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UPFC MODEL FOR POWER FLOW STUDIES

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Abstract:
The UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission systems. It offers major potential advantages for the static and dynamic operation of transmission lines. The UPFC was devised for the real-time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the power industry. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line. Alternatively, it can independently control both the real and reactive power flow in the line unlike all other controllers.
Keywords: UPFC, power flow,

1. INTRODUCTION

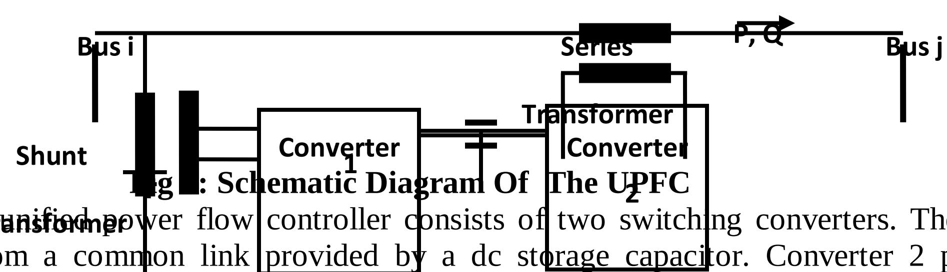

Fig 1: Schematic Diagram Of The UPFC

The unified power flow controller consists of two switching converters. These converters are operated from a common link provided by a dc storage capacitor. Converter 2 provides the main function of the UPFC by injecting an ac voltage with controllable magnitude and phase angle in series with the transmission line via a series transformer. The basic function of converter 1 is to supply or absorb the real power demand by converter 2 at the common dc link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation. The injection model is obtained by replacing the voltage for the line. Converter 2 supplies or absorbs locally required reactive power and exchanges the active power as a result of the series injection voltage.

2. UPFC MODEL FOR POWER FLOW STUDIES

In the following section, a model for UPFC which will be referred as UPFC injection model is derived. This model is helpful in understanding the impact of the UPFC on the power system in the steady state. Furthermore, the UPFC injection model can easily be incorporated in the steady state power flow model. Since the series voltage source converter does the main function of the UPFC, it is appropriate to discuss the modeling of a series voltage source converter first.

2.1 Series Connected Voltage Source Converter Model

Suppose a series connected voltage source is located between nodes i and j in a power system. The series voltage source converter can be modeled with an ideal series voltage V_s in series with a reactance X_s. In Figure-3.4, V_s models an ideal voltage source and represents a fictitious voltage behind the series reactance:

$$V_i^{'} = V_s + V_i \quad (1)$$

The series voltage source is controllable in magnitude and phase, i.e.:

$$V_s = rV_i e^{j\gamma} \quad (2)$$

Where $0 < r < r_{max}$ and $0 < \gamma < 2\pi$

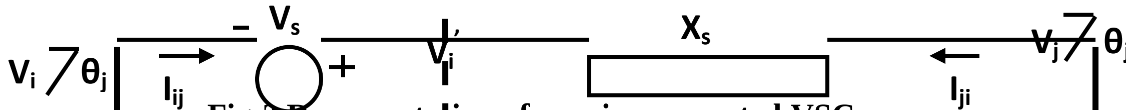

Fig-2 Representation of a series connected VSC

The equivalent circuit vector diagram is shown in Fig-4.3

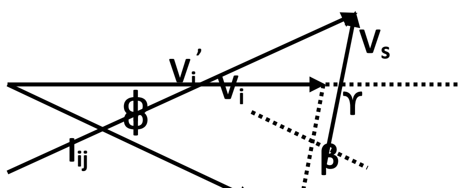

Fig-3 Vector diagram of the equivalent circuit of VSC

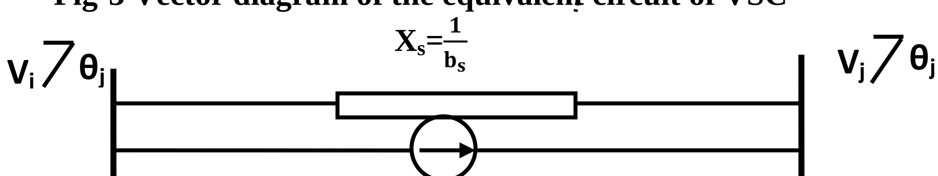

Fig-4 Replacement of a series voltage source by a current source

The current sources I_s corresponds to the injection powers S_{is} and S_{js}, where:

$S_{is} = V_i\,(-I_s)^*$ $\qquad$ $S_{js} = V_j\,(-I_s)^*$

The injection power S_{is} and S_{js} are simplified to:

$$S_{is} = V_i[\,jb_s\, r\, V_i\, e^{j\gamma}]^*$$

$$= -b_s\, rV_i^2 \sin\gamma - jb_s\, r\, V_i^2 \cos\gamma \quad (3)$$

If we define: $\theta_{ij} = \theta_i - \theta_j$, we have:

$$S_{js} = V_j[-\,jb_s\, r\, V_i e^{j\gamma}\,]^*$$

$$= b_s\, rV_i\, V_j \sin(\theta_{ij} + \gamma) + jb_s\, r\, V_i\, V_j \cos(\theta_{ij} + \gamma) \quad (4)$$

Based on the explanation above, the injection model of a series connected voltage source can be seen as two dependent loads as shown in Fig.-4.5

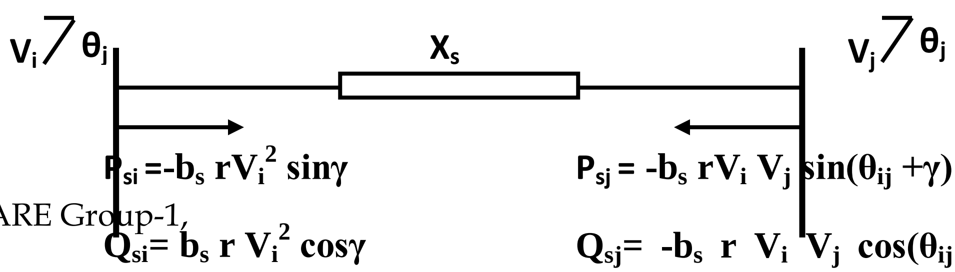

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Fig. -4.5: Injection model for a series connected VSC

2.2 UPFC Model

In UPFC, the shunt connected voltage source (Converter 1) is used mainly to provide the active power which is injected to the network via the series connected voltage source:

$$P_{CONV1} = P_{CONV2} \quad (5)$$

The equality above is valid when the losses are neglected. The apparent power supplied by the series voltage source converter is calculated from:

$$S_{CONV1}=V_s\, I_{ij}{*}=re^{j\gamma}V_i\left(\frac{V_i'-V_j}{jX_s}\right)* \quad (6)$$

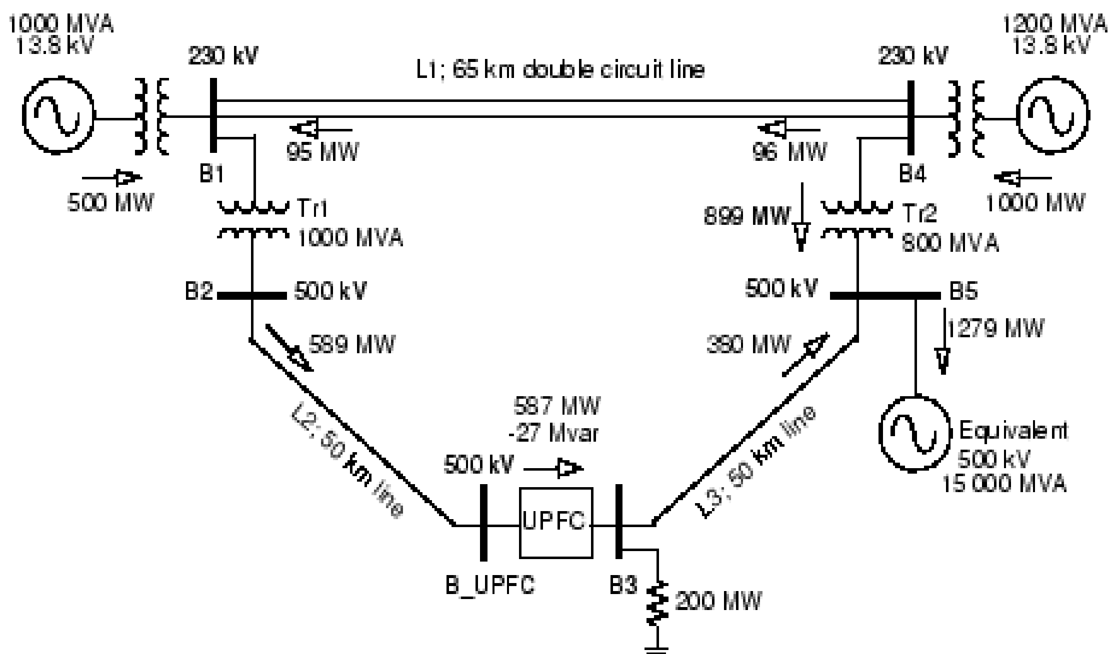
Active and reactive powers supplied by Converter 2 are distinguished as:

$$P_{CONV2}= b_s\, rV_i\, V_j \sin(\theta_{ij} +\gamma)- b_s\, rV_i^2 \sin\gamma \quad (7)$$

$$Q_{CONV2}=-b_s\, r\, V_i\, V_j \cos(\theta_{ij} +\gamma)+ b_s\, r\, V_i^2 \cos\gamma+r^2\, b_s\, V_i^2 \quad (8)$$

