Modeling and Digital Simulation of DPFC System using Matlab Simulink

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Abstract: This paper deals with modeling and simulation of Distributed Power Flow Controller (DPFC) system. Circuit models are developed for two bus system with and without DPFC. The DPFC employs a shunt based Static Compensator (STATCOM) and multiple series converters to improve the power quality. DPFC has advantages like improved voltage profile and reduced power loss. The simulation results of two bus system with and without DPFC are presented in this paper.

I. Introduction

The growing demand and aging of networks make it desirable to control the power flow in power transmission system fast and reliability. Flexible AC transmission system (FACTS) technology is the application of power electronics in transmission system. The main purpose of this technology is to control and regulate the electric variables in the power system and hence therefore increases the power transfer capability and can be utilized for power flow control.

Currently unified power flow controller (UPFC) is the most powerful device which can simultaneously control all the parameters of the system. Ex. line impedance, the transmission angle and bus voltage etc. the main reason behind the wide spread of the UPFC are its ability to pass the real power flow bidirectionally, maintaining well regulated DC voltage, work ability in the wide range of operating condition etc. Simplified representation of UPFC as shown in Fig.1a

UPFC is the combination of static compensator (STATCOM) and static synchronous series compensator (SSSC) coupled via a common DC link to allow bidirectional flow active power between the series output terminal of the SSSC and shunt output terminal of the STATCOM.

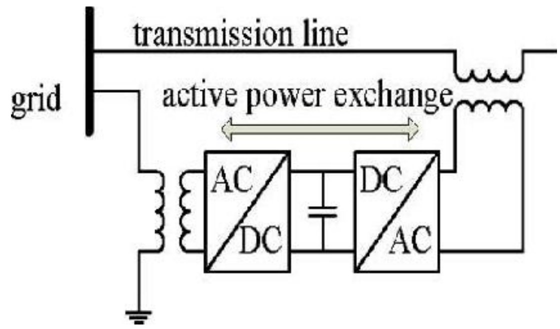

Fig.1a Simplified representation of a UPFC

The two converters operated from a DC link provided by a DC storage capacitor. The UPFC is not widely applied in practice due to their high cost and the redundancy to failure. Since the components of the UPFC handle the voltages and current with high rating, therefore the total cost of the system is high.

Due to the common DC link interconnection a failure that happens at one converter will influence the whole system. To achieve the required reliability for power systems, bypass circuit or redundant back ups are needed which leads to increase the cost.

The same as the UPFC, The Distributed Power Flow Controller (DPFC) recently presented in is a power flow device within the FACTS family, which provides much lower cost and higher reliability than the conventional FACTS devices. It is derived from the UPFC and has the same capability of simultaneously adjusting all the parameters of power system like line impedances, transmission angle and bus voltage magnitude. The DPFC Flow chart and configuration are shown in Fig.1b and Fig.1c respectively.

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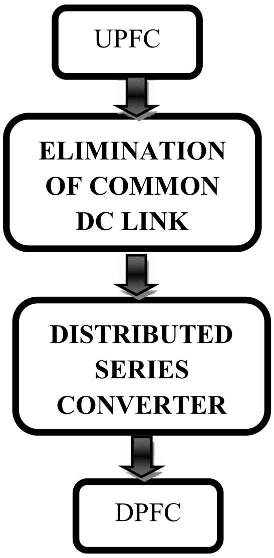


Fig.1b Flow chart from UPFC to DPFC

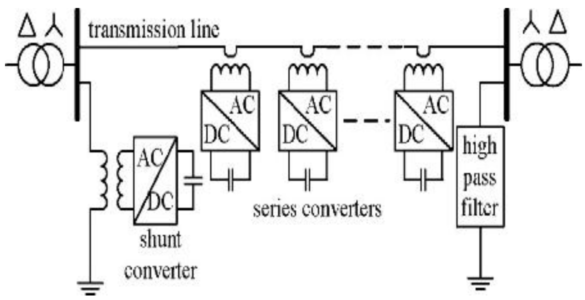


Fig.1c configuration of DPFC

The DPFC eliminates the common DC link between the shunt and series converters and uses the transmission line to exchange active power between converters at the 3rd harmonic frequencies. Instead of one large 3 phase converter, the DPFC employ multiple single phase converters as the series compensator. This concept not only reduces the rating of the component but also provides a high reliability because of the redundancy.

II. Principle of DPFC

Two approaches are applied to the UPFC to increase the reliability and to reduce the cost; They are as follows: First, eliminating the common DC link of the UPFC and second distributing the series converter, as shown in Fig. 1b. By combining these two approaches, the new FACTS device—DPFC is achieved.

