Research Journal of Applied Sciences, Engineering and Technology 3(7): 612-616, 2011
ISSN: 2040-7457

Received: April 14, 2011 Accepted: June 10, 2011 Published: July 25, 2011

Experimental Results of Interline Power Flow Controller Systems

[1]G. Irusapparajan and [2]S. Rama Reddy
[1]Bharath University, Chennai, India
[2]Jerusalem Engineering College, Chennai, India

Abstract: This study deals with experimental verification of inter line Power Flow Controller. Interline Power Flow Controller (IPFC) is a Concept of Flexible AC Transmission System (FACTS) controller with the unique capability for series compensation with the unique capability of power flow management among multi-line of a substation. The results of simulation and hardware are presented. The experimental results are compared with the simulation results.

Key words: IPFC, SSSC, STATCOM, UPFC, VSC

INTRODUCTION

Flexible AC Transmission System (FACTS) and dc links are a proven solution. Hingorani and Gyugyi (2000) to rapidly enhancing reliability and upgrading transmission capacity on a long-term and cost-effective basis. It has been considered as an excellent controller in a power system network after considerable effort on the development of power electronics-based power flow controller (Klaus and O'Leary, 2000). As power systems are encountering increasing power demand however, it becomes difficult to build new transmission lines for power management. The concept of FACTS controller was timely and appropriate. Due to the advance in power semiconductor industry, high power rating and high-speed gate turn-off power electronic devices are introduced practically in power system applications.

These developments provide a new generation of FACTS controllers called VSC based FACTS controllers (Prakash and Helonde, 2010) with promising features in flexible power flow control, transient stability and power systemoscillation damping enhancement. Thefamily of compensators and power flow controllers based on VSC are the Static Synchronous (shunt) Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) and the Unified Power Flow Controller (UPFC). The UPFC is used as a powerful tool for the cost effective utilization of individual transmission lines by facilitating the independent control both the real and reactive power flow. While the Interline Power Flow Controller (IPFC) concept provides a solution for the problem (Naresh *et al.*, 2010) of compensating a number of transmission lines at a given substation. Any inverters within the IPFC are able to transfer real power to any other and thereby facilitate real power transferamong the lines, together with independently controllable reactive series compensation of each individual line. The main objective of the IPFC is to optimize (Strzelecki *et al.*, 2001) both real and reactive power flow among multi-lines, transfer power from overloaded to underloaded lines. However, it can also be utilized to compensate against reactive voltage drops and the corresponding reactive line power, and to increase the effectiveness of the compensating system against dynamic disturbances (Stefan, 2002).

PRINCIPLE OF OPERATION OF THE IPFC SYSTEMS

Let's imagine two Systems: 1 and 2. In this situation IPFC consists from two back-to-back, series connected with lines, dc to ac inverters, as it is on Fig. 1a.

Each of the series inverters controls power flow by injecting (Laszlo *et al.*, 1999) fully controllable voltages V_{c1} and V_{c2}. This is shown functionally on Fig. 1b. Where two back-to-back dc to ac inverters arerepresented by voltage sources V_{c1} and V_{c2}. System 1 is represented by reactance X_1, has a sending-end bus with voltage phasor V_{11} and receiving-end bus with voltage V_{21}. Respectively System 2 is represented by reactance X_2 and voltage phasors V_{21} and V_{22}. Let's determine equation on power which series inverter (for example in System 1) can not generate internally. For this purpose we have to definevoltage phasors:

$$\overline{V}_{11} = V_{11}\cos\varphi_{11} + jV_{11}\sin\varphi_{11} \tag{1}$$

$$\overline{V}_{21} = V_{21}\cos\varphi_{21} - jV_{21}\sin\varphi_{21} \tag{2}$$

$$\overline{V}_{cl} = V_{cl}\cos\varphi_{cl} + jV_{cl}\sin\varphi_{cl} \tag{3}$$

On the base of those equations we can define active and reactive components of current:

