

Fuzzy-PI Current Controlled D-STATCOM

Resul COTELİ^{1*}, Besir DANDİL¹, Fikret ATA²

¹ *Firat University, Faculty of Technical Education, Department of Electric Education, TURKEY*

² *Firat University, Faculty of Engineering, Electric and Electronic Engineering, TURKEY*

Received: 13.09.2010 Accepted: 18.10.2010

ABSTRACT

Effort for improvement of power quality in distribution systems has been gradually increased. Traditionally, fixed, mechanical switched reactor/capacitor banks and Static Var Compensator have been used for improving the power quality issue in distribution systems. In recent years, applications of inverter based power quality conditioner have been growing for reactive power compensation in distribution systems, since their response is faster than that of the conventional compensators. Distribution STATCOM (D-STATCOM) is an inverter based power quality conditioner device used to improve the power quality issues in distribution systems. Control of D-STATCOM is generally realized by PI controllers with fixed parameter. However, desired control performance couldn't be obtained due to its nonlinear structure. In this paper, Fuzzy-PI controller which has a nonlinear and robust structure is proposed for control of D-STATCOM's d and q-axis currents. Simulation of Fuzzy-PI current controlled D-STATCOM is performed by MATLAB/Simulink software. In simulation study, the dynamic response of D-STATCOM is observed by changing the reference reactive current. Simulation results compared with conventional PI controller are given.

Key Words: *Reactive power compensation, power quality conditioner, D-STATCOM, Fuzzy-PI.*

1. INTRODUCTION

Reactive power compensation is a necessity since reactive power causes increasing losses and various power quality problems [1]. Fixed, mechanical switched reactor/capacitor banks and Static Var Compensator (SVC) have been widely used for reactive power compensation. These types of compensation have some disadvantages such as limited bandwidth, big size and more losses and slower response. Today, inverter based power quality conditioner devices have been proposed for improving the power quality problems in distribution systems because of their fast response, small size and low losses [2-4]. Distribution STATCOM (D-STATCOM) is an inverter based power quality conditioner device connected in shunt with ac system. It is used for power factor correction, load balancing, voltage regulation and harmonic filtering in distribution systems.

In the control of D-STATCOM, reference values for d and q-axis currents are generally obtained from Proportional+Integral (PI) controllers designed with

linear control methods. In the design of PI controllers, linear mathematical model of controlled system is required. Parameters of these controllers are tuned to obtain the best performance for a particular region of operation and conditions [5]. But, it is difficult to obtain and what fails to perform satisfactorily under parameter variation, load disturbance, unmodelled and nonlinear dynamics of the plant [6]. To cope with disadvantages of linear control methods, some researchers suggested nonlinear control methods like H_∞ , differential algebra theory, exact linearization with feedback [7-9]. Such control methods need exact mathematical model and parameters of controlled system. Besides, controller design with these methods has a more complex structure and is more difficult to realize than linear controllers [10]. Recently, intelligent controllers like Fuzzy Logic Controllers (FLC) and Artificial Neural Network (ANN) as alternative linear and nonlinear control techniques have been used in the control of D-STATCOM [11-16]. The mathematical model of system to be controlled isn't

*Corresponding author, e-mail: rcoteli@firat.edu.tr

necessary for these controllers. Moreover, they can provide efficient control over a wide range of system operating conditions, which distinguishes them from conventional linear controllers [10].

In this paper, Fuzzy-PI controller which is a robust controller is proposed for D-STATCOM's d and q-axis currents control. Model of power system and D-STATCOM and controller unit are developed in MATLAB/Simulink environment. Two Fuzzy-PI are used for the control of d and q-axis currents separately. Inputs of Fuzzy-PI controllers are chosen as errors of d and q-axis currents and change in these errors. Steady state error is eliminated by using the external integrator in outputs of Fuzzy-PI controllers. Compared results of

simulation with Fuzzy-PI controller and the linear PI with fixed parameters are given for the variations in reference reactive current.

2. BASIC OPERATIONAL PRINCIPLE AND MATHEMATICAL MODELLING OF D-STATCOM

Schematic presentation of D-STATCOM is presented in Figure 1. As shown in Figure 1, D-STATCOM consists of inverter, dc-link capacitance (C) supplying the dc voltage for inverter, coupling inductance (L) to exchange reactive power and filter out the current harmonics and a control unit to generate PWM signals for the switches of inverter. In figure, R_{dc} and R represent switching losses in inverter and winding resistance of coupling inductance respectively.

