POWER QUALITY IMPROVEMENT USING F- BASED DISTRIBUTED POWER FLOW CONDITIONER

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Abstract: Electricity demand is increasing day by day and of this demand on power grids which are providing high quality electrical power. This demand is to be considering for the power quality improvement. This paper considers power quality issues of voltage sag and swell with the (DPFC) distributed power flow controller. The DPFC is a new facts device which is similar to (UPFC) unified power flow controller. The DPFC is designed with the elimination of DC link, the shunt and series converter circuit is eliminated. The performance of DPFC and the power quality improvement is controlled by fuzzy logic system (intelligent system).This will be simulated in MATLAB / simulink environment. The presented simulink results are validated and the improvement of power quality

Kew Words: DPFC, Power Quality, Fuzzy logic systems, control adaption, voltage sag, voltage swell.

I. INTRODUCTION:

"Power quality problem is any power problem manifested in voltage, current, or frequency deviation that results in failure or misoperation of customer equipment". Power Quality (PQ) has caused a great concern to electric utilities with the growing use of sensitive and susceptive electronic and computing equipment (e.g. personal computers, computer-aided design workstations, uninterruptible power supplies, fax machines, printers, etc) and other nonlinear loads (e.g. fluorescent lighting, adjustable speed drives, heating and lighting control, industrial rectifiers, arc welders, etc). All nonlinear and time varying temporal type electric loads fall generally in two wide categories, namely the analog arc (inrush/saturation) type and digital converter (power electronic) switching type.

FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity of the present transmission system. The opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, phase angle, and damping of oscillations at various frequencies below the rated frequency. These constraints cannot be overcome otherwise, while maintaining the required system stability, by mechanical means without lowering the useable transmission capacity. By providing added flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating. Mechanical switching needs to be supplemented by rapid-response power electronics.

Among the FACTS components, Unified Power Flow Controller (UPFC), is the most complete. It is able to control independently the throughput active and reactive powers. The UPFC is capable to act over three basic electrical system parameters: line voltage, line impedance, and phase angle, which determine the transmitted power.

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. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude.

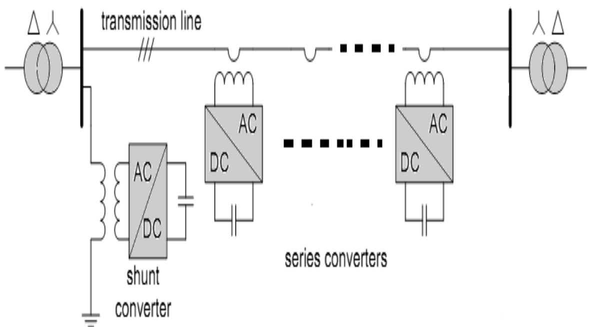

Fig. 1 Structure of DPFC

II. DPFC Working Principle:

In comparison with UPFC, the main advantage offered by DPFC is eliminating the huge DC-link and instate using 3rdharmonic current to active power exchange [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:

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

Where *Vi* and *Ii* are the voltage and current at the *ith* harmonic, respectively, and *φi* is the angle between the voltage and current at the same frequency. Equation (1) expresses the active power at different frequency components is independent. Based on this fact, a shunt converter in DPFC can absorb the active power in one frequency and generates output power in another frequency. 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. Meanwhile, 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 (Fig. 3). 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 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.

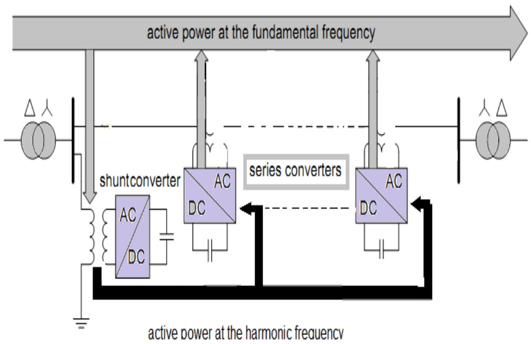

Fig. 2.Active power exchange between DPFC converters

In modern power systems, there is a great demand to control the power flow actively.

