International Journal of Exclusive Global Research - Vol I Issue 7 July

A Three Phase D-Statcom to Compensate AC and DC loads by using Fuzzy Logic DC Link Voltage Controller

***Kolli Nageswar Rao**

*Asst. Professor in Sree Vahini Institute of Science & Technology, Tiruvuru. Andhra Pradesh.

Abstract :

A FuzzyLogic control the transirent response of the distribution static compensator (D-STATCOM) is very important while compensating rapidly varying unbalanced and nonlinear loads. Any change in the load affects the dc-link voltage directly. The sudden removal of load would result in an increase in the dc-link voltage above the reference value, where as a sudden increase in load would reduce the dc-link voltage below its reference value. The proper operation of D-STATCOM requires variation of the dc-link voltage with in the prescribed limits. Conventionally, a proportional integral (PI) controller is used to maintain the dc-link voltage to the reference value. A Fuzzy Logic controls the transient response of the distribution static compensator (D-STATCOM) is very important while compensating rapidly varying unbalanced and nonlinear loads. It uses deviation of the capacitor voltage from its reference value as its input. However, the transient response of the conventional PI dc-link voltage controller is slow. In this paper, a fast-acting dc-link voltage controller based on the energy of a dc-link capacitor is proposed. Mathematical equations are given to compute the gains of the conventional controller based on fast-acting dc-link voltage controllers to achieve similar fast transient response. The detailed simulation and experimental studies are carried out to validate the proposed controller.

Keywords: *DC-Link voltage Controller, distribution static compensator (DSTATCOM), fast transient response, harmonics, load compensation, power factor, power quality (PQ), unbalance, voltage-source inverter (VSI)*

1. Introduction

The proliferation of power-electronics-based equipment, nonlinear and unbalanced loads, has aggravated the power-quality (PQ) problems in the power distribution net-work. They cause excessive neutral currents, overheating of electrical apparatus, poor power factor, voltage distortion, high levels of neutral-to-ground voltage, and interference with communication systems [1], [2]. The literature records the evolution of different custom power devices to mitigate the above power-quality problems by injecting voltages/currents or both into the system [3]–[6]. The shunt-connected custom power device, called the distribution static compensator (DSTATCOM), injects current at the point of common coupling (PCC) so that harmonic filtering, power factor correction, and load balancing can be achieved. The DSTATCOM consists of a current-controlled voltage-source inverter (VSI) which injects current at the PCC through the interface inductor. The operation of VSI is sup-ported by a dc storage capacitor with proper dc voltage across it. In some of the electric power consumers, such as the telecommunications industry, power-electronics drive applications, etc., switch-mode rectifiers to support dc bus voltage. Such an arrangement draws nonlinear load currents from the utility. This causes poor power factor and, hence, more losses and less efficiency. Clearly, there are PQ issues, such as unbalance, poor power factor, and harmonics produced by telecom equipment in power distribution networks. Therefore, the functionalities of the conventional DSTATCOM should be increased to mitigate the aforementioned PQ problems and to supply the dc loads from its dc link as well. The load sharing by the ac and dc bus depends upon the design and the rating of the VSI.

This DSTATCOM differs from conventional one in the sense that its dc link not only supports instantaneous compensation but also supplies dc loads. However, when the dc link of the DSTATCOM supplies the dc load as well, the corresponding dc power is comparable to the average load power and, hence, plays a major role in the transient response of the compensator. Hence, there are two important issues. The first one is the regulation of the dc-link voltage within prescribed limits under transient load conditions. The second one is the settling time of the dc–link voltage controller. Conventionally, a PI controller is used to maintain the dc-link voltage. It uses the deviation of the capacitor voltage from its reference value as its input. However, the transient response of the conventional dc-link voltage controllers is slow, especially in applications where the load changes rapidly. Some work related to dc-link voltage controllers and their stability is reported in [15].

However, the work is limited to rectifier units where switching patterns are well defined and analysis can be easily carried out. In this paper, a fast-acting dc-link voltage controller based on the dc-link capacitor energy is proposed. The detailed modeling, simulation, and experimental verifications are given to prove the efficacy of this fast-acting dc-link voltage controller. There is no systematic procedure to design the gains of the conventional PI controller used to regulate the dc link voltage of the DSTATCOM. Herewith, mathematical equations are given to design the gains of the conventional controller based on the fast-acting dc-link voltage controllers to achieve similar fast transient response.

