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Simulation and Analysis of Distributed Interline Power Flow Controller (DIPFC)

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Abstract:- Flexible AC Transmission Systems (FACTS) devices are used to control power flow in the transmission lines. This paper describes the concept of power flow control in transmission line by Distributed FACTS (D-FACTS), called Distributed Interline Power Flow Controller (DIPFC). The DIPFC is taken from the Unified Power Flow Controller (UPFC). The DIPFC can be considered as to be eliminated common dc link UPFC. Same as UPFC, DIPFC also having series and shunt converters. DIPFC having multiple small sizes single phase three series converters and single three phase shunt converter. The three single phase series converters are located to connecting the two transmission lines to moderate the voltage sag and swell as to improve the power quality problems. In DIPFC the operation of both the converters are independent. The active power substitute between the shunt and series converters, which is throughout the universal dc link in the UPFC, now the active power throughout the transmission lines at the third-harmonic frequency. Modelling and principle of operation is presented in this paper. Distributed Interline Power Flow Controller (DIPFC) is located connecting the two parallel transmission lines of infinite bus. The case studies are simulated in MATLAB/ Simulink and the results validate the DIPFC has ability to improve the power quality.

Keywords:- FACTS, Power Quality, Sag and Swell improvement, Distributed Power Flow Controller (DPFC), Distributed Interline Power Flow Controller (DIPFC)

I. INTRODUCTION

In the last decade, the electrical power quality issue has been the main concern of the power companies [1]. Power quality is defined as the index which both the delivery and consumption of electric power affect on the performance of electrical apparatus [2]. From a customer point of view, a power quality problem can be defined as any problem is manifested on voltage, current, or frequency deviation that results in power failure [3]. The power electronics progressive, in particular in flexible alternating-current transmission system (FACTS) and convention power devices, affect power quality improvement [4]. Generally, custom power devices, e.g., dynamic voltage restorer (DVR)[5], are used in medium-to-low voltage levels to improve customer power quality [6]. Most serious threats for sensitive equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage). These disturbances occur due to some events, e.g., short circuit in the grid, inrush currents involved with the starting of large machines, or switching operations in the grid. The FACTS devices, such as unified power flow controller (UPFC) and synchronous static compensator (STAT-COM), are used to improve the disturbance and improve the power system quality and reliability [8]. In this paper, a distributed power flow controller, introduced in as a new FACTS device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC structure is derived from the UPFC structure that is included one shunt converter and several small independent series converters, as shown in Fig. 1 [9].

The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude [10]. The Interline Power Flow Controller (IPFC) is comprised of a number of SSSCs with the common link at their DC sides. The IPFC provides series compensation for multiple lines. This compensation can be both active and reactive. The reactive power required for the series compensation is generated by the series converter itself and the required active power is exchanged from other converters Similar to the DPFC, the DIPFC consists of multiple single-phase series converters, which are independent from each other. As the DIPFC is a power flow control solution for multiple transmission lines, the series converters are installed in different line.

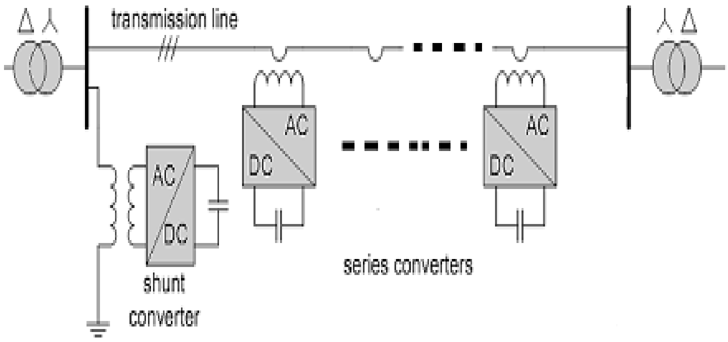

Fig. 1. The DPFC Structure

II. DPFC PRINCIPLE

In comparison with UPFC, the main advantage offered by DPFC is eliminating the enormous amount of DC-link and instate using 3rd harmonic current to active power exchange. In the following subsections, the DPFC basic concepts are explained.