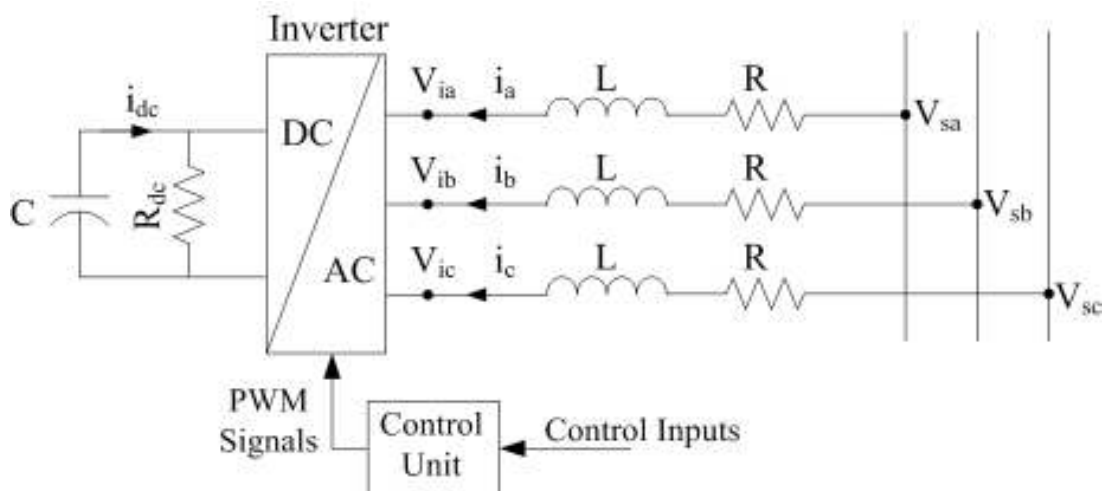


Figure 1. Schematic presentation of D-STATCOM.

Basic operation principle of D-STATCOM is similar to rotating synchronous compensator and can be explained by phasor diagrams presented in Figure 2. These phasor diagrams are drawn for ideal case (by neglecting active power losses). If output voltage of D-STATCOM is equal to ac system voltage, reactive power is delivered to ac

grid; D-STATCOM operates in stand-by mode (Figure 2(a)). If output voltage of D-STATCOM is greater than ac system voltage, reactive power is delivered to ac grid; D-STATCOM operates in capacitive mode (Figure 2(b)) and vice versa (Figure 2(c)).

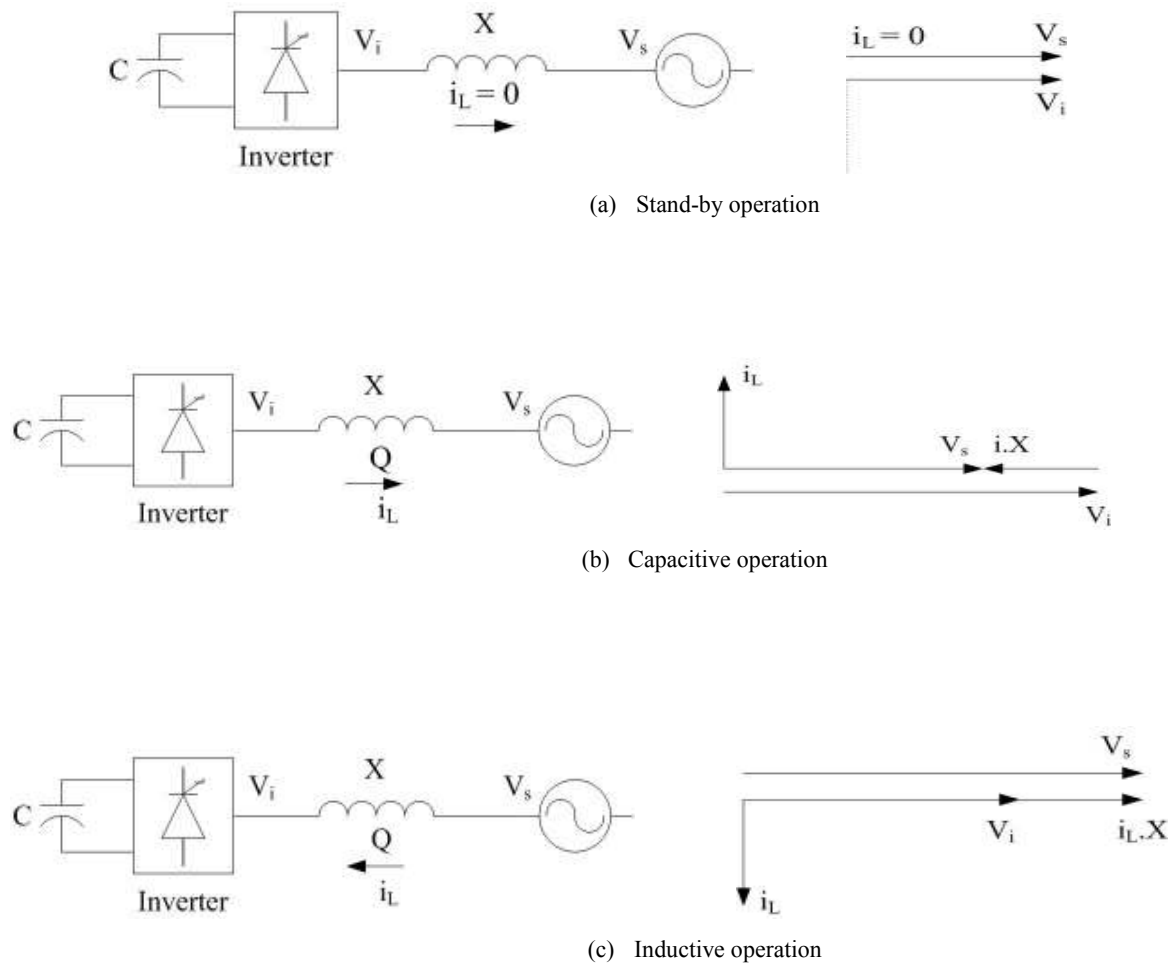


Figure 2. Phasor diagrams for operation modes of D-STATCOM.

