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# Mitigation of Voltage Sag/Swell 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 (distributed power flow controller) is a new FACTS (Flexible Alternating current Transmission system) device, which its structure is similar to unified power flow controller (UPFC). In spite of UPFC, in DPFC (distributed power flow controller) 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 deliveryand consumption of electric power affect on the performanceof electrical apparatus [2]. From a customer pointofview, 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-currenttransmission system (FACTS) and custompowerdevices, affects power quality improvement [4],[5]. Generally, custom power devices, e.g., dynamic voltage restorer (DVR), areused in medium-to-low voltage levels to improvecustomerpower 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 (flexible alternating-current transmission system) device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC(Distributed power flow controller) Structure is derived from the UPFC(Unified power flow controller) structure that is included one shunt converter and several small independent series converters, as shown in Fig.1.1 The shunt converter is similar to the STATCOM(Static Compensator) while the series converter employs the D-FACTS(Distribution flexible alternating-current transmission system concept)[9]. The DPFC (Distributed power flow controller) has same capability as UPFC (unified power flow controller) to balance the lineparameters, i.e., line impedance, transmission angle, and busvoltage magnitude [10].

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

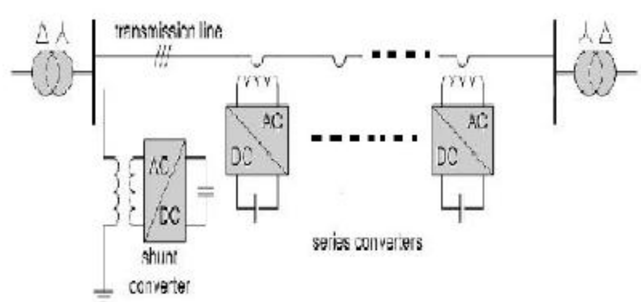


Fig.1.1 DPFC structure

## 2. DPFC PRINCIPLE

In comparison with UPFC (Unified power flow controller), the main advantage offered by DPFC (Distributed power flow controller) is eliminating the huge

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DC-link and instate using3rd-harmonic current to active power exchange [9]. Theoretically the third, sixth, and ninth harmonic frequencyare all zero sequence and all can be used to exchange activepower in the DPFC (Distributed power flow controller), as it is well known the capacity of atransmission line to deliver power depends on its impedance,
since the transmission line impedance is inductive andproportional to the frequency, high transmission frequencieswill cause high impedance. Consequently the zero sequenceharmonic with the lowest frequency –third harmonic isselected [9], In the following subsections, the DPFC (distributed power flow controller) basicconcepts are explained.

### A. Eliminate DC Link and Power Exchange

Within the DPFC (Distributed power flow controller), the transmission line is used as aconnection between the DC terminal of shunt converter andthe AC terminal of series converters, instead of directconnection using DC-link for power exchange betweenconverters. The method of power exchange in DPFC (Distributed power flow controller) is basedon power theory of non-sinusoidal components [9]. Based onFourier series, a non-sinusoidal voltage or current can bepresented as the sum of sinusoidal components at differentfrequencies. The product of voltage and current componentsprovides the active power. Since the integral of some termswith different frequencies are zero, so the active powerequation is as follow:

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

Where $V_i$and $I_i$ are the voltage and current at the $i^{th}$ harmonic,respectively, and $\varphi_i$ is the angle between the voltage andcurrent at the same frequency. Equation (1) expresses theactive power at different frequency components isindependent.

The above equation (1) describes that the active power atdifferent frequencies is isolated from each other and thevoltage and current in one frequency has no influence on the
active power at other frequencies. So by this concept the shuntconverter in DPFC (Distributed power flow controller) can absorb active power from the grid atthe fundamental frequency and inject the current back into thegrid at a harmonic frequency [9]. Based on this fact, a shuntconverter in DPFC (Distributed power flow controller) can absorb the active power in onefrequency and generates output power in another frequency,and also according to the amount of active power required atthe fundamental frequency, the DPFC (distributed power flow controller) series convertergenerate the voltage at the harmonic frequency there byabsorbing the active power from harmonic components.Assume a DPFC (Distributed power flow controller) is placed in a transmission line of a two-bussystem, as shown in Fig.1. While the power supply generatesthe active power, the shunt converter has the capability toabsorb power in fundamental frequency of current. In thethree phase system, the third harmonic in each phase isidentical which is referred to as “zero sequence”. The zerosequence harmonic can be naturally blocked by Y-Δtransformer.
So the third harmonic component is trapped in Y-Δtransformer [9]. Output terminal of the shunt converter injectsthe third harmonic current into the neutral of Δ-Ytransformer. Consequently, the harmonic current flowsthrough the transmission line. This harmonic current controlsthe DC voltage of series capacitors. Fig. 2 illustrates how theactive power is exchanged between the shunt and seriesconverters in the DPFC (Distributed power flow controller). The third-harmonic is selected toexchange the active power in the DPFC (Distributed power flow controller) and a high-pass filteris required to make a closed loop for the harmonic current.

