May 2013 IJMIE Volume 3, Issue 5 ISSN: 2249-0558

INTERLINE POWER FLOW CONTROLLER (IPFC) TO ENHANCE THE OPTIMAL POWER FLOW

Venkata Padmavathi S[*]
SaratKumar Sahu[**]
A Jayalaxmi[***]

ABSTRACT

This paper presents a mathematical model of IPFC, termed as power injection model (PIM). This model is incorporated in Newton-Raphson (NR) power flow algorithm to study the power flow control in transmission lines in which IPFC is placed. By utilizing this device(IPFC), an enhanced controllability over independent transmission systems or those lines whose sending-end are connected to a common bus, can be obtained. The power flow through the line can be regulated by controlling both magnitudes and angles of the series voltages injected by an IPFC. Generally, the IPFC employs multiple dc-to-ac inverters providing series compensation for a different line respectively. A program in MATLAB has been written in order to extend conventional NR algorithm based on this model. Numerical results are carried out on a standard 2 Machine 5 Bus system. The results without and with IPFC are compared in terms of voltages, active and reactive power flows to demonstrate the performance of the IPFC model.

Key words: *FACTS, IPFC, OPF, NR.*

---

[*] Ph.D Scholar, JNTUH. & Asst Prof. EEE Dept., GITAM University, Hyderabad, A.P, India

[**] Prof. EEE Dept., M.V.G.R Engg Coll., Vizianagaram, A.P, India

[***] Assoc.Prof. EEE Dept., JNT University Hyderabad, A.P, India

INTRODUCTION

The concept of Flexible AC Transmission Systems (FACTS) was first defined by N.G. Hingorani, in 1988 [1]. A Flexible Alternating Current Transmission System (FACTS) is a system comprised of static equipment used for the AC transmission of the electrical energy. It is meant to enhance controllability and increase power transfer capability of the network. Most electrical networks are widely interconnected for economic reasons – optimum sharing of electrical power, optimum utilization of resources and deregulation of electric market. Bulk power is transmitted to the load centre via transmission lines connected to the most economic sources generally located far away from the load centre. The operation of ac transmission lines is generally constrained by limitations of one or more network parameters (e.g. line impedance) and operating variables such as voltages and currents. As a result, a transmission line may not be able to transfer the required power demand and there may be a necessity to build a costly parallel transmission line. The optimal use of existing system may overcome the costly construction of parallel transmission lines. The cost-effective tool for optimum/economical use of transmission line and improving system stability and power flow through medium and long ac transmission line is the use of series capacitor compensation. Series Capacitor-Compensated transmission lines eliminate the need for building parallel transmission lines. Although it is the cheapest means to achieve higher power transfer, it has potential adverse impacts like distorted and excessively large transformer exciting currents, due to saturation, hunting of synchronous machines. Addition of new transmission lines is an almost impossible solution due to environmental and other considerations, and developing new approaches to Power System Operation and Control is the need of the hour for overload relief and efficient and reliable operation.

The use of static power converters in electricity networks has the potential of increasing the capacity of transmission of the electric lines and improving the supply quality of the electric energy. The devices used to achieve this, are the FACTS (Flexible Alternating Current Transmission Systems). The FACTS technology has a collection of controllers, that can be used individually or co-ordinate with other controls installed in the network, thus permitting to profit better of the network‘s characteristics of control.

The FACTS controllers offer a great opportunity to regulate the transmission of Alternating Current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents.

Flexible Alternating Current Transmission System (FACTS) is static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability. It is generally power electronics based device.

FACTS[1] is defined by the IEEE as “A Power electronic based system and other static equipment that provide control of one or more AC transmission system and increase the capacity of power transfer”

. The power systems of today are mechanically controlled and as a result there is no high-speed control. Also, such mechanical controls cannot be initiated frequently because mechanical device tend to wear out very quickly compared to static electronic devices. The FACTS technology is essential to alleviate some but not all of these difficulties by enabling utilities to get the most service from their transmission facilities and enhance grid reliability. The possibility that current through a line can be controlled at a reasonable cost enables a large potential of increasing the capacity of existing lines with larger conductors, and use of one of the FACTS controllers to enable corresponding power to flow through such lines under normal and contingency conditions. FACTS controllers can enable a line to carry power closer to its thermal rating.

Flexible AC transmission system (FACTS) is an emerging technology and its principal role is to enhance the controllability and the power transfer capability in ac systems. FACTS [4] technologies use switching power electronic devices to control the power flow in the range of a few tens to a few hundreds of Mega Watts.

