Simulation and Analysis of DPFC and DIPFC

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***Abstract*—The power system comprises of generation, transmission, distribution and utilization. The more power requirement by the electrical utilities made the power system complex and dynamic. In order to improve the power at the receiving end FACTs has facilitated the power system engineers. An attempt is done in this paper to study the two device controlled Distributed Power Flow Controller (DPFC) and Distributed Interline Power Flow controller (DIPFC) with power quality issues like voltage regulation, THD. A case study of the simulation is carried out with IEEE standard 5-bus system.**

***Keywords*— FACTS; DPFC; DIPFC;**

I. Introduction

Electrical Power is the major demand requirement of the modern world. The increase in demand has put many challenges in generation and transmission domain. Thus the transmission network is subjected to complexities mainly power quality. The developments in the higher rating power electronic devices led to another area known as Flexible AC Transmission Systems (FACTS). These devices are used in series, parallel, series parallel combinations depending upon the requirements.

This controlling is done using power electronic devices. FACTS are the power electronic devices which are used to improve the power quality issue in the transmission system that includes like voltage sag, swell and reduction of harmonics can be effectively improved by FACTS controller.[1][2][3]

Many FACTS devices are implemented to overcome different issues in power system and each device has its own significance and unique applications.[4]

The growth of electricity demand and the increased number of non-linear loads in power grids, providing a high quality electrical power should be considered. Variation of voltages namely voltage sag and swell of the power quality issues are studied and DPFC is used to mitigate the voltage deviation and improve power quality. The DPFC is a new FACTS device, which its structure is similar to unified power flow controller (UPFC). In spite of UPFC, in DPFC the common dc-link between the shunt and series converters is eliminated and three-phase series converter is divided to several single-phase series distributed converters through the line. The case study contains a DPFC sited in a single-machine infinite bus power system including two parallel transmission lines, which simulated in MATLAB/Simulink environment. The presented simulation results validate the DPFC ability to improve the power quality. [5]

FACTS devices are used for power flow control in AC transmission grids, improving power line utilization and performance. Nowadays, UPFC are one of the most useful FACTS, allowing the simultaneous control of the bus voltage and line active and reactive power. However, due to high costs and reliability concerns, the utilization of this technology has been limited in such applications. The concept of Distributed FACTS (DFACTS) and DPFC are studied as a low cost alternative for power flow control. The paper presents a distributed power flow controller that uses third-harmonic frequency currents transmitted through the line to independently control active and reactive power flow at fundamental frequency. Simulations were carried in the MATLAB/Simulink environment and the results validate the same. [6]

The flexible ac-transmission system (FACTS) family has many device controllers and one is distributed power flow controller (DPFC). The DPFC is a derived version of the unified power flow controller (UPFC) with elimination of common dc link. The active power exchange between the shunt and series converters, which is through the common dc link in the UPFC, is now through the transmission lines at the third-harmonic frequency. The DPFC is to use multiple small size single phase converters instead of large size three phase series converter in the UPFC. The large number of series converters provides redundancy, thereby increasing the system reliability. As the Distributed -FACTS converters are single phase and floating with respect to the ground, there is no high voltage isolation required between the phases. The cost of the DPFC system is lower than the UPFC. The DPFC has the same control capability as the UPFC, which comprises the adjustment of the line impedance, the transmission angle, and the bus voltage. Due to the high control capability DPFC can also be used to improve the power quality and system stability, such as low frequency power oscillation damping, voltage sag restoration or balancing asymmetry.[7]

A new concept for power flow control by distributed UPFC is analysed in this paper. The system, called distributed power flow controller (DPFC), consists of several low-power series converters and one shunt large-power converter without common dc link. Also new is that the power exchange between the shunt and series parts is through the existing transmission line at a harmonic frequency. The solution enables the DPFC to fully control all power system parameters, and it reduces the cost and increases the reliability of device at the same time. [8]

Transmission system is very complex in the present power system scenario and plays on vital role to transmit power from generating station to distribution system. For efficient and effective transmission of power, FACTS is used in transmission line. Among the FACTS device, distributed power flow controller (DPFC) is the latest technology which is used in the transmission system for more effective transfer of power. To classify and locate the fault in the DPFC compensated transmission system is complex when compare to other FACTS devices. In order to classify and locate the fault in the transmission system, discrete wavelet transformer (DWT) tool is introduced. The classification and location of fault is carried out accurately and efficiently with the help of DWT coefficients for the given test system. [9]

