RESEARCH ARTICLE OPEN ACCESS

Performance Of Distributed Power Flow Controller (DPFC) Under Fault Condition

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Abstract :
In this paper power quality issues are improved using Distributed Power Flow Controller (DPFC). The DPFC is basically derived from the unified power-flow controller (UPFC) and DPFC has the same control capability as the UPFC. The UPFC can be replaced by the DPFC with elimination of common dc link. In the DPFC active power takes place between the shunt and series converters through the transmission lines at the 3rd harmonic frequency. The DPFC employs the distributed FACTS (D-FACTS) idea, which is to use multiple small-size single phase converters instead of the one large-size three-phase as in UPFC. So the cost of the DPFC system is lower than the UPFC. The dynamic performance of the DPFC has been studied in this paper by considering symmetrical three phase fault near to the load end. Finally MATLAB/SIMULINK results indicate improved performance in voltage sag mitigation, notable reduction in harmonic of load voltage and enhance power flow control.
Keywords- DPFC, sag mitigation, load voltage harmonic reduction, power flow control.

I. Introduction

The emphasise of high quality electrical power is owing to increase in electricity requirements and also due to increase in non linear loads increase in electricity requirement and in number of non-linear loads in power grids [1]. Flexible alternating current transmission system (FACTS) and custom power devices, improves power quality improvement progressively [2]. The effective FACTS device is one which can simultaneously control all system parameters: the bus voltage, the transmission angle and the line impedance. The unified power-flow controller (UPFC) is the most powerful FACTS device, which can simultaneously control all the above system parameters [3]. The UPFC is the combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC), both are linked via a common dc link, to permit bidirectional flow of active power between output terminals of the SSSC and the STATCOM as shown in Fig. 1. The UPFC converters 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. But in practice the UPFC is not widely applied, because firstly the components of the UPFC handle the currents and voltages of high rating; so, the total cost of the system becomes very high and secondly due to the common dc-link which is an interconnection between series and shunt convertors therefore on any failure that happens at one converter will influence the whole system.

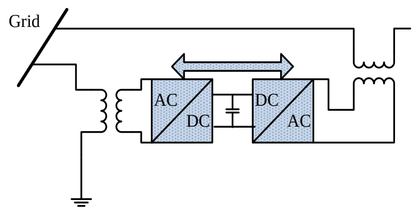

Fig. 1 Block representation of a UPFC.

The UPFC can be considered as a DPFC with an elimination of common dc link between series and shunt convertor as shown in Fig. 2. And the active power exchange between the shunt and the series converter is now through the transmission line at the 3rd harmonic frequency [4].

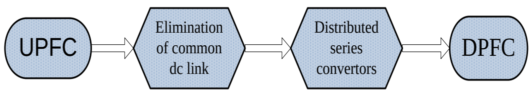

Fig. 2 Conversion from UPFC to DPFC.

The DPFC has two major advantages over the UPFC: 1) low cost because of the low voltage isolation and the low component rating of the series converter and 2) high reliability because of the redundancy of the distributed series converters. The structure of the DPFC is derived from the UPFC structure that which includes one shunt converter and number of small independent series converters, as shown in Fig. 3.

In this paper a symmetrical fault is considered near the load end. By taking appropriate controlling parameters of DPFC, DPFC mitigates the load voltage sag as well as reduces the load voltage harmonics in seconds. Further the dynamic performance of DPFC is studied and results indicate improvement power quality and enhanced power flow control.

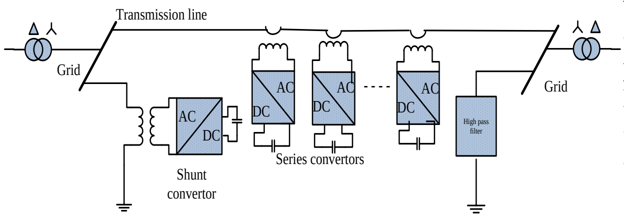

Fig. 3 Simplified DPFC structure.