Corresponding Author: G. Irusapparajan, Bharath University, Chennai, India

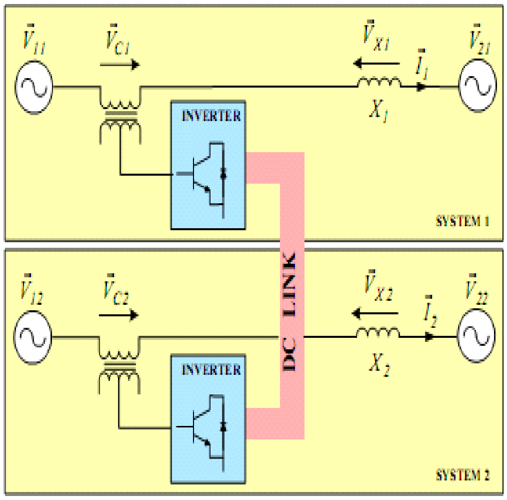

Fig. 1a: Two systems IPFC

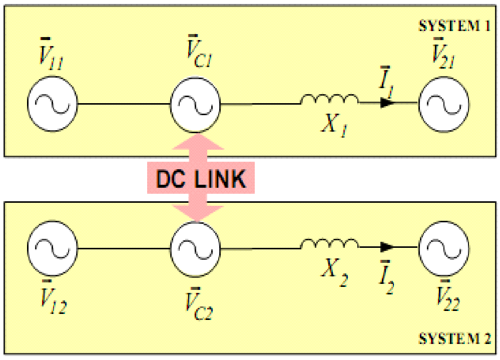

Fig. 1b: Equivalent single phase diagram

$$I_{lp} = \frac{V_{11}\sin\varphi_{11} + V_{21}\sin\varphi_{21} + V_{cql}}{X_1} \qquad (4)$$

$$I_{lp} = \frac{V_{21}\cos\varphi_{21} - V_{11}\cos\varphi_{11} - V_{cpl}}{X_1} \qquad (5)$$

After simply transformations equations on active and reactive powers transmitted to the receiving-end bus are as follows:

$$P_{21} = \frac{V_{21}V_{11}}{X_1}\underbrace{\left(\cos\varphi_{21}\sin\varphi_{11} + \cos\varphi_{11}\sin\varphi_{21}\right)}_{\sin\delta_1} + \underbrace{\frac{V_{21}V_{cl}}{X_1}\cos\varphi_{21}\sin\varphi_{cl}}_{=V_{cql}} + \underbrace{\frac{V_{21}V_{cl}}{X_1}\sin\varphi_{21}\cos\varphi_{cl}}_{=V_{cpl}} \qquad (6)$$

$$Q_{21} = \frac{V_{21}V_{11}}{X_1}\underbrace{\left(\cos\varphi_{21}\cos\varphi_{11} - \sin\varphi_{21}\sin\varphi_{11}\right)}_{\cos\delta_1} - \frac{V_{21}^2}{X_1} + \underbrace{\frac{V_{21}V_{cl}}{X_1}\cos\varphi_{21}\cos\varphi_{cl}}_{=V_{cpl}} - \underbrace{\frac{V_{21}V_{cl}}{X_1}\sin\varphi_{21}\sin\varphi_{cl}}_{=V_{cql}} \qquad (7)$$

Except "classical" (well known elements) there are in equations additional parts. Those parts are "telling" what the contribution of the active Vcp1 is and reactive V_{cq1} components on power delivered to the receiving-end bus.IPFC has to control (Valentin, 2008) both active and reactive power delivered to the receiving-end bus. Let's determine desired powers as follows:

P^*_{21}=Constant (8)
Q*21=0 (9)

On the base of earlier determined equations we do have:

$$P_{21}^{*} = \frac{V_{21}V_{11}}{X_1}\sin\delta_1 + \frac{V_{21}V_{cql}}{X_1} \qquad (10)$$

$$Q_{21}^{*} = \frac{V_{21}V_{11}}{X_1}\cos\delta_1 - \frac{V_{21}^2}{X_1} + \frac{V_{21}V_{cpl}}{X_1} = 0 \qquad (11)$$

$$I_{lp} = \frac{V_{11}\sin\delta_1 + V_{cql}}{X_1} \qquad (12)$$

$$I_{lq} = \frac{V_{21} - V_{11}\cos\delta_1 - V_{cpl}}{X_1} = 0 \qquad (13)$$

$$V_{cpl} = \left(Q_{21}^{*} + \frac{V_{21}^2}{X_1} - \frac{V_{21}V_{11}}{X_1}\cos\delta_1\right)\frac{X_1}{V_{21}} \qquad (14)$$

$$V_{cql} = \left(P_{21}^{*} - \frac{V_{21}V_{11}}{X_1}\sin\delta_1\right)\frac{X_1}{V_{21}} \qquad (15)$$

So the active power demand of the series inverter's in ith system is:

$P_{IPFC1} = I_{p1}V_{cp1} = (V_{21} - V_{11}\cos\delta_1)\,P^*_{21}/V_{21}$ (16)

On the base of this equation we can tell that:

When PIPFC1 > 0, System 1 absorbs active power from System 2;

When PIPFC1 < 0, System 2 sends active power to System 2;

System 2 (or System 1) can keep PIPFC = cons.
Even controlling its own power flow, (Fig. 2a, b).

