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POWER QUALITY IMPROVEMENT IN TRANSMISSION LINE USING DPFC

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Abstract : *This project presents the MATLAB Simulation model of the Distributed Power Flow Controller in Transmission line. This work will be a new component with the flexible ac transmission system, called as distributed power flow controller (DPFC). The DPFC will be derived from the unified power flow controller system (UPFC). The DPFC can be considered as a UPFC with a common dc link which is eliminated. The active power exchange between the series and shunt converters, through the common dc link in the UPFC, is now through the transmission lines at the third-harmonic frequency. DPFC has the same control ability as the UPFC, which adjusts line impedance, bus voltages, and the transmission lines.*
Keywords : *AC/DC converters, DPFC, MATLAB, Power electronics, Power flow controller, Third harmonic frequency, Transmission line parameters control.*

I. INTRODUCTION

The aging of networks and increasing demand make it desirable for power flow, to control the power transmission system reliable and fast to the flexible ac transmission system, which is the application of power electronics in transmission system. The main aim of this technology is to regulate and control the electric variables in the power system.

The DPFC is the new concept. It is the advance version of the UPFC (Unified Power Flow Controller). The Distributed power flow controller is derived from the Unified Power Flow Controller (UPFC). The DPFC can be compared to a UPFC with an eliminated common dc link. The active power ex-change between the series and shunt converters, which is through the common dc link in the UPFC, is now through the transmission lines at the third-harmonic frequency. The DPFC employs the distributed FACTS (D-FACTS) concept, which is used for multiple small-size single phase converters instead of the one large-size three phase series converter in the UPFC. The multiple 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. According to this, the cost of the DPFC system is lower than the UPFC. The DPFC and UPFC has same control capabilities, which comprises the adjustment of the line impedance, the bus voltages and, the transmission angle.

Advantages of the DPFC over UPFC:
The DPFC can be considered as a UPFC that employs the Distributed FACTS concept and the concept of exchanging power through harmonic. Therefore, the DPFC inherits all the advantages of the UPFC and the Distributed 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 bus voltages and, the transmission angle, the elimination of the common dc link enables separated installation of the DPFC converters. The series and shunt converters can be placed at the most effectively location. Due to the high control capability, the DPFC can also be used to improve the power quality and system stability, such as low-frequency power oscillation damping, restoration the voltage sag, or balancing asymmetry.

2) High reliability

The redundancy of the series converter improves reliability. In addition, the series and shunt converters are independent, and the failure at one place will not influence to the other converters. In the series converter when a failure occurs, the converter will be short circuited by bypass protection, thereby having little impact to the network. In the case of failure in the shunt converter, the shunt converter will trip and the series converter will stop providing active compensation and will act as the Distributed FACTS controller.

3) Low cost

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

II. DPFC OPERATING PRINCIPLE

2.1Active power exchange with eliminated DC link

Within the Distributed power flow controller, the transmission line presents a common connection between the AC ports of the series and the shunt converters. Therefore, it can exchange active power through the AC ports. This purpose is based on power theory of non-sinusoidal components. According to the Fourier system analysis, non-sinusoidal voltage and current can be derived as the sum of sinusoidal functions in different amplitudes with different frequencies. The active power resulting from this non-sinusoidal current and voltage is defined as the mean value of the product of current and voltage. Due to the integrals of all the cross terms with various frequencies are zero, produced active power can be expressed as,

$$\mathrm{P} = vI\ iI \cos \emptyset I \qquad (1)$$

By applying this method to the Distributed Power Flow Controller, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the power back at a harmonic frequency. This active power harmonics flows through a transmission line supplied with series converters. According to the required active power at the fundamental frequency, the DPFC series converters generate a voltage at the harmonic frequency, therefore it actives power from harmonic components. Neglecting losses, the active power generated at the fundamental frequency is equal to the absorbed power at the harmonic frequency.

2.2 Using third harmonic components

Due to the unique features of third harmonic frequency components in a three-phase system, the 3rd harmonic is applied for active power exchange in the DPFC. In a three-phase system, the third harmonic in each phase is identical, which means they are "Zero Sequences" components. Because the zero-sequence harmonic can be blocked by star-delta transformers and these are widely absorbed in power systems, as there is no extra filter required to prevent harmonic leakage.