II. Operating Principle Of Dpfc

There are two approaches that applied to the UPFC for modelling of DPFC

A. Elimination of DC Link

In case of DPFC, the transmission line is used as a connection between the dc terminal of shunt converter and the ac terminal of series converters, instead of direct connection using dc-link for power exchange between converters. The method of power exchange in DPFC is based on power theory of non-sinusoidal components [4]. Based on Fourier series, a non-sinusoidal voltage or current can be presented as the sum of sinusoidal components at different frequencies. The product of voltage and current components provides the active power, since the integral of some terms with different frequencies are zero. Mathematically the active power equation is as follow:

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

From equation (1) the active power 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. After applying the above concept to the DPFC, the shunt converter can take active power from the grid at the fundamental frequency and inject the power back to grid at a harmonic frequency as shown in Fig. 4. The transmission line carries dual power one at fundamental frequency and other at 3rd harmonic frequency, using Superposition theorem both power can be attained. The high-pass filter in the DPFC structure blocks the fundamental frequency components and allows the harmonic components to pass in ground, thereby providing a return path for the harmonic components. The series and shunt converters, the ground, and the high-pass filter form the closed loop for the harmonic current. Due to the unique characters of 3rd harmonic frequency components, it is selected to exchange the active power between series and shunt convertors in the DPFC. The reasons to select 3rd harmonic for exchange of active power between shunt and series convertors are as following:

- Higher transmission frequencies will cause high impedance and lead to an increase of voltage level of converters.
- The third harmonic in each phase is identical in a three-phase system.
- The third harmonic is same as the zero-sequence. The zero sequence current can be naturally blocked by Y–Δ transformers there is no any requirement of costly filter to block of harmonic current from receiving end.

B. Distributed Series Converters Concept

For a lower cost and higher reliability, the distributed FACTS was invented [5]. Distributed FACTS device (D-FACTS) is the concept to use multiple low-power converters attached to the transmission line by single turn transformers [6]. The converters are hanging on the line so that no costly high voltage isolation is required. The distributed series convertors take the active power at 3rd harmonic frequency from transmission line and inject it back into the line at fundamental frequency as per disturbances.

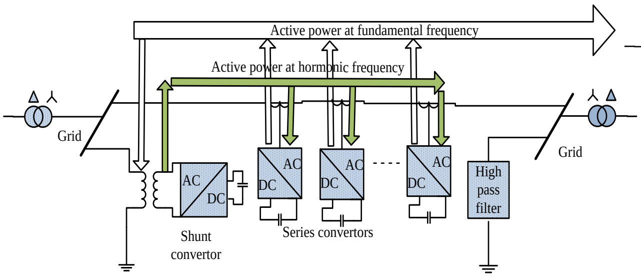

Fig. 4 Active power exchange between converters of DPFC.

C. *The DPFC Advantages*

The DPFC has some advantages over UPFC, as follows:

- High Control Capability
  The DPFC alike UPFC, can control all parameters of transmission network, such as line impedance, bus voltage magnitude and transmission angle.
- High Reliability
  The distributed series converters redundancy increases the DPFC reliability during these converters operation. It means, if one of distributed series converters fails, the other converters can continue to work.
- Low Cost

The single-phase distributed series converters rating are less than one three-phase converter. Furthermore, the series converters do not need any high voltage isolation in transmission line connecting in the DPFC; single-turn transformers can be used to floating the series converters.

III. CONTROL Of DPFC

The DPFC consists of three types of controllers to control the converters:

A. Central Control

The central control generates the reference signals for both the shunt and series converters of the DPFC as shown in Fig. 5. Its control function depends on the specifics of the DPFC application at the power system level. By using concept of single phase to d-q transformation, according to the system requirements, the central control provides corresponding current signal for the shunt converter and voltage reference signals for the series converters [7]. All the reference signals for series and shunt generated by the central control concern the fundamental frequency components.

