A Review Paper on Power Quality Improvement and Mitigation Case Study Using Distributed Power Flow Controller

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ABSTRACT

According to growth of electricity demand and the increased number of non-linear loads in power grids, providing a high quality electrical power should be considered. In this paper, voltage sag and swell of the power quality issues are studied and distributed power flow controller (DPFC) is used to mitigate the voltage deviation and improve power quality. The DPFC is a new FACTS device, which its structure is similar to unified power flow controller (UPFC). In spite of UPFC, in DPFC 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 case study contains a DPFC sited in a single-machine infinite bus power system including two parallel transmission lines, which simulated in MATLAB/Simulink environment. The presented simulation results validate the DPFC ability to improve the power quality.
Keywords: FACTS, Power Quality, Sag and Swell Mitigation, Distributed Power Flow Controller

I. INTRODUCTION

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 of electrical apparatus [1].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 [2]. The power electronics progressive, especially inflexible treating urgent transmission and consumption of electric power effect on the performance system (FACTS) and custom power devices, affects power quality improvement [3], [4].Generally, custom power devices, e.g., dynamic voltage restorer (DVR),are used inmediumtolow voltage levels to improve customer power quality [5]. 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 In this paper, a distributed power flow controller, introduced in [6]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 inFig.1.1The shunt converter is similar to the STATCOM while the series converter employs the DFACTS concept [6]. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude [7].The paper is organized as follows: in section II, the DPF Principle is discussed. The DPFC control is described inspection III. Section IV is dedicated to power quality improvement by DPFC. Simulation results are presented inspection V.
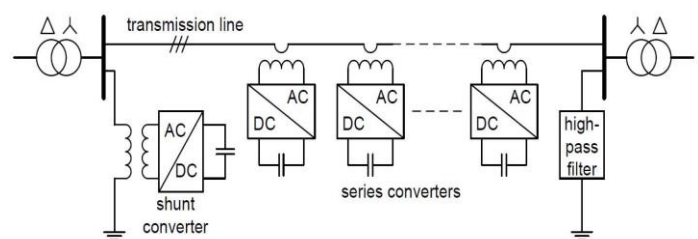

Figure 1. The DPFC Structure

II. METHODS AND MATERIAL

DPFC PRINCIPLE

In comparison with UPFC, the main advantage offered by DPFC is eliminating the huge DC link and instate using 3rd harmonic current to active power exchange [6]. In the following subsections; the DPFC basic concepts are explained.

A. Eliminate DC Link and Power Exchange

Within the DPFC, the transmission line is used as a connection between the DC terminals of shunt converter and the AC terminal of series converters, insted of direct connection using DC link for power exchange between converters. The method of power exchange in DPFC is based on power theory of nonsinusoidal components [6]. Based on Fourier series, a nonsinusoidal 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, so the active power equation is as follow:

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

Where V_i and I_i are the voltage and current at the ith harmonic, respectively, and φ_i is the angle between the voltage and current at the same frequency. Equation (1) expresses the active power at different frequency components is independent.

The above equation (1) describes that the active power at different frequencies is isolated from each other and the voltage and current in one frequency has no influence on the active power at other frequencies. so by this concept the shunt converter in DPFC can absorb power from active the grid at the fundamental frequency and inject the current back into the grid at a harmonic frequency[9]. Based on this fact, a shunt converter in DPFC can absorb the active power in one frequency and generates output power in another frequency, and also according to the amount of active power required at the fundamental frequency, the DPFC series converter generate the voltage at the harmonic frequency there by absorbing the active power from harmonic components. Assume a DPFC is placed in a transmission line of a two-bus system, as shown in Fig.1. While the power supply generates the active power, the shunt converter has the capability to absorb power in fundamental frequency of current. In the 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 transformer.

