International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-2 Issue-4, April 2013

Improvement of A C System Stability using Fuzzy Logic based HVDC Controls

B. Nagu, M. Sydulu, P.V. Ramana Rao

Abstract:-In this paper, investigation is carried out for the improvement of power system stability by utilizing auxiliary controls for controlling HVDC power flow. The current controller model and the line dynamics are considered in the stability analysis. Transient stability analysis is done on a multi-machine system, where, a fuzzy logic controller is developed to improve the stability of the power system. The results show the application of the fuzzy controller in AC-DC power systems and case studied at different fault locations.

Keywords- HVDC, Power System Stability, Multi – Machine Stability, Fuzzy Logic controller

I. INTRODUCTION

HVDC power transmission system offers several advantages, one of which is to rapidly control the transmitted power. Therefore, they have a significant impact on the stability of the associated AC power systems. Moreover, HVDC link is effective for frequency control and improves the stability of the system using fast load-flow control. The importance of AC-DC power transmission systems regarding improvement of stability has been a subject to much research. An HVDC transmission link is highly controllable. It is possible to take advantage of this unique characteristic of the HVDC link to augment the transient stability of the ac systems

A proper design of the HVDC controls is essential to ensure satisfactory performance of overall AC/DC system [1]. In recent years, the HVDC systems model used are simpler models; such models are adequate for general purpose stability studies of systems in which the DC link is connected to stronger parts of the AC system. But the preference is to have a flexible modeling capability with a required range of detail [2].

Supplementary controls are often required to exploit the controllability of DC links for enhancing the AC system dynamic performance. There are a variety of such higher level controls used in practice. Their performance objectives vary depending on the characteristics of the associated AC systems. The supplementary controls make use of signals derived from the ac systems to modulate the dc quantities.

The modulating signals in case of a multi machine system may be derived from relative angular deviations of the machines, relative speed deviations of the machines and average difference in accelerations of the machines. The particular choice depends on the system characteristics and the desired results. Apart from conventional controllers, a fuzzy logic controller may also be used to modulate the power order of the dc-control, which in turn modulates the dc power for better performance.

Manuscript published on 30 April 2013.
* Correspondence Author (s)
Nagu. B is with the National Institute of Technology, Warangal, India.
Sydulu. M is with the National Institute of Technology, Warangal, India.
Ramana Rao P.V is with the National Institute of Technology, Warangal,India.

II. AC/DC TRANSIENT STABILITY

In transient stability studies it is a prerequisite to do AC/DC load flow calculations in order to obtain system conditions prior to the disturbance. While the conventional approaches are available for conducting the calculations, the eliminated variable method is used here which treats the real and reactive powers consumed by the converters as voltage dependent loads. The dc equations are solved analytically or numerically and the dc variables are eliminated from the power flow equations. The method is however unified in the sense that the effect of the dc- link is included in the Jacobian. It is, however, not an extended variable method, since no dc variables are added to the solution vector.

A. DC system Model

The equations describing the steady state behavior of a monopolar DC link can be summarized follows.

$$V_{dr} = \frac{3\sqrt{2}}{\pi} a_r V_{tr} \cos\alpha_r - \frac{3}{\pi} X_c I_d \qquad (2.1)$$

$$V_{di} = \frac{3\sqrt{2}}{\pi} a_i V_{ti} \cos\gamma_i - \frac{3}{\pi} X_c I_d \qquad (2.2)$$

$$V_{dr} = V_{di} + r_d I_d \qquad (2.3)$$

$$P_{dr} = V_{dr} I_d \qquad (2.4)$$

$$P_{di} = V_{di} I_d \qquad (2.5)$$

$$S_{dr} = k \frac{3\sqrt{2}}{\pi} a_r V_{tr} I_d \qquad (2.6)$$

$$S_{di} = k \frac{3\sqrt{2}}{\pi} a_i V_{ti} I_d \qquad (2.7)$$

$$Q_{dr} = \sqrt{S_{dr}^2 - P_{dr}^2} \qquad (2.8)$$

$$Q_{di} = \sqrt{S_{di}^2 - P_{di}^2} \qquad (2.9)$$

B. Eliminated Variable Method

The real and reactive powers consumed by the converters can then be written as functions of their ac terminal voltages, V_{tr} and V_{ti}. It is not needed to derive explicit functions for the real and reactive powers, only to find a sequence of computations such that the real and reactive powers and their partial derivatives w.r.t. the AC terminal voltages can be computed.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N \\ J & L \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V/V \end{bmatrix} \quad (2.10)$$

