International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 9 (2019) pp. 2148-2155

Analysis of AC Transmission System Using Fuzzy Logic Controller for Damping of Low Frequency Oscillations with Interline Power Flow Controller

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Abstract

The series compensating FACTS device Interline Power Flow Controller (IPFC) for series compensation of Active and reactive power with the unique capability of power flow management among the multiple transmission lines in transmission system. During the disturbances in power system, the stability of system causes deviation from stable operation and causes variation in different parameters of power system like load angle and Rotor speed. To suppress the oscillations in load angle and rotor speed, the Fuzzy logic controller (FLC) with IPFC is proposed in this paper to improve the stability of power system. IEEE 14 bus system using IPFC with FLC is considered for analysis. Analysis is carried out using MATLAB/Simulink for different fault conditions.

Keywords: Flexible AC Transmission System, Interline Power Flow Controller , Voltage Source Converter, Stability, Fuzzy logic controller, load angle, Rotor speed.

1. INTRODUCTION

Present large power networks are experiencing large variation in loads leading to stability of the system. In addition to this, if any disturbance occurs in any part of the system, stability will be altered. Generally the frequent faults takes place in transmission lines rather than faults at reaming parts of power systems. The disturbances occur in transmission lines causes deviation in normal operation of other parts of power systems like Generators, turbines, governors etc. The deviation in normal operation of system causes instability of power system in terms of oscillations in load angle and rotor speed [1].

To overcome such drawbacks, embedding Flexible AC Transmission System (FACTS) controllers in power system plays an important role and offers good control and satisfactory performance. Hingorani [2] proposed thyristor based FACTS technology for application in power systems to improve the performance under disturbances. With advent of high power electronic devices such as IGBT and GTO, now the converter based FACTS technology is finding improved application. Gyugi [2] developed Inter line power flow controller (IPFC) and its specialty is not only its multi functionality but also its controllability of multi transmission lines in large scale power system.

Sebba et al. [3] carried out with UPFC in a 2-area 4-machine system using fuzzy tuned adaptive PI controller to suppress damping of oscillations. Saoudi et.at. [4] reported with STATCOM using adaptive sliding controller capable of stabilizing an electric power system in terms of transient stability of the system and is tested on a single-machine infinite bus (SMIB) power system for symmetrical three-phase short circuit fault. Kanchanaharuthai et al. [5] carried out using advanced nonlinear control methods such as an immersion and invariance (I&I) control and a backstepping control have been applied on the power system in terms of power angle stability, frequency and voltage regulation to find transient stability.

In this paper, the FACTS device namely IPFC is used to damp power oscillations [6] with the advantages of individual control of each transmission line. IPFC is located between buses 1 and 12 of IEEE 14 bus system. The IPFC is utilized to damp the power oscillations for different faults and are further applied between buses 7 and 8 using Fuzzy controller.

In this paper, the Fuzzy Logic Controller (FLC) based IPFC designed and its performance under disturbances in damping oscillations is tested using IEEE 14 bus multi machine power system [7].

2. SYSTEM CONSIDERED TO STUDY THE PERFORMANCE OF IPFC

IEEE-14 bus system as shown in Fig 1, is considered for studying the performance of IPFC, under disturbance conditions. The details of the system are given in Appendix 1.

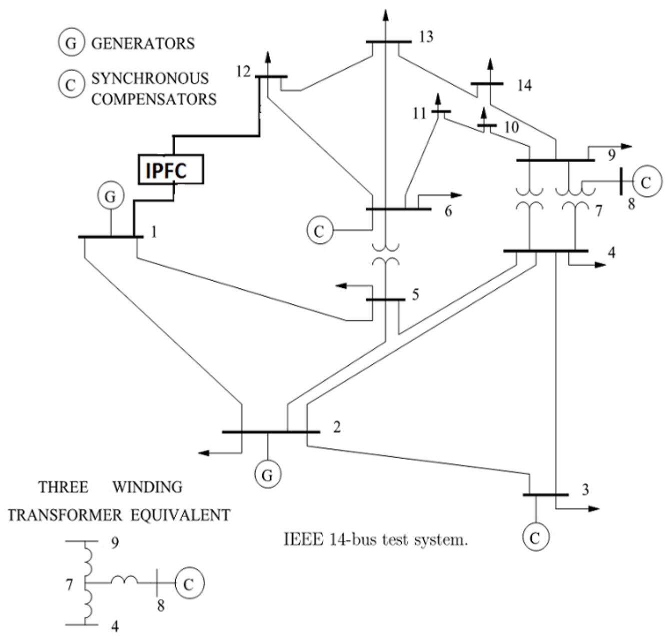

Fig.1 IEEE 14 bus test system

3. INTERLINE POWER FLOWCONTROLLER

The IPFC consists of two VSC converters via a dc link. The VSC-1 and VSC-2, shown in Fig. 2 converts DC to AC, provides series compensation for transmission lines. The dc-to-ac converters are series connected through dc link and are connected to transmission lines via coupling transformers. This series connection has a common dc link.