The third harmonic current is trapped in trapped in Δ-windingof transformer. Hence, no need to use the high-pass filter atthe receiving-end of the system. In other words, by using thethird-harmonic, the high-pass filter can be replaced with acable connected between Δ-winding of transformer andground. This cable routes the harmonic current to ground.

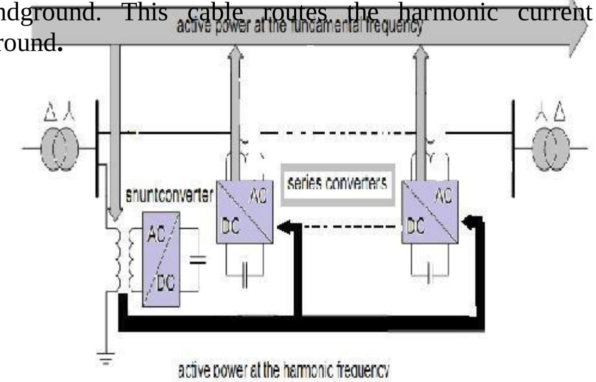


Fig: 2.1: Active power exchange

### B.TheDPFC (Distributed power flow controller) Advantages

The DPFC (Distributed power flow controller) in comparison with UPFC (Unified power flow controller) has some advantages, as follows:

*1. High Control Capability*

The DPFC (distributed power flow controller) similar to UPFC (Unified power flow controller), can control all

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parameters oftransmission network, such as line impedance, transmissionangle, and bus voltage magnitude.

*2. High Reliability*

The series converters redundancy increases the DPFC (Distributed power flow controller)reliability during converters operation [10]. It means, if one ofseries converters fails, the others can continue to work.

*3. Low Cost*

The single-phase series converters rating are lower thanone three-phase converter.Furthermore, the series converters do not need any highvoltage isolation in transmission line connecting; single-turntransformers can be used to hang the series converters.Reference [9] reported a case study to explore the feasibilityof the DPFC (distributed power flow controller), where a UPFC (Unified power flow controller) is replaced with a DPFC (distributed power flow controller) in theKorea electric power corporation [KEPCO].To achieve thesame UPFC (Unified power flow controller) control capability, the DPFC (distributed power flow controller) constructionrequires less material [9].

## 3.DISTRIBUTED POWER FLOW CONTROL

The DPFC (Distributed power flow controller) has three control strategies:

**A. Central Control**

This controller manages all the series and shunt controllersand sends reference signals to both of the shunt and seriesconverters of the DPFC (distributed power flow controller).According to the systemrequirements, the central control gives corresponding voltagereference signals for the series converters and reactive currentsignal for the shunt converter. All the reference signals aregenerated by central control are at the fundamentalfrequency.[9]

