A FUZZY CONTROLLER FOR ENHANCEMENT OF POWER SYSTEM STABILITY WITH FACTS DEVICE

[1]K.R.SUDHA, [2]K.Harinadha Reddy

[1]Department of Electrical Engineering, Andhra University,Visakhapatnam India

[2]Department of Electrical Engineering ,LBR College of Engineering,Mylavaram, India

E-mail: [1]arsudhaa@gmail.com, [2]kadapa_hari@yahoo.co.in

ABSTRACT

This paper presents the design of fuzzy controller for Unified Power Flow Controller to improve the transient stability performance of a power system. The fuzzy controller uses a numerical consequent rule base of the Takagi-Sugno type, which can either linear or non linear-producing control gain variation over a very range. A fuzzy logic power system stabilizer has been developed using speed and rotor angle deviation as controller input variables. The tuned stabilizer has been tested by performing non linear simulations using a synchronous machine-infinite bus model.

Index Terms—*FACTS, Unified Power Flow Controller (UPFC), Fuzzy Power System Stabilizer (FPSS).*

1. INTRODUCTION

Power systems are large-scale, nonlinear, nonstationary, multivariable, complex systems distributed over large geographical areas. System-wide disturbances in power systems are a challenging problem for the utility industry. Further, because of new constraints placed by economical and environmental factors, the trend in power system planning and operation is toward maximum utilization of existing electricity infrastructure, with tight operating margins, and increased penetration of renewable energy sources such as wind power. A fuzzy-control approach for flexible AC transmission systems (FACTS) based on load angle and difference are considered for design of rule base in is presented in this paper.

Under dynamic conditions such as faults, line openings, generator tripping and load throw off, etc. protective systems are designed with more emphasis on protecting the equipments than concern to the system security and stability. However, judicious use of dynamic controls at generating systems, excitation/governor systems, HVDC systems, static compensators and more recently FACTS devices will help to maintain the system security/stability. In a day-to-day operation it may be beyond the operator's scope to take any control decision during emergencies and use various control devices.

The first justification is correct, but does not characterize the unique nature of fuzzy systems theory. In fact , almost all theories in engineering characterize the real world in an approximate manner. For example, most real systems are non linear, but we put a great deal of effort in the study of linear system. A good engineering theory should be precise to the extent that it characterizes the key features of the real world and , at the same time , it is trackable for mathematical analysis. In aspect , fuzzy systems theory does not differ from other engineering practices.

2. SYSTEM MODEL

For modelling purpose, the theoretical analysis of the single machine infinite-bus system is considered for transient stability simulations at the first instance. The power system and its detailed circuit model are shown in Fig. 1. The synchronous generator is represented by a 3rd order machine model and the generator excitation system has a simple automatic voltage regulator.

$$\omega = \omega_0 + \frac{d\partial}{dt}$$

$$\frac{d\omega}{dt} = \left(P_m - P_e\right)/M$$

$$\frac{de_q^1}{dt} = \left(E_{fd0} + \Delta E_{fd} - e_q^1 - \left(x_d - x_d^1\right)i_d\right)/\tau_{d0}^1$$

$$\frac{d\Delta E_{fd}}{dt} = K_e\left(V_{ref} - V_t + u\right)/\tau_e$$

$$P_e = e_q^1 i_q + \left(x_q - x_q^1\right)i_d i_q$$

Unified Power Flow Controller is a multifunctional flexible ac transmission (FACTS) device with its potential application in power system for the power flow control, voltage control, transient stability improvement and damping of oscillations. In a power system, the power flow for a two-bus system depends on the magnitude of bus voltages, their phase difference and the impedance of the transmission line. UPFC controls the power flow [1-3] by controlling one of the three basic parameters (voltage, impedance or phase angle) of a transmission line or a combination of these parameters. UPFC consists of two voltage-sourced converters connected back-to-back through a common DC link capacitor. One of the converters is connected in parallel with transmission line through an excitation transformer whereas the other in series with line by a series or boosting transformer. The series and shunt parts of UPFC can control power flow and AC voltage respectively, when a constant voltage is maintained across the DC link capacitor. Like other power electronic devices, UPFC is also a nonlinear, multi-input multi-output and parameter sensitive device and therefore design of a closed loop controller is a challenging job.