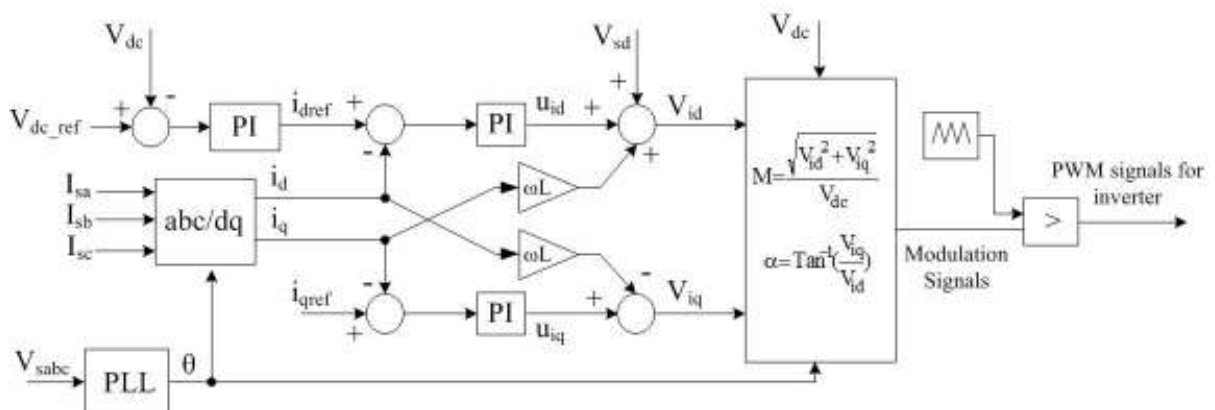


Figure 3. Complete block diagram of D-STATCOM's control algorithm.

3.FUZZY-PI CONTROLLER DESIGN FOR D-STATCOM'S CURRENT CONTROL

Linear PI controllers are well established in classical control system and it is often used as a benchmark against the other types of controllers. Since this controller is

linear, they are not usually suitable for strongly nonlinear systems. Fuzzy Logic Controllers (FLC) is alternative to classical PI controllers in such cases [22]. FLC has been widely used in systems with complex structure because it doesn't need mathematical model of controlled system. Figure 4 shows schematic representation of FLC. As

^{*}Corresponding author, e-mail: rcoteli@firat.edu.tr

shown in Figure 4, FLC consists of five main parts. These are fuzzification, knowledge base, rule base, inference

and defuzzification.

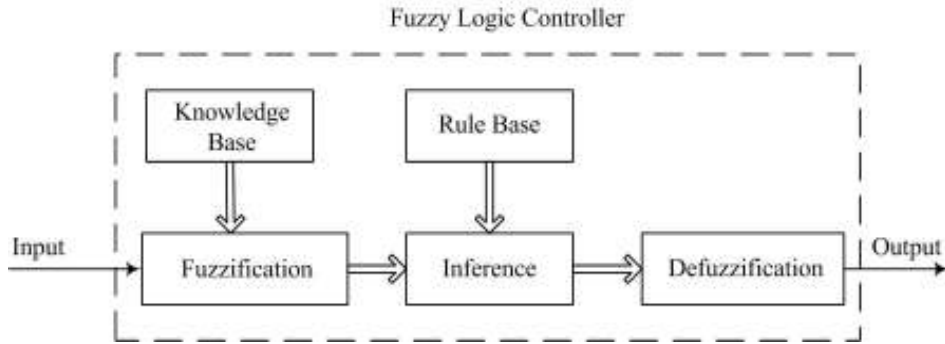


Figure 4. Schematic representation of FLC.

In fuzzification part, crisp values of input are converted into fuzzy values, so that these values are compatible with the fuzzy set representation in the rule base. The choice of fuzzification strategy is dependent on the inference engine [23]. The knowledge base consists of a database of the plant. It provides all the necessary definitions for the fuzzification process. Rule base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristic as a set of IF-THEN rules. The rules are based on the fuzzy inference. Inference called fuzzy model applies fuzzy reason to rule base to obtain a proper output. Mamdani and Takagi-Sugeno fuzzy systems are the most commonly used fuzzy inference mechanisms. Mamdani is suitable for the systems with slow-changing dynamic while Takagi-Sugeno is suitable for the systems with fast-changing dynamic. Results obtained from fuzzy process are converted into crisp values by using any defuzzification method such as maxima methods and centre of area.

The structure of the Fuzzy-PI controller used in simulation study is shown Figure 5. It has two inputs and one output. Inputs of controller are errors of d and q-axis currents and derivative of these errors. In addition, an external integrator is used to eliminate the steady state error in output of FLC.



Figure 5. Structure of Fuzzy-PI controller.

In this study, normalized triangular membership functions are preferred for input variables and output variable as shown in Figure 6. Rule base for Fuzzy-PI controller consists of 25 rules and are given in Table 1.

