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Designing of Distributed Power Flow Controller

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Abstract- In modern power systems, there is huge demand in order to control the power stream actively. Power flow controlling devices (PFCDs) are required for such reason, on the grounds that the power flow over the lines is the nature consequence of the impedance of each line. Because of the control abilities of various sorts of PFCDs, the pattern is that mechanical PFCDs are gradually being supplanted by Power Electronics (PE) PFCDs. Among all PE PFCDs, the Unified Power Flow Controller (UPFC) is the most flexible device. The goal of this exploration is to build up another PFCD that offers a similar control capacity as the UPFC, at a decreased cost and with an expanded dependability. The new device, so-called Distributed Power Flow Controller (DPFC), is developed and exhibited in this exploration work. The DPFC is a further advancement of the UPFC. It has been demonstrated that the DPFC satisfies each of the three of the listed objectives. The DPFC disposes of the regular DC connect inside the UPFC, to empower the autonomous operation of the shunt and the series converter. The D-FACTS concept is utilized in the outline of the series converter. Multiple low-rating single-phase converters replace the high-rating three-phase series converter, which significantly reduces the cost and increases the reliability. The active power that used to exchange through the common DC link in the UPFC, is now transferred through the transmission line at the 3rd harmonic frequency.

Keywords:- Power flow controlling devices (PFCDs), Unified Power Flow Controller (UPFC), Distributed Power Flow Controller (DPFC), **Distributed Interline Power Flow Controller (DIPFC), Total Harmonic Distortion (THD) & Fuzzy Logic Controller.**

I. INTRODUCTION

Power flow is controlled by adjusting the parameters of a system, for example, voltage magnitude, and line impedance and transmission edge. The device that attempts to differ system parameters to control the power flow can be depicted as a Power Flow Controlling Device (PFCD). Contingent upon how devices are associated in systems, PFCDs can be partitioned into shunt devices, series devices, and consolidated devices (both in shunt and series with the system). A shunt device is a device that interfaces between the grid and the ground. Shunt devices produce or retain reactive power at the purpose of association accordingly controlling the voltage size. Since the transport voltage size must be changed inside specific points of confinement, controlling the power flow along these lines is restricted and shunt devices chiefly fill different needs. For instance, the voltage bolster given by a shunt device at the midpoint of a long transmission line can support the power transmission limit. Another use of shunt devices is to give reactive power locally, along these lines diminishing undesirable reactive power flow through the line and optimizing power losses. A device that is associated in arrangement with the transmission line is referred to as a 'series device'. Series devices impact the impedance of transmission lines. The standard is to change (decrease or increment) the line impedance by embeddings a reactor or capacitor. To make up for the inductive voltage drop, a capacitor can be embedded in the line to diminish the line impedance. By expanding the inductive impedance of the line, series devices are likewise used to confine the limit the through specific lines to avert overheating.

A combined device is a two-port device that is connected to the grid, both as a shunt and in a series, to enable active power exchange between the shunt and series parts. Combined devices are suitable for power flow control because they can simultaneously vary multiple system parameters, such as the transmission angle, the bus voltage magnitude and the line impedance. There is another term – Flexible AC Transmission System (FACTS) - that overlaps with the PE PFCDs. According to the IEEE, FACTS is defined as an ‘alternating current transmission system incorporating power electronic based and other static controllers to enhance controllability and increase power transfer capability’.

Normally, the High Voltage DC transmission (HVDC) and PE devices that are applied at the distribution network, such as a Dynamic Voltage Restorer (DVR), are also considered as FACTS controllers. Most of the FACTS controllers can be used for power flow control.

However, the HVDC and the DVR are out of the scope of the PFCD. According to the above considerations of different types of PFCDs, it can be concluded that PE combined PFCDs (also referred to as combined FACTS) have the best control capability among all PFCDs. They inherit the advantages of PE PFCDs and combined PFCDs, which is the fast adjustment of multiple system parameters.

The Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC) are currently the most powerful PFCDs; they can adjust all system parameters: line impedance, transmission angle, and bus voltage.

