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Comparison of Responses of the Pi and the Artificial Neural Network Controlled Closed Loop Dpfc Systems

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Abstract: Distributed power flow controls (DPFC) are generally used to improve the power quality of radial systems. The proposed work deals with comparison of the PI and the Artificial Neural Network 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 two bus radial test system and the results are presented. The results of comparative study are presented to show the improvement in dynamic response.

Key words: DPFC systems · Dynamic response · Voltage across · Transmission systems.

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. 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. A test dynamic DC link power balancing scheme for a PWM inverter system is given by Namho [11]. The concept of the DPFC is presented by Yuan [12]. Control of DPFC using active power from homo polar line current is given by Martin [13]. The scheme of the DPFC in a simple two-bus System is illustrated in the Fig.1.

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

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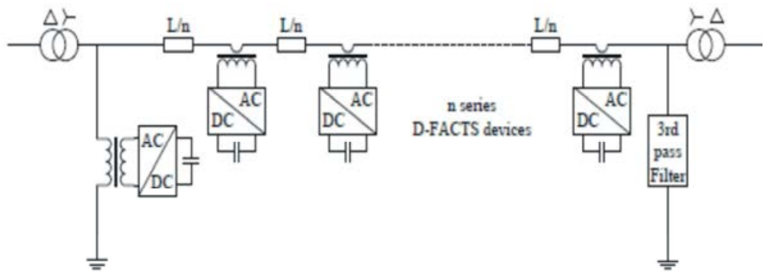

Fig. 1: Distributed power flow controller

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 Artificial Neural Network controllers. The objective of this paper is to study the improvement in dynamic response using Artificial Neural Network controller.

Principle of the DPFC

Introduction of the DPFC: Multiple individual converters cooperate together and compose the DPFC, as depicted in 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. 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:

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

wehere *n* is the order of the harmonic frequency and $_n$ *is* the angle between the current and voltage of the nth 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.

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.

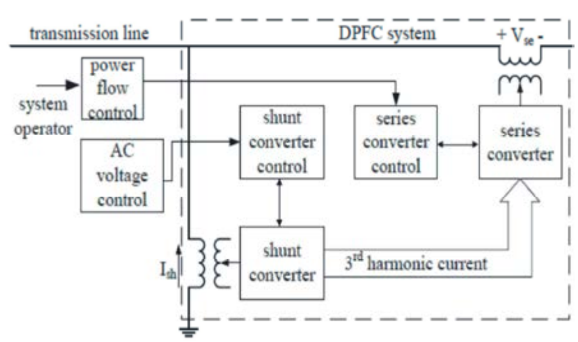

Fig. 2: Block diagram for the control of a DPFC

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.

RESULTS AND DISCUSSION

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 the Fig 3(a).

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

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 the Fig 3(c).

Closed Loop Controlled DPFC System with PI Controller: Closed loop reactive power controlled system using PI controller is shown in the Fig 4(a). The real and reactive powers are measured using PQ block.

The 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 the Fig 4(b). The peak value is around 9000V.

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 the Fig 4(c). The reactive power decreases and then reaches value of 4.8×10^4 VAR.

Closed Loop Controlled DPFC system with the ANN Controller: The Simulink model of the DPFC system with Artificial Neural Network Controller is shown in the Fig 5(a).