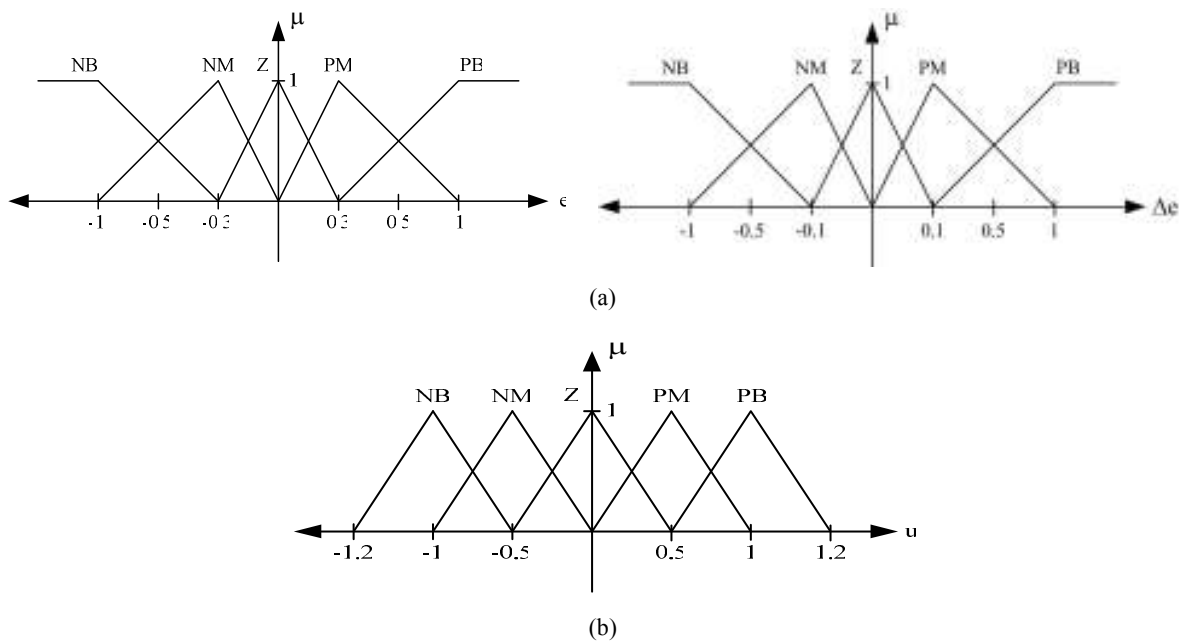


Figure 6. Triangular membership functions, a) for input variables, b) for output variable.

Table 1. Rule base for Fuzzy-PI controller.

e/Δe	NB	NM	Z	PM	PB
NB	NB	NB	NB	NM	Z
NM	NB	NB	NM	Z	PM
Z	NB	NM	Z	PM	PB
PM	NM	Z	PM	PB	PB
PB	Z	PM	PB	PB	PB

Fuzzy-PI controller designed as described above is replaced with PI controller used in control of d and q-axis

current. Complete block diagram of Fuzzy-PI current controlled D-STATCOM is shown in Figure 7.

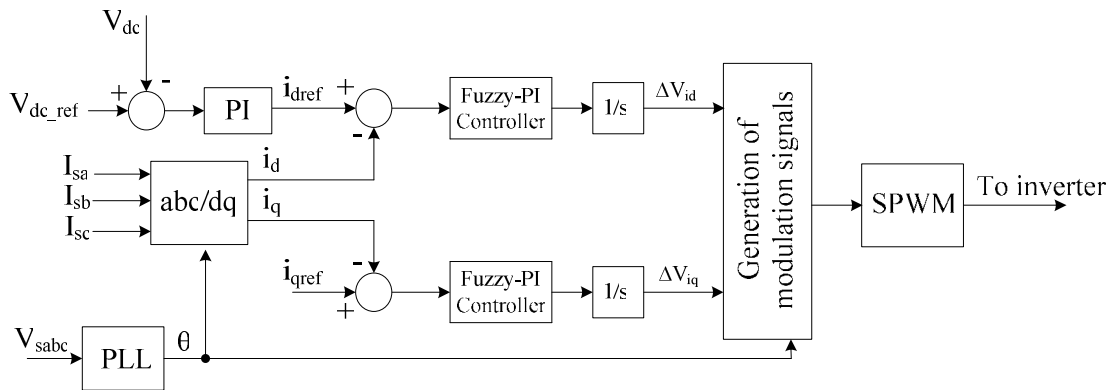


Figure 7. Complete block diagram of Fuzzy-PI current controlled D-STATCOM.

4. SIMULATION RESULTS

In this study, the model of power system, D-STATCOM and controller are developed in MATLAB/Simulink environment and shown in Figure 8. Here, power system is three-phase balanced. ac side and dc side mathematical model of D-STATCOM is used to obtain d and q-axis currents and dc average voltage value respectively. The dc bus voltage is controlled by a PI controller with fixed parameter to compensate for active power losses in the transformer and inverter and reference value for d-axis current is obtained from output of this controller.

Reference value for q-axis current is given as step command. Firstly, the d and q-axis currents are controlled by a PI controller with fixed parameter and then these PI controllers are replaced with Fuzzy-PI controllers. The outputs of the d and q-axis current controllers are the desired d and q-axis voltages to be generated by the inverter. These voltages are converted to three-phase in order to generate modulation signals required for control of inverter. Phase Locked Loop (PLL) is used to synchronize the inverter output voltage with power system voltage.