Although the UPFC and the IPFC have superior capability to control power flow, there is no commercial application currently. The main reasons are:

- The first concern with a combined FACTS is cost. To give voltage isolation, 3-phase high-voltage transformers are fundamental; moreover, the series configured transformers require a much higher rating to deal with blame voltages and streams. Secondly, as the FACTS devices are installed at different locations for different purposes, each of them is unique. As a result, each FACTS device requires custom design and manufacturing, which leads to a long building cycle and high cost. Lastly, a FACTS is a complex system, and requires a large area for installation and also well-trained engineers for maintenance.

- The second concern is possible failures in the combined FACTS. There are two major issues are considered: the reliability of the device itself and its influence on power system security. The combined FACTS are a complex system, which contains a large number of active and passive components. The large component number results that, without proper precautions, the combined FACTS have a bigger chance of failure than other PFCDs.

To develop a new power flow controlling device that has the following characteristics:

- Comparable performance as the combined FACTS device - the UPFC or IPFC.

Acceptable cost to electric utilities.

- Acceptable reliability for power systems.

The approach to develop such a device consists of the following steps:

- Analyze the UPFC and IPFC to determine their performance of power flow control.

- Find ways to reduce the cost and increase the reliability of combined FACTS devices.

II. UPFC & IPFC

Unified Power Flow Controller

The Unified Power Flow Controller (UPFC) is comprised of a STATCOM and a SSSC, coupled by means of a typical DC connection to permit bi-directional flow of active power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM. Each converter can independently generate (or) absorb reactive power at its own AC terminal. The two converters are operated from a DC link provided by a DC storage capacitor. The configuration of a UPFC is shown in Figure

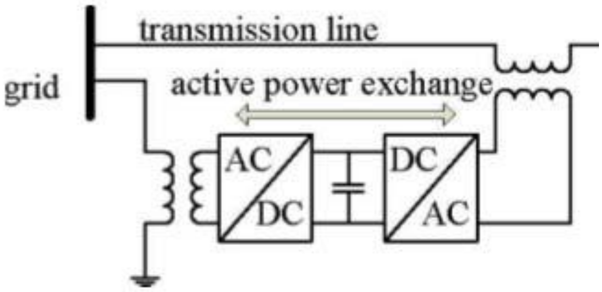


Fig 1. Unified Power Flow Controller

The series converter executes the main function of the UPFC by injecting a voltage, with controllable magnitude and phase angle, in series with the transmission line. It is controlled to provide concurrent active and reactive series compensation without an external energy source. The UPFC can have the functions:

- Voltage regulation by continuously varying in-phase/anti-phase voltage injection

that is similar to a tap-change transformer.

- Series reactive compensation by injecting a voltage that is in quadrature to the line current. Functionally, this is similar to an SSSC that can provide a controllable inductive and capacitive series compensation.

- Phase shifting by injecting a voltage with an angular relationship with respect to the bus voltage. By varying the magnitude of this voltage, the phase shift can be controlled. The listed functions of the UPFC can be executed simultaneously, which makes the UPFC the most powerful PFCD. However, due to high voltage VSCs and corresponding protection requirements, UPFC is quite expensive, which limits its practical application.

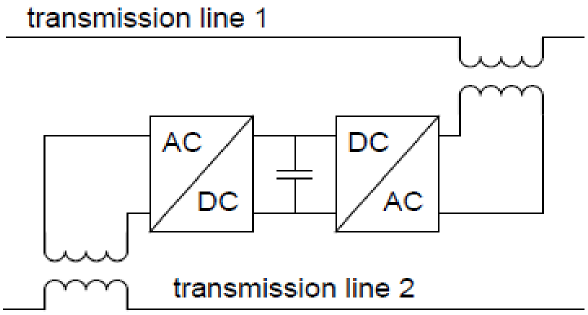


Fig 2. Interline Power Flow Controller

Interline Power Flow Controller

The Interline Power Flow Controller (IPFC) comprises of the (at least two) series converters in various transmission lines that are between associated by means of a typical DC interface, as appeared in Figure.

Not at all like different FACTS has devices that plan to control the parameter of a unity transmission line, the IPFC is considered for the compensation and control of power flow in a multi-line transmission system.

Each converter can provide series reactive compensation of its own line, just as an SSSC can. As the converters can exchange active power through their common DC link, the IPFC can also provide active compensation. This allows the IPFC to provide both active and reactive compensation for some of the lines and thereby optimize the utilization of the overall transmission system. Note that the active power supplied to one line is taken from the other lines. If required, the IPFC can be complemented with an additional shunt converter to provide active power from a suitable shunt bus.