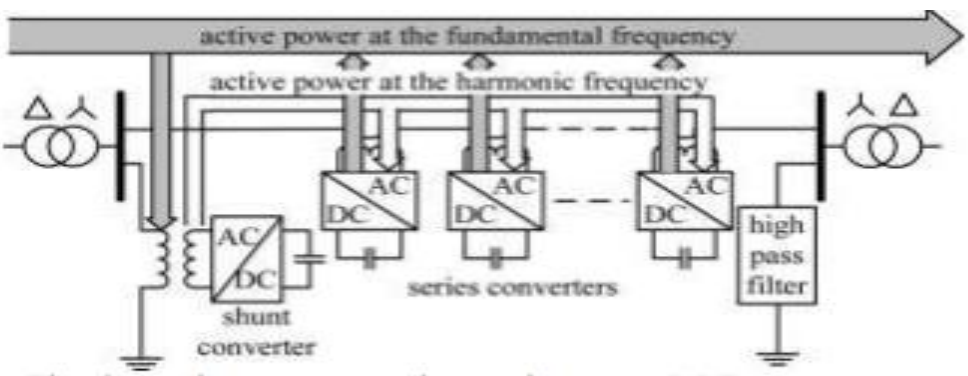

Figure 1: Active power exchange between DPFC converters

III. DPFC CONTROL

To control small size multiple converters, a DPFC consists of three types of controllers: central control, shunt control and series control, the series and shunt control are localized controllers and are responsible for maintaining their own converters parameters. The central control satisfies 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 series and shunt converters of the DPFC. It controls function of DPFC which 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 requirements, the central control gives voltage reference signals for the series converters and reactive current signal for the shunt converter. All the reference signals generated by the central control bothered the fundamental frequency components.

• Series control

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

• Shunt control

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

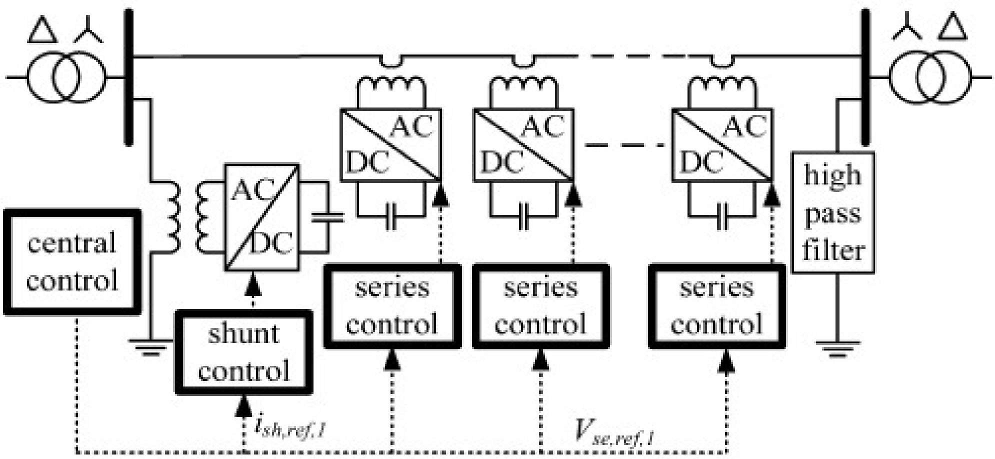

Figure 2: DPFC configuration

IV. ANALYSIS OF DPFC

In this steady-state behaviour of the DPFC is analysed, and the control capability of the DPFC is expressed in the parameters of the network and the DPFC.

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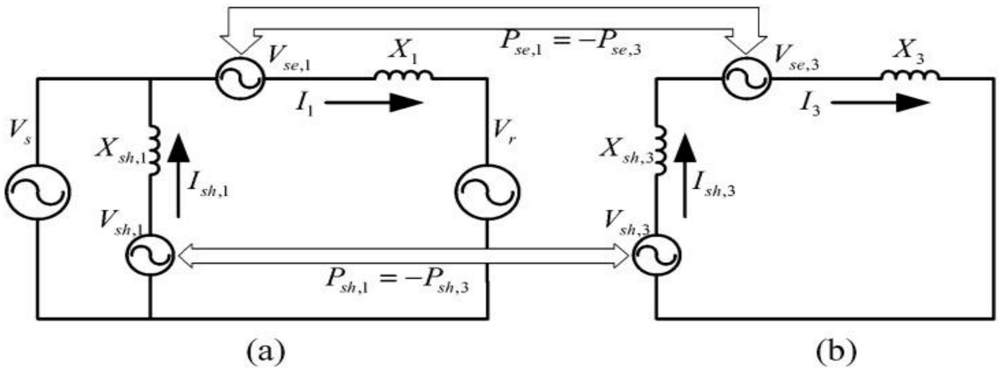

Figure 3: DPFC equivalent circuit a)Fundamental

4.1 Fundamental frequency circuit

To simplify the distributed power flow controller (DPFC), the converters are replaced by controllable voltage sources in series with impedance. Since at two different frequencies, each converter generates the voltage, it is represented by two series connected controllable voltage sources, one at the fundamental frequency and the other at the third harmonic frequency. Assuming that the transmission lines and the converters are lossless, the total active power generated by the two frequency voltage sources will be zero. The small size multiple series converters are simplified as one large. In fig 3 a) Fundamental frequency circuit is shown.