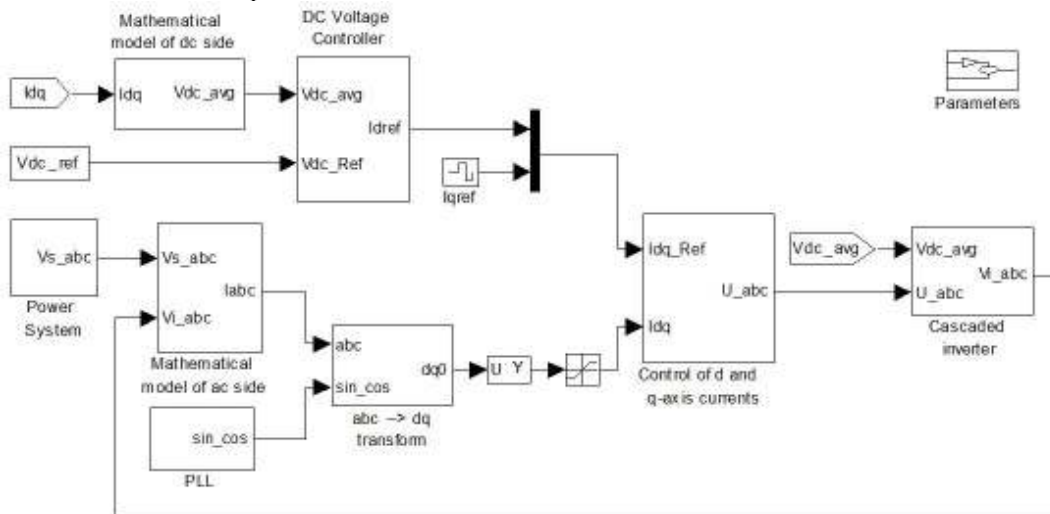


Figure 8. Simulink model of Fuzzy-PI current controlled D-STATCOM.

The D-STATCOM output is obtained from three-level cascaded inverter which has advantages such as modularized circuit layout, using the least number of components to achieve the same number of output voltage levels between other multilevel inverter topologies and possibility of packaging. This inverter is modeled with ideal switches. Control of inverter is realized by Multilevel Sinusoidal Pulse Width

Modulation (SPWM) technique with carrier frequency of 1.25 kHz [24-27]. A coupling reactance with an inductance of 3mH and winding resistance of 0.1ohm is used to filter out and realize the exchanging of reactive power. Single phase leg of inverter and generation of PWM for inverter are shown in Figure 9(a) and (b) respectively.

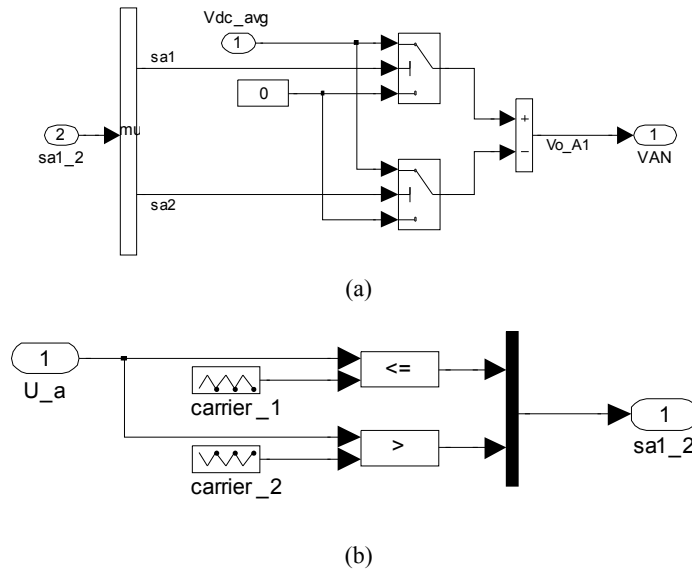


Figure 9. (a) Single phase leg of inverter, (b) Generating of PWM signals for single phase.

The subsystem of control of d and q-axis currents in Figure 8 is shown in Figure 10. It includes two Fuzzy-PI

controllers that control the d and q-axis currents and generation of modulation signals.

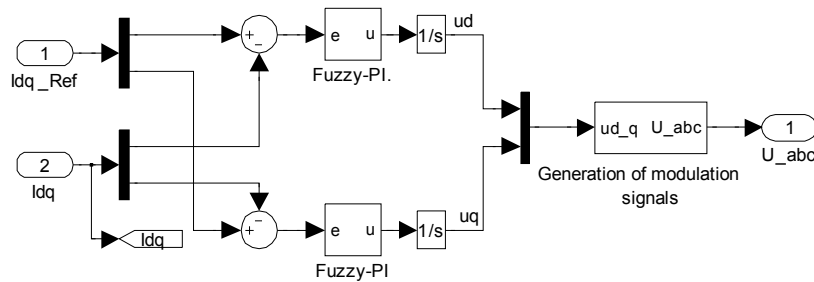


Figure 10. Subsystem of d and q-axis currents control.

The subsystem of Fuzzy-PI used in d-axis is shown in Figure 11 and it is identical with Fuzzy-PI used in q-axis. Here, Fuzzy-PI controllers have two inputs and one output. Inputs to Fuzzy-PI controller used in control of d-axis current are error and change in error of d-axis current. Similarly inputs to Fuzzy-PI controller used in control of q-axis current are error and change in error of q-axis current. Outputs of these controllers are the d and q-axis voltages (u_d and u_q) which have to be generated by inverter.

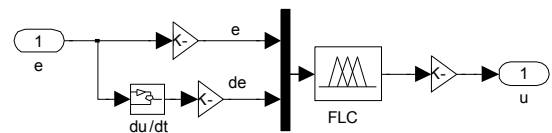


Figure 11. Subsystem of Fuzzy-PI used in d-axis.

Simulation study is done for changing of I_{qref} from 0A to +200A at 0.5 sec., +200 A to -200 at 0.8 sec. and -200A to 0A at 1.1 sec. Performance of Fuzzy-PI current controlled D-STATCOM is evaluated for changes in i_{qref}

and the compared simulation results with PI controller with fixed parameter are presented. Figure 12 shows tracking performance of Fuzzy-PI controller and PI controller with fixed parameter when i_{qref} is changed from

0A to +200A at 0.5 sec. Simulation result shows that Fuzzy-PI controller reaches the reference value faster

than PI controller.