A review was given of mechanical-and PE-based PFCDs. In view of high control ability, the PE-based consolidated PFCs, particularly UPFC and IPFC are reasonable for the future power system. Nonetheless, the UPFC and IPFC are not broadly connected by and by, because of their high cost and the defenselessness to disappointments. For the most part, the unwavering quality can be enhanced by reducing the quantity of components; however, this is impractical because of the complex topology of the UPFC and IPFC. To decrease the failure rate of the parts by choosing components with higher evaluations than should be expected or utilizing repetition at the segment or system levels are additionally alternatives.

Unfortunately, these solutions increment the underlying venture important, refuting any cost related advantages. In like manner, new methodologies are required with a specific end goal to build dependability and diminish cost of the UPFC and IPFC in the meantime. In the wake of concentrate the disappointment method of the consolidated FACTS devices, it is found that a typical DC connect between converters minimize the unwavering quality of a device, in light of the fact that a disappointment in one converter will pervade the entire device however the DC interface. By eliminate this DC interface, the converters inside the FACTS devices are worked autonomously, along these lines expanding their unwavering quality.

The elimination of the basic DC connect likewise permits the DSSC idea to be connected because of the repetition given by the disseminated arrangement converters. In addition, series converter dissemination minimizes cost in light of the fact that no high-voltage isolation and high power rating segments are required at the series part. By applying the two methodologies taking out the basic DC interface and circulating the series converter, the UPFC is additionally formed into another consolidated FACTS device: the Distributed Power Flow Controller (DPFC), as appeared in Figure

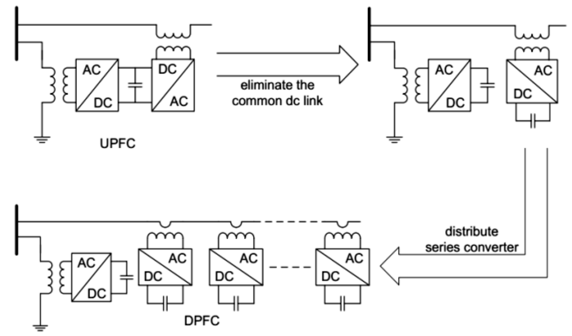


Fig 3. Flowchart from UPFC to DPFC

The operation of the DPFC is presented, followed by a steady-state analysis of the DPFC. During the analysis, the control ability and the impact of the DPFC on the network are investigated. The guideline and examination of another device that rises up out of the IPFC, the purported Distributed Interline Power Flow Controller (DIPFC), is likewise presented.

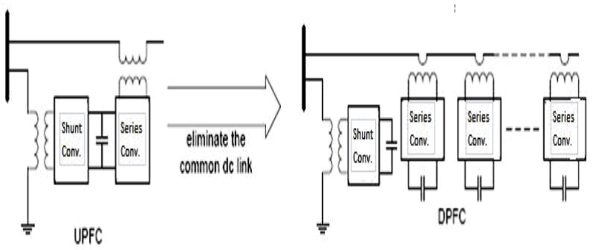


Fig. 4 conversion from UPFC to DPFC

Distributed Power Flow Controller (DPFC)

TOPOLOGY

By presenting the two methodologies sketched out in the past segment (elimination of the normal DC connection and dissemination of the series converter) into the UPFC, the DPFC is accomplished. Comparative as the UPFC, the DPFC comprises of shunt and series associated converters.

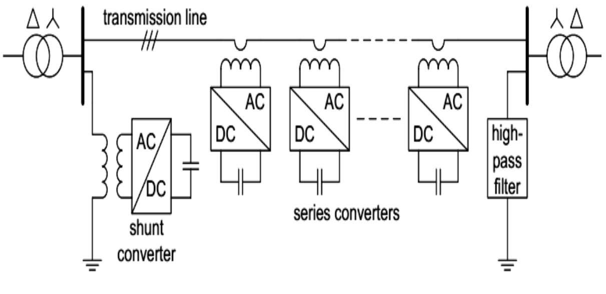


Fig. 5 DPFC configuration

The shunt converter is comparative as a STATCOM, while the series converter utilizes the DSSC idea, which is to utilize different single-phase converters instead of one three-phase converter. Every converter inside the DPFC is autonomous and has its own DC capacitor to give the required DC voltage. The arrangement of the DPFC is appeared in Figure

As shown, other than the key component - shunt and series converters, a DPFC likewise requires a high pass filter that is shunt associated with the opposite side of the transmission line and a Star-Delta transformer on each side of the line. The explanation behind these additional parts will be clarified later. The interesting control ability of the UPFC is given by the consecutive association between the shunt and series converters, which enables the active power to openly exchange. To insure the DPFC has similar control ability as the UPFC, a strategy that permits active power exchange between converters with a eliminated DC connection is required.