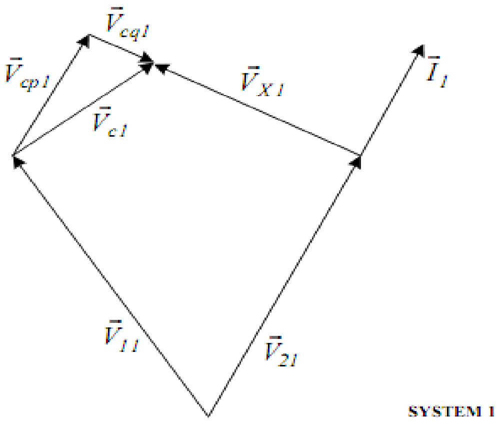

Fig. 2a: Phasor diagram for system 1

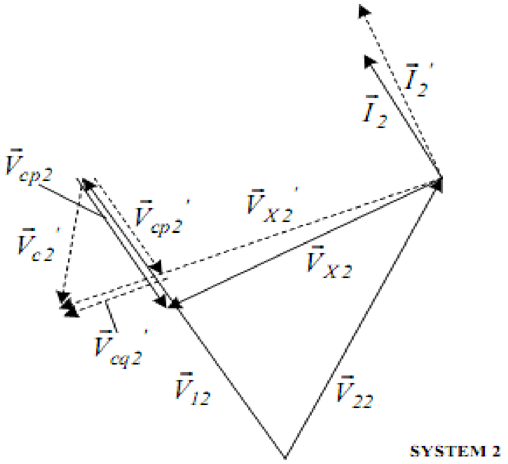

Fig. 2b: Phasor diagram for system 2

$$P_{parallel} = \sum_{i=1}^{n} P_{IPFCi}{}^{\max} = \sum_{i=1}^{n}\left[\left(1-\frac{V_{11}^{\min}}{V_{21}^{\max}}\cos\delta_i^{\max}\right)\frac{P_{21}^{*\max}}{V_{21}^{\max}}\right] \tag{17}$$

RESULTS

Simulation results: Simulation is done using matlab and the results are presented (Usha Rani and Rama Reddy, 2010) four bus system with IPFC is shown in Fig. 3a. Current fed converter is shown in Fig. 3b. Voltage across load 1, load 2 and IPFC are shown in Fig. 3c and d.The voltage decreases and comes to normal value. Hence IPFC is capable of mitigating the sag.

Experimental results: The laboratory model of IPFC is fabricated and tested. Top view of the hardware is shown in Fig. 4a. A.C. input