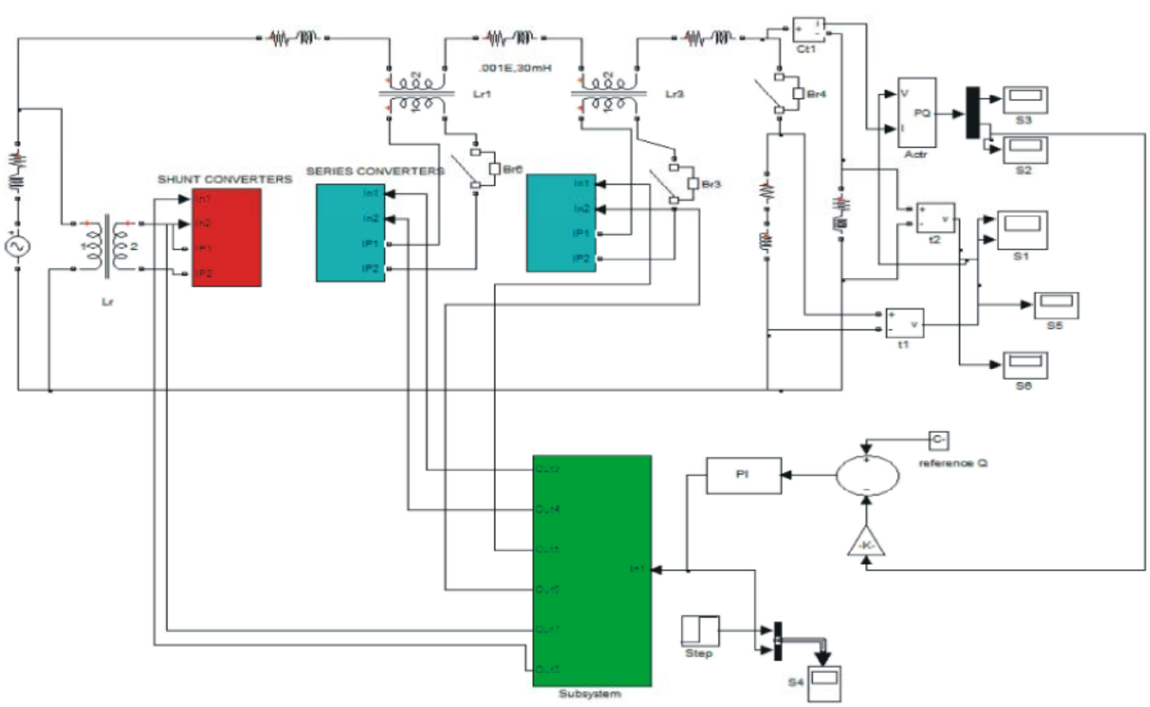

Fig. 3(a): Open loop controlled DPFC system

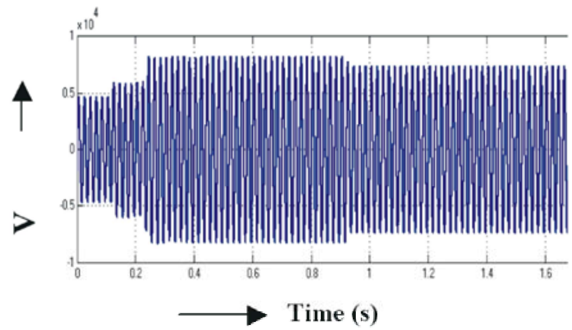

Fig. 3(b): Voltage at the Receiving end

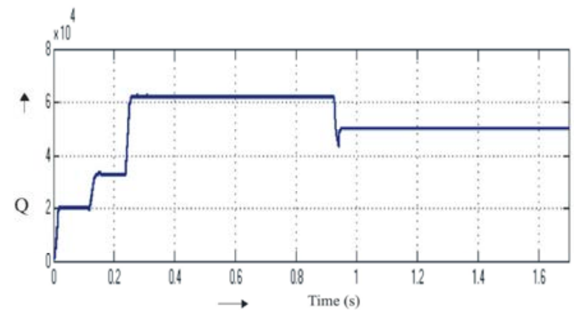

Fig. 3(c): Reactive power

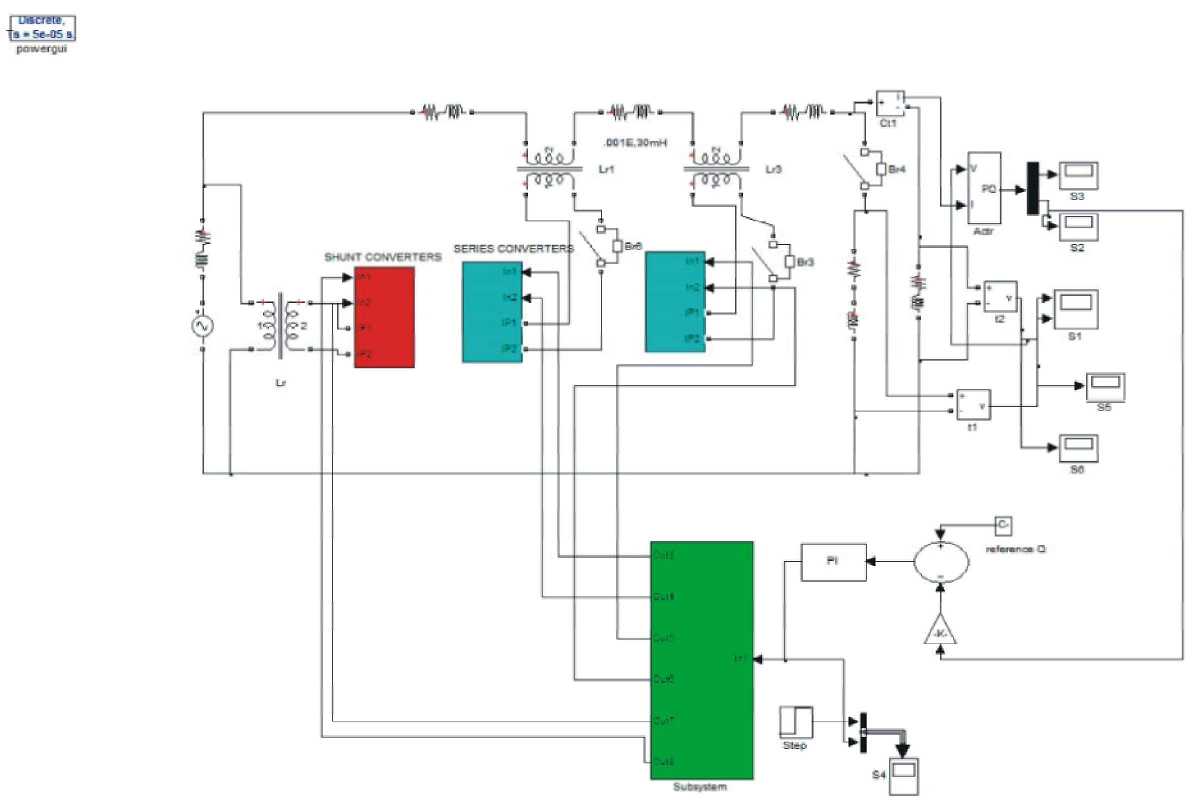

Fig. 4(a): Closed Loop System with the PI Controller

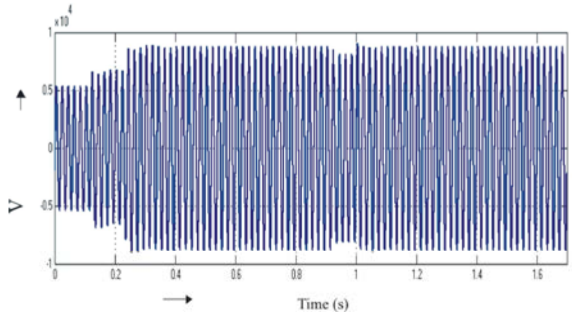

Fig. 4(b): Voltage at the receiving end

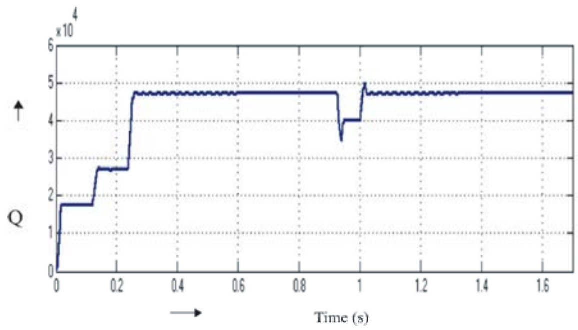

Fig. 4(c): Reactive power

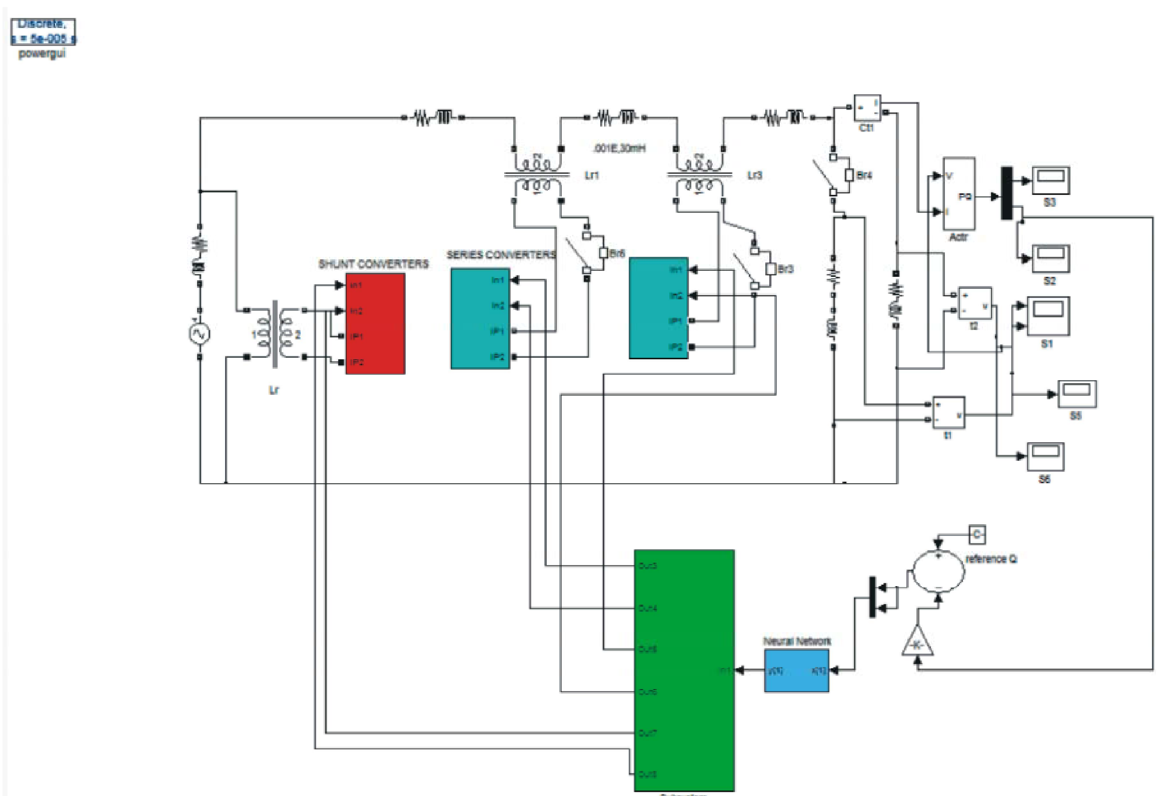

Fig. 5(a): The Simulink model of DPFC with ANN

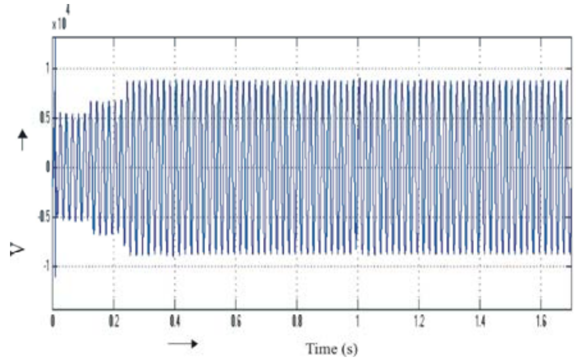

Fig. 5(b): Receiving end voltage Waveform

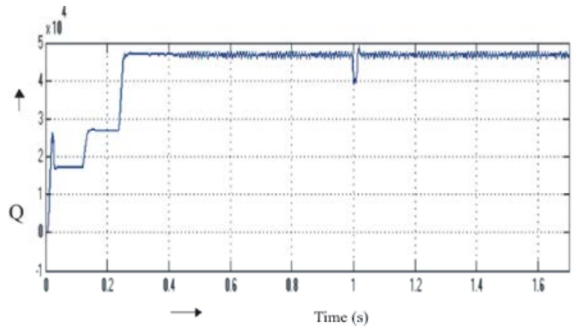

Fig. 5(c): Reactive Power Wave form.

Table 1: Comparison of PI & ANN 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
ANN	0.01	0.015	0.02	0.1

The reactive power is measured and it is compared with the reference power. The error and change in error are the inputs to the Artificial Neural Network Controller. The pulse width is adjusted to regulate the reactive power. Receiving end voltage is shown in the Fig. 5(b) & Reactive Power Wave form is shown in the Fig.5(c). the peak value of receiving end voltage is 0. 8×10^4 V. the reactive power is 4. 8×10^4VAR

The comparisons of various systems are given in Table 1.

The settling time is reduced from 1.1 to 0.02 seconds using ANN controller. The steady state error is reduced from 10V to 0.1V

The response indicates that Artificial Neural Network Controller produces smoother response. The reactive power reaches set value without any peak over shot.

CONCLUSION

DPFC systems controlled by PI and Artificial Neural Network 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. It was observed that DPFC is a better alternative than DVR toimprove the voltage quality of buses. The response of Artificial Neural Network Controller controlled system was found to be superior to the PI 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 two bus system using PI & Artificial Neural Network Controllers. The studies will be extended to higher bus system to improve the power quality.

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