

Comparison of Responses of the PI and the Fuzzy Logic Controlled Closed Loop DPFC Systems

S. Vadivel, B. Baskaran

Abstract: The proposed work deals with comparison of the PI and the fuzzy logic controlled closed loop DPFC systems. The voltage across the load decreases due to the addition of extra load and the load voltage are restored back to normal value by using closed loop system. The ability of closed loop system to bring the voltage and reactive power back to the set value is represented in this paper. The simulation studies for open loop and closed loop systems are performed on a standard ten bus radial test system.

Index Terms: DPFC - Distributed power flow control, DVR - Dynamic Voltage Regulator, E_{SS} - Steady State Error, FACTS - Flexible AC Transmission System, Q - Reactive Power, STATCOM - Static Compensator, T_s - Settling Time, UPFC - Unified power flow control, V - Voltage, VAR - Voltage Ampere Reactive, V_P - Peak Over Shoot Voltage.

I. INTRODUCTION

Power Quality is becoming an important issue for both electric utilities and end users [1]. Unbalanced voltages and currents in a network are one of the concerns under the power quality issue. The unbalance is mainly produced by the great number of single-phase loads which are unevenly distributed over the phases [2]. The unbalance voltages can cause extra losses in components of the network, such as generators, motors and transformers, while unbalanced currents cause extra losses in components like transmission lines and transformers [3]. Active filters and power factor corrector can be applied to compensate the unbalance at the load side. However their contribution to transmission systems is not large because they are focused on single load [4], [5].

FACTS devices can be employed to compensate the unbalanced currents and voltages in transmission systems. Unfortunately, it is found that the capability of most of FACTS devices to compensate unbalance is limited. Series and shunt FACTS device can only provide compensation of unbalanced reactive currents [6], and the most powerful device – the UPFC [7] cannot compensate zero-sequence unbalance current, because of the converter topology [8]. DPFC can compensate both active and reactive powers. The zero and negative sequence unbalanced currents can also be compensated.

The Distributed Power Flow Controller (DPFC) recently presented in [9], is a powerful device within the family of FACTS devices, which provides much lower cost and higher reliability than conventional FACTS devices.

Revised Version Manuscript Received on February 29, 2016.

S. Vadivel, Department of Electrical Engg., Annamalai University, Annamalainagar-608002.

Dr. B. Baskaran, Department of Electrical Engg., Annamalai University, Annamalainagar-608002.

It is derived from the UPFC and has the same capability of simultaneously adjusting all the parameters of the power system such as line impedance, transmission angle, and bus voltage magnitude [7]. Within the DPFC, the common DC link between the shunt and series converters is eliminated, which provides flexibility for independent placement of series and shunt converters. The DPFC uses the transmission line to exchange active power between converters at the third harmonic frequency [9]. Instead of one large three-phase converter, the DPFC employs multiple single-phase converters (D-FACTS concept [10]) as the series compensator. This concept not only reduces the rating of the components but also provides a high reliability because of the redundancy. The scheme of the DPFC in a simple two-bus System is illustrated in Fig.1.

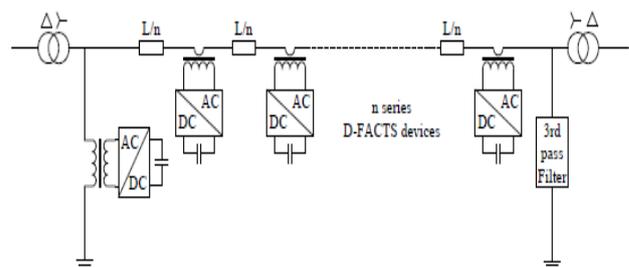


Fig. 1. Distributed power flow controller

As the series converters of the DPFC are single-phase, it gives the DPFC the opportunity to control current in each phase independently, which implies that both negative and zero sequence unbalanced current can be compensated. Additional controllers are supplemented to the existing DPFC controller. Their control principle is to monitor the negative and zero sequences current through the transmission line and to force them to zero. The above literature does not deal with the comparison of closed loop controlled DPFC system using PI and Fuzzy Logic controllers. The objective of this paper is to study the improvement in dynamic response using Fuzzy Logic controller.