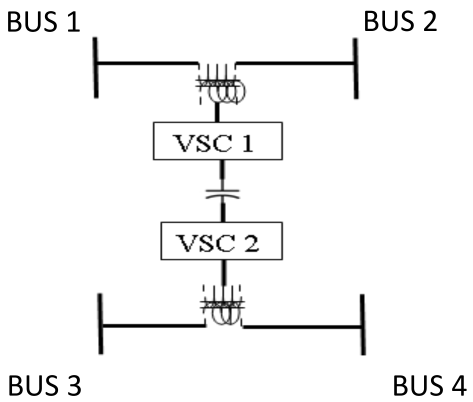

Fig 2 Interline power flow controller (IPFC)

Therefore this IPFC can allow reactive and active power to flow in the multiline power network simultaneously; the problem of oscillation is damped out by dc link [9]. The DC link parameters of IPFC used in present power system are $V_{dc} = 1.4e^5$and $C_{dc}= 1000e^{-3}$. The controller structure for present power system with IPFC for stability analysis is shown in Fig.3. The MATLAB/SIMULINK diagram of IEEE 14 bus system using IPFC [10] with fault location is shown in Fig.4.

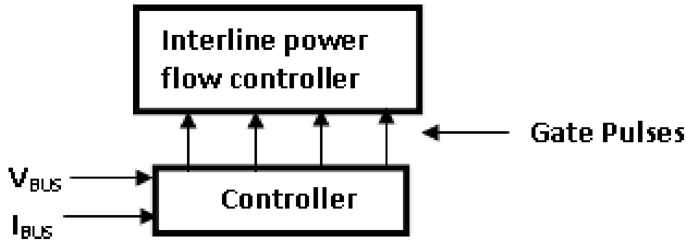

Fig. 3 Controller structure with IPFC

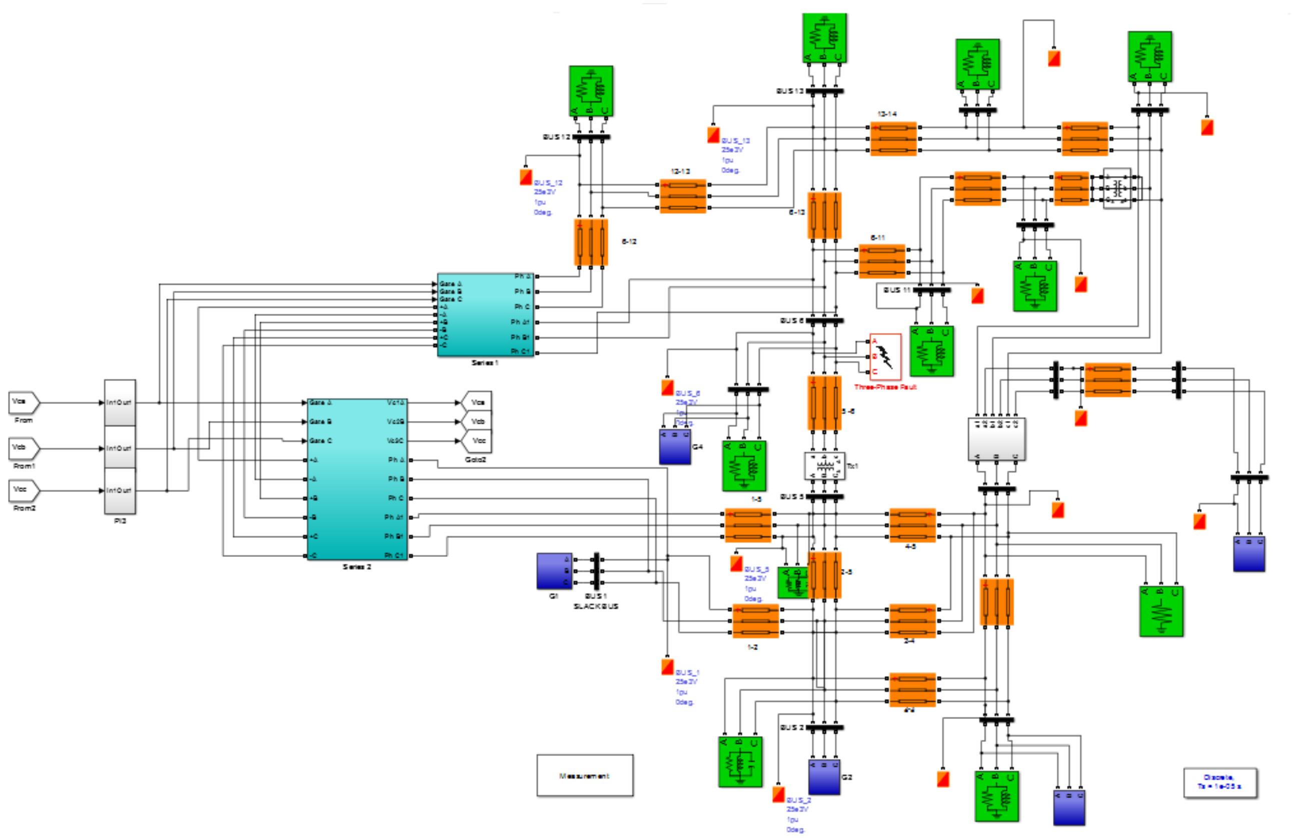

Fig.4. MATLAB/SIMULINK diagram of IEEE 14 bus system using IPFC with fault.

4. FUZZY CONTROLLER

The control strategy of Fuzzy logic controller is shown Fig. 5. Here the V_{ref} is compared with corresponding bus voltage V_{ph-ph} and the error obtained, V_{error}, is applied to FLC control block, Here the limiter output V^* is applied to the PWM generator. The PWM generator output is compared with the carrier signal using a comparator, to get desired gate pulses which are used for IPFC. The MATLAB / SIMULINK diagram of FLC is shown in Fig. 6.

