International Journal of Emerging Trends in Engineering and Basic Sciences (IJEEBS)
ISSN (Online) 2349-6967
Volume 2, Issue 3(May-June 2015), PP 30-37

Enhancement of Power Quality by Using Distributed Power Flow

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Abstract :- This paper presents the overview of Distributed Power Flow Controller which is a recent inclusion in D-FACTS family. The deregulated power environment demands low cost, high impact power quality devices. The DPFC emerges from the UPFC and inherits the control capability of the UPFC, which is the simultaneous adjustment of the line impedance, the transmission angle, and the bus-voltage magnitude. DPFC controllers have more reliability and cost saving approachover UPFC controller. The reliability of the DPFC is greatly increased because of the redundancy of the series converters.

Keywords :- FACTS, D-FACTS, UPFC, DPFC, power quality, converters, steady state analysis.

I. INTRODUCTION

Power quality is a major concern when it is delivered to large industrial consumers. The reforms to achieve the set target for restructuring in power sector are taking shape closer to its perfection. FACTS controllers are typically high power, high voltage converters used in transmission and distribution networks.In general, FACTS controllers are divided into four categories namely series, shunt, combined series-series and combined series-shunt controller. A distributed FACTS (D-FACTS) device has been recently introduced in the FACTS family and gaining importance because of several merits over conventional FACTS devices. It also has several configurations such as series and shunt and their combinations. DFACTS exhibits much lower cost and higher reliability than the conventional FACTS devices mainly UPFC. A Distributed Power Flow Controller (DPFC) has been derived from UPFC and has same capability of simultaneously adjusting all the parameters of power system such as line impedance, transmission angle and bus voltage magnitude.The prime advantage of DPFC is the elimination of common DC link between shunt and series converters and uses transmission line to exchange active power between converters at 3rdharmonic frequencies. Instead of one large 3 phase converter, it employs multiple single phase converters as series compensator. This concept reduces the rating of componentsand provides a high reliability because of its redundancy.

II. DPFC PRINCIPLE

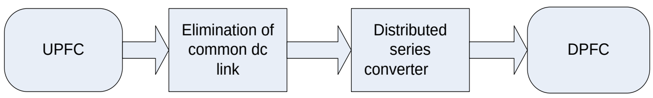

Figure. 1 DPFC Block Diagram

Figure 1 shows block diagram representation of DPFC. It has one shunt and several series converters. The shunt converter resembles a STATCOM whilethe series converter employs the D-FACTS concept, which uses multiple single-phase converters instead of one large converter. Eachconverter within the DPFC is independent andhas its own dc capacitor to provide the required dc voltage. Theconfiguration of the DPFC is shown in Fig. 2. DPFC also requires a high-pass filter thatis shunt connected at the other side of the transmission line, andtwo Y–Δ transformers at each side of the line.The high-pass filter within the DPFC blocks the fundamental frequency components and allows the harmonic components topass, thereby providing a return path for the harmonic components.The shunt and series converters, the high-pass filter, andthe ground form the closed loop for the harmonic current. The unique control capability of UPFC is given by theback-to-back connection between the shunt and series converters,which allows the active power to exchange freely. To ensurethat the DPFC have the same control capability as the UPFC,a method that allows the exchange of active power betweenconverters with eliminated dc link is the prerequisite.

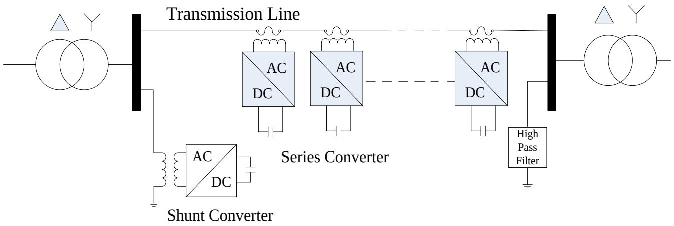

Figure. 2 Configuration of DPFC

The third harmonic is selected for its unique characteristics to exchange the active power in the DPFC. In a three-phase system, the 3rd harmonic in eachphase is identical, which means they are zero-sequence components. Because the zero-sequence, harmonic canbe naturally blocked by star-delta transformers and these are widely incorporated in power systems (as a meansof changing voltage), there is no extra filter required to prevent harmonic leakage. The third-, sixth- & ninth harmonic frequencies are all zero-sequence (theoretically), and all can be used to exchange active power in the DPFC.As it is well known, the capacity of a transmissionline to deliver power depends on its impedance. Sincethe transmission-lineimpedance is inductive and proportionalto the frequency, high-transmission frequencies will cause highimpedance. Consequently, the zero-sequence harmonic with thelowest frequency—third harmonic is selected.

