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Enhanced Small Disturbance Stability of Power Systems through Coordinated Control of D-FACTS

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ABSTRACT: Modern power utilities have to respond to a number of challenges such as growth of electricity demand specially in non-linear loads in power grids. So, there is a great demand to control the power flow in the lines. Power Flow Controlling Devices (PFCDs) are required for such purposes because power flow over the lines mainly depends on the impedance of the line. Nowadays the trend is to replace mechanical PFCDs with Power Electronics PFCDs. Among all Power Electronics PFCDs, Unified Power Flow Controller (UPFC) is the most versatile one. But it is not applied widely in utility grids due to its high and low reliability. A new PFCD called Distributed Power Flow Controller (DPFC) that offers the same controlling capability as that of UPFC with reduced cost and increased reliability have been highlighted in this paper. DPFC can be thought of as emerged from UPFC with some modifications in it. The DPFC eliminates the common DC link within the UPFC to enable the independent operation of shunt and series converters. The D-FACTS concept is employed in the design of series converters. High rating three phase series converters are being replaced by multiple low rating single phase converters which greatly reduces cost thereby increasing reliability and stability. The active power exchange takes place through transmission line at third harmonic frequency which in UPFC was done through common DC link.

I. INTRODUCTION

Nowadays the power system becomes very complex due to the increasing load demand of the electricity and the aging of the networks. There is a great desire for the power flow control in the transmission lines with fast operation and reliability [1]. All the FACTS devices can be utilized for the control of power flow in the transmission system. UPFC (Unified Power Flow Controller), is one of the power flow controller in the FACTS family, which can control the transmission line impedance, transmission angle and bus voltage. Recent developments in the electric utility industry are encouraging the entry of power quality issue. In the last decade, the electrical power quality issue has been the main concern of the power companies. Power quality is defined as the index which both the delivery and consumption of electric power affect on the performance of electrical apparatus. From a customer point of view, a power quality problem can be defined as any problem is manifested on voltage, current, or frequency deviation that results in power failure.

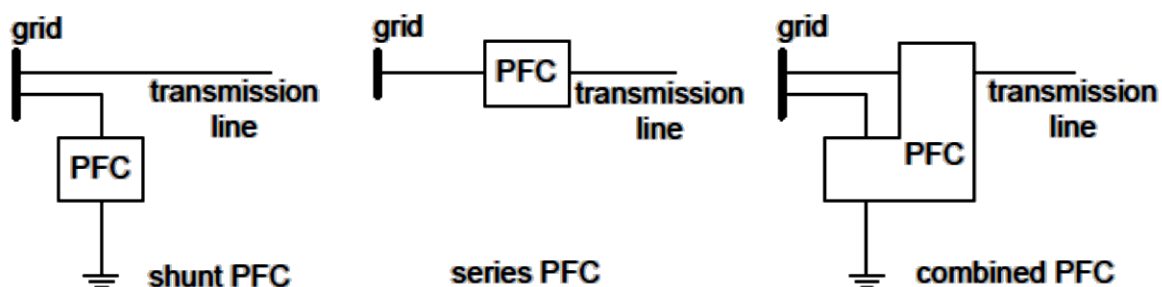


Fig.1.1 Simplified diagram of shunt, series and combined devices

PFCDs are used to fulfil the given objectives. Among all FACTS devices UPFC is the most versatile device due to its ability to pass real power flow bidirectional, maintaining well-regulated DC voltage, working ability in the wide range of operating condition, etc. But due its high cost, it is not widely used. In this paper, the use of a new PFCD called Distributed Power Flow Controller (DPFC) is highlighted that has the same controlling capability as that of UPFC with reduced cost and increased reliability. DPFC has been modelled using d-q fame on the basis of which its basic control is developed. The basic control ensures that the converter injects voltage according to the command from central

control. DPFC consists of a shunt converter and a number of series converters. The shunt converter injects constant current at third harmonic frequency while the series converter injects voltage of controllable magnitude and phase at fundamental frequency thereby controlling the flow of active and reactive power through the transmission line.

II. PROPOSED METHODOLOGY

The UPFC and IPFC are not widely applied in practice, due to their high cost and the susceptibility to failures. The D-FACTS concept not only reduces the ratings of the devices but also improves the reliability of the system because of redundancy and reducing the cost of high voltage isolation. The reliability of the DPFC is improved because of the redundancy of the series converters before failure. If any one of the series converters fails, that will stop voltage injecting into the transmission line and the other series converter units will continue the operation. The performance of DPFC is improved by considering better control scheme during the series converter failure. The control schemes adapted for DPFC corresponding simulation results before and after the failure of any one series converter unit are also presented.

