

Modeling of IPFC for Power Flow control in 3-Phase line –Further Aspects And its Limitations

B. Karthik and S. Chandrasekar

Abstract—The IPFC (Interline Power Flow Controller) is among the FACTS devices aimed at simultaneously controlling the power flow in multilines systems. This paper presents the IPFC main features and limitations while controlling the power flow. In order to observe these advantages and disadvantages, a mathematical model based on the d-q orthogonal coordinates was developed. Issues like the relationship between the transmission angle and the IPFC controlled region as well as the converters operative region in steady-state will also be presented. It is also used the real power being transferred between the compensated lines. For this purpose, 3 phase transmission line model associated with the converter station has been developed and incorporated in an IPFC model using SIMULINK. The results indicate that IPFC improves system reliability.

Index Terms—IPFC, reliability, transmission line, voltage source converter.

I. INTRODUCTION

In recent years, a large demand has been placed on the transmission network, and demands will continue to increase due to an increasing number of non utility generators and intensified competition among them. Increasing transmission capacity requirements can be achieved by either constructing new transmission lines or increasing the transfer capability of existing transmission facilities. An effective solution is, thus, to consider the use of transmission controllers (e.g., power electronics-based transmission controllers).

Flexible ac transmission system (FACTS) controllers have the potential to increase the capacity of existing transmission networks through functional versatility and control flexibility. FACTS controllers have the capability of direct control of transmission-line flows by changing the main transmission parameters (e.g., voltage, line impedance, and power angle of transmission corridors).

In recent years, considerable attention has been devoted to the development and applications of FACTS controllers and their ability to enhance power system security. This has been done by focusing on the ability of FACTS controllers on both damping of power system oscillations and improving voltage stability. On the other hand, less work has been conducted to investigate the impact of FACTS controllers on power system adequacy.

The interline power-flow controller (IPFC) is a new and

advanced FACTS controller, which can be used for dynamic compensation and effective power-flow management among transmission corridors. This paper investigates the impact of IPFC on the reliability of composite generation and transmission power systems and is arranged in the following order. Explains the structure and the principle function of the IPFC. A state-space Markov model associated with different operation modes of IPFC is developed. The application of IPFC in the IEEE-RTS is examined. Two types of performance indices designated as delivery-point and system indices are introduced to illustrate the impacts of employing IPFC in power systems. The study results and the effectiveness of the proposed technique and the developed model are illustrated. The conclusions drawn from the analysis are provided.

II. BASIC STRUCTURE & FUNCTION OF IPFC

The schematic representation of an IPFC. There are two back-to-back voltage-source converters (VSCs), based on the use of gate-turnoff (GTO) thyristor valves. The VSCs produce voltages of variable magnitude and phase angle. These voltages are injected in series with the managed transmission lines via series transformers. The injected voltages are represented by the voltage phasors. The converters labeled VSC1 and VSC2 are coupled together through a common dc link. Illustrates the IPFC phasor diagram. With respect to the transmission-line current, in phase and quadrature phase components of injected voltage, respectively, determine the negotiated real and reactive powers of the respective transmission lines. The real power exchanged at the ac terminal is converted by the corresponding VSC into dc power which appears at the dc link as a negative or a positive demand. Consequently, the real power negotiated by each VSC must be equal to the real power negotiated by the other VSC through the dc lines. VSC1 is operated at point A. Therefore, VSC2 must be operated along the complementary voltage compensation line, such as point B, to satisfy the real power demand of VSC1. This is given by:

$$P_{se1} + P_{se2} = V_{1p} I_1 + V_{2p} I_2 = 0$$

The protective actions can be divided into two levels in each converter station. In case a failure occurs and affects all components, the protection system will bypass all of the components. For instance, a failure in a series transformer may result in bypassing the associated SSSC with the bypass breaker. There are a number of failures affecting only a single component, and the protective actions involve exclusively bypassing the affected component. For example,

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when a failure occurs within the GTO thyristor module in a valve of the VSC, the GTO module is by past.

