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Introduction and Control Approach of Distributed Power Flow Controller (DPFC)

Shivanand[1] Rituraj Jalan[2] V K Maurya[3]

Abstract: This paper represents a new dimension of the Flexible AC Transmission System (FACTS) called as Distributed Power-Flow Controller (DPFC). The present paper describes the introduction and control of power in transmission line equipped with FACTS (DPFC) devices. Detailed simulations are carried out to illustrate the control features of DPFC and its influence to increase power transfer capability and improve system reliability. The DPFC is derived from the unified power -flow controller (UPFC) and DPFC has the same control capability as the UPFC. The DPFC can be considered as a UPFC with an eliminated 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.

Index Terms: FACTS, Power Flow Controlling Devices, UPFC, DPFC, Active power Exchange, Third harmonics, D-Facts, Series control, Shunt control, Central control.

I . INTRODUCTION

The growing demand and aging of networks make it desirable to control the power flow in power transmission system fast and reliability The flexible ac transmission system (FACTS) technology is the application of power electronics in transmission systems. The main purpose of this technology is to control and regulate the electric variables in the power systems. Currently, the unified power-flow controller (UPFC) shown in Fig. 1, is the most powerful FACTS device, which can simultaneously control all the parameters of the system: The line impedance, the transmission angle, and bus voltage. The UPFC is the combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC), which are coupled via a common dc link, to allow bidirectional flow of active power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM. The two converters operated from a DC link provided by a DC storage capacitor. The UPFC is not widely applied in practice due to their high cost and the redundancy to failure.Since the components of the UPFC handle the voltages and current with high rating, therefore the total cost of the system is high. Due to the common DC link interconnection a failure that happens at one converter will influence the whole system. To achieve the required reliability for power systems, bypass circuit or redundant back ups are needed which leads to increase the cost.

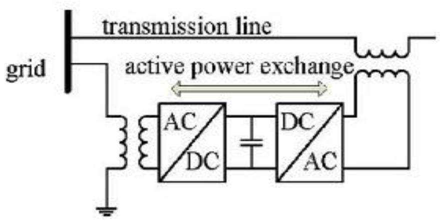

Fig.1 Simplified representation of a UPFC

The same as the UPFC, The Distributed Power Flow Controller (DPFC) recently presented in is a power flow device within the FACTS family, which provides much lower cost and higher reliability than the conventional FACTS devices. It is derived from the UPFC and has the same capability of simultaneously adjusting all the parameters of power system like line impedances, transmission angle and bus voltage magnitude. The DPFC Flow chart and configuration are shown in Fig.2 and Fig.3 respectively.

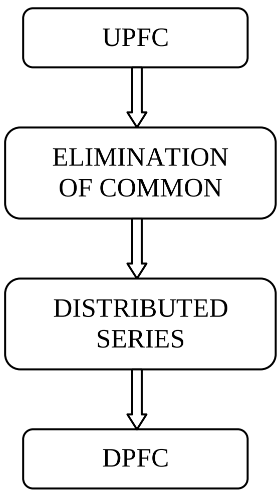

Fig.2 Flow chart from UPFC to DPFC

II . DPFC OPERATING PRINCIPLE

The DPFC consists of one shunt and several series-connected converters. The shunt converter is similar as a STATCOM, while concept, which is to use multiple single-phase converters instead of one large rated converter. Each converter within the DPFC is independent and has its own dc capacitor to provide the required dc voltage.

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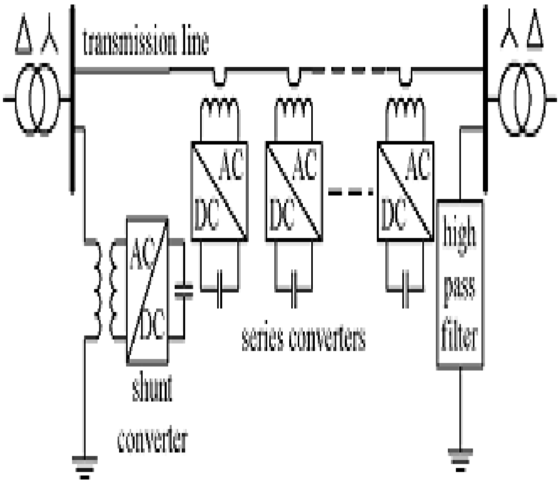

Fig. 3 DPFC configuration

The configuration of the DPFC is shown in Fig. 3.
Besides the key components, namely the shunt and series converters, the DPFC also requires a high-pass filter that is shunt connected at the other side of the transmission line, and two Y–Δ transformers at each side of the line. To ensure that the DPFC have the same control capability as the UPFC, a method that allows the exchange of active power between converters with eliminated dc link is the prerequisite.