Distributed Series Converter

The idea of the D-FACTS to use a large number of controllers with low rating instead of one large rated controller. A single phase converter is the small controller attached to the transmission lines by a single phase transformer. For avoiding the high cost of isolation, the converters are hanged on the line.The single-turn transformeruses the transmission line as the secondary winding, insertingcontrollable impedance into the line directly.

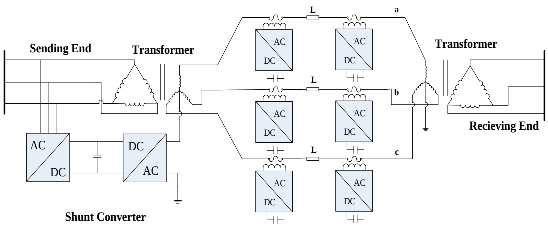

Figure. 3 DPFC Connections in Three Phase

DPFC Control

DPFC consists of three types of controllers; they are central controller, shunt control, and series control. The central control takes account of the DPFC functions at the power-system level. The shunt and series control are local controllers maintains their own converter's parameters.

Central Control

The reference signals for both the shunt and series converters of the DPFC are generated by the central controller. 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. Based on the system requirement, the central control gives corresponding voltage-reference signals for the series converters and reactive current signal for the shunt converter. At the fundamental frequency, all reference signals generated by the central control.

Series Control

Series converters have individual series control. The controller is used to maintain the capacitor dc voltage of its own converter by using the third-harmonic frequency components and to generate series voltage at the fundamental frequency that is prescribed by the central control. The third-harmonic frequency control is the major control loop with the DPFC series converter control. The principle of the vector control is used here for the dc-voltage control. The third-harmonic current through the line is selected as the rotation reference frame for the single-phase park transformation, because it is easy to be captured by the phase-locked loop (PLL) in the series converter. As the line current contains two frequency components, a third high-pass filter is needed to reduce the fundamental current. The d-component of the third harmonic voltage is the parameter that is used to control the dc voltage, and its reference signal is generated by the dc-voltage control loop. To minimize the reactive power that is caused by the third harmonic, the series converter is controlled as a resistance at the third-harmonic frequency. The q-component of the third-harmonic voltage is kept zero during the operation.

There will be voltage ripple at the dc side of each converter. The frequency of the ripple depends on the frequency of the current that flows through the converter. As the current contains the fundamental and third harmonic frequency component, the dc-capacitor voltage will contain 100-, 200-, and 300-Hz frequency component. There are two possible ways to reduce this ripple. One is to increase the turn ratio of the single-phase transformer of the series converter to reduce the magnitude of the current that flows into the converter. The other way is to use the dc capacitor with a larger capacitance.

Shunt Control

The shunt control injects a constant third harmonic current into the line to provide active power for the series converters. The third-harmonic current is locked with the bus voltage at the fundamental frequency. A PLL is used to capture the bus-voltage frequency, and the output phase signal of the PLL is multiplied by three to create a virtual rotation reference frame for the third-harmonic component. The shunt converter's fundamental frequency control aims to inject a controllable reactive current to grid and to keep the capacitor dc voltage at a constant level. The control for the fundamental frequency components consists of two cascaded controllers. The current control is the inner control loop, which is to modulate the shunt current at the fundamental frequency. The q-component of the reference signal of the shunt converter is obtained from the central controller, and d-component is generated by the dc control.

ISSN (Online) 2349-6967
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III. STEADY STATE ANALYSIS

The steady-state behavior and the control capability of the DPFC are analyzed and expressed in the parameters of both the network and DPFC itself. For simplification, the converters are replaced by controllable voltage sources in series with impedance. Each converter generates voltages at two different frequencies; so 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. 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.This representation consists of both the fundamental frequency and 3rdharmonic frequency components. For an easier analysis, based on the superposition theorem, the circuit can be further simplified by splitting it into two circuits at different frequencies. The two circuits are isolated from each other, and the link between these circuits is the active power balance of each converter, as shown in Fig 4.The power flow control capability of the DPFC can be illustrated by the active power Pr and reactive power Qrat the receiving end, shown in Fig. 4 and Fig. 5.