A. Eliminate DC Link and Power Exchange

Inside the DPFC, the transmission line is used as to connection between the DC terminal of shunt converter and the AC terminal of series converters, instead of direct connection using DC-link for power exchange between converters. The strategy for power trade in DIPFC depends on power hypothesis of non-sinusoidal parts. In view of Fourier arrangement, a non-sinusoidal voltage or current can be existing as the entirety of sinusoidal segments at diverse frequencies. The result of voltage and current segments gives the dynamic force. As the basic of a few terms with diverse frequencies are zero, so the active power comparison is as take after:

$$P = \sum_{i=1}^{\infty} V_i I_i \cos \varphi i \qquad (1)$$

Where V_i and I_i are the voltage and current at the i^{th} harmonic, respectively, and $\varphi_i$is the angle between the voltage and current at the same frequency. Equation (1) expresses the active power at different frequency components is independent. Based on this fact, a shunt converter in DPFC can assimilate the active power in one frequency and creates output power in another frequency. Assume a DPFC is placed in a transmission line of a two-bus system, as shown in Fig.1. While the power supply generates the active power, the shunt converter has the capability to absorb power in major frequency of current. In the mean time, the third harmonic part is trapped in Y-Δtransformer. Output terminal of the shunt converter injects the third harmonics current into the impartial of Δ-Y transformer (Fig.3). Thus, the consonant current moves through the transmission. This harmonic current controls the DC voltage of series capacitors. Fig. 2 delineates how the active power is traded between the shunt and series converters in the DPFC. The third harmonic is chosen to trade the active power in the DPFC and a high-pass filter is required to make a closed loop for the harmonic current. The third-harmonic current is trapped in Δ-winding of transformer. Hence, no need to use the high-pass filter at the receiving-end of the system. In other words, by using the third-harmonic, the high-pass filter can be replaced with a cable connected between Δ-winding of transformer and ground. This cable routes the harmonic current to ground.

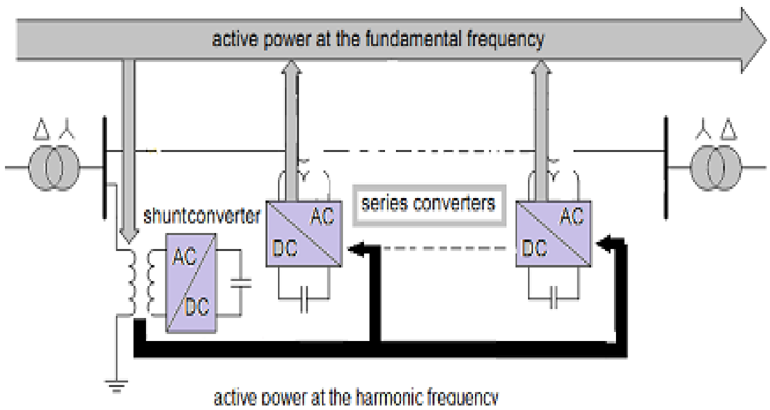

Fig. 2.Active power exchange between DPFC converters

B. The DPFC Advantages

The DPFC in examination with UPFC has a few points of interest, as takes after:

• High Control Capability the DPFC similar to UPFC can control all parameters of transmission network, for example, line impedance, transmission angle, and bus voltage magnitude.

• High Reliability The series converters excess expands the DPFC dependability during converters operation [10]. That is to say, if one of series converters comes up short, the others can keep on working.

• Low Cost the single-stage series converters rating are lower than one three-phase converter. Furthermore, the series converters do not need any high voltage isolation in transmission line connecting; single-turn transformers can be used to hang the series converters. Reference [9] reported a case study to explore the feasibility of the DPFC, where a UPFS is replaced with a DPFC in the Korea electric power corporation (KEPCO). To achieve the same UPFC control capability, the DPFC development requires less material [9].

III. DPFC CONTROL

The DPFC has three control methodologies: central controller, series control, and shunt control, as appeared in Fig. 3.

A. Central Control

This controller deals with every one of the series and shunt controllers and sends reference signs to them two.

B. Series Control

Every single-stage converter has its own particular series control through the line. The controller inputs are series capacitor voltages, line current, and series voltage reference in the dq frame. The block diagram of the series converters in Mat lab/Simulink environment is demonstrated in Fig. 4.