The reactive power delivered or absorbed by converter 1 is independently controllable by UPFC and can be modeled as a separate controllable shunt reactive source. In view of above, we assume that Q_{CONV1} = 0. Consequently, the UPFC injection model is constructed from the series connected voltage source model (Figure-4.5) with the addition of a power equivalent to $P_{CONV} + j0$ to node i. Thus, the UPFC injection model is shown in Figure-4.6. The model shows that the net active power interchange of UPFC with the power system is zero, as is it expected for a lossless UPFC.

$V_i\angle\theta_i$ X $V_j\angle\theta_j$



P_{si} =-b_s rV_i

Q_{si}= b_s r V_i

3. TEST SYSTEM

Fig.

A UPFC is used to control the power flow in a 500 kV /230 kV transmission system. The system, connected in a loop configuration, consists essentially of five buses (B1 to B5) interconnected through three transmission lines (L1, L2, L3) and two 500 kV/230 kV transformer banks Tr1 and Tr2. Two power plants located on the 230 kV system generate a total of 1500 MW which is transmitted to a 500 kV, 15000 MVA equivalent and to a 200 MW load connected at bus B3. Each plant model includes a speed regulator, an excitation system as well as a power system stabilizer (PSS). In normal operation, most of the 1200 MW generation capacity of power plant #2 is exported to the 500 kV equivalent through two 400 MVA transformers connected between buses B4 and B5. For this demo we are considering a contingency case where only two transformers out of three are available (Tr2= 2*400 MVA = 800 MVA). The load flow shows that most of the power generated by plant #2 is transmitted through the 800 MVA transformer bank (899 MW out of 1000 MW) and that 96 MW is circulating in the loop. Transformer Tr2 is therefore overloaded by 99 MVA. The example illustrates how a UPFC can relieve this power congestion. The UPFC located at the right end of line L2 is used to control the active and reactive powers at the 500 kV bus B3, as well as the voltage at bus B_UPFC. The UPFC consists of two 100 MVA, IGBT-based, converters (one shunt converter and one series converter interconnected through a DC bus). The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2.

4.1 Model Block of Single Line Diagram

The single line diagram illustrated in Figure 7 is implemented on MATLAB SIMULINK to check the validity of the UPFC controller. The Model of UPFC will generate two kinds of results. First is based upon the simulations at power flow control mode and second on voltage injection Mode. The important keys to note in the block diagram are,

1. Use of Bypass breaker – Used to connect or disconnect UPFC Block from Power System
2. The reference power inputs – Reference for power flow control
3. The reference voltage Vdref – Reference for voltage injection
4. Power flow analysis at load flow indicated by arrows – Comparison with & without UPFC

4.2 Power Flow Control with the UPFC

Parameters of the UPFC are given in the dialog box. In the Power data parameters that the series converter is rated 100 MVA with a maximum voltage injection of 0.1 pu. The shunt converter is also rated 100 MVA. Also, in the control parameters, that the shunt converter is in Voltage regulation mode and that the series converter is in Power flow control mode. The UPFC reference active and reactive powers are set in the magenta blocks labeled Pref(pu) and Qref(pu). Initially the Bypass breaker is closed and the resulting natural power flow at bus B3 is 587 MW and -27 Mvar. The Pref block is programmed with an initial active power of 5.87 pu corresponding to the natural power flow. Then, at t=10s, Pref is increased by 1 pu (100 MW), from 5.87 pu to 6.87 pu, while Qref is kept constant at -0.27 pu.