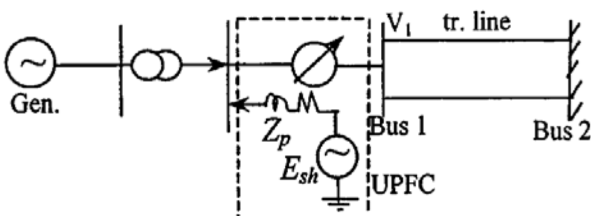

Fig.1 . UPFC Model

Series Converter:

The series converter injects a variable voltage source and the shunt converter a variable current . The simplified representation of the differential[3] and algebraic equations for the generator, excitation systems are given.

Vd = -Vcd + Vb Sinδ – xe(iq+isq)

Vq = -Vcq + Vb Cosδ – xe(id+isd)

$$V_t = \sqrt{V_d^2 + V_q^2} \qquad V_c = \sqrt{V_{cd}^2 + V_{cq}^2}$$

Shunt Converter:

The d and q-axes of the shunt converter are chosen in such a way that d-axis voltage coincide with the terminal voltage of the UPFC bus. Hence the axes representation of the shunt converter is as shown.Thus the direct and quadrature equations of the shunt convers are

eD = rs iD – xsiQ+Vt

eQ = rs iQ – xsiD

When expressed in terms of the d–q axes fixed to rotor of the

synchronous generator the voltage esd, esq are

$$\begin{bmatrix} e_{sd} \\ e_{sq} \end{bmatrix} = \begin{bmatrix} \sin\delta_t & -\cos\delta_t \\ \cos\delta_t & \sin\delta_t \end{bmatrix} \begin{bmatrix} e_D \\ e_Q \end{bmatrix}$$

$$\delta_t = \tan^{-}\left(\frac{v_d}{v_q}\right)$$

$$e_D = \kappa\rho_C V_{dc}\cos\alpha \qquad e_Q = \kappa\rho_C V_{dc}\sin\alpha$$

Shunt converter voltage, $E_s = \sqrt{e_D^2 + e_Q^2}$

The capacitor voltage dynamics[2-4] is obtained as

$$\frac{dV_{dc}}{dt} = \left[-V_t i_D + V_{cd} i_{cd} + V_{cp} i_{cp}\right] / CV_{dc}$$

$$i_{cd} = i_d + i_{sd}$$

$$i_{cq} = i_q + i_{sq}$$

For the transient stability enhancement, the active voltage

component is controlled using either the reactive power deviation(ΔQ) or voltage deviation (ΔV1) at the bus no. 1. The quadrature voltage component of the series converter is controlled by the real power deviation ΔP at the bus-1. Instead of using and directly, a more realistic control is obtained using the in-phase and quadrature voltage components [15] , and with the line current

$$I_c = \sqrt{i_{cd}^2 + i_{dq}^2}$$

$$V_{cd} = V_{cp}\sin\theta - V_{cr}\cos\theta$$

$$V_{cq} = V_{cp}\cos\theta - V_{cr}\sin\theta$$

$$\theta = \tan^{-}\left(\frac{i_{cd}}{i_{cq}}\right)$$

$$\Delta V_{cd} = V_{dcref} - V_{dc}$$

3. DESIGN OF FUZZY CONTROLLER FOR UPFC

Fuzzy systems are to be precisely defined and fuzzy control is a special kind of non linear control that also will be precisely defined. In other words, although the phenomenon that fuzzy systems theory[19] characteristic may be fuzzy, theory itself is precise. In the literature, there are two kinds of justification for fuzzy theory.In the literature, there are two kinds of justification for fuzzy theory. They are.

1. The real world is too complicated for precise descriptions to be obtained; therefore approximation (fuzziness) must be introduced in order to obtain a reasonable, yet trackable model.
2. As we move into information era, human knowledge becomes more important. We need a theory to formulate human knowledge is a systematic manner and put it into engineering systems, together with other information like mathematical model and sensory information.

The action modeled in PSS is base on fuzzy logic applications. The structure of fuzzy logic PSS is show in figure. Control action formation includes four stages.

A)Getting the input values of parameter deviation

B)Fuzzification (transforming into fuzzy form) of the inputs

C)Determination of fuzzy control action

D)De-fuzzification (transforming the linguistic values into quantitative form) of the control action.