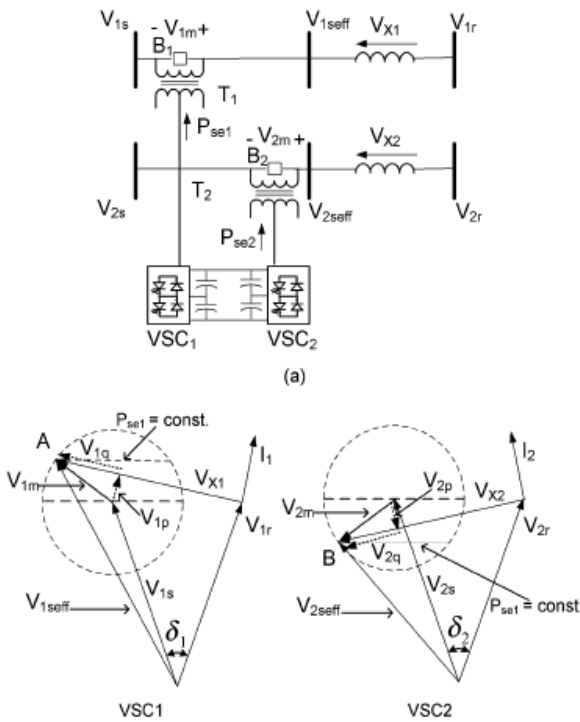


Fig.1 (a) Schematic representation b) Phasor diagram.

III. BASIC OPERATING PRINCIPLES

The IPFC addresses the problem of compensating a number of transmission lines at a given substation. Standing alone series capacitive compensators normally are used to increase the transmittable active power over a given line however they are unable to control the reactive power flow in, and thus the proper load balancing of the line. Therefore in an IPFC, series VSCs are tied together at their DC link capacitors. Because of the common DC circuit there is possible to Exchange the real power between transmission lines and therefore series VSCs can provide also reactive power flow. In an IPFC, the exchanged real power can flow bidirectionally between AC lines which may be of different frequencies, thus making the IPFC an asynchronous tie.

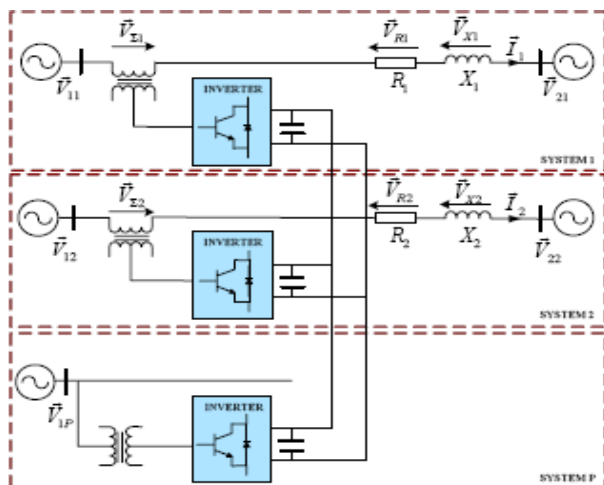
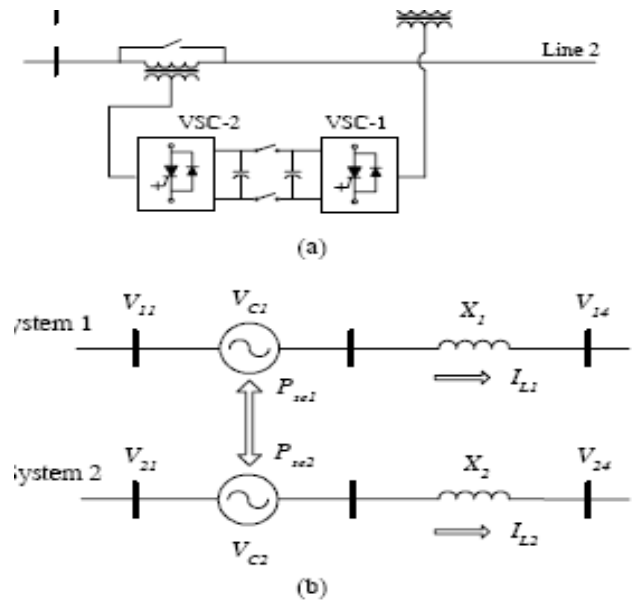


Fig. 2. Single line diagram of an interline power flow controller with two series VSCs and one parallel VSC.

