HARMONICS REDUCTION AND POWER QUALITY IMPROVEMENT BY USING DPFC

Akula.N.V.V. Rajasekhar
Assistant Professor: EEE Department
ST. Ann's College of Engineering & Technology
Chirala, Andhra Pradesh
blosoms2007@gmail.com

Mamidi. Naveen Babu
Assistant Professor: EEE Department
ST. Ann's College of Engineering & Technology
Chirala, Andhra Pradesh
naveenbabumamidi@gmail.com

***Abstract*— The DPFC is derived from the unified power-flow controller (UPFC). The DPFC can be considered as a UPFC with an eliminated common dc link. The active power exchange between the shunt and series converters which is through the common dc link in the UPFC is now through the transmission lines at the third-harmonic frequency. The DPFC employs the distributed concept, in which the common dc-link between the shunt and series converters are eliminated and three-phase series converter is divided to several single-phase series distributed converters through the line. According to the growth of electricity demand and the increased number of non-linear loads in power grids harmonics, voltage sag and swell are the major power quality problems. DPFC is used to mitigate the voltage deviation and improve power quality. Simulations are carried out in MATLAB/Simulink environment. The presented simulation results validate the DPFC ability to improve the power quality.**

Keywords— ***load flow control, FACTS, Power Quality, harmonics, Sag and Swell Mitigation, Distributed Power Flow Controller, Y–Δ transformer***

I. INTRODUCTION

The increased demand and the aging of networks make it desirable to control the power flow in power-transmission systems fast and reliably. 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. A power quality problem can be defined as any problem is manifested on voltage, current, or frequency deviation that results in power failure. The power electronics progressive, especially in flexible alternating-current transmission system (FACTS) and custom power devices, affects power quality improvement. Currently, the unified power-flow controller (UPFC) is the most powerful FACTS device, which can simultaneously control all the parameters of the system. The components of the UPFC handle the voltages and currents with high rating; therefore, the total cost of the system is high. Due to the common dc-link interconnection, a failure that happens at one converter will influence the whole system. To achieve the required reliability for power systems, bypass circuits and redundant backups are needed, which on other hand, increase the cost. Accordingly, the UPFC has not been commercially used, even though, it has the most advanced control capabilities.

This paper introduces a new concept, called distributed power-flow controller (DPFC) that is derived from the UPFC. The same as the UPFC, the DPFC is able to control all system parameters. The DPFC eliminates the common dc link between the shunt and series converters. The active power exchange between the shunt and the series converter is through the transmission line at the third-harmonic frequency. The series converter of the DPFC employs the distributed FACTS concept.

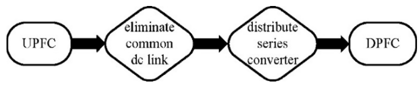

Fig. 1. Flowchart from UPFC to DPFC.

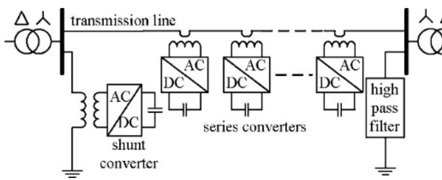

Fig. 2. DPFC configuration.

Comparing with the UPFC, the DPFC have two major advantages: 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 series converters.

II. DPFC PRINCIPLE

Two approaches are applied to the UPFC to increase the reliability and to reduce the cost. They are as follows. First, eliminating the common dc link of the UPFC and second distributing the series converter, as shown in Fig.1. By combining these two approaches, the new FACTS device—DPFC is achieved.

The DPFC consists of one shunt and several series-connected converters. The shunt converter is similar as a STATCOM,

978-1-4673-9939-5/16/$31.00 ©2016 IEEE

while the series converter employs the D-FACTS concept, which is to use multiple single-phase converters instead of one large rated converter. Each converter within the DPFC is independent and has its own dc capacitor to provide the required dc voltage. The configuration of the DPFC is shown in Fig. 2. Besides the key components, namely the shunt and series converters, the DPFC also requires a high-pass filter that is shunt connected at the other side of the transmission line, and two Y–Δ transformers at each side of the line.

The unique control capability of the UPFC is given by the back-to-back connection between the shunt and series converters, which allows the active power to exchange freely. To ensure that the DPFC have the same control capability as the UPFC, a method that allows the exchange of active power between converters with eliminated dc link is the prerequisite.

A. ELIMINATE DC LINK

Within the DPFC, there is a common connection between the ac terminals of the shunt and the series converters, which is the transmission line. Therefore, it is possible to exchange the active power through the ac terminals of the converters.

