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A Modern Distribution Power Flow Controller With A PID-Fuzzy Approach : Improves The Power Quality

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ABSTRACT- Technological improvements have led to an increase of nonlinear loads, which in turn has a significant impact on the quality of power transmission. It is imperative that the level of energy purity conveyed by a transmission line be elevated. The key factors influencing power transmission are line impedance, sending end voltage, and receiving end voltage. Harmonic currents are made by nonlinear loads, which can cause system resonance, capacitor overloading, less efficiency, and a change in the amount of the voltage. The Distributed Power Flow Controller (DPFC) is a recently developed Flexible AC Transmission System (FACTS) device that utilizes the distributed FACTS (D-FACTS) idea. Unlike the Unified Power Flow Controller (UPFC), which employs a single large-sized three-phase series converter, the DPFC incorporates several small-sized single-phase converters. There are a multitude of series converters available that offer redundancy, hence enhancing the dependability of the system. The Distributed Power Flow Controller (DPFC) possesses similar control functionalities to the Unified Power Flow Controller (UPFC), including the capacity to regulate line impedance, gearbox angle, and bus voltage. This article presents the theoretical framework and analysis of DPFC, along with the associated experimental findings. The suggested methodology enhances power quality by integrating a low-cost Distributed Power Flow Controller (DPFC) with an Infinite Bus system. The integration of fuzzy logic with standard DPFC is implemented with the aim of enhancing power quality. The control circuit is implemented via Fuzzy Logic Control methodology and afterwards simulated through the MATLAB – SIMULINK software.

Keywords: Distributed Power Flow Controller, Flexible AC Transmission System, Fuzzy Controller, PID Controller, Power Quality.

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1. INTRODUCTION

Over the course of the previous decade, power companies have placed significant emphasis on ensuring the integrity of electrical power. Power quality refers to the measurement of how the transmission and use of electrical power impact the operational efficiency of electrical devices, as perceived by the end user. A power quality issue refers to any departure from the expected values of voltage, current, or frequency that results in a disruption of power supply [1]. In order to enhance the quality of power for consumers, specialized power devices, such as the dynamic voltage restorer (DVR), are commonly utilized within the medium-to-low voltage range. Voltage sags, characterized by a fall in voltage, and voltage surges, characterized by over voltages, present a significant risk to delicate electrical equipment within electrical grids [2]. The disruptions are a result of several occurrences, such as a short circuit in the power grid, the surges of electrical current that occur when heavy machinery is activated, and the procedures involved in switching the power grid.[3].

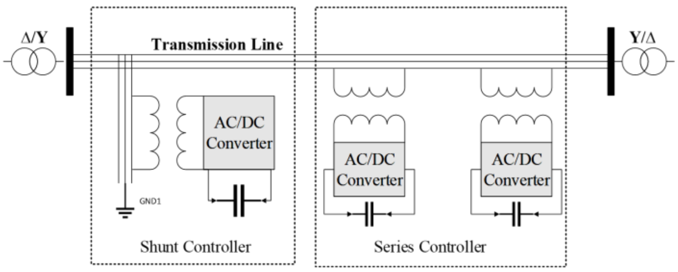

Figure 1. The DPFC Structure

In this article, a proposed device known as a distributed power flow controller. This device is employed to effectively address the fluctuations of voltage and current, hence enhancing power

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quality within a short time frame. Voltage variations were found at the receiving end for different loads. In order to ensure a consistent voltage at the receiving end, it is imperative that the current remains constant [5], [6].

The objective of the fuzzy logic controller is to ensure consistent maintenance of both load voltage and load current, while simultaneously retaining a stable voltage profile. In order to improve the compensation of reactive power, the acquired results were validated and integrated into the creation of a fuzzy rule foundation. Variations in the values of load resistance, inductance, and capacitance result in corresponding variations in the load voltage. The primary objective of a proposed controller is to effectively adjust the discharge angle of a converter in order to maintain a constant voltage at the receiving end [7] [8].