Power flow controlling devices (PFCDs) are required for such purpose, because the power low over the lines is the nature result of the impedance of each line. Due to the control capabilities of different types of PFCDs, the trend is that mechanical PFCDs are gradually being replaced by Power Electronics (PE) PFCDs. Among all PE PFCDs, the Unified Power Flow Controller (UPFC) is the most versatile device. However, the UPFC is not widely applied in utility grids, because the cost of such device is much higher than the rest of PFCDs and the reliability is relatively low due to its complexity. The objective of this thesis is to develop a new PFCD that offers the same control capability as the UPFC, at a reduced cost and with an increased reliability. The new device, so-called Distributed Power Flow Controller (DPFC), is invented and presented in this thesis. The DPFC is a further development of the UPFC. It has been shown that the DPFC fulfills all three of the listed goals. This thesis starts with the review the state-of-art of current PFCDs, followed by the research at the DPFC device level, including the operation principle, the modeling and control, and experimental demonstrations. At the end, the thesis presents the research at the system level, which includes the DPFC applications to improve power system controllability and stability, and the feasibility of the DPFC for real networks the elimination of the common DC link also allows the DSSC concept to be applied to series converters. In that case, the reliability of the new device is further improved due to the redundancy provided by the distributed series converters. In addition, series converter distribution reduces cost because no high-voltage isolation and high power rating components are required at the series part. By applying the two approaches – eliminating the common DC link and distributing the series converter, the UPFC is further developed into a new combined FACTS device: the Distributed Power Flow Controller (DPFC), as shown in Figure 3

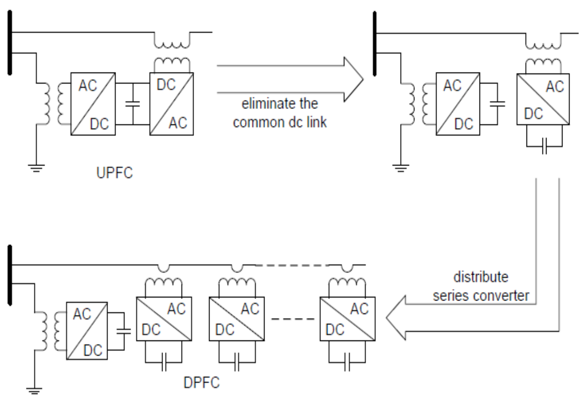

Fig 3. Power Flow Controller (DPFC)

III. Principle Of The Control

Two operation modes are defined for the series converter control:

a) Full-control mode: In this mode, the DPFC operates in normal conditions. The series converters inject both controllable active and reactive components into the grid at the fundamental frequency and the DC voltage is stabilized by absorbing active power from the 3rd harmonic frequency components.

b) Limited-control mode: The DPFC operates in this mode when there is a shunt converter failure. Due to incapability of exchanging active power between converters, the series converters can only provide reactive compensation to the line which means that they can only control line impedance(similarly to an SSSC) [Gyug 00, Pill 03]. The DC voltage of the series converter is stabilized by the active power at the fundamental frequency instead of the 3rd harmonic frequency. In this mode, there is no component injected at the 3rd harmonic frequency by the series converters. Because the series converters lose the capability of active compensation, the DPFC can only control the active power flow through the line by the injection of reactive power. The principle of the supplementary control for the shunt converter failure is to use a different frequency current to maintain the DC voltage of the series converters in different conditions.

