Available at: www.researchpublications.org

Implementation of Distributed Power Flow Controller to Improve Power Quality

Gaurav V. Waghulde #, Prasad D. Kulkarni *

#PG Student, Department of Electrical Engineering, (M.E.-EPS)
KCE's College of Engineering and IT,Jalgaon, India.
gauravwaghulde007@gmail.com
**Assistant Professor,Department of Electrical Engineering, (M.E.-EPS)*
KCE's College of Engineering and IT,Jalgaon, India.
prasadonly1@yahoo.com

***Abstract*- In the last few decades as the more increase in population occurred so the usage of electric power is increasing day by day, the operation of power systems has become complex due to growing consumption and increased number of non-linear loads because of which compensation of multiple power quality issues has become a compulsion. Hence the power companies are concentrating not only on quantity of the power but also the quality of the power. Here the new component within the flexible AC-transmission system (FACTS) family, called distributed Power-flow controller (DPFC) is presented in this paper. The day by day electricity demand and non-linear load in system are increased, so the power quality problems are also increased with increased complexity in system. The main power quality problems like voltage sag and swell are studied in this paper. The distributed power flow controller (DPFC) is used to improve power quality and minimize voltage deviation. The DPFC is derived from unified power flow controller (UPFC), by eliminating common DC link between series and shunt converters from UPFC. The three-phase series converter is split into number of single-phase series distributed converters through the line. The active power is exchange between the series and shunt converter at third harmonic frequency through transmission line in DPFC.**

***Keywords*- FACTS, Distributed Power Flow Controller, Power Quality, Sag and Swell Mitigation.**

I. INTRODUCTION

In the last few decades, the main concerns of the power companies are about power quality issues. The index which both the demand and delivery of electrical power affect on the performance of electrical apparatus is known as power quality. From the consumer point of view, any problem occur about current, voltage or the frequency deviation that results in power failure is called power quality problems. The power quality improvement mainly affect by the power electronics devises used by consumers and used in FACTS devices. Generally, customer power devices like dynamic voltage restorer (DVR), are used in medium to low voltage levels to improve customer power quality [7].

In the Unified Power Flow Controller (UPFC) is structured from SSSC and STATCOM. Both are coupled via a common DC link. The bi-directional active power flow is allowed to flow between the shunt output terminal of the STATCOM and series output terminals of the SSSC [6]. The reactive power is absorb or generate by each converter independently at its own AC terminal. The converters are connected by DC storage capacitor through common DC link. The configuration of a UPFC is shown in Figure1.

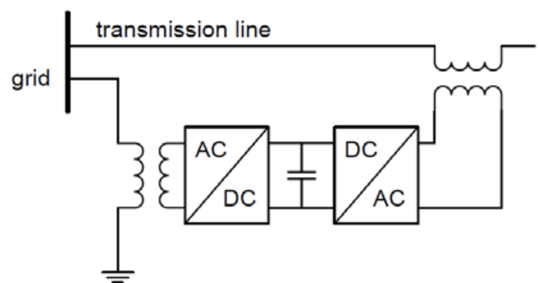

Figure-1: UPFC Configuration.

Most serious threats for sensitive equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage) [5]. 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 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.2 [6][4]. The shunt converter is similar to the STATCOM while the series converter employs the D-FACTS concept. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude [4].

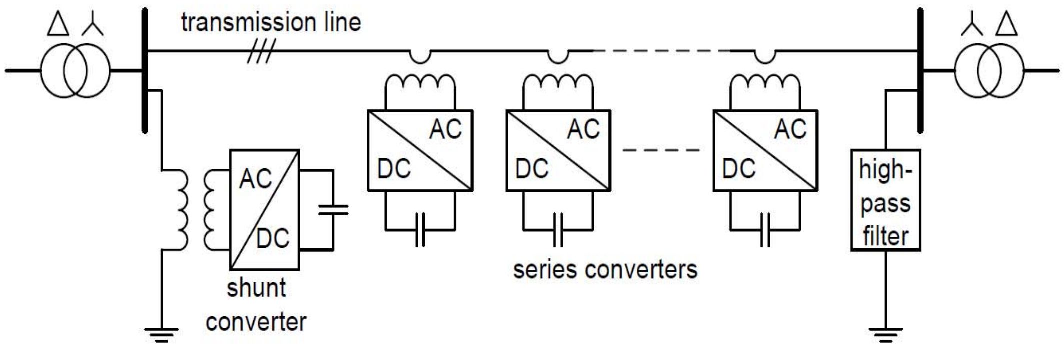

Figure-2: DPFC structure

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 [2]. Theoretically the third, sixth, and ninth harmonic frequency can be used to exchange active power in the DPFC, which are generally zero sequence frequencies. The capacity of a transmission line to deliver power depends on its impedance. The transmission line impedance is inductive and proportional to the frequency, so the high transmission frequencies will cause high impedance. Because of this the third harmonics frequency is selected which is lowest zero sequence harmonic frequency. In the following subsections; the DPFC basic concepts are explained.