$$N'(tr,tr) = V_{tr}\frac{\partial P_{tr}^{ac}}{\partial V_{tr}} + V_{tr}\frac{\partial P_{dr}(V_{tr}, V_{ti})}{\partial V_{tr}} \quad (2.11)$$

$$N'(tr,ti) = V_{ti}\frac{\partial P_{tr}^{ac}}{\partial V_{ti}} + V_{ti}\frac{\partial P_{dr}(V_{tr}, V_{ti})}{\partial V_{ti}} \quad (2.12)$$

$$N'(ti,tr) = V_{tr}\frac{\partial P_{ti}^{ac}}{\partial V_{tr}} - V_{tr}\frac{\partial P_{di}(V_{tr}, V_{ti})}{\partial V_{tr}} \quad (2.13)$$

$$N'(ti,ti) = V_{ti}\frac{\partial P_{ti}^{ac}}{\partial V_{ti}} - V_{ti}\frac{\partial P_{di}(V_{tr}, V_{ti})}{\partial V_{ti}} \quad (2.14)$$

L' is modified analogously. Thus, in the eliminated variable method, four mismatch equations and up to eight elements of the Jacobian have to be modified, but *no new variables* are added to the solution vector, when a DC-link is included in the power flow.

C. Generator Representation

The synchronous machine is represented by a voltage source, in back of a transient reactance, that is constant in magnitude but changes in angular position neglecting the effect of saliency and assumes constant flux linkages and a small change in speed.

$$\frac{d\delta}{dt} = \omega - 2\pi f \quad (2.15)$$

$$\frac{d^2\delta}{dt^2} = \frac{d\omega}{dt} = \frac{\pi f}{H}(P_m - P_e)$$

D. *Load Representation*

The static admittance Y_{po} used to represent the load at bus P, can be obtained from

$$Y_{po} = \frac{I_{po}}{E_p}$$

where,

$$I_{po} = \frac{P_{lp} - jQ_{lp}}{E_p^*} \quad (2.16)$$

E. HVDC Representation

Each DC system tends to have unique characteristics tailored to meet the specific needs of its application. Therefore, standard models of fixed structures have not been developed for representation of DC systems in stability studies. The current controller employed here (fig.1) is a proportional integral controller and the auxiliary controller is taken to be a constant gain controller.

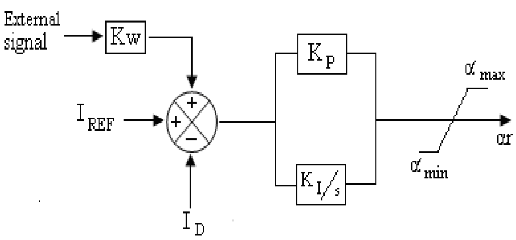

Fig.1 Current controller and auxiliary controller

HVDC line is represented using transfer function model [4] as shown in the figure 2.

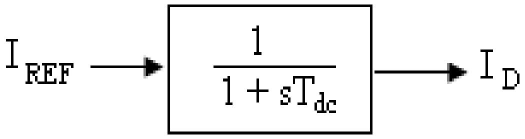

Fig.2 Transfer function model.

F. Steps For Ac/Dc Transient Stability Study

The basic structure of transient stability program is given below [5]:

1) The initial bus voltages are obtained from the AC/DC load flow solution prior to the disturbance. After the AC/DC load flow solution is obtained, the machine currents and voltages behind transient reactance are calculated. The initial speed is equated to 2 π f and the initial mechanical power is equated to the real power output of each machine prior to the disturbance.
2) The network data is modified for the new Representation . Extra nodes are added to represent the generator internal voltages. Admittance matrix is modified to incorporate the load representation.
3) Set time, t=0;
4) If there is any switching operation or change in fault condition, modify network data accordingly and run the AC/DC load flow.
5) Using Runge-Kutta method, solve the machine differential equations to find the changes in the internal voltage angle and machine speeds.
6) Internal voltage angles and machine speeds are updated and are stored for plotting.
7) Advance time, t=t+Δt.
8) Check for time limit, if $t \le t_{max}$ repeat the process from step 6, else plot the graphs of internal voltage angle variations and stop the process.

