Description of Control Scheme of Distributed Power Flow Controller (DPFC)

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***Abstract*—** *Distributed Power Flow Controller (DPFC) is a new concept in FACTs Technology. It employs the principle of UPFC and D-FACTs. It has the same control capability as that of UPFC and its series converter is distributed over the transmission line as that in D-FACTs. It is cheaper and highly reliable as compared to UPFC. It employs two converters i.e. series and shunt converter and each converter needs a controlling circuit and an additional central controlling circuit which provides reference voltage to series and shunt controlling circuit. This paper gives an overview of controlling scheme of DPFC.*

***Keywords*—** *power system; FACTS devices; power flow controlling device; DPFC Control; Distributed Power Flow Controller Control*

I. INTRODUCTION

DPFC consist of two converters i.e. series and shunt converter. These two converters exchange active power through transmission line at 3rd harmonic frequency. The shunt converter takes active power at fundamental frequency and produces 3rd harmonic current which is fed to the transmission line and thus gives active power to the line at 3rd harmonic frequency. This power is utilized by series converters and produces active power at fundamental frequency.
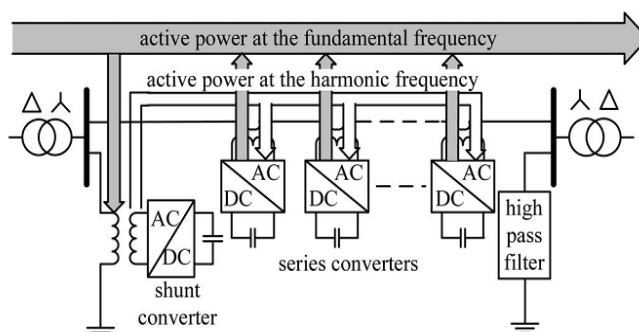

Fig. 1. DPFC Operating Principle

II. BASIC CONTROL OF DPFC

Controllers for each converter are needed to enable the control of DPFC. To control the DPFC, vector control method is employed. And the calculation of control parameter is based on Internal Model control (IMC) [1].

A. Control of Series Converter

Each series converter of DPFC need local controller and they should be identical. Separate control loops are required for two frequency components. The 3rd harmonic control loop is used for DC voltage control. Series converter control scheme is shown in figure 2.
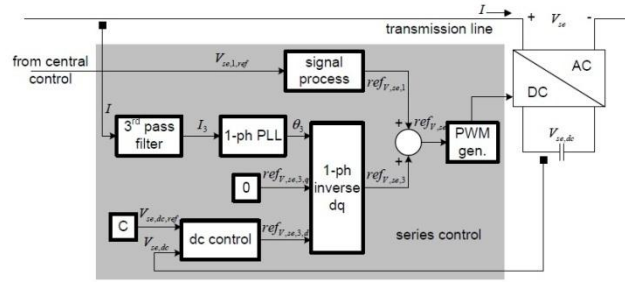
Fig. 2. Series converter controller

Vector control principal is used here for DC voltage control. Here the 3rd harmonic current through the line is selected as it is easily measured by the series converter. Since the line current contains two frequency components, a 3rd band pass filter is needed to extract the 3rd harmonic current. The single-phase (PLL), creates a rotation reference frame from the 3rd harmonic current. The d component of the 3rd harmonic voltage is used to control the DC voltage. The control signal is generated by the DC voltage control loop. The q component is kept at zero during the operation because the q component of the 3rd harmonic voltage will only cause reactive power injection to the AC network.

1) DC Control Scheme: The DC voltage control loop is used for maintaining the DC voltage of the series converter. Within the series converter control, both frequency component currents are taken as their rotating reference frame for Park's transformation. By projecting the currents to themselves, the q components I1,q and I3,q that are perpendicular to the current, will be zero and dc voltage can be written as:

$$C_{se}\frac{dV_{se,dc}}{dt} = \frac{1}{2}\left(ref_{V,se,1,d}I_{1,d} + ref_{V,se,3,d}I_{3,d}\right) \qquad (1)$$

To design the controller, (1) is transformed from the time-domain to the frequency domain. By selecting refV,se,3,d as the control parameter and Vse,dc as the control object, the transfer function from refV,se,3,d to Vse,dc is given by:

$$G(s) = \frac{V_{se,dc}(s)}{ref_{V,se,3,d}(s)} = \frac{I_{3,d}}{2C_{se}\,s} \qquad (2)$$