A. DC Link Elimination and Power Exchange:

In the DPFC, instead of common DC link, the transmission line is used as a connection between theca terminal of series converters and DCterminal of shunt converter, for power exchange between converters [2] [6]. The power theory of non-sinusoidal components is used to exchange power in DPFC. A non-sinusoidal voltage or current can be presented as the sum of sinusoidal components at different frequencies is based on Fourier series. The multiplication of current and voltage components gives the active power. Since the integral of some terms with different frequencies are zero, so the active power equation is given as:

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

Where $V_i$and $I_i$are the voltage and current at the ithharmonic, respectively, and ϕ_i is the angle between the voltage andcurrent at the same frequency. Equation (1) expresses theactive power at different frequency components isindependent.

From the above equation (1), the current and voltage in one frequency has no influence on the active power at other frequencies. The active power atdifferent frequencies is isolated from each other.

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. 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.

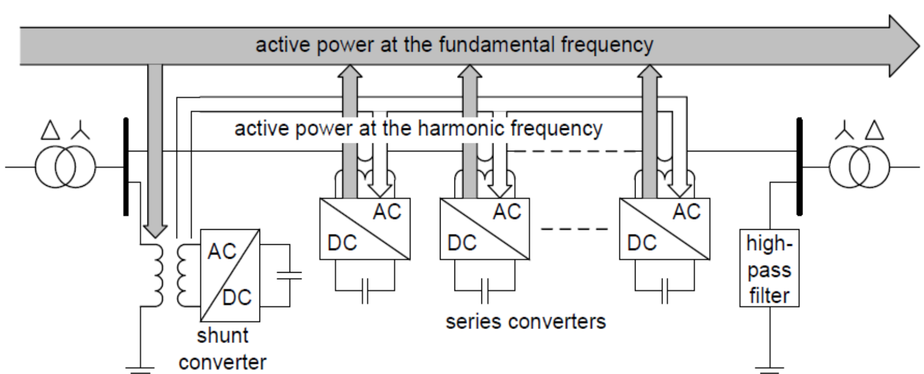

Figure-3: Active Power Exchange

Assume a DPFC is placed in a transmission line of a two-bus system, as shown in Figure 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 as shown in figure 4.

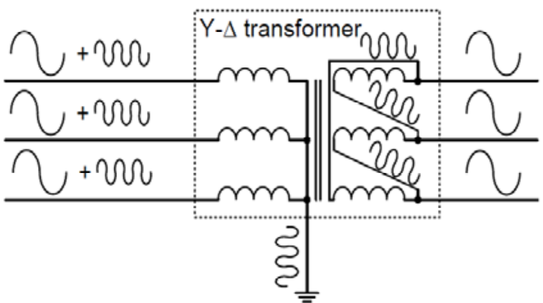

Figure- 4: Utilize grounded Y-Δ transformer to filter zero-sequence harmonic

So the third harmonic component is trapped in Y-Δ transformer. 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. 3 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 as shown in figure 5.

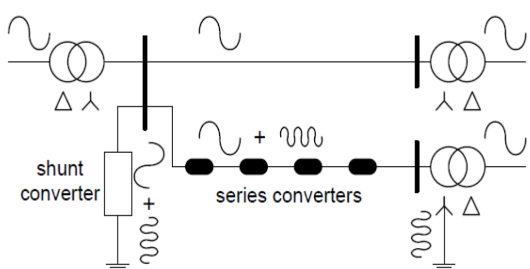

Figure- 5: Route the harmonic current by using the grounding of the Y-Δ transformer

B. The DPFC Advantages:

The DPFC has some advantages as comparison to other FACTS devices, given as follows:

i. *High Control Capability:* The DPFC similar to UPFC,it can control all parameters of transmission network, like transmission angle line impedance, and bus voltage magnitude.

ii. *High Reliability :*The division of series converters in number of part increases the DPFC reliability during converters operation [1]. It means that if one of series converters fails, the others can continue to work.

iii. *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 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.