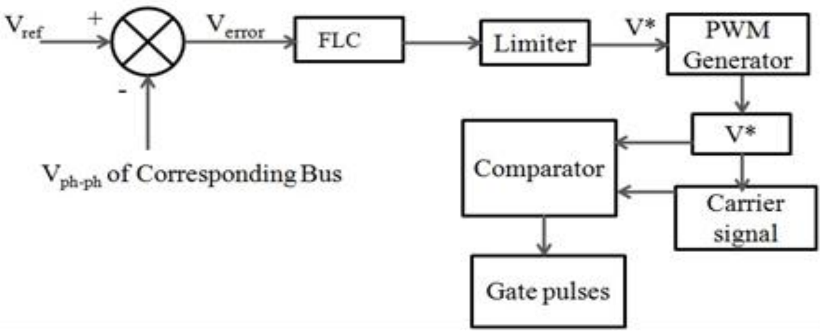

Fig 5. Block diagram for control strategy for Fuzzy controller

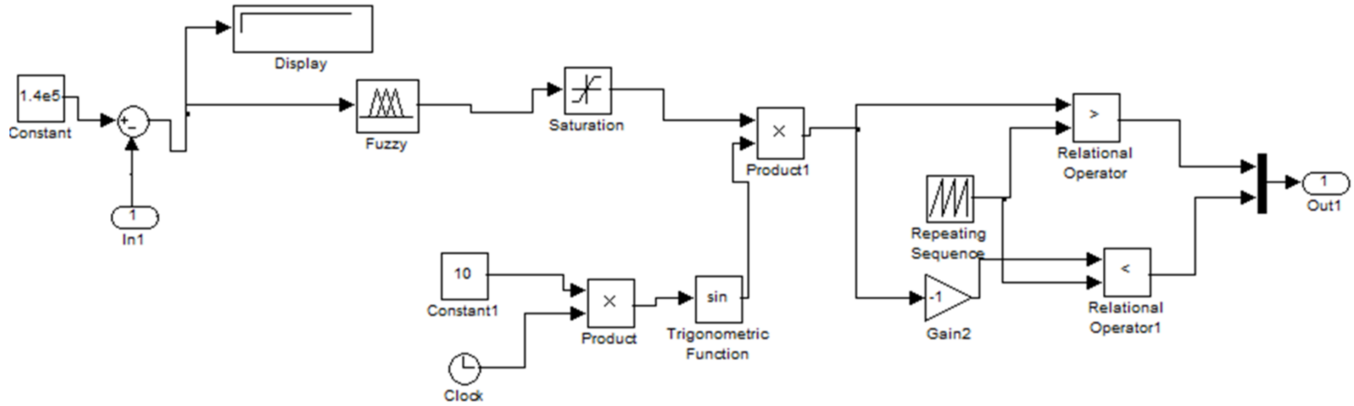

Fig 6. MATLAB/SIMULINK diagram of Fuzzy controller

Rules framed for Mamdani FLC with the combination of error and changes in error voltage [8] are listed below and tabulated in Table 1.

Table 1: Fuzzy Rule Table

Error / Change of error	Small(S)	Medium(M)	Big(B)
Small (S)	S	M	M
Medium(M)	M	M	M
Big (B)	M	B	B

5. SIMULATION RESULTS

Digital Simulation studies are carried out using MATLAB/Simulink. The study is carried to find the effectiveness of IPFC in damping the oscillations using Fuzzy controller for different disturbances such as i) LG fault ii) LLG fault iii) LLLG fault.

The simulation results obtained for load angle (load angle vs time) without IPFC for all these three faults are shown in Fig. 7, 8 and 9 respectively. The simulation results (load angle vs time) are also obtained for all the three faults with IPFC using Fuzzy logic controller are shown in Fig.10, 11 and 12 respectively [10].

The responses obtained for the speed of the rotor (rotor speed vs time) without Fuzzy controller for all the three faults viz. LG, LLG and LLLG [11] are plotted in Fig. 13, 14 and 15 respectively. The IPFC performance with Fuzzy controller is further carried out by plotting the rotor speed against time for all the three faults in Fig. 16, 17 and 18 respectively.

The other generators are further analyzed without IPFC for all the three faults in connection with rotor angle and speed with respect to amplitude of oscillations and settling time, and are tabulated in Tables 2, 3 and 4 respectively. Also the analysis is made on the other generators with IPFC using Fuzzy logic controller for all the three faults are also tabulated in Tables 5, 6 and 7 respectively.

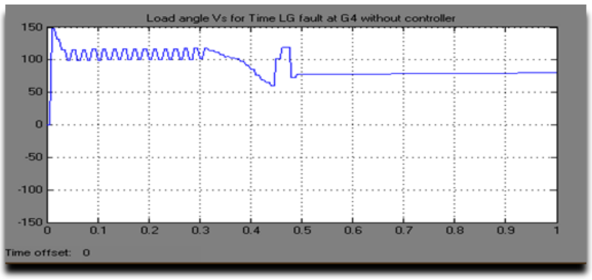

Figure 7. Load angle Vs time, LG fault at G4 without controller

From Fig.7 it is manifest that LG fault applied between 0.3 and 0.5s without controller and overshoot is around 50% in amplitude and settling time is of 0.48s is obtained for a applied set point of 100. The response is varied in terms of transient response and settling time.