DPFC Operating Principle

Active Power Exchange With Eliminated DC Link

Within the DPFC, the transmission line displays a typical association between the AC ports of the shunt and the series converters. Along these lines, it is conceivable to exchange active power through the AC ports. The technique is based on power hypothesis of non-sinusoidal segments. As per the Fourier analysis, non-sinusoidal voltage and current can be communicated as the whole of sinusoidal capacities in various frequencies with various amplitudes. The active power coming about because of this non-sinusoidal voltage and current is characterized as the mean estimation of the result of voltage and current. Since the integrals of the entire cross result of terms with various frequencies are zero, the active power can be communicated by:

$$P = \sum_{i=1}^{\infty} V_i \, I_i Cos\phi_i$$

Where Vi and Ii are the voltage and current at the harmonic frequency separately, and Ø is the comparing angle between the voltage and current. Condition demonstrates that the active powers at various frequencies are autonomous from each other and the voltage or current at one frequency has no impact on the active power at different frequencies.

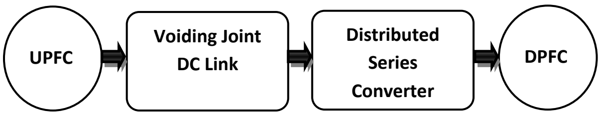


Fig. 6 Diagrams from Unified Power Flow Controller to Distributed Power Flow Controller

The independence of the active power at various frequencies gives the likelihood that a converter without a power source can create active power at one frequency and retain this power from different frequencies. By applying this strategy to the DPFC, the shunt converter can retain active power from the grid at the basic frequency and infuse the power back at a harmonic frequency. This harmonic active power flows through a transmission line outfitted with series converters. According to the amount of required active power at the fundamental frequency, the DPFC series converters generate a voltage at the harmonic frequency, thereby absorbing the active power from harmonic components. Neglecting losses, the active power generated at the fundamental frequency is equal to the power absorbed at the harmonic frequency. For a better understanding, Figure indicates how the active power is exchanged between the shunt and the series converters in the DPFC system.

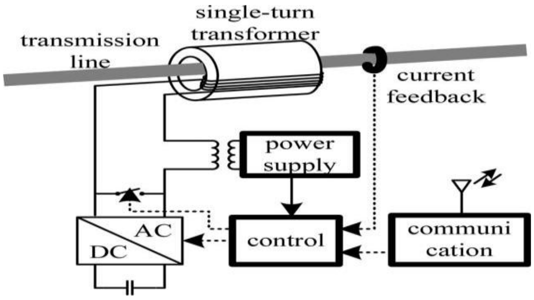


Fig. 7 D-FACTS unit configuration

The high-pass filter inside the DPFC obstructs the essential frequency segments and enables the harmonic segments to pass, in this way giving an arrival way to the harmonic parts. The shunt and series converters, the high pass filter and the ground form a closed loop for the harmonic current.

DPFC Control

To control multiple converters, a DPFC consists of three types of controllers: central control, shunt control and series control, as shown in Figure

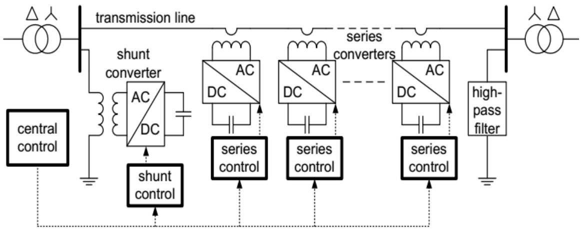


Fig. 8 DPFC Control block diagram

The shunt and series control are localized controllers and are responsible for maintaining their own converters' parameters. The central control takes care of the DPFC functions at the power system level. The function of each controller is listed:

Central Control- The central control generates the reference signals for both the shunt and series converters of the DPFC. Its control function depends on the specifics of the DPFC application at the power system level, such as power flow control, low frequency power oscillation damping and balancing of asymmetrical components. According to the system requirements, the central control gives cor- responding voltage reference signals for the series converters and reactive current signal for the shunt converter. All the reference signals generated by the central control concern the fundamental frequency components.