III.DPFC CONTROL

[1]*Control Strategies:*

The DPFC has three control strategies

a. *Central Control:*

In this control strategy, the reference signal sends by DPFC to both series and shunt converter. The central control gives corresponding reactive current signal for the shunt converter and voltage reference signals for the series converters as per requirement. All the reference signals are generated by central control are at the fundamental frequency [2].

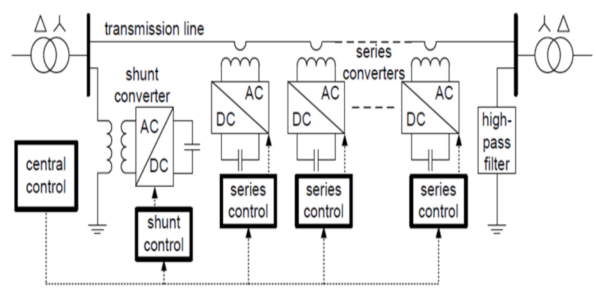

Figure- 6: Central Controls

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 dependson 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 [5].The PWM-Generator block manages switching processes.

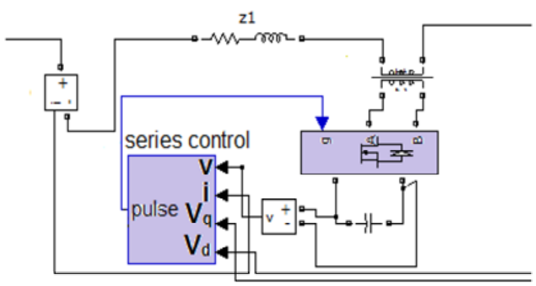

Figure- 7: Block diagram of the series converters in Matlab/Simulink

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.

Each converter has its own controller at different frequency operation (fundamental and third-harmonic frequency). The shunt control structure block diagram is shown in Fig. 8.

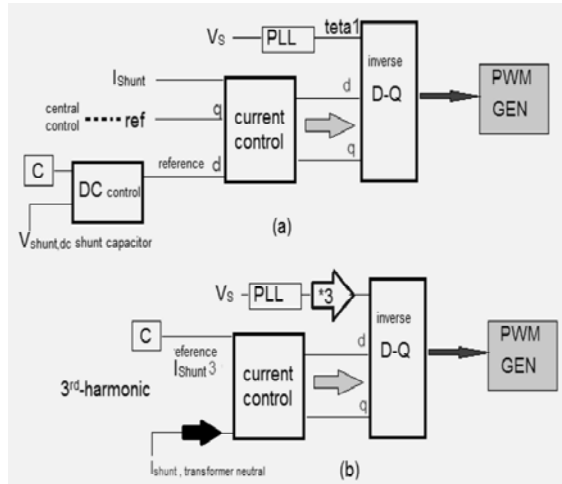

Figure-8:The shunt control configuration:
(a) For fundamental frequency (b)For third-harmonic frequency

[2] *Variation of the Shunt Converter:*

In the DPFC, the shunt converter should be a relatively large three-phase converter that generates the voltage at the fundamental and 3rd harmonic frequency simultaneously. A conventional choice would be a three-leg, three-wire converter. However, the converter is an open circuit for the 3rd harmonic components and is therefore incapable of generating a 3rd harmonic component. Because of this, the shunt converter in a DPFC will require a different type of 3-phase converter. There are several 3-phase converter topologies that can generate 3rd harmonic frequency components, such as multi-leg, multi-wire converters or three single-phase converters. These solutions normally introduce more components, thereby increasing total cost. A new topology for the DPFC shunt converter is proposed. The topology utilizes the existing Y-Δ transformer to inject the 3rd harmonic current into the grid. A single phase converter is connected between the transformer's neutral point and the ground, and injects a 3rd harmonic current into the neutral point of the transformer. This current evenly spreads into the 3-phase line through the transformer. The converter can be powered by an additional back-to-back converter connected to the low-voltage side of the transformer. The circuit scheme of this topology is shown in Figure 9.