2. D-Statcom for Compensating Ac And Dc Loads

Various VSI topologies are described in the literature for realizing DSTATCOM to compensate unbalanced and nonlinear loads [21]–[29]. Due to the simplicity, the absence of unbalance in the dc-link voltage and independent current tracking with respect to other phases, a three-phase H-bridge VSI topology is chosen. Fig. 1 shows a three-phase, four-wire-compensated system using an H-bridge VSI topology-based DSTATCOM compensating unbalanced and nonlinear ac load.

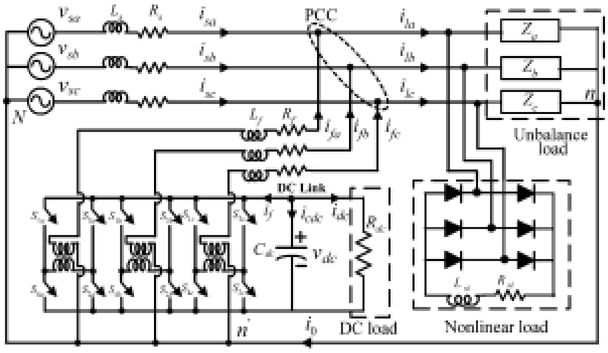


Fig.1Three-phase, four-wire compensated system using the H-bridge VSI topology-based DSTATCOM

In addition to this, a dc load is connected (R_{dc}) is connected across the dc link. The DSTATCOM consists of 12 insulated-gate bipolar transistor (IGBT) switches each with an anti parallel diode, dc storage capacitor, three isolation transformers, and three interface inductors. The star point of the isolation transformers (n') is connected to the neutral of load (n) and source (N). The H-bridge VSIs are connected to the PCC through interface inductors. The isolation transformers prevent a short circuit of the dc capacitor for various combinations of the switching states of the VSI. The inductance and resistance of the isolation transformers are also included in L_f and R_f the source voltages are assumed to be balanced and sinusoidal. With the supply being considered as a stiff source, the feeder impedance (L_s, R_s) shown in Fig. 1 is negligible and, hence, it is not accounted in state-space modeling. To track the desired compensator currents, the VSIs operate under the hysteresis band current control mode due to their simplicity, fast response, and being independent of the load parameters [30]. The DSTATCOM injects currents into the PCC in such a way as to cancel unbalance and harmonics in the load currents. The VSI operation is supported by the dc storage capacitor with voltage across it. The dc bus voltage has two functions, that is, to support the compensator operation and to supply dc load. While compensating, the DSTATCOM maintains the balanced sinusoidal source currents with unity power factor and supplies the dc load through its dc bus.

3. Dc-Link Voltage Controllers

As mentioned before, the source supplies an unbalanced nonlinear ac load directly and a dc load through the dc link of the D-STATCOM, as shown in Fig. Due to transients on the load side, the dc bus voltage is significantly affected. To regulate this dc-link voltage, closed-loop controllers are used. The proportional- integral-derivative (PID) control provides a generic and efficient solution to many control problems. The control signal from PID controller to regulate dc link voltage is expressed as

$$V_C = K_p(V_{dcref} - V_{dc}) + K_i \int(V_{dcref} - V_{dc})dt + K_d \frac{d(V_{dcref} - V_{dc})}{dt} \quad \ldots\ldots\ldots\ldots (1)$$

$K_{p,}$ K_d and K_i are proportional, integral, and derivative gains of the PID controller, respectively. The proportional term provides overall control action proportional to the error signal. An increase in proportional controller gain K_p reduces rise time and steady-state error but increases the overshoot and settling time. An increase in integral gain K_i reduces steady state error but increases overshoot and settling time. Increasing derivative gain K_d will lead to improved stability. However, practitioners have often found that the derivative term can behave against anticipatory action in case of transport delay. A cumbersome trial-and-error method to tune its parameters made many practitioners switch off or even exclude the derivative term. Therefore, the description of conventional and the proposed fast-acting dc-link voltage controllers using PI controllers are given in the following subsections.

