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Improvement of Power System Stability Using IPFC and UPFC Controllers

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***Abstract:** The IPFC (Interline Power Flow Controller) and UPFC (Unified Power Flow control) among the FACTS devices aimed to the power flow control .power system stability plays a vital role in the factor of reliability and power quality. Power quality mainly depends on the compensation of reactive power and level of voltages. In past the capacitive banks are used to compensate these parameters. Recent advances in FACTS Controllers improves the power system stability. In this paper, modeling and interfacing of facts controllers discussed in real time power systems. Simulations investigate the effect of UPFC and IPFC in power systems by series injected voltage and reactive power support. Finally the simulink results have been presented to indicate the reactive power support and improvement in transfer capability of lines.*

Index Terms: **Interfacing, UPFC, IPFC, Reactive power.**

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 [4] 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). The FACTS devices aimed to the power flow control. [1]

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).

Among the FACTS components, Unified Power Flow Controller (UPFC) [2] and Interline Power Flow Controller (IPFC) [3] are the most advanced in FACTS controllers. These are able to control independently the throughput active and reactive powers. The UPFC is capable to act over three basic electrical system parameters [4]: line voltage, line impedance, and phase angle, which determine the transmitted power.

Power Flow [1] through an alternative current line is a function of the line impedance, the magnitude of the sending-end and receiving-end voltage and the phase angle between these voltages .The power flow can be increased, firstly by decreasing the line impedance with a capacitive reactance, secondly by increasing the voltages and finally by increasing the phase angle between these voltages. In our work, the power flow is controlled by controlling the sending and receiving bus voltage. Also, the control of the shunt and series element of the UPFC will be studied in this paper.

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 [7] 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 UPFC

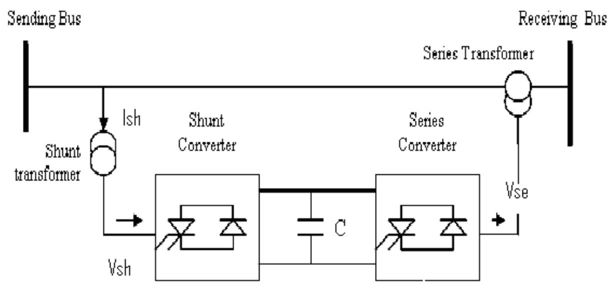

Fig.1 Basic structure of UPFC

It can be seen. That the UPFC consists of a series and a shunt converter is connected back-to-back through a common dc link. The shunt converter is connected also in parallel with the line transmission by transformer, allows controls the UPFC bus Voltage/shunt reactive power and the dc capacitor voltage [6]

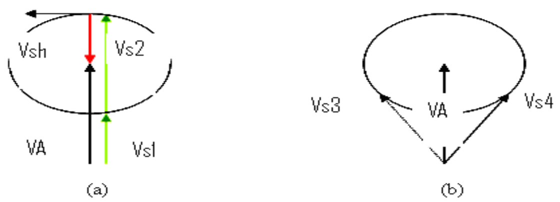

Fig.2. Power exchange of the Shunt Converter

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Figure 2a shows the exchange of the reactive power between the UPFC and the electrical system. The shunt converter generates a voltage Vs1 in phase with VA but with variable magnitude. If Vs=Vs1. The UPFC injects some reactive power, if Vs=Vs2 the UPFC absorbs some reactive power and no reactive power is exchanged for Vs=VA.In order to compensate the series converter losses, figure 3b shows very clearly. That the active power is exchanged between UPFC and the electrical system. The Voltage generated by shunt converter is no it in phase with the voltage of the system but of the same magnitude. Whereas the series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The UPFC can provide multiple power flow control functions by adding the injected voltage phasor with appropriate magnitude Vse and phase angle Ө to the sending-end-voltage phasor.