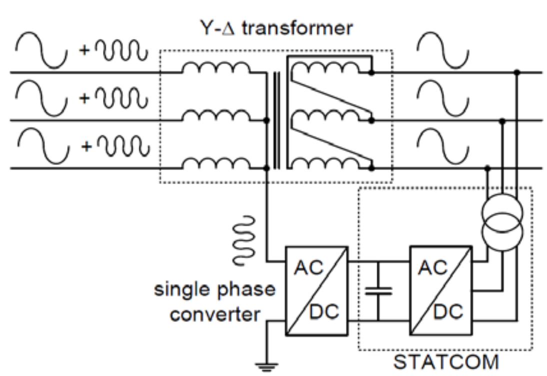

Figure- 9: DPFC shunt converter configuration.

For a symmetrical system, the voltage potential at the neutral point and fundamental frequency is zero. Accordingly, the single-phase converter only handles the 3rd harmonic voltages, which are much lower than the voltage at the fundamental frequency. As the single-phase converter is only used to provide active power for the series converter, the voltage and power rating are small. In addition, the single-phase converter uses the already present Y-Δ transformer as a grid connection. The single-phase converter is powered by another converter through a common DC link. In the case of the system with a STATCOM, the single-phase converter can be directly connected back-to-back to the DC side of the STATCOM, as shown in Figure 9.

IV. POWER QUALITY IMPROVEMENT:

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) [3] [8]. As shown in Fig. 10, 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. 11. [1][2]

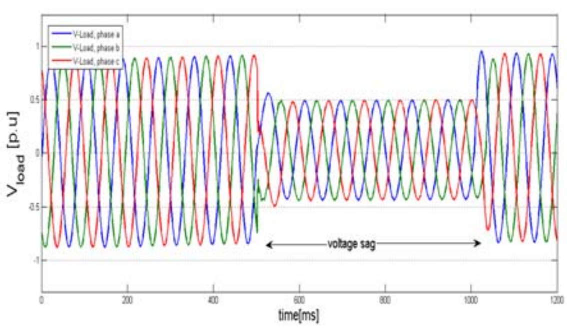

Fig. 10: Three-phase load voltage sag waveform.

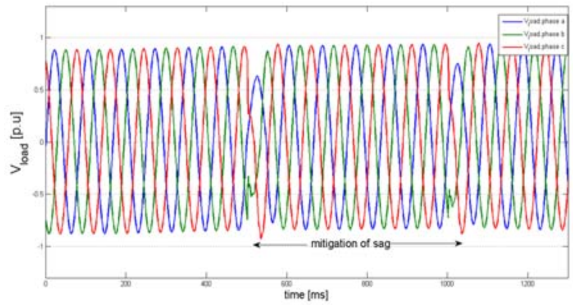

Fig. 11: Mitigation of three phase load voltage sag with DPFC

Fig. 12depicts 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. 13 [1].

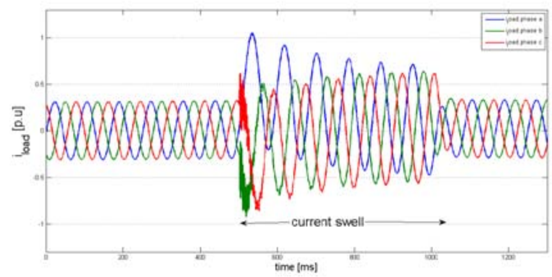

Figure- 12: Three phase load current swell waveform without DPFC

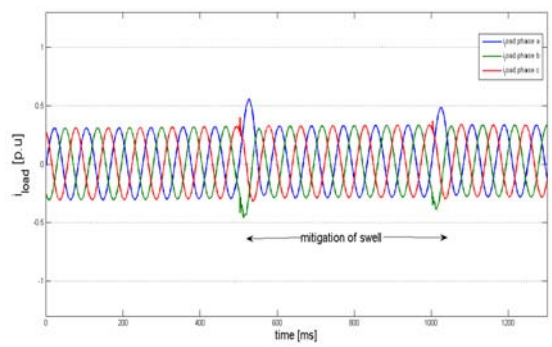

Figure- 13: Mitigation of three-phase load current swell with DPFC

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). 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 modelled 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.

