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Fuzzy Logic Controller Based Interline Power Flow Controller and its Performance Analysis

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Abstract

There is a growing interest in studying, designing and implementing power converter, with high performance static and other controllers in power system application, which is popularly known as FACTS controllers. The latest converter based FACTS controllers like Interline Power Flow Controller (IPFC) plays an important role in power system control as they have multi functionality and dynamic responsibility. But classical controllers are rigid in nature since the control methods are designed at one nominal operating point and they are not able to respond satisfactorily in dynamic operating point like supply variations and load disturbances. This main challenge is addressed in this work and a Fuzzy Logic Controller (FLC) is designed for that. Simulation is done using MATLAB Simulink.

Keywords: Flexible AC Transmission System (FACTS), Fuzzy logic controller, SSSC, PI controller, Voltage Source converter (VSC)

1 Introduction

Nowadays in the deregulated competitive energy market, the main problem is to increase transmittable power for sustain the system stability. In this context, the concept of Flexible AC Transmission System (FACTS) was introduced and growing with the advancement in power semiconductor industry, for practical power system applications. The latest FACTS controller - Inter line power flow controller (IPFC), was proposed by Gyugi in 1998, which can control the power flow in the multi transmission lines unlike its forerunner controller like STATCOM, SSSC and UPFC are meant for single transmission lines [1]. As the demand of electrical power is increased the power systems are facing a lot of complex power quality problems due to the rapid growth in the density of the inter connections.

Since FACTS devices are always installed in multi machine system, the coordination between Facts devices and other controllers is important task in power flow control. The FACTS devices not only accurate and fast dynamic controllability but also make the system so complex, because FACTS devices with other static controllers always accompanied with non-linearity and uncertainties. Deriving mathematical model of such a test system with FACTS devices is too hard. In case of fuzzy logic controller there is no need of mathematical of the system going to be controlled for a wide range of operating conditions. These increase the suitability of the fuzzy logic controller and make it as a controller for tomorrow. In general Fuzzy logic controller is rule based one and the set of rules are represents the control decision mechanisms required to adjust the effect of certain cases

By controlling the magnitude and phase angle of the injected voltage in series with the transmission lines through a series transformer, the real power and limited reactive power flow control is possible. To achieve this function, minimum three PI controllers are needed and coordination of these controllers is a challenging task. But the conventional control methods like P, PI, and PID cannot perform well under large parameter or load variations with minimum settling time [2]. The IPFC need to control the steady state load flow and improve the transient stability of the system. This can be achieved by controlling and modulating the reference values. But in general, the voltage source inverter (VSI) control law is in nonlinear [book], also the interaction of the two VSI and system through DC link capacitor, make it complex [4]. Since the PID controller is linear and its performance in nonlinear system like HVAC system is not satisfied.

The proposed fuzzy logic controller plays well due to its linguistic nature. The paper is organized as follows. In section 1, the introduction is given in terms of the necessity of IPFC and an efficient controller. Section 2 summarizes the basic principle of IPFC and its mathematical modeling. The fuzzy set theory and its control is explained in section 3. The performance analysis of IPFC controller with Fuzzy logic controller is established in MATLAB/SIMULINK is illustrated in section 4. The conclusions drawn from the simulation studies carried out are described in section 5.

2 Working Principles and Modeling of IPFC

An elementary IPFC scheme consists of two back-to-back DC-to-AC converters; each compensating a transmission line by series voltage injection is shown in Fig1. The reactive power control can be totally independent in each converter whereas the real power flowing into or out of each converter has to be coordinated in such a way that the DC link voltage is kept constant also the overall surplus power from the under-utilized lines can be used by other over loaded lines for real power compensation. The DC to AC converter is basically voltage source converter and can inject a controllable voltage into the transmission line irrespective of the transmission line current. Hence the effective impedance of the transmission line is changed as either inductive or capacitive in nature that is reactive series compensation is obtained.

In general the transmission lines are inductive in nature as its resistance is very small compared to its inductive reactance. Hence $|Z| = X_L$ and $\theta=90^0$. The real power transfer from the sending end is given by

$$P_{s1} = \frac{V_s V_r}{X_L}\sin(\delta)=\frac{V^2}{X_L}\sin(\delta) \qquad (1)$$

Where Vs- is the magnitude of sending end voltage
V_r - is the magnitude of receiving end voltage
δ - is the phase difference between sending and receiving end voltages.

