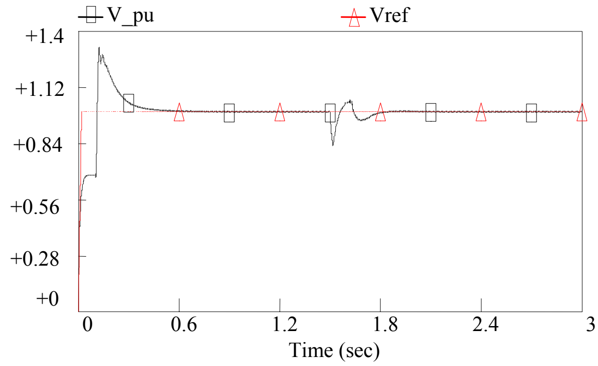


Fig. 12a. Voltage of bus 2 and its reference value when a 3 phase fault is occurred and STATCOM is installed.

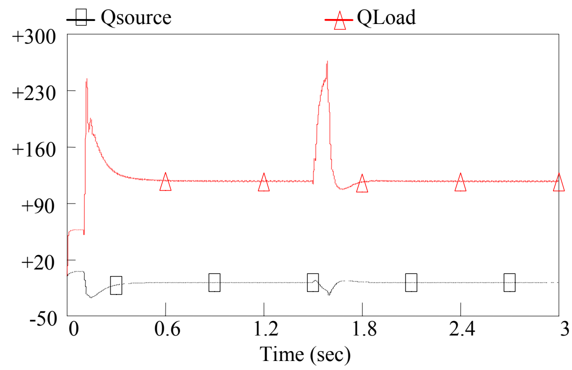


Fig. 12b. Reactive power of load and genrator1 when a 3 phase fault is occurred and STATCOM is installed.

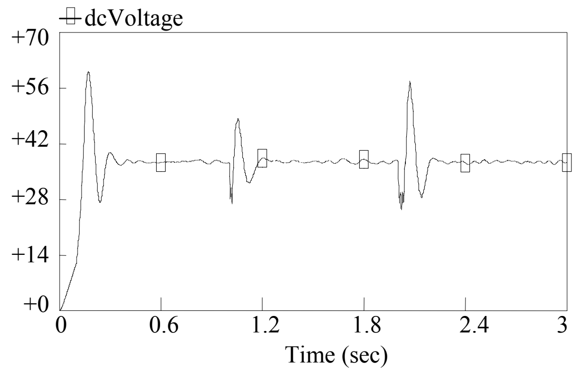


Fig.13a. DC capacitor voltage when load is changed.

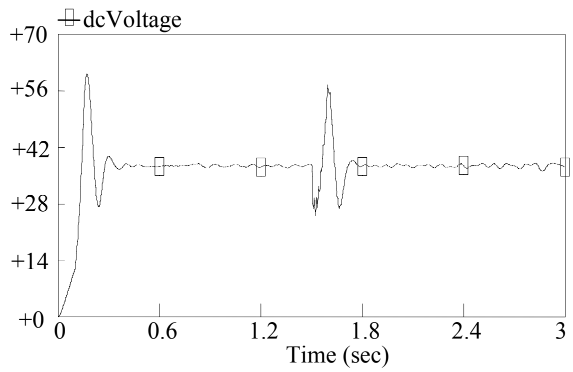


Fig.13b. DC capacitor voltage when a 3 phase fault is occurred.

6 Conclusion

In this paper, the fuzzy logic controllers are successfully designed using rule base table method for STATCOM. The presented control system has two loops. The first loop is named main controller and regulates the AC bus voltage under steady state and transient conditions. The second control loop is named supplementary controller and regulates the DC capacitor voltage. The presented simulation results show that STATCOM with FLC is capable to enhancing the system transient stability. The simulation results support the applications of fuzzy controllers in power systems.

In this paper the SPWM technique is used for decreasing of STATACOM output voltage harmonics.

Appendix A

Test system and STATCOM data are:

Generator1:

(R+jX)=0.066+j0.4 (pu) & 13.8KV

Generator2:

(R+jX)=0.066+j0.4 (pu) & 13.8KV

Parameters of transmission line1:

R=0.035 (ohm/Km) & L=0.8674e-3 (H/Km)

C=13.41e-9(F/Km) & Length=150 (Km)

Parameters of transmission line2:

R=0.035 (ohm/Km) & L=0.8674e-3 (H/Km)

C=13.41e-9(F/Km) & Length=150 (Km)

Parameters of transmission line3:

R=0.023 (ohm/Km) & L=0.5184e-3 (H/Km)

C=5.158e-9(F/Km) & Length=25 (Km)

Parameters of STATCOM:

C=300e-6 (F)

Snubbers of IGCT:

R=10 (ohm) & C= 0.22e-6 (F)

Coupling Transformer:

V1/V2 = 23/230 KV & R= 0.1 pu & X=0.145 pu

IGCT parameters:

Ron=0.01 (ohm) & Lon=1e-6 (H)

Forward voltage = 1 V

Diodes parameters:

Ron=0.01 (ohm) & Lon=1e-6 (H)

Forward voltage = 0.8 V

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