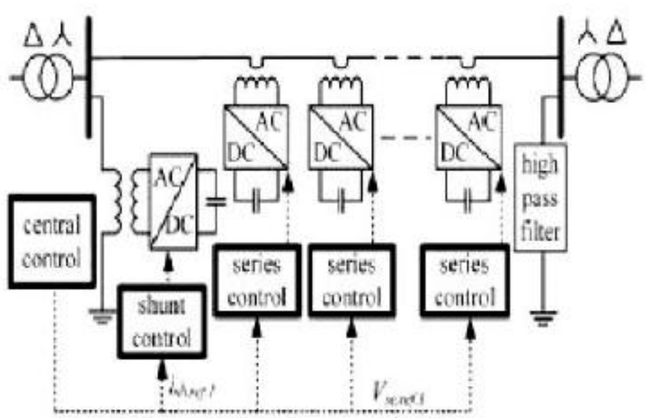


Fig: 3.1 Central Control

**B. Series Control**

Each single-phase converter has its own series controlthrough the line. The controller is used to maintain dc voltageof a capacitor by using third harmonic frequency and togenerate series voltage at a fundamental frequency which isprescribed by central control. Because of single phase seriesconverter voltage ripple will occur whose frequency dependson frequency of current that flows through converter. Soeliminate this ripples there are two possible ways one isincreasing of turns ratio of single phase transformer and thesecond is use of dc capacitor of large capacitance. Any seriescontroller has a low-pass and a 3rd-pass filter to createfundamental and third harmonic current, respectively. Twosingle-phase phase lock loop (PLL) are used to takefrequency and phase information from network [11].ThePWM-Generator block manages switching processes.

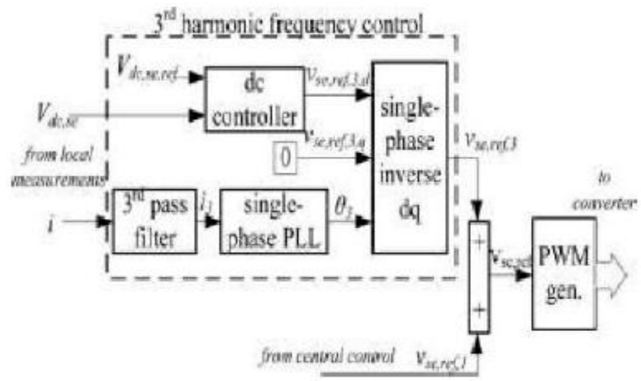


Fig: 3.2 Series Control

**C. Shunt Control**

The shunt converter includes a three-phase converterconnected back-to-back to a single-phase converter. Thethree-phase converter absorbs active power from grid atfundamental frequency and controls the dc voltage ofcapacitor between this converter and single-phase one. Othertask of the shunt converter is to inject constant third-harmoniccurrent into lines through the neutral cable of Δ-Ytransformer.

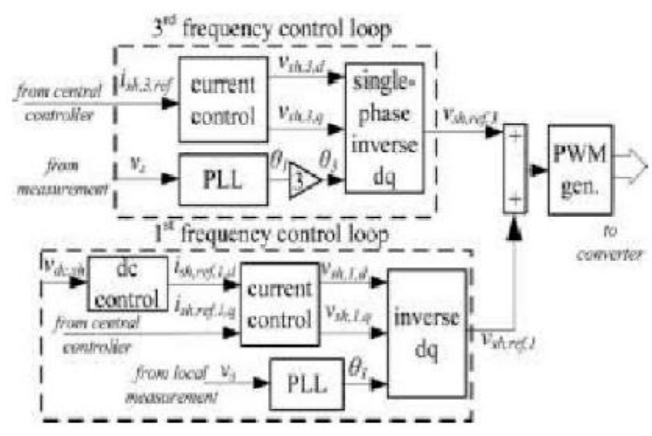


Fig: 3.3 Shunt Control

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## 4. SIMULATION MODEL FOR DPFC (Distributed Power Flow Controller)

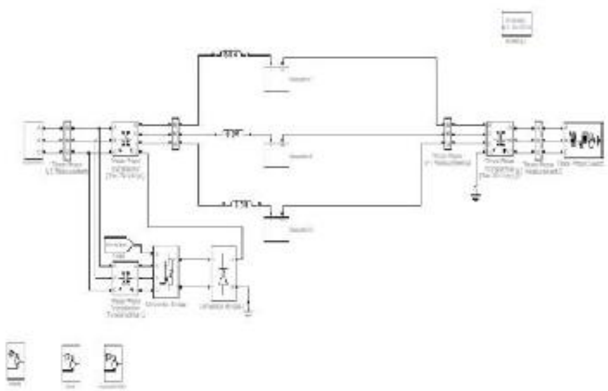

Fig: 4.1.Simulated model for DPFC (distributed power flow controller)

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.

