International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 9, September - 2013

A New Distributed Power Flow Controller to Improve the Power Quality by Mitigating Voltage Sag and Swell

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Abstract- Now -a-days the power demanded by different consumers is much higher than the past days. This demand is due to the increased usage of electric power for different types of loads in balanced and unbalanced conditions. When the load on the consumer side is unbalanced, the current will flow through the neutral wire. Hence due to I^2R losses voltage drop will occur in neutral. As a result the quality of distribution of power gets decreases.

In order to improve the quality of power different techniques are adopted. Voltage sag and swell of the power quality issues are studying and the quality of power can be increased by using a FACTS device called Distributed Power Flow Controller (DPFC). This is used to mitigate the voltage deviation and improve power quality. The structure of this device is similar to that of UPFC (Unified Power Flow Controller), in spite the common dc-link between the shunt and series converters is eliminated and three-phase series converter is divided to several single-phase series distributed converters through the line.The operation and the control of DPFC which is connected to a single-machine infinite bus power system including two parallel transmission lines, the analysis is calculated/simulated in MATLAB/Simulink environment to improve the quality of power.

Key words – ***FACTS, Power Quality, Sag and Swell Mitigation, Distributed Power Flow Controller***

I.INTRODUCTION

For the last decade, the power quality problems has been the major concern of the power companies [1]. Power quality is defined as both the delivery and consumption of electric power affect on the performance of electrical apparatus [2]. From a customer point of view, power quality problem can be defined as any problem I manifested on voltage, current, or frequency deviation that results in power failure [3]. The power electronics progressive, especially in flexible alternating-current transmission system (FACTS) and custom power devices, affects power quality improvement [4], [5]. Generally, custom power devices, e.g., dynamic voltage restorer (DVR), are used in medium-to-low voltage levels to improve customer power quality [6]. Most serious threats for sensitive equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage) [1]. These disturbances occur due to some events, *e.g.*, short circuit in the grid, inrush currents involved with the starting of large machines, or switching operations in the grid. The FACTS devices, such as unified power flow controller (UPFC) and synchronous static compensator (STAT-COM), are used to alleviate the disturbance and improve the power system quality and reliability [7], [8]. In this paper, a distributed power flow controller, introduced in as a new FACTS device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC structure is derived from the UPFC structure that is included one shunt converter and several small independent series converters, as shown in Fig. 1. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle,and bus voltage magnitude .

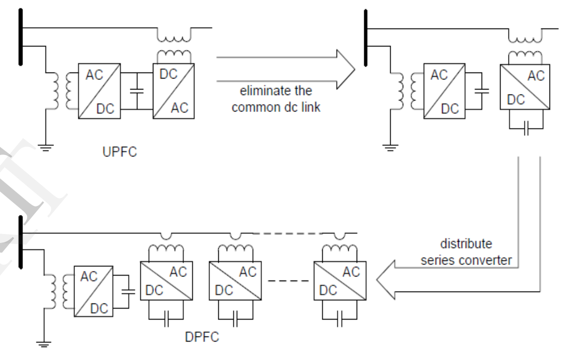

Fig 1: Flowchart from UPFC to DPFC

II. DISTRIBUTED POWER FLOW CONTROLLER

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. The shunt converter is similar as a STATCOM, while the series converter employs the DSSC concept, which is to use multiple single-phase converters instead of one three-phase 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 below Figure

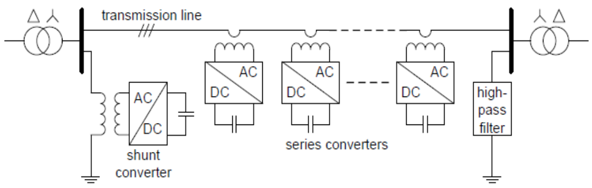

Fig 2: DPFC configuration

As shown, besides the key components - shunt and series converters, a DPFC also requires a high pass filter that is shunt connected to the other side of the transmission line and a Y-_ transformer on each side of the line. The reason for these extra components will be explained later. 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 freely exchange. To ensure the DPFC has the same control capability as the UPFC, a method that allows active power exchange between converters with an eliminated DC link is required.

DPFC OPERATING PRINCIPLE

ACTIVE POWER EXCHANGE WITH 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 Distributed Power Flow Controller (DPFC) 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

:

$$P = \sum_{i=1}^{\infty} V_i I_i \cos\phi_i \qquad (3.1)$$

where Vi and Ii are the voltage and current at the ith harmonic frequency respectively, and φ_i is the corresponding angle between the voltage and current. Equation (3.1) 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. By applying this method to the DPFC, the shunt converter can absorb active power from the grid at the fundamental frequency and inject the power back at a harmonic frequency. This harmonic active power flows through a transmission line equipped with series 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. Neglecting losses, the active power generated at the fundamental frequency is equal to the power absorbed at the harmonic frequency. For a better understanding, Figure 2 indicates how the active power is exchanged between the shunt and the series converters in the DPFC system. 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.