In Fig, the DPFC is placed in a two-bus system with the sending end voltages and the receiving end voltages Vs and Vr, respectively. The transmission line system is represented by an inductance L with the line current I. The injected voltages by all the DPFC series converters are Vse,1 and Vse,3 at the fundamental and the third harmonic frequency, respectively. The shunt converter is connected to the sending end bus through the inductor Lsh and generates the voltage Vsh,1 and Vsh,3; the injected current by the shunt converter is Ish. The active power and reactive power flow at the receiving end are Pr and Qr, respectively.

This representation consists of both the third harmonics frequency and fundamental frequencies components. Based on the superposition theorem, the circuit in Fig can be further simplified by being separated into two circuits at different frequencies. The two circuits are isolated from each other, and the link the power flow control capability of the DPFC can be illustrated by the active power Pr and reactive power Qr received at the receiving end. Due to these the DPFC circuit at the fundamental frequency behaves the same as the UPFC, the active and reactive power flow can be derived as follows:

$$(P_r - P_{ro})^2 + (Q_r - Q_{ro})^2 = \left(\frac{|V||V_{Se,1}|}{X_1}\right)^2 \tag{2}$$

$$P_{se,1} = \mathrm{Re}\,(V_{se,1}\, I_1^*) = \frac{X_1}{|V_r|^2}\,|S_r||S_{r0}|\,\sin(\varphi_{r0} - \varphi_r) \tag{3}$$

Fig, illustrates the relationship between Pse,1 and the power flow at the receiving end at a certain power angle θ. Consequently, the series converter at the required active power can be written as follows:

$$Pse,1 = CA_{(}o, r0, r) \tag{4}$$

According to the Fig, the relationship between the power flow control range and the maximum active power requirement can be represented by:

$$P_{se,1,\,max} = \frac{|X1||Sr0|}{|V_r|^2}\left|S_{r,c}\right| \tag{5}$$

Where |Sr, c | is the control range of the Distributed power flow controller

At the same time each converter in the DPFC generates two frequency voltages. According to these, the voltage rating of each converter should be the sum of the maximum voltage of the two frequencies component.

$$V_{se,\,max} = |V_{se,1,max}| + |V_{se,3,max}| \tag{6}$$

During the operation, the active power requirement of the series converter varies with the injected voltage at the fundamental frequency. When it is low required, the series voltage at the third harmonic frequency will be smaller than |Vse, 3, max|. This potential voltage which is in between Vse,3 and |Vse,3, max| can be used to control the power flow at the fundamental frequency, thereby increasing the power flow control region of the DPFC. When Sr, c is perpendicular to the uncompensated power Sr0, the maximum active power required by series converters, and the radius of the DPFC control region is given by:

$$|S_{r,c}| = \frac{|V_r||V_{se,1,max}|}{X_1} \tag{7}$$

If Sr,c is in the same line as Sr0 , the series converters only provide the reactive compensation and the boundary of the DPFC control region will extended to:

$$|S_{r,c}| = \frac{|V_r|(|V_{se,1,max}|+|V_{se,3,max}|)}{X_1} = \frac{|V_r||V_{se,max}|}{X_1} \tag{8}$$