2. PROPOSED SCHEME

2.1 Using DPFC to improve power quality

One significant benefit of DPFC in comparison to UPFC is its ability to substitute the extensive DC-link with 3rd harmonic current for the purpose of active power exchange [9].

In the proposed system, the DC terminal of the shunt converter is connected to the AC terminal of the series converters by a transmission line, as opposed to a direct DC-link connection. The power exchange methodology employed by DPFC is grounded in the power theory of non-sinusoidal components. The representation of a non-sinusoidal voltage or current can be achieved by the utilization of the Fourier series [10] [11]. Voltage and current are fundamental components of active power. The *equation (1)* provided characterizes active power by exploiting the property of specific terms with different frequencies having an integral value of zero.

$$P = \sum_{m=0}^{\infty} Vm * Im * cos\emptyset m \quad (1)$$

The voltage at the mth harmonic, denoted as Vm, is related to the current Im and the phase angle φ. *Equation (1)* states that the active power remains independent across different frequency components. Hence, a shunt converter integrated within a DPFC possesses the capability to absorb active power at a specific frequency and afterwards generate output power at a different frequency. *Figure 2* illustrates the integration of a Distributed Power Flow Controller (DPFC) within transmission line. During the intervening period, the Y-transformer effectively captures the third harmonic component. The transmission line is responsible for carrying the third harmonic current, as it is injected into the neutral of the Y transformer by the output terminal of the shunt converter [12] [13].

The present mechanism regulates the direct current (DC) voltage across a series of interconnected capacitors. *Figure 2* illustrates the real power transfer occurring between the shunt & series converters. In order to facilitate the interchange of active power within a Distribution Power Flow Controller (DPFC), the utilization of the third harmonic is employed [14] [15]. The third-harmonic current is limited to the windings of the transformer. There is no need for a high-pass filter to be implemented at the receiving end of the system. The high-pass filter can be replaced by a cable connected between the winding of the transformer and the ground, through the utilization of the third harmonic. This cable facilitates the transmission of harmonic current that is grounded to the Earth [16][17].

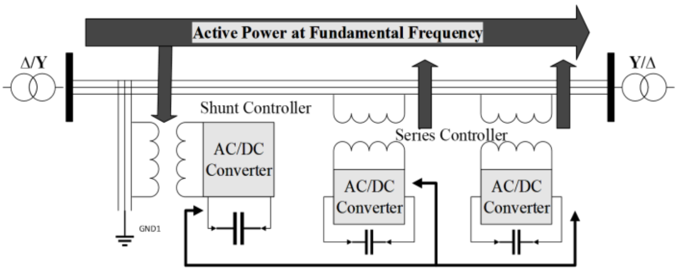

Figure 2. Active power exchange between DPFC

2.2 DPFC Control Strategies

As depicted in *figure 3*, the DPFC encompasses three distinct control techniques, including the central controller, series control, and shunt control.

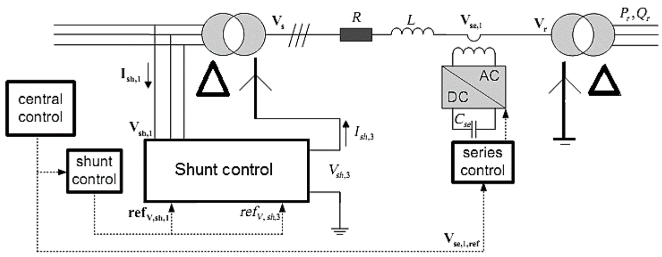

Figure 3. DPFC control structure

2.2.1 Central Control Approach

The generation of DPFC reference signals is performed by the central control system for both the shunt and series converters. The primary focus of this study pertains to Distributed Power Flow management (DPFC) jobs within the power system. As per the specified system requirements, the central control unit is responsible for supplying voltage-reference signals to the series converters and reactive current signals to the shunt converters [18] [19].

