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Power Quality Improvement Using Distributed Power Flow Controller (DPFC)

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ABSTRACT:

Recent developments in the electric utility industry are encouraging the entry of power quality issue. For the generation and transmission engineers power quality is a measure of how the elements affect the system as a whole but from the customer point of view, power quality issue is concerned about current, voltage and frequency deviation which results in power failure. To solve the power quality problem in such a situation, one of the power electronic devices called Flexible AC Transmission Systems (FACTS) are used.

FACTS are used to control power flow in the power grid to relieve congestion and limit loop flows. This paper presents a new FACTS device called DPFC, which is derived from UPFC. The DPFC is a solution to control the power flow in single transmission line by eliminating the common DC link and distributing the three phase series converters of the UPFC. Detailed simulations are carried out on simple four bus system to illustrate the control features of these device and their influence to increase power transfer capability

KEYWORDS:

FACTS, DPFC, Power transmission, device modeling, power quality improvement.

I. INTRODUCTION:

The static Compensator (STATCOM) [2] is a shunt connected device that is able to provide reactive power support at a network location far away from the generators. Through this reactive power injection, the STATCOM can regulate the voltage at the connection node. The static synchronous series compensator (SSSC) [2] is a series device which injects a voltage in series with the transmission line.

Ideally, this injected voltage is in quadrature with the line current, such that the SSSC behaves like an inductor or a capacitor for the purpose of increasing or decreasing the overall reactive voltage drop across the line, and thereby, controlling the transmitted power.The Unified Power Flow Controller (UPFC) is comprised of a STATCOM and a SSSC [3], coupled via a common DC link to allow bi-directional flow of active power between the series output terminals of the SSSC and the shunt output terminals of the STATCOM [4].Each converter can independently generate (or) absorb reactive power at its own AC terminal.

The two converters are 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 susceptibility to failures. Generally, the reliability can be improved by reducing the number of components; however, this is not possible due to the complex topology of the UPFC. To reduce the failure rate of the components, selecting components with higher ratings than necessary or employing redundancy at the component or system levels. The same as the UPFC, the DPFC is able to control all system parameters like line impedance, transmission angle & bus voltage.

II. STRUCTURE OF DPFC:

The DPFC consists of shunt and series connected converters. The shunt converter is similar as a STATCOM, while the series converter employs the Distributed Static series compensator (DSSC) concept, which is to use multiple single-phase converters instead of one three phase series converters. Each converter within the DPFC is independent and has its own DC capacitor to provide the required DC voltage. The flow chart for DPFC is shown in Figure 1. And the configuration of the DPFC is shown in figure 2

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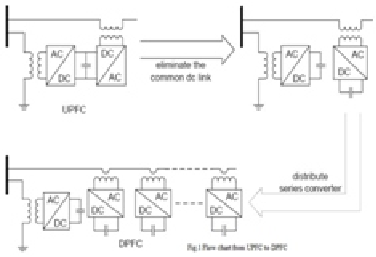

Fig.1 Flow chart from UPFC to DPFC

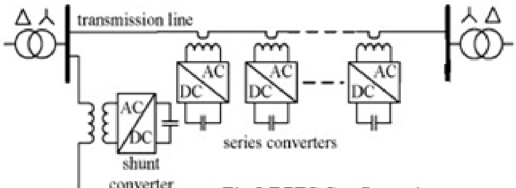

Fig.2 DPFC Configuration

III. WORKING OF DPFC:

1. EXCHANGE OF ACTIVE POWER THROUGH ELIMINATED DC LINK:

Within the DPFC, the transmission line presents a common connection between the AC ports of the shunt and the series converters. Therefore, it is possible to exchange active power through the AC ports. The method is based on power theory of non-sinusoidal components. According to the Fourier analysis, non- sinusoidal voltage and current can be expressed as the sum of sinusoidal functions in different frequencies with 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 integrals of all the cross product of terms with different frequencies are zero, the active power can be expressed by:

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

Equation (1) shows that the active powers at different frequencies are independent from each other and the voltage or current at one frequency has no influence on the active power at other frequencies. The independence of the active power at different frequencies gives the possibility that a converter without a power source can generate active power at one frequency and absorb this power from other frequencies. Figure 3 shows how the active power is exchanged between the shunt and the series converters in the DPFC system.