The triangular membership function is used for both input and and output. A function of a vector, x, and depends on three scalar parameters a, b, and c, as given by

$$f\left(x,a,b,c\right)=\begin{cases} 0, & x \le a \\ \dfrac{x-1}{b-1}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}$$

Or, more compactly, by

$$f(x,a,b,c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-a}{c-b}\right), 0\right)$$

The parameters a and c locate the “feet” of the triangle and the parameter b locates the peak.

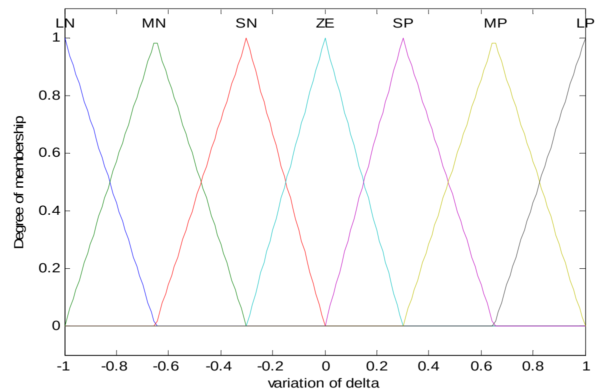

Fig 2 . Fuzzy membership functions

The development of the fuzzy logic approach here is limited to the controller structure and design. The second term of (2) is replaced with a fuzzy logic rule-base using the filtered speed deviation and acceleration of the machine. That is the deviation from synchronous speed and acceleration of the machine are the error, e, and error change. &, signals, respectively. For the controller the control output, u. is the stabilizing signal Vs. Each control rule R, is of the form:

IF e is Ai

AND ė is bi

THEN u is Ci

Where Ai, Bi and Ci are fuzzy sets with triangular membership functions as shown normalized between -1 and 1. These same fuzzy sets are used for each variable of interest: only the constant of proportionality is changed. These constants are Ke, Kė and K for the error. Error change and control output, respectively. The error and error changes are classified according to these fuzzy membership functions modified by an appropriate constant. A specific signal may have non-zero membership in more than one set. Similarly, a specific control signal may represent the contribution of more than one rule. Rule conditions are joined by using the minimum intersection operator so that the resulting membership function for a rule is:

$$\mu_R\left(e,\dot{e}\right)=\min\left(\mu_{Ai},(e),\mu_{Bi},\left(\dot{e}\right)\right)$$

The suggested control output from rule I is the center of the membership function C1 Rules are then combined using the center of gravity method to determine a normalized Control output U.

ẹ / e	LN	MN	SN	ZE	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	ZE
MN	LP	MP	MP	MP	SP	ZE	SN
SN	LP	MP	SP	SP	ZE	SN	MN
ZE	MP	MP	SP	ZE	SN	MN	MN
SP	MP	SP	ZE	SN	SN	MN	LN
MP	SP	ZE	SN	MN	MN	MN	LN
LP	ZE	SN	MN	MN	LN	LN	LN

Fig 3 . Fuzzy Rule Base Table

(LP=large positive: MP= medium positive: SP=small positive; ZE=zero: SN=small negative; MN=medium negative; SN= small negative)

The idea behind the FLC[9] is to fuzify the controller inputs,then infer the proper fuzzy control decision based on defined rules.The FLC output is then produced by defuzzifying this inferred control decision.Fuzzyfication is the process of transferring the crisp input variables to corresponding fuzzy variables. Speed ω and speed deviation Δω are fuzzified according to membership functions shown in figure.2.

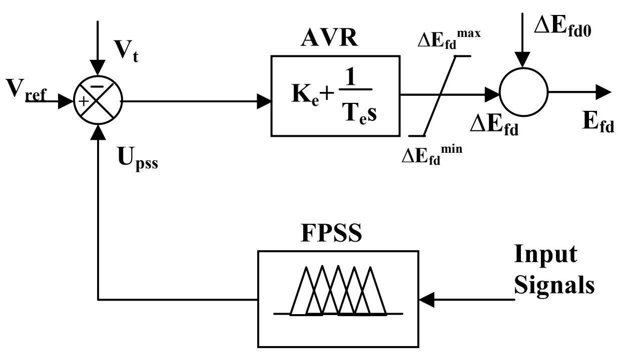

Fig.4. Proposed FPSS control scheme

The output variables of the fuzzy inference system must be converted into numerical output. Using Zadeh's rules for operation and general centroid defuzzifier method is use for the output of the fuzzy controller