Basing on the plots, that we get from the above procedure it can be decided whether the system is stable or unstable. In case of multi machine system stability analysis the plot of relative angles is done to evaluate the stability.

III. CONVENTIONAL CONTROLLER

A WSCC-9 system is taken for stability analysis, it is given in the below figure 3.

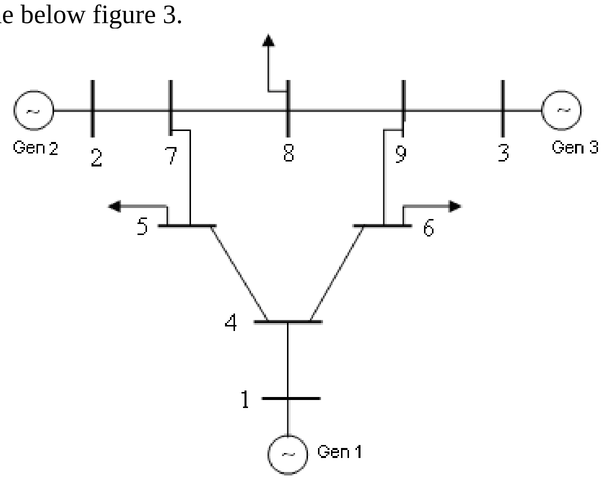

Fig.3: WSCC 9 Bus System

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

A. HVDC between 4-5 and fault between 4-6

A fault is assumed to occur on Line 4-6, at initial time zero. It is assumed that a grounded fault occurred near to Bus 6 and the line from Bus 4 to Bus 6 is removed after 4 cycles. The HVDC line is located between buses 4 –5. Under these conditions, the impact of HVDC on system stability is presented. Initially, a case in which the HVDC line maintains the same control as in the normal state, in which the post-fault HVDC power flow setting remains the same as before, is investigated. It was found that, the system becomes unstable. Then a controller is designed to stabilize the system.

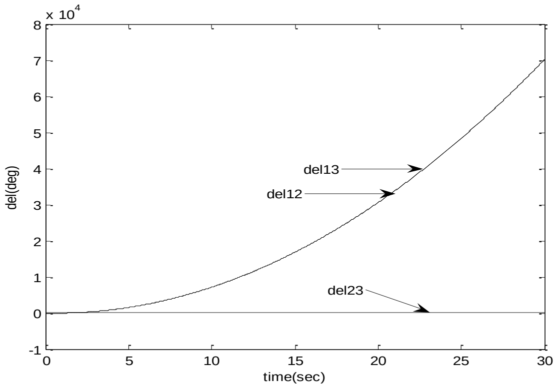

Fig .4 Plot of relative angles without any control.

It is clearly seen that the system is becoming unstable, generator 2 and generator 3 are moving together whereas generator 1 falling out of synchronism, with this group. To stabilize the system, it is necessary to make equal accelerations of all the generators. So an error signal representing average difference in accelerations of the generators is considered. In case of multi machine system, the relative angles are to be maintained within limits to maintain the stability of the system. So, error signals derived from the average difference in the relative angles and average difference in the relative speeds of the generators are considered.

These error signals are shown below.

$$error_1 = \left[\left[\frac{(\omega(2)-\omega(1))+(\omega(3)-\omega(1))}{2}\right]-[\omega(2)-\omega(3)]\right] \quad (3.1)$$

$$error_2 = \left[\left[\frac{(del(2)-del(1))+(del(3)-del(1))}{2}\right]-[del(2)-del(3)]\right] \quad (3.2)$$

$$error_3 = \left[\frac{\frac{P\_mis(3)}{H(3)}+\frac{P\_mis(2)}{H(2)}}{2}\right]-\left[\frac{P\_mis(1)}{H(1)}\right] \quad (3.3)$$

Different combinations of the above three signals are considered, in order to improve the stability. Gains of the signals are varied in order to get better transient and dynamic performance. When $error_3$ signal alone is considered for improving the stability of the system as suggested [2], the plot of relative angles is shown in Figure 5 which reveals that the considered signal is inadequate to improve the stability of the system.