A. Eliminate DC Link

Within the DPFC, transmission line is the common connection between the AC terminal of the shunt and series converters. Therefore it is possible to exchange the active power though the terminals of the converters. The method is based on power theory of non sinusoidal components. According to the Fourier analysis, a non sinusoidal voltage and current can be expressed by the sum of sinusoidal functions in different frequencies wit different amplitudes. The active power resulting from this non sinusoidal voltage and current is defined as the mean value of the product of voltage and current. Since the integral of all the cross product of terms with different frequencies are zero, the power can be expressed by:

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

Where V_i and I_i are the voltage and current at the i^{th} harmonic frequency, respectively, and φ_i is the corresponding angle between the voltage and current.
From this equation active power at different frequencies is isolated from each other and voltage or current in one frequency has no influence on active power at other frequencies.

The independency of the active power at different frequencies gives the possibility that a converter without power source can generate active power at one frequency and absorb this power from other frequencies. By applying this method to the DPFC the shunt converter can absorb the active power from the grid at the fundamental frequency and inject the current back into the grid at a harmonic frequency. Due to unique features of 3^{rd} harmonic frequency components in a three phase system, the 3^{rd} harmonic is selected for active power exchange. In a three phase system the 3^{rd} harmonic each phase is identical, which means they are zero sequence components. Because the zero sequence harmonic can be naturally blocked by star delta transformers and these are widely incorporated in power systems, there is no extra filter required to prevent harmonic leakage. Fig.4 shows Active power exchange between DPFC converters.

B. Distributed Series Converter

The D-FACTS is a solution for the series connected FACTS, which can dramatically reduce the total cost and increase the reliability

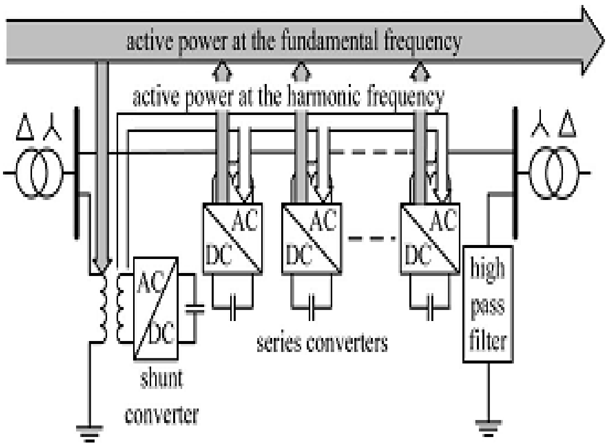

Fig.4 Active power exchange between DPFC converters

of the series FACTS device. The idea of the D-FACTS is to use a large number of controllers with low rating instead of one large rated controller. The small controller is a single-phase converter attached to transmission lines by a single-turn trans-former. The converters are hanging on the line so that no costly high-voltage isolation is required. The single-turn transformer uses the transmission line as the secondary winding, inserting controllable impedance into the line directly. Each D-FACTS module is self-powered from the line and controlled remotely by wireless or power-line communication shown in Fig.5. The structure of the DFACTS results in low cost and high re-liability. As DFACTS units are single-phase devices floating on lines, high-voltage isolations between phases are avoided.

The unit can easily be applied at any transmission-voltage level, be-cause it does not require supporting phase-ground isolation. The power and voltage rating of each unit is relatively small. Further, the units are clamped

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on transmission lines, and therefore, no land is required. The redundancy of the D-FACTS provides an uninterrupted operation during a single module failure, thereby giving a much higher reliability than other FACTS devices.

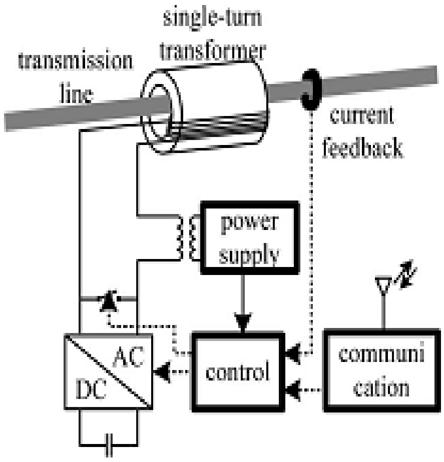

Fig.5 D-facts Concept

C. Advantages of DPFC

The DPFC can be considered as a UPFC that employs the DFACTS concept and the concept of exchanging power through harmonic. Therefore, the DPFC inherits all the advantages of the UPFC and the D-FACTS, which are as follows**.**

1) High control capability: The DPFC can simultaneously control all the parameters of the power system: the line impedance, the transmission angle, and the bus voltage.

2) High reliability: The redundancy of the series converter gives an improved reliability. In addition, the shunt and series converters are independent, and the failure at one place will not influence the other converters. When a failure occurs in the series converter, the converter will be short-circuited by bypass protection, thereby having little influence to the network.