4. SIMULATION RESULTS

Simulation results are obtained for the single-machine infinite-bus as shown in figure.9 to 10. The UPFC control scheme consists of controlling voltage components and by using real and reactive power deviations or real power and voltage deviations. The current of the shunt converter is obtained from the power balance equations at every control instant. The following large disturbance cases are considered for evaluating the performance of these controllers. At the pre disturbance condition

The operating level of the generator is then changed to a high power case with p.u., and p.u. and the same fault is created. Fig. 5 shows transient response of the power system for this operating condition with either UPFC or the Fuzzy controller. Variation of rotor angle with respect to time is shown in fig.5.Time response is observed with fuzzy controller.

From the response, it can be ascertained that the electromechanical oscillations are damped very quickly in case of the new controller proving its superiority over the conventional controllers used. Variation of oscillation shown in fig.5 given operaring conditions with and without fuzzy controller.

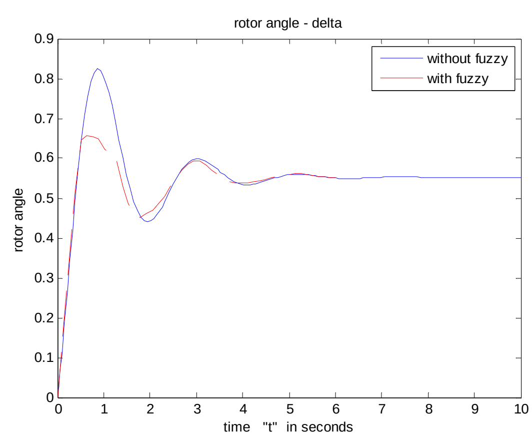

Fig.5. Variation of rotor angle

Variation of speed angle with respect to time is shown in fig.6.Time response is observed with fuzzy controller.

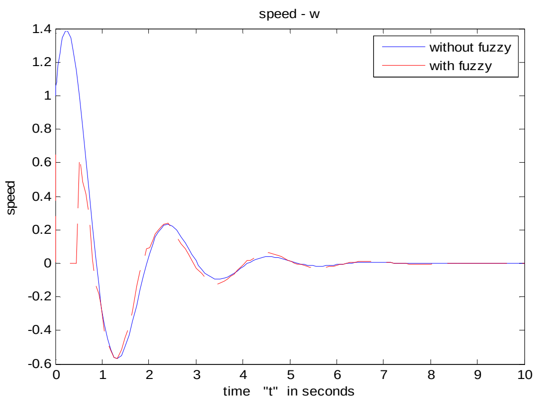

Fig.6. Variation of speed

5. CONCLUSION

In this paper the fuzzy logic stabilizer for Unified Power Flow Controller (UPFC) is performed. This control structure uses both conventional and FPSS. In particular, using as input signal the speed deviation of machine and active power of line (where Unified Power Flow Controller is connected) for fuzzy power system stabilizer.

The simulation results obtained on the single machine with fuzzy logic controller improves power system dynamic performance. By use of this method not only the damping behaviour but also the transient stability is improved significantly.

APPENDIX I

1) Generator Data

xd = 1.9, xq=1.6, xd1=0.17, τdo1=4.314s

H=4s, xe=0.3,

Ke=50 τe = 0.1s

2) UPFC Data

Vdcbase=31.113Kv,

MVAbase = 100, C=5500μF

Limits of UPFC data in p.u. Vcp= ±0.2, Vcr= ±0.2

3) Controllers data

Kpp = 0.3, Kip = 3, Kpq = 0.5, Kiq = 1; Kpv = 0.1, Kiv = 1

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Dr.K.R.Sudha received her B.E. degree in Electrical and Electronics Engineering from GITAM; Andhra University 1991.She did her M.E in Power Systems 1994. She was awarded her Doctorate in Electrical Engineering in 2006 by Andhra University. During 1994-2006, she worked with GITAM Engineering College and presently she is working as Professor in the Department of Electrical Engineering, Andhra University, Visakhapatnam, India

K. Harinadha Reddy was born in India on july 02,1974. He received B.Tech degree in electrical engineering from K.U. in 1997 and M.Tech degree in electrical power systems emphasis high voltage engineering from JNTU in 2005.At present he is working as associate professor at LBR College of engineering. His research interests include HVDC transmission using FACT controllers, AI techniques and their applications to power system stability problems