Performance of power system improvement by using FACTS device : Interline power flow controller

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Abstract :– In the power system, the cost of the transmission lines plays important role in the network company. An interline power flow controller (IPFC) is a series-series converter based FACTS controller with capability of controlling power flow among muti-lines within the same corridor of the transmission line. In this paper, the performance of multi-machine power system with & without interline power flow controller (IPFC) under various system conditions in MATLAB environment is studied. The IPFC is designed to achieve power flow control and damp the oscillations during disturb codition. This paper presents comparative study of power flow analysis with IPFC and without IPFC considering the cases i.e. I) normal load condition II) with the increasing 10% load and III) with the 3-ph –ground fault in area1. Series FACTS devices are most powerful controllers used for power flow, power oscillation damping and improving transient stability of the system. Results are validated by using MATLAB.

Key-Words: - Power system, Multi-machine system, FACTS, VSC, IPFC, transient stability

1. Introduction

In general the FACTS controller can be divided into non-converter based FACTS controller which includes Static Var Compensator (SVC) and Thyristor-controlled series capacitor (TCSC). These controllers generate or absorb reactive power without the use of ac capacitors and reactors. Other group is converter based FACTS controller which includes STATCOM, SSSC, UPFC and IPFC. These controllers have the capability of individually control the active and reactive power flow on the transmission line [1]. Series FACTS devices are used for controlling power flow in transmission lines and for damping the oscillations present in power system. Static synchronous series compensator (SSSC) injects the voltages or absorbs voltages from transmission line where it is connected. When it is fed with some supplementary signals from the connected system, SSSC is capable to participate in oscillation damping by changing the compensated reactance of the transmission line [3] and [6]. Synchronous voltage source, implemented by gate turn-off thyristor (GTO) based voltage sourced inverter, provides controllable series compensation. SSSC also provides controllable compensating voltage over an identical compensating voltage over identical capacitive and inductive range independent of the magnitude of the transmission line current. External dc power supply compensates the voltage drop across the resistive component of the line impedance [4]. A combined multi-pulse and multilevel inverter topology for high power applications has been proposed in [5]. The paper [7] presents the application and comparison of an optimal direct and indirect adaptive neuro-fuzzy control scheme to damp power system oscillations using the SSSC and reliable operation of power systems, were studied. A hybrid adaptive neuro-fuzzy B-spline wavelet-based control technique was successfully applied to a multi-machine power system for damping local and inter-area modes of oscillations. The MATLAB Simulink environment was used to generate the results for different fault in system.

An interline power flow controller (IPFC) is a series-series converter based FACTS controller with capability of controlling power flow among muti-lines within the same corridor of the transmission line. Switching level simulation modeling of IPFC has been proposed in [8] and [9]. The simple mathematical model of IPFC was proposed in [11] for the optimal control of power flow on the transmission line. The [12] paper represents the self-tuned fuzzy damping control scheme for an interline power flow controller to remove the inter-area mode of oscillations in a multi-machine power system. The controller for nonlinear adaptive damping is based on coordinated operation of two fuzzy inference systems.
The feasibility of the proposed technique is validated by using PSCAD simulation program and paper represents the proposed damping scheme for IPFC works better than the SSSC, which utilizes the same damping scheme in reducing the inter-area oscillations.

Day-by-day demand for electricity goes on increasing. To meet with that demanded power it is not possible to replace existing power system. So some technology has to be added with existing power system to increase the capacity of the system. The FACTS controllers are one of the best devices for compensation of this problem.

2. IPFC modeling

The IPFC consist of two or more than two SSSC linked together with the common DC link as shown in figure 1. Each SSSC provide the reactive power compensation to the individual line. Also it has the capable of transmitting the real power from lightly-loaded line to the overloaded line through a common dc link.