i. Conventional DC-link voltage controller:

The conventional PI controller used for maintaining the dc-link voltage is shown in Fig. 2. To maintain the dc-link voltage at the reference value, the dc-link capacitor needs a certain amount of real power, which is proportional to the difference between the actual and reference voltages. The power required by the capacitor can be expressed as follows

$$P_{DC} = K_p(V_{dcref} - V_{dc}) + K_i \int (V_{dcref} - V_{dc})dt$$

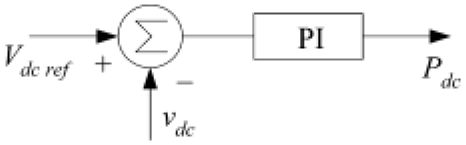


Fig. 3 Schematic diagram of the conventional dc-link voltage controller.

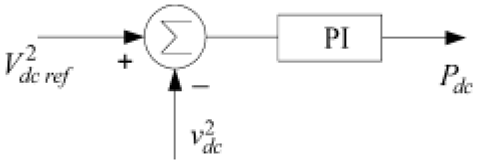


Fig. 4 Schematic diagram of the fast-acting dc-link voltage controller

The dc-link capacitor has slow dynamics compared to the compensator, since the capacitor voltage is sampled at every zero crossing of phase supply voltage. The sampling can also be performed at a quarter cycles depending upon the symmetry of the dc-link voltage waveform. The drawback of this conventional controller is that its transient response is slow, especially for fast-changing loads. Also, the design of PI controller parameters is quite difficult for a complex system and, hence, these parameters are chosen by trial and error. Moreover, the dynamic response during the transients is totally dependent on the values of K_p and K_i when is comparable to P_{lavg}.

ii. *Fast-Acting DC Link Voltage Controller*

To overcome the disadvantages of the aforementioned controller, an energy-based dc-link voltage controller is proposed. The energy required by the dc-link capacitor W_{dc} to charge from actual voltage V_{dc} to the reference value V_{dcref} can be computed as

$$W_{dc} = \frac{1}{2} C_{dc}(V_{dcref}^2 - v_{dc}) \text{ .... } (2)$$

In general, the dc-link capacitor voltage has ripples with double frequency, that of the supply frequency. The dc power P'_{dc} required by the dc-link capacitor is given as

$$P_{dc} = \frac{W_{dc}}{T_c} = \frac{1}{2T_c}(V_{dcref}^2 - v_{dc}^2) \text{ .... } (3)$$

Where T_C is the ripple period of the dc-link capacitor voltage. Some control schemes have been reported in [33] and [34]. However, due to the lack of integral term, there is a steady-state error while compensating the combined ac and dc loads. This is eliminated by including an integral term. The input to this controller is the error between the squares of reference and the actual capacitor voltages.

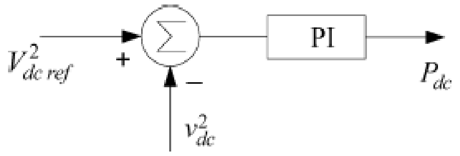


Fig. 5 Schematic diagram of the fast-acting dc-link voltage controller

This controller is shown in Fig. 5 and the total dc power required by the dc-link capacitor is computed as follows:

$$P_{DC} = K_p\left(V_{dcref} - V_{dc}\right) + K_i \int \left(V_{dcref} - V_{dc}\right)dt$$

The coefficients K_{pe} and K_{ie} are the proportional and integral gains of the proposed energy-based dc-link voltage controller. As an energy-based controller, it gives fast response compared to the conventional PI controller. Thus, it can be called a fast acting dc-link voltage controller. The case in the calculation of the proportional and integral gains is an additional advantage.