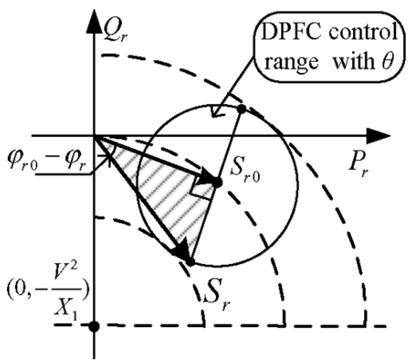

Figure. 4. Maximum Active Power Requirement of Series Converter

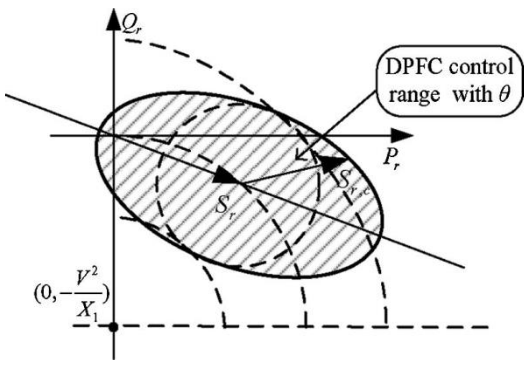

Figure .5 DPFC power-flow control range.

$$Pr+Qr= VI^* = \frac{Vr(Vs-Vr-Vse,1)}{jX1}$$

Where the phasor values are used for voltages and currents, * means the conjugate of a complex number and X1 = ωL is the line impedance at the fundamental frequency. The power flow (Pr,Qr) consists of two parts: the power flow without DPFC compensation (Pr0,Qr0) and the part that is varied by the DPFC (Pr,c,Qr,c). The power flow without DPFC compensation (Pr0, Qr0) is given by (fig 4e),

$$Pr0+Qr0 = VI^* =\left[\frac{Vr(Vs-Vr)}{jX1} \right]^* \quad ....(3)$$

Accordingly, by substituting (3) into (2), the DPFC control range on the power flow can be expressed as:

$$Pr,c+Qr,c= VI^* =\left(\frac{Vse}{jX1} \right)^* ....(4)$$

As the voltage at the receiving end and the line impedance are fixed, the power flow control range of the DPFC is proportional to the maximum voltage of the series converter. Because the voltage V*se,1can be rotated 360◦, the control range of the DPFC is a circle in the complex PQ-plane, whose center is the uncompensated power flow (Pr0,Qr0) and whose radius is equal to |Vr||Vse,1|/X1. By assuming that the voltage magnitude at the sending and receiving ends are both V, the control capability of the DPFC is given by the following formula,

$$(P_r-P_{r0})^2+ (Q_r-Q_{r0})^2 = \left(\frac{|V|\ |Vse,1|}{X1}\right)^2 .... (5)$$

In the complex PQ-plane, the locus of the power flow without the DPFC compensation f(Pr0,Qr0) is a circle with radius |V| 2 / X1 around its center (defined by coordinates P = 0 and Q = |V| 2 / X1 . Each point of this circle gives Pr0 and Qr0 values of the uncompensated system at the corresponding transmission angle θ. The boundary of the attainable control range for Pr and Qr is obtained from a complete rotation of the voltage Vse, 1 with its maximum magnitude. Figure 10 shows the power flow control range of the DPFC with the transmission angle θ.

IV. SOLUTION METHODOLOGY

To simulate the effect of the DPFC on distributed system is processed using MATLAB, oneshunt converter and two single phase series converters arebuilt and tested. The test data specifications of the DPFC in MATLAB are listed below.