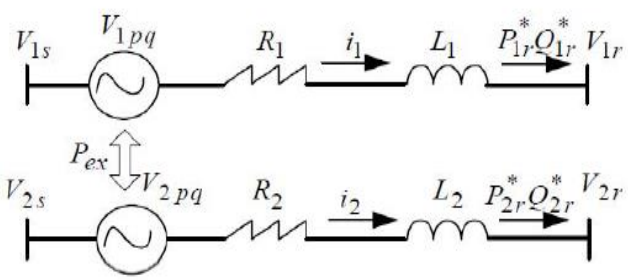


Fig.1. Basic Two-Inverter Interline Power Flow Controller

The circle shown in the fig.2. determines the limit of the output voltages of the two inverters. The voltage compensation line which crosses the center of the circle and have the same direction as V_1, is the locus of the output voltages which doesn't exchange energy with the transmission lines.The voltage compensation lines which is in the right side of central compensating line, are corresponding to the output voltages which cause the injection of active power to the transmission line. And the voltage compensation line which is in the left side of central compensating line, are corresponding to the output voltages which cause the absorption of active power from transmission line.

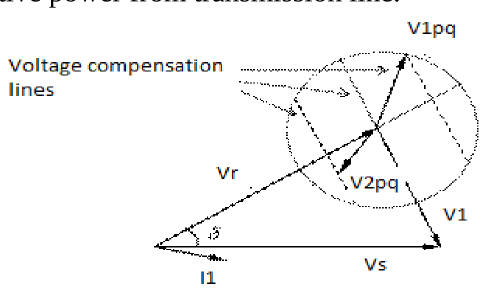


Fig.2. Vector diagram of IPFC

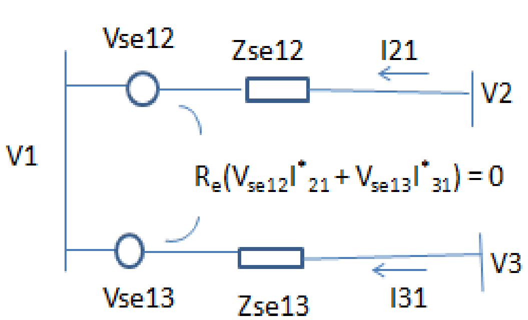


Fig.3. Mathematical modeling of IPFC

The model for mathematical modelling is as shown in figure 3. For modelling the assumption is that the power flowing across the dc link is zero. If V_{sein} is replaced by I_{sein} in parallel with transmission line and resistance of transmission line & the series coupling transformers are neglected then current source can be expressed as [11]-

$$I_{sein} = -jb_{sein} V_{sein} \quad (1)$$

Complex power injected at 1st bus is

$$S_{inj1} = \sum_{n=2,3} V_1(-I_{sein})^* \quad (2)$$

$$S_{inj,1} = \sum_{n=2,3} V_1(jb_{sein}V_{sein})^* \quad (3)$$

Active & reactive power injections at 1st bus are

$$P_{inj,1} = \mathrm{Re}(S_{inj,1}) = \sum_{n=2,3}(V_1V_{sein}b_{sein}\sin(\theta_1-\theta_{sein}))$$
$$Q_{inj,1} = \mathrm{Im}(S_{inj,1}) = -\sum_{n=2,3}(V_1V_{sein}b_{sein}\cos(\theta_1-\theta_{sein})) \quad (4)$$

Similarly, complex power, active power & reactive power injections at nth bus (n=2,3) is

$$S_{inj,n} = V_n(I_{sein})^* = V_n(-jb_{sein}V_{sein})^*$$
$$P_{inj,n} = \mathrm{Re}(S_{inj,n}) = -V_nV_{sein}b_{sein}\sin(\theta_n-\theta_{sein}) \quad (5)$$
$$Q_{inj,n} = \mathrm{Im}(S_{inj,n}) = V_nV_{sein}b_{sein}\cos(\theta_n-\theta_{sein})$$