So the third harmonic component is trapped in Y-Δ transformer [6]. Output terminal of the shunt converter injects the third harmonic current into the neutral of ΔY transformer. Consequently, the harmonic current flows through the transmission line. This harmonic current controls the DC voltage of series capacitors. Fig. 2 illustrates how the active power is exchanged between the shunt and series converters in the DPFC. The third harmonic is selected to exchange the active power in the DPFC and a highpass filter is required to make a closed loop for the harmonic current.
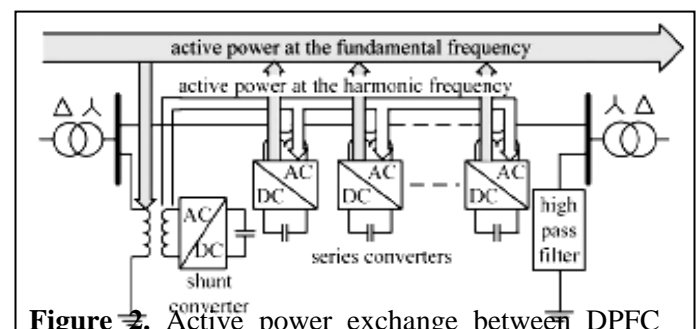
Figure 2. Active power exchange between DPFC convertes

B. The DPFC Advantages

The DPFC in comparison with UPFC has some advantages, as follows:

1. High Control Capability
The DPFC similar to UPFC, can control all parameters of transmission network, such as line impedance, transmission angle, and bus voltage magnitude.

2. High Reliability
The series converters redundancy increases the DPFC reliability during converters operation [7]. It men's, if one of series converters fails, the others can continue to work.

3. Low Cost

The single-phase series converters rating are lower than one three-phase converter. Furthermore, the series converters do not need any high voltage isolation in transmission line connecting; singleurntransformers can be used to hang the series converters. Reference [6] reported a case study to explore the feasibility of the DPFC, where a UPFS is replaced with a DPFC in the Korea electric power corporation [KEPCO].To achieve the same UPFC control capability, the DPFC construction requires less material [6].

DPFC CONTROL

The DPFC has three control strategies: central controller,series control, and shunt control, as shown in Fig. 3.

A. Central Control

This controller manages all the series and shunt control lersand 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 theseries onverters inMatlab/Simulink environment is demons racted in Fig. 4.
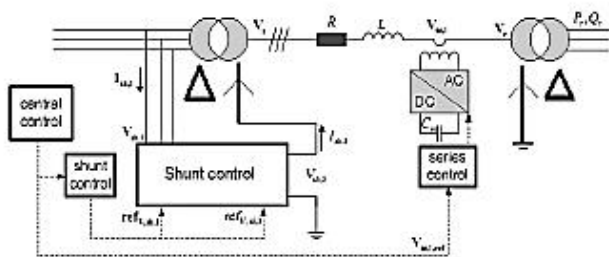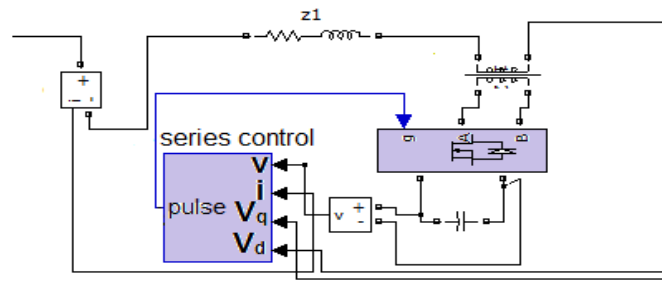