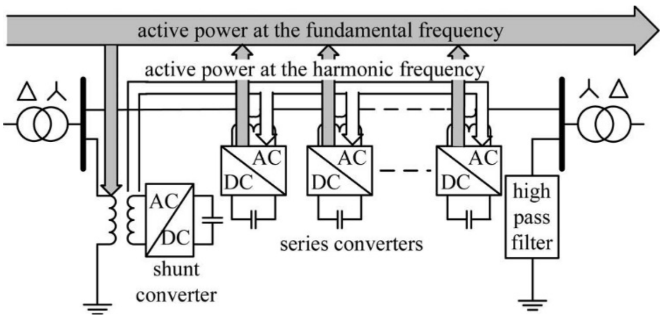

Fig. 3. Active power exchange between DPFC converters.

The method is based on the power theory of non-sinusoidal components. According to the Fourier analysis, a non-sinusoidal voltage and current can be expressed by 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

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

where V_i and I_i are the voltage and current at the ith harmonic frequency, respectively, and φ_i is the corresponding angle between the voltage and current. Equation (1) describes that the active power at different frequencies is isolated from each other and the voltage or current in one frequency has no influence on the active power at other frequencies. The independency of the active power at different frequencies gives the possibility that a converter without power source can generate active power at one frequency and absorb this power from other frequencies.

By applying this method to the DPFC, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the current back into the grid at a harmonic frequency. This harmonic current will flow through the transmission line. 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. Assuming a lossless converter, the active power generated at fundamental frequency is equal to the power absorbed from the harmonic frequency. For a better understanding, Fig. 3 indicates how the active power exchanges between the shunt and the series converters in the DPFC system.

The high-pass filter within the DPFC blocks the fundament 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 the closed loop for the harmonic current. Due to the unique characters of third-harmonic frequency components, the third harmonic is selected to exchange the active power in the DPFC. In a three-phase system, the third harmonic in each phase is identical, which is referred to as "zero-sequence." The zero-sequence harmonic can be naturally blocked by Y–Δ transformers, which are widely used in power system to change voltage level.

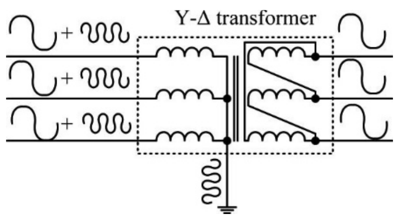

Fig. 4. Utilize grounded Y–Δ transformer to provide the path for the zero sequence third harmonic.

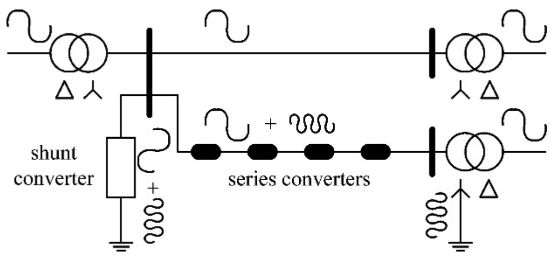

Fig. 5. Route the harmonic current by using the grounding status of the Y–Δ transformer.

Therefore, there is no extra filter required to prevent the harmonic leakage to the rest of the network. In addition, by using the third harmonic, the costly high-pass filter, as shown in Fig.3, can be replaced by a cable that is connected between the neutral point of the Y–Δ transformer on the right side in

Fig.2 and the ground. Because the delta winding appears open circuit to the third-harmonic current, all harmonic current will flow through the star winding and concentrate to the grounding cable, as shown in Fig. 4. Therefore, the large-size high-pass filter is eliminated.

Another advantage of using third harmonic to exchange active power is that the way of grounding of Y–Δ transformers can be used to route the harmonic current in a meshed network. If the branch requires the harmonic current to flow through, the neutral point of the Y–Δ transformer at the other side in that branch will be grounded and *vice versa*. Fig. 5 demonstrates a simple example of routing the harmonic current by using a grounding Y–Δ transformer. Because the transformer of the line without the series converter is floating, it is open circuit for third-harmonic components. Therefore, no third-harmonic current will flow through this line.

Theoretically, the third-, sixth-, and ninth-harmonic frequencies are all zero-sequence, and all can be used to exchange active power in the DPFC. As it is well known, the capacity of a transmission line to deliver power depends on its impedance. Since the transmission-line impedance is inductive and proportional to the frequency, high-transmission frequencies will cause high impedance. Consequently, the zero-sequence harmonic with the lowest frequency third harmonic is selected.

B. DISTRIBUTED SERIES CONVERTER

The D-FACTS is a solution for the series-connected FACTS, which can dramatically reduce the total cost and increase the reliability of the series FACTS device. The idea of the D-FACTS is to use a large number of controllers with low rating instead of one large rated controller.

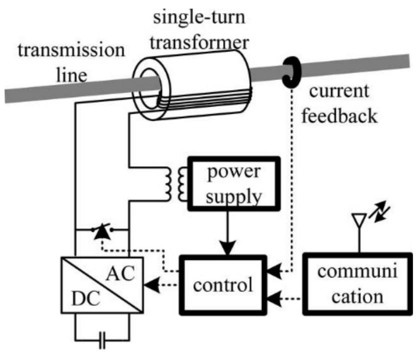

Fig. 6. D-FACTS unit configuration.