2.1 Control scheme for IPFC

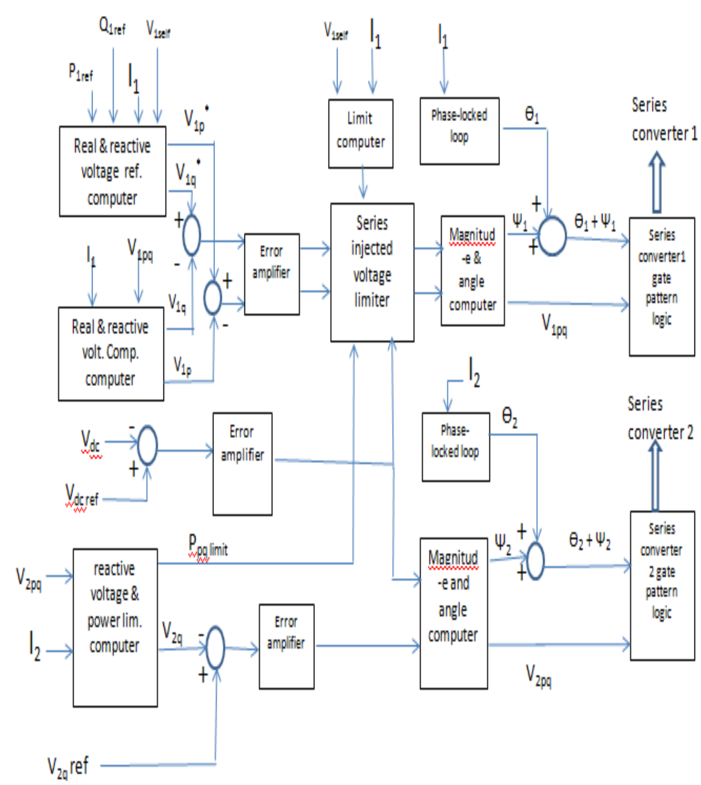
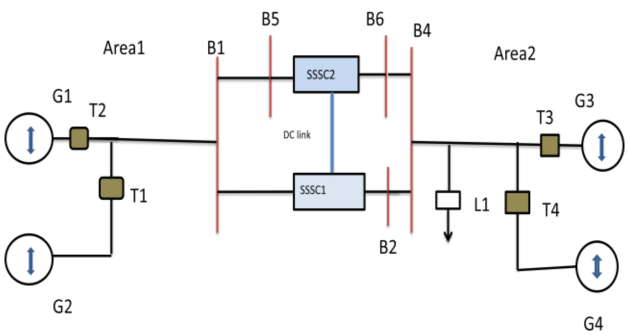


Fig.4. Basic control scheme for two converter IPFC

Control scheme as shown in fig.4 is designed on the consideration of converter 1 is worked as prime converter and converter 2 is worked as supportive converter for converter 1 [1]. The active power limit is set by converter 2 for converter 1. Separate phase-locked loop is used for each converter which produced the phase angle. These phase angle is compared with injected voltage phase angle and produces the firing pulses for converter.

2.2 System model

The system consists of two areas in which two salient pole type generators are connected in each area as shown in fig. 5. These two areas are connected together with the help of two parallel lines each are 220 km long and 500kv rated. Load L1 is connected in area2. The power is measured at buses 1, 2, and 6 respectively. Voltage injected by IPFC is 10% i.e. 0.1 pu. The detail system data is given in Appendix A.



. Fig.5. Multi-machine system with IPFC FACTS device

3. Simulation results

Multi-machine system is validated by using MATLAB simulink under various cases.

<u>Case 1:- Normal load condition (L1=5000MW)</u>

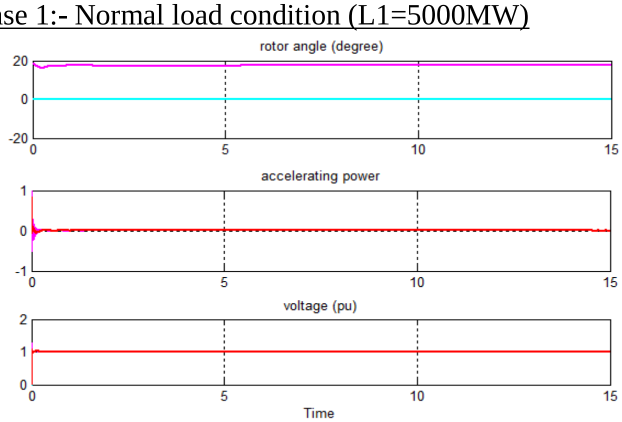


Fig.6. System without IPFC Under normal load condition

Rotor angle remain steady state. Accelerating power is zero and voltages remain 1 pu in system.