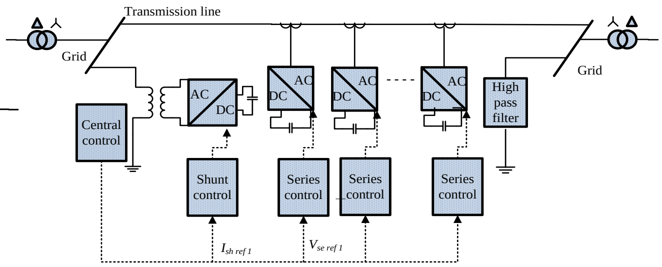

Fig. 5 DPFC central control block diagram.

B. Series Control

Every series converter has its own series control. The controller is used to maintain the dc capacitor voltage of its own converters, by using 3rd harmonic frequency components, in order to generate series voltage at the fundamental frequency as need by the central control The controller inputs are line current, series voltage reference in the d-q frame, and series capacitor voltages. The 3rd harmonic frequency control is the main control loop with the DPFC series converter control as Fig. 6. Vector control principle is used for the dc voltage control [7].

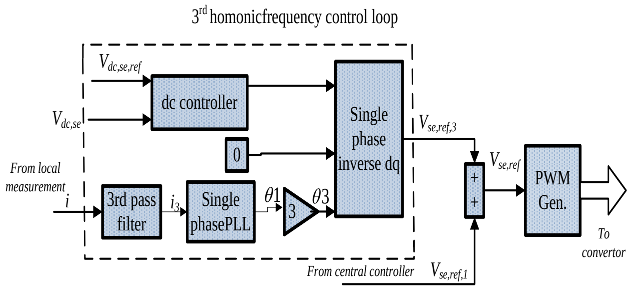

Fig. 6 DPFC series converter control.

C. Shunt Control

The main objective of the shunt control is in order to inject a constant 3rd harmonic current into the transformer neutral to supply active power for the series converters. At the same time, shunt control maintains the dc capacitor voltage of the shunt converter at a constant value by taking active power from the grid at the fundamental frequency and injecting the required reactive current at the fundamental frequency into the grid [8]. The fundamental frequency components control has two cascaded controllers to generate 3rd harmonic current. The current control is the inner control loop, which modulates the shunt current at the fundamental frequency. And dc controller control loop is used to maintain constant dc capacitor voltage.

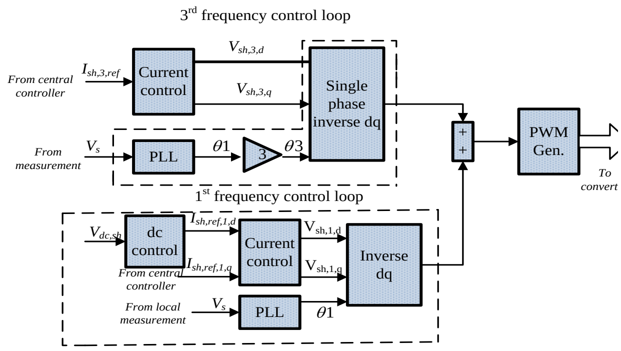

Fig. 7 shunt converter control.

IV. Power Quality Improvement

The whole model of system under study is shown in Fig. 8 and Fig 9. This system contains two three-phase identical sources at two buses and a nonlinear RLC load is connected at bus 2 and transmission line of 100km length. The DPFC is placed in transmission line, which the shunt converter is connected to the transmission line in parallel through a Δ- Y three-phase transformer, and series converters is distributed among the line. The system parameters are listed in appendix Table I. To simulate the dynamic performance of DPFC, a three-phase fault is considered near the load end. The time duration of the fault is from 0.2 seconds to 0.3 seconds. As shown in Fig. 10, significant voltage sag is observable during the fault, without any compensation (without DPFC). The voltage sag value is about 0.5 per unit. After adding a DPFC, load voltage sag can be mitigated effectively, as shown in Fig. 11.

