A Revolutionary Idea to Improve Power Quality by Using Distributed Power Flow Controller [DPFC]

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Abstract: In the last few decades as the more increase in population occurred so the usage of electric power is increasing day by day and also the power companies are concentrating not only on quantity of the power but also the quality of the power. Here the new FACTS device is used called DPFC reduces the voltage sag and voltage swell and improves the power quality. 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.

Keywords: Distributed power flow controller, Power Quality, Sag and Swell Mitigation.

I. INTRODUCTION

In the last decade, the electrical power quality issue has been the main concern of the power companies [1]. Power quality is defined as the index which both the delivery and consumption of electric power affect on the performance of electrical apparatus [2]. 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 [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 In this paper, a distributed power flow controller, introduced in [9] 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.1.1The shunt converter is similar to the STATCOM while the series converter employs the D-FACTS concept[9]. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude [10].

The paper is organized as follows: in section II, the DPFC principle is discussed. The DPFC control is described in section III. Section IV is Simulation models. Results in section V.and section VI is conclusion

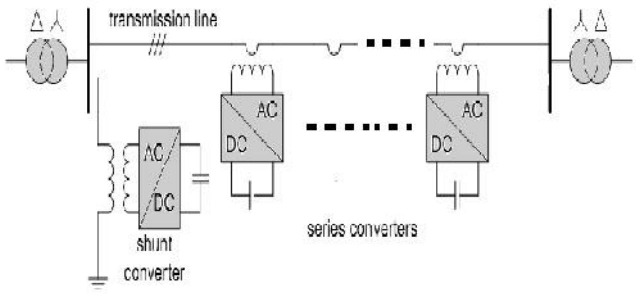

Fig.1.1 DPFC structure

II. 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 [9] Theoretically the third, sixth, and ninth harmonic frequency 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

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harmonic with the lowest frequency –third harmonic is selected [9], 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 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 [9]. 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, so the active power equation is as follow:

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

Where V_i and I_i are the voltage and current at the i^{th} 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 active power from 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 [9]. Output terminal of the shunt converter injects the third harmonic current into the neutral of Δ-Y 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 high-pass filter is required to make a closed loop for the harmonic current. The third harmonic current is trapped in trapped in Δ-winding of transformer. Hence, no need to use the high-pass filter at the receiving-end of the system. In other words, by using the third-harmonic, the high-pass filter can be replaced with a cable connected between Δ-winding of transformer and ground. This cable routes the harmonic current to ground.

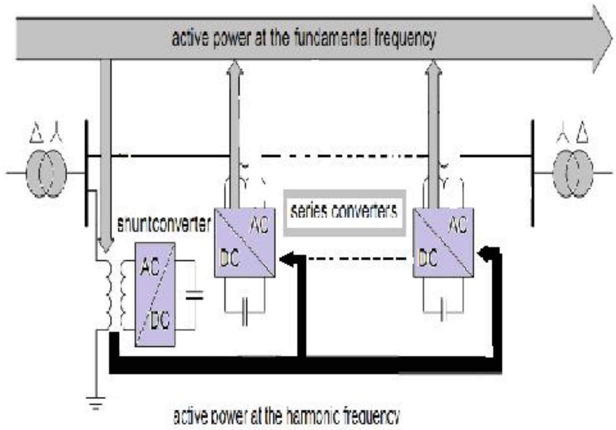

Fig: 2.1: Active power exchange

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 [10]. It means, 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; single-turn transformers can be used to hang the series converters. Reference [9] 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 [9].