IV. IPFC – 3 PHASE MODEL ANALYSIS

In this first part, a brief introduction of the IPFC operational characteristics is presented. This explanation applies to both an elementary IPFC (Fig. 3) and a multi converter IPFC arrangement. The injection of V_{C1} on System 1 usually results in an exchange of P_{se1} and Q_{se1} between converter VSC-1 and the line. Commonly, the $V_{C1,2}$ voltage is split into its $d-q$ components which eases the analysis of the system as a whole. The V_{C1q} component has predominant effect on the line real power, while the in-phase component (V_{C1d}) has over the line's reactive power. The reactive power exchange Q_{se1} is supplied by the converter itself; however, the active power (P_{se1}) imposes a demand to be fulfilled at the DC terminals. Converter VSC-2 is in charge of fulfilling this demand through the $P_{se1} + P_{se2} = \text{const}$ constraint. Unlike VSC-1 (in the primary system) the operation of VSC-2 (secondary system) has its freedom degrees reduced; thus, its series voltage V_{C2} can compensate only partially to its own line. This is because converter VSC-2 also has the task of regulating the dc-link voltage. So, the P_{se2} component of VSC-2, shown in Fig. 3(b) is predefined. This imposes a restriction to this line in that only the quadrature component of V_{C2} can be specified to control its power flow. Under this condition, the primary system will have priority over the secondary system in achieving its set-point requirements.



Two-converter (elementary) IPFC, (b) Equivalent circuit
Fig. 3. (a) Two converter (elementary) IPFC (b) Equivalent circuit

The IPFC depicted in Fig. 4 will be used to establish a practical mathematical model. The equivalent sending and receiving-end sources in both AC systems are regarded as stiff. The condition for which the switch CB is closed (i.e. $V_{11}=V_{21}=V$ equivalent) also applies to the analysis presented in this section. For ease of analysis, it will also be assumed that both AC systems have identical line parameters.

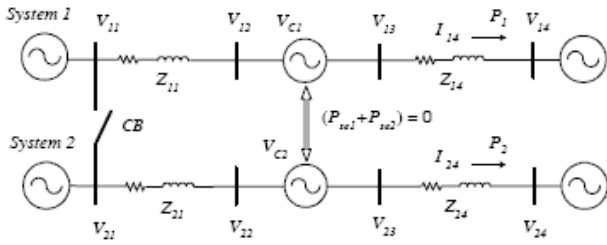


Fig. 4. The IPFC depicted

As previously stated, all the system variables will be decomposed into their d - q orthogonal co-ordinates. It is also assumed that each converter injects an ideal sinusoidal waveform, having only a fundamental frequency. The steady-state power balance of the n number of converters (same number of compensated lines) can be represented by (1):

$$\sum_{i=1}^n P_{se_i} = 0 \quad (1)$$

As in our $n=2$, we will have,

$$P_{se1} + p_{se2} = 0 \quad (2)$$

So for each line it can be written,

$$P_{se1} = V_{C1d} I_{14d} + V_{C1Q} I_{14Q} \quad (3)$$

$$P_{se2} = V_{C2d} I_{24d} + V_{C2Q} I_{24Q} \quad (4)$$

Equations (2) through (8) allow the main parameters of the elementary IPFC (Fig. 4) to be calculated. Unlike the case of the GIPFC addressed in the unknown variable $VC2d$ will be a function of $VC1$ (specified). Once computed the unknown variables (i.e. the d - q components of $V12$, $V22$, $I14$, $I24$ and $VC2d$), the power flow in the receiving-end of Systems 1 and 2, with or without the effect of the series voltage, can be calculated through (9)