The control scheme to improve and maintain the power quality of an electrical power system by design of distributed power flow controller. Generally, in modern power utilities have challenges like growth of electricity especially of non-linear loads in grid connected systems. A modified FACTS method i.e. distributed power flow controller which is similar to other series-shunt controller types has several advantages. This DPFC method is also used like UPFC to mitigate voltage sag and swell as a power quality issue. The common dc link capacitor is eliminated and instead of single three phase series converter it has three individual single phase converters. The control circuit is designed by using series referral voltages, branch currents and the evaluated values are obtained by using MATLAB/SIMULINK. [10]

Flexible AC Transmission Systems 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. As in UPFC, DIPFC also have 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 the 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. [11]

Distributed power flow controller (DPFC) structure is derived from UPFC which consists of one shunt converter and multiple series converter. The DPFC has same behaviour as that of the UPFC that balances the line parameters i.e. line impedances, transmission angle and bus voltage magnitude. The other FACTS device is distributed interline power flow controller that is derived from IPFC which consists of two sets of multiple series converter which are connected to two different transmission line.

II. DISTRIBUTED POWER FLOW CONTROLLER (DPFC)

The structural configuration of DPFC is similar to that of UPFC structure with little modification as eliminating the DC link present between the shunt and series converter. The active power exchange that is between the DC link present in UPFC is now through the transmission line at third harmonic frequency. The main reason of eliminating the DC link interconnection is that, if a failure happens in any one of the converter will influence the entire line. There is another modification in the structure of DPFC from UPFC that is instead of one large three phase series converter, multiple single phase series converter is used. This modification provides redundancy and also increases the system reliability. The shunt converter is the same as that of UPFC here STATCOM is used as the shunt converter. The configuration of DPFC is as shown in figure 1.

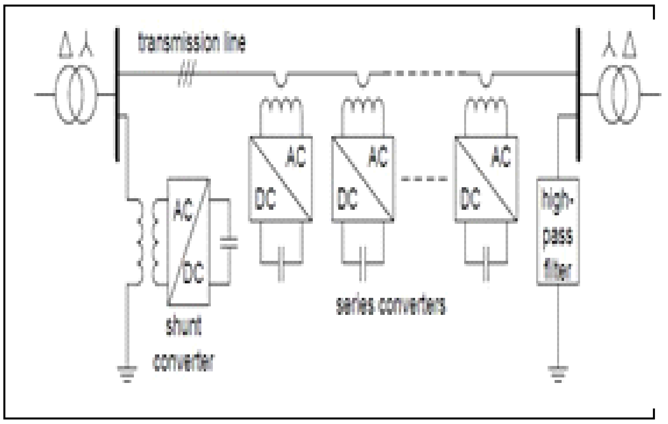


Figure 1: Configuration of DPFC

Principle of operation DPFC

A) Elimination of common DC link

The principle on which DPFC operates is the elimination of DC link between the shunt and series converter which was present in the UPFC for active power exchange. Now the power exchange is done through the AC network by harmonics. The principal depends on the definition of active power that is the mean value of the product of voltage and current, this voltage and current consists of fundamental and harmonic components [3]. Since the integrals of all the cross product of terms with different frequencies are zero, the active power can be expressed by,

$$P = \sum V_n I_n \cos\Phi_n \quad \text{------------------------(1)}$$

where n is the order of the harmonic frequency and Φ_n is the angle between the voltage and current of the n^{th} order harmonic frequency. Equation (1) indicates that the active power with different frequency is different and they are isolated from each other. The voltage or the current at any of the particular frequency is independent from the active power at any other frequency [4]. The shunt converter connected at the sending end of the system takes the active power at the fundamental frequency and this power is distributed to the series converter at the harmonic order frequency via transmission neutral to the transmission line from shunt converter. The harmonics here choosen is third order because this harmonic can be easily filtered out by Y-Δ transformer.

A) Analysis of third harmonic component

In power at high frequency level the current flowing through transmission line gives high impedance which result in increase in the voltage levels of the series converter connected to the transmission line. And hence the third harmonic frequency component is choosen as it is the smallest harmonic order frequency which has less impedance due to which the voltage level of the converter is also less. The third harmonic current component is similar to that of the zero sequence current components. In three phase system the zero sequence current components is naturally blocked by the Y-Δ transformer. Thus there is no necessary of any additional filters to block the flow of third harmonic current towards receiving end [2] [4].