In general FACTS controllers can be divided into four categories:

1) Series controllers mainly TCSC and SSSC

2) Shunt controllers mainly STATCOM and SVC

3) Series-Series controllers such as IPFC and

4) Combined Series-Shunt controllers Ex. UPFC [2]

INTERLINE POWER FLOW CONTROLLER

The Interline Power Flow Controller (IPFC) [7], proposed by Gyugyi with Sen and Schauder in 1998, addresses the problem of compensating a number of transmission lines at a given substation. Conventionally, series capacitive compensation (fixed, thyristor – controlled or SSSC-based) is employed to increase the transmittable real power over a given line and also to balance the loading of a normally encountered multi-line transmission system. However, independent of their means of their implementation, series reactive compensators are unable to control the reactive power flow in, and thus the proper load balancing of, the lines. This problem becomes particularly evident in those cases where the ratio of reactive to resistance line impedance(X/R) is relatively low. Series reactive compensation reduces only the effective reactive impedance X and, thus, significantly decreases the effective X/R ratio and thereby increases the reactive power flow and losses in the line. The IPFC [9] [10] scheme, together with independently controllable reactive series compensation of each individual line, provides a capability to directly transfer real power between the compensated lines.

This capability makes it possible to: equalize both real and reactive power flow between the lines; reduces the burden of overloaded lines by real power transfer; compensate against resistive line voltage drops and the corresponding reactive power demand; and increase the effectiveness of the overall compensating system for dynamic disturbances. In other words, the IPFC can potentially provide a highly effective scheme for power transmission management at a multi-line substation.

The IPFC is the combination of two or more Static Synchronous Series Compensators which are coupled via a common dc link to facilitate bi-directional flow of real power between the ac terminals of the SSSCs and are controlled to provide independent reactive compensation for the adjustment of real power flow in each line and maintain the desired distribution of reactive power flow among the lines. The equivalent circuit of IPFC is shown in

Figure 1

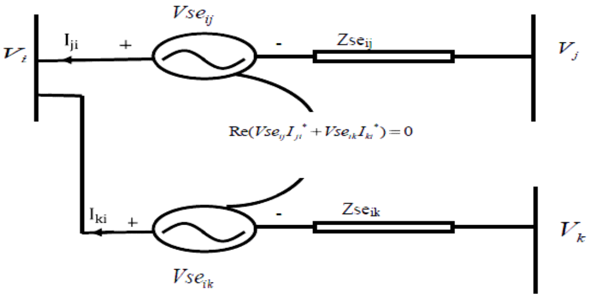

Figure:1 Equivalent Circuit of two Converter IPFC

In Figure:1, Vi, Vj and Vk are the complex bus voltages at the buses i,j and k respectively, defined as Vx=Vc$\underline{|\alpha_x}$ (x=i,j and k). Vse_{in} is the complex controllable series injected voltage source. The power flow through the line can be regulated by controlling both magnitudes and angles of the series voltage injections. The converters have the capability of independently generating or absorbing the reactive power.

The complex power injected by series converter which is connected in between bus i and bus j can be written as

$$S_{ij} = P_{ij} + JQ_{ij}$$
$$= V_i(I_{ij})^*$$
$$= V_i\underline{|\alpha_i}\left[\frac{V_i\underline{|\alpha_i} - Vse_{ij}\underline{|\alpha_{ij} - V_j\underline{|\alpha_j}}}{Zse_{ij}}\right]^*$$

The active power (Pij) and reactive power (Qij) injected is given by

Pij = Re [Sij]

The complex power injected by series converter which is connected in between bus i and bus k can be written as

$$S_{ik} = P_{ik+}JQ_{ik}$$
$$= V_i(I_{ik})^*$$
$$= V_{i\underline{|\alpha_i}}\left[\frac{\left[V_i\underline{|\alpha_i} - Vse_{ik}\underline{|\alpha_{ik} - V_k\underline{|\alpha_k}}\right]}{Zse_{ik}}\right]^*$$

The active power (Pik) and reactive power (Qik) injected is given by

Pik = Re[Sik]

Similarly, the complex power injected by series converter which is connected in between bus j and bus i can be written as

$$\begin{aligned} S_{ji} &= P_{ji} + JQ_{ji} \\ &= V_i \left(I_{ji} \right)^* \\ &= V_j \underline{|\alpha_j} \left[\frac{V_j \underline{|\alpha_j} + Vse_{ji} - V_i \underline{|\alpha_i}}{Zse_{ji}} \right]^* \end{aligned}$$

The active power (Pji) and reactive power (Qji) injected is given by

Pji = Re [Sji]

As IPFC neither absorbs nor injects active power with respect to the ac system, the active power exchange between the converters via the dc link is zero

SOLUTION METHODOLOGY

The overall solution procedure for Newton-Raphson (NR) method with IPFC model can be summarized as follows.

1) Read the load flow data and IPFC data.

2) Assume flat voltage profile and set iteration count K=0

3) Compute active, reactive power mismatch and also, the Jacobian matrix [3] [8] using NR method equations.

4) Modify power mismatch and jacobian using IPFC mathematical model.

5) If the maximal absolute mismatch is less than a given tolerance, it results in output. Otherwise, go to step 6

6) Solve the NR equations; obtain the voltage angle and magnitude correction vector dx.

7) Update the NR solution by x=x+ dx.

8) Set K=K+1, go to step 3.

CASE STUDY AND RESULTS

In this chapter, numerical results are carried out on a standard 2-Machine 5-bus system. The 5 bus test system with IPFC Bus 1 is considered as slack bus, while bus 2 as generator bus and other buses are load buses. For all the cases, the convergence tolerance is 1e-12 p.u. System base MVA is 100.