Series Control- Each series converter has its own series control. The controller is used to maintain the capacitor DC voltage of its own converter, by using 3rd harmonic frequency components, in addition to generating series voltage at the fundamental frequency as required by the central control.

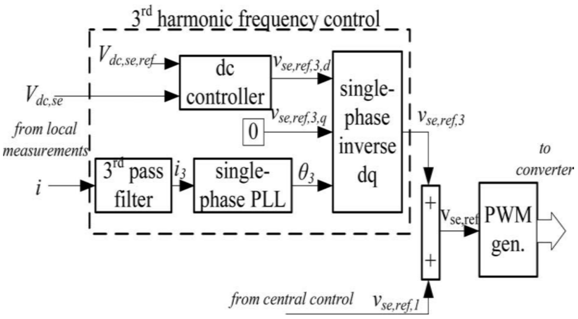


Fig. 9 Block diagram of the series converter control.

Shunt Control: The objective of the shunt control is to inject a constant 3rd harmonic current into the line to supply active power for the series converters.At the same time, it maintains the capacitor DC voltage of the shunt converter at a constant value by absorbing active power from the grid at the fundamental frequency and injecting the required reactive current at the fundamental frequency into the grid.

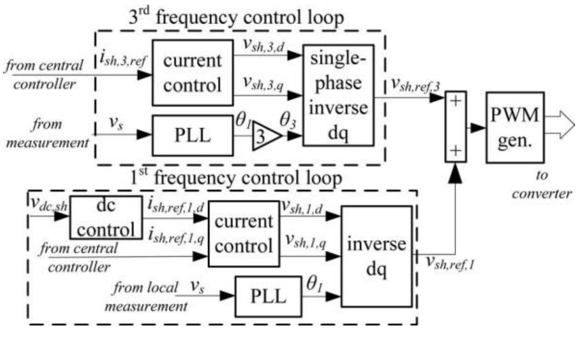


Fig. 10 Block diagram of the shunt converter control

III. PROPOSED METHODOLOGY

The proposed work in the IEEE 6 BUS system is interconnected with 5 three phase voltage sources and one RL load with DPFC associated in line where the load is associated and is synchronized according to voltage and frequency. Subsystems are given in each line independently and shunt pulses and series pulses are produced by series and shunt control separately. General extensions are associated at the load side. The harmonics are recreated or made by the RL load itself. No outer blame conditions are taken. THD is about 20.69% without compensation. For power flow enhancement & harmonic mitigation DPFC is designed for the above mentioned problem and the proposed control strategy using FLC is implemented for the generation of both reference voltage for series inverter and the reference current for shunt inverter which provides an effective mitigation of harmonics. The effectiveness of proposed FLC based DPFC is checked by comparing the simulation results with the conventional PI controller based DPFC.

Control Strategy

In this research another device DPFC is intended for power flow issues relief and its execution is improved by building up a novel control technique utilizing FLC. The advantages of FLC over the ordinary controller are that FLC even work without a flawless scientific model. Also FLC is capable of handling nonlinearities and is more robust compared to conventional PI controller which also improves the performances of DPFC. The control strategy used in this work is described below:

Conventional Pi Control Strategy

In this sort of system both shunt and series controllers utilize PI controllers. In series controller, a consistent esteem and one output from the subsystem square of each line is added and sustained to PI controller, whose output is multiplexed with a constant value upto a functional block. Here, 2nd order filters of cutoff frequency 150 hz are utilized independently for each branch whose output is given to phase bolt circle hinder, whose output is demuxed and duplicated with output of practical piece. PWM generators are utilized toward the finish of each line hinder whose outputs are delayed by a unit delay and bolstered as series pulses to the subsystems. The value of Proportional gain Kp =2 and Integral gain Ki=12 in series controllers. And in shunt controllers abc to dq transformation is used whose outputs are send to PI controllers along with Timers and Adders. The output of PI controller is in form of current references which is then applied to another set of PI controller along with adder and constant values. PWM generatorsis used at the output of controller and output is in the form of shunt pulses to universal bridge with capacitors. The value of Proportional gain Kp=25 and Integral gain Ki=11 in shunt controllers.