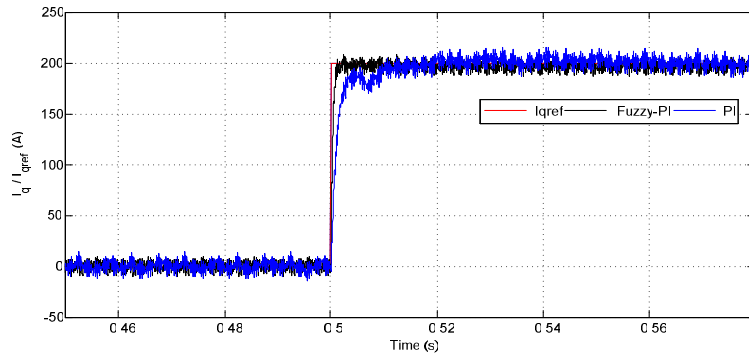


Figure 12. Simulation result for variation of i_{qref} from 0A to +200A.

Performance of Fuzzy-PI and conventional PI controller are also tested for reference changing from positive to negative (+200A to -200A) and depicted in Figure 13. As

shown in Figure 13, Fuzzy-PI controller is superior to conventional PI controller in terms of reaching reference value.

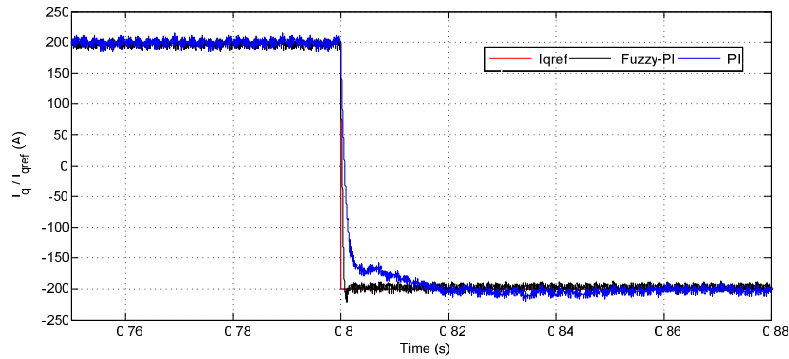


Figure 13. Simulation result for variation of i_{qref} from +200A to -200A.

Simulation result obtained from Fuzzy-PI and conventional PI controller for variation of i_{qref} from -200A to 0A is given in Figure 14. From figure, Fuzzy-PI

controller reaches the reference value more quickly than PI controller.

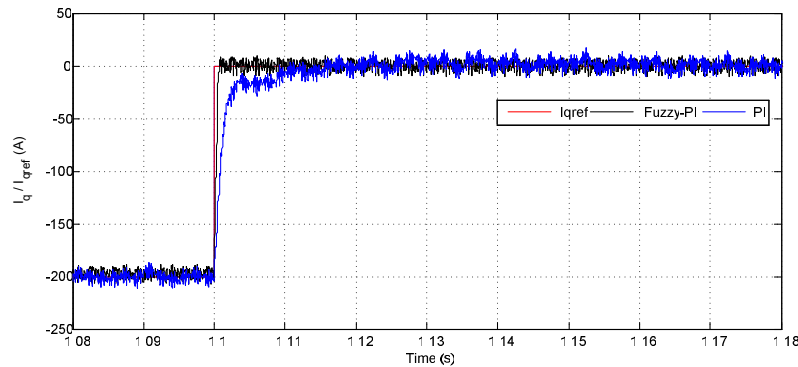


Figure 14. Simulation result for variation of i_{qref} from -200A to 0A.

Figure 15(a), (b) and (c) show phase-a fundamental voltage and phase-a current of D-STATCOM as pu while

i_{qref} is changed from 0A to +200A, +200A to -200A and -200A to 0 A respectively.