III. DPFC OPERATING PRINCIPLE

By introducing the two approaches outlined in the previous section (elimination of the common DC link and distribution of the series converter) into the UPFC, the DPFC is achieved. Similar as the UPFC, the DPFC consists of shunt and series connected converters. 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.

$$P = \sum_{i=1}^{\infty} V_i I_i \cos \phi_i$$

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.

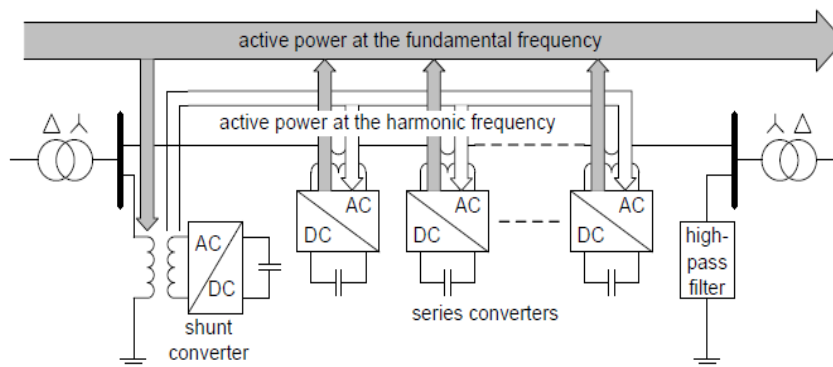


Figure 1.2: Active power exchange between DPFC converters

According to the amount of required active power at the fundamental frequency, the DPFC series converters generate a voltage at the harmonic frequency, thereby absorbing the active power from harmonic components.

IV. DPFC CONTROL

To control multiple converters, a DPFC consists of three types of controllers: central control, shunt control and series control, as shown in Figure 1.2. The shunt and series control are localized controllers and are responsible for maintaining their own converters' parameters. The central control takes care of the DPFC functions at the power system level. The function of each controller is listed:

1. Central control:

The central control generates the reference signals for both the shunt and series converters of the DPFC. Its control function 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 system requirements, 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 concern the fundamental frequency components.

2. 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 3rd harmonic frequency components, in addition to generating series voltage at the fundamental frequency as required by the central control. The functions of the series control can be summarized as:

- Maintain the capacitor DC voltage of its own converter by using the 3rd harmonic frequency components.
- Generate the series voltage at the fundamental frequency that is prescribed by the central control.

3. Shunt control:

The objective of the shunt control is to inject a constant 3rd 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. The functions of the shunt control are:

- Inject a constant 3rd harmonic current into the line to supply active power for series converters.
- Maintain the capacitor DC voltage of the shunt converter by absorbing active power from the grid at the fundamental frequency.
- Inject reactive voltage at the fundamental frequency to the grid as prescribed by the central control.

V. MODELLING AND SIMULATION

To design a DPFC control scheme, the DPFC must first be modelled. This section presents such modelling of the DPFC. As the DPFC serves the power system, the model should describe the behaviour of the DPFC at the system level, which is at the fundamental and the 3rd harmonic frequency.