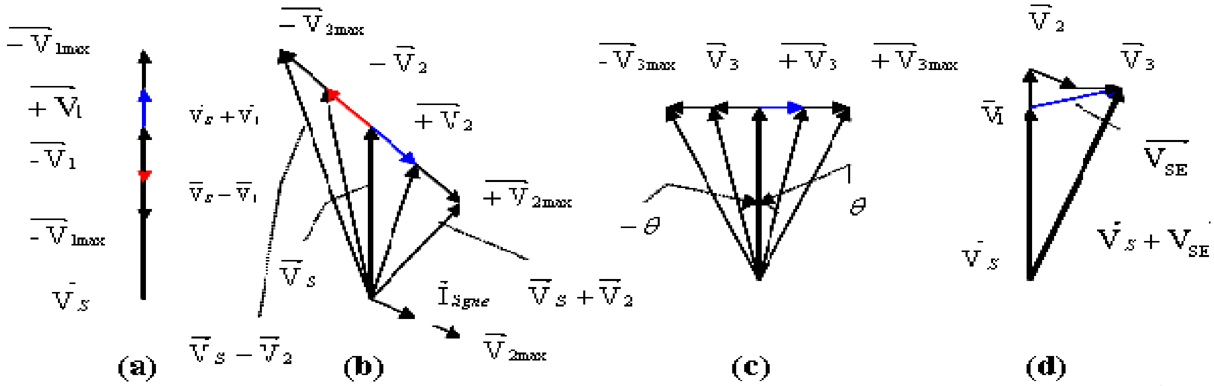

Fig. 3 Series Voltage Injected Phasor diagrams

As illustrate in figure 3, by the appropriate choice (control) of phasor Vse, the three customary power flow control functions:

1) Voltage regulation
2) Series reactive compensation.
3) Phase Shift.

Simultaneous control of terminal voltage, line impedance and phase angle allows the UPFC to perform multifunctional power flow control. In order to simulate a power system that contains a UPFC, the UPFC needs to be modeled. Fig shows a diagram for UPFC; all the variables used in UPFC model are denoted in fig with bold fonts representing phasors .Per unit system and MKS units are jointly used in modeling. The ac system uses par unit system with its variables calculated based on the system-side SB and VB, while the dc variables are expressed in MKS units. We first consider the UPFC dc link [5] capacitor charging dynamics. The current Id1, Id2 (see fig .5.) and the capacitor voltage and current have the following relation with harmonics neglected

$$I_d = C\frac{dV_d}{dt}$$

$$I_d = I_{d1} + I_{d2}$$

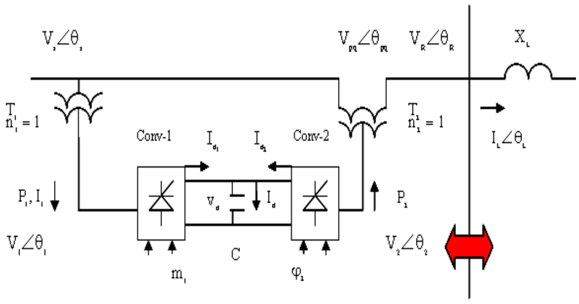

Fig. 4 Transmission line with UPFC installed

If we assume the inverters are ideal, the real power exchange with the ac system will be (*P*1 and *P*2 are in p.u.): Fig shows a diagram for UPFC; all the variables used in UPFC model are denoted in fig with bold fonts representing phasors We first consider the UPFC dc link [5] capacitor charging dynamics.

$$P_1 = \frac{V_d I_{d1}}{S_B}$$

$$P_2 = -\frac{V_d I_{d2}}{S_B}$$

From above equations we have:

$$CC_d = -\frac{dV_d}{dt}(P_1 - P_2)S_B$$

From ac system, we know that *P*1 and *P*2 calculated by:

$$\mathbf{P}_1 = \mathbf{R}_e\left(V_1 I_1^*\right) = \mathbf{R}_e\left(V_1\left(\frac{n_1 V_s - V_1}{jX_{t1}}\right)^*\right)$$

$$\mathbf{P}_2 = \mathbf{R}_e\left(V_{pq} I_L^*\right) = \mathbf{R}_e\left(V_{pq}\left(\frac{V_S + V_{pq} - V_R}{jX_{t2}}\right)^*\right)$$

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Applying modern PWM control technique two the two voltage source converters, the relations between the inverter dc-and ac-side voltages can be expressed by

$$V_1 = m_1 \frac{V_d}{V_B}$$

$$V_2 = m_2 \frac{V_d}{V_B}$$

Where coefficient *m1* and *m2* represent the PWM control effects in order to maintain desired inverter ac-side voltages *V1* and *V2* respectively. The desired *m*1 and *m2* are UPFC main control outputs. *V1* and *V2* are in p.u. and *VB* is the ac system base voltage. The phase angle of (*V1*) and (*V2*) are denoted as (*Θ1*) and (*Θ2*) respectively. They are controlled through firing angle (*φ1*) and (*φ2*) of two converters:

$$\theta_1 = \theta_s - \varphi_1$$
$$\theta_2 = \theta_s - \varphi_2$$

The desired m1, φ1, m2 and φ2 can be obtained from UPFC main control system, therefore based on equation together with UPFC control system equations and ac network interface equation.

III. BASIC STRUCTURE & FUNCTION OF IPFC

The schematic representation of an IPFC. There are two back-to-back voltage-source converters (VSCs) [6], 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 [10] 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 [6] 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 [6] 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, when a failure occurs within the GTO thyristor module in a valve of the VSC, the GTO module is by past. The real power exchanged at the ac terminal is converted by the corresponding VSC [8] into dc power which appears at the dc link as a negative or a positive demand.