3) Low cost: There is no phase-to-phase voltage isolation required by the series converter. Also, the power rating of each converter is small and can be easily produced in series production lines.

III . DPFC CONTROL SCHEMES

To control the multiple converters, DPFC consists of three types of controllers; they are central controller, shunt control, and series control, as shown in Fig. 6. The shunt and series control are local controllers and are responsible for maintaining their own converters' parameters. The central control takes account of the DPFC functions at the power-system level. The function of each controller is listed next.

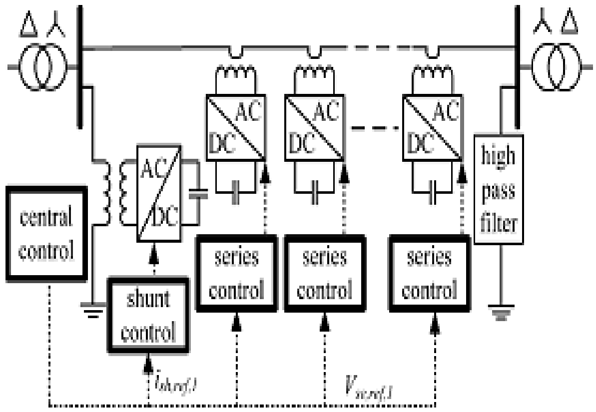

Fig. 6 DPFC control block diagram

A. Central Control

The central control generates the reference signals for both the shunt and series converters of the DPFC. It is focused on the DPFC tasks at the power-system level, such as power-flow control, low-frequency power oscillation damping, and balancing of asymmetrical components. According to the system requirement, the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt converter. All the reference signals generated by the central control are at the fundamental frequency.

B. 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 3^{rd} harmonic frequency components, in addition to generating series voltage at the fundamental frequency as required by the central control.

C. Shunt control

The objective of the shunt control is to inject a constant 3^{rd} 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.

IV . SIMULATION MODEL

An simulink setup has been built to verify the principle and control of the DPFC. One shunt converter and three single phase series converters are built and tested in a scaled network. Within the setup, multiple series converters are controlled by a central controller. There are basically three control schemes. 1. Series control 2. Shunt control 3. Central control. The central controller

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gives the reference voltage signals for all series converters. The voltages and currents within the setup are measured by an oscilloscope and processed in computer by using the MATLAB. The specifications of the DPFC in MATLAB are listed below.

Parameter	Value
Sending end voltage (Vs)	200 V
Receiving end voltage (Vr)	200 V
Series converter voltage (Vse)	120 V
Shunt converter voltage (Vsh)	120 V
Line resistance (r)	0.3864 Ω/km
Line inductance (L)	4.1264 mH/km
Source resistance (rs)	0.8929 Ω
Source inductance (Ls)	16.58 mH
Series capacitor (Cse)	1 μF
Shunt capacitor (Csh)	1 μF

V . SIMULATION RESULTS

First we run this model and observe the waveform for 3rd harmonics and fundamental current component. Fig.7 shows input current to shunt converter. The waveform has fundamental and harmonics contents.

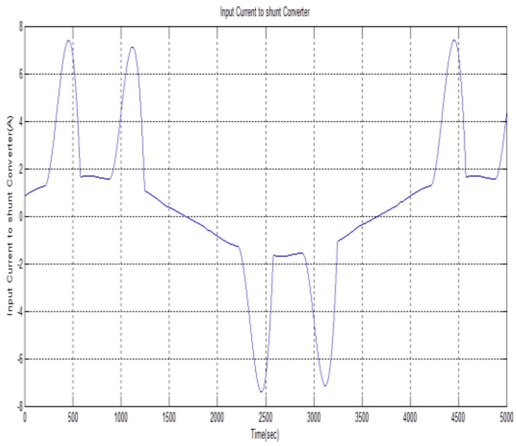

Fig. 7 Input Current to Shunt Converter

Fig. 8 Contains two Frequency components i.e., fundamental and 3rd Harmonic frequency components. The constant 3rd Harmonic current injected by shunt converter.

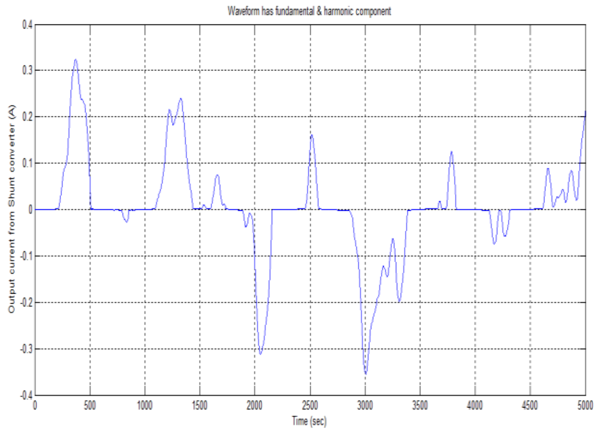

Fig. 8 Fundamental + 3rd Harmonic Current (output voltage of Shunt converter)

Now its necessary to remove third harmonics components. The output of shunt converter is now fed to series converter which blocks the third harmonics components of input current.