II. PRINCIPLE OF THE DPFC

A. Introduction of the DPFC

Multiple individual converters cooperate together and compose the DPFC, see Fig (1). The converters connected in series with the transmission lines are the series converters. They can inject a controllable voltage at the fundamental frequency; consequently they control the power flow through the line.



Comparison of Responses of the PI and the Fuzzy Logic Controlled Closed Loop DPFC Systems

The converter connected between the line and ground is the shunt Converter. The function of the shunt converter is to compensate reactive power to the grid, and to supply the active power required by the series converter.

In a normal UPFC, there is active power exchange through the DC link that connects the series converter with the shunt converter. Since there is no common DC link between the shunt and series converters in the DPFC, the active power is exchanged by harmonics and through the AC network. The principle is based on the definition of active power, which is the mean value of the product of voltage and current, where the voltage and current comprise fundamental and harmonics. Since the integrals of all the cross-product of terms with different frequencies are zero, the time average active power can be expressed by:

$$P = \sum_{n=1}^{\infty} V_n I_n \cos \phi_n \quad (1)$$

Where n is the order of the harmonic frequency and ϕ_n is the angle between the current and voltage of the n th harmonic. Equation 1 describes that active powers at different frequencies are isolated from each other and that voltage or current in one frequency component has no influence on other frequency components. The 3rd harmonic is chosen here to exchange the active power, because it can easily be filtered by using Y- Δ transformers.

B. Control Principle of DPFC

The DPFC system consists of two types of converters, and each type of converter requires a different control scheme. The block diagram of the DPFC and its control are shown in Fig (2). The shunt converter is controlled to inject a constant third harmonic current into the transmission line, which is intended to supply active power for the series converters.

The shunt converter extracts some active power from the grid at the fundamental frequency to maintain its DC voltage. The DC voltage of the shunt converter is controlled by the d component of the current at the fundamental frequency, and the q component is utilized for reactive power compensation. The series converters generate a voltage with controllable phase angle at fundamental frequency, and use the voltage at the third harmonic frequency to absorb active power to maintain its DC voltages at a constant value. The power flow control function is realized by an outer control loop, the power flow control block. This block gets its reference signals from the system operator, and the control signals for DPFC series converters are sent remotely via wireless or PLC communication method.

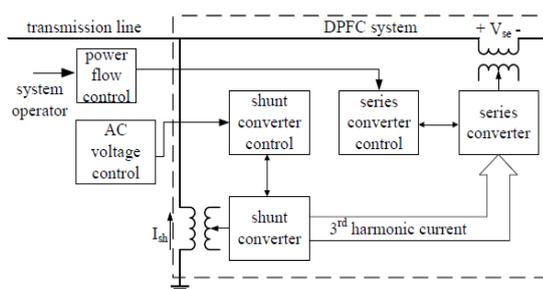


Fig.2. Block diagram of the control of a DPFC

The functions of each control block shown in Fig (2) are described here:

- Power flow control:** It receives the set point for power flow from the system operator, and calculates the fundamental frequency voltage that should be injected by the series converters.

- Series converter control:** It generates switching signals according to the received data, and stabilizes DC capacitor voltage by controlling third harmonic components.

- AC voltage control:** gives the set points to shunt converter for reactive power compensation at the fundamental frequency.

- Shunt converter control:** generates 3rd harmonic current, the reactive current at the fundamental frequency and stabilizes the DC voltage.

III. SIMULATION RESULTS

A. Open loop controlled DPFC system

Open loop controlled DPFC system is shown in Fig 3(a). A shunt converter is connected in parallel with the alternator at the sending end. Two inverters inject the voltage in series with the line as shown in Fig 3(a).