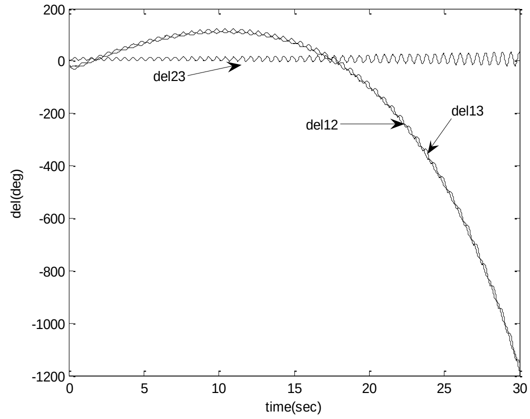

Fig. 5: Plot of relative angles with $error_3$ as the control signal

Considering the combination of $error_1$, $error_2$ and $error_3$ signals to generate the control signals, and it was found that by considering all the three signals the stability of the system is improved. The signal $error_2$ is the equivalent to the integral of the signal $error_1$ and the signal $error_3$ is equivalent to the differential of the signal $error_1$. Hence, the controller is equivalent to a PID controller [7].

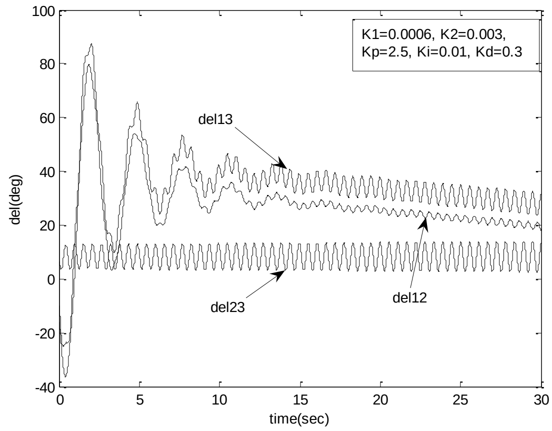

Fig.6: Plot of relative angles with PID controller

Then the control signal can be equivalently represented in the following equation

$$error= K_p\, e(t)+K_i\, Ie(t)+K_d\, De(t) \quad (3.4)$$

$$error = K_p{*}error_1+ K_i{*}error_2 + K_d{*}error_3 \quad (3.5)$$

B. HVDC between 4-5 and fault between 8-9

A fault is assumed to occur on Line 8-9, at initial time zero. It is assumed that a grounded fault occurred near to Bus 8 and the line from Bus 8 to Bus 9 is removed after 4 cycles. The HVDC line is located between buses 4 –5. Under these conditions, the impact of HVDC on system stability is presented. Initially, a case in which the HVDC line maintains the same control as in the normal state, in which the post-fault HVDC power flow setting remains the same as before, is investigated. It was found that, the system becomes unstable. Then a controller is designed to stabilize the system.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

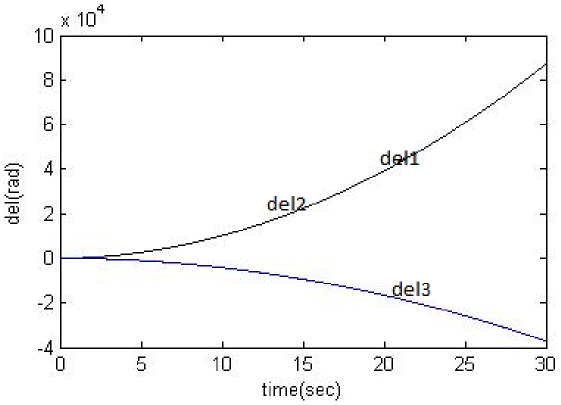

Fig .6 Plot of absolute angles without any control.

It is clearly seen that the system is becoming unstable, generator 1 and generator 2 are moving together whereas generator 3 falling out of synchronism, with this group. To stabilize the system, it is necessary to make equal accelerations of all the generators. So an error signal representing average difference in accelerations of the generators is considered. In case of multi machine system, the relative angles are to be maintained within limits to maintain the stability of the system. So, error signals derived from the average difference in the relative angles and average difference in the relative speeds of the generators are considered.