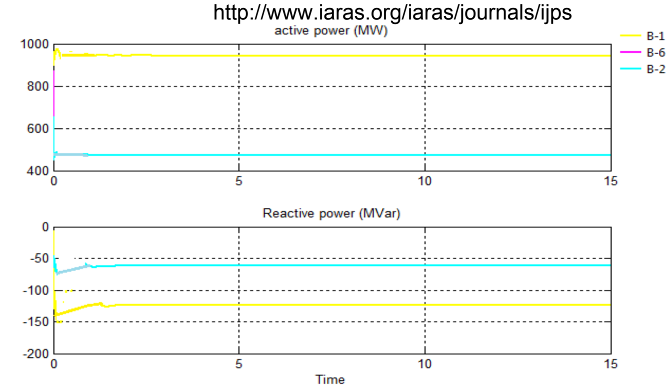


Fig.7. Active & Reactive power without IPFC

Active power and reactive power across buses B-1 is 942 MW & -124 Mvar, B-2 is 471 MW & -62 Mvar and B-6 is 471MW & -62 Mvar respectively .

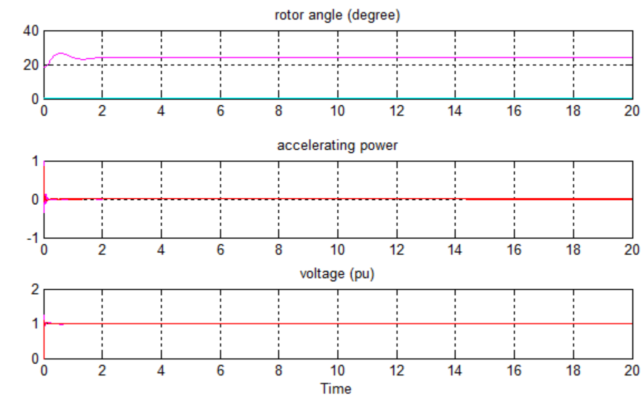


Fig.8. System with IPFC under normal load condition.

Rotor angle remain steady state. Accelerating power is zero and voltages remain 1 pu in system with IPFC FACTS device.

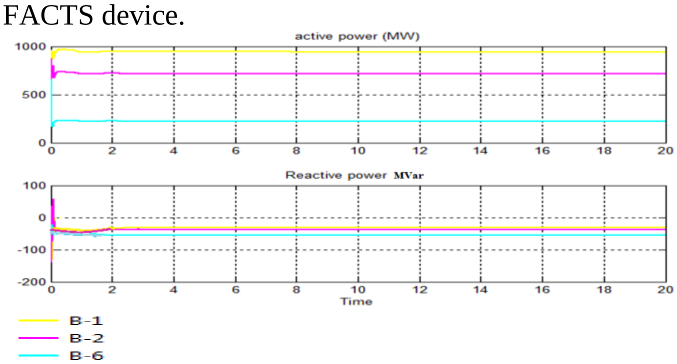


Fig.9. Active & Reactive power with IPFC under normal load condition

Active power and reactive power across buses B-1 is 942 MW & -28 Mvar, B-2 is 710 MW & -28 Mvar and B-6 is 232 MW & -56 Mvar respectively . The power flowing across the bus B-2 is increased from 471 MW to 710 MW.

<u>Case 2 :- Under 10% increased load condition (L1= 5500MW)</u>

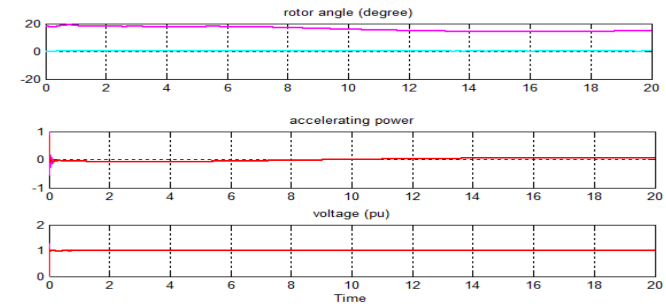


Fig.10. System without IPFC

Rotor angle takes large time to settle down to it's steady-state value as shown in figure 10.