iii. *Selection of the DC-link capacitor*

The value of the dc-link capacitor can be selected based on its ability to regulate the voltage under transient conditions. Let us assume that the compensator in first Fig. 1 is connected to a system with the rating of X kilovolt amperes. The energy of the system is given by $X * 1000\, J/s$. Let us further assume that the compensator deals with half (i.e.,$\frac{X}{2}$) and twice (i.e.,$2X$) capacity under the transient conditions for n cycles with the system voltage period of T_S. Then, the change in energy to be dealt with by the DC capacitor is given as

$$\Delta E = (2X - X/2)nT.$$

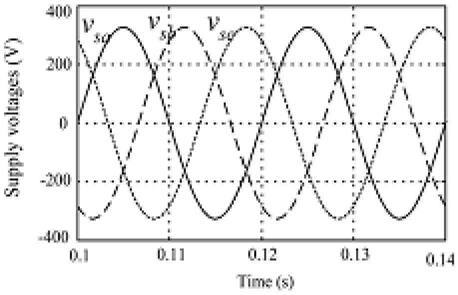
Now this change in energy (21) should be supported by the energy stored in the dc capacitor. Let us allow the dc capacitor to change its total dc-link voltage from 1.4 V_m to 1.8 V_m during the transient conditions where V_m is the peak value of phase voltage. Hence, we can write

$$\frac{1}{2}C_{dc}[(1.8\,V_m)^2-(1.4\,V_m)^2]=(2X-X/2)nT$$

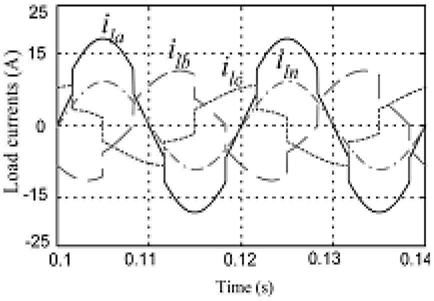
4. Simulation Results

The load compensator with H-bridge VSI topology as shown in Fig is realized by digital simulation by using MATLAB. The load and the compensator are connected at the PCC. The ac load consists of a three-phase unbalanced load and a three-phase diode bridge rectifier feeding a highly inductive R-L load. A dc load is realized by an equivalent resistance R_{dc} as shown in the figure. The dc load forms 50% of the total power requirement. The system and compensator parameters are given in Table.1 By monitoring the load currents and PCC voltages, the average load power is computed. At every zero crossing of phase a voltage, P_{dc} is generated by using the dc-link voltage controller. The state-space equations are solved to compute the actual compensator currents and dc-link voltage. These actual currents are compared with the reference currents given by using hysteresis current control. Based on the comparison, switching signals are generated to compute the actual state variables by solving the state-space model. The source voltages and load currents are plotted in Fig (a) and (b).

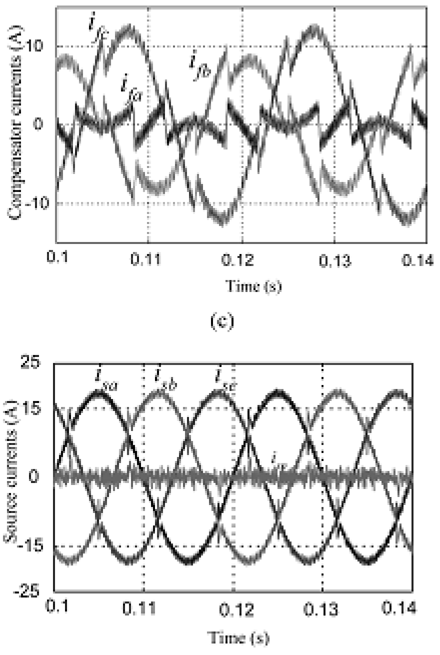
The load currents have total harmonic distortions of 8.9%, 14.3%, and 21.5% in phases a, b and c, respectively. The unbalance in load currents results in neutral current as illustrated in the figure. The compensator currents and compensated source currents are shown in Fig. (c) and (d). As seen from Fig. (d), the source currents are balanced sinusoids; however, the switching frequency components are superimposed over the reference currents due to the switching action of the VSI. The currents have a unity power factor relationship with the voltages in the respective phases. The THDs in these currents are 3.6%, 3.7%, and 3.9% in phases a, b and c, respectively



(a)



(b)



(c)

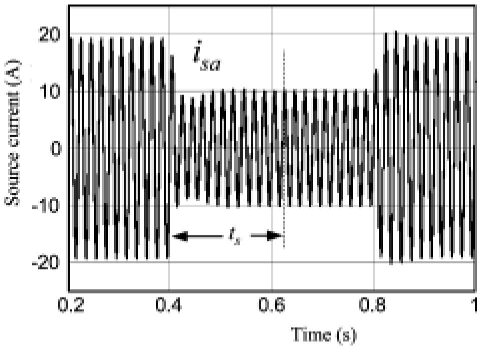
(d)

Fig .6: (a) Supply voltages. (b) Load currents. (c) Compensator currents (d) Compensated source currents.