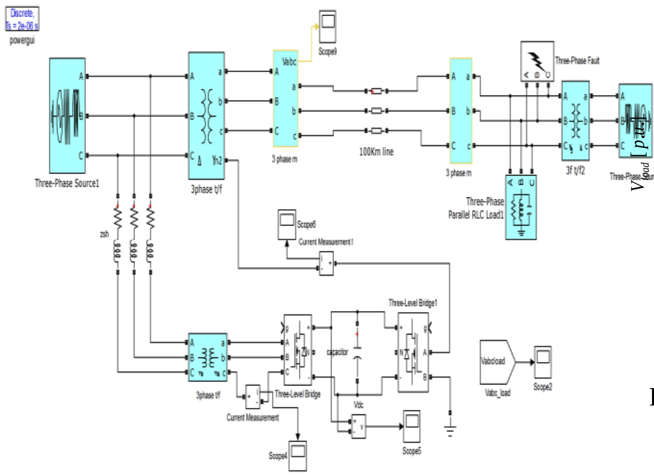

Fig. 8 Simulation model of system without the DPFC.

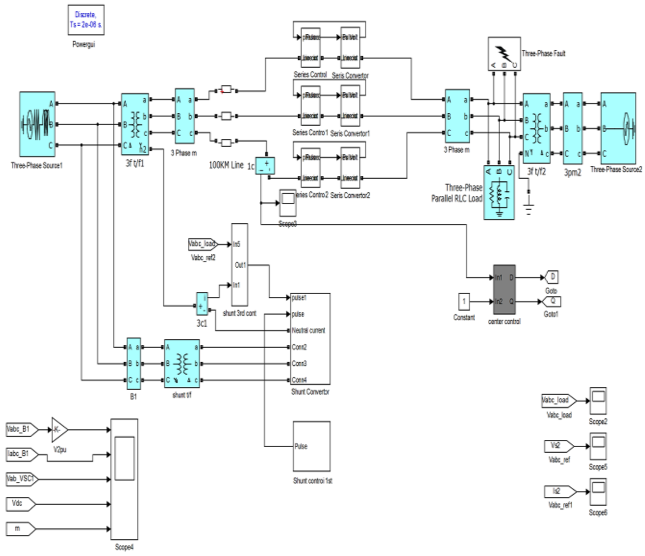

Fig. 9 Simulation model of system with the DPFC

V. Study Of Simulation Results

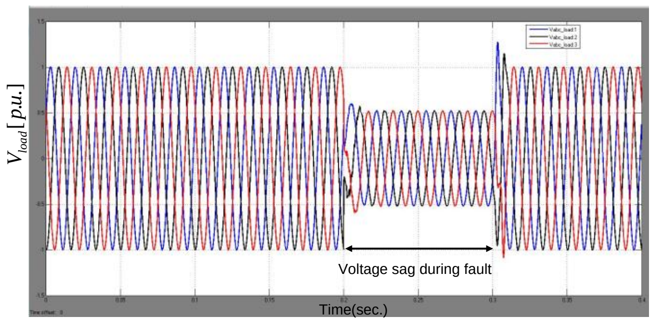

Fig. 10 Three-phase load voltage sag waveform during fault.

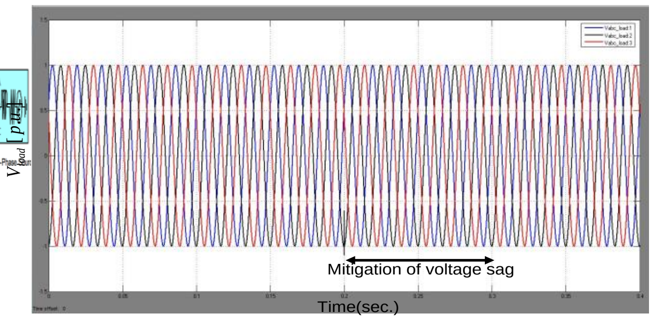

Fig. 11 Mitigation of three-phase load voltage sag with DPFC.