The small controller is a single-phase converter attached to transmission lines by a single-turn transformer. The converters are hanging on the line so that no costly high-voltage isolation is required. The single-turn transformer uses the transmission line as the secondary winding, inserting controllable impedance into the line directly. Each D-FACTS module is self-powered from the line and controlled remotely by wireless or power-line communication.

The structure of the D-FACTS results in low cost and high reliability. As D-FACTS units are single-phase devices floating on lines, high-voltage isolations between phases are avoided. The unit can easily be applied at any transmission-voltage level, because it does not require supporting phase-ground isolation. The power and voltage rating of each unit is relatively small. Further, the units are clamped on transmission lines, and therefore, no land is required. The redundancy of the D-FACTS provides an uninterrupted operation during a single module failure, thereby giving a much higher reliability than other FACTS devices.

III. DPFC CONTROL

To control the multiple converters, DPFC consists of three types of controllers. They are central controller, shunt control and series control as shown in Fig.7. The shunt and series control are local controllers and are responsible for maintaining their own converters parameters. The central control takes account of the DPFC functions at the power-system level.

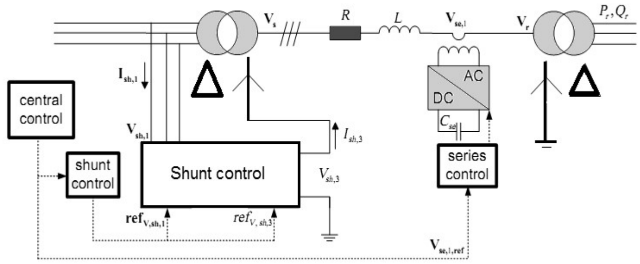

Fig.7. DPFC control structure

A. A. 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.

B. B. 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 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. As the series converter is single phase, 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 contain100-,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.

C. Shunt Control

The objective of the shunt control is to inject 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.

IV. POWER QUALITY IMPROVEMENT

The system contains a three-phase source connected to a nonlinear RLC load through parallel transmission lines (Line 1 and Line 2) with the same lengths. The DPFC is placed in transmission line, which the shunt converter is connected to the transmission line 2 in parallel through a Y-Δ three-phase transformer, and series converters is distributed through this line. To simulate the dynamic performance, a three-phase fault is considered near the load. The time duration of the fault is 0.5 seconds (500-1000 millisecond). As shown in Fig. 8, a significant voltage sag is observable during the fault, without any compensation. The voltage sag value is about 0.5 per unit. After adding a DPFC, load voltage sag can be mitigated effectively.