With FLC Block

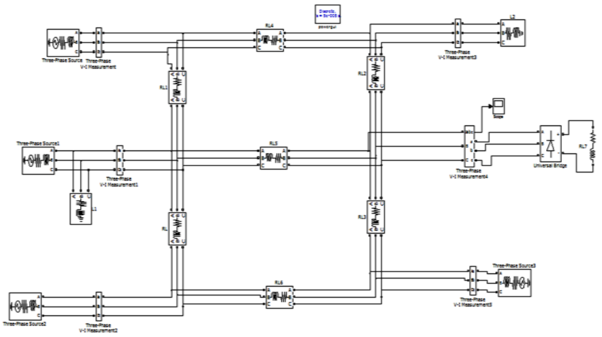
In this control technique series control is kept same as with the customary PI control system. Yet, in the shunt control Fuzzy controller is kept set up of one PI controller, other PI controllers are kept same as in regular system. The output of this Fuzzy controller is delayed by a unit delay and acts as a current references pulse which is then fed to other set PI controller as in the conventional control strategy and output is taken from PWM generators in the form of shunt pulses which are fed to the universal bridge connected with a capacitor at shunt side. Value of Proportional gain Kp=12 and Integral gain Ki=2 in PI controllers used with fuzzy logic controller.

IV. SIMULATION RESULTS

The proposed system is executed by coordinating IEEE 6 transport system and furthermore synchronized concerning voltage and frequency utilizing MATLAB Simulink. The viability of the proposed system is approved by considering three distinct cases. The simulation of Power flow problem problems and the implementation of DPFC along with proposed FLC and conventional PI controller are shown by the subsequent cases.

Uncompensated System

In the proposed system, 5 three phase voltage sources are chosen in IEEE 6bus system. The nonlinear load is associated which makes load voltage harmonics in a grid and is indicated Fig. The Total Harmonic Distortion (THD) in the source voltage of an uncompensated system is shown by the FFT analysis in Fig



Fig, 11 Uncompensated IEEE 6bus system with RL load

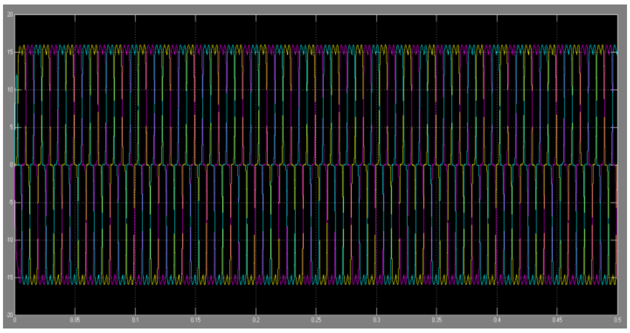


Fig. 12 waveform for harmonics due to Non Linear load

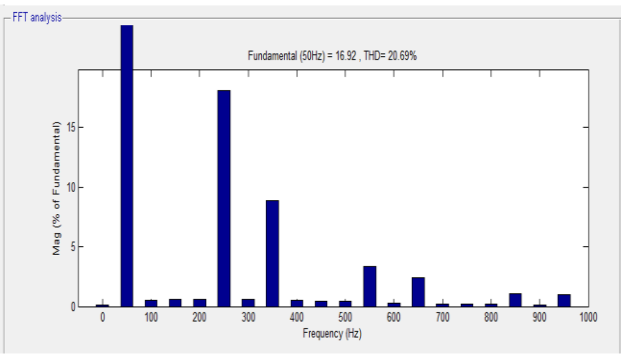


Fig. 13 THD of Source voltage of Uncompensated system

DPFC With PI Controller

The custom power device DPFC is executed with customary PI controller to remunerate harmonics in the proposed system. The estimations of P and I are picked by experimentation technique proper for compensation. The simulation results for load voltage is shown in fig .The THD spectrum for load voltage is also shown in Fig. Here proportional gain Kp= 25 and integral gain Ki=11 for shunt controller, and Kp=2 & Ki=12 for series controller.