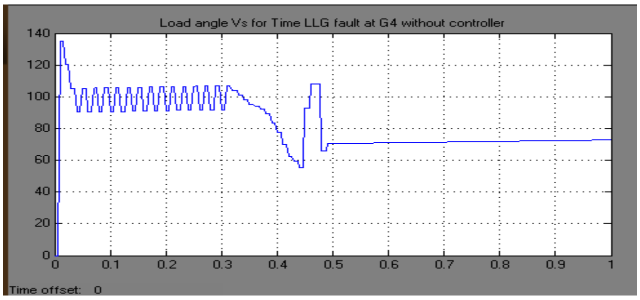

Figure 8. Load angle Vs time, LLG fault at G4 without controller

From Fig.8 it is evident that LLG fault applied between 0.3 and 0.5s without controller and overshoot is around 38% in amplitude and settling time is of 0.48s is obtained for the set point of 100 is applied. The response is largely varied in terms of transient response (overshoot and undershoot) and settling time.

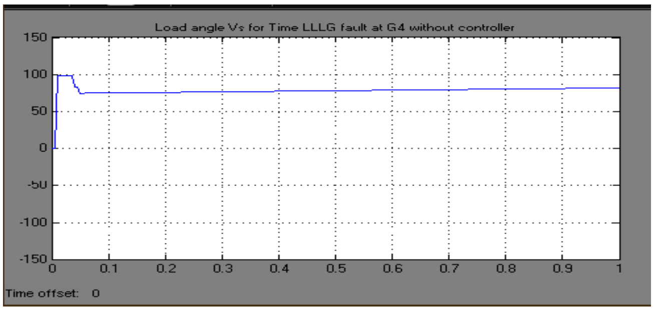

Figure 9. Load angle Vs time, LLLG fault at G4 without controller

From Fig. 9 it is evident that LLLG fault applied between 0.3 and 0.5s without controller and overshoot is around 25% in amplitude and settling time is of 0.05s is obtained for the set point of 100 is applied. The response is not affected for transient response (overshoot and undershoot) and settling time.

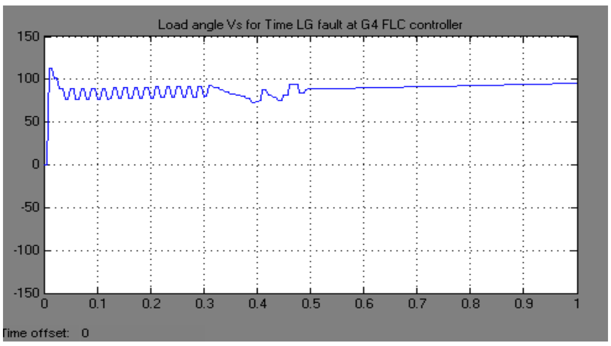

Figure 10. Load angle Vs time, LG fault at G4 with IPFC using FLC

From Fig.10 it is apparent that the LG fault applied between 0.3 and 0.5s with FLC controller and the overshoot is around 12% in amplitude and settling time is of 0.15s is obtained for the set point of 100 is applied. The response is varied in terms of transient response (overshoot and undershoot) and settling time.

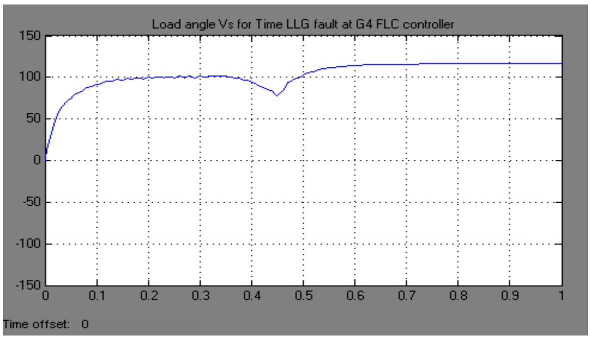

Figure 11. Load angle Vs time, LLG fault at G4 with IPFC using FLC

From Fig.11,it is evident that LLG fault applied between 0.3 and 0.5s with FLC controller and the overshoot of 0.85% is reduced in amplitude and settling time is of 0.5s is obtained for the set point of 100 is applied. The response has a delay time of 0.1s of response and settling time.

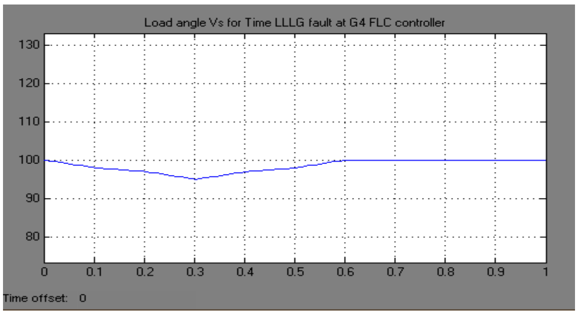

Figure 12. Load angle Vs time, LLLG fault at G4 with IPFC usingFLC

From Fig.12 it is manifest that LLLG fault applied between 0.3 and 0.5s with FLC controller and overshoot OF 0.92% is reduced in percentage of amplitude and settling time is of 0.09s is obtained for the set point of 100 is applied. The response has a delay time of 0.3s of response and settling time.