III.DPFC CONTROL

The DPFC has three control strategies:

A. Central Control

This controller manages all the series and shunt controllers and sends reference signals to both of the shunt and series converters of the DPFC.According to the system requirements, the central control gives corresponding voltage reference signals for the series converters and reactive current signal for the shunt converter. All the reference signals are generated by central control are at the fundamental frequency.[9]

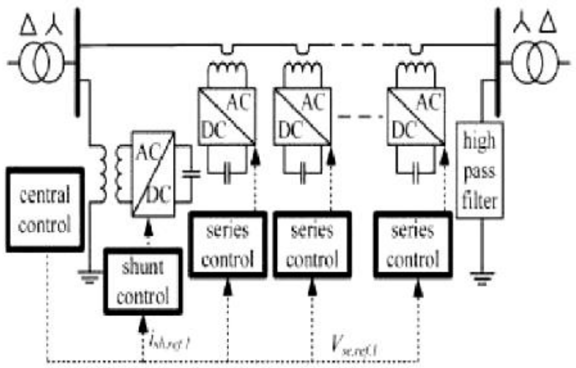

Fig: 3.1 Central Control

B. Series Control

Each single-phase converter has its own series control through the line. The controller is used to maintain dc voltage of a capacitor by using third harmonic frequency and to generate series voltage at a fundamental frequency which is prescribed by central control. Because of single phase series converter voltage ripple will occur whose frequency depends on frequency of current that flows through converter. So eliminate this ripples there are two possible ways one is increasing of turns ratio of single phase transformer and the second is use of dc capacitor of large capacitance. 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 [11].The PWM-Generator block manages switching processes.

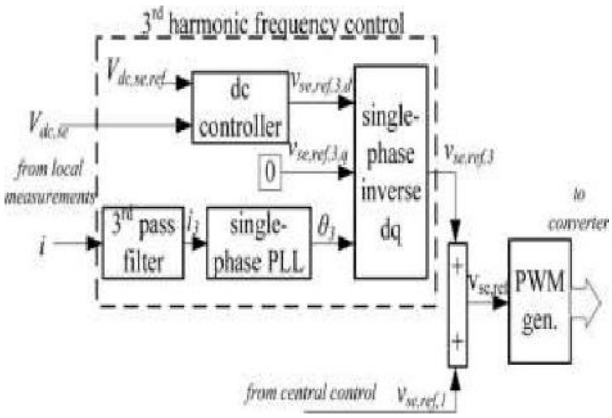

Fig: 3.2 Series control

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.

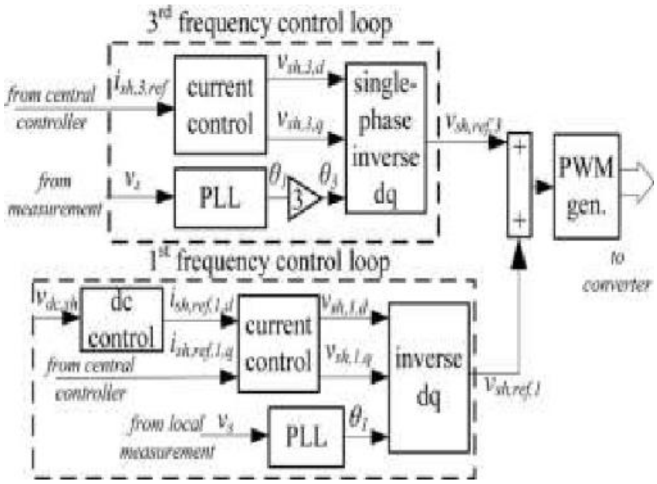

Fig: 3.3 Shunt Control

IV. SIMULATION MODEL FOR DPFC

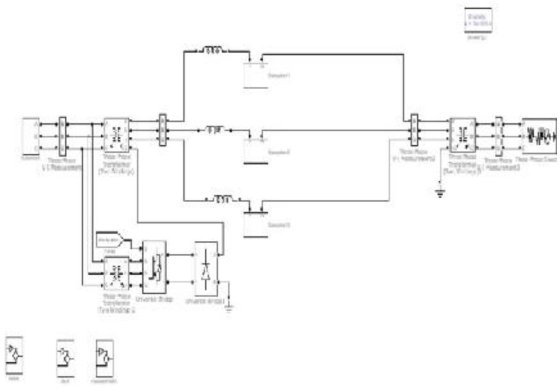

Fig: 4.1.Simulated model for DPFC

Within the setup, multiple series converters are controlled by a central controller. The central controller gives the reference voltage signals for all series converters. The voltages and current within the setup are measured by its simulink outputs.