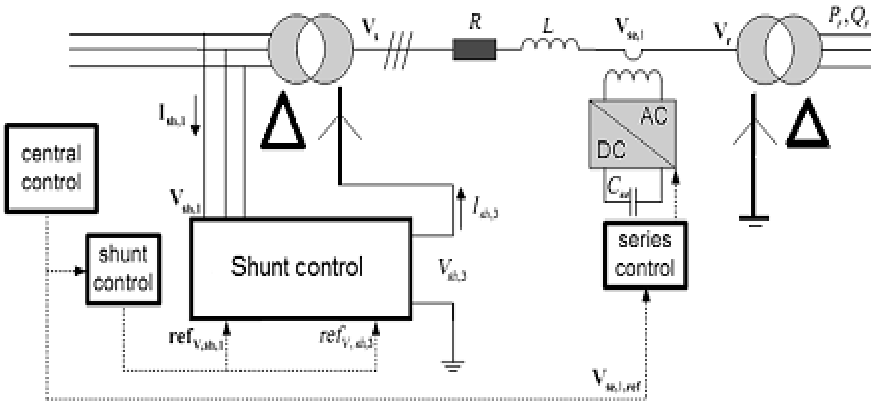

Fig. 3. DPFC control structure

Any series controller has a low-pass and a third pass filter to make central and third harmonics current, individually. Two single-phase lock loop (PLL) are utilized to take frequency and phase data from system [11]. The block diagram of series controller in Matlab/Simulink is shown in Fig. 5. The PWM-Generator block manages switching processes.

C. Shunt Control

The shunt converter incorporates a three-phase converter joined consecutive to a single-phase converter. The three-phase converter absorbs active power from grid at basic frequency and controls the dc voltage of capacitor between this converter and single-phase one. Other task of the shunt converter is to inject constant third-harmonic current into lines through the neutral cable of Δ-Y transformer.

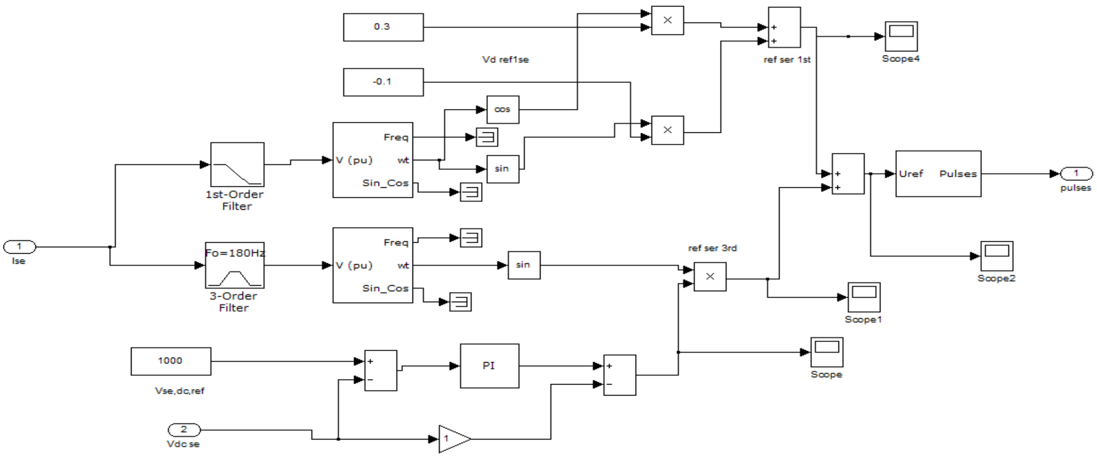

Fig. 5. Block diagram of series control structure in Matlab/Simulink

Each converter has its own controller at different frequency operation (fundamental and third-harmonic frequency). The shunt control structure block diagram is shown in Fig. 6