2.2.2 Series Control Approach

The controllers employed third-harmonic frequencies in order to regulate the dc voltage of the capacitor in their respective converters, as well as to produce series voltage at the fundamental frequency specified by the central control [20]. The presence of the fundamental and third harmonic frequency components in the current results in the inclusion of frequency components in the dc-capacitor voltage. There exist two approaches to reduce this wave [21]. An alternative approach involves the utilization of a dc capacitor with a higher capacitance value.

Every series controller is furnished with filters to produce fundamental and 3rd harmonic currents, correspondingly. This

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study utilized two single-phase phase lock loops (PLLs) to effectively get network frequency and phase information [22].

2.2.3 Shunt Control Approach

Which consists of a parallel connection between a single-phase converter and a 3-φ converter, arranged in a successive manner. The operation of the three-phase converter involves the consumption of active power from the grid at the fundamental frequency. Additionally, it involves the regulation of the direct current (DC) voltage of the capacitor positioned between the converter and the single-phase converter [23].

2.3.The DPFC Advantages [24] [25]

- The ability to exert a significant level of control. The DPFC, akin to the UPFC, have the capability to regulate many characteristics.
- The concept of high reliability refers to the ability of a system or organisation to consistently perform its intended functions without failure or error. This implies that in the event of a failure of one converter within a series, the other converters are capable of sustaining their operational functionality.[26]

3. RESULTS AND DISCUSSION

The proposed methodology is now being implemented and evaluated on a selection of established benchmark functions. It can be inferred that the proposed technique yields superior outcomes in comparison to alternative approaches. Therefore, the proposed strategy is utilized to enhance the power quality in a structured power system.

3.1 Diagram of the DPFC

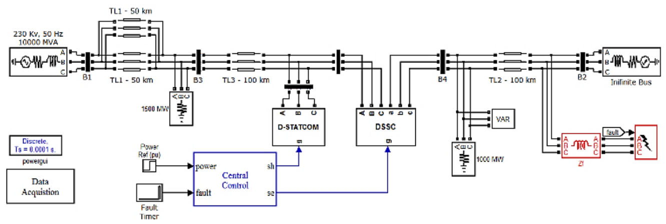

Figure 5. Simulink Diagram of DPFC

Figure 5 illustrates the entire depiction of the system under investigation. The proposed device is strategically located along a line. The converter (shunt) is electrically coupled to second line in a parallel configuration through the utilization of a 3-φ transformer. The series converters are thereafter connected along this line.

The depicted *figures (6 to 15)* illustrate the system's responses. There is a clear and observable discrepancy in performance between the scenarios in which the scheme is absent and present. This is visible as the system demonstrates a decrease in overshoot.

Figures 6 to 8 represents voltage sag, swell and fault are created in bus.