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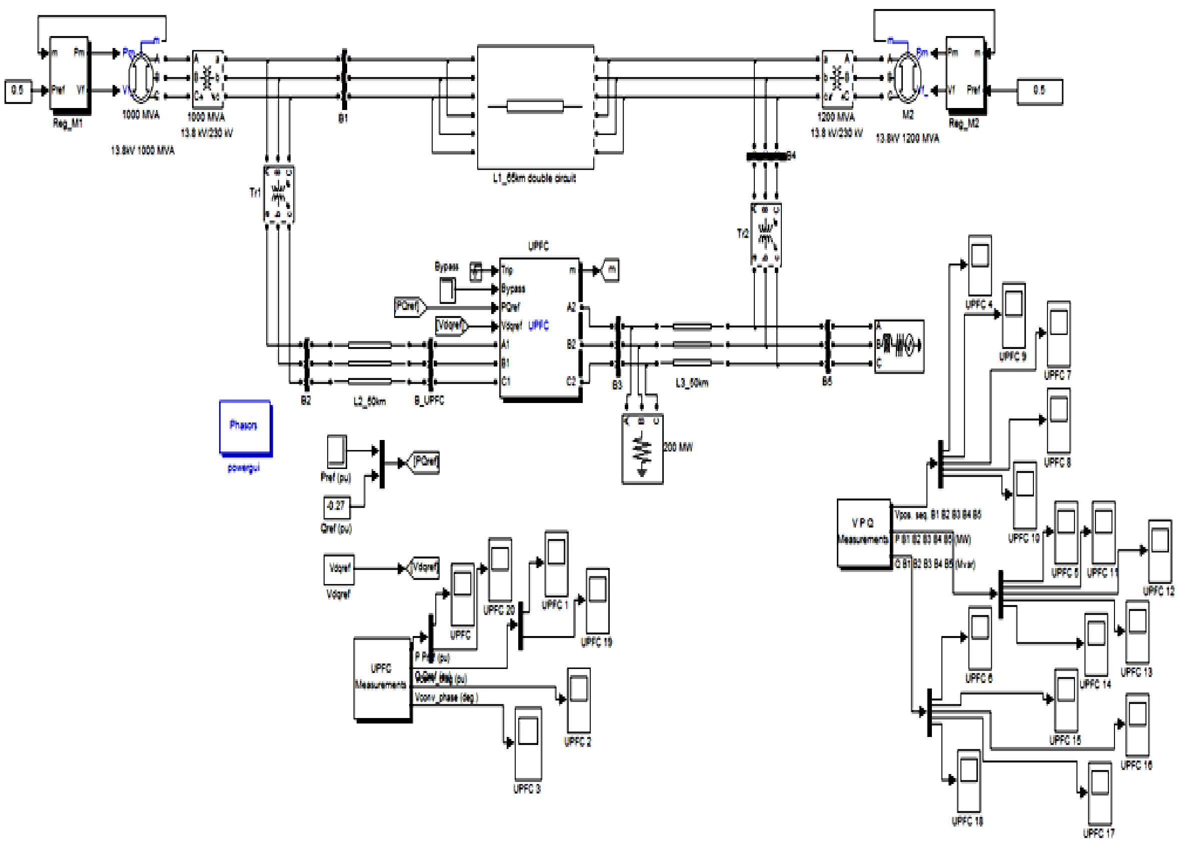
5 MODEL OF THE UPFC CONTROLLING POWER ON A 500 KV/230 KV POWER SYSTEM

Fig.- 8: Simulink Diagram Of UPFC



6 CONCLUSION

The performance of a generalized UPFC with a test system has been studied in this chapter. The power transfer takes place via DC link thus regulating the voltage. The analysis has been performed assuming the equality between shunt and series converters i.e., the power consumed/supplied by the converters from/to AC source is zero.

REFERENCES

[1]. N.G. Hingorani, L. Gyugyi, "*Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems," IEEE Press*, N.Y., 2000.

[2]. Y.H. Song, A.T. Johns, "*Flexible AC Transmission Systems – FACTS," IEE Press*, London, UK, 1999.

[3]. K. R. Padiyar, "FACTS Controllers in Power Transmission and Distribution", *New Age International (P) Limited Publishers* (formerly Wiley Eastern Limited), 2007, New Delhi.

[4]. H.Saadat," Power System Analysis," *Tata McGraw-Hill* Edition, 2002.

[5]. P. Kundur, "Power System Stability and control", *New York, McGraw-Hill*, 1994

[6]. R.L.V. Arnez, L.C. Zanetta Jr., "48-Pulse Based SSSC (Static Synchronous Series Compensator) an Evaluation of its Performance," in Proc. WSEAS *International Conferences on: System Science, Applied Mathematics & Computer Science and Power Engineering Systems 2002*, Rio de Janeiro, Brazil, Oct. 21-24, 2002.

[7]. S. R. Aali, D. Nazarpour, "48-Pulse GTO Interline Unified Power Flow Controller" 1st Power Electronic & Drive Systems & Technologies Conference.