Figure 3. DPFC control structure

Figure 4. Block diagram of the series converters in Mat lab/Simulink

Any series controller has a lowpass and a 3rd pass filter tocreate fundamental and third harmonic current, respectively.Two singlephase phase lock loop (PLL) are used to takefrequency and phase information from network[8].Theblock diagram of series controller in Matlab/Simulink isshown in Fig. 5. The PWM Generator block manages switching processes.
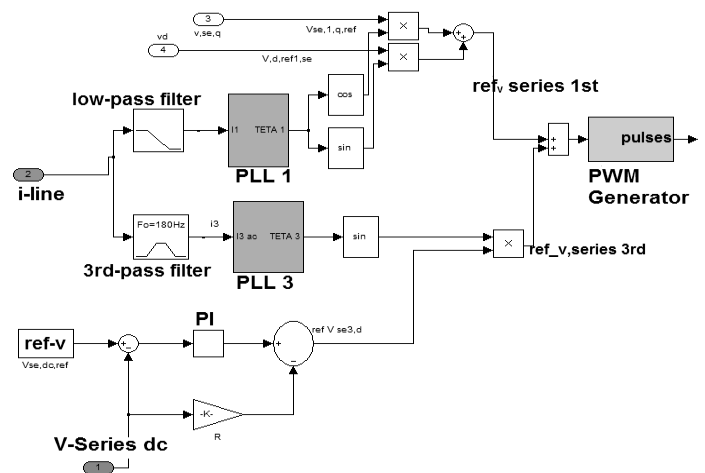

Figure 5. Block diagram of series control structure in Matlab/Simulink

C. Shunt Control

The shunt converter includes a threephase converter connected backtoback to a singlephase converter. Thethreephase converter absorbs active power from grid atfundamental frequency and controls the dc voltage ofcapacitor between this converter and singlephase one. Othertask of the shunt converter is to inject constant thirdharmoniccurrent into lines through the neutral cable of Δ-Ytransformer.Each converter has its own controller at different frequencyoperation (fundamental and thirdharmonic frequency). Theshunt control structure blockdiagram is shon in Fig. 6.
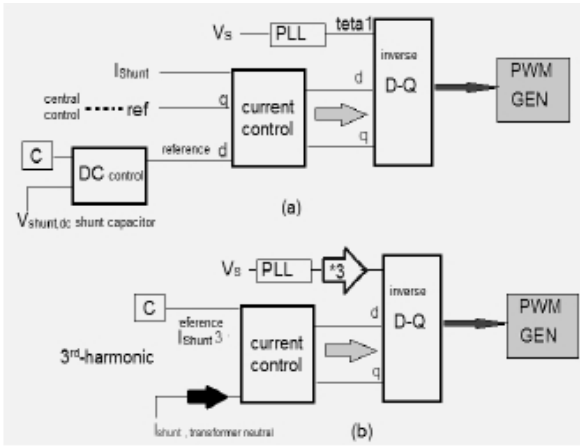
Figure 6. The shunt control configuration:

(a) for fundamental frequency

(b) for third-harmonic frequency

III. RESULTS AND DISCUSSION

POWER QUALITYIMPROVEMENT:

The system is in under study. The system contains a three-phase source connected to a nonlinear RLC load through parallel transmission lines with the same lengths. The DPFC is placed in transmission line, which the shunt converter is connected to the transmission line 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) [9][1]. As shown in Fig. 7, 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, as shown in Fig. 8. [1][2]
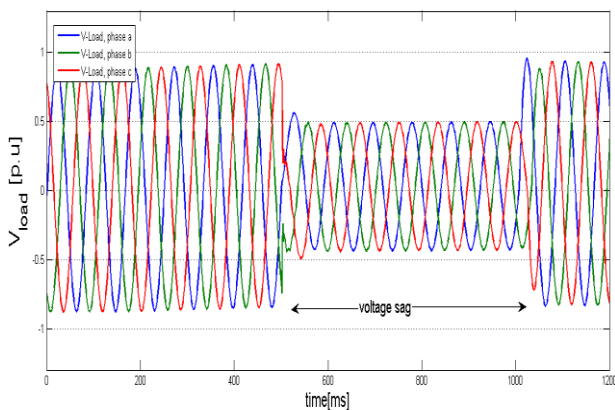