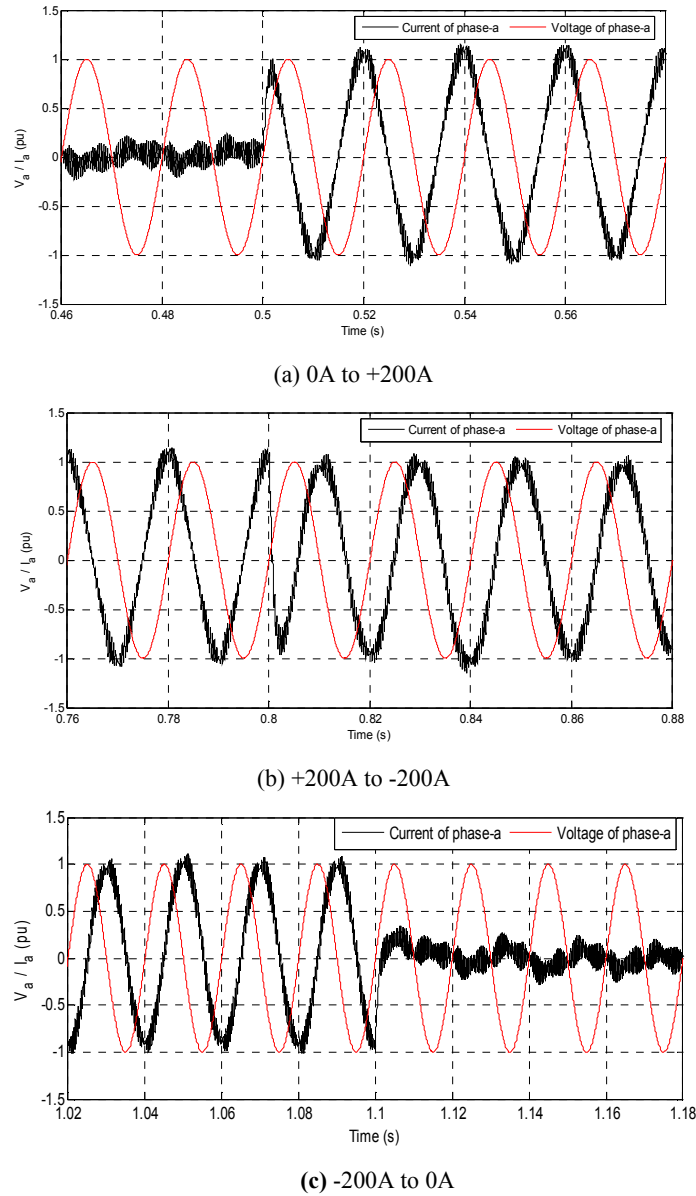
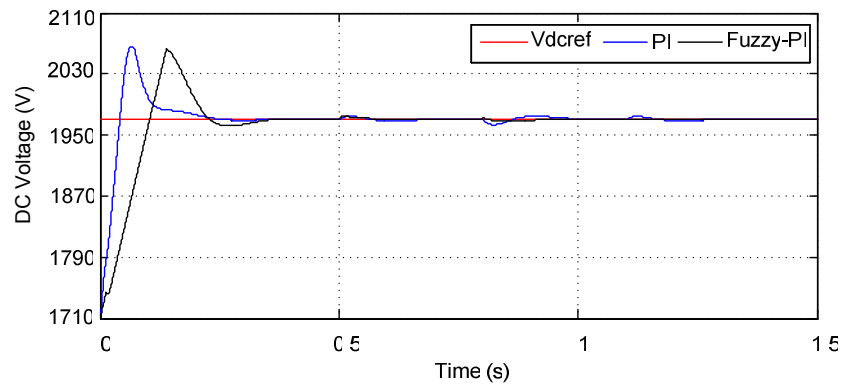


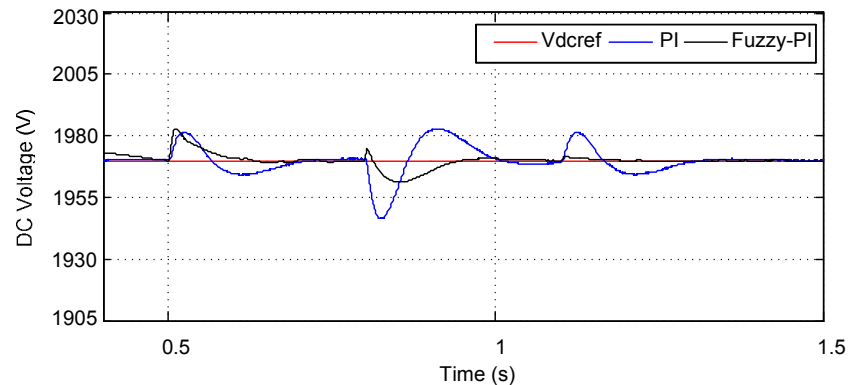
Figure 15. Variation of i_{qref} from -200A to 0A.

Variation of average dc voltage is shown in Figure 16(a) and (b) in case of using the Fuzzy-PI and PI controller with fixed parameter controller in control of d and q-axis

currents. Figure 16(b) shows that dc voltage has less fluctuation during changing in q-axis current if Fuzzy-PI controller is used in control of d and q-axis currents.



(a)



(b)

Figure 16. Variation of average dc voltage.

5. CONCLUSION

In this paper, Fuzzy-PI current controlled D-STATCOM is realized in MATLAB/Simulink environment. Compared simulation results with conventional PI controller are given. Simulation results show that Fuzzy-PI controller gives a good response in changes of reference reactive current over conventional PI controller. In addition, the Fuzzy-PI controller is easily designed and don't need the mathematical model of system to be controlled. Therefore, these features of fuzzy controller make it attractive.

