Enhancement of DPFC Performance during Series Converter Failures

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ABSTRACT – In this paper new facts device is introduced called DPFC (Distributed power flow controller).The DPFC and UPFC has the same control capability, which comprises the adjustment of the line impedance, the transmission angle, and the bus voltage. The DPFC can compensate active and reactive power, zero and negative sequence unbalanced currents. Adapted control schemes are employed to every series converters, which can automatically switch the series converter between the full control mode and limited-control mode. The reliability of the whole DFPC system is improved with the adapted control. Here control scheme is enhanced to improve the performance of the DPFC when one of the series converters fails. DPFC can independently control active and reactive power flow through the line.

Keywords* – *D-FACTS (DPFC), Active power flow control, distributed flexible AC transmission systems (D-FACTS)

I. INTRODUCTION
II.

The Distributed Power Flow Controller (DPFC) recently presented in is a powerful device within the FACTS family, which provides much lower cost and higher reliability than conventional FACTS devices. It is derived from the UPFC and has the same capability of simultaneously adjusting all the parameters of the power system: line impedance, transmission angle, and bus voltage magnitude. The DPFC eliminates the common dc link between the shunt and series converters, and uses the transmission line to exchange active power between converters at the 3rd harmonic frequency. Instead of one large three-phase converter, the DPFC employs multiple single phase converters (D-FACTS) as the series compensator. This concept reduces the rating of the components and provides a high reliability because of the redundancy. Since the DPFC can instantaneously control the active and reactive power flow and the voltage magnitude. As the series converters of the DPFC are single-phase, it gives the DPFC the opportunity to control current in each phase independently, which implies that both negative and Zero sequence unbalanced current can be compensated. The objective of this paper is to investigate the capability of the DPFC to balance the network. Additional controllers are supplemented to the existing DPFC controller. Their control principle is to monitor the negative and zero sequences current through the transmission line and to force them to be zero. The principle of DPFC is introduced followed by series converter principle and controller design in the paper.

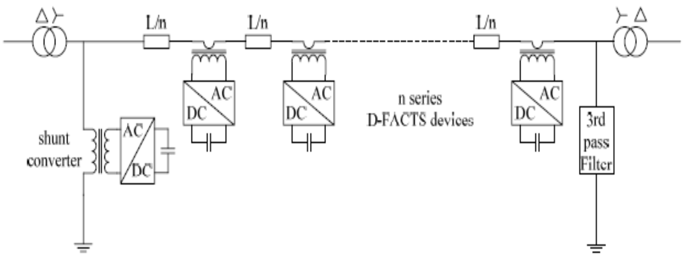

Fig .1 Distributed power flow controller

2. DPFC EQUIVALENT CIRCUIT

The DPFC, the converters are replaced by controllable voltage sources in series with impedance. Since each converter generates voltages at two different frequencies, they are represented by two series connected controllable voltage sources, one at the fundamental frequency and the other at the 3rd harmonic frequency. Assuming the converters and the transmission line have no loss, the total active power generated by the two voltage sources will be zero. The multiple series converters are simplified as one large converter with a voltage that is equal to the voltages of all series converters. The DPFC is placed in a two-bus system with the sending end and the receiving end voltages V_s and V_r. The transmission line is represented by an inductance L with the line current I. The voltage injected by all the DPFC series converters is $V_{se,}$ 1 and Vse, 3 at the fundamental and 3rd harmonic frequencies, respectively. The shunt converter is connected to the sending bus through the inductor L_{sh} and generates the voltage $V_{sh,1}$ and $V_{sh,3}$, and the current injected by the shunt converter is I_{sh}. The active and reactive power flows at the receiving end are P_r and Q_r. Arrow A represents the active power exchange within the converter itself and arrow B indicates the power exchange between the shunt and the series converter through the 3rd harmonic.