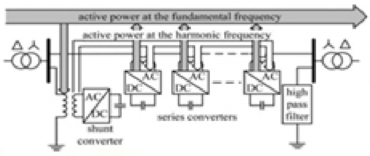

Fig. 3 Active power exchange between DPFC converters

The high-pass filter within the DPFC blocks the fundamental frequency components and allows the harmonic components to pass, thereby providing a return path for the harmonic components. The shunt and series converters, the high pass filter and the ground form a closed loop for the harmonic current.

2.THIRD HARMONIC CURRENT FLOW IN DPFC:

Due to the unique features of 3rd harmonic frequency components in a three phase system, the third harmonic is selected for active power exchange in the DPFC is shown in figure 4. In a three- phase system, the 3rd harmonic in each phase is identical, which means they are zero sequence components.

Because the zero-sequence harmonic can be naturally blocked by Y- Δ transformers and these are widely incorporated in power systems (as a means of changing voltage), there is no extra filter required to prevent harmonic leakage.

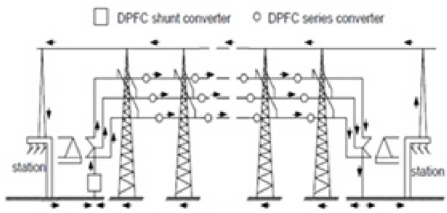

Fig.4 Third Harmonic Current flow in DPFC

By using the zero-sequence harmonic, the costly filter can be replaced by a cable that connects the neutral point of the Y- Δ transformer on the right side in Figure 5. with the ground. Because the Δ - winding appears open-circuit to the 3rd harmonic current, all harmonic current will flow through the Y- winding and concentrate to the grounding cable.

The harmonic at the frequencies like 3rd, 6th, 9th... are all zero-sequence and all can be used to exchange active power in the DPFC. However, the 3rd harmonic is selected, because it is the lowest frequency among all zero-sequence harmonics

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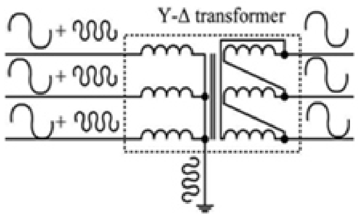

Fig. 5 Utilize grounded star-delta transformer to filter

IV. CONTROLLERS OF DPFC:

To control multiple converters, a DPFC consists of three types of controllers: central control, shunt control and series control.

1. 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. The block diagram of the DPFC series converter control is shown in fig.6.

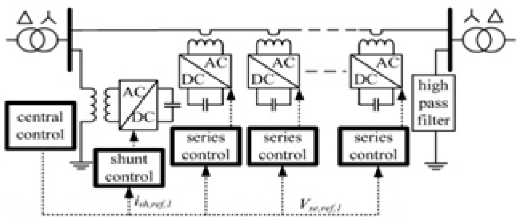

Fig. 6 Block diagram of DPFC Central Control

2. SERIES CONTROL:

Each DPFC series converter is locally controlled by its own controller, and the scheme for each series control is identical. To control the series converter, separate control loops are employed for the two frequency components. The 3rd harmonic control loop is used for DC voltage control. The block diagram of the DPFC series converter control is shown in fig.7.

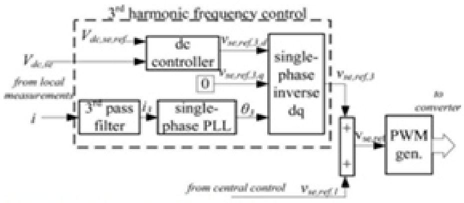

Fig. 7 Block diagram of DPFC Series control

3. SHUNT CONTROL:

The shunt converter contains two converters. The single- phase converter injects the constant 3rd harmonic current into the grid. The three-phase converter maintains the DC voltage at a constant value and generates reactive power to the grid.