The load voltage harmonic analysis without presence of DPFC is illustrated in Fig. 12. It can be seen, after DPFC implementation in system, the even harmonics are eliminated, the odd harmonics are reduced within acceptable limits, and total harmonic distortion (THD) of load voltage is minimized from

0.12 to 0.01 percentage (Fig. 13), i.e., the standard THD is less than 5 percent in IEEE standard. The shunt convertor voltage is almost constant as shown in Fig. 14 which provides the active power for series convertors.

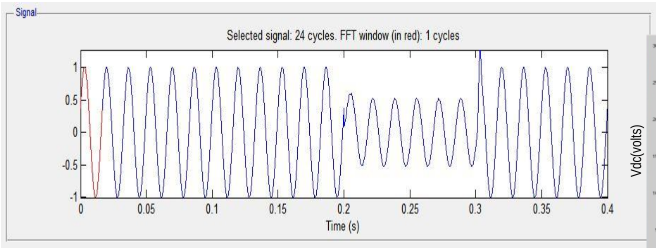

Fig. 12(a)

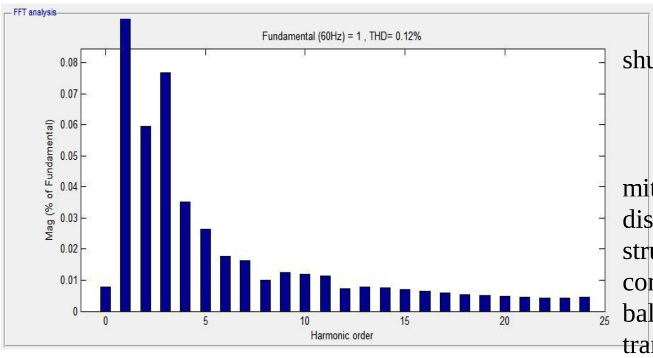

Fig. 12(b)

Fig. 12 (a). Load voltage signal selected for calculating THD

b). Total harmonic distortion in Fig. 12(a), without DPFC.

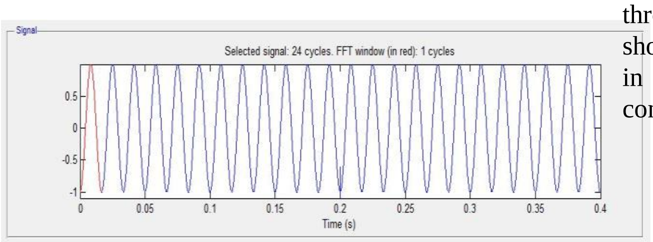

Fig. 13(a)

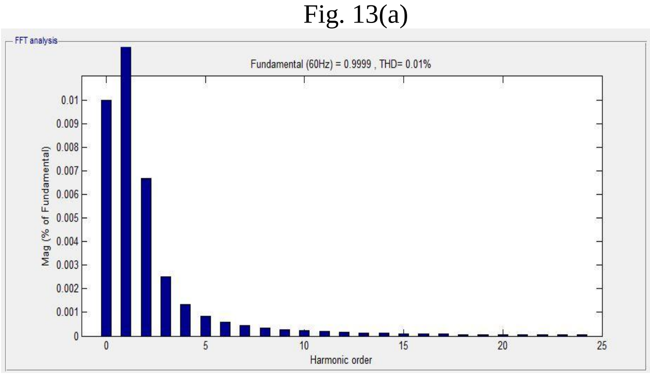

Fig. 13(b)

Fig. 13 (a). Load voltage signal selected for calculating THD

(b). Total harmonic distortion in Fig. 13(a), with DPFC.