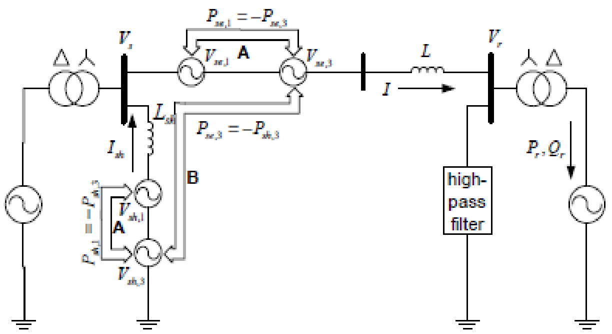

Fig 2 DPFC simplified representation

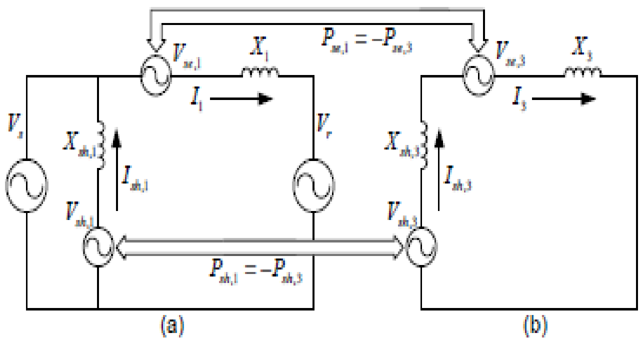

Fig.3 DPFC equivalent circuit: (a) the fundamental frequency; (b) the 3rd harmonic frequency

3. CONTROLLERS IN DPFC

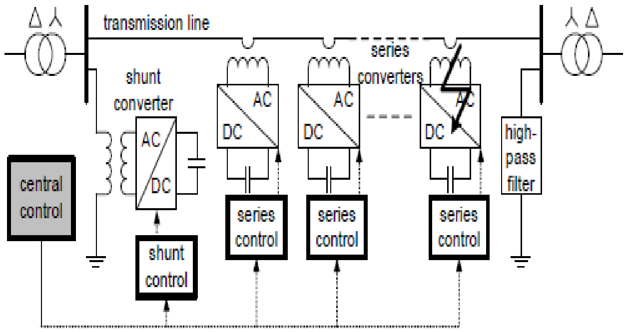

Fig. 4 Location of the supplementary control for the series converter failure

There are three controllers in DPFC. The functions of controllers are:

Central control: The central control generates the reference signals for both the shunt and series converters of the DPFC. 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.

Shunt control: injects a constant 3rd harmonic current into the line to supply active power for the series converters by maintaining the capacitor dc voltage of the shunt converter. by absorbing active power from the grid at the fundamental frequency, and injects required reactive current at the fundamental frequency to the grid.

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 the 3rd harmonic frequency components, and to generate series voltage at the fundamental frequency that is required by the central control.

4. DPFC CONTROL PRINCIPLE

The DPFC system consists of different type of converters, and each type of converter requires a different control scheme. The shunt converter is controlled to inject a constant 3rd harmonic current into the transmission line, which is intended to supply active power for the series converters. The shunt converter extracts some active power from the grid at the fundamental frequency to maintain its dc voltage. The dc voltage of the shunt converter is controlled by the *d* component of the current at the fundamental frequency, and the *q* component is utilized for reactive power compensation. The series converters generate a voltage with controllable phase angle at fundamental frequency, and use the voltage at the 3rd frequency to absorb active power to maintain its dc voltages at a constant value. The power flow control function is realized by an outer control loop, the power flow control block. This block gets its reference signals from the system operator, and the control signals for DPFC series converters are sent remotely via wireless or PLC communication method.

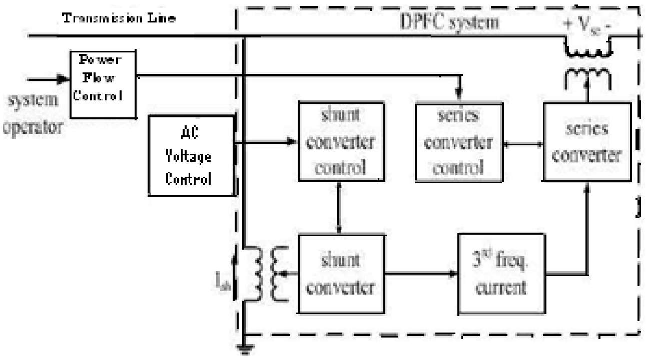

Fig. 5 Block diagram of the control of a DPFC

5. PRINCIPLE OF CONTROL IN SERIES CONVERTER FAILURE

The principle of the supplementary control is to let the remaining converters in the phase with the faulty converter inject higher voltages to maintain the voltage between phases at the fundamental frequency. Because the series converters are centrally controlled, this supplementary control is within the central control.