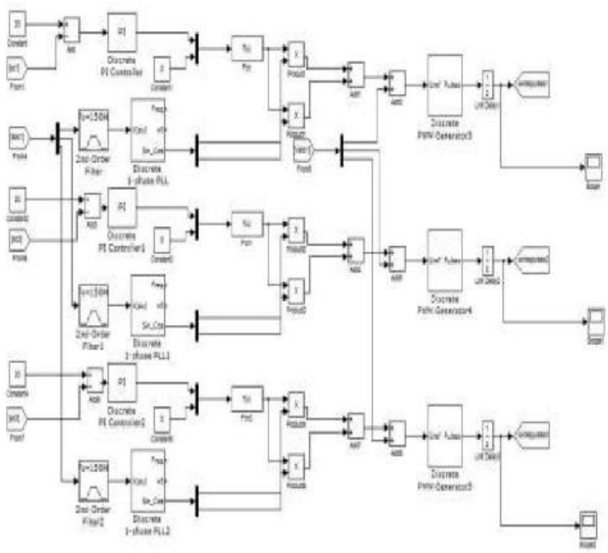

Fig: 4.2.Series Converter SIMULINK Model

The basic function of the shunt converter is to supply or absorb the active power demanded by the series converter. The shunt converter controls the voltage of the DC capacitor by absorbing or generating active power from the bus, therefore it acts as a synchronous source in parallel with the system. To verify the DPFC principle, two situations are demonstrated: the DPFC behavior in steady state and the step response. In steady state, the series converter is controlled to insert a voltage vector with both *d*- and *q*-component, which is Vse,d,ref = 0.3 V and Vse,q,ref = −0.1 V. The voltage injected by the series converter, the current through the line, and the voltage and current at the side of the transformer.