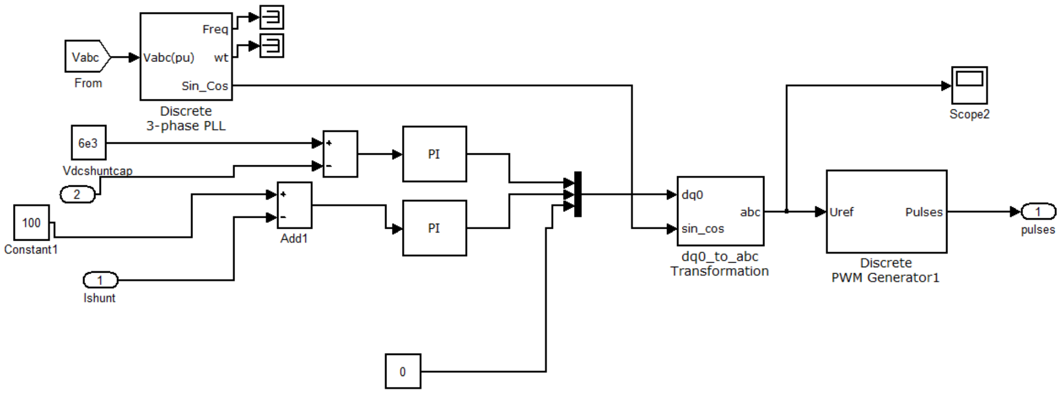

Fig. 6. The shunt control configuration: (a) for fundamental frequency

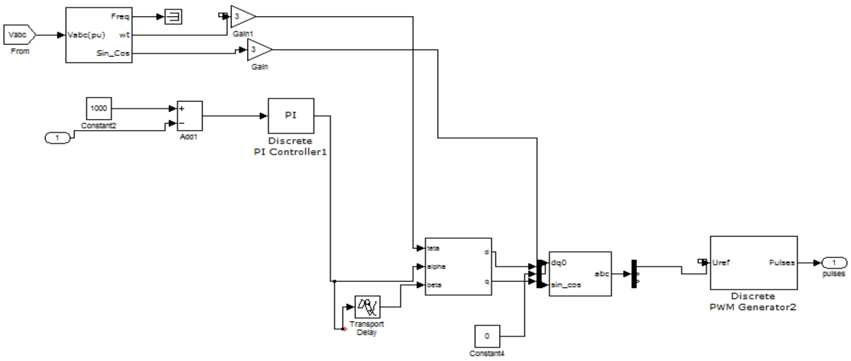

Fig. 6.1. The shunt control configuration: (b) for third-harmonic frequency

IV. DISTRIBUTED INTERLINE POWER FLOW CONTROLLER

The Distributed Interline Power Flow Controller (DIPFC) consists of the two (or more) series converters in different transmission lines that are inter-connected via a common DC link, as shown in Figure 7. Unlike other FACTS devices that aim to control the parameter of a single transmission line, the IPFC is conceived 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 DIPFC can also provide active compensation.

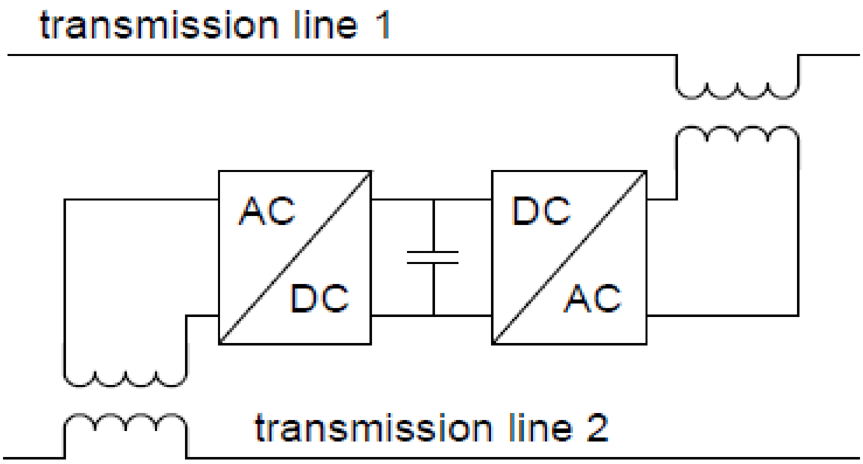

Figure 7: IPFC configuration

Similar to the DPFC, the DIPFC consists of multiple single-phase series converters, which are independent from each other. As the DIPFC is a power flow control solution for multiple transmission lines, the series converters are installed in different lines. The DIPFC can also include shunt converters, but these are not compulsory. The single line diagram of a DIPFC is shown in Figure 8.There is an exchange of active power between the DIPFC converters and this active power is exchanged in the same transmission line at the 3rd harmonic frequency. If the DIPFC is without a shunt converter, the series converters in one transmission line will exchange active power with the converters in the other lines. If there is a shunt converter in the DIPFC, the shunt converter will supply the active power for each series converter.