The DPFC consists of one shunt and several series-connected converters. The shunt converter is similar as a STATCOM, while the series converter employs the D-FACTS concept, which is to use multiple single-phase converters instead of one large rated converter. Each converter within the DPFC is independent and has its own DC capacitor to provide the required DC voltage. The configuration of the DPFC is shown in Fig. 1c. As shown, besides the key components, namely the shunt and series converters, the DPFC also requires a high-pass filter that is shunt connected at the other side of the transmission line, and two Y–Δ transformers at each side of the line. The reason for these extra components will be explained later.

The unique control capability of the UPFC is given by the back-to-back connection between the shunt and series converters, which allows the active power to exchange freely. To ensure that the DPFC have the same control capability as the UPFC, a method that allows the exchange of active power between converters with eliminated DC link is the prerequisite.

A. Elimination of DC Link

Within the DPFC, transmission line is the common connection between the AC terminal of the shunt and series converters. Therefore it is possible to exchange the active power though the terminals of the converters. The method is based on power theory of non sinusoidal components. According to the Fourier analysis, a non sinusoidal voltage and current can be expressed by the sum of sinusoidal functions in different frequencies wit different amplitudes. The active power resulting from this non sinusoidal voltage and current is defined as the mean value of the product of voltage and current. Since the integral of all the cross product of terms with different frequencies are zero, the power can be expressed by

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

Where V_i and I_i are the voltages and current at the i^{th} harmonic respectively. φ_i is the corresponding angle between voltage and current. From this equation active power at different frequencies is isolated from each other and voltage or current in one frequency has no influence on active power at other frequencies. The independency of the active power at different frequencies gives the possibility that a converter without power source can generate active power at one frequency and absorb this power from other frequencies. By applying this method to the DPFC the shunt converter can absorb the active power from the grid at the fundamental frequency and inject the current back into the grid at a harmonic frequency.

Due to unique features of 3rd harmonic frequency components in a three phase system, the 3rd harmonic is selected for active power exchange I the DPFC. In a three phase system the 3rd harmonic each phase is identical, which means they are zero sequence components. Because the zero sequence harmonic can be naturally blocked by star delta transformers and these are widely incorporated in power systems, there is no extra filter required to prevent harmonic leakage.

B. Distributed Series Converter

The D-FACTS is a solution for the series-connected FACTS, which can dramatically reduce the total cost and increase the reliability of the series FACTS device. The idea of the D-FACTS is to use a large number of controllers with low rating instead of one large rated controller. The small controller is a single-phase converter attached to transmission lines by a single-turn trans-former. The converters are hanging on the line so that no costly high-voltage isolation is required. The single-turn transformer uses the transmission line as the secondary winding, inserting controllable impedance into the line directly. Each D-FACTS module is self-powered from the line and controlled remotely by wireless or power-line communication shown in Fig.1d The structure of the D-FACTS results in low cost and high re-liability. As D-FACTS units are single-phase devices floating on lines, high-voltage isolations between phases are avoided. The unit can easily be applied at any transmission-voltage level, be-cause it does not require supporting phase-ground isolation. The power and voltage rating of each unit is relatively small. Further, the units are clamped on transmission lines, and therefore, no land is required. The redundancy of the D-FACTS provides an uninterrupted operation during a single module failure, thereby giving a much higher reliability than other FACTS devices

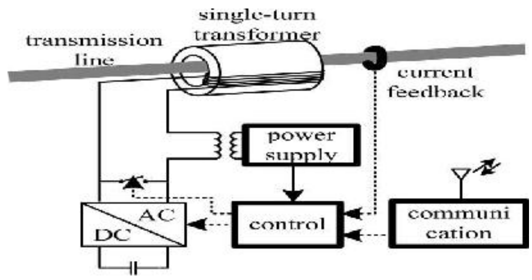


Fig. 1d Configuration D-FACTS Unit

C.Advantages of DPFC

The DPFC can be considered as a UPFC that employs the D-FACTS concept and the concept of exchanging power through harmonic. Therefore, the DPFC inherits all the advantages of the UPFC and the D-FACTS, which are as follows.

1. High control capability. The DPFC can simultaneously control all the parameters of the power system: the line impedance, the transmission angle, and the bus voltage. The elimination of the common dc link enables separated installation of the DPFC converters. The shunt and series converters can be placed at the most effectively location. Due to the high control capability, the DPFC can also be used to improve the power quality and system stability, such as low-frequency power oscillation damping voltage sag restoration, or balancing asymmetry.

2. High reliability. The redundancy of the series converter gives an improved reliability. In addition, the shunt and series converters are independent, and the failure at one place will not influence the other converters. When a fail-ure occurs in the series converter, the converter will be short-circuited by bypass protection, thereby having little influence to the network.