There are two requirements for the supplementary control:

• The controller should be able to distinguish the phase with the faulty converter and should adapt voltage reference signals for the remaining converters in the faulty phase.
• The reference signals for the converters in different phases should be independent to enable the series converters in one phase to generate a different voltage than the other phases.
The proposed method measures the fundamental-frequency voltages at the sending and the receiving ends (V_s and V_r) and the current through the line I. According to the measured information, the total voltage injected by all series converters $V_{se,\ 1,\ cal}$ can be calculated by the following equation:

$$V_{se,\ 1,\ cal} = V_s - V_r - I \cdot X \qquad (1)$$

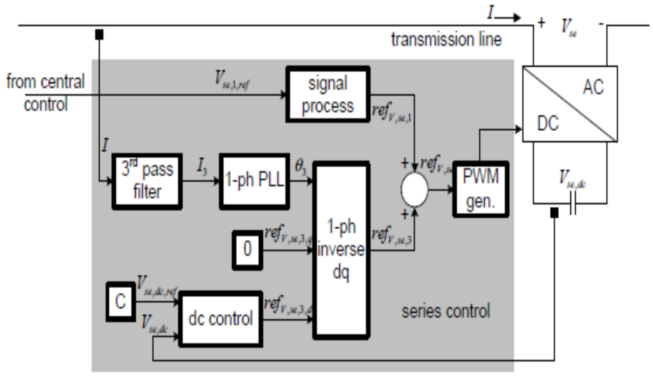

Fig.6 Control scheme of the series converter

5.1 Control of the fundamental frequency component:

The reference voltage at the fundamental frequency for the series converters is generated by the central control and transmitted to each converter through a communication channel. The signal-process block is utilized to transform the 'communication voltage' to the AC reference voltage at the fundamental frequency. This AC signal, superimposed with the signal generated by the 3rd harmonic control, is sent to the PWM generator to drive the switches of the series converter.

5.2 Control of the third harmonic frequency component:

The major control loop with the DPFC series converter control is 3rd harmonic frequency control is to maintain the DC capacitor voltage. The principle of vector control is used here for DC voltage control. The voltage is used as the rotation reference frame for Park's transformation. Here the 3rd harmonic current is easily measured by the series converter. As the line current contains two frequency components, a 3rd band pass filter is needed to extract the 3rd harmonic current. The single-phase Phase-Lock-Loop (PLL), creates a rotation reference frame from the 3rd harmonic current. The d component of the 3rd harmonic voltage is the parameter used to control the DC voltage. The control signal is generated by the DC voltage control loop. Because the q component of the 3rd harmonic voltage will only cause reactive power injection to the AC network, the q component is kept at zero during the operation.

6. COMPENSATION CONTROLLER DESIGN

The compensation controller is a close-loop control, with Vse,1,ref as the reference, Vse,1,cal as the feedback and Vse,1,ref,adp as the output. A saturation block is added to limit the output of the controller. For simplicity, the subscript se, 1 is omitted within the symbols of this subsection.

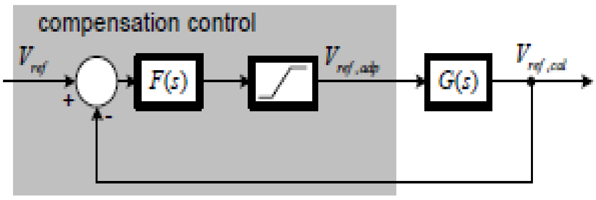

Fig. 7 Scheme of the controller for faulty series converter compensation

The open loop transfer function G(s) from $V_{ref,\ adp}$ to $V_{ref,\ cal}$ should be found to design a controller. The calculated voltage $V_{ref,\ cal}$ equals to the multiplication of the number of series converters per phase and the adapted reference $V_{ref,\ adp}$. However, due to the measurement and the response time of series converter control, there will be a delay between the two components. This delay is assumed to be a first order system, then the transfer function from $V_{ref,\ adp}$ to $V_{ref,\ cal}$ can be written as:

$$G(s) = \frac{V_{ref,cal}}{V_{ref,adp}} = n\frac{1}{sT_r + 1} \qquad (2)$$

The parameters of the controller function according to the internal model control (IMC) method are calculated by,

$$F(s) = \frac{\alpha}{s}G(s)^{-1} \qquad (3)$$

Since G(s) is a first order system, the control is a PI regular with the parameters:

$$K_i = \frac{\alpha}{n}, K_p = \frac{\alpha T_r}{n} \qquad (4)$$

7. SPECIFICATIONS OF THE DPFC FOR SERIES CONVERTERS

Voltage rating (V)	10
Current rating (A)	13

TABLE I

Parameter	value	Parameter	value
V_x (pu)	1	I_{3ref} (pu)	0.166
V_r (pu)	1	$V_{se,dc,ref}$ (pu)	0.087
Θ (°)	1.5	C_{se} (μF)	2200
R (pu)	0.095		
X (pu)	0.178		

TABLE II

8. SIMULATION RESULTS

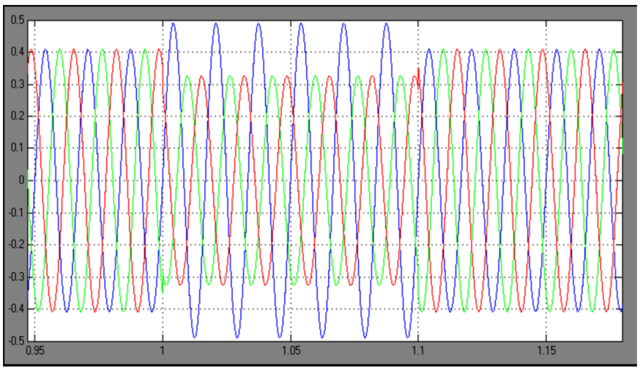

Fig. 9 Three-phase current at the delta side of a transformer

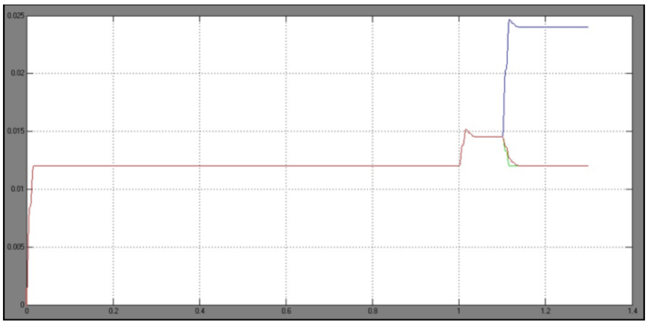

Fig. 10 The magnitude of the series converter reference voltage

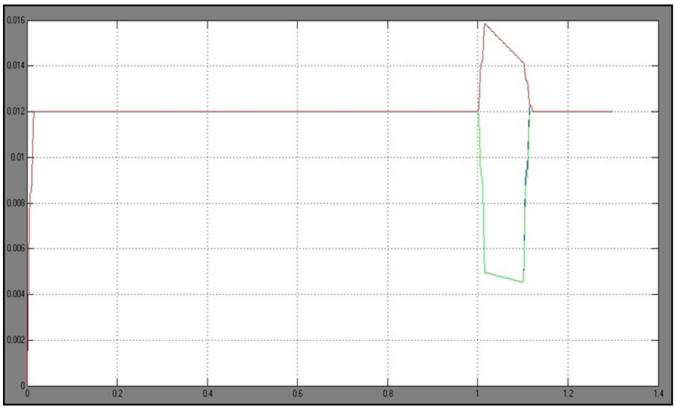

Fig. 11 The magnitude of the voltage injected by all series converters

9. CONCLUSION

For DPFC during Series converter failure the supplementary control is added for series converter at central control. When series converter fails it appears as a short circuit in the transmission line. An injected voltage becomes unbalanced. So the unsymmetrical current occurs at the fundamental frequency. The supplementary control is to make the zero and negative sequence currents to zero. These unbalanced and asymmetric currents have to be compensated in Matlab/simulink using this control scheme proposed during the failure of single series converter.

10. REFERENCES

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