TABLE I:
Simulation system parameters

Parameters	Values
Three Phase Source	
Rated Voltage	220 KV
Rated Power/ Frequency	100 MW/60 Hz
X/R	3
Short Circuit Capacity	11000 MW
Transmission Line	
Resistance	0.012 pu/km
Inductance/ Capacitive Reactance	0.12/0.12 pu/km
Length of Transmission Line	100 km
Shunt Converter 3-phase	
Nominal Power	60MVAR
DC link Capacitor	600 µF
Coupling Transformer (shunt)	
Nominal Power	100 MVA
Rated Voltage	220/15 KV
Series Converters	
Nominal Power	6 MVAR
Rated Voltage	6 KV
Three-phase Fault	
Type	ABC-G
Ground Resistance	0.01Ω

ACKNOWLEDGMENT

I would like to express the deepest appreciation to my guide Prof. P.D. Kulkarni for their help to complete this paper. I would also like to thank my HOD Prof. K.R. Patil for their great support. At last but not least, I would like to thanks co-ordination body to organize international conference at Dr. V.B. Kolte COE, Malkapur and give me chance to present my work.

REFERENCES

[1] Ahmad Jamshidi, S. MasoudBarakati, 2012,"Power Quality Improvement and Mitigation Case Study Using Distributed Power Flow Controller", IEEE. pp.464-468
[2] Mr. N. Peddaiah, Mr. K. VeeraSekhar, Mr. J. Lakshman and Mr. G. Rajashekhar,April-2013'"A Revolutionary Idea to Improve Power Quality by Using Distributed Power Flow Controller [DPFC]", 'International Journal of Emerging Trends in Electrical and Electronics (IJETEE) Vol. 2, Issue. 1. pp.1-5.
[3] Bhim Singh, Kamal Haddad,October 1999, "A Review of Active Filters for Power Quality Improvement", IEEE Transactions on Industrial Electronics, Vol. 46. pp. 960-971.
[4] Ch.Pushpanadham, Tegala. SrinivasaRao,October 2013,"A Novel Power Quality Improvement Technique Using Multi-Connected Distributed Power Flow Controller (MC-DPFC)", 'International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering', Vol. 2, Issue 10. pp.5232-5242.
[5] Sai Lakshmi K, Mrs G.Ujwala, Dr. K. Ramesh Reddy, July 2014,"Mitigation Of Voltage Sag And Swell For Power Quality Improvement Using Distributed Power Flow Controller", 'International Journal of Professional Engineering Studies' Volume Ii/Issue 4. pp.78-84.
[6] P. Ramesh, M. Damodara Reddy,2012,"Power Transfer Capability & Reliability Improvement in a Transmission Line using Distributed Power Flow Controller", 'International Journal of Electrical and Computer Engineering (IJECE)', Vol.2, No.4. pp. 553-562.
[7] S. MasoudBarakati, ArashKhoshkbarSadigh and EhsanMokhtarpour, 2011, "Voltage Sag and Swell Compensation with DVR Based on Asymmetrical Cascade Multicell Converter", North American Power Symposium (NAPS), pp.1-7.
[8] Alexander Eigels Emanuel, John A. McNeill 1997, "Electric Power Quality". Annu. Rev. Energy Environ, pp. 263-303.
[9] Alexander Eigels Emanuel, John A. McNeill "Electric Power Quality". Annu. Rev. Energy Environ 1997, pp. 263-303.
[10] I Nita R. Patne, Krishna L. Thakre "Factor Affecting Characteristics of Voltage Sag Due to Fault in the Power System" Serbian Journal of Electrical engineering. vol. 5, no.1, May2008, pp. 171-182.
[11] J. R. Enslin, "Unified approach to power quality mitigation," in Proc. IEEE Int. Symp. Industrial Electronics (ISIE '98), vol. 1, 1998, pp. 8-20.
[12] P. Pohjanheimo and E. Lakervi, "Steady state modeling of custom power components in power distribution networks," in Proc. IEEE Power Engineering Society Winter Meeting, vol. 4, Jan. 2000, pp. 2949–2954.
[13] Zhihui Yuan, Sjoerd W.H de Haan, Braham Frreira and DaliborCevoric "A FACTS Device: Distributed Power Flow Controller(DPFC)" IEEE Transaction on Power Electronics, vol.25, no.10, October 2010.
[14] Zhihui Yuan, Sjoerd W.H de Haan and Braham Frreira "DPFC control during shunt converter failure" IEEE Transaction on Power Electronics 2009.
[15] R. Zhang, M. Cardinal, P. Szczesny and M. Dame. "A grid simulator with control of single-phase power converters in D.Q rotating frame", Power Electronics Specialists Conference, IEEE 2002.