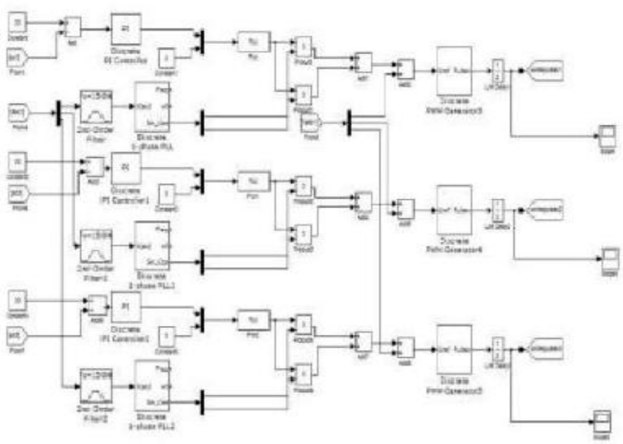

Fig: 4.2.Series Converter SIMULINK Model

The basic function of the shunt converter is to supply orabsorb 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 thesystem. To verify the DPFC (distributed power flow controller) principle, two situations aredemonstrated: the DPFC behavior in steady state and the stepresponse. In steady state, the series converter is controlled toinsert a voltage vector with both *d*- and *q*-component, whichis $V$se,d,ref = 0.3 V and $V$se,q,ref = −0.1 V. The voltageinjected by the series converter, the current through the line,and the voltage and current at the side of the transformer.

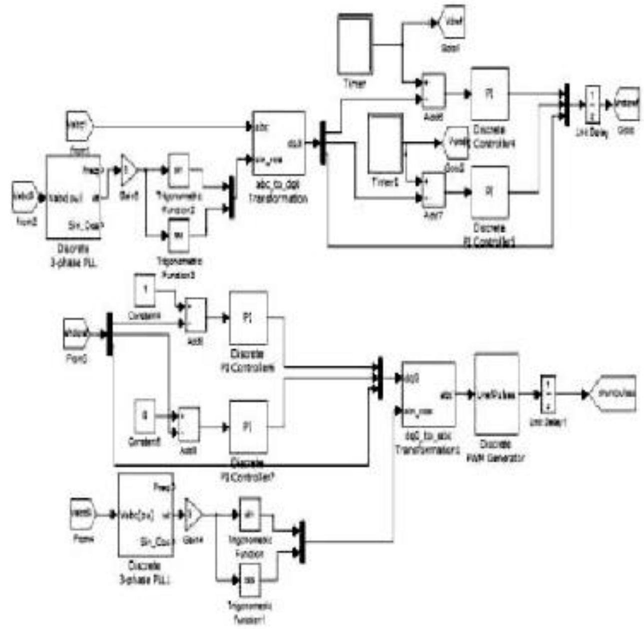

Fig: 4.3.Shunt Converter SIMULINK Model

## 5. RESULTS

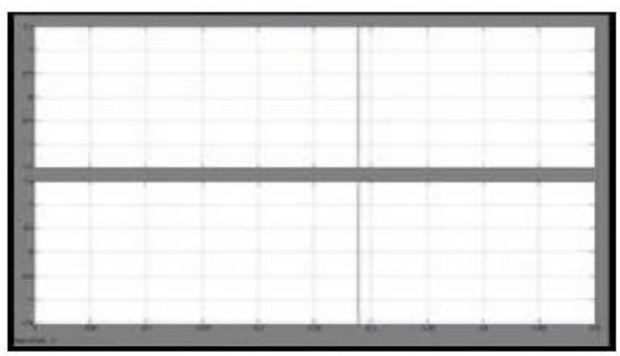

Fig: 5.1: Reference voltage for the series converters

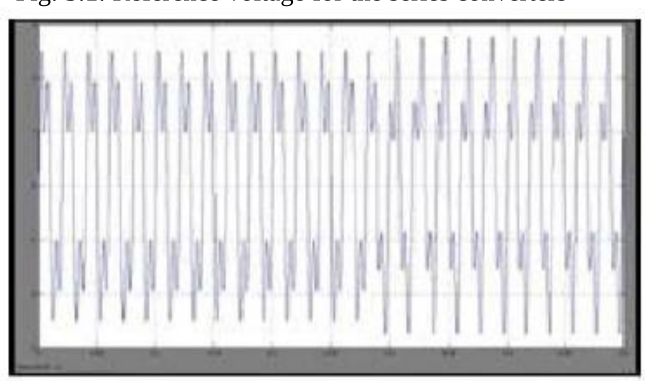

Fig: 5.2: Step response of the DPFC (Distributed power flow controller): line current:

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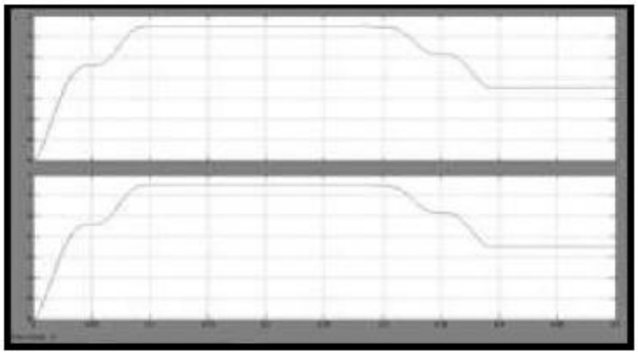

Fig: 5.3: Step response of the DPFC (Distributed power flow controller): active and reactive power injected by the Series converter:

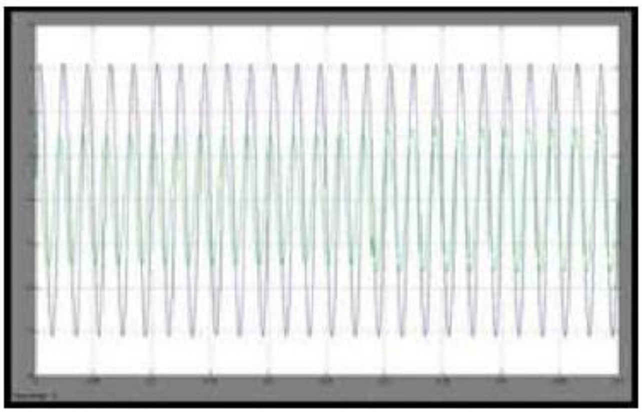

Fig: 5.4: Step response of the DPFC (Distributed power flow controller): bus voltage and current

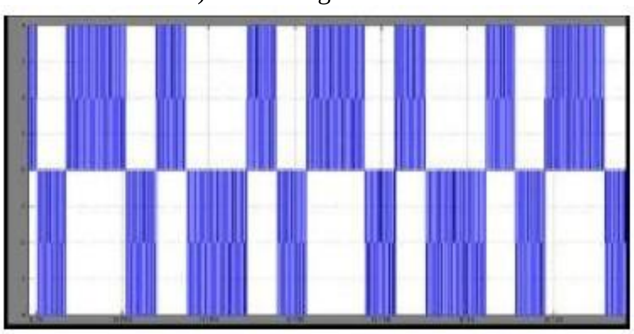

FIG: 5.5: Step Response of the DPFC (Distributed power flow controller):Series Converter Voltage.

## 6. CONCLUSION

To improve power quality in the power transmissionsystem, there are some effective methods. In this paper, thevoltage sag and swell mitigation, using a new FACTS (Flexible Alternating current Transmission system) devicecalled distributed power flow controller (DPFC) is presented.The DPFC (distributed power flow controller) structure is similar to unified power flowcontroller (UPFC) and has a same control capability tobalance the line parameters, i.e., line impedance, transmissionangle, and bus voltage magnitude. However, the DPFC offerssome advantages, in comparison with UPFC, such as highcontrol capability, high reliability, and low cost. The DPFC (Distributed power flow controller) ismodeled and three control loops, i.e., central controller, seriescontrol, and shunt control are design. The system under studyis a single machine infinite-bus system, with and withoutDPFC. It is shown that the DPFC (Distributed power flow controller) gives an acceptableperformance in power quality mitigation and power flow control.

APPENDIX

| Symbol | Description | Value | Unit |
|---|---|---|---|
| $V_s$ | Nominal Voltage of Grid s | 220 | V |
| $V_r$ | Nominal Voltage of Grid r | 220 | V |
| $\theta$ | Transmission angle between grid s and r | 1 | 0 |
| L | Line Inductance | 6 | MHz |
| $V_{sh,max}$ | Shunt Converter maximum ac voltage | 50 | V |
| $I_{sh,max}$ | Shunt Converter maximum ac current | 9 | A |
| $V_{sh,dc}$ | Shunt Converter dc source supply | 20 | V |
| $I_{sh,ref,3}$ | Reference third-i.e. current injected by the shunt converter | 3 | A |
| $F_{sw}$ | Switching Frequency for the shunt and series converter | 6 | kHz |
| $V_{se,max}$ | Maximum ac voltage at line side of series converter | 7 | V |
| $I_{se,max}$ | Maximum ac current at line side of series converter | 15 | A |

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