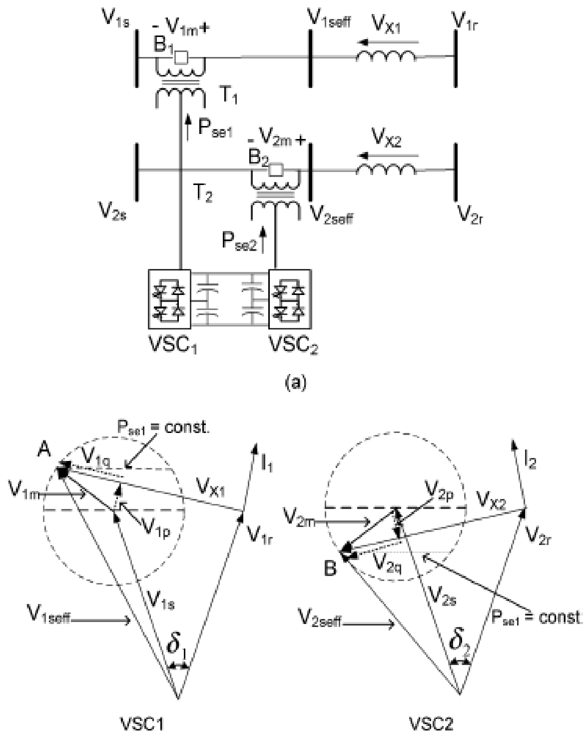

Fig. 5. Principle of IPFC.

Fig.5 (a) Schematic representation b) Phasor diagram

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. The IPFC [10] depicted in Fig. 4 will be used to establish a practical mathematical model.

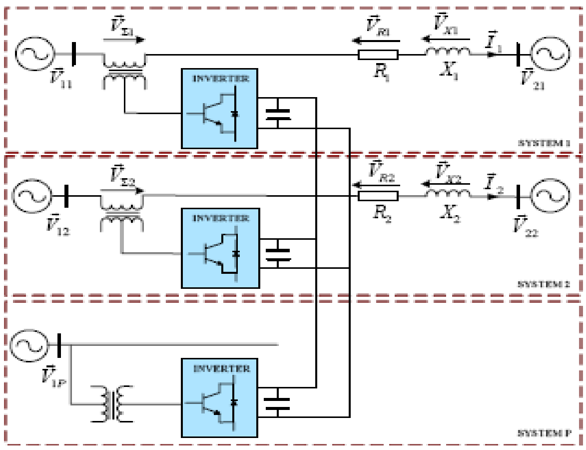

Fig. 6 Single line diagram of an interline power flow controller with two series VSCs and one parallel VSC

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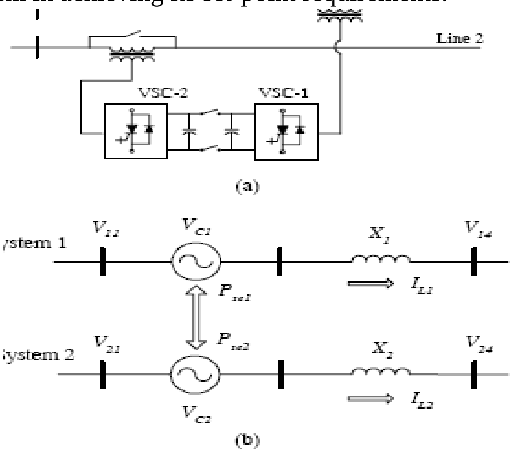
In this first part, a brief introduction of the IPFC operational characteristics is presented. This explanation applies to both an elementary IPFC (Fig. 6) and a multi converter IPFC arrangement. The injection of *VC1* ohm System 1 usually results in an exchange of *Pse1* and *Qse1*between converter VSC-1 and the line. Commonly, the *VC1,2* voltage is split into its *d-q* components which eases the analysis of the system as a whole. The *VC1q* component has predominant effect on the line real power, while the in phase component (*VC1d*) has over the line's reactive power. The reactive power exchange *Qse1* is supplied by the converter itself; however, the active power (*Pse1*) imposes a demand to be fulfilled at the DC terminals. Converter VSC- 2 is in charge of fulfilling this demand through the Unlike VSC-1 (in the primary system) the operation of VSC-2(secondary system) has its freedom degrees reduced; thus, its series voltage *VC2* 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 *Pse2* component of VSC-2, shown in Fig. 6(b) is predefined. This imposes a restriction to this line in that only the quadrature component of *VC2* 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.7. (a)Two converter (elementary) IPFC (b) Equivalent circuit