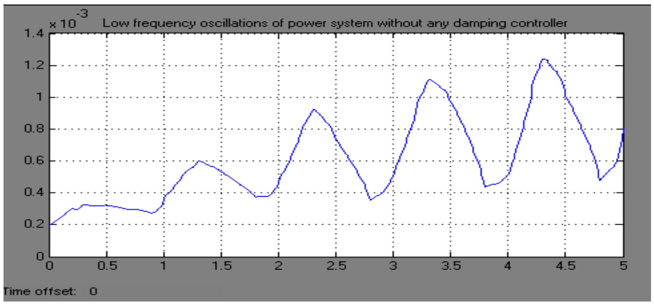

Figure 13. Rotor speed Vs time, LG fault at G4 without IPFC

From Fig.13 it is evident that LG fault applied between 0.3 and 0.5s without controller and graph increases exponentially and not converged, so the response seems to be unstable

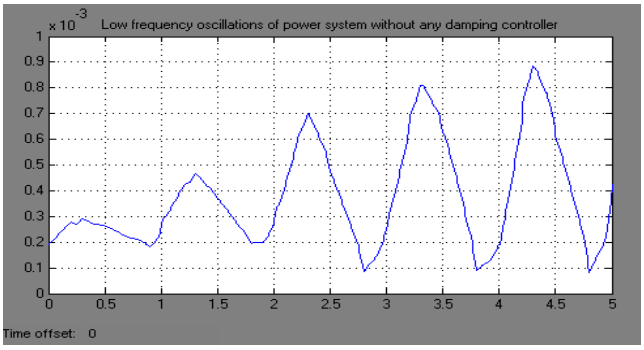

Figure 14. Rotor speed Vs time, LLG fault at G4 without IPFC

From Fig.14 it is apparent that with LLG fault applied between 0.3 and 0.5s without controller and graph increases exponentially and not converged, so the response seems to be unstable.

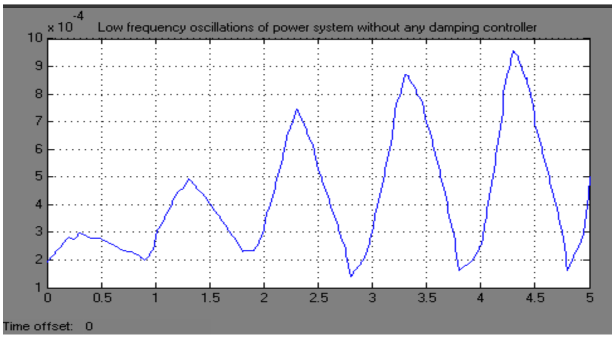

Figure 15. Rotor speed Vs time, LLLG fault at G4 without IPFC

From Fig.15 it is evident that with LLLG fault applied between 0.3 and 0.5s without controller and graph increases exponentially and not converged, so the response seems to be more unstable

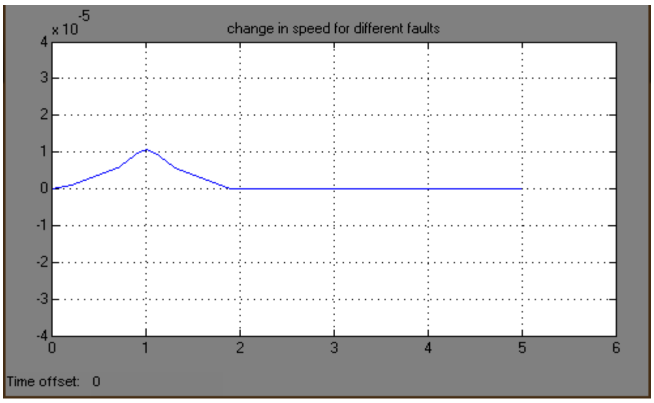

Figure 16. Rotor Speed Vs time, LG fault at G4 with IPFC using FLC

From Fig.16 it is manifest that the LG fault is applied between 0.3 and 0.5s with FLC controller and first overshoot of 2e-5; undershoot of -2e-5 in amplitude and settling time of 1.8s .When compared to without damping controller the response with FLC is stable and improved.

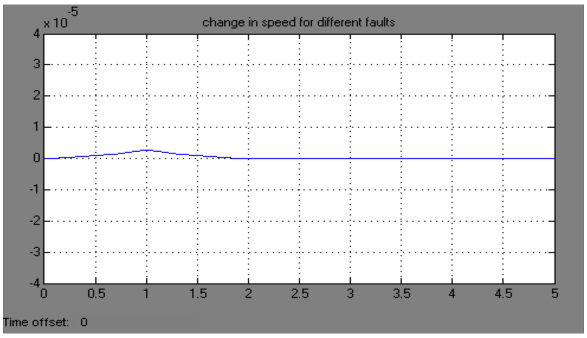

Figure 17. Rotor Speed Vs time, LLG fault at G4 with IPFC using FLC

From Fig.17, it is apparent that LLG fault applied between 0.3 and 0.5s and the first overshoot of 3.25e-4; undershoot of -3.25e-4 in amplitude and settling time of 1.6s.when compared to without damping controller the response with FLC for LLG fault is improved.

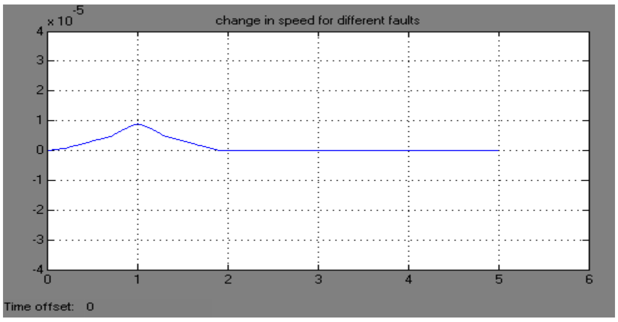

Figure 18. Rotor Speed Vs time, LLLG fault at G4 with IPFC using FLC

From Fig.18, it is evident that the LLLG fault applied between 0.3 and 0.5s with controller and the first overshoot of 0.94e-4; undershoot of -0.92e-4 in amplitude and settling time of 1.8s.When compared to without damping controller the response with FLC for LLG fault is improved.