The control of each converter is independent. A block diagram of the shunt converter control is shown in fig.8.

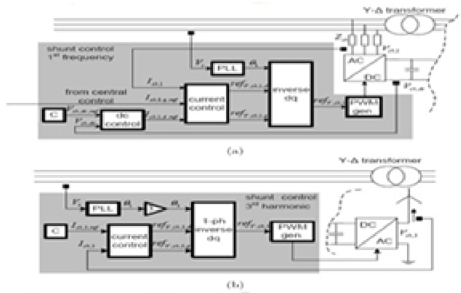
Fig. 8 Block digaram of DPFC Shunt control (a) for fundamental frequency (b) for third harmonic frequency

V. SIMULATION RESULTS:

To simulate the effect of the DPFC on Distributed system is processed using MATLAB. One shunt converter and three single phase series converters are built-in and tested.

Simulation model of DPFC is carried out in simple 4-bus system and compared the real and reactive powers existing in each bus when DPFC not placed and when DPFC is placed in the system.

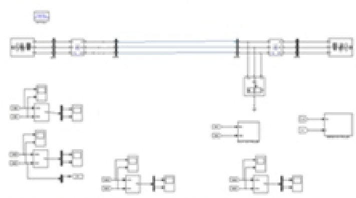
Fig. 9 Simple 4-bus system when DPFC not placed

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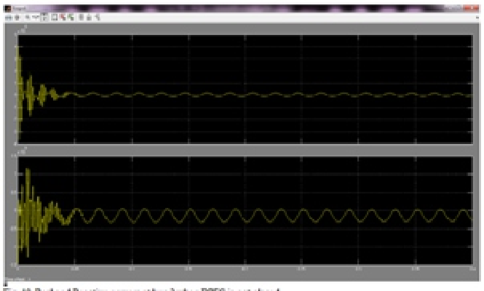