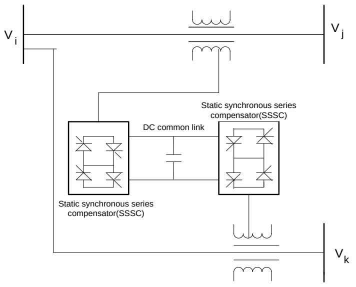


Figure 1. Schematic diagram of IPFC

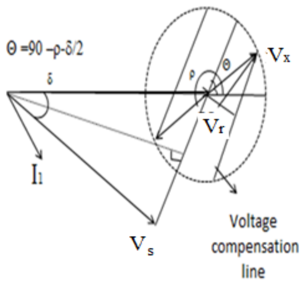


Figure 2.Vector diagram of IPFC

When series connected converter inject voltage in quadrature with the transmission line current it can emulate either inductive or capacitive reactance in the line. Consider eqn (1) and assume the series converter inject a controllable voltage in the transmission line in such a way to emulate capacitance effect. Hence the net effective reactance of the line is reduced and power transmission capacity is increased.

$$P_{s3}=\frac{V^2}{X_{L-X_C}}\sin(\delta) \qquad (2)$$

It is clear that for the same values of V and δ the transmittable real power P_{s3} is higher than the $P_{s2.}$ The increase in transfer power is given by

$$\frac{P_{S3}}{P_{S2}} = \frac{X_L}{X_{L-X_C}} = \frac{X_L}{X_L(1-\frac{X_C}{X_L})} = \frac{1}{1-K} \qquad (3)$$

The factor K is known as degree of compensation. %. The maximum real power and reactive at receiving end is given by

$$P_{r1}=\frac{V^2}{X_L}\sin(\delta) \qquad (4)$$

$$Q_{r1}=\frac{V_R V_S}{X_L}\cos(\delta) - \frac{V_R^2}{X} \qquad (5)$$

By using dq transformation a symmetrical three phase system can be transformed into a synchronously rotating orthogonal system a given bellow;

$$\begin{bmatrix} v_{xds} \\ v_{xqs} \\ 0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{1}{2} & -\frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} v_{xa} \\ v_{xb} \\ v_{xc} \end{bmatrix} \qquad (6)$$

For simplicity assuming balanced conditions with fundamental frequency and neglecting transformer losses. The instantaneous real and reactive power injected by the inverter to the transmission lines are calculated as bellow:

$$|v_x| = \sqrt{v_{xd}^2 + v_{xq}^2} \text{ and } \theta = \tan^{-1}\frac{v_{xq}}{v_{xd}} \qquad (7)$$

Where v_{xd} is the real or direct component v_{xq} is the reactive or quadrature component of the injected voltage respectively. Assume $v_{xq=0}$ and the d-axis is always coincident with the voltage amplitude, then $|v_x| = |v_{xd}|$ and hence the instantaneous real and reactive power as bellow;

$$p_x(t) = \frac{3}{2}v_{xd}\, i_{xd} \qquad (8)$$

$$q_x(t) = \frac{3}{2}v_{xd}\, i_{xq} \qquad (9)$$

Similarly at the receiving end the instantaneous real and reactive power can be calculated.

$$p_r(t) = \frac{3}{2}v_{rd}\, i_{dline} \qquad (10)$$

$$q_r(t) = \frac{3}{2}v_{rd}\, i_{qline} \qquad (11)$$

Where i_{dline} and i_{qline} are the direct and quadrature component of the line current and from this equation the reference values of d-q line currents may calculated as bellow;

$$i_{dline}^{*} = \frac{2}{3}\ \frac{p_r^{*}}{v_{rd}} \quad (12)$$

$$i_{qline}^{*} = \frac{2}{3}\ \frac{q_r^{*}}{v_{rd}} \quad (13)$$

Where p_r^{*} and q_r^{*} the reference values of the instantaneous values of the real and reactive power that is the power required at the receiving end.

3. Fuzzy logic controller

In conventional controller we have control gain or control loss, which are combination of numerical values. In FLC the equivalent term is rules and they are linguistic in nature [11]. Such a rule may be in the form as given in equation 14.

IF E is A_i and CE is B_i then output is C_i (14)

Whereas A_i, B_i and C_i are the labels of linguistic variables of Error (E), Change of Error (CE) and output respectively. E, CE and output represent degree of membership. The fuzzy logic controller has many advantages than the conventional PI controllers. The main reason for fuzzy controller is that it does not need any accurate mathematical model of the system which is going to be control and can work with imprecise inputs. Also it can handle nonlinearity and more robust than conventional nonlinear controllers [12]. Practically it doesn't need fast processors and it needs less data storage in the form of membership functions and rules than conventional look up table for nonlinear controllers. Power converters are inherently nonlinear. The causes of nonlinearity in the power converters include a variable structure within a single switching period, saturating inductances, voltage clamping etc. 5.

The error and changing error of instantaneous real power is processed and the corresponding reference signal for PWM switching technique is obtained and hence it is possible to make the system to track the set reference value. Fuzzy tool box in MATLAB simulink model is used. In this study the min inference rule and centroid defuzzification technique have been used. The input membership function and output membership function are shown in Figure3 and 4. The rules set are shown in Figure5.