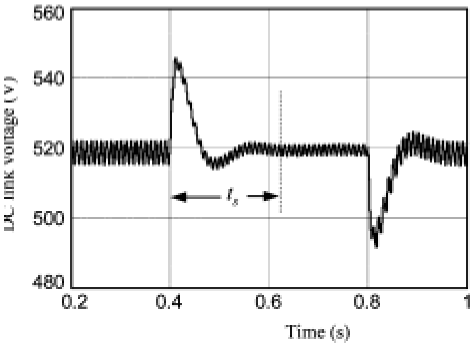
There are notches in the source currents due to finite bandwidth of the VSI. The transient performance of the conventional and fast-acting dc-link voltage controllers are studied by making sudden changes in the ac load supplied by the ac load bus as well as the dc load supplied by the dc link. In the simulation study, the load is halved at the instant t=0.4 s and brought back to full load at t=0.8 s. The transient performance is explained in the following subsections.

i. Transient Performance of Conventional DC-Link Voltage Controller

The conventional dc-link voltage controller is used to generate the dc load power P_{DC} which is inclusive of losses in the inverter. The transient performance of the compensator is shown in Fig. 7 (a) and (b).



(a)



(b)

Fig. 7: Transient response of the conventional controller. (a) Compensated source current in phase A b) DC-link voltage.

The total load, which is a combination of linear unbalanced and nonlinear load (as given in Table), is halved at the instant t=0.4 s. Due to a sudden reduction in the load, the dc-link capacitor absorbs surplus power from the source. Therefore, there is an increase in dc-link capacitor voltage above the reference value. Based on the values of PI controller gains, the dc-link capacitor voltage controller will be brought back to the reference value after a few cycles.

Similarly, when the load is switched back to the full load at instant t=0.8 s, the dc capacitor supplies power to the load momentarily and, hence, the dc-link voltage falls below the reference value. Due to the PI controller action, the capacitor voltage will gradually build up and reach its reference value. If gains of the conventional dc-link voltage controller are not properly chosen, the dc-link voltage would have undesirable overshoot and considerably large settling time. Consequently, the performance of the load connected to the dc link also gets affected due to the above factors. It can be observed from Fig.7 (a) and (b) that the conventional dc-link voltage controller takes about a ten cycle period to reach the reference voltage during load transient. This is indicated by time duration t_s in these figures.

ii. Transient Response of the Conventional fuzzy logic Controller

By using the fuzzy logic controller instead of the PI controller we will get the better transient response. The load is halved at t=0.4s .so the dc-link voltage is suddenly increased above the reference value .And it is brought back to its reference value due to the fuzzy controller action at the instant of t=0.42s as shown in the Fig.10.and when the load is switched back to the full load at instant t =0.8 s, the dc capacitor supplies power to the load. Hence dc-link voltage is falls below the reference value and it is brought back to the reference value at t=0.82s as shown in the Fig. 8.