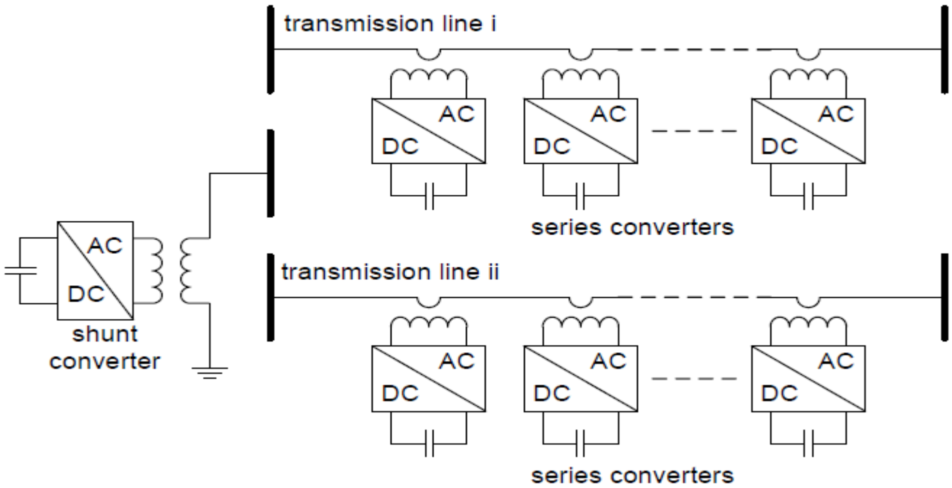

Figure 8: DIPFC configuration

V. POWER QUALITY IMPROVEMENT

The whole model of system under study is shown in Fig. 9. The system contains a three-phase source connected to a nonlinear RLC load through parallel transmission lines (Line 1 and Line 2) with the same lengths. The DPFC is placed in transmission line, which the shunt converter is connected to the transmission line 2 in parallel through a Y-Δthree-phase transformer, and series converters is distributed through this line. The system parameters are listed in appendix TABLE I. To simulate the dynamic performance, a three-phase fault is considered near the load. The time duration of the fault is 0.5 seconds (500-1000millisecond). As shown in Fig. 10, significant voltage sag is observable during the fault, without any compensation. The voltage sag value is about 0.5 per-units. After adding a DPFC, load voltage sag can be mitigated effectively, as shown in Fig. 10.

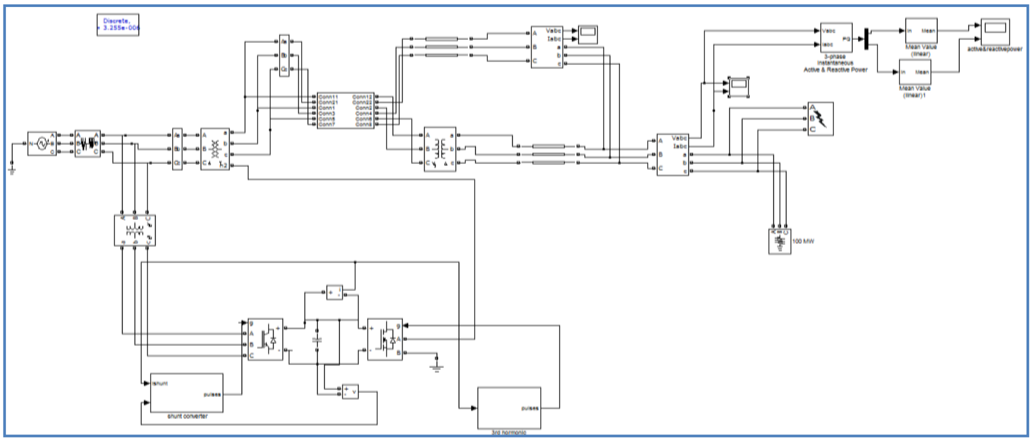

Fig. 9. Simulation model of the DIPFC.

