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ANALYSIS OF DAMPING PERFORMANCE USING VALIDATED SMALL-SIGNAL MODELS OF IPFC AND UPFC

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Abstract

This paper gives the small signal model for the Interline Power Flow Controller (IPFC). Using this model, the damping performance of the IPFC is analyzed and compared with the AC Transmission System (FACTS) based controllers such as the Unified Power Flow Controller (UPFC).The results obtained from small signal analysis are validated with EMTP-type simulation. It is shown that series branches of IPFC and UPFC in constant power control mode effectively cut the connected transmission line and thus this change in structure of system may be used to improve damping of the system without a tuned feedback controller. Thus IPFC having two series branches has more potential for improving system's dynamic performance.

Introduction

Today power demand and consumption has increased largely. To meet this complex interconnected systems are been constructed. These networks are subjected to power oscillations. Power oscillations can be defined as change in machine rotor angle around its steady state value at the natural frequency of the total electromechanical system due to disturbance. There are different types of oscillations such as local oscillations, inter area oscillations ,inter plant oscillations etc. In order to maintain the system stability damping of these oscillations is essential.

This paper studies dynamic performance of IPFC by developing a small-signal model with decoupled control system. Then it is combined with small- signal representation of 12-bus four generator network to investigate damping in multi modal power network. Damping performance of IPFC is then compared with UPFC. The results obtained from small signal analysis are validated with EMTP-type simulation.

Test System For Ipfc Evaluation

Test system used here is 12-bus system (six 230 kV buses, two 345 kV buses and four 22 kV buses) and it cover three areas. Area 1 is a generation center and area 3 is a load center. It is shown in Fig.1.

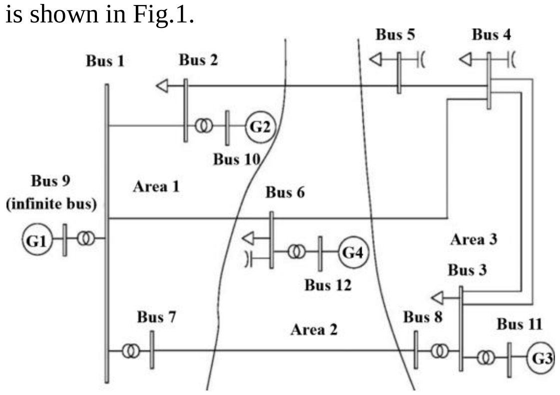

Figure.1 12-bus system

Power-flow studies (see Table I) show that the system has congestion following partial generation loss or tripping of a critical transmission line. Also, Table II, obtained from small-signal analysis, shows three of the least damped modes. It is clear that two oscillation modes are significantly under damped (i.e., Damping<5%). These issues can be resolved with the installation of a FACTS device. One solution is to place a UPFC on line 1–6 or 7–8. Placing the UPFC series branch in series with line 7–8 alleviates the congestion in line 1–6 and improves damping [8]. Another solution is investigated further in this paper- that of placing an IPFC on two of the three lines (line 1–2, 1–6 and 7–8). Since the IPFC has one more series branch than a UPFC, Fig. 2. IPFC small-signal model which have a stronger influence on the power flow and on oscillatory modes. The test system is used to validate the IPFC small-signal model and demonstrate potential performance improvements.

TABLE I
POWER FLOW OF THE SYSTEM

	Line 1-6 (limit: 250MVA)	Under-voltage (pu)
Normal	210.8	
Line 4-5 tripped	295.2	V4=0.943
G3 loss 120 MW	248.5	V5=0.922
G4 loss 80 MW	255.5	

TABLE II
OSCILLATION MODE WITHOUT FACTS

Eigenvalues λ=σ±jω	Frequency (Hz)	Damping ratio(%)	Dominant generator
-0.058±5.331i	**0.85**	1.0	G2
-0.222±7.069i	**1.12**	3.1	G3
-0.320±4.728i	**0.75**	6.5	G4

Small Signal Model

This section develops a small-signal model for the IPFC and incorporates into the small-signal model of the overall test system.

Ipfc Model

The IPFC small-signal model is shown in Figure. 2.

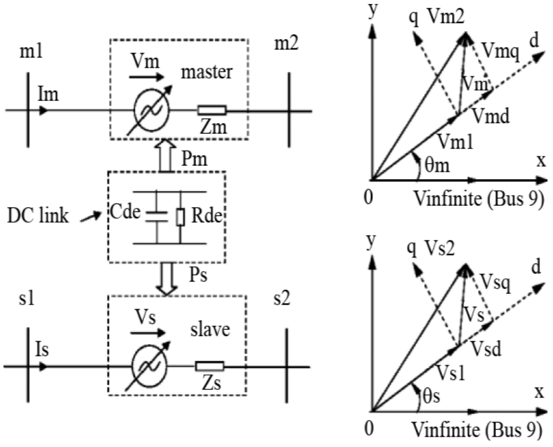

Figure 2. IPFC small-signal model.