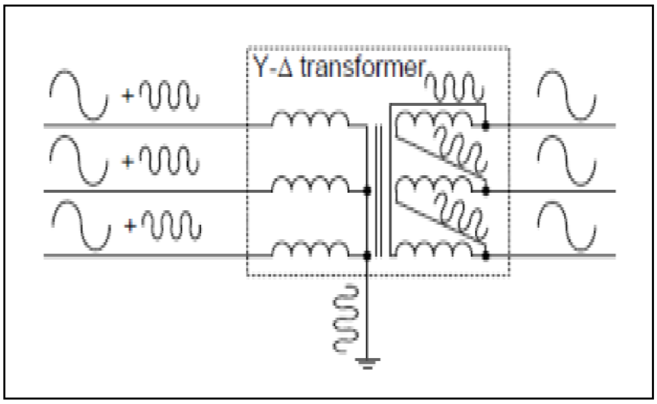


Figure 2: Star-Delta transformer providing path for the zero sequence or third harmonic [4]

B) Multiple distributed series converter concept

Using of multiple series single phase converter than three phase large series converter helps in controlling the reactive power of transmission system and also controls the line impedance. The smooth active power flow in the transmission network is facilitated by this arrangement. The function of multiple series converter is to take the current harmonics frequency from the line via single turn transformer and then it injects back to the transmission line at fundamental frequency as per requirement [4].

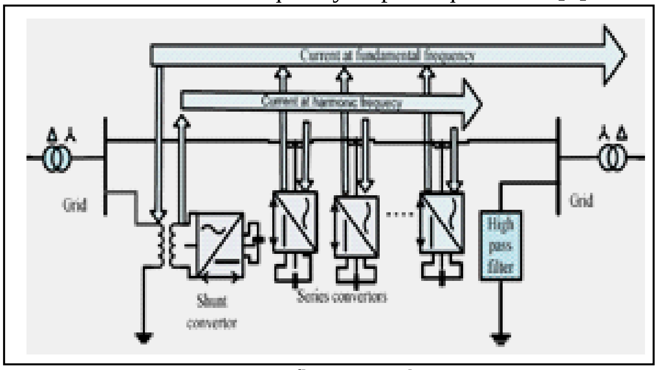


Figure 3: Active power flow among the DPFC converter

The DPFC system consists of two types of converters each converters have individual different function. DPFC consists of three types of controllers: central controller, shunt controller and series controller [3].

- *Central Controller:* The central controller generates control signals for both shunt and series converter control. The central controller has current reference signal for shunt converters and reference voltage for multiple series converter. The central controller action depends on the specific application of DPFC at power system level, as per the power system requirement gives as per requirement [4].

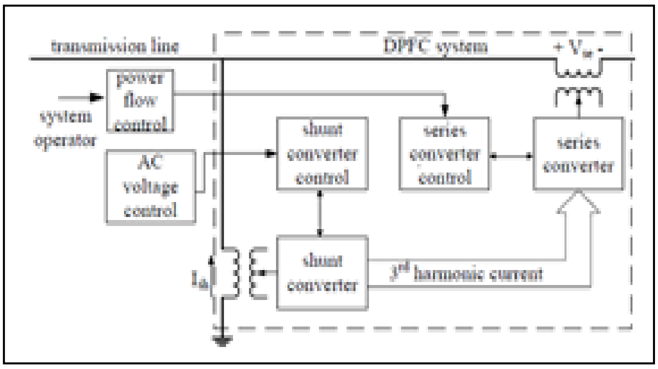


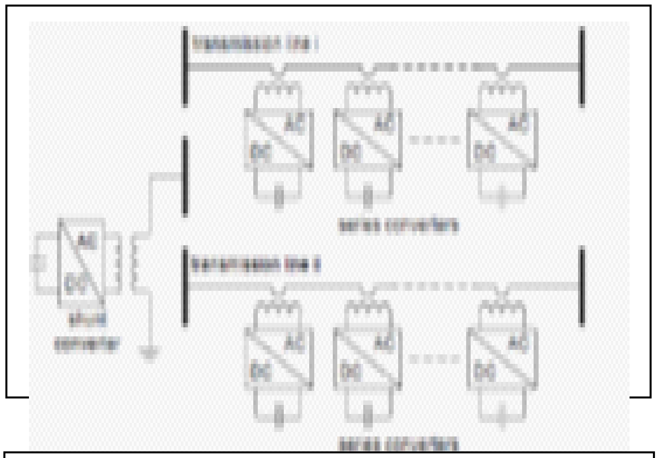
Figure 4: Block Diagram of DPFC Controller [1]

- *Series Controller:* In DPFC there is multiple series converter for each series converter there is individual series controller. The inputs to the series controller are series capacitor voltages, line current and series voltage reference in the quadrature axis (dq) frame. The main purpose of this controller is to keep the voltage of the capacitor constant at its corresponding converter by using the third harmonic frequency component. The series voltage generated by the controller is as per the central controller at fundamental frequency. Every series controller has a low frequency and third pass filter to create fundamental and third harmonic current respectively [4][1].
- *Shunt Controller:* The three-phase shunt converter absorbs active power from the system at fundamental frequency and it also controls the DC voltage of the

capacitor. Another main advantage of shunt controller is to inject the constant third harmonic current to the transmission line through neutral cable of the star-delta transformer. The current control and the DC capacitor voltage control are the two controllers which controls the fundamental frequency component.