[8]. Gyugyi, L.: "Unified power-flow control concept for flexible AC transmission systems", *Generation, Transmission and Distribution [see also IEE Proceedings-Generation, Transmission and Distribution], IEE Proceedings* C, 1992.

[9]. L. Gyugyi, C. D. Schauder, S. L. Torgerson, and A. Edris, "The unified power flow controller: A new approach to power transmission control," *IEEE Trans. Power Delivery*, vol. 10, pp. 1088–1097, Jan. 1995.

[10]. Z. Huang, et al., "Application of Unified Power Flow Controller in Interconnected Power Systems –Modeling, Interface, Control Strategy and Study Case," *IEEE Transactions on Power Systems*, vol. 15, No. 2, 2000, 817-824.

[11]. Keri A.F.J., Lombard X., et al., "Unified Power Flow Controller (UPFC): Modeling and Analysis," IEEE *Transactions on Power Delivery*, vol. 14, No. 2, 1999, pp. 648-654.

[12]. K.K. Sen, E.J. Stacey, "UPFC-Unified Power Flow Controller: Theory, Modeling and Applications," *IEEE Transactions on Power Delivery*, vol. 13, No. 4, 1998, 1953-60.

[13]. Nabavi-Niaki, M. R. Iravani, "Steady State and Dynamic Models of United Power Flow Controller (UPFC) for Power System Studies ", *IEEE Transactions on Power systems*, Vol. 11, No. 4, November 1996.

[14]. H. Fugita, Y. Watanabe, H. Akagi, "Control and Analysis of a Unified Power Flow Controller," *IEEE Transactions on Power Electronics*, vol. 14, No. 6, 1999, pp. 1021-1027.

[15]. K. R. Padiyar and A. M. Kulkarni, "Control design and simulation of unified power flow controller," *IEEE Trans. Power Delivery*, vol. 13, no. 4, pp. 1348–1354, Oct. 1998.

[16]. C. D. Schauder, M. R. Lund, D. M. Hamai, T. R. Rietman, D. R. Torgerson, and A. Edris, "Operation of the Unified Power Flow Controller (UPFC) under Practical Constraints," *IEEE Transactions on Power Delivery*, vol. 13, pp. 630-637, 1998.

[17]. R.L. Vasquez-Arnez, L.C. Zanetta Jr., "Unified Power Flow Controller (UPFC): its Versatility in Handling Power Flow and Interaction with the Network," *In Proc. IEEE/PES Transmission & Distribution Conference 2002*, Asia Pacific, Yokohama, Japan, 2002, vol. 2, pp. 1338-1343.

[18]. Tang, S. Cheng "Study of the Impacts of UPFC upon Dynamic Power Quality", *Journal of Electrical and Electronics Engineering*, Istanbul University, vol. 5, No. 1, 2005, pp. 1315-1321.

[19]. J. Bian, D. G. Ramey, R. J. Nelson, and A. Edris, "A Study of Equipment Sizes and Constraints for a Unified Power Flow Controller," *IEEE Transactions on Power Delivery*, vol. 12, pp. 1385 – 1391, 1997.

[20]. B. Fardanesh, "Optimal Utilization, Sizing, and Steady-State Performance Comparison of Multiconverter VSC-Based FACTS Controllers," *IEEE Transactions on Power Delivery*, Vol. 19, No. 3, pp. 1321-1327, July, 2004.

[21]. R. Billinton, M. Fotuhi-Firuzabad, S. O. Faried, and S. Aboreshaid, "Impact of unified power flow controllers on power system reliability," *IEEE Trans. Power Syst.*, vol. 15, no. 1, pp. 410–415, Feb. 2000.

[22]. C. Schauder, E. Stacey, M. Lund, L. Gyugyi, L. Kovalsky, A. Keri, A. Mehraban, A. Edris, "AEP UPFC Project: Installation, Commissioning and operation of the ±160 MVA STATCOM (Phase I),", *IEEE Transactions on Power Delivery*, vol. 13, No.4, Oct. 1998, pp. 1530-35.

[23]. C. Schauder, M. Gernhardt, E. Stacey, T. Lemak, L. Gyugyi, T. W. Cease, and A. Edris, "TVA STATCOM Project: Design, Installation, and Commissioning," *CIGRE Meeting*, Paris, August, 1996, Paper 14-106.

[24]. L. Sun, S. Mei; Q. Lu; J. Ma, "Application of GUPFC in China's Sichuan Power Grid - Modeling, Control Strategy and Case Study," *Proc. IEEE Power Engineering Society General Meeting*, Vol. 1, July 13-17, 2003, pp. 175-181.