Fig. 9 Shows the Output Current from Series converter, which also has some harmonics. Extra high pass filters and Star-Delta transformers are used to remove harmonics completely from the input current waveform

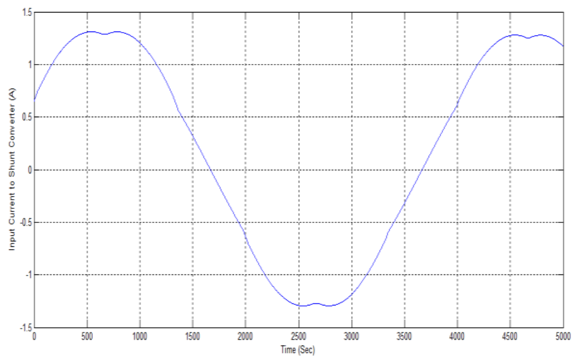

Fig. 9 Output Current from Series converter

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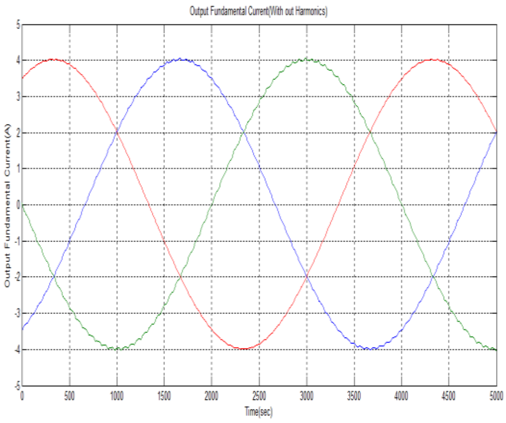

Fig. 10 Output Fundamental Current (Series converter output)

VI . CONCLUSION

The DPFC emerges from the UPFC and inherits the control capability of the UPFC, which is the simultaneous adjustment of the line impedance, the transmission angle, and the bus-voltage magnitude. The common dc link between the shunt and series converters, which is used for exchanging active power in the UPFC, is eliminated. This power is now transmitted through the transmission line at the third-harmonic frequency. The total cost of the DPFC is also much lower than the UPFC, because no high-voltage isolation is required at the series converter part and the rating of the components is low. The simulation results, obtained by MATLAB show the efficiency of DPFC, in controlling line both active and reactive power flow. It is proved that the shunt and series converters in the DPFC can exchange active power at the third-harmonic frequency, and the series converters are able to inject controllable active and reactive power at the fundamental frequency.

VII . FUTURE SCOPE

DPFC can control line impedances, transmission angles and bus voltages magnitude. Power is transmitted through the transmission line by third harmonic frequency.

Congestion is a growing problem in the modern power system, as systems are interconnected and are always operating near stability limit which results in rapid voltage drop due to heavy load demand. Line voltage stability index is used to identify the critical lines under the condition of congestion, where DPFC has been installed.

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BIOGRAPHIES

Shivanand pursuing his M.Tech degree in Power System and Control from Babu Banarasi Das University, Lucknow, (U.P). He obtained his B.Tech degree in Electrical Engineering from Babu Banarasi Das National Institute of Technology and Management, Lucknow, (U.P) in 2010. Currently He is working as Lecturer in Electrical Engineering Department in BBDNITM, Lucknow, (U.P.). His areas of current interest include Power System and Control System, Power Electronics and Drives, FACTS.

Rituraj Jalan received his M.Tech degree in Power System and Operational Control from Rajasthan Technical University , Rajasthan in 2014. He obtained his B.Tech degree in Electrical Engineering from UPTU in 2007. Currently he is working as Assist. Professor in Electrical Engineering Department in BBDNITM, Lucknow, (U.P.). His areas of current interest include Power System, Power Electronics and Electric Machines.

Virendra Kumar Maurya received his M.Tech degree in Power System and Operational Control from SEC , Rajasthan in 2014. He obtained his B.Tech degree in Electrical Engineering from MMMEC, Gorakhpur, in 2003. He obtained his Diploma in Electronic Engineering from Govt. Poly. Lucknow, in 1998 Currently he is working as Assist. Professor in Electrical Engineering Department in BBDU, Lucknow, (U.P.). His areas of current interest include Power System, Cadd,Emft, and Electric Machines.