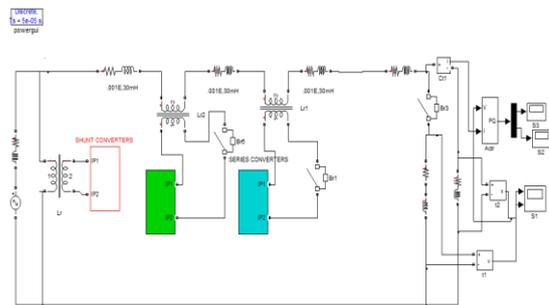


Fig 3(a) Open loop controlled DPFC System

Additional load can be added to the existing load by using a breaker. The voltage at the receiving end is shown in Fig 3(b).

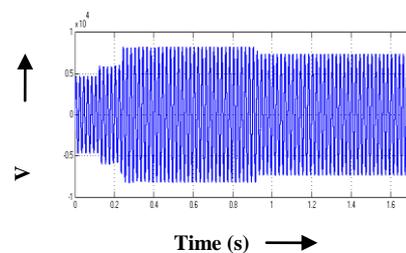


Fig 3(b) voltage at the Receiving end

At $t = 0.9$ sec, the second load is connected. The voltage decreases from 6350 V to 6210V. The reactive power also decreases as shown in Fig 3(c).

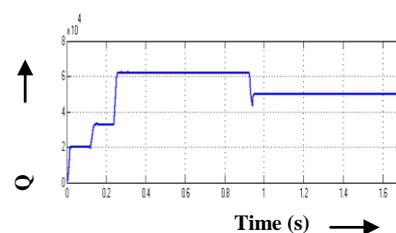


Fig 3(c) Reactive power

B. Closed loop controlled DPFC system with PI Controller

Closed loop reactive power controlled system using PI controller is shown in Fig 3(d). The real and reactive powers are measured using PQ block.

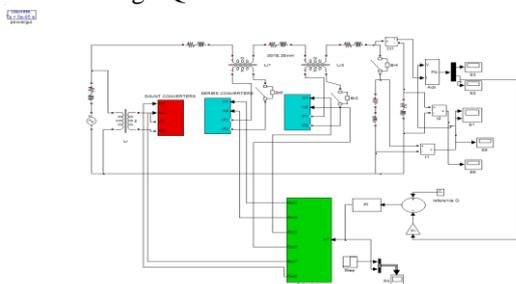


Fig 3(d) Closed Loop System with the PI Controller

Actual reactive power is compared with the reference reactive power and the error is applied to the PI controller. The control circuit increases the pulse width so that the voltage at the receiving end is improved. The voltage at the receiving end is shown in Fig 3(e).

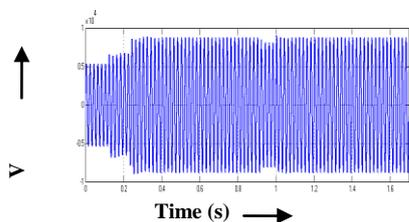


Fig 3(e) voltage at the receiving end

The voltage initially decreases and then reaches normal value due to the action of the closed system. The voltage reaches normal value at $t = 1$ sec. The variation of reactive power is shown in Fig 3(f). The reactive power decreases and then reaches the set value.

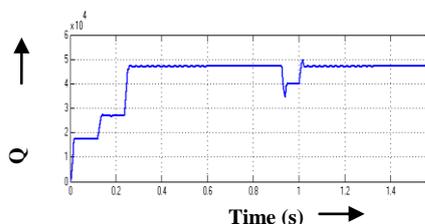


Fig 3(f) Reactive power

C. Closed loop controlled DPFC system with the PID Controller

Closed loop controlled DPFC system with PID controller is shown in Fig 3(g).