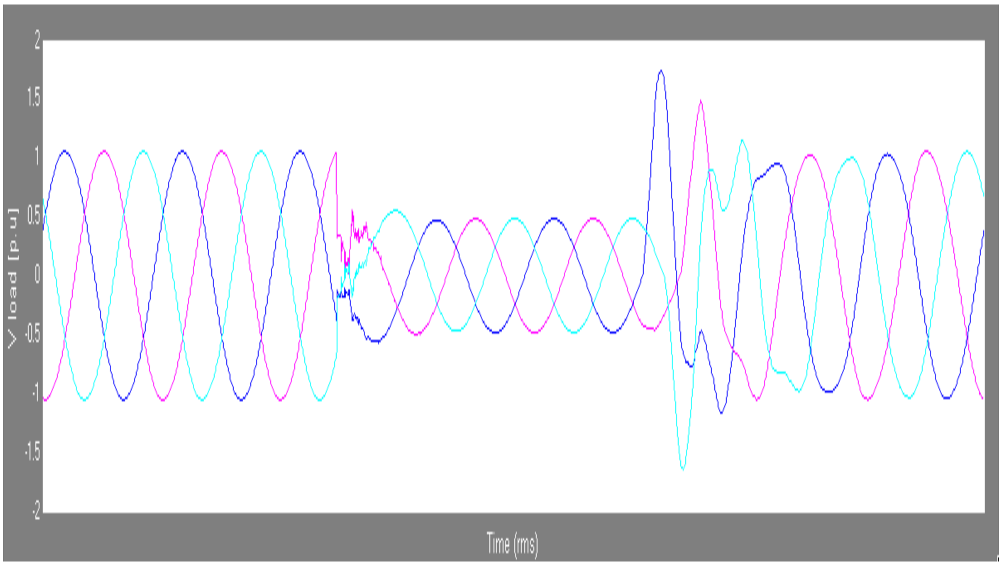

Fig. 10. Three-phase load voltage sag waveform.

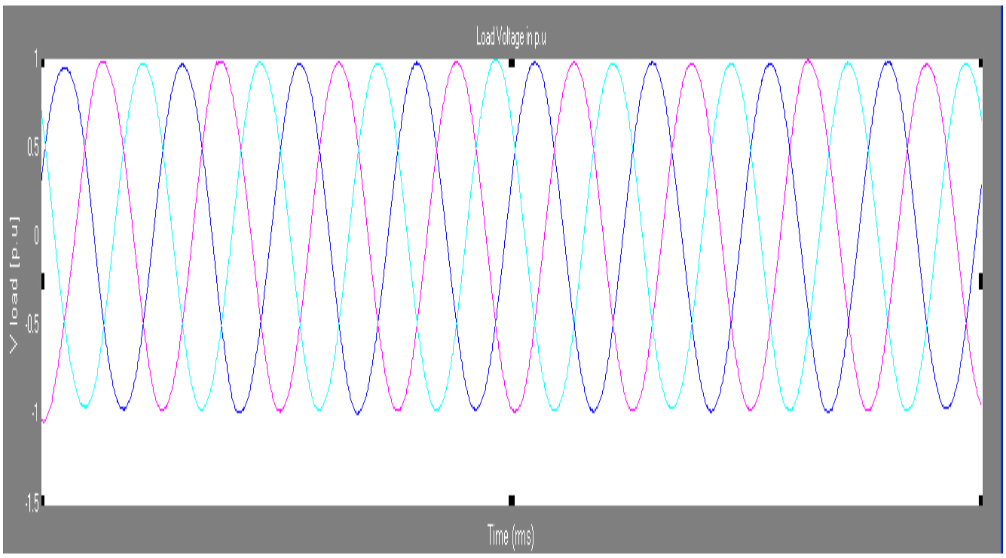

Fig. 11. Mitigation of three-phase load voltage sag with DPFC

Fig.12 depicts the load current swell about 1.1 per- unit, during the fault. After implementation of the DPFC, the load current swell is removed effectively. The current swell mitigation for this case can be observed from Fig. 12