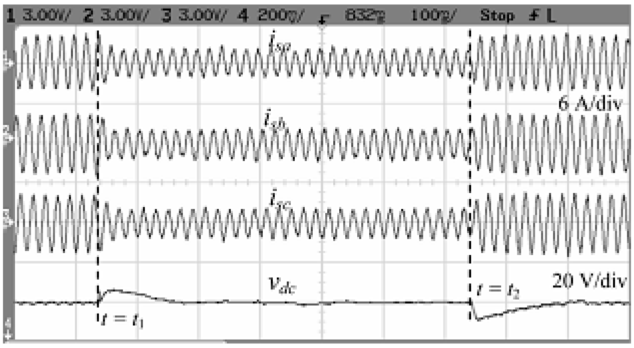


Fig. 8: Transient response of the fast acting fuzzy logic controller

5. Conclusion

A VSI topology for DSTATCOM compensating ac unbalanced and nonlinear loads and a dc load supplied by the dc link of the compensator is presented. The state-space modeling of the DSTATCOM is discussed for carrying out the simulation studies. An energy-based fast-acting dc-link voltage controller is suggested to ensure the fast transient response of the compensator. Mathematical equations are developed to compute the gains of this controller. The efficacy of the proposed controller over the conventional dc-link voltage controller is established through the digital simulation and experimental studies. It is observed from these studies that the proposed dc-link voltage controller gives fast transient response under load transients. By using fuzzy logic controller instead of these two controllers the transient response is very fast. The conventional fuzzy logic controller gives the better transient response than that of the conventional PI controller. The fast acting fuzzy logic controller gives the fast transient response than that of all previous controllers which are discussed above. The efficacy of the proposed controller is established through a digital simulation. It is observed from the above studies the proposed fast acting fuzzy logic controller gives the fast transient response for fast varying loads.

VI. References

[1] Mahesh K.mishra member IEEE and K.karthikayan "A fast acting dc-link voltage controller for three phase dstatcom to compensate ac and dc loads" IEEE *Transctions on power delivery*, vol., 24,no.4, October 2009

[2] M. H. J. Bollen, Understanding Power Quality Problems: Voltage Sags and Interruptions. New York: IEEE Press, 1999.

[3] W. M. Grady and S. Santoso, Proc. IEEE Power Eng. Rev. Understanding Power System

Harmonics, vol. 21, no. 11, pp. 8–11,2001.

[4] N. Hingorani, "Introducing custom power," *IEEE Spectr.*, vol.32,no.6,pp.41–8,Jun.1995.

[5] V. Dinavahi, R. Iravani, and R. Bonert, "Design of a real-time digital simulator for a DSTATCOM system," *IEEE Trans. Ind. Electron.*, vol.51, no. 5, pp. 1001–1008, Oct. 2004.

[6] M.K.Mishra,A. Ghosh, and A. Joshi, "A new STATCOM topology to compensate loads containing ac and dc components," in *Proc. IEEE Power Eng. Soc. Winter Meeting*, Singapore, Jan. 23–27, 2000, vol. 4, pp. 2636–2641.

[7] A. Nabae, I. Takahashi, and H. Akagi, "A new neutral-point-clamped PWM inverter," *IEEE Trans. Ind. Appl.*, vol. IA-17, no. 5, pp. 518–523, Sep. 1981.

[8] M. Aredes, J. Häfner, and K. Heumann, "Three-phase four-wire shunt active filter control strategies," *IEEE Trans. Power Electron.*, vol. 12, no. 2, pp. 311–318, Mar. 1997.

[9] B. Singh, K. Al-Hadded, and A. Chandra, "A review of active filters for power quality improvements," *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, pp. 960–971, Oct. 1999.

[10] M. El-Habrouk, M. K. Darwish, and P. Mehta, "Active power filters: A review," *Proc. Inst. Elect. Eng., Electr. Power Appl.*, vol. 147, no. 5, pp. 403–413, Sep. 2000.

[11] A. S. Kislovski, "Telecom power-supply plants using three-phase rectifiersand active filters," in *Proc. 2nd Int. Telecommunications EnergySpecial Conf.*, Budapest, Hungary, Apr. 22–24, 1997, pp. 127–13 4.

[12] A. Prodic´ and G. D. Marques, "Compensator design and stability assessment for fast voltage loops of power factor correction rectifiers,"*IEEE Trans. Power Electron.*, vol. 22, no. 5, pp. 1719–1730, Sep. 2007.

[13] D. Zhao and R. Ayyanar, "Space vector PWM with DC link voltage control and using

sequences with active state division," in *Proc., IEEE Int. Symp. Industrial Electronics*, Montreal, QC, Canada, Jul. 9–12, 2006, vol. 2, pp. 1223–1228.

14] P.Hoang, K.Tomosovic, "Design and an analysis an adaptive fuzzy power system stabilizer", Vol. 11, No. 2.June 1996;

[15] WenxinLiu, Ganesh K.Venayagamoorthy, DonaldC.wunseh. Adaptive neural network based power system stabilizer design, IEEE 2003 , page2970-2975.