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. *V11=V21=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. 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 Equations allow the main parameters of the elementary IPFC [10] (Fig. 8) 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 the equations It is also assumed that each converter injects an ideal sinusoidal waveform, having only a fundamental frequency

$$\sum_{i=1}^{n} P_{Se\_i} = 0$$

As in our n=2, we will have,

$$P_{se1} + p_{se2} = 0$$

So for each line it can be written,

$$P_{se1} = V_{C1d} I_{14d} + V_{C1Q} I_{14Q}$$

$$P_{se2} = V_{c2d} I_{24d} + V_{C2Q} I_{24Q}$$

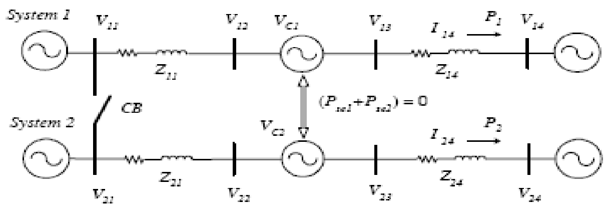
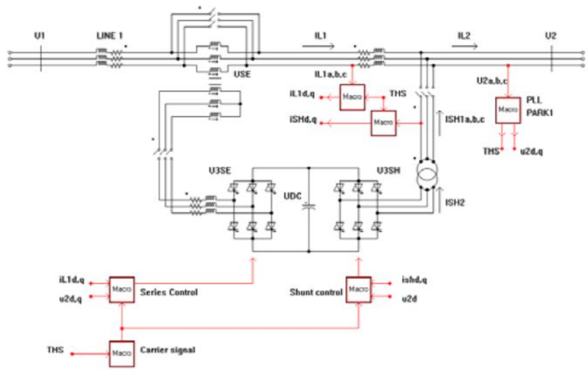


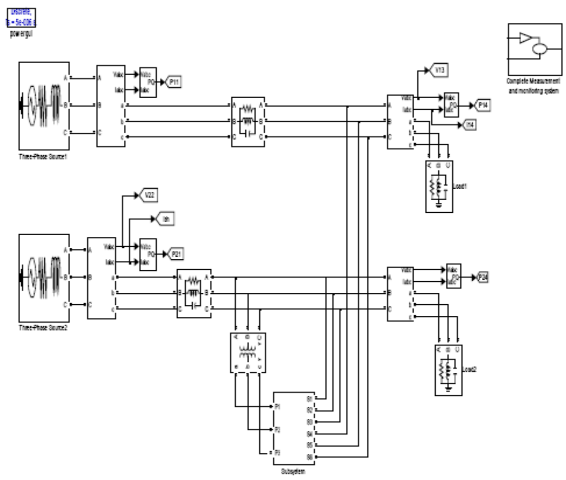
Fig. 8. The IPFC depicted

IV. SIMULATION RESULTS

UPFC (Unified Power Flow control):



IPFC **(Interline Power Flow Controller):**



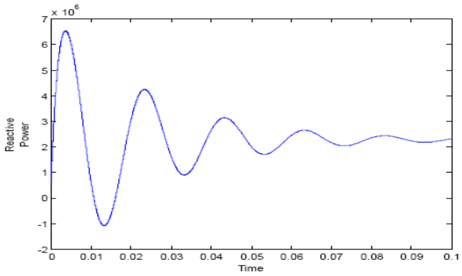


Fig 9: Reactive power with FACTS controllers

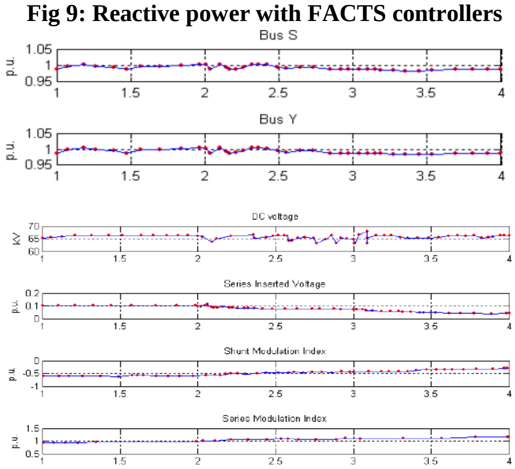


Fig10: Voltage waveforms with FACTS controllers

V. CONCLUSION

In this paper, the compensation of an electrical system by using UPFC, IPFC -FACTS device are been studied. Two important coordination problems have been addressed in this paper related to UPFC control. One, the problem of real power coordination between the series and the shunt converter control system. Second, the problem of excessive UPFC bus voltage excursions during reactive power transfers requiring reactive power coordination. The simulation results, obtained by Mat lab show the efficiency of UPFC and IPFC, in controlling line both active and reactive power flow.

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