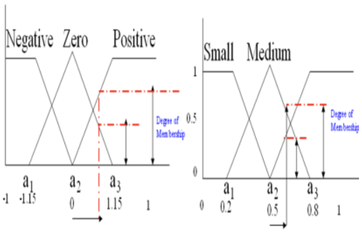


Figure.3. Input Membership Function

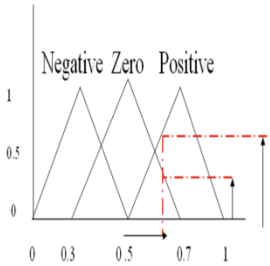


Figure.4. Output Membership Function

	Small	Medium	large
Negative	Positive	Positive	Zero
Zero	Positive	Zero	Negative
Positive	Positive	Zero	Negative

Figure.5. Set of Rules (IPFC)

4. Discussion of Simulation Results and Conclusion

In this paper, circuit model of IPFC with a three phase standard test system is developed and its performance is studied under various working conditions and the corresponding waveforms are obtained. The three phase voltage source converter output voltage and current wave forms are obtained and its THD of the converter output voltage is shown in Figure6 which is around 31.7%. This high value may be reduced to the acceptable range that is around 5% by properly design the filter circuit. From the simulation results, it is observed that power factor of the system with inductive load is get improved by series reactive compensation of the converter. For that the line current and voltage are superimposed and shown in Figure7. Also from the investigations it is found that for a transmission system, the series converters are suitable for enhancement of real power by reactive power compensation.

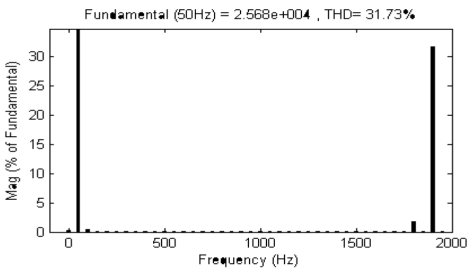


Figure. 6. THD of converter output voltage

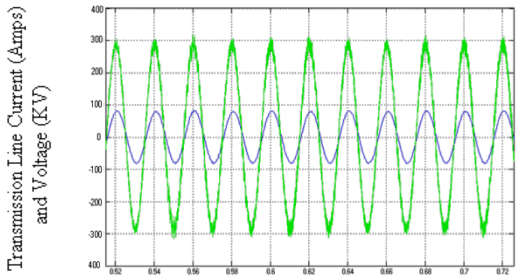


Figure. 7. Transmission line current and voltage

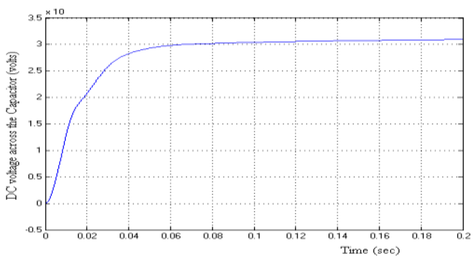


Figure 8. DC link voltage with PI Controller

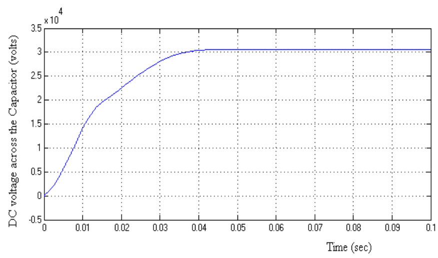
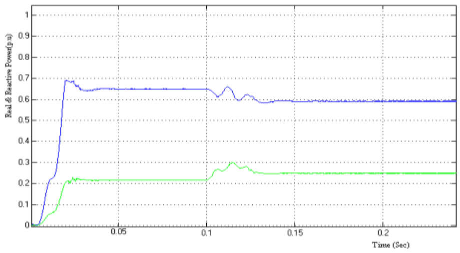
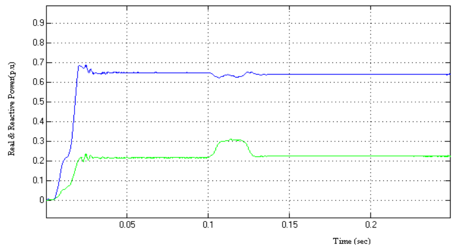


Figure. 9. DC link voltage with Fuzzy Logic controller





P $_{ref}$ = 0.65, Q $_{ref}$ = 0.2; Real power (pu), Reactive Power (pu)
Load $_1$: 280 Mw, 180 MVAR at t = 0 sec; Load $_2$: 5 MW, 100 MVAR at t = 0.1 sec

Figure.10. Real and Reactive Power with controller

Figure.11. Real and Reactive Power with PI Fuzzy controller

From Figure 8 and 9 the DC link voltage waveform, it may be concluded that the fuzzy controller is sluggish in nature but accurate one. With a limited stability margin the transient response of the test system is improved due to the presence of fuzzy logic controller in the series converter than PI controller. For this a step variation at load side is created by using a circuit breaker and the tests results are given in Figure10, which clearly indicate that fuzzy controller provide better performance. Also it can improve the voltage profile and power factor at the point of connection. In future this work may extend to an IPFC with multiline transmission system.

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