III. Simulation Results

The circuit of a two bus system is modeled using the linear elements available in MATLAB SIMULINK.

TWO BUS SYSTEM WITHOUT DPFC

The circuit model of 2-bus system without DPFC is shown in Fig.3a. The alternator is represented as series combination of R, L and emf. The line is represented as the series combination of R&L. The two loads at the receiving end are represented as series combination of R&L. The voltage across load 2 and load 1 are shown in Fig.3b. Additional load is applied at t=0.2seonds. The receiving end voltage decreases due to the addition of extra load. The real power shown in Fig.3c. The variation of reactive power is shown in Fig.3d. The real and reactive powers increase due to the addition of extra load.

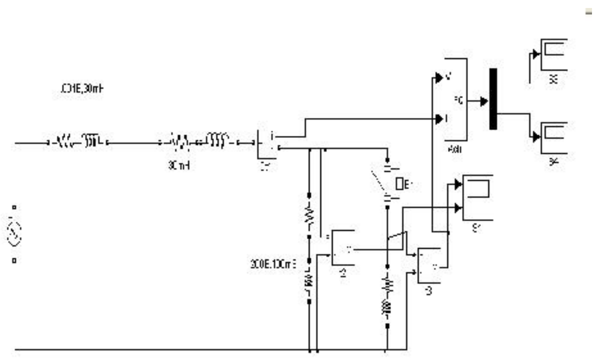


Fig. 3a Two bus system without DPFC

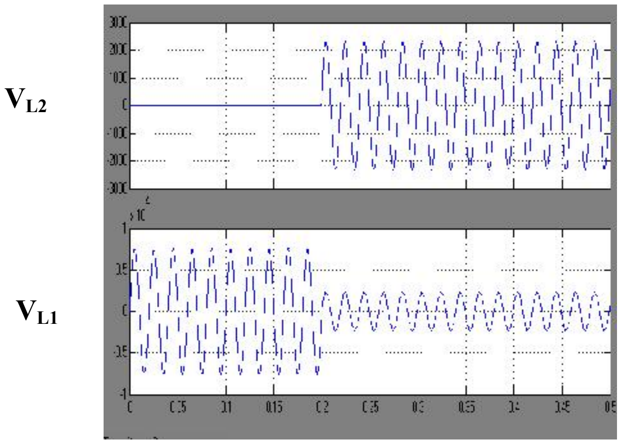


Fig.3b The voltage across load 2 and load 1

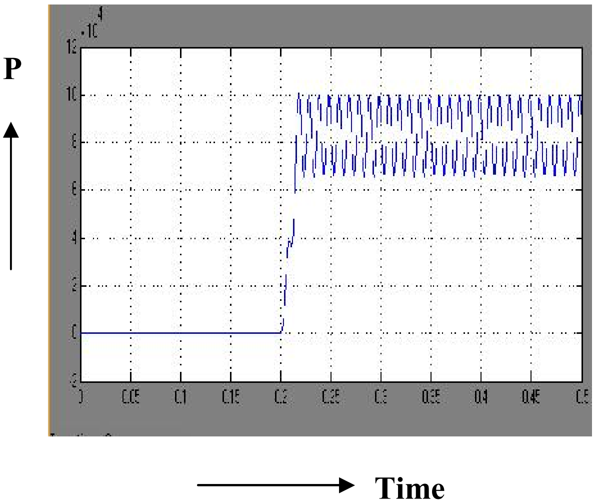


Fig. 3c variation of real power

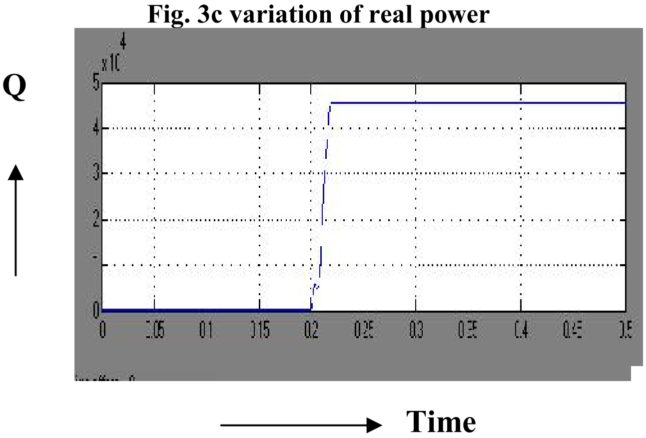


Fig. 3d variation of reactive power

TWO BUS SYSTEM WITH DPFC

The circuit model of two bus system with Distributed Power Flow Controller (DPFC) is shown in Fig.3e. The shunt converter is connected to supply the reactive power required by the receiving end. Two series converters are added to compensate the voltage sag. Voltage across load 1 and load2 are shown in Fig. 3f. The voltage reduces at t=o.2seconds due to the addition of load. The voltage recovers partially at t=0.3seconds due to the addition of one Dynamic voltage restorer (DVR). The voltage fully recovers at t=0.6 seconds due to the addition of 2nd DVR. The variation of real power is shown in Fig.3g the variation of reactive power is shown in Fig.3h. The real and reactive power increases at every step due to the injection of voltage by the Dynamic voltage restorer (DVR).