III..DISTRIBUTED INTERLINE POWER FLOW CONTROLLER (DIPFC)

IPFC is applied for multiple transmission line. DIPFC is derived from IPFC with eliminating dc link and having multiple series converter replacing single large rated series converter. The DIPFC controller can also include shunt converter for exchange of active power. If shunt converter is not included then the active power exchange is from series converter in one transmission line to series converter of another transmission line.



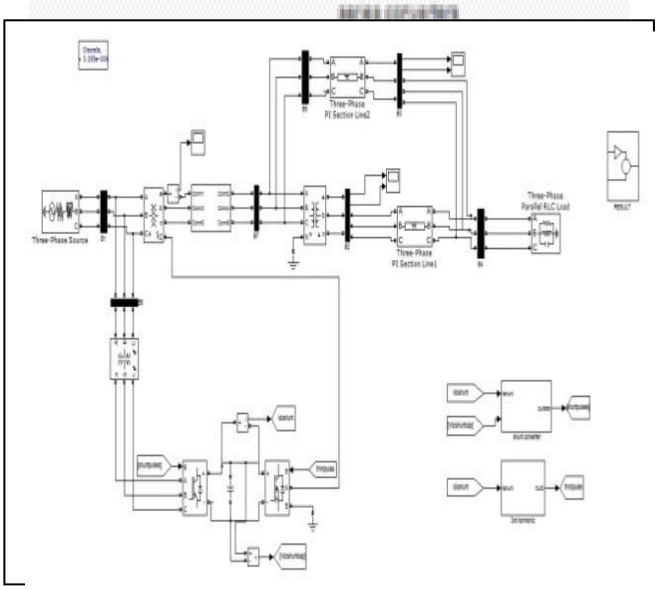


Figure 6: Simulink model of system connected with DPFC controller

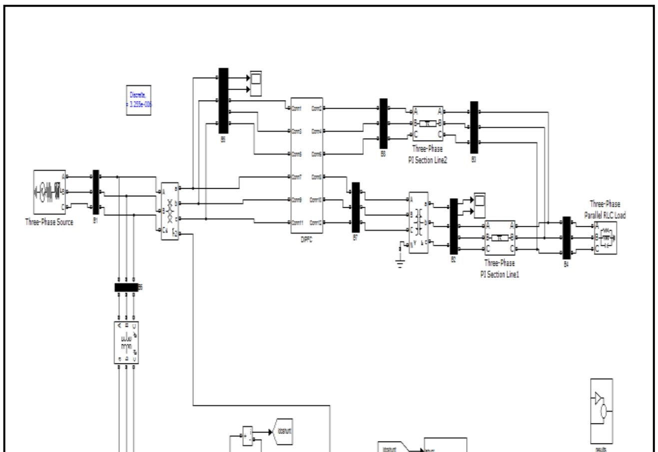


Figure 7. Simulink model with DIPFC Controller

The DIPFC controller is divided into three section central control, master control and slave control. Each section controls independently and maintains DC voltage. Central control generates the control signals for series converter at fundamental frequency.

- *Central Control:* Central control generates the predetermined or preset reference signals for master and slave. The master control receives voltage signal containing active and reactive component whereas the slave control receives only reactive component.
- *Master control:* Master control receives reference voltage signal from central control at fundamental frequency. It also receives reactive voltage from slave controller at constant third order harmonic frequency component. It maintains the DC voltage constant of every converter on its own by third order harmonic frequency.
- *Slave control:* The slave controller behaves similar to shunt controller in DPFC. Slave controller primarily injects third order harmonic current into line to supply the real power to master controller. The voltage at the DC capacitor of slave converter is maintained constant by absorbing real power from the grid at fundamental frequency.

IV. SIMULATION MODEL AND RESULTS

Study of power system is considered in a MATLAB/SIMULINK environment (Fig6 and 7). The system consists of a three phase AC source connected to the transmission line of various lengths. The study is carried out for the single machine infinite bus system for different line lengths; the system behaviour is studied for improvement in-

- voltage regulation for varying line length
- Improving the THD of the system.
- different types of faults

- The fault analysis is carried for two conditions with and without controller for transmission line length of 800km.