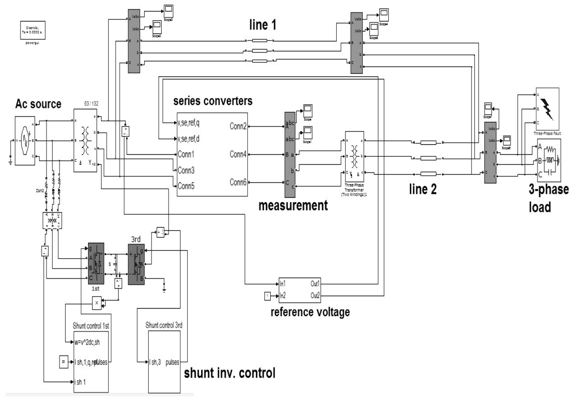

Fig.8 simulation model of DPFC

V. EXAMINING SIMULATION RESULTS

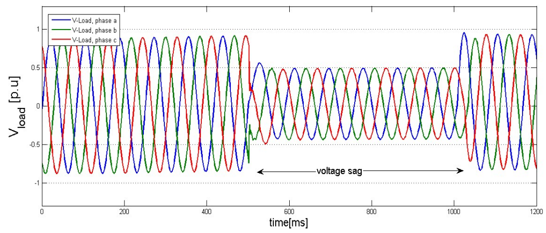

Fig 9. three phase voltage sag waveform without DPFC

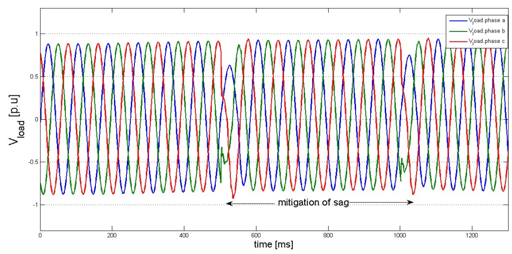

Fig. 10 three phase voltage sag waveform with DPFC

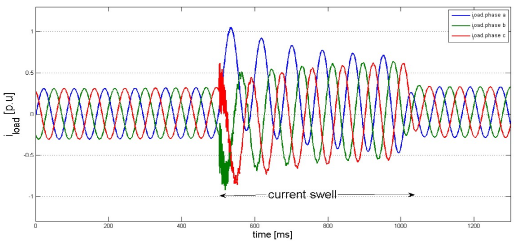

Fig.11 3-ϕ load current swell waveform without DPFC

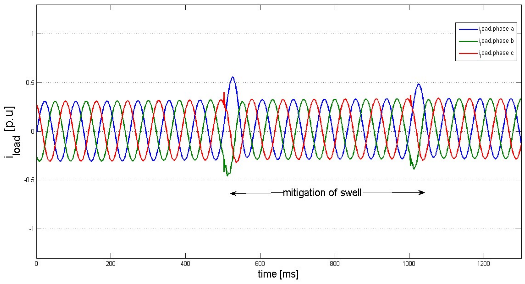

Fig.12 Mitigation of 3-ϕ load current swell with DPFC

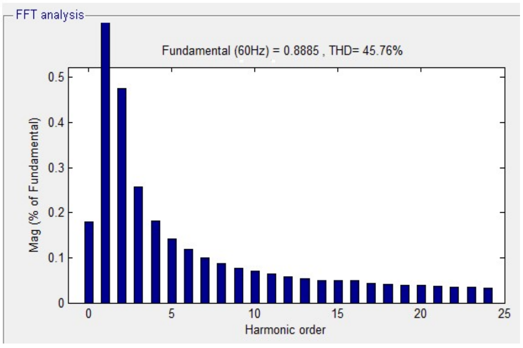

Fig.13 Total harmonic distortion of load voltage without DPFC

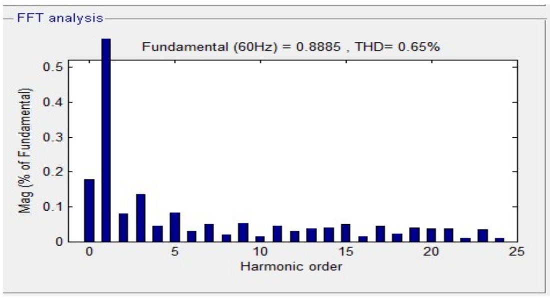

Fig.14Total harmonic distortion of load voltage with DPFC

VI. CONCLUSION

This paper has presented a new concept called DPFC. 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. 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 series converter of the DPFC employs the D-FACTS concept, which uses multiple small single-phase converters instead of one large-size converter. The reliability of the DPFC is greatly increased because of the redundancy of the series converters. 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 of is low. To improve power quality in the power transmission system, the harmonics due to nonlinear loads, voltage sag and swell are mitigated. To simulate the dynamic performance, a three-phase fault is considered near the load. It is shown that the DPFC gives an acceptable performance in power quality improvement and power flow control.

REFERENCES

[1] S.Masoud Barakati Arash Khoshkbar sadigh and Mokhtarpour.Voltage Sag and Swell Compensation with DVR Based on Asymmetrical Cascade Multicell Converter North American Power Symposium (NAPS),pp.1-7,2011.

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

[3] Zhihui Yuan, Sjoerd W.H de Haan and Braham Frreira “DPFC control during shunt converter failure*” IEEE Transaction on Power Electronics* 2009.

[4] 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, no. 1, pp. 642–649, Jan. 2007.

[5] D. Divan and H. Johal, “Distributed facts—A new concept for realizing grid power flow control,” in *Proc. IEEE 36th Power Electron. Spec. Conf. (PESC)*, 2005, pp. 8–14.

[6] Y. Zhihui, S. W. H. de Haan, and B. Ferreira, “Utilizing distributed power flow controller (dpfc) for power oscillation damping,” in *Proc. IEEE Power Energy Soc. Gen. Meet. (PES)*, 2009, pp. 1–5.

[7] Y. Zhihui, S. W. H. de Haan, and B. Ferreira, “Dpfc control during shunt converter failure,” in *Proc. IEEE Energy Convers. Congr. Expo. (ECCE)*, 2009, pp. 2727–2732.

[8] Y. Sozer and D. A. Torrey, “Modeling and control of utility interactive inverters,” *IEEE Trans. Power Electron.*, vol. 24, no. 11, pp. 2475–2483, Nov. 2009.

[9] L. Huber, B. T. Irving, and M. M. Jovanovic, “Review and stability analysis of pll-based interleaving control of dcm/ccm boundary boost pfc converters,” *IEEE Trans. Power Electron.*, vol. 24, no. 8, pp. 1992–1999, Aug. 2009.

[10] M. Mohaddes, A. M. Gole, and S. Elez, “Steady state frequency response of statcom,” *IEEE Trans. Power Del.*, vol. 16, no. 1, pp. 18–23, Jan. 2001.