Table 2. Results obtained for all generators when LG fault applied at G4 without IPFC

Generator No	Rotor angle		Rotor speed	
	Settling time (s)	Amplitude of oscillations (degrees)	Settling time (s)	Amplitude of oscillations (degrees)
1	1.2	120	2.5	4.5e-4
2	1.05	110	3.2	5.8e-4
3	1.1	56	2.1	4.5e-4
4	0.5	50	5	8.1e-4
5	1.3	65	6.2	2.5e-4

The results obtained for rotor angle and rotor speed versus time at G4 for LG fault applied between 0.3 and 0.5s without IPFC are tabulated in Table 2 for all generators. From Table 2, it is noticed that, the rotor speed and rotor angle are affected in terms of the amplitude and settling time. The rotor speed is very high in magnitude and settling time.

Table 3. Results obtained for all generators when LLG fault applied at G4 without IPFC

Generator No	Rotor angle		Rotor speed	
	Settling time (s)	Amplitude of oscillations (degrees)	Settling time (s)	Amplitude of oscillations (degrees)
1	1.75	45	2.5	3.25e-3
2	1.82	89	3.2	0.5e-3
3	1.23	92	0.95	5.28e-3
4	0.49	35	4.5	1.25e-3
5	0.8	112	1.1	6.42e-3

The results obtained for rotor angle and rotor speed versus time at G4 for LLG fault applied between 0.3 and 0.5s without IPFC are tabulated in Table 3 for all generators. From Table 3 it is noticed that, the rotor speed and rotor angle are affected in terms of amplitude and settling time. The rotor speed is comparatively less in magnitude and settling time.

Table 4. Results obtained for all generators when LLLG fault applied at G4 without IPFC

Generator No	Rotor angle		Rotor speed	
	Settling time (s)	Amplitude of oscillations (degrees)	Settling time (s)	Amplitude of oscillations (degrees)
1	2.75	56	5.5	1.15e-3
2	3.28	78	2.2	2.05e-3
3	3.23	72	0.95	2.28e-3
4	0.8	63	1.65	0.9e-3
5	1.23	102	1.95	2.28e-3

The results obtained for rotor angle and rotor speed versus time at G4 for LLLG fault applied between 0.3 and 0.5s without IPFC are tabulated in Table 4 for all generators. From Table 4 it is noticed that, the rotor speed and rotor angle are affected in terms of amplitude and settling time. The rotor speed and rotor angle are less increased in magnitude and settling time.

Table 5. Results obtained for all generators when LG fault applied at G4 with IPFC using FLC

Generator No	Rotor angle		Rotor speed	
	Settling time (s)	Amplitude of oscillations (degrees)	Settling time (s)	Amplitude of oscillations (degrees)
1	1.16	70	0.93	4.0e-4
2	0.9	85	3.1	0.4e-5
3	1.06	40	2.23	1.1e-5
4	0.85	25	1.82	1.0e-5
5	1.21	60	0.92	5.2e-5

The results obtained for rotor angle and rotor speed versus time at G4 for LG fault applied between 0.3 and 0.5s using FLC with IPFC are tabulated in Table 5 for all generators. From Table 5 it is noticed that the rotor speed and rotor angle are increased in terms of amplitude for rotor angle and settling time in terms of rotor speed.

Table 6. Results obtained for all generators when LLG fault applied at G4 with IPFC using FLC

Generator No	Rotor angle		Rotor speed	
	Settling time (s)	Amplitude of oscillations (degrees)	Settling time (s)	Amplitude of oscillations (degrees)
1	1.22	41	2.1	6.5e-5
2	1.75	21	0.94	4.0e-5
3	1.20	36	0.8	3.0e-5
4	0.7	16	1.83	0.2e-5
5	1.08	52	1.00	1.7e-5

The results obtained for rotor angle and rotor speed versus time at G4 for LLG fault applied between 0.3 and 0.5s using FLC are listed in Table 6 for all the generators. From Table 6 it is observed that, the rotor speed and rotor angle are affected in terms of amplitude for rotor angle and settling time in terms of rotor speed.

Table 7. Results obtained for all generators when LLLG fault applied at G4 with IPFC using FLC

Generator No	Rotor angle		Rotor speed	
	Settling time (s)	Amplitude of oscillations (degrees)	Settling time (s)	Amplitude of oscillations (degrees)
1	1.75	45	0.9	1.00e-3
2	1.82	72	2.0	0.45e-5
3	1.23	40	1.0	1.15e-5
4	0..6	10	1.9	0.9e-5
5	0.75	60	1.05	3.31e-5

The results obtained for rotor angle and rotor speed versus time at G4 for LLLG fault applied between 0.3 and 0.5s using FLC are listed in Table 7 for all generators. From Table 7, it is observed that the rotor speed is affected in terms of amplitude and settling time, whereas in rotor angle the amplitude and settling time are improved.

Hence IPFC provides control in both amplitude of oscillations with respect to load angle, rotor speed and settling times for different faults.