USING THIRD HARMONIC COMPONENTS

Due to the unique features of 3rd harmonic frequency components in a three-phase sys-tem, the 3rd harmonic is selected for active power exchange in the DPFC. 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-_ trans-formers and these are widely incorporated in power systems (as a means of changing voltage), there is no extra filter required to prevent harmonic leakage. As introduced above, a high-pass filter is required to make a closed loop for the harmonic current and the cutoff frequency of this filter is approximately the fundamental frequency. Because the voltage isolation is high and the harmonic frequency is close to the cutoff frequency, the filter will be costly. By using the zero-sequence harmonic, the costly filter can be replaced by a cable that connects the neutral point of the Y-_ transformer on the right side in with the ground. Because the _-winding appears open-circuit to the 3rd harmonic current, all harmonic current will flow through the Y- winding and concentrate to the grounding cable. Therefore, the large high-pass filter is eliminated.

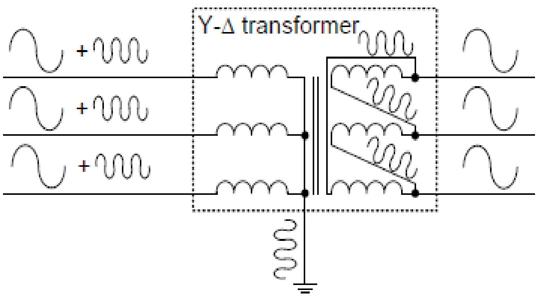

Fig 3: Utilize grounded Y transformer to filter zero-sequence harmonic

III. DPFC CONTROL

The DPFC has three control strategies: central controller, series control, and shunt control, as shown in Fig. 4.

A. Central Control

This controller manages all the series and shunt controllers and sends reference signals to both of them.

B. *Series Control*

Each single-phase converter has its own series control through the line. The controller inputs are series capacitor voltages, line current, and series voltage reference in the dqframe. The block diagram of the series converters in Matlab/Simulink environment is demonstrated in Fig. 5.

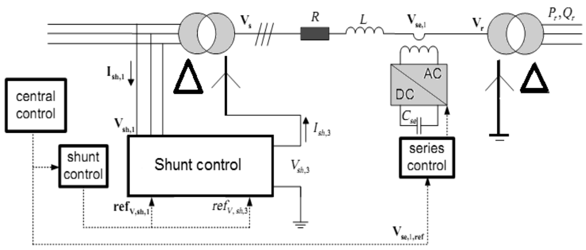

Fig. 4. DPFC control structure

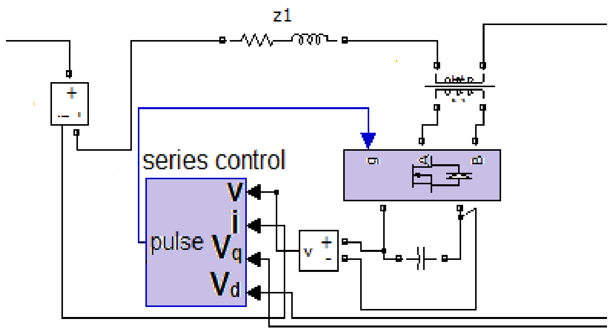

Fig. 5. Block diagram of the series converters in Matlab/Simulink

Any series controller has a low-pass and a 3rd-pass filter to create fundamental and third harmonic current, respectively. Two single-phase phase lock loop (PLL) are used to take frequency and phase information from network . The block diagram of series controller in Matlab/Simulink is shown in Fig. 5. The PWM-Generator block manages Switching processes.

C. Shunt Control

The shunt converter includes a three-phase converter connected back-to-back to a single-phase converter. The three-phase converter absorbs active power from grid at fundamental frequency and controls the dc voltage of capacitor between this converter and single-phase one. Other task of the shunt converter is to inject constant third-harmonic current into lines through the neutral cable of Δ-Y transformer.

IV. POWER QUALITY IMPROVEMENT

The whole model of system under study is shown in Fig. 7. The system contains a three-phase source connected to a nonlinear RLC load through parallel transmission lines (Line 1and 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. The system parameters are listed in appendix TABLE I. 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, significant voltage sag is observable during the fault, without any compensation. The voltage sag value is about 0.5 perunit. After adding a DPFC, load voltage sag can be mitigated effectively, as shown in Fig. 9.