As the pole of the transfer function is at the origin. To improve disturbance rejection, an inner feedback loop is introduced for active damping [5] as a part of the DC voltage control loop. The DC voltage control scheme is shown in Fig. 3.
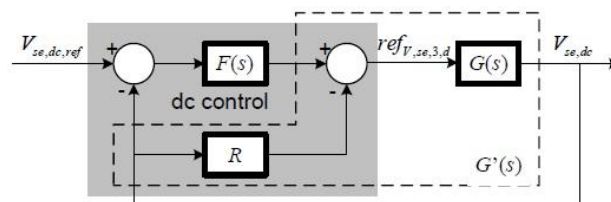

Fig. 3. DC voltage control loop

Here, F(s) is the control function and R is the active damping taken as feedback in the controller. The active damping R and G(s) results in a new virtual system G'(s). The transfer function of G'(s) is given by:

$$G'(s) = \frac{G(s)}{1+RG(s)} = \frac{I_{3,d}}{2sC_{se} + RI_{3,d}} \qquad (3)$$

The virtual system G'(s) is a first order system and according to the IMC method, the control function for a first order system is given by:

$$F(s) = \frac{\alpha_d}{s}G'(s)^{-1} \qquad (4)$$

Where α_d is a design parameter, and it is the desired bandwidth of the closed-loop system. The relationship between the bandwidth and the rise time trise is given by:

$$\alpha_d = \frac{\ln 9}{t_{rise}} \qquad (5)$$

Placing the pole of G'(s) at $-\alpha_d$, gives the active damping R and thus,

$$R = \frac{2C\alpha_d}{I_{3,d}} \qquad (6)$$

B. Shunt Converter Control

The shunt converter contains two converters. The single- phase converter injects the constant 3rd harmonic current into the grid and it is connected between neutral of Y-Δ transformer and the ground. The three-phase converter maintains the DC voltage at a constant value and generates reactive power to the grid and is connected between line and single – phase converter. The control of each converter is independent. A block diagram of the shunt converter control is shown in Fig. 4 and 6.

Accordingly, the parameters of PI controllers kp and ki within the DC voltage control can be calculated from the following equations:

$$k_p = \frac{2C\alpha_d}{I_{3,d}}, \qquad k_i = \frac{2C\alpha_d^2}{I_{3,d}} \qquad (7)$$
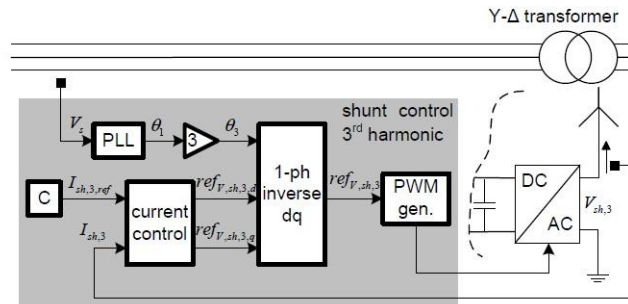
1) 3rd harmonic component Control:

Fig. 4. Single Phase Converter Control (for 3rd harmonic component)

a) *Current Control Scheme:* The current control loop is the major loop within the shunt converter's 3rd harmonic control. In order to design the current control, the relationship between the 3rd harmonic current and the shunt voltage should be determined and it is given by:

$$V_{sh,3} = L_3 \frac{dI_{sh,3}}{dt} + R_3 I_{sh,3} + V_{se,3} \qquad (8)$$

By applying park's transformation and transforming into frequency domain the transfer functions voltage Vsh,3 to the current Ish,3 for both d and q components are the same and can be expressed as:

$$G(s) = \frac{1}{R_3 + sL_3} \qquad (9)$$

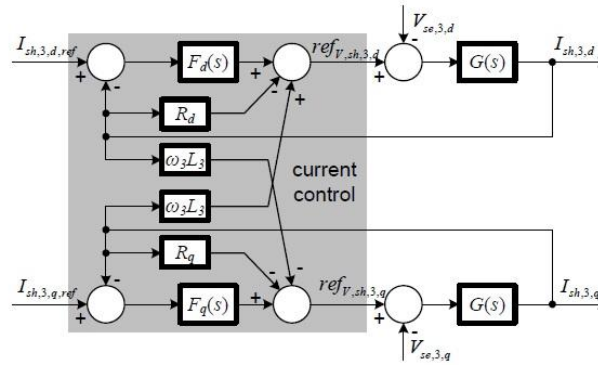Consequently, the scheme of the current control is shown in Fig. 6