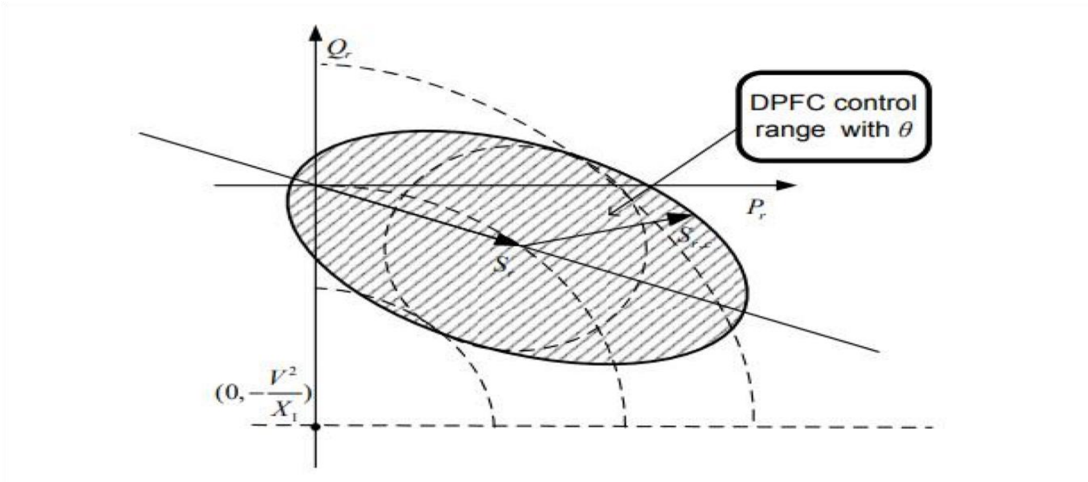

Figure 4: DPFC Power flow control range

4.2 Third harmonic frequency circuit

The 3rd harmonic component within the DPFC system is used to exchange active and reactive power between the shunt and series converters. In fig 3 b) Third harmonic frequency circuit shown. Therefore, the voltages and currents at the 3rd harmonic frequency are related to the required active power at the fundamental frequency. For the series converters, there is:

$$(V_{se,}3I_3^*) = -P_{se,1} \tag{9}$$

Absorbed power by the series converters at the third harmonic frequency is given by:

$$P_{se,3} + jQ_{se,3} = V_{se,}3I_3^* \tag{10}$$

$$= V_{sh,3}\left(\frac{V_{sh,3} - V_{se,3}}{X_3'}\right)^*$$

Where X′3 = X3 + Xsh,3. By splitting the real and imaginary parts, the absorbed active and reactive power at 3rd harmonic frequency can be expressed as:

$$P_{se,3} = \frac{|V_{se,3}||V_{sh,3}|}{X_3'} \sin\theta_3 \tag{11}$$

$$Q_{se,3} = \frac{|V_{se,3}|}{X_3'} \left(|V_{sh,3}| \cos\theta_3 - |V_{se,3}|\right)$$

Although here θ3 is the phase angle difference between the voltages Vsh,3 and Vse,3. For the series converters, any of the reactive power at the third harmonic frequency results in unnecessary extra currents and voltages. Therefore, the reactive power flowing through the series converters at the third harmonic frequency is controlled to be zero, which is Qse,3 = 0. It shows that the relationship between the voltages Vsh,3 and Vse,3 is:

$$|V_{se,3}| = |V_{sh,3}| \cos\theta_3 \tag{12}$$

$$P_{se,3} = \frac{|V_{sh,3}|}{X_3'} \cos\theta_3 \sin\theta_3$$

The maximum value of cos θ3 sin θ3 is equal to 1/2, when the angle θ3 is 45∘. Therefore, to efficiently supply the active power requirement Pse, 1, max, the injected voltage by the shunt converter at the third harmonic frequency should be:

$$|V_{sh,3,max}| \geq \sqrt[2]{2|P_{se,1,max}|X_3'} \tag{13}$$

The maximum voltage of the series converters at the 3rd harmonic frequency should comply with:

$$|V_{se,3,max}| \leq |V_{sh,3,max}| \tag{14}$$

V. CONCLUSION

The DPFC appears from the UPFC and inherits the control capability of the UPFC, which is the simultaneous adjustment of the line impedance, the bus voltage magnitude, and the transmission angle. The total cost of the DPFC is also lower than the UPFC, because no high voltage isolation is required at the series converter part and the components rating is low. To improve power quality in the power transmission system, the harmonics due to nonlinear loads, voltage swell and voltage sag are mitigated. By employing the Distributed FACTS concept, the series converters of the UPFC and IPFC are distributed. Because of the redundancy of the series converters, the reliability of the distributed power flow controller is increased without additional backup components. To reduce the investment, the shunt converter can be adjusted from a STATCOM. A single-phase AC to DC converter can be connected back-to-back to the DC side of the STATCOM, and its AC terminals are connected between the Star-Delta transformer's neutral point and the ground. The DPFC can simultaneously adjust the line impedance, the bus voltage, and the transmission angle. To obtain the same control capability as the UPFC and IPFC, the rating of the DPFC converter at the fundamental frequency should be the same as the UPFC. Because the currents and voltages at the 3rd harmonic frequency have to be added, the rating of the DPFC converter is slightly huge than the UPFC and IPFC.

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