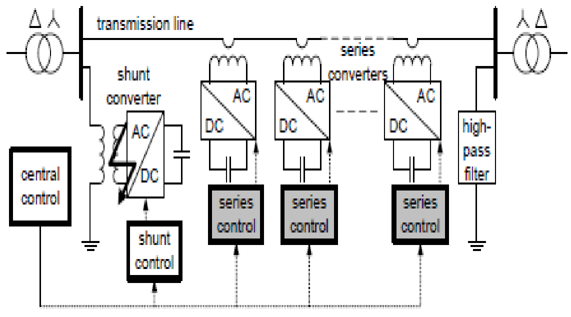

Fig 4: Location of the supplementary control for shunt converter failure

c) Series control adaption

The supplementary scheme is implemented in the DSP control of each series converter. In principle, two DC voltage control loops are required to enable the series converter to operate in the two modes. In the full-control mode, the DC control loop that uses the 3rd harmonic components is active and in the limited-control mode, the loop that uses the fundamental frequency components is active. This solution increases the computational effort required from the DSP because two loops need to be processed simultaneously although only one loop is active.

d)Central Control Adaption

The power flow controller of DPFC within the central controller is designed for controlling both active and reactive power flow independently. However, during shunt converter failure the DPFC is operated in limited-control mode. Because the series converters can only inject reactive power while in limit-control mode, it is impossible to control active and reactive power flow independently. Therefore, one of the controllers must be disabled during the shunt converter failure. As active power flow control has priority in a normal power system, the remaining control freedom, namely to vary the line impedance, is utilized for controlling the active power flow through the line. The output of the reactive power flow control loop is disabled by the signal selector according to the magnitude of 3rd harmonic current.

Simulation and Experiments Results:

To simulate shunt converter failure, the shunt converter is shut down at the time t = 2 s and the DC voltages of the series converters are shown in Figure 5

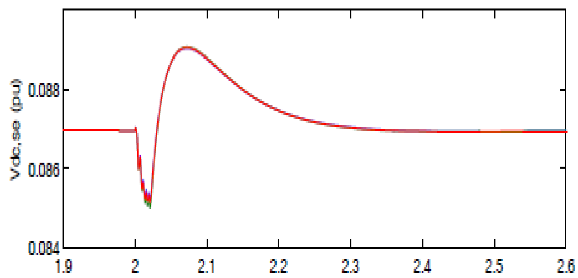

Fig5: DC voltages of the series converters after the shunt converter failure at t = 2 s.

The DC voltages of the series converters in all three phases are well maintained after the failure of the shunt converter. The ripple of the DC voltage is less than 1% during In this setup, to represent the circuit breaker tripping the shunt converter, the shunt converter is manually turned off at the time t = 0.08 s. The reference signals of the series converters at the fundamental frequency are fixed during operation. The line current and voltage injected by one series converter are shown in Figure 6. For easier viewing, only the waveforms of one series converter are shown.

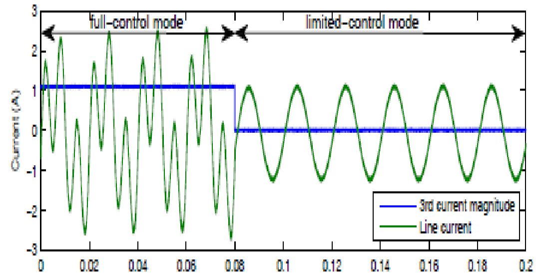

Fig 6(a)

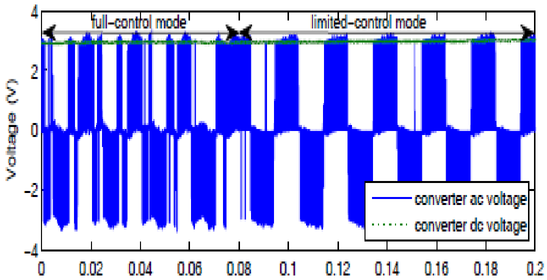

Fig6: DPFC behaviors during the shunt converter failure: (a) line current; (b) converter voltages at both AC and DC sides

The voltage injected by the series converter is in PWM format. Preceding the shunt converter failure, the voltage contains both the fundamental and 3rd harmonic frequency components. After the failure, no current at 3rd harmonic frequency exists in the system and the series converter successfully stabilized the DC voltage at a constant value.