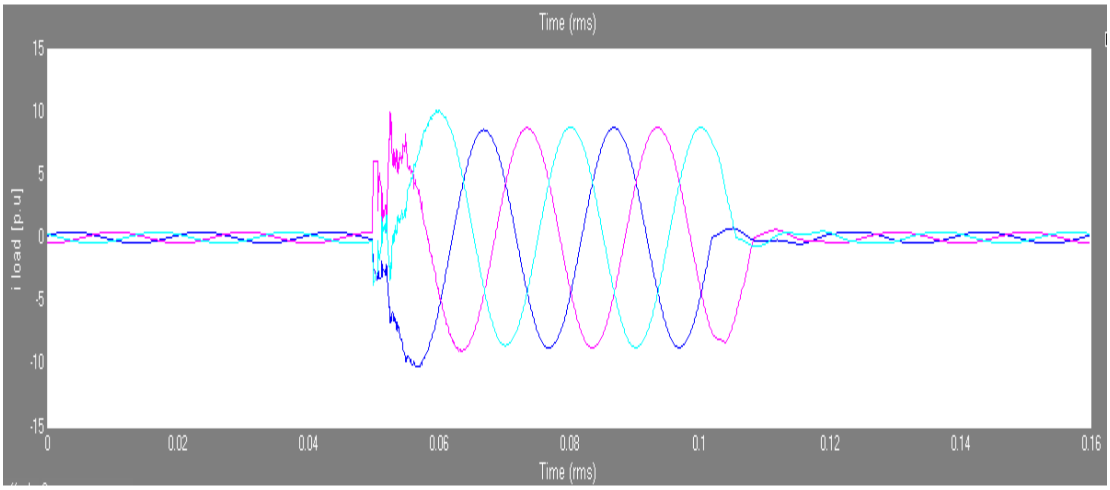

Fig. 12. Three-phase load current swell waveform without DPFC

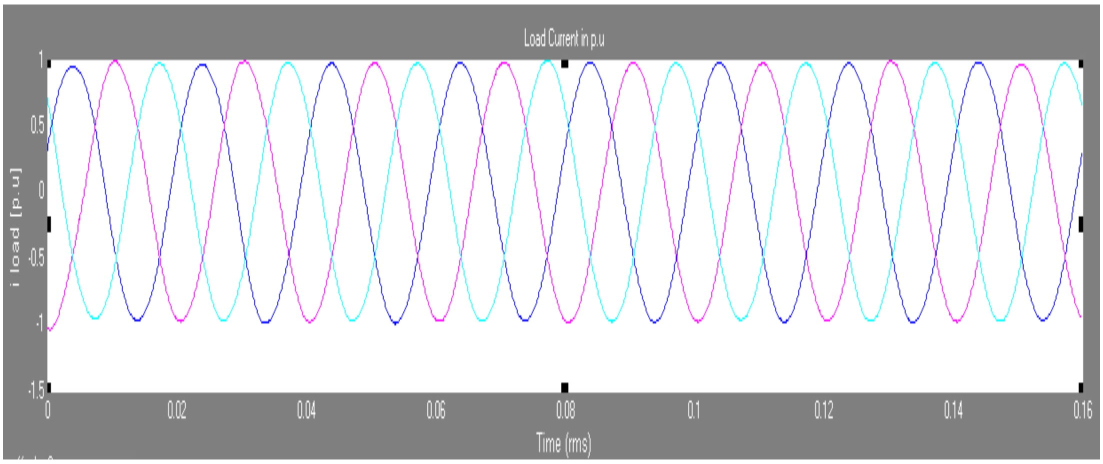

Fig. 13. Mitigation of three-phase load current swell with DPFC

The load voltage harmonic analysis without presence of DPFC is illustrated in Fig. 13. It can be seen, after DPFC and DIPFC implementation in system, the even harmonics is eliminated, the odd harmonics are reduced within acceptable limits, and total harmonic distortion (THD) of load voltage is minimized from 45.67 to 0.71 percentage and also total harmonic distortion (THD) of load voltage is minimized 0.39 percentage (Fig. 13), i.e., the standard THD is less than 5 percent in IEEE standards.