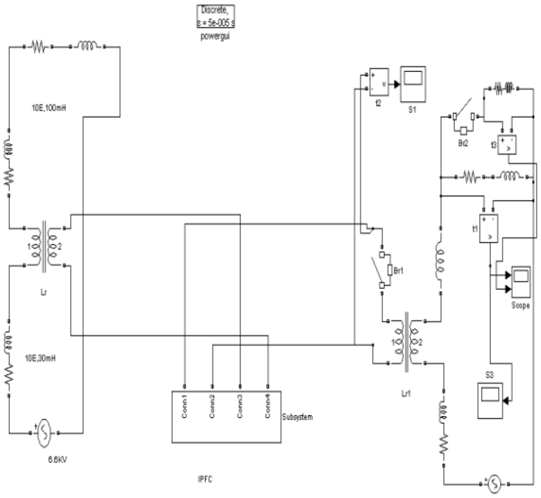

Fig. 3a: Four bus system with IPFC

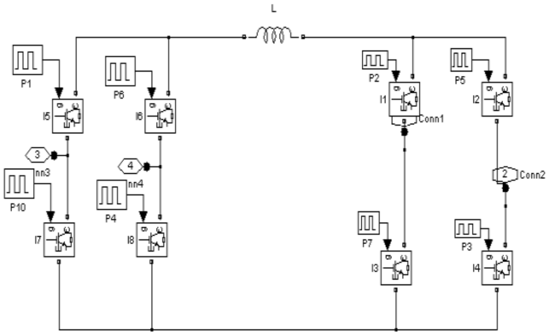

Fig. 3b: Current fed IPFC System

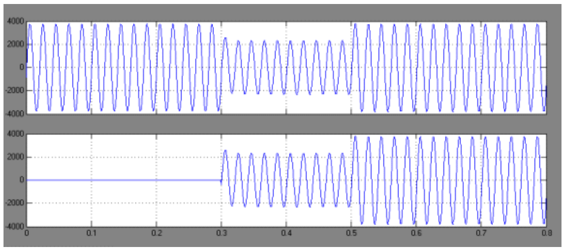

Fig. 3c: Voltage across load1and load2

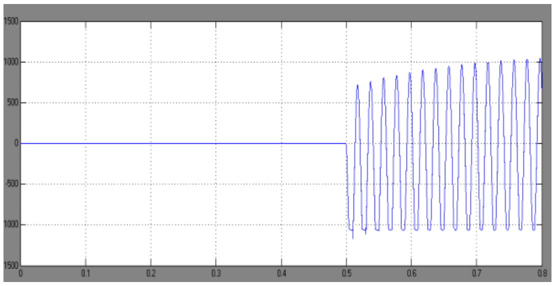

Fig. 3d: Voltage across IPFC

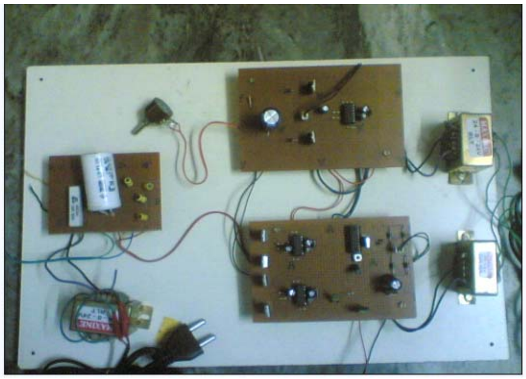

Fig. 4a: Top view of hardware

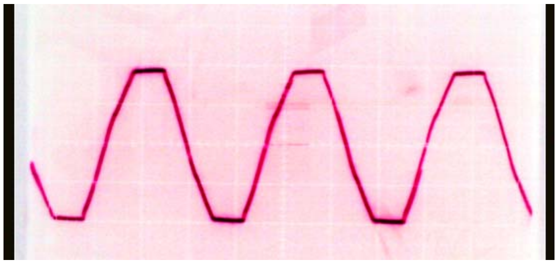

Fig. 4b: A.C. Input Voltage

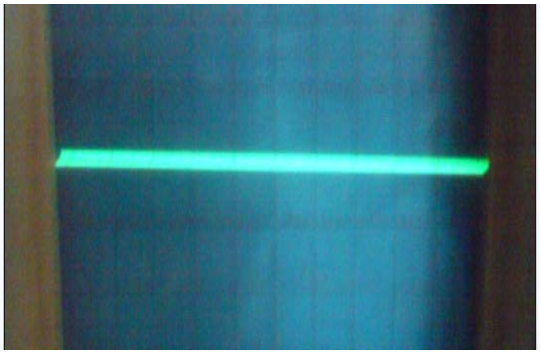

Fig. 4c: Rectifier output voltage

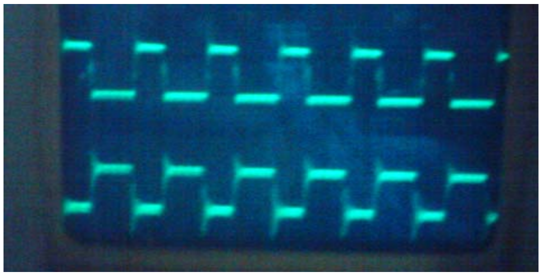

Fig. 4d: Driving pulses for inverter

voltage is shown in Fig. 4b. Rectifier Output Voltage is shown in Fig. 4c. Driving pulses are shown in Fig. 4d.