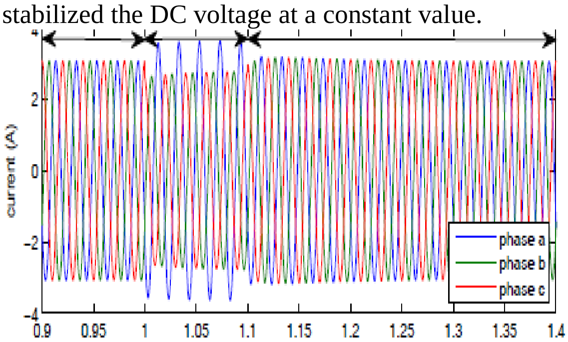

Figure 7(a)

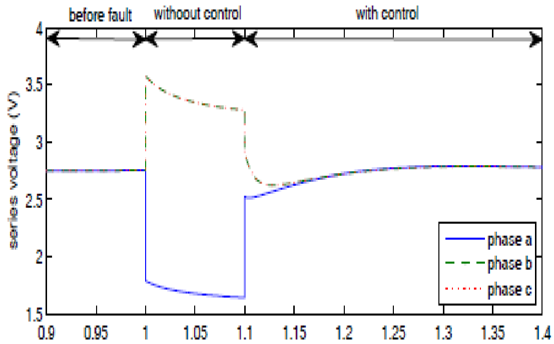

Fig7: DPFC behaviors during a series converter failure: (a) Three-phase current atthe delta side of a transformer; (b) magnitude of the voltage injected by all series converters

As shown, without the controller, the 3-phase current through the line becomes asymmetrical during the converter failure. The supplementary controller successfully compensates the phase difference caused by the series converter failure. The reference signals of the series voltage are shown in Figure 9.

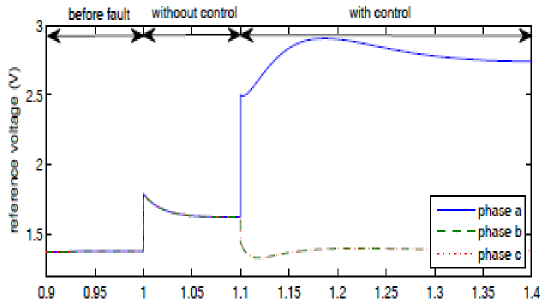

Fig8: Reference signals for the series converters in three phases

IV. Fuzzy Logic Controller

The structure of a complete fuzzy control system is composed from the following blocs:

Fuzzification, Knowledge base, Inference engine, Defuzzification. Figure 1 shows the structure of a fuzzy logic controller.

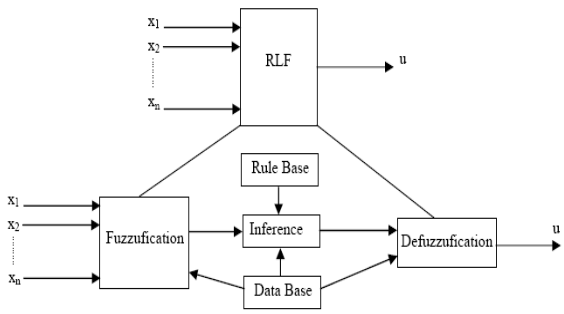

Fig9. The structure of a fuzzy logic controller

The fuzzification module converts the crisp values of the control inputs into fuzzy values. A fuzzy variable has values, which are defined by linguistic variables (fuzzy sets or subsets) the shape fuzzy sets can be triangular, trapezoidal, etc [11]. A fuzzy control essentially embeds the intuition and experience of a human operator, and sometimes those of a designer and researcher. The rule base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristics; it contains a collection of fuzzy conditional statements expressed as a set of IF-THEN rules, Where: (*x1*, *x2*, . . . , *xn*) is the input variables vector, *Y* is the control variable, *M* is the number of rules, *n* is the number fuzzy variables, (*F1*, *F2*, . . .*Fn*) are the fuzzy sets. The composition operation is the method by which such a control output can be generated using the rule base.