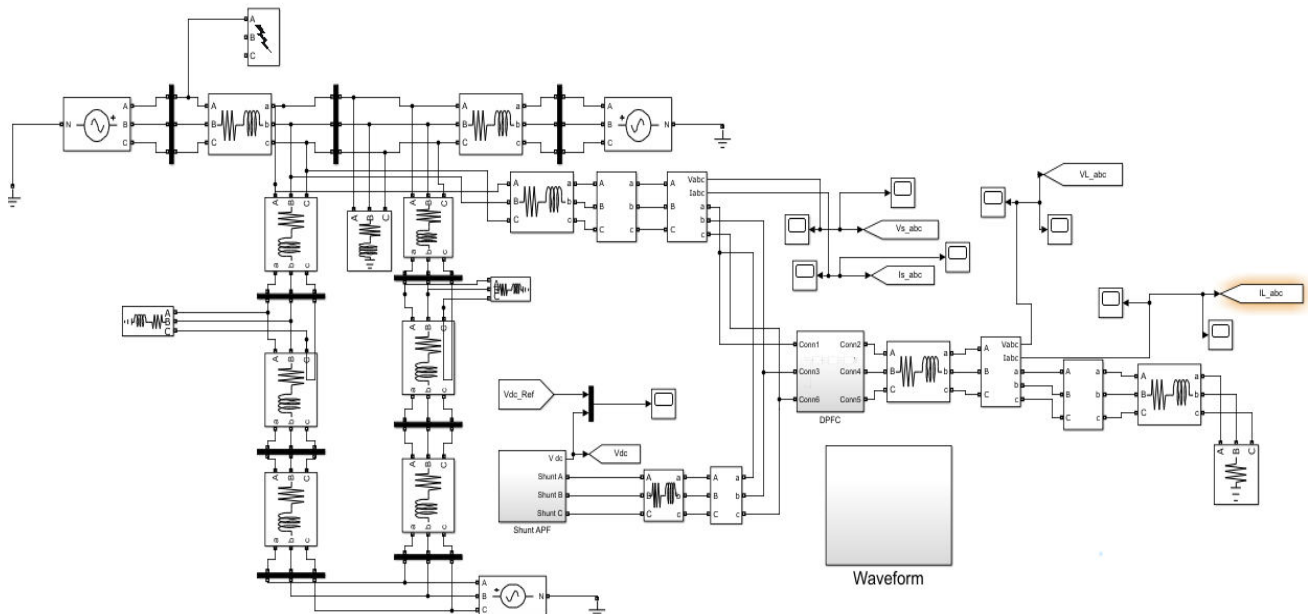


Figure1.3: Simulink model of DPFC based System

The DPFC series converters are identical, as are their models. The series converter is PWM control single-phase converter. Its simplified configuration is shown in Figure 1.4. As mentioned before, the switching behavior of the converter is not considered. To simplify the analysis, the loss of the converter is neglected.

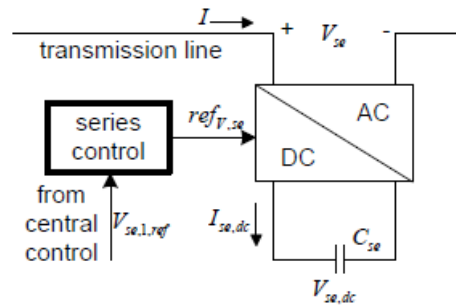


Fig 1.4 Simplified diagram of a series converter

The shunt converter consists of a three-phase converter that is back-to-back connected to a single-phase converter. Similar as a STATCOM, the three-phase converter is connected to the low-voltage side of the Y transformer to absorb active power from the grid.

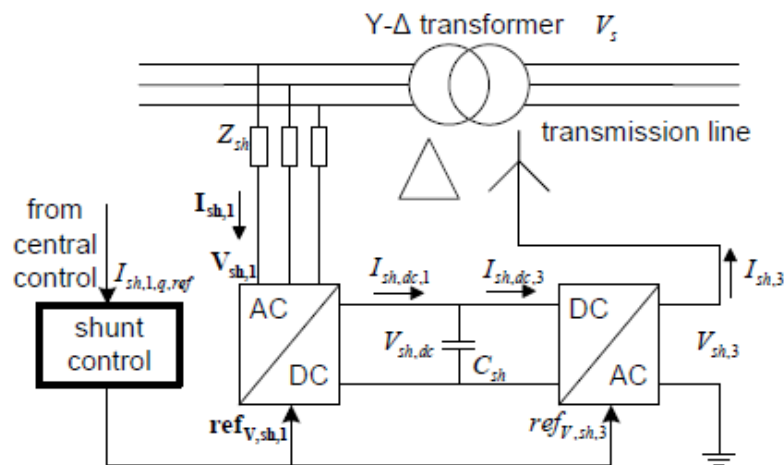


Figure 1.5 Simplified diagram of the shunt converter

VI. DPFC BASIC CONTROL

Based on the DPFC model presented previously, the control can now be further developed. The DPFC basic control consists of the series control and the shunt 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 shunt converter contains two converters as described in Figure 1.5. 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.

VII. SIMULATION RESULTS AND DISCUSSION

The DPFC modeling and control are simulated in the Mat lab Simulink. The schematic of the DPFC system in the simulation is shown in Figure 1.6. To simplify the calculation, one set of series converters is used to represent the distributed converters.