Fig. 5. Current control in single phase converter

Using the IMC method to design the current control, the parameters of the control functions F(s) can be calculated as:

$$F_d(s) = \alpha_d L_3 + \frac{\alpha_d (R_3 + R_d)}{s} \qquad (10)$$

$$F_q(s) = \alpha_q L_3 + \frac{\alpha_q (R_3 + R_q)}{s} \qquad (11)$$

And the reactive damping R is given by:

$$R_d = \alpha_d L_3 - R_3 \qquad (12)$$

$$R_q = \alpha_q L_3 - R_3 \qquad (13)$$

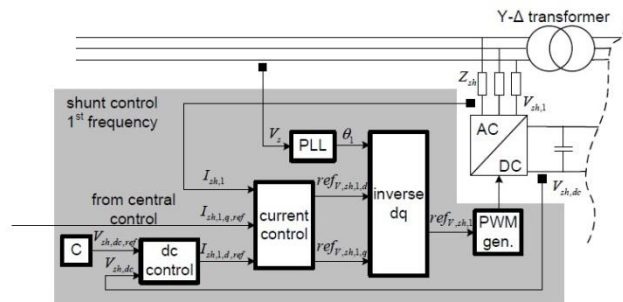*2) Fundamental frequency component control*

Fig. 6. Three phase converter control (for fundamental component)

As shown in Fig. 6 the control scheme consists of two major blocks i.e. the current control and the DC control. The current control is the inner control loop, which controls the current Ish,1. The reference of the q component of the current is from the central control and the reference signal of the d component is generated by the DC control. For Park's transformation, the rotational reference frame is created by the PLL using the bus voltage as input.

a) Current Control Scheme: This control scheme is almost similar to the current control scheme for 3rd harmonic components and it is shown in fig. 7.
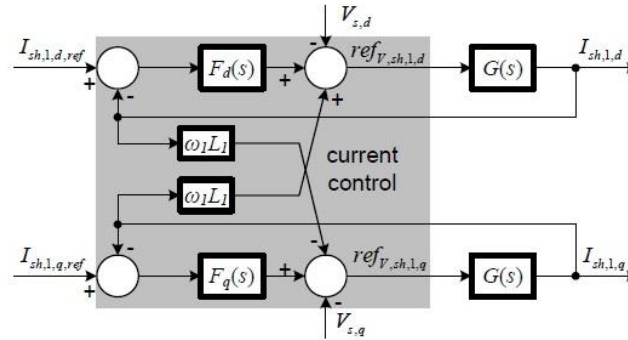
Fig. 7. Current control scheme

$$F_d(s) = \alpha_d L_1 + \frac{\alpha_d R_1}{s} \qquad (14)$$

$$F_d(s) = \alpha_q L_1 + \frac{\alpha_q R_1}{s} \qquad (15)$$
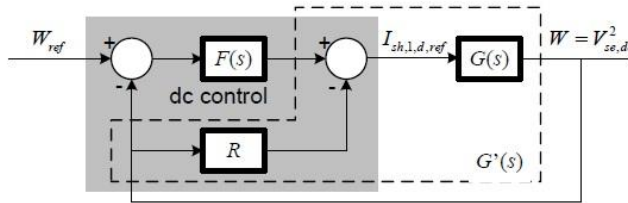
b) DC Control Scheme

Fig. 8. DC control Scheme

Here also an inner feedback loop is added for damping the pole at the origin. And the DC control scheme is shown in fig. 8.

Here, F(s) is a PI controller and its parameters are given by:

$$K_p = \frac{\alpha C}{3v_{s,d}}, \qquad K_i = \frac{\alpha^2 C}{3v_{s,d}}, \qquad R = \frac{\alpha C}{3v_{s,d}} \quad (16)$$

And the transfer function of V2dc,sh to Ish,1,d is G(s) and is given by:

$$G(s) = \frac{3V_{s,d}}{sC_{sh}} \qquad (17)$$

III. CONCLUSION

The control scheme of dpfc is studied and presented. The control scheme consists of individual control of each converter. The shunt converter is having a 3-phase and a single phase converter, the controlling scheme for each part of shunt converter is also presented. The central control is only meant for supplying reference voltages to series and shunt converter.

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