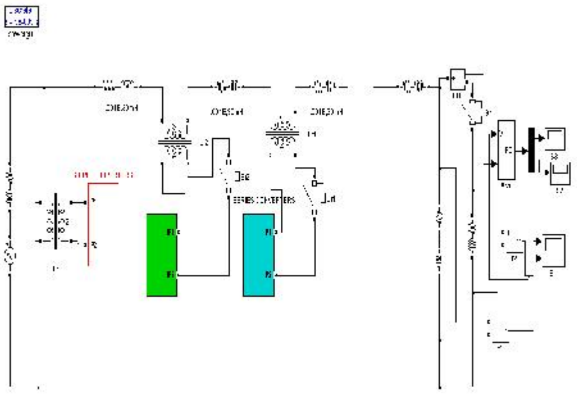


Fig.3e two bus system with Distributed Power Flow Controller (DPFC)

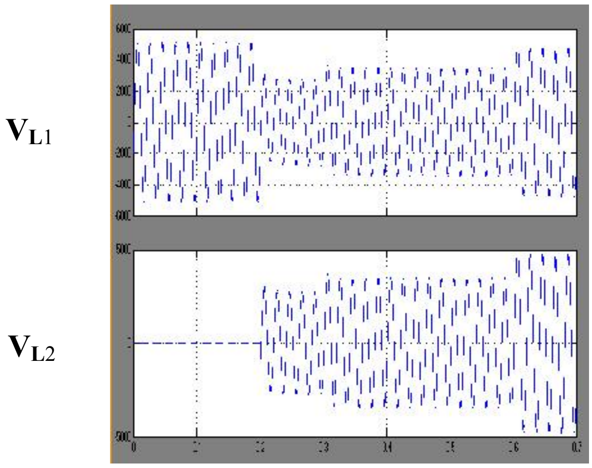
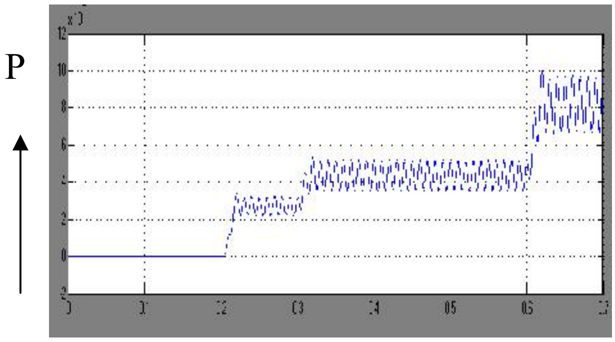


Fig.3f Voltage across load 1 and load2



Time

Fig.3g. Variation of Real Power

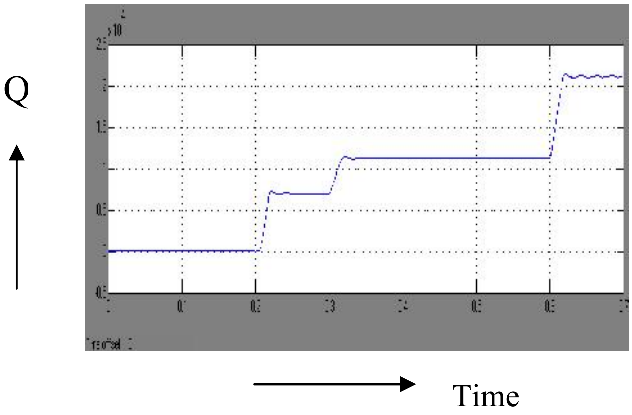


Fig.3h Variation of Reactive Power

CONCLUSION

Simulink circuit model is proposed for two bus system with DPFC. This system is realized Without DC link between the shunt and series converters. Reactive power required by the load is partially supplied by the STATCOM and partially by the generator at the sending end. The DPFC used in this work can successfully mitigate the sag. The scope of this work is simulation of DPFC using single phase circuit model. The simulation using three phase model is yet to be done. The sag is successfully mitigated by using DPFC system

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