TABLE 1

Parameters	Value
Sending end voltage (Vs)	200 V
Receiving end voltage (Vr)	200 V
Series converter voltage (Vse)	120 V
Shunt converter voltage (Vsh)	120 V
Line resistance (r)	0.3864 Ω/km
Line inductance (L)	4.1264 mH/km
Source resistance (rs)	0.8929 Ω
Source inductance (Ls)	16.58 mH
Series capacitor (Cse)	1 μF
Shunt capacitor (Csh)	1 μF

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V. RESULTS

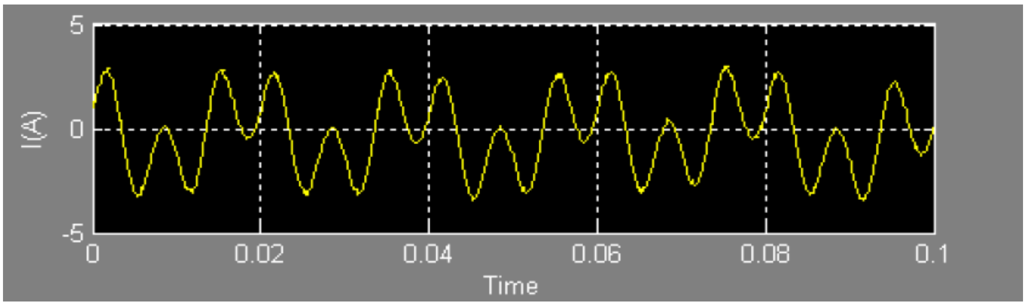

Figure. 6 DPFC operation in steady-state: line current

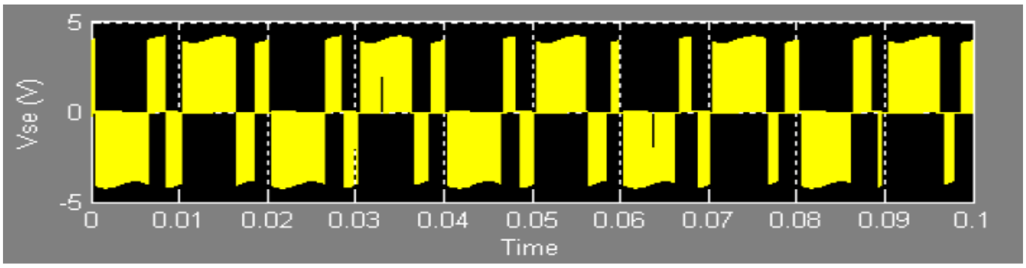

Figure. 7 DPFC operation in steady-state: series converter voltage

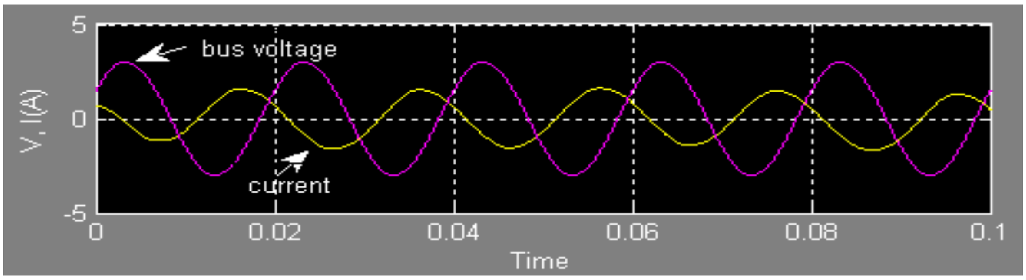

Figure. 8 DPFC operation in steady-state: bus voltage and current at the Δ side of the transformer