B. Knowledge Base Proposed

Figure 10 and 11 shows respectively the triangle-shaped membership functions of error (*e*) and change of error (*ce*). The fuzzy sets are designated by the labels: NB (negative big), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (positive medium), PB (positive big), NVS (negative very small) and PVS (positive very small).

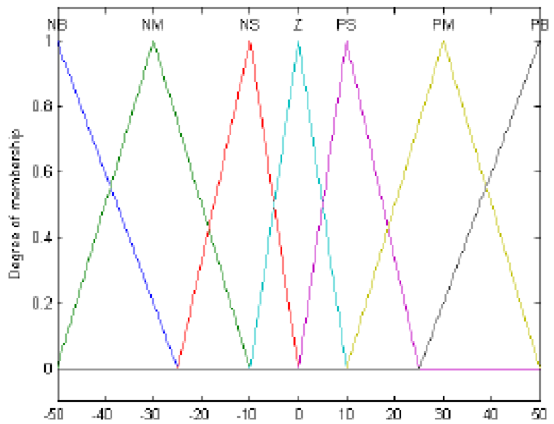

Fig10. Membership functions for input e

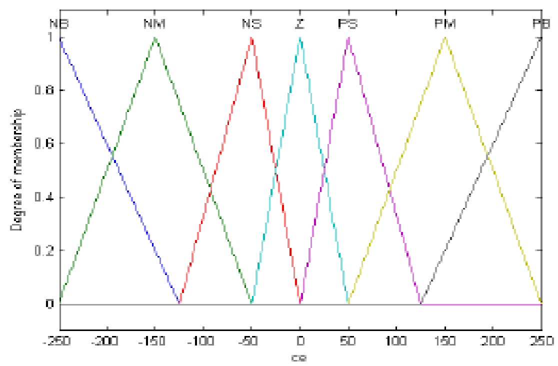

Fig11. Membership functions for input ce

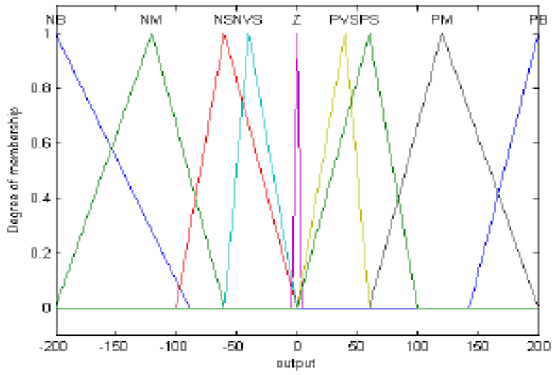

Fig12. Membership functions for output

Figure 10 shows the proposed membership functions for output variable. In this paper, the triangular membership function, the max-min reasoning method, and the center of gravity defuzzification method are used, as those methods are most frequently used in many literatures [11]. The inference strategy used in this system is the Mamdani algorithm.

Table 1. Linguistic Rule Table

ce \ e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NS	NVS	Z
NM	NB	NB	NM	NS	NVS	Z	PVS
NS	NB	NM	NS	NVS	Z	PVS	PS
Z	NM	NS	NVS	Z	PVS	PS	PM
PS	NS	NVS	Z	PVS	PS	PM	PB
PM	NVS	Z	PVS	PS	PM	PB	PB
PB	Z	PVS	PS	PM	PB	PB	PB

All the membership functions (MFs) are asymmetrical because near the origin (steady state), the signals require more precision.

V.CONCLUSIONS

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. To simulate the dynamic performance, a three-phase fault is considered near the load. It is shown that the DPFC gives an acceptable performance in power quality mitigation and power flow control.

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