6. CONCLUSION

The load angle of the machine increases during faulted period and it decreases during post fault period. The settling time for the load angle is low for the system with IPFC for balanced and unbalanced faults. The speed of the machine increases during faulted period and it decreases during post fault period. The settling time for the speed is low for the system with IPFC for balanced and unbalanced faults. Hence, it is inferred that the IPFC controller provides better damping of load angle and speed deviations. Fuzzy based IPFC coordination system, gave better results there by reducing the disturbances in the power angle and also the post fault settling time also got reduced a lot. The system stabilizes quickly, thus damping the local mode oscillations and reducing the settling time immediately after the occurrence of the fault. The developed control strategy is not only simple, reliable, and easy to implement in real time applications.

REFERENCES

[1] P. Kundur et al., "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions', IEEE Transactions on Power Systems, vol. 19, no. 3, pp. 1387-1401, Aug. 2004.

[2] G. Hingorani and L. Gyugi, 'Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems," IEEE Press, 1999.

[3] Sebba, M., Bekhechi, O., Chaker, A., A Fuzzy Tuned Adaptive PI Controller Based UPFC to Improve Power Oscillations Damping in Multi Machine Power System', International Review on Modelling and Simulations (IREMOS), 8 (3), pp. 307-314, 2015

[4] Saoudi, Y., Abdallah, H, 'Contribution of FACTS Dev ice for Persisting Optimal Grid Performance despite Wind Farm Integration', International Review on Modelling and Simulations (IREMOS), 8 (2), pp. 147-153. 2015

[5] Kanchanaharuthai, A., Boonyaprapasorn, A., 'A Backstepping-Like Approach to Coordinated Excitation and STATCOM Control for Power Systems', International Review of Automatic Control (IREACO), 9 (2), pp. 64-71. 2016

[6] R. H. Adware, P. P. Jagtap and J. B. Helonde, 'Power System Oscillations Damping Using UPFC Damping Controller', 3rd International Conference on Emerging Trends in Engineering and Technology (ICETET), Goa, 2010, pp. 340-344.

[7] Sameh Kamel Mena Kodsi, Claudio A. Canizares "Modeling and simulation of IEEE 14 bus system with FACTS controllers', Technical report 2003; 3.

[8] Mohsen Bakhshi, Mohammad Hosein Holakooie, Abbas Rabiee, 'Fuzzy based damping controller for TCSC using local measurements to enhance transient stability of power systems, International Journal of Electrical Power & Energy Systems, Volume 85, 2017, pp. 12-21

[9] T. Kerdphol, K. Hongesombut, Y. Weerakamaeng, 'Robust Interline Power Flow Controller Design for Damping of Low Frequency Oscillations in Power System with Wind Power Sources, International Review of Automatic Control (IREACO),6(2). 2016.

[10] F. Milano, 'Power System Modeling and Scripting', Power Systems series, Springer, 2010.

[11] Paul M. Anderson, "Analysis of Unsymmetrical Faults: Three Component Method," in Analysis of Faulted Power Systems, 1, Wiley-IEEE Press, 1995, pp.36-70.

APPENDIX -1

IEEE-14 BUS SYSTEM CONSIDERED FOR ANALYSIS

Fig.1 shows IEEE 14 bus system. This system has five T-G units with IEEE type-1 exciters, twenty AC transmission lines, three transformers and 14 buses. This system has total load 259 MW and 81.3 MVAr with 11 loads. The system data considered from [7]. Bus 1 is chosen as slack bus. The generator G1 is considered as reference. To meet the demand of the real power, the three synchronous compensators are considered as generators. The generators are modeled with both P and Q limits as standard PV buses, loads are considered as constant PQ loads. The considered base values for this system are 100 MVA and 100kV [7]

APPENDIX - 2:

MATLAB/SIMULINK FIS EDITORS

Matlab/Simulink FIS rule editor is shown in fig. 19. Fig.20 shows Matlab/Simulink FIS Editor with two Inputs. i..e. error and change of error for Voltage of Mamdani FLC .Fig.21 shows Matlab/Simulink Membership functions of Input–1 .i.e. error of Mamdani FLC and Fig.22 shows Matlab/ Simulink

Membership functions of Input–2.i.e.change in error of Mamdani FLC. Fig.23 shows Matlab/Simulink Membership functions of Output–1 of Mamdani FLC and Fig.24 shows Matlab/Simulink Surface Rule Viewer of Mamdani FLC.