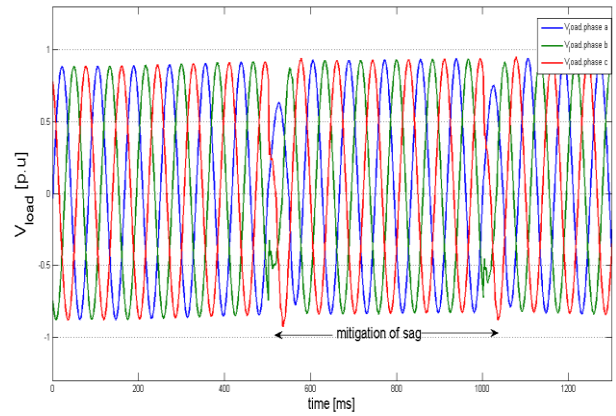**Figure 7** : Three-phase load voltage sag waveform.

Figure 8 : Mitigation of three phase load voltage sag with DPFC

Fig. 9 depicts the load current swell about 1.1 per unit, during the fault. After implementation of the DPFC, the load current swell is removed effectively. The current swell mitigation for this case can be observed from Fig. 10 [1].
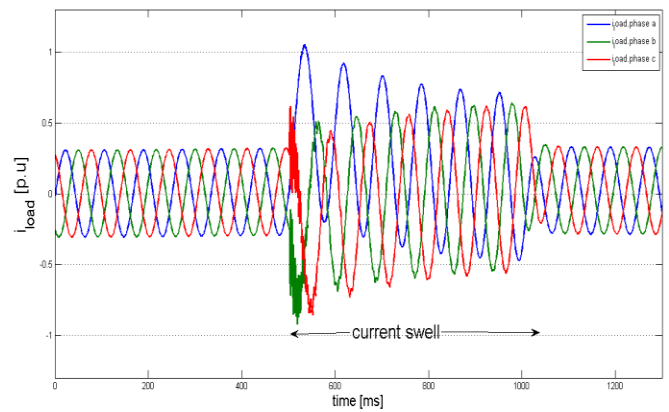

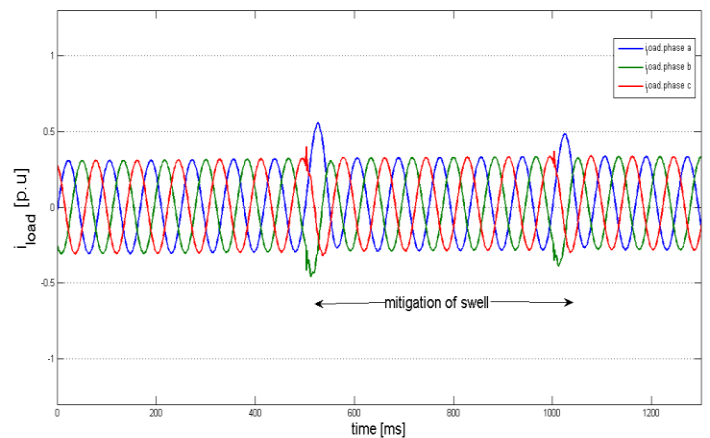**Figure 9 :** Three Phase Load Current Swell Waveform Without DPFC

Figure 10 : Mitigation of three-phase load current swell with DPFC

IV. CONCLUSION

To improve power quality in the power transmission system, there are some effective methods. In this paper, the voltage sag and swell mitigation, using a new FACTS device called distributed power flow controller (DPFC) is presented. The DPFC structure is similar to unified power flow controller (UPFC). It has a same control capability to balance the line parameters like transmission angle, line impedance and bus voltage magnitude. However, the DPFC has some advantages, as compare to UPFC, such as high reliability, high control capability and low cost. The DPFC is modeled and three control loops, i.e., central controller, series control, and shunt control are design. The system under study is a single machine infinite-bus system, with and without DPFC. It is shown that the DPFC gives an acceptable performance in power quality mitigation and power flow control.

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