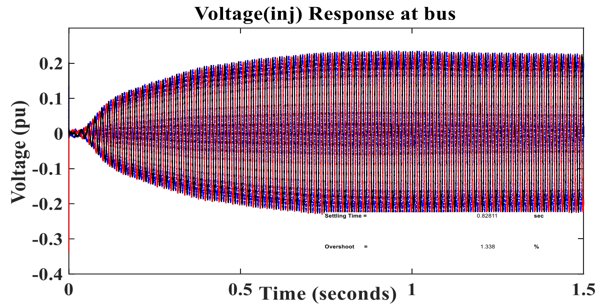

Figure 6. Voltage response created for fault at bus

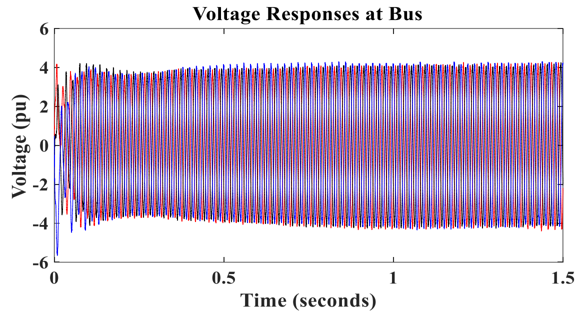

Figure 7. Voltage response created for sag at bus

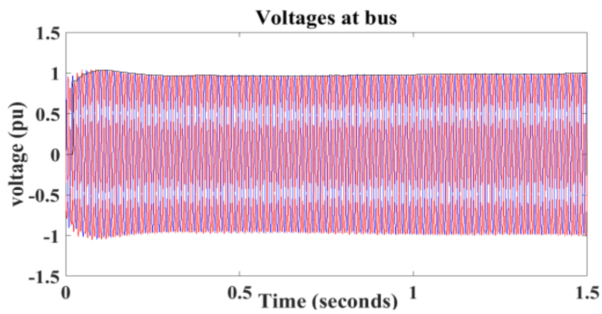

Figure 8. Voltage response created for swell at bus

Initially the power of 400 megawatts is given to the Distributed Power Flow Controller (DPFC), and the corresponding results are depicted in *figure 5*. The presented plot demonstrates that the DPFC system employing PID Control requires 0.8 seconds to attain the desired reference value, while the DPFC system utilizing Fuzzy Logic control achieves this in 0.6 seconds. The voltage and power associated with the bus connection at the Distributed Power Flow Controller is depicted in *figure 9-10.*

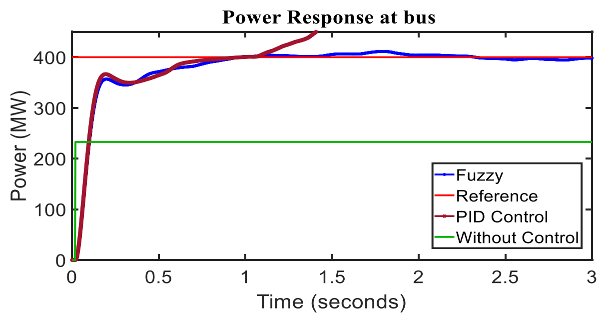

Figure 9. Power response of infinite bus

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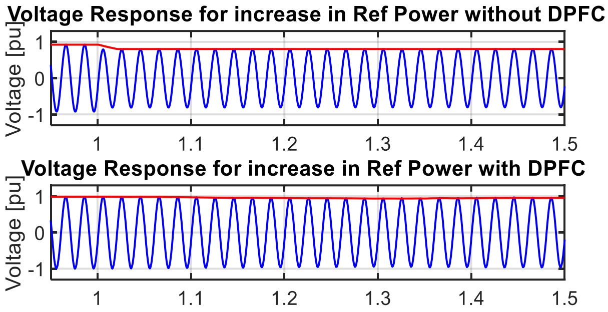

Figure 10. Voltage Response for power command 400 MW

Figures 11 illustrates the power response resulting from an increase in power from 400 to 500 MW. The results indicate that the settling time for PID Control is 2.37 seconds, while for Fuzzy Control it is 1.5 seconds.

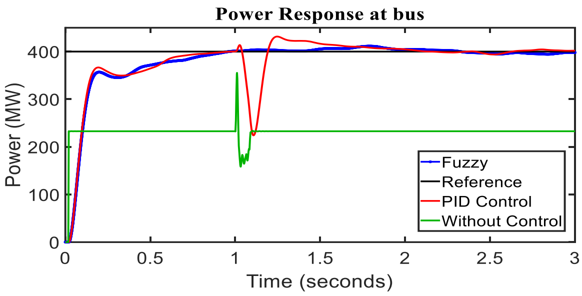

Figure 11. Power for Change in power command from 400MW to 500MW

Figures 12-13 illustrates the voltage sag and swell responses resulting from changes of power in *pu* values. The results indicate that the voltage changes with proposed approach and without technique.