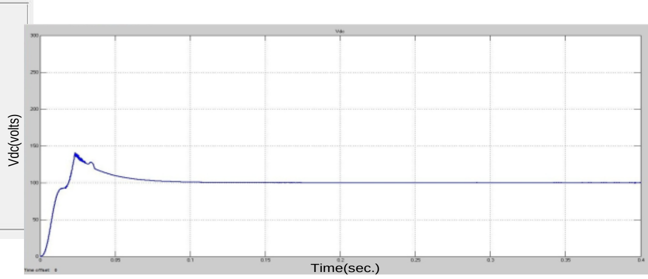

Fig. 14 Voltage across the capacitor of shunt converter.

IV. CONCLUSION

This paper presents, the voltage sag mitigation using a new FACTS device called distributed power flow controller (DPFC). The structure of DPFC is similar to unified power flow controller (UPFC) and has a same control capability to balance the line parameters, i.e., the bus voltage, the transmission angle and the line impedance. However, the DPFC offers some advantages, in comparison with UPFC, such as high control capability, high reliability, and low cost. The DPFC is modelled using three control loops. The system under study is a two machine infinite-bus system, with and without DPFC. To simulate the dynamic performance of DPFC, a three-phase fault is considered near the load end. It is shown that the DPFC has an acceptable performance in power quality improvement and for power flow control.

APPENDIX

TABLE I. The Simulated System Parameters

Symbols	Descriptions	Value	Unit
f	Rated frequency	60	Hz
V_s	Nominal voltage of sending end bus 's'	230	KV
V_r	Nominal voltage receiving end bus r	230	KV
θ	Transmission angle between buses s and r	1	degree
	Line length	100	km
L	Line inductance	6	mH
	Shunt convertor nominal power	50	KVA
V_{dc}	Shunt convertor capacitor voltage	100	V
	DC link capacitor	1800	μF
	Series coupling transformer turns ratio	5:25	
	Three phase fault type	ABC	
	Fault resistance	.111	Ohm

References

[1] Y. H. Song and A. Johns, *Flexible AC Transmission Systems (FACTS)* (IEE Power and Energy Series), vol. 30, London, U.K.: Institution of Electrical Engineers, 1999.

[2] N. G. Hingorani and L. Gyugyi, *Understanding FACTS : Concepts And Technology of Flexible AC Transmission Systems*. New York: IEEE Press, 2000.

[3] L. Gyugyi, C. D. Schauder, S. L. Williams, T. R. Rietman, D. R. Torgerson, and A. Edris, "The Unified Power Flow Controller: A New Approach to Power Transmission Control," *IEEE Trans. Power Del.*, vol. 10, no. 2, pp. 1085–1097, Apr. 1995.

[4] Zhihui Yuan, Sjoerd W.H de Haan, Braham Frreira and Dalibor Cevoric "A FACTS Device: Distributed Power Flow Controller (DPFC)," *IEEE Trans. on Power Electronics*, vol. 25, no. 10, Oct. 2010.

[5] Deepak Divan and Harjeet Johal, "Distributed FACTS – A New Concept For Realizing Grid Power Flow Control," *IEEE Power Electronics Specialists Conference*, pp. 8-14, June 2005.

[6] M. D. Deepak, E. B. William, S. S. Robert, K. Bill, W. G. Randal, T. B. Dale, R. I. Michael, and S. G. Ian, "A Distributed Static Series Compensator System For Realizing Active Power Flow Control on Existing Power Lines," *IEEE Trans. Power Del.*, vol. 22, pp. 642-649, Jan. 2007.

[7] Salaet, J. Alepuz, S. Gilabert and A. Bordonau, "DQ Transformation Development For Single Phase Systems to Compensate Harmonic Distortion And Reactive Power," *IEEE Power Electronics Specialists Conference*, pp. 177-182, Oct. 2004.

[8] K. Ramya and C. Christober Asir Rajan, "Analysis And Regulation of System Parameters Using DPFC," *IEEE International Conference on Advances in Engineering, Science And Management (ICAESM)*, pp. 505-509, March 2012.