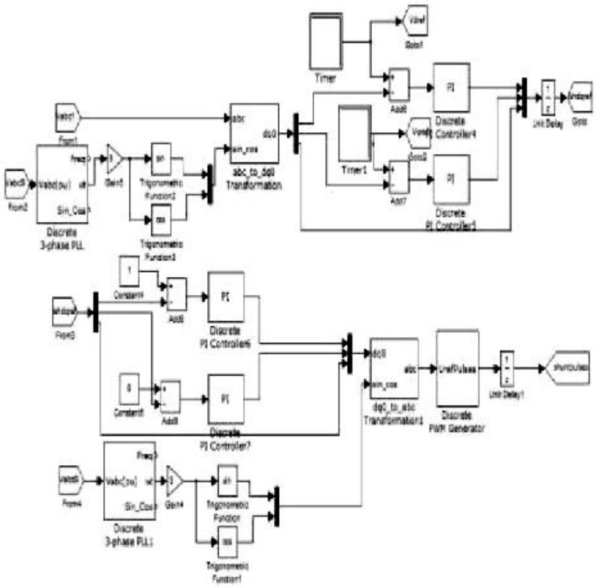

Fig: 4.3.Shunt Converter SIMULINK Model

V. RESULTS

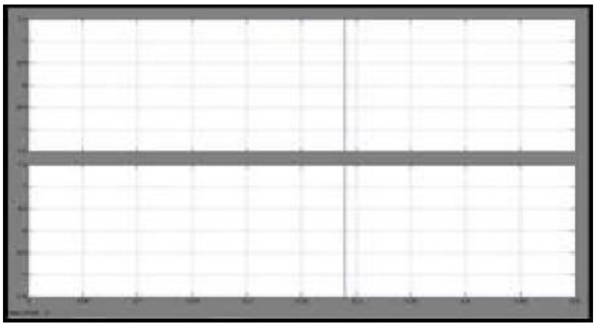

Fig: 5.1: Reference voltage for the series converters

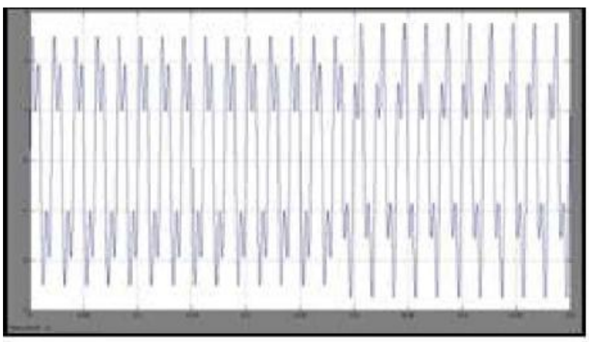

Fig: 5.2: Step response of the DPFC: line current:

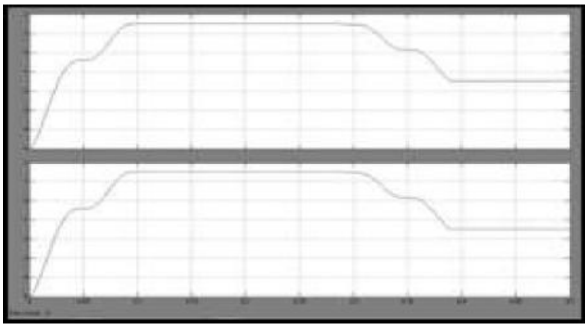

Fig: 5.3: Step response of the DPFC: active and reactive power injected by the Series converter:

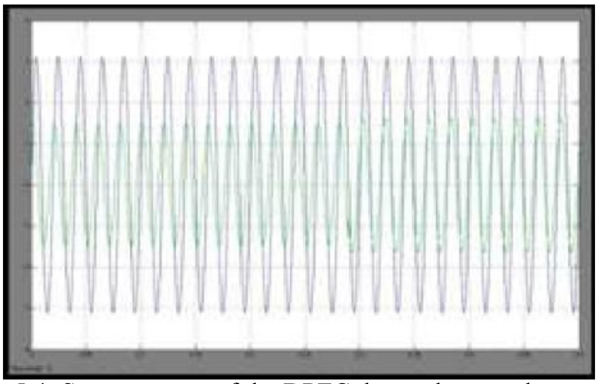

Fig: 5.4: Step response of the DPFC: bus voltage and current

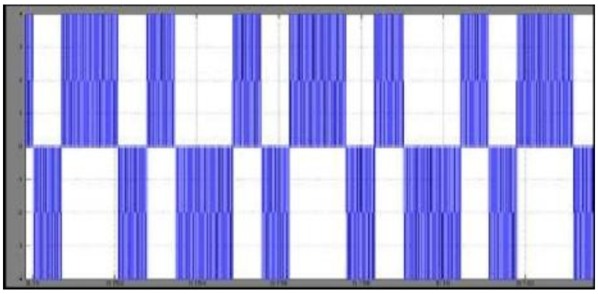

FIG: 5.5: STEP RESPONSE OF THE DPFC:SERIES CONVERTER VOLTAGE.

VI. 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) and has a same control capability to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude. However, the DPFC offers some advantages, in comparison with UPFC, such as high control capability, high reliability, 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.

APPENDIX

Symbol	Description	Value	Unit
Vs	Nominal voltage of grid s	220	V
Vr	Nominal voltage of grid r	220	V
Θ	transmission angle between between grid s and r	1	°
L	Line inductance	6	MH
Vsh,ma,x	Shunt Converter maximum ac voltage	50	V
Ish,max	Shunt Converter maximum ac voltage	9	A
Vsh,dc	Shunt Converter dc source supply	20	V
Ish,ref,3	Reference third-ie current injected by the shunt converter	3	A
Fsω	Switching frequency for the shunt and series converter	6	kHz
Vse,ma x	maximum ac voltage at line side of series converter	7	V
Ise,max	maximum ac current at line side of series converter	15	A

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