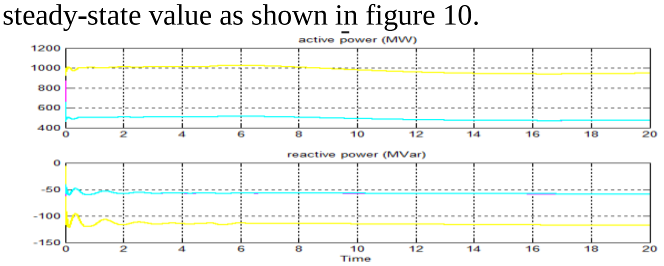


Fig.11. Active & Reactive power without IPFC

Active power across the buses also takes large time to settle down to steady-state value.

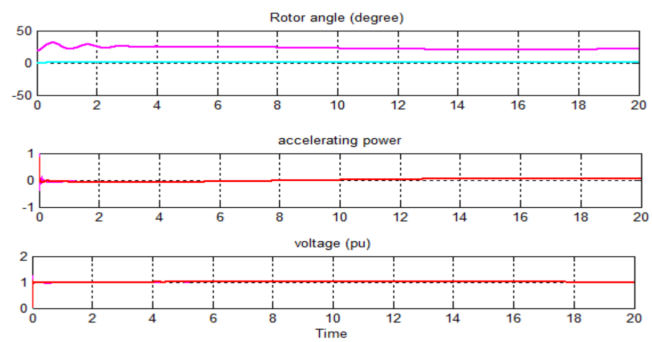


Fig.12. system with IPFC under increased load condition

Rotor angle reach to the steady state value in less time as shown in figure12. Accelerating power is zero. Voltage is 1 pu .

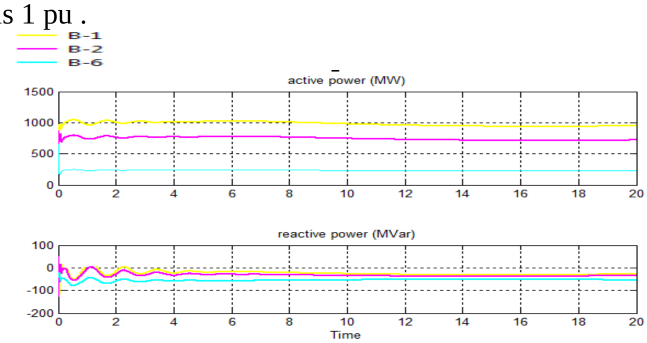


Fig.13. Active power and reactive power under increased load condition

Power across the buses reach to steady state values.

Case3:- Under fault condition

Fault type L-L-L-G in area 1 near bus 1. Fault occurring time is 1 sec. and clearing time 1.02 sec.

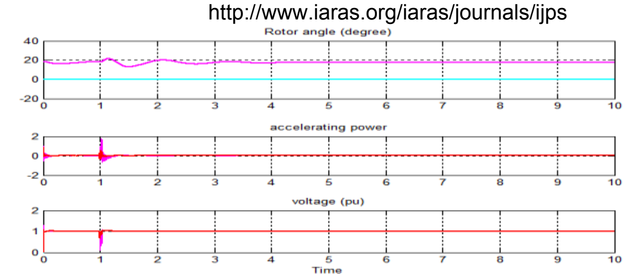


Fig.14. System without IPFC under fault condition.

Rotor angle reach to the steady state value after fault clearing. Accelerating power is zero. Voltage is 1 pu as shown in figure 14.

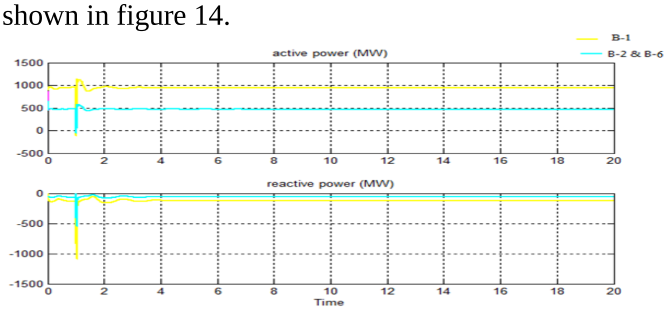


Fig.15. Active & Reactive power of system without IPFC

Active power and reactive power across buses B-1 is 942 MW & -124 Mvar, B-2 is 471 MW & -62 Mvar and B-6 is 471MW & -62 Mvar respectively . First peak of active power across B-1 after fault clearing is 1150 MW as shown in figure 15.