I. APPENDIX

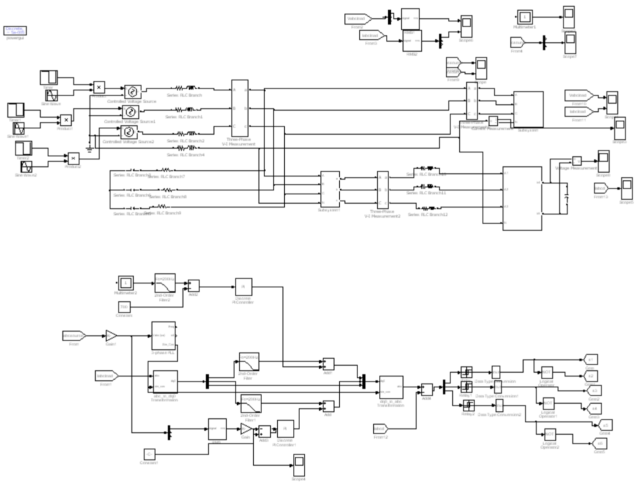


Fig. 9 Conventional Fuzzy logic control of three-phase D-STATCOM

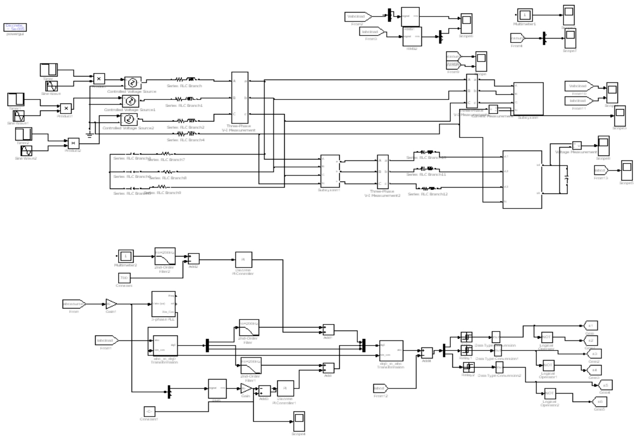


Fig. 10 Conventional diagram of three-phase D-STATCOM

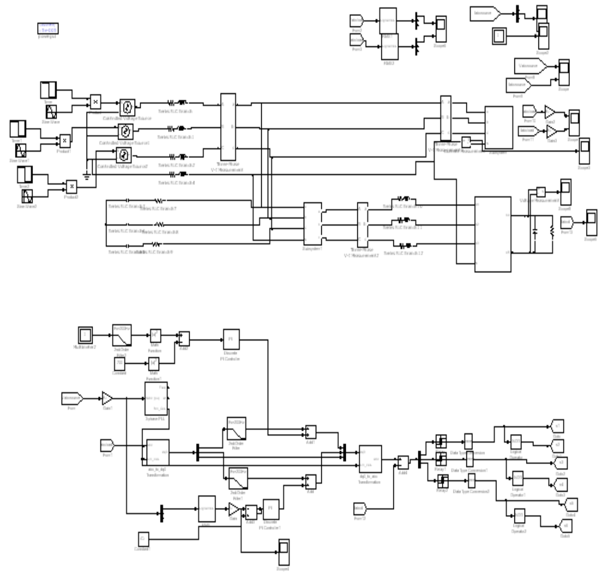


Fig. 11 Proposed model of three-phase DSTATCOM with fast acting fuzzy logic controller

Table 1 Experimental parameters

System Parameters	Values
Supply voltage	76 V (L-L), 50 Hz
Unbalanced load	$Z_a = 11 + j12.5\ \Omega$, $Z_b = 12 + j12.5\ \Omega$ and $Z_c = 14.5 + j18.8\ \Omega$
Nonlinear load	Three phase full wave rectifier feeding an R-L load of 82.5 Ω, 60 mH
DC load	$R_{dc} = 100\ \Omega$
DC capacitor	$C_{dc} = 2000\ \mu F$
Interface inductor	$L_f = 20$ mH, $R_f = 1.0\ \Omega$
Reference dc link voltage	$V_{dc\ ref} = 100$ V
Hysteresis band	$\pm h = 0.16$ A
Gains of conventional dc link voltage controller	$K_p = 10$, $K_i = 1.0$
Gains of fast acting dc link voltage controller	$K_p = 0.11$, $K_i = 0.055$