Fig. 10 Real and Reactive powers at bus 2 when DPFC is not placed

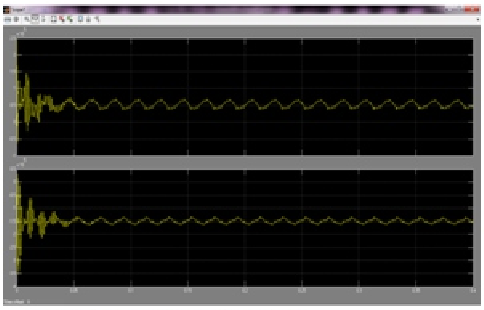

Fig. 11 Real and Reactive Power at Bus 3 When DPFC is not placed

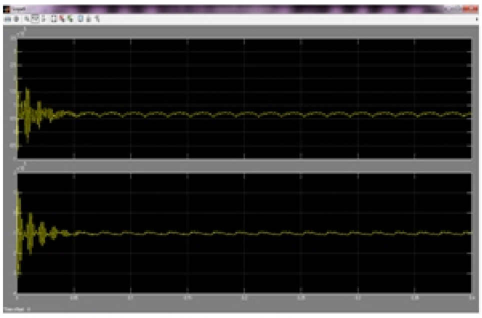

Fig. 12 Real and Reactive Power at Bus 4 When DPFC is not placed

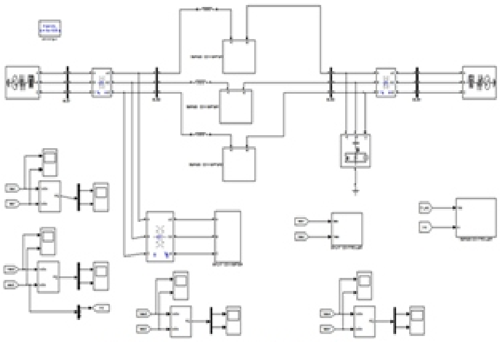

Fig. 13 Simple four bus system when DPFC is placed

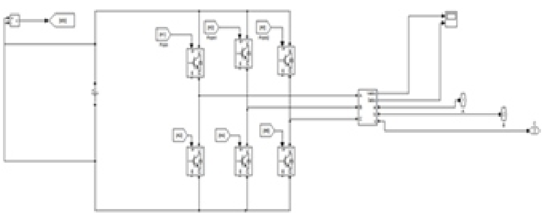

Fig. 14 Shunt converter circuit

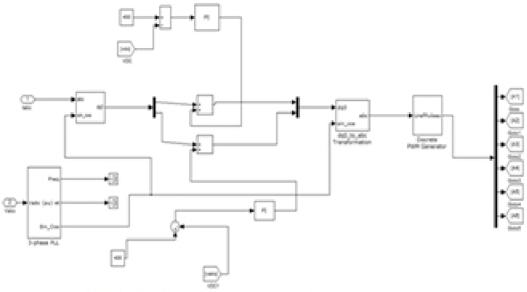

Fig. 15 control technique for shunt converter

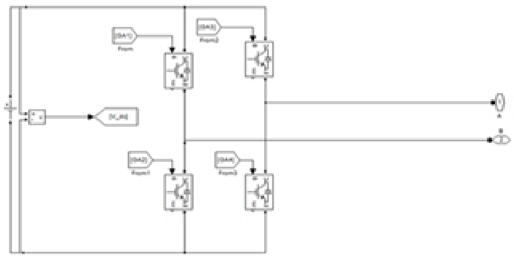

Fig.16 Series converter circuit

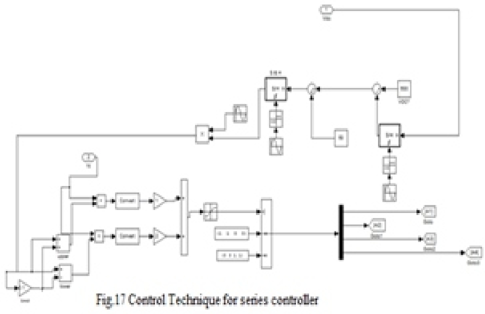

Fig.17 Control Technique for series controller

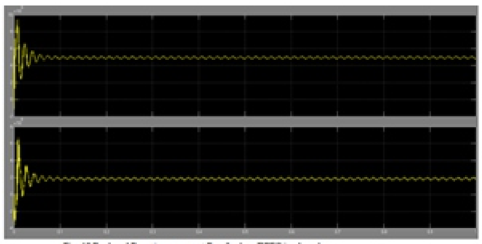

Fig. 18 Real and Reactive power at Bus 2 when DPFC is placed

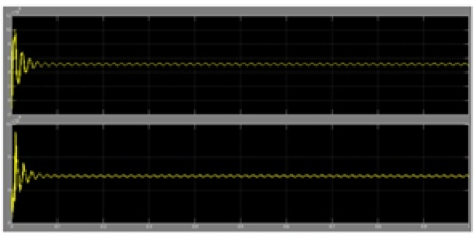

Fig. 19 Real and Reactive power at Bus3 when DPFC is placed

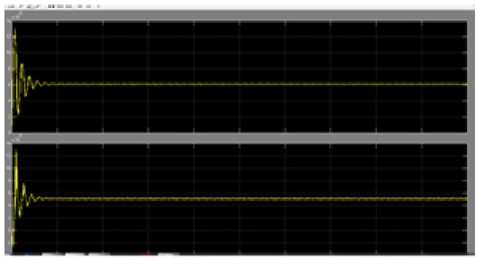

Fig. 20 Real and Reactive power at Bus 4 when DPFC is placed

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VI. CONCLUSION:

The DPFC comes from the UPFC and it consists of control capability of the UPFC, i.e., 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 both active and reactive power flow.

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