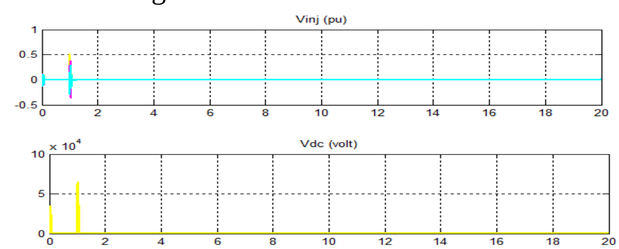


Fig.16. Injected voltage & dc link voltage of IPFC

Injected voltage by IPFC device is 0.1pu. During fault time voltage across dc link is increased to limit the sudden rise of power in transmission line.

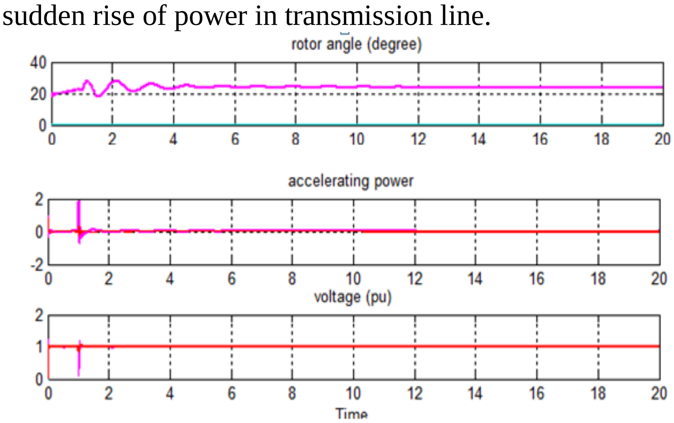


Fig.17. System with IPFC under fault condition

Fault occurs at 1 second and remain for 0.02 seconds in the system. Rotor angle reach to steady state value after fault clearing as shown in figure 17. The accelerating power is zero after fault clearing and voltage is 1 pu.

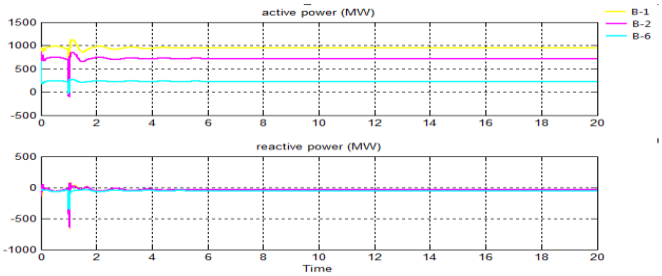


Fig.18. Active & Reactive power of system with IPFC under fault condition.

During fault condition peak reduced by (1150 - 1128 = 22MW) nearly 2% after installing IPFC FACTS device in system as shown in figure 18.

4. Conclusions

The IPFC consist of two or more than two SSSC linked together with the common DC link. Each SSSC provide the reactive power compensation to the individual line. IPFC has the capability of transmitting the real power from lightly- loaded line to the overloaded line through a common dc link.

Rotor angle indicates steady state condition under no fault condition. System with IPFC achieve steady state value in increased load demand within short time as compared to system without IPFC . During fault condition first peak reduced significantly after installing IPFC FACTS device in system. System parameters reach to steady state value after fault clearing.

Appendix A :- Multi-machine system data

Area1	Transmission line	Area2
G1=G2=500MVA, F=60Hz	L1=L2=220km,	G3=G4=500MVA, F=60Hz
Vrms=13.8 kv	V=500kv	Vrms=13.8 kv
X_d=1.305pu, X_d'=0.296pu , X_d''=0.252pu	Resistance per unit length= [0.0001*529 1.61]	X_d=1.305pu, X_d'=0.296pu , X_d''=0.252pu
X_q=0.474pu , X_q''= 0.243 pu, X_l=0.18pu	Inductance per unit length= [0.001*529/(377) 0.0061]	X_q=0.474pu , X_q''= 0.243 pu X_l=0.18pu
T1=T2=500 MVA , 13.8kv/500kv Rm=Lm= 500pu	Capacitance per unit length= [0.00175/529/(377) 5.2489e-9]	T3=T4= 2500 MVA, 13.8kv/500kv, Rm=Lm=500pu .

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