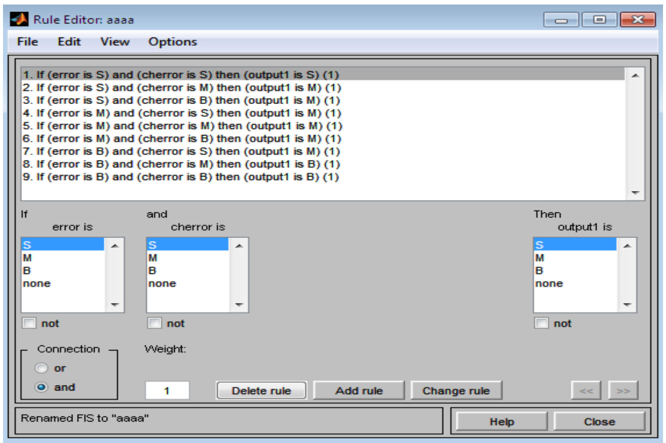

Fig.19 FIS Rule Editor

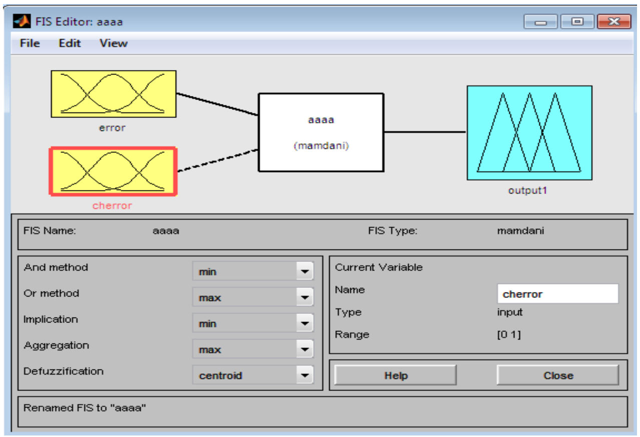

Fig.20 FIS Editor with two Inputs error and change of error for Voltage

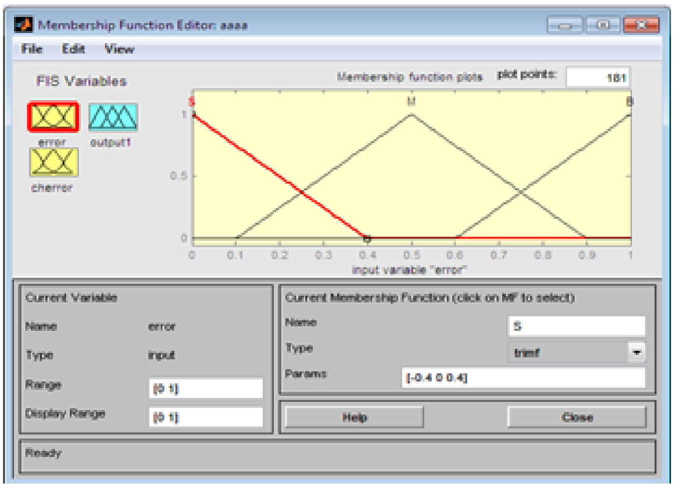

Fig.21 Membership functions of Input – 1

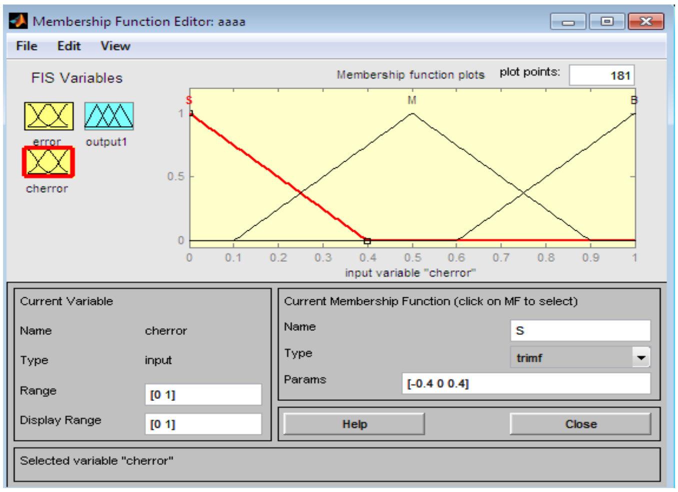

Fig.22 Membership functions of Input – 2

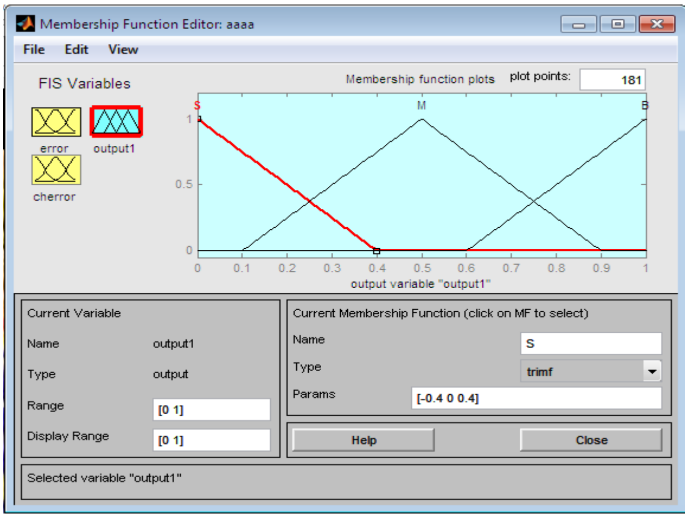

Fig.23 Membership functions of Output – 1

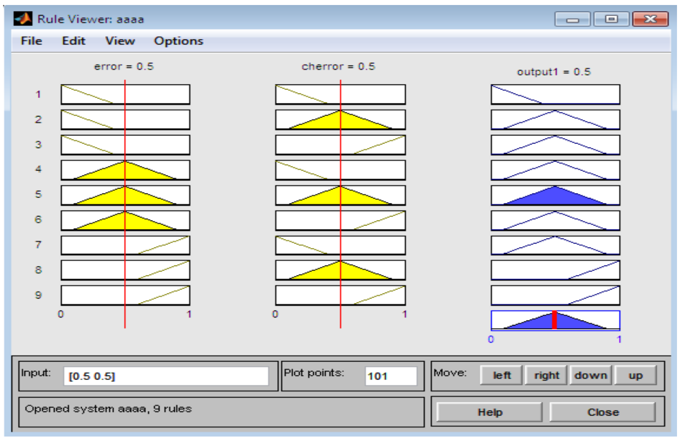

Fig.24 Surface Rule Viewer