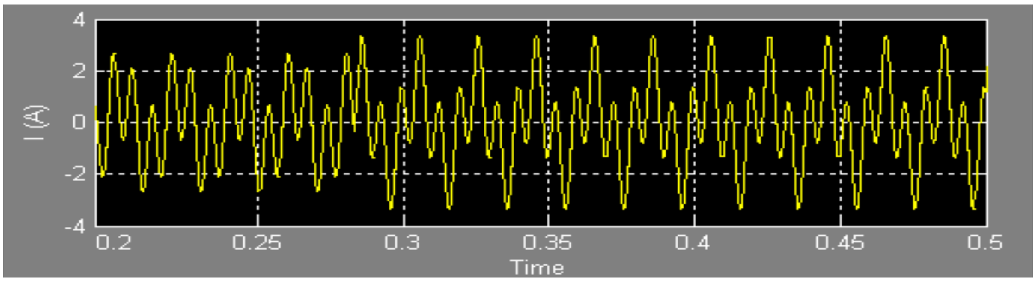

Figure. 9 Step response of the DPFC: line current

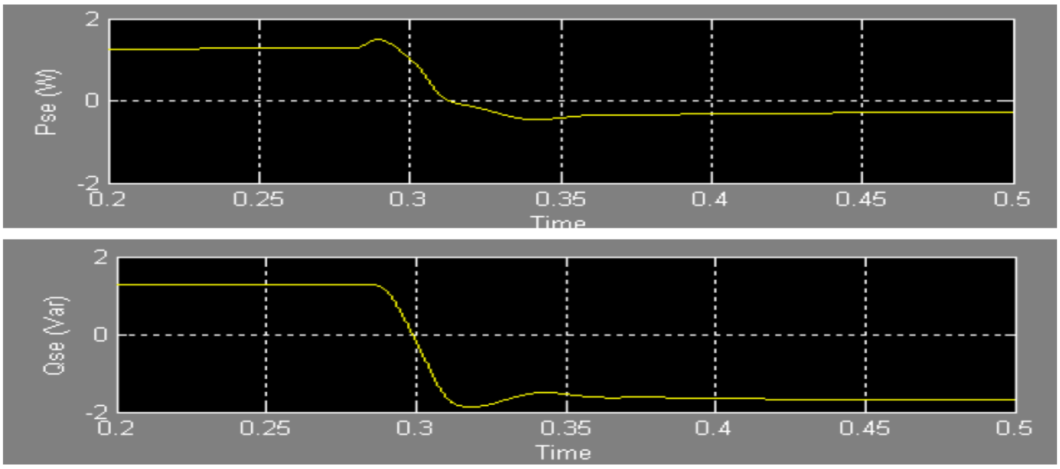

Figure. 10 Step response of the DPFC: active and reactive power injected by the series converter at the fundamental frequency

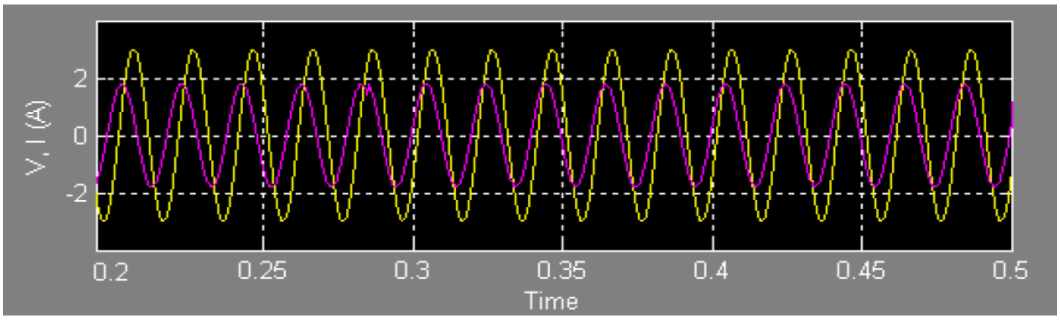

Figure. 11 Step response of the DPFC: bus voltage and current at the Δ side of the transformer

Under steady-state conditions the series converter is controlled to inject a fundamental voltage of 2V. The line current, voltage injected by the series converter and the voltage and current at the Δ-side of the transformer are shown in Fig. 6 to 8. The constant third harmonic current injected by the shunt converter evenly disperses to the three phases and is superimposed on the fundamental current as shown in Fig. 6. It is observed from Fig. 7.that the voltage injected by series converter is a pulse width modulated (PWM) waveform containing two frequency components. The amplitude of the waveform represents the dc-capacitor voltage at the line side of the transformer.

The step response results are shown in Fig. 9.to 11. A step change of the fundamental reference voltage of the series converter is made as shown in Fig. 10. It consists of both active and reactive variations. The dc voltage of the series converter is stabilized before and after the step change. The line current through the line is shown in Fig. 9. It is observed that the change in the voltage injected by the series converter changes the current flowing through the line. The active and reactive powers injected or absorbed by the series converter are shown in Fig. 10.

It is observed from Fig. 11.that the Δ-side of the network contains no 3rd harmonic component.

VI. CONCLUSION

The above discussion reflects various work and philosophies are covered in the area of DPFC. It provides widespread, versatile control for power systems. Due to the high control capability, the DPFC can alsobe used to improve the power quality and system stability,such as low-frequency power oscillation damping, voltage sag restoration, or balancing asymmetry. The shunt and series converters are independent, and the failure at one place will not influence the other converters.DistributedFACTS devices may offer a new approach to meeting this criticalneed.

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