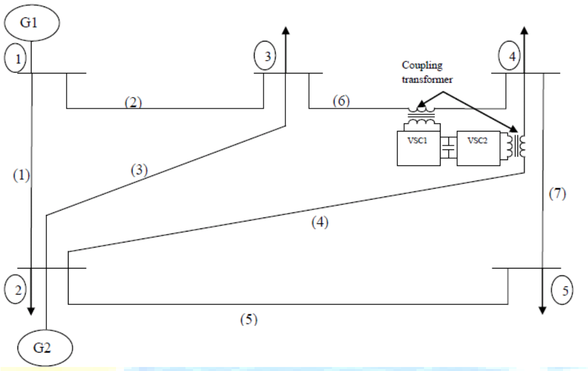

Fig: 2 2-Machine 5-bus system

The two converters of IPFC are embedded in lines 4 and 6 respectively and bus 4 is selected as common bus for the two converters. Transformer reactance is assumed as 0.1 p.u. The complex bus voltages, active and reactive power flows of the test system without and with IPFC are summarized in Table 1 and 2 respectively.

From Table 1, it can be seen that the voltages at slack bus and generator bus are same without and with IPFC and there is a change in load bus voltages. Especially, the voltage at bus 4 increases from 0.9912 to 0.9931 p.u to which IPFC converters are connected. Also, from Table 2, it is clear that the active power flow in line 4 increases from 27.689 MW to 29.8676 MW and reactive power flow changes from -3.596 MVAR to -6.049 MVAR. Similarly, the active power flow in line 6 increases

TABLE .1

Bus Voltages without and with IPFC

Bus No	Magnitude of Voltages (pu)		Angle of Voltage (degrees)	
	Without IPFC	With IPFC	Without IPFC	With IPFC

1	1.06	1.06	0.00	0.00
2	1.00	1.00	-2.0565	-2.0170
3	0.9940	0.9924	-4.7405	-4.8851
4	0.9912	0.9931	-5.0636	-3.8913
5	0.9773	0.9781	-5.8402	-5.4217

TABLE 2
Line Flows without and with IPFC

Line no	Active Power Flow(MW)		Reactive Power Flow (MVAR)	
	Without IPFC	With IPFC	Without IPFC	With IPFC
1	89.200	88.089	77.405	77.731
2	41.845	43.024	16.687	17.089
3	24.449	26.297	-4.232	-3.876
4	27.689	29.867	-3.596	-6.049
5	54.579	49.468	2.509	3.180
6	19.480	22.371	2.881	3.198
7	6.662	11.629	3.572	2.459

The voltage injected by the series converter I (VSC1) = $0.0473<-99.0837^0$ p.u.

The voltage injected by the series converter II (VSC2) = $0.0538<-94.1275^0$ p.u

CONCLUSION

A power injection model of the inter line power flow controller (IPFC) and its implementation in Newton-Raphson power flow method has been presented. In this model, the complex impedance of the series coupling transformer is included. Numerical results on the test system have shown the convergence and the effectiveness of the IPFC model .It shows that the incoming of IPFC can increase the bus voltage to which IPFC converters are connected and there is a significant change in the system voltage profile at the neighboring buses, increase in active power flow and change in reactive power flow through the lines.

REFERENCES

[1] N.G. Hingorani, L. Gyugyi "Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems," Wiley-IEEE Press, 1999.

[2] Enrique Acha, Hugo Ambriz-Pe´rez,-"FACTS Modeling and Simulation in Power Networks".

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

[4] N.G. Hingorani and L.Gyugi, "Understanding FACTS –Concepts and Technology of Flexible Ac Transmission Systems", Standard Publishers Distributors, IEEE Press, New York, 2001.

[5] L. Gyugyi, K. K. Sen, and C. D. Schauder, ―The interline power flow controller concept a new approach to power flow management in transmission systems, IEEE Trans. Power Del., vol. 14, no. 3, pp. 1115–1123, Jul. 1999.

[6] Y. Xiao, Y.H. song, and Y.Z. sun, "Power flow control approach to power systems with embedded FACTS devices", IEEE Trans. Power Syst., vol. 17, no. 4, pp.943-950, Nov.2002.

[7] X. P. Zhang, " Modeling of the interline power flow controller and the generalized unified power flow controller in Newton power flow ", IEE Proc.-Gener. Transmission and Distribution, Vol. 150, No. 3, May 2003.

[8] X.P. Zhang, "Advanced modeling of the multicontrol functional static synchronous series compensator (SSSC) in Newton power flow", IEEE Trans. Power Syst. 18 (November (4)) (2003).

[9] Jun Zhang and Akihiko Yokoyama, "Optimal power flow for congestion management by interline power flow controller (IPFC)," IEEE, Int. Conf. on Power System Technology, Chongqing, China, Oct.2006.

[10] V. Diez-Valencia, U.D. Anna age, D. Jacobson, "Interline Power Flow Controller (IPFC) Steady State Operation", IEEE Canadian Conference on Electrical & Computer Engineering, 2002, pp. 280-284.