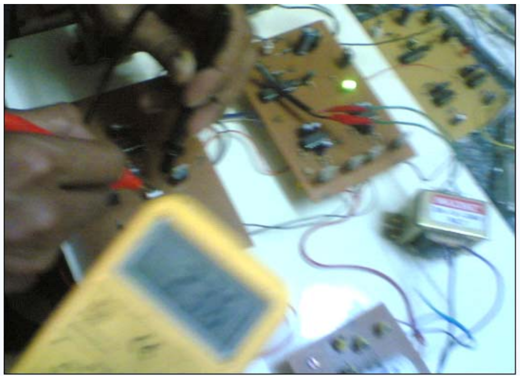

Fig. 4e: Load voltage before compensation

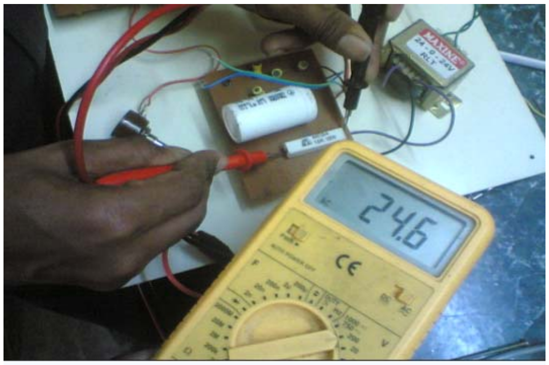

Fig. 4f: Load voltage after compensation

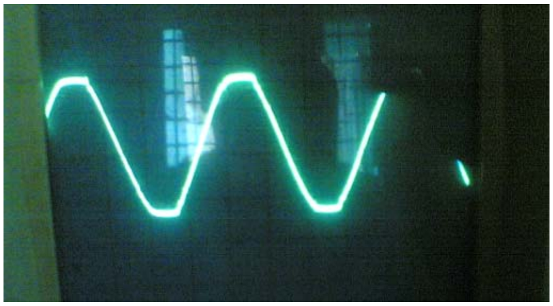

Fig. 4g: Load voltage after compensation

Load Voltage before Compensation in Fig. 4e. Load Voltage after Compensation in Fig. 4f. The oscillogram of output voltage is shown in Fig. 4g.

CONCLUSION

Interline Power Flow Controller (IPFC) is simulated with the help of Simulink and is fabricated. The simulation is based on the assumption of balanced load. Single phase circuit model is considered for simulation studies. Simulation and experimental results are presented. The experimental results are similar to the simulation results.

ACKNOWLEDGMENT

The simulation studies are conducted in the power system simulation lab, Bharath University. The authors would like to thank HOD, EEE, Bharath University for providing the facilities.

REFERENCES

Hingorani, N. and G. Gyugyi, 2000. Understanding FACTS. Concepts and Technology of Flexible AC Transmission Systems. IEEE Press, New York.

Klaus, H. and D. O'Leary, 2000. Power Transmission and Distribution Group of Siemens AG, FACTS For Cost Effective and Reliable Transmission of Electrical Energy. A paper reviewed by the World Bank, 24: 1-11.

Laszlo, G., S. Kalyank and C.D. Schauder, 1999. The interline power flow controller concept: A new approach to power flow management in transmission system. IEEE Tran. Power Delivery, 14(3).

Naresh, B., A.V. Sivanagaraju, S. Padmanabharaju and T. Ramana, 2010. Power Flow Analysis of a power system in the in presence of Interline Power Flow Controller (IPFC) ARPN. J. Eng. Appl. Sci., 5(10).

Prakash, G.B. and J.B. Helonde, 2010. JATIT by using genetic algorithm method for optimal location of FACTS devices in the deregulated power. J. Theor. Appl. Infor. Technol., 3(4): 64-71.

Stefan, E., 2002. Flexible AC Transmission Systems Combined Compensators: Unified Power Flow Controller (UPFC) and Interline Power Flow Controller (IPFC).

Strzelecki, R., G. Benysek and J. Bojarski, 2001. Interline Power Flow Controller. SENE Conference, POLAND, 2: 591-596.

Valentin, A., and R. Mihalic, 2008. The control strategy for an IPFC based on the energy function. IEEE Tran. Power Sys., 23(4).

Usha Rani, A.P. and S. Rama Reddy, 2010. Modeling and digital simulation of interline power flow controller system. Int. J. Comput. Elec. Eng., 2(3): 1793-8163.