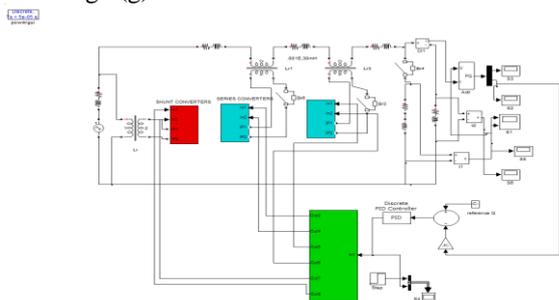


Fig 3(g) closed loop system with the PID controller

The receiving end voltage is shown in Fig 3(h).

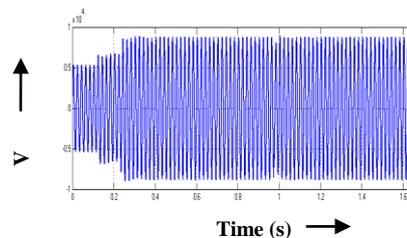


Fig 3(h) voltage at the receiving end

The voltage decreases and then gets corrected due to the increased pulse width of injected voltage. The variation of reactive power is shown in Fig 3(i). The reactive power resumes to the normal value as shown in Fig 3(i).

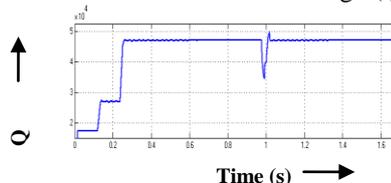


Fig 3(i) Reactive power

The Simulink model of DPFC systems with Fuzzy Logic Controller is shown in Fig 3(j).

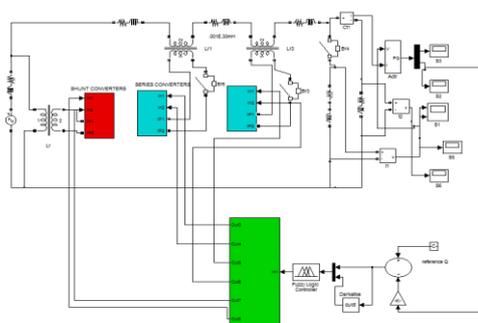


Fig 3(j) The Simulink model of DPFC with FLC

The reactive power is measured and it is compared with the reference power. The error and change in error are the inputs to the Fuzzy Logic Controller. The pulse width is adjusted to the regulated reactive power. Output voltage is shown in Fig. 3(k) & Reactive Power Wave form is shown Fig. 3(l).

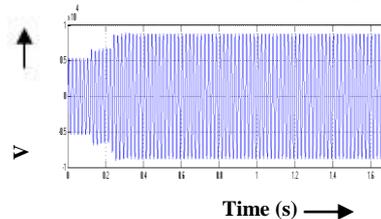


Fig. 3(k) Output voltage Waveform

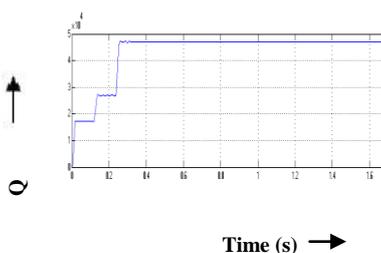


Fig 3(l) Reactive Power Wave form.

Comparison of Responses of the PI and the Fuzzy Logic Controlled Closed Loop DPFC Systems

The comparisons of various systems are given in table 1.

Table-1. Comparison of PI, PID & FLC Based systems.

Controllers	Rise time (s)	Peak time (s)	Settling time (s)	Steady state error (E_{SS})
PI controller	0.25	1.09	1.10	10
PID controller	0.23	1.01	1.00	8
FLC	0.20	-	-	-

The response indicator that Fuzzy Logic Controller produces smoother response. The reactive power reactor set value without any peak over shot.