REFERENCES

- [1] Masand, D., Jain, S., Agnihotri, G., "Control Strategies for Distribution Static Compensator for Power Quality Improvement", *IETE Journal of Research*, 54(6): 421-428 (2008).
- [2] Miller, T.J.E., "Reactive Power Control in Electric Systems", Toronto, Ontario, Canada, *Wiley*, (1982).
- [3] Mathur, R.M., "Static Compensators for Reactive Power Control", *Contexts Publications*, Winnipeg, Canada, (1984).
- [4] Singh, B., Mittal, A.P., Gupta, J.R.P., "Modelling and Control of DSTATCOM for Three-Phase, Four-Wire Distribution Systems", *Industry Applications Conference, 2005. Fourtieth IAS Annual Meeting, Conference Record of the 2005*, 4: 2428-2434 (2005).
- [5] Venayagamoorthy, G.K., Harley, R.G., "Computational Intelligence Techniques for Control of FACTS Devices", *Applied Mathematics for Restructured Electric Power Systems Optimization*, *Control and Computational Intelligence*, 201-237 (2005).
- [6] Hosseini, S.H., Rahnavard, R., Ebrahimi, Y., "Reactive Power Compensation in Distribution Networks with STATCOM by Fuzzy Logic Theory Application", *Power Electronics and Motion Control Conference, IPEMC 2006*, CES/IEEE 5th International, 1-5 (2006).
- [7] Liu, F., Mei, S., Lu, Q., Ni, Y., Wu, F.F., Yokoyama, A., "The Nonlinear Internal Control of STATCOM: Theory and Application", *International Journal of Electrical Power & Energy Systems*, 25: 421 – 430 (2003).
- [8] Petitclair, P., Bacha, S., Rognon, J.P., "Averaged Modelling and Nonlinear Control of an Advanced Static Var Compensator", *Proceedings of the Power Electronics Specialists Conference*, 1: 753-758 (1996).
- [9] Yao, Z., Kesimpar, P., Donescu, V., Uchevin, N., Rajagopalan, V., "Nonlinear Control for STATCOM Based on Differential Algebra", *29th Annual IEEE Power Electronics Conference*, May, 1: 329-334 (1998).
- [10] Mohagheghi, S., "Adaptive Critic Designs Based Neuro-controllers for Local and Wide Area Control of a Multimachine Power System with a Static Compensator", Ph. D. Thesis, *Georgia Institute of Technology*, 369 (2006).
- [11] Kazmierkowski, M.P., Malesani, L., "Current Control Technique for Three-Phase Voltage Source PWM Converters", *IEEE Trans. Ind. Electron.*, 45(5): 691–703 (1998).
- [12] Malesani, L., Tomasin, P., "PWM Current Control Techniques of Voltage Source Converters—A Survey", *Int. Conf. Proc. Industrial Electronics, Control and Instrumentation*, IECON'93, 2: 670–675 (1993).
- [13] Li, C., Jiang, Q., Xie, X., Wang, Z., "Rule-Based Control for STATCOM to Increase Power System Stability", *Proc.Int. Conf. Power System Technology*, POWERCON, 1(1): 372–376 (1998).
- [14] Li, C., Jiang, Q., Wang, Z., Retzmann, D., "Design of A Rule-Based Controller for STATCOM", *Proc. Industrial Electronics Society*, 1: 467–472 (1998).

- [15] Chen, W., Liu, Y., Chen, J., Wu, J., "Control of Advanced Static VAR Generator by Using Recurrent Neural Networks", *Proc. Power System Technology*, POWERCON'98 (2): 839-842 (1998).
- [16] Mohaddes, A.M., Gole, A.M., McLaren, P.G., 'A Neural Network Controlled Optimal Pulse-Width Modulated STATCOM', *IEEE Trans.Power Deliv.*, 14(2): 481-488 (1999).
- [17] Schauder, C., Mehta, H., "Vector Analysis and Control of Advanced Static VAR Compensators", *Generation, Transmission and Distribution, IEE Proceedings C*, 140: 299-360 (1993).
- [18] Sahoo, N.C., Panigrahi, B.K., Dash, P.K., Panda, G., "Application of A Multivariable Feedback Linearization Scheme for STATCOM Control", *Electric Power Systems Research*, 62: 81-91 (2002).
- [19] Blasko, V., Kaura, V., "A New Mathematical Model and Control of A Three-Phase AC-DC Voltage Source Converter", *IEEE Transactions on Power Electronics*, 12: 116-123 (1997).
- [20] Adzic, M.E., Grabic, S.U., Katic, V.A., "Analysis and Control Design of STATCOM in Distribution Network Voltage Control Mode", *Sixth International Symposium Nikola Tesla*, (2006).
- [21] Suul, J.A., Molinas, M., Norum, L., Undeland, T., "Tuning of Control Loops for Grid Connected Voltage Source Converters", *2nd IEEE International Conference on Power and Energy (PECon 08)*, 797-802 (2008).
- [22] Akbıyık, B., Eksin, İ., Güzelkaya, M., Yeşil, E., "Evaluation of the Performance of Various Fuzzy PID Controller Structures on Benchmark Systems", *ELECO '2005, 4rd International Conf. on Electrical and Electronics Engineering*, (2005).
- [23] Cirstea, M.N., Dinu, A., Khor, J.G., McCormick, M., "Neural and Fuzzy Logic Control of Drives and Power Systems", NEWNES, Jordan Hill, *Oxford*, 399, (2002).
- [24] Agelidis, V.G., Calais, M., "Application specific harmonic performance evaluation of multicarrier PWM techniques", *In Proc. IEEE PESC'98, Fukuoka*, Japan (1998).
- [25] Bhagwat P.M., Stefanovic, V.R., "Generalized Structure of a Multilevel PWM Inverter," *IEEE Transactions on Industry Applications*, 19: 1057-1069 (1983).
- [26] Calais, M., Agelidis, V.G., Dymond, M.S., "When to Switch Which Switch in a Five Level Single Phase Cascaded Inverter", *In Conference Proceedings of the AUPEC/EECON'99*, Darwin, Australia, September (1999).
- [27] Choi, N.S., Cho, J.G., Cho, G.H., "A General Circuit Topology of Multilevel Inverter", *IEEE PESC'91*, 96-103 (1991).

APPENDIX

System parameters used in simulation study

Network voltage	: 2kV
Coupling inductance	: 3mH
Winding resistance of coupling inductance	: 0.1Ω
DC link capacitance	: 6mF
Reference DC voltage	: 1970V
Carrier frequency	: 1.25kHz
Sampling time	: 1×10^{-5} s

Parameters of PI controllers

K_{pdc}	: 0.9
K_{idc}	: 34
K_p	: 2
K_i	: 25