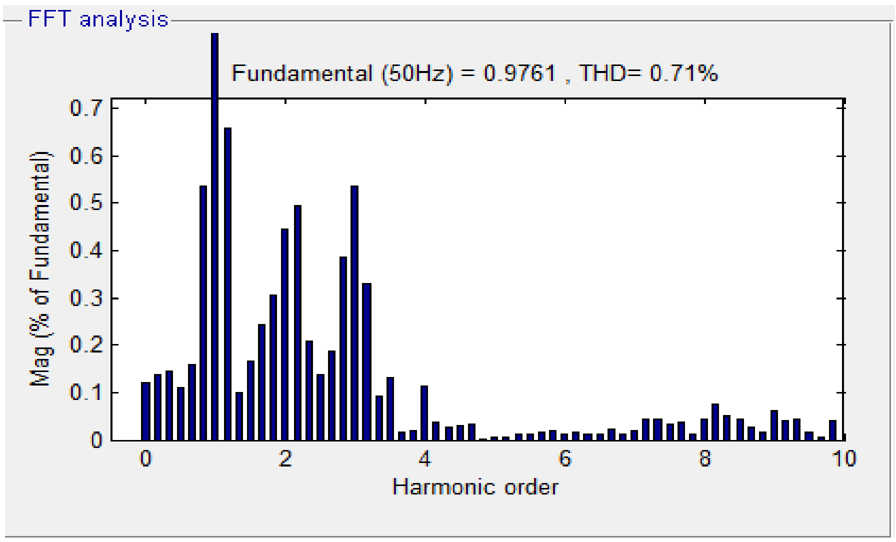

Fig. 14. Total harmonic distortion of load voltage with DPFC

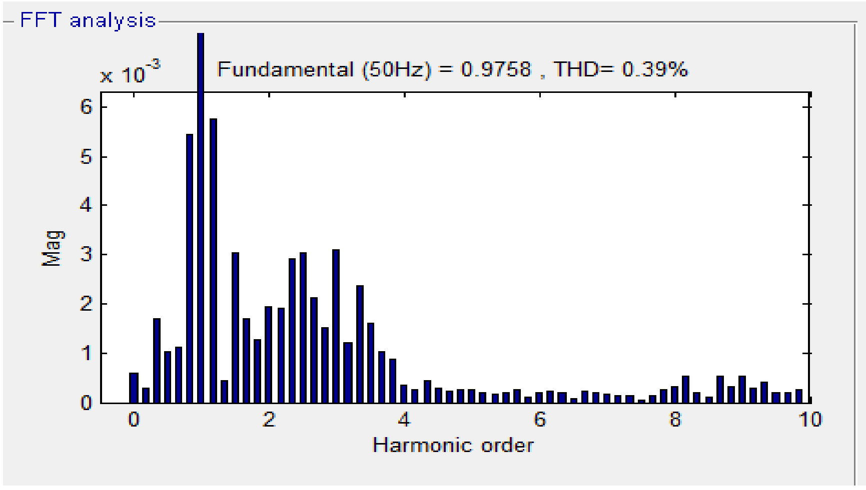

Fig. 15. Total harmonic distortion of load voltage with DIP

VI. CONCLUSION

In power sector the power quality improvement of the power transmission systems is an essential issue. In this revise, the appliance of DPFC and DIPFC as a novel FACTS device, in the voltage sag and swell mitigation of a system composed of a three-phase source connected to a non-linear load through the parallel transmission lines is simulated in Matlab/Simulink background. By implementing a three-phase fault close to the system load voltage dip is investigated. To identify the voltage sags and find out the three single phase reference voltages of DIPFC, the SRF scheme is used as a detection and determination method. The simulation results show the efficiency of DIPFC in power quality improvement, particularly in sag and swell mitigation when compared with DPFC.

Table 1 Simulation System Parameters

Parameters	Values
Three phase source	
Rated voltage	500 kV
Rated power/Frequency	100MW/60HZ
X/R	3
Short circuit capacity	11000MW
Transmission line	
Resistance	0.012 pu/km
Inductance/ Capacitance reactance	0.12/0.12pu/km
Length of transmission line	100 km
Shunt Converter 3-phase	
Nominal power	60 MVAR
DC link capacitor	600 µF

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