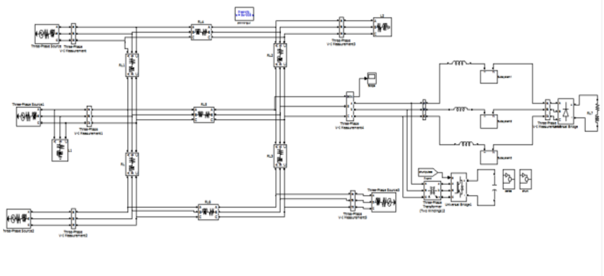


Fig. 14 three phase IEEE 6 bus system with DPFC including PI controller

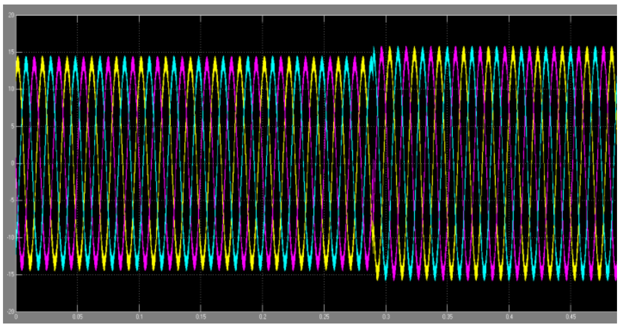


Fig. 15 voltage waveform of compensated system with PI controller

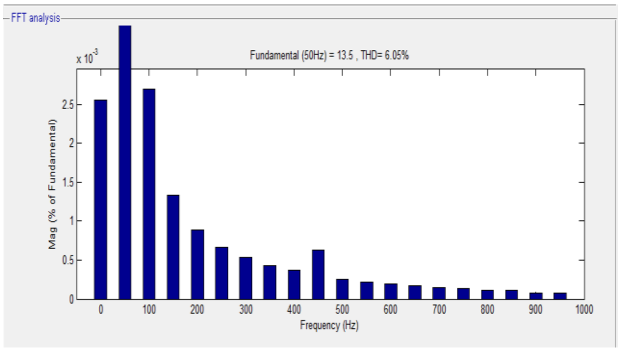


Fig. 16 THD level of voltage with PI controller

DPFC With Fuzzy Logic Controller

The point by point Simulation of the Proposed DPFC with Fuzzy Logic Controller is appeared in Fig and the plan qualities are additionally appeared in Table 1. The proposed Fuzzy Logic controller based DPFC is put into service to compensate voltage harmonics. The simulation end results are shown in Fig and Fig. The THD for voltage is also shown in next Fig