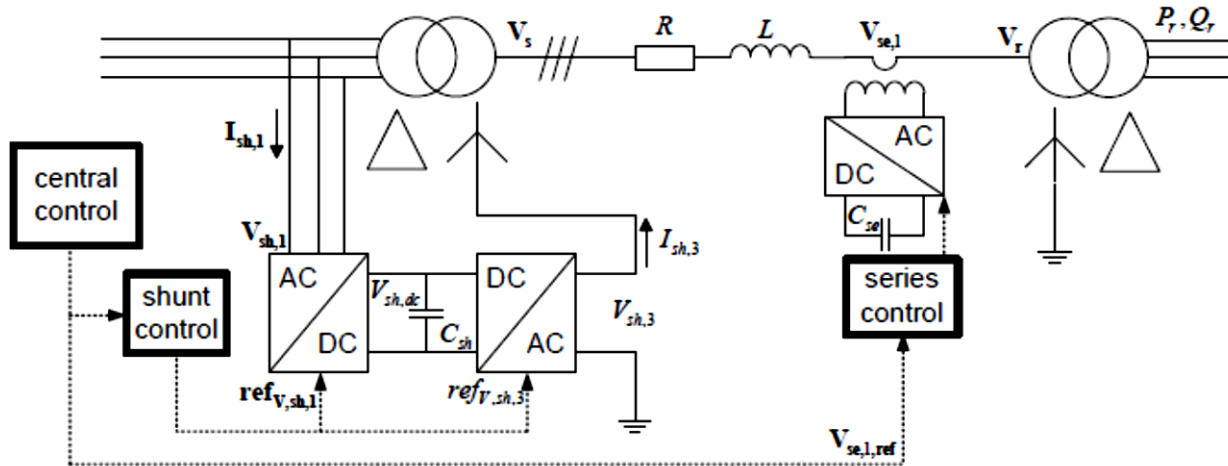


Figure1.6: DPFC system in the simulation

The capability of injecting a controllable 360° series voltage is signified by the independent control of the active power flows at the receiving end. A step change of the reference of the active power flows is made for the DPFC as shown in Figure1.7

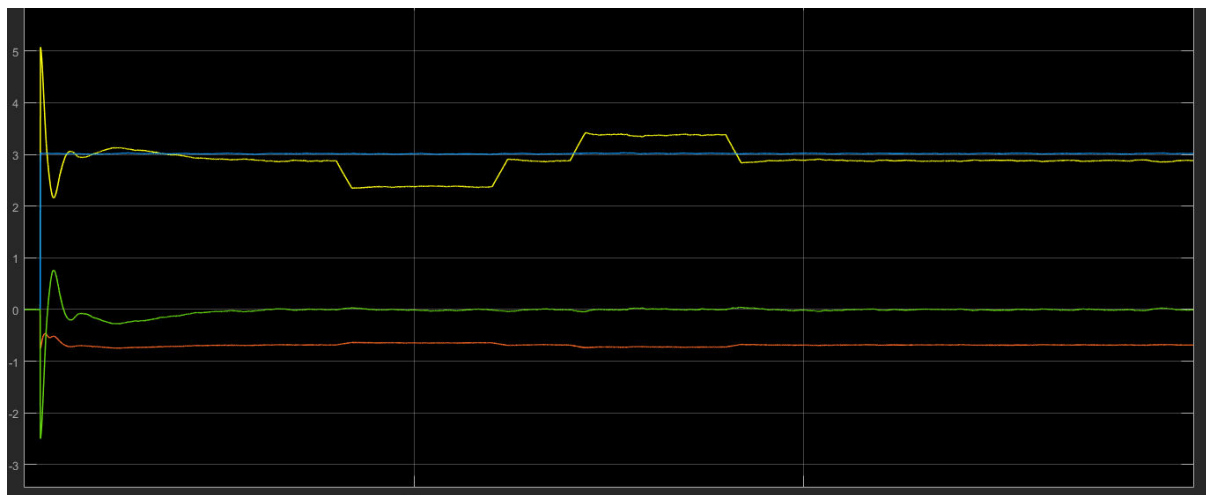


Figure1.7: Active power flow

As shown, the active power (Blue color- Source active power, Yellow color- Load active power, Green Color- Series Controller active power, Red color- Shunt controller active power) can be independently controlled, which indicates that the DPFC is capable of injecting the 360° controllable voltage at the fundamental frequency. The transients are caused by the variation in the DC voltages of the series converters. The DC voltages of the DPFC converters are shown in the following figures:

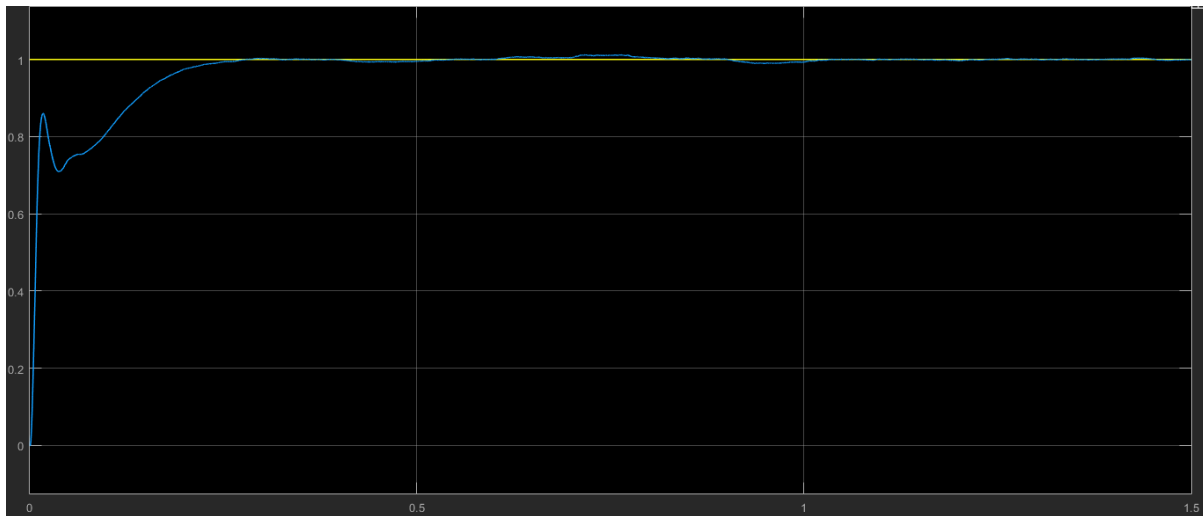


Figure1.8: Reference and Real DC voltages of the DPFC

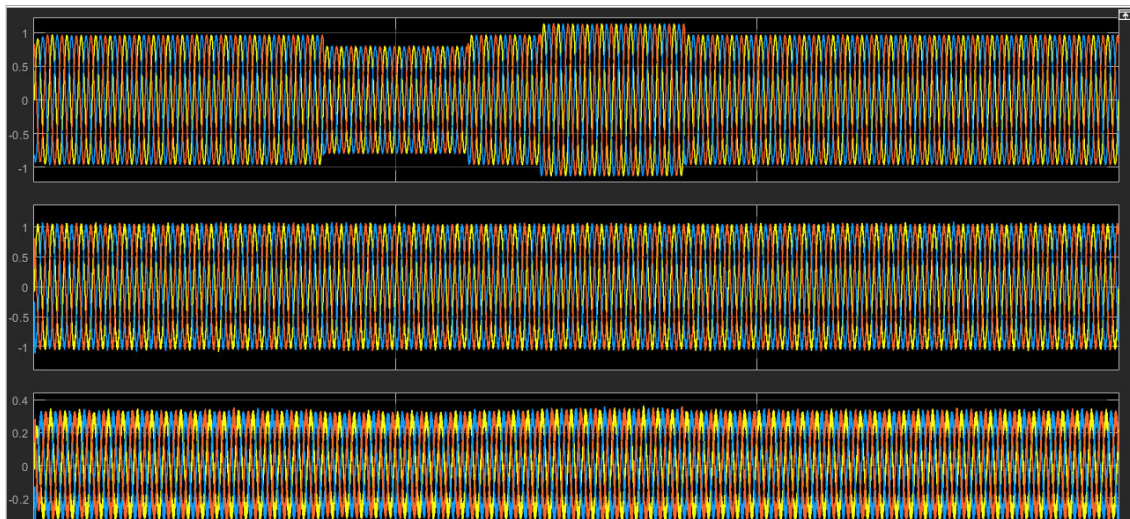


Fig.1.9 Source, Load, Series controller voltages

VIII. CONCLUSION

DPFC can be seen as an advanced or modified version of UPFC. It also inherits the control capability of the UPFC, which is the simultaneous adjustment of the line impedance, transmission angle and the magnitude of the bus voltage. The common DC link between the series and shunt converters, used to exchange active power in the UPFC is removed. The series converter of DPFC uses the concept D-FACTS, which uses multiple small single phase converters instead of a large inverter. DPFC reliability is greatly increased due to the redundancy of the series converters. The total cost of DPFC is also much lower than the UPFC, because no high voltage isolation is required and the rating of the components is quite low.

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