IV. CONCLUSION

DPFC systems controlled by PI, PID and Fuzzy Logic Controllers were designed, modeled and simulated using Matlab Simulink. The simulation results of open loop and closed loop systems were presented. The proposed reactive power loop was successfully employed to maintain constant reactive power. The response of Fuzzy Logic Controller controlled system was found to be superior to the PID controlled system. This was due to reduction in the peak time, the peak overshoot and the steady state error. The advantages of DPFC are improved voltage and reactive power profiles. The disadvantage of DPFC is the requirement of about six inverters, six driver circuits and injection transformers.

The scope of the work is modeling and simulation of reactive power controlled ten bus system using PI & Fuzzy Logic Controllers. The studies will be extended with Artificial Neural Network controller to improve the dynamic response.

REFERENCES

1. R. C. Dugan and ebrary Inc, Electrical power systems quality, 2nd Ed. New York: McGraw-Hill, 2003.
2. M. Chindris, A. Cziker, A. Miron, H. Balan, A. Iacob, and A. Sudria, "Propagation of unbalance in electric power systems," in Electrical Power Quality and Utilisation, 2007. EPQU 2007. 9th International Conference on, 2007, pp. 1–5.
3. J. Pedra, L. Sainz, F. Corcoles, and L. Guasch, "Symmetrical and unsymmetrical voltage sag effects on three-phase transformers," Power Delivery, IEEE Transactions on, vol. 20, no. 2, pp. 1683–1691, 2005.
4. K. Nohara, A. Ueda, A. Torii, and D. Kae, "Compensating characteristics of a series-shunt active power filter considering unbalanced source voltage and unbalanced load," in Power Conversion Conference - Nagoya, 2007. PCC '07, 2007, pp. 1692–1697.
5. Soares, P. Verdelho, and G. D. Marques, "An instantaneous active and reactive current component method for active filters," Power Electronics, IEEE Transactions on, vol. 15, no. 4, pp. 660–669, 2000.
6. Nunez, V. Cardenas, G. Alarcon, and M. Oliver, "Voltage disturbances and unbalance compensation by the use of a 3-phase series active filter," in Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual, vol. 2, 2001, pp. 571–576 vol.2.
7. L. Gyugyi, "Unified power-flow control concept for flexible ac transmission systems," Generation, Transmission and Distribution [see also IEE Proceedings-Generation, Transmission and Distribution], IEE Proceedings C, vol. 139, no. 4, pp. 323–331, 1992.
8. Y. Ikeda and T. Kataoka, "A upfc-based voltage compensator with current and voltage balancing function," in Applied Power Electronics Conference and Exposition, 2005. APEC 2005. Twentieth Annual IEEE, vol. 3, 2005, pp. 1838–1844 Vol. 3.
9. Z. Yuan, S. W. H. de Haan, and B. Ferreira, "A new facts component: Distributed power flow controller (dpfc)," in Power Electronics and Applications, 2007 European Conference on, 2007, pp. 1–4.

11. Divan and H. Johal, "Distributed facts - a new concept for realizing grid power flow control," in Power Electronics Specialists Conference, 2005. PESC'05. IEEE 36th, 2005, pp. 8–14.
12. H. Namho, J. Johan, and N. Kwan ghee, "A fast dynamic dc-link power-balancing scheme for a pwm converter-inverter system," Industrial Electronics, IEEE Transactions on, vol. 48, no. 4, pp. 794–803, 2001.
13. Z. Yuan, S.W.H. de Haan, B. Ferreira, A new FACTS component – distributed power flow controller (DPFC), in: European Conference on Power Electronics and Applications, Aalborg, September, 2007, pp. 1–4.
14. Z. Yuan, S.W.H. de Haan, J.B. Ferreira, D. Cvoric, A FACTS device: distributed power-flow controller (DPFC), IEEE Trans. Power Electron. 25 (October) (2010)2564–2572.
15. I.M. Martins, F.A. Silva, S.F. Pinto, I.E. Martins, Control of distributed power flow controllers using active power from homo polar line currents, in: IEEE 13th International Conference OPTIM 2012, Brasov, May, 2012, pp. 806–813.