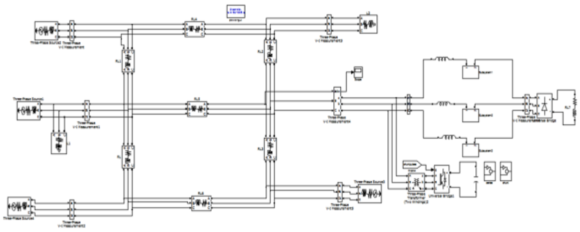


Fig. 17 DPFC with fuzzy logic controller

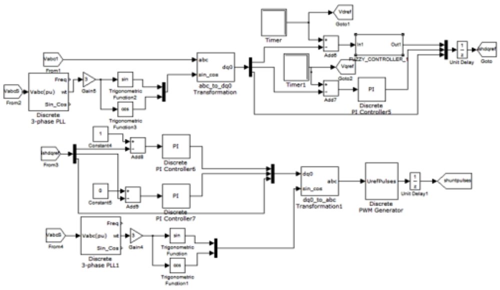


Fig. 18 shunt control with fuzzy logic controller

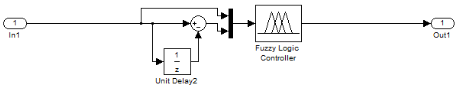


Fig. 19 fuzzy logic controller

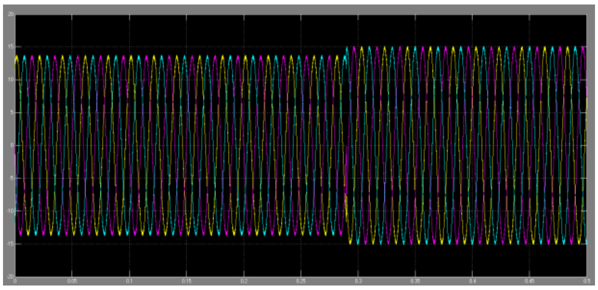


Fig. 20 voltage waveform for compensated system with Fuzzy logic controller

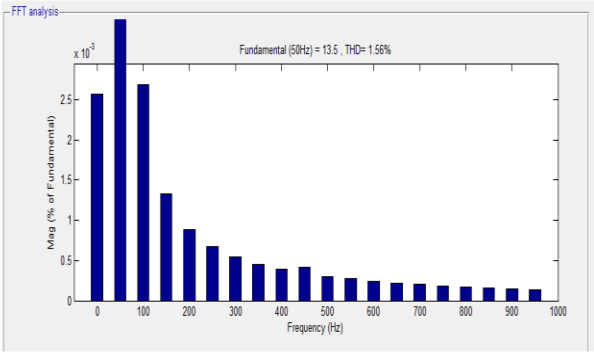


Fig. 21 THD level of voltage with fuzzy logic controller

Performance Comparison

The proposed Fuzzy controlled DPFC for mitigating voltage source harmonics is actualized in a three phase IEEE 6 transport system. The accomplishment of the proposed system is demonstrated by contrasting the proposed fluffy control methodology and regular PI controller. The performance comparison results of DPFC with PI and Fuzzy logic controller is shown in Table 1.

System	**Source Current THD**
Uncompensated System	20.69%
DPFC with PI Controller	6.05%
DPFC with Fuzzy Logic Controller	1.56%

Table 1 Performance comparison of different controller

By comparing the THD of load voltage, DPFC with PI Controller the source voltage harmonics achieved is 6.05% and the UPQC with Fuzzy Logic Controller the source voltage harmonics achieved is 1.56%., which shows the proposed FLC based DPFC offers effective and proficient compensation for harmonics. Thus the performance of DPFC is greatly improved by reducing the amount of harmonics contained in supply voltage and is kept within acceptable IEEE norms. The Power flow problem voltage harmonics are simulated using MATLAB in a three phase power system. The fuzzy controlled DPFC is implemented for Power flow enhancement to diminish supply voltage harmonics and the simulation results are also compared with conventional PI controller. From the simulation results, the PI controlled DPFC mitigates voltage harmonics but the THD level is still not very less i.e. 6.05%. The proposed Fuzzy Logic Controlled DPFC reduces THD level upto 1.56 %.

Thus the proposed Fuzzy controlled DPFC is successfully proven as an efficient device through its outstanding performance for mitigating supply harmonics in a three phase IEEE 6bus power system. There is a huge interest for power flow control in present day power systems. The pattern is that mechanical Power Flow Controlling Devices (PFCDs) are gradually being supplanted by Power Electronics (PE) PFCDs. Among all PE PFCDs, the Unified Power Flow Controller (UPFC) is the most versatile device. However, the UPFC is not widely applied in the utility grid due to its high cost and relatively low reliability.

V. CONCLUSION & FUTURE SCOPE

This work spot lights the harmonic mitigation technique in IEEE 6bus system. The Power flow issue voltage harmonics are simulated utilizing MATLAB in a three phase power system. The fuzzy controlled DPFC is actualized for Power flow enhancement to reduce supply voltage harmonics and the simulation outcome is additionally contrasted and ordinary PI controller. From the simulation outcome, the PI controlled DPFC mitigates voltage harmonics but the THD level is still not very low i.e. 6.05%. The proposed Fuzzy Logic Controlled DPFC reduces THD level up to 1.56 %. In this way the proposed Fuzzy controlled DPFC is effectively demonstrated as a proficient device through its exceptional execution for moderating supply harmonics in a three phase IEEE 6bus power system. There is a substantial interest for power flow control in current power systems. The pattern is that mechanical Power Flow Controlling Devices (PFCDs) are gradually being supplanted by Power Electronics (PE) PFCDs. Among all PE PFCDs, the Unified Power Flow Controller (UPFC) is the most flexible device. Be that as it may, the UPFC is not generally connected in the utility grid because of its high cost and moderately low dependability.

The research demonstrates that the DPFC has a lower cost and ought to be more solid than the UPFC. In any case, the DPFC likewise realizes some new issues. The issues that ought to be addressed by future research are: Communications, Weight Reduction of the Series Converter, 3rd Harmonic Current Management & Centralized Control For Multiple DPFC

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