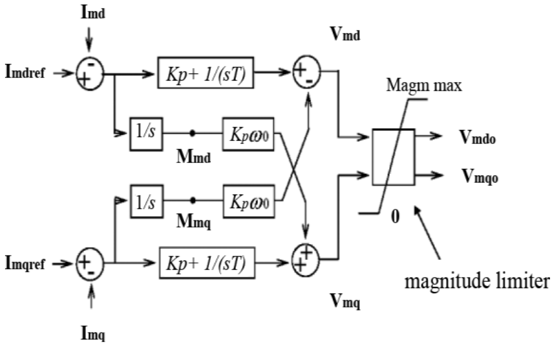

Figure. 3. Decoupled controller of the IPFC's master branch

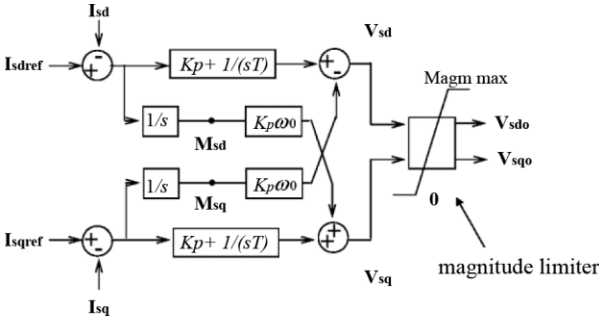

Figure. 4. Decoupled controller of the IPFC's slave branch

The dynamic behavior of the IPFC is represented by two groups of state equations. One represents the dynamics of its dc capacitor; the other, the control system. In this paper, the popular decoupled control method is assumed, as shown in Figs. 3and 4 for the IPFC's master and slave branches, respectively. The controllers attempt to maintain the real and reactive current of these branches at their set-point values. With decoupled control, the and axis current loops do not interact with each other and the real and reactive current can be independently adjusted without perturbation to the other.

Validation Of Small Signal Model

The small-signal model state equations were implemented in MATLAB. This state variable formulation can be used for small-signal stability analysis through eigenvalue calculation. It can also be numerically integrated to produce time-domain results. Results from the numerical simulation can be compared with a detailed EMT model for validation purposes. This validation was carried out by comparing the simulation results from the small-signal model with an EMT program (PSCAD/EMTDC).

In this paper, the UPFC is selected as the basis for comparison of the performance with the IPFC. The following five cases are considered:

Case 1) the original system without any FACTS device;
Case 2) an IPFC is placed in line 1–6 and 7–8: it relieves congestion of line 1–6 and improves the utilization of the transfer capacity of line 7–8;
Case 3) a UPFC is placed in line 1–6: it relieves congestion of line 1–6, but the extra power sent to Area 3 is on lines 7–8 and 1–2, which may result in the possibility of loop flow of power;
Case 4) a UPFC is placed in line 7–8: it transfers more power through line 7–8; it will relieve the congestion of line 1–6, but also may result in undesirable loop flow in line 1–2;
Case 5) an IPFC is placed in line 1–2 and 7–8: it transfers more power through line 7–8, but line 1–6 (congested line) is not directly controlled by the IPFC.

The validation effort consisted of comparing the detailed EMT simulation of a full nonlinear system and small-signal simulation results for disturbances to the systems of cases 1 through 5 before. An agreement indicates that linearization is truly representative of the full detailed system at the operating point. It also adds confidence that no algebraic errors were made during the derivation of the small-signal model.

Damping Performance Analysis

The developed small-signal model was used to investigate the damping performance of the IPFC. This section summarizes the results of this study.

In small-signal analysis, the controllability index indicates the influence of a given input to a mode. Table III shows the controllability indices of cases 2-5 .

TABLE III
CONTROLLABILITY INDICES OF CASES 2~5

	mode	I_{md} (IPFC) Ibd (UPFC)	Imq (IPFC) Ibq (UPFC)	Ibd (IPFC) Ieq (UPFC)
Case 2	2	-.2+0.0i	-0.1-0.1i	-0.0-0.3i
	3	1.4-.4i	-3.4-1.6i	**-12.6-14.7i**
	4	**21.3+15.2i**	.1-5.2i	**2.8+431i**
Case 3	2	0	0	-0.02+0.0i
	3	0	0.1i	0.0
	4	5.3-8.87i	4.0-1.6i	-1.3-0.4i
Case4	2	-0.1i	-.1+.1i	0
	3	**-22.2+10.6i**	1.6-4.7i	-.1-.3i
	4	-4.3-5.5i	3.4-.5i	-0.2i
Case5	2	**-7.7-52.1i**	-11.3-6i	**3.4-37.1i**
	3	-.5-.4i	-1i	**14.2+17.4i**
	4	-4.8+1.5i	-2.9-1.3i	**24.6-3.9i**

1. for the IPFC cases (Cases 2 and 5), the largest controllability index, for any of the modes is in columns corresponding to real-power-related variable. Similarly for the UPFC cases (Cases 3 and 4), the largest values appear in the “Ibd ” column, again associated with the real-power flow. This is as expected because real power plays a dominant role in sustaining or damping rotor oscillations and, hence, these variables are significantly more effective in damping than those associated with reactive power;

2. in Cases 2 and 5, the IPFC can control at least two modes, while in Cases 3 and 4, the UPFC can only control one mode. Again, this is as expected, because the IPFC is able to directly control the real power flow in two lines, as opposed to the UPFC which can only control the flow precisely in one line. This shows the IPFC’s advantage over the UPFC for low frequency damping control.