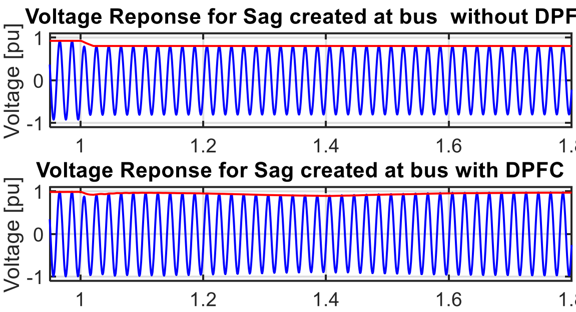

Figure 12: Mitigation of voltage sag with DPFC

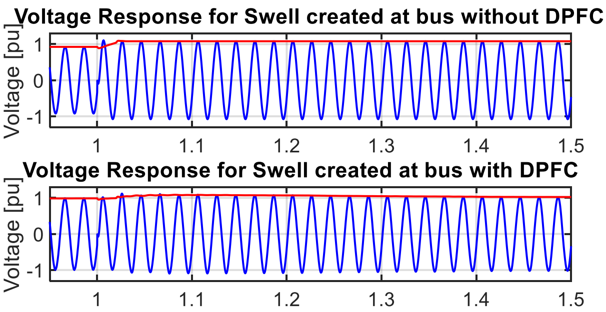

Figure 13. Mitigation of voltage swell with DPFC

Figures 14-15 illustrates the power response resulting from an increase in power from 400 to 500 MW with different loads such as inductive and capacitive. The results indicate that the settling time for PID Control is 2.45 and 2.39 seconds, while for Fuzzy Control it is 1.9 and 1.87seconds.

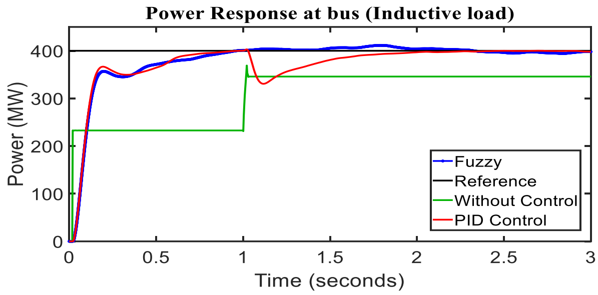

Figure 14. Power response with DPFC (Mitigation of sag)

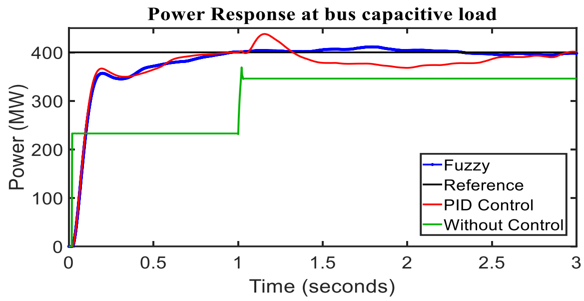

Figure 15. Power response with DPFC (Mitigation of sag)

Table I. Comparison of DPFC settling times across various topologies [16]

Load	Initial stage Power		Power		Voltage Sag		Voltage Swell	
	PID	Proposed	PID	Proposed	PID	Proposed	PID	Proposed
Voltage	2.85	2.03	2.05	1.06	2.032	1.52	2.41	1.98
Power	1.2	1.6	2.48	1.96	1.84	1.81	2.53	2.1

4. CONCLUSION

There exist a multitude of pragmatic methodologies for enhancing power quality within the power transmission system. This research paper introduces a novel FACTS device known as the distributed power flow controller (DPFC) and explores its effectiveness in mitigating voltage sag and swell occurrences. Distributed Power Flow Controller (DPFC) possesses several notable advantages. These include a heightened control capability, enhanced dependability, and reduced cost. The system being analyzed is an infinite-bus system that incorporates and omits the use of a Distributed Power Flow Controller (DPFC).

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