$$V_{12d} = V_{14D} - V_{CID} - X_{14} I_{14d} \quad (5a)$$

$$V_{12q} = V_{14Q} - V_{C1Q} + X_{14} I_{14q} \quad (5b)$$

$$V_{22d} = V_{24d} - V_{C2d} - X_{24} I_{24d} \quad (6a)$$

$$V_{22Q} = V_{24Q} - V_{C2Q} + X_{24} I_{24Q} \quad (6b)$$

$$I_{14d} = K_1 (V_{11q} - V_{14Q} + V_{C1Q}) \quad (7a)$$

$$I_{14q} = K_1 (-V_{11d} + V_{14d} - V_{C1d}) \quad (7b)$$

$$I_{24d} = K_2 (V_{21Q} - V_{24Q} + V_{C2Q}) \quad (8a)$$

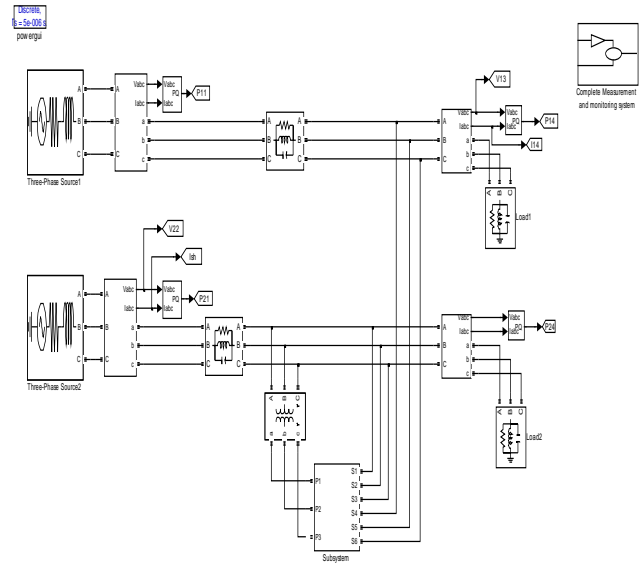
$$I_{24q} = K_2 (-V_{21d} + V_{24d} - V_{C2d}) \quad (8b)$$

$$S_1 = (P_1 + JQ_1) = V_{14} I_{14} \quad (9a)$$

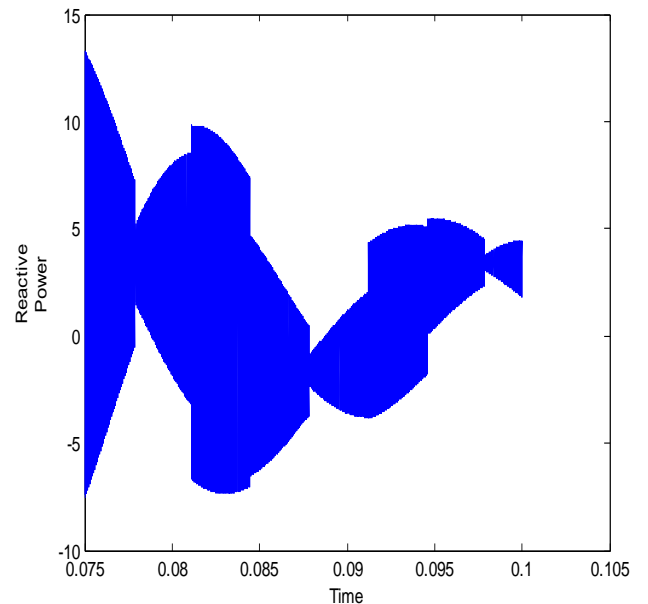
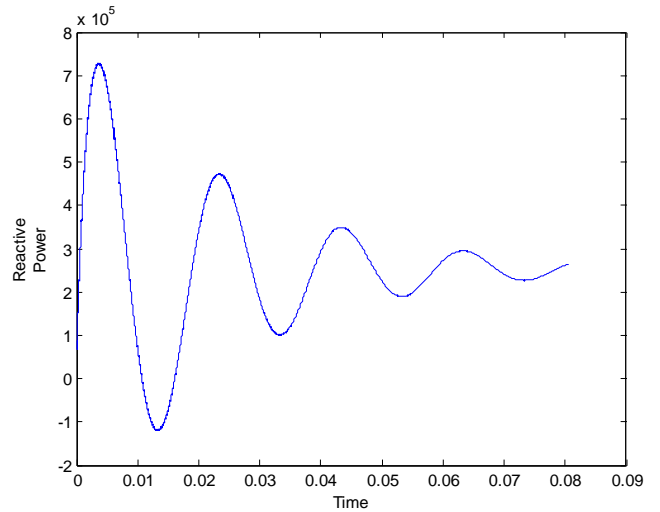
$$S_2 = (P_2 + JQ_2) = V_{24} I_{24} \quad (9b)$$