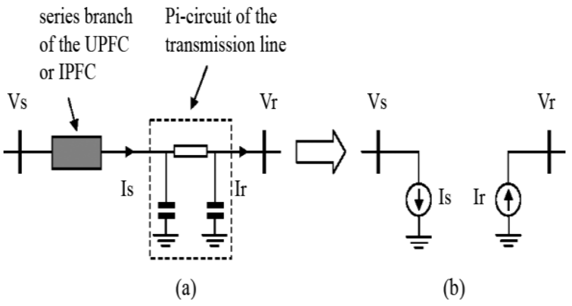

Figure.10. Equivalent disconnected circuit of the series branch of the UPFC

Interpretation Of The Damping Characteristics

In a conventional damping controller, such as a PSS on an electrical machine, changing the PSS gains usually retains the resonance frequencies near their original values but increases the damping. In contrast, when a UPFC or IPFC is included, the aforementioned results not only indicate improved damping, but also show a significant change in the resonant frequencies (eigenvalues) of the network.

The series branch is the main contributing part of the UPFC and IPFC in controlling power flow. In the UPFC, the series converter is operated to provide the ordered real and reactive power into the line. For power-flow control and congestion management, the series branch is given a constant real and reactive power setpoint, as in sample cases 2–5 before. For power-flowcontrol and congestion management, the series branch is given a constant real and reactive power setpoint, as in cases 2–5 before. In this operation, the incremental real power in the line is zero. From a machine acceleration point of view, this is tantamount to having no incremental power transfer through the line.With this control, the system behaves as if the line were not present.

To validate the aforementioned idea, a test case (Case 6) was created by modifying the UPFC controller case (Case 3). Line 1–6 was cut and replaced with an equivalent circuit with one constant current source at each side of the line [Fig. 10]. The current sources do not contribute to the dynamics but only ensure that the steady-state power flow at either end is maintained. If the proposed theory discussed before is valid, then the oscillation frequency and damping ought to be nearly identical to that with the UPFC in line 1–6.

Now the altered mode frequencies and damping can be identified as being those of a new network structure one in which existing transmission lines have been cut. If the cut is introduced at a suitable location, the new structure can exhibit better damping. Improved dynamic behavior is a result of the segmentation of the network rather than by the selection of suitable controller parameters. This approach does not require classical feedback controller tuning methods for designing the controller, but merely requires the selection of a suitable line to cut.

Conclusion

This paper presents the small-signal model of the IPFC. The model is validated via EMT simulation using a 12-bus network capable of modeling multiple oscillatory modes. The damping performance of the IPFC is evaluated by using the validated IPFC small-signal model. The damping performance is also compared with that of a UPFC. IPFC having two series branches has more potential for improving system's dynamic performance.

Reference

[1] Nabavi-Niaki and M. R. Iravani, "Steady state and dynamic models of unified power flow controller (UPFC) for power system studies," *IEEE Trans. Power Syst.*, vol. 11, no. 4, pp. 1937–1943, Nov. 1996.

[2] H. F.Wang and F. J. Swift, "A unified model for the analysis of FACTS devices in damping power system oscillations. I. Single-machine infinite- bus power systems," *IEEE Trans. Power Del.*, vol. 12, no. 2, pp. 941–46, Apr. 1997.

[3] Z. Huang, Y. Ni, C. M. Shen, F. F. Wu, S. Chen, and B. Zhang, "Application of unified power flow controller in interconnected power systems-modeling, interface, control strategy, and case study," *IEEE Trans. Power Syst.*, vol. 15, no. 2, pp. 817–824, May 2000.

[4] C. D. Schauder, L. Gyugyi, 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 Trans. Power Del.*, vol. 13, no. 2, pp. 630–639, Apr. 1998.

[5] Y. Zhang, Y. Zhang, and C. Chen, "A novel power injection model of IPFC for power flow analysis inclusive of practical constraints," *IEEE Trans, Power Syst.*, vol. 21, no. 4, pp. 1550–1556, Nov. 2006.

[6] S. Arabi, H. Hamadanizadeh, and B. B. Fardanesh, "Convertible static compensator performance studies on the NY state transmission system," *IEEE Trans. Power Syst.*, vol. 17, no. 3, pp. 701–706,

[7] S. Jiang, U. D. Annakkage, and A. M. Gole, "A platform for validation of facts models," *IEEE Trans. Power Del.*, vol. 21, no. 1, pp. 484–491,Jan. 2006.

[8] P.Kundur, *Power System Stability and Control*. New York: McGraw- Hill, 1994.

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