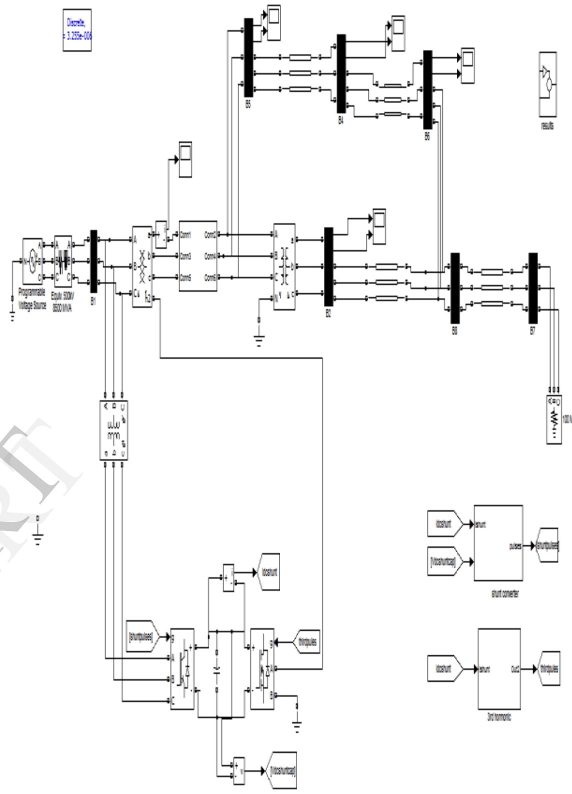

Fig 6 : Simulation model of the DPFC

V. EXAMINING SIMULATION RESULTS

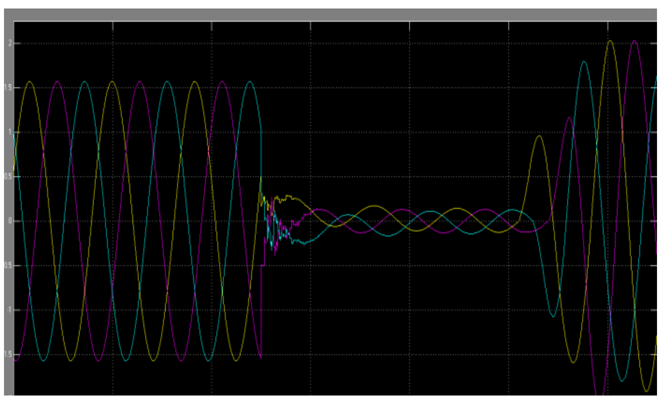

Fig. 7. Three-phase load voltage sag waveform

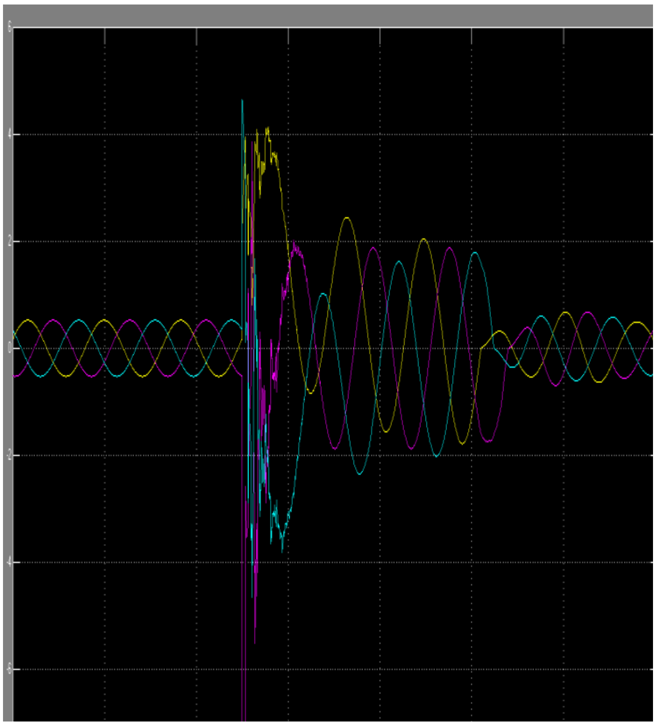

Fig. 8. Three-phase load current swell waveform without DPFC

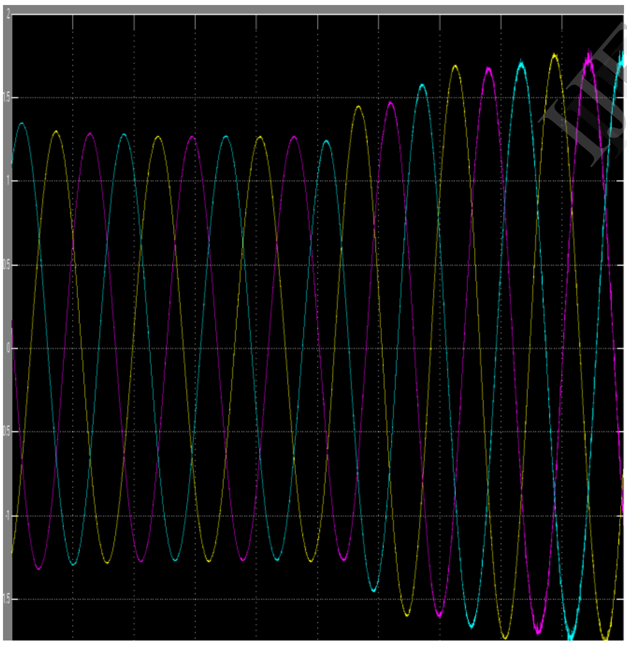

Fig. 9. Mitigation of three-phase load voltage sagl with DPFC

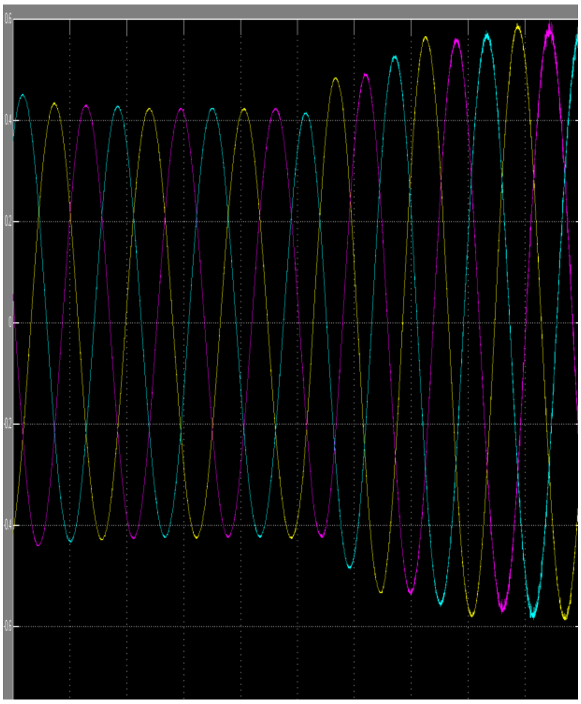

Fig.10. Three- phase load current swell waveform with DPFC

The load voltage harmonic analysis with DPFC is illustrated in Fig. 11. It can be seen, after DPFC implementation in system, the even harmonics is eliminated, the odd harmonics are reduced within acceptable limits, and total harmonic distortion (THD) of load voltage is minimized from 45.67 to 1.69 percentage (Fig. 11), i.e., the standard THD is less than 5 percent in IEEE standards.

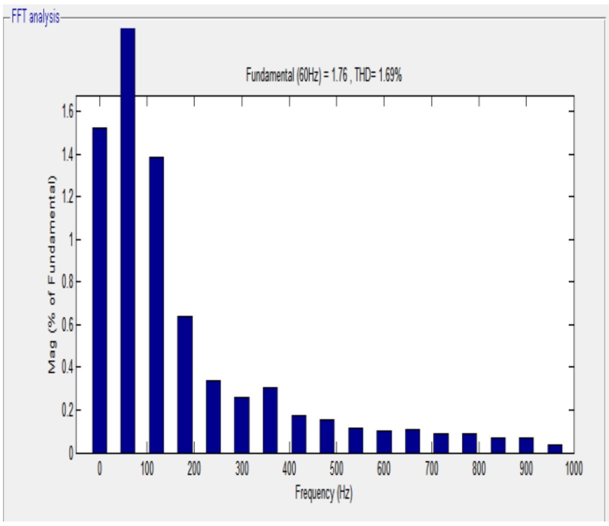

Fig. 11. Total harmonic distortion of load voltage with DPFC

VI. CONCLUSION

In the transmission system so many methods are there to improve power quality . But in this paper, mitigating the voltage sag and swell by using a new FACTS device called distributed power flow controller (DPFC) is presented. The DPFC structure is similar to unified power flow controller (UPFC) and has a same control capability to balance the line parameters, i.e., transmission angle, line impedance and bus voltage magnitude. The main advantages of DPFC compared with the UPFC are low cost, high control capability and high reliability. The DPFC has contains the modeled and three control loops, i.e., series control, central controller and shunt control are design. The system under study is a single machine infinite-bus system, with and without DPFC. To simulate the dynamic performance of a three-phase fault is considered near the load. This is shown that the DPFC gives an acceptable performance in power quality mitigation and power flow control .

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