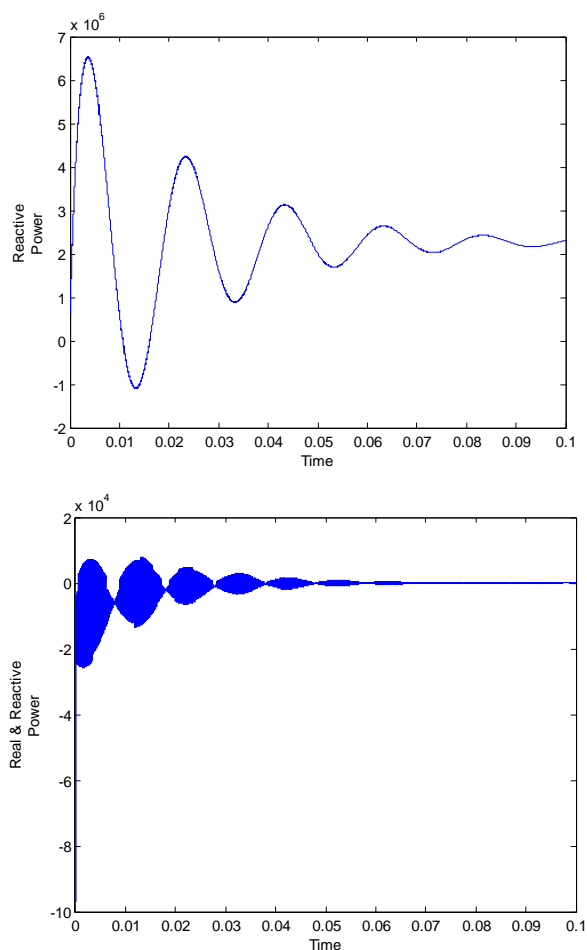
Note that System 1 will have two independently controlled variables (i.e. $VC1$, $\theta C1$). Conversely, System 2 will only have one variable ($VC2q$) to be independently controlled.

V. SIMULINK MODEL



VI. RESULTS





VII. LIMITATIONS AND CONCLUSIONS

The main attributes and disadvantages characterizing the operation of the IPFC, whilst controlling the power flow in multilane systems, were presented in this paper. It was shown that the mathematical model presented can easily be extended to systems with more than two transmission lines. Although in theory the secondary system can be chosen independently of any restriction, it was shown that this line should be chosen regarding its strength so as not to degrade significantly its own operation. Various operational conditions such as the effect of the transmission angle variation over both primary and secondary systems as well as upon the response of the converters were also addressed. The IPFC, in its simplest form (i.e. with only two series converters), can be very useful in relieving congested systems. Issues like the IPFC instantaneous response and its dynamic behavior, along with their respective simulations, are currently underway

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