Table I: Voltage regulation

Transmission Line length (km)	Voltage regulation (%)		
	without controller	with DPFC	with DIPFC
100	9.47	1.89	2.52
200	10.52	2.73	2.19
300	12	2.34	2.17
400	13.33	1.30	1.11
500	18.88	2.24	1.66
600	20	3.22	2.37
700	21.11	3.37	3.93
800	23	4.54	4.54
900	27.78	5.68	5.02
1000	32.22	6.74	6.11
1100	34.53	7.86	6.25
1200	35.55	8.26	7.32
1300	38.04	8.9	7.99
1400	40.22	9.55	8.88

Table II: Reduction of THD

Line length (km)	Total harmonic distortion (%)			
	DPFC		DIPFC	
	Without	With	Without	With
100	15.44	0.27	12.42	0.66
200	15.08	0.28	11.82	0.42
300	14.73	0.25	11.38	0.48
400	14.40	0.36	10.00	0.32
500	18.30	0.39	10.04	0.35
600	18.44	0.42	10.07	0.39
700	18.50	0.45	10.10	0.42
800	18.52	0.46	10.14	0.43
900	18.56	0.48	10.17	0.46
1000	18.58	0.52	10.20	0.49
1100	18.59	0.56	10.22	0.52
1200	18.61	0.65	10.25	0.58
1300	18.63	0.70	10.28	0.61
1400	18.64	0.78	10.31	0.66

Table III: Fault analysis

Types of Faults	Fault Current (MA)		
	Without Controller	With DPFC	With DIPFC
LL	0.08241	0.08005	0.02726
LG	0.61968	0.21412	0.10231
LLG	0.70781	0.27879	0.11364
LLL	0.89185	0.37975	0.1234
LLLG	0.89158	0.37907	0.12331

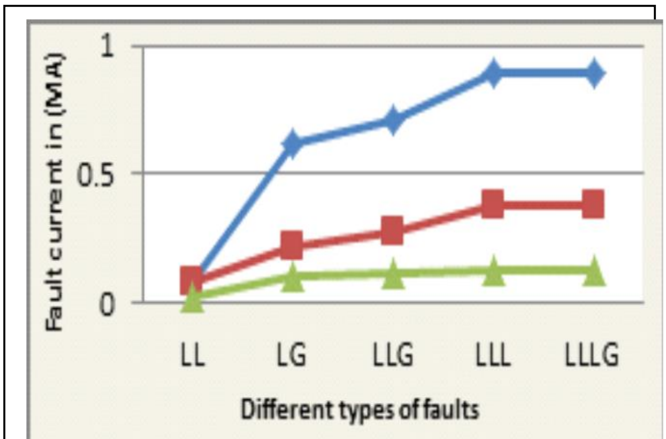


Figure 8. Fault currents

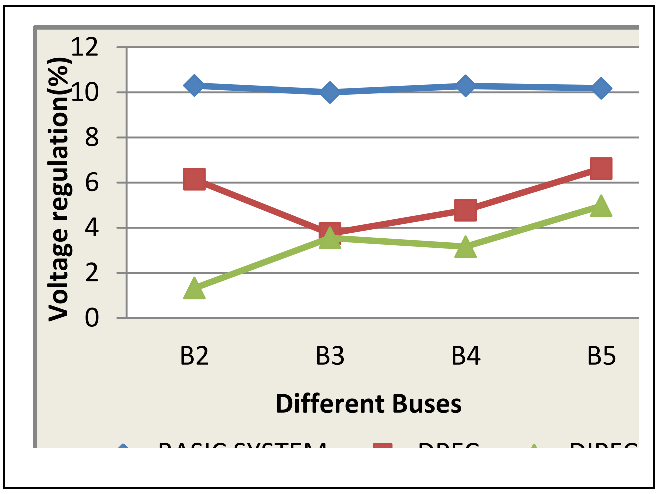


Figure 9: Voltage regulation in IEEE- 5 bus system

CONCLUSIONS

- Both the controller techniques improve the receiving or load end voltage profile of the transmission line system. DPFC has better voltage regulation up to 800km, after 800km- 1400km DIPFC maintains better voltage profile.
- Both the controllers reduce the harmonics thus contribute for voltage waveform improvement, increase in line length and the range of DPFC is more than DIPFC. The reduction in the harmonics contributes for improving the power quality.
- Introduction of controllers in the transmission line transients have been reduced appreciably and DIPFC has better impact.
- These controllers mitigate voltage sag, swell thus improves the voltage and current waveforms.
- Simulation on IEEE standard 5-bus supports the reduction of voltage at the load side and DIPFC performance is better as compared with DPFC.

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