These error signals are shown below.

$$error_1 = \left[\left(\frac{(\omega(2)-\omega(3))+(\omega(1)-\omega(3))}{2}\right)-(\omega(2)-\omega(1))\right] \quad (3.6)$$

$$error_2 = \left[\left(\frac{(del(2)-del(3))+(del(1)-del(3))}{2}\right)-(del(2)-del(1))\right] \quad (3.7)$$

$$error_3 = \left[\left(\frac{\frac{P\_mis(1)}{H(3)}+\frac{P\_mis(2)}{H(2)}}{2}\right)-\left(\frac{P\_mis(3)}{H(1)}\right)\right] \quad (3.8)$$

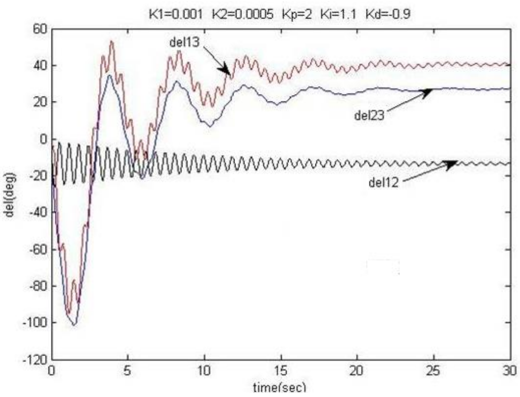

Fig.8: Plot of relative angles with PID controller

IV. FUZZY LOGIC CONTROLLER

As shown in the above technique [7], the gain constants are taken using trial and error method, so instead of using these gains a Fuzzy logic controller can be used. A Fuzzy Controller used here, is equivalent to the non-linear PI controller. In the Fuzzy logic controller the error and rate of change of the error signal are taken as input variables for the controller using fuzzy membership functions. These variables evaluate the control rules using the compositional rules of inference. In this fuzzy logic controller, $error_1$ and $error_3$ have been adopted, as input and output variables respectively, for the purpose of enhancing the stability of the multi-machine power systems, utilizing HVDC power modulation. In this scheme, the error signals $error_1$ and $error_3$ control signal as specified in the last section, are fuzzified at very sampling interval, accordance to a set of linguistic control rules and in conjunction with fuzzy logic at output fuzzy value is de-fuzzified using min-max method. This feature is desirable because as the operating conditions of a system begin to change, as deterioration in performance will result if a fixed gain controller is applied. Consequently, the proposed control scheme has the advantages over conventional PID controller.

A. Fuzzy Controller Design Methodology

In general, FLC design consists of the following steps:

1. Identification of input and output variables.
2. Construction of control rules.
3. Establishing the approach for describing system state in terms of fuzzy sets, i.e., establishing fuzzification method and fuzzy membership functions.
4. Selection of the compositional rule of inference.
5. Defuzzification method, i.e., transformation of the fuzzy control statement into specific control actions.

B. Design Of The Fuzzy Controller For Power System Stability

To determine the resultant error output from the measured system variables $error_3$ and $error_1$, a fuzzy relation matrix R, which gives the relationship between the fuzzy set characterizing inputs and the fuzzy set characterizer output, is computed as follows.

C. Fuzzy Relation

Let A and B be two fuzzy sets with membership functions $\mu_A(x)$ and $\mu_B(x)$, respectively. A fuzzy relation R from A to B can be visualized as a fuzzy graph and can be characterized by the membership function $\mu_R(x,y)$ which satisfies the composition rule as follows:

$$\mu_B(y)= \max_x (\min(\mu_R(x , y)\ \mu_A(x))) \quad (4.1)$$

In many cases it is convenient to express the membership function of a fuzzy subset of the real line in terms of a standard function whose parameters may be adjusted to fit a specified membership function in a suitable fashion.

Step 1: Use membership functions to representstabilizer inputs $error_3$ and $error_1$ in fuzzy set notation.

Step 2: Use the composition rule in eqn. 4.1 to determine the membership function of the resultant error output.

Step 3: Determine a proper resultant error output from the membership function of the output signal.Here by above example we can understand the above rule.

V. FLC FOR HVDC BETWEEN BUS 4 AND 5 AND FAULT BETWEEN BUS 4 AND 6 NEAR TO BUS 6

A. Establish The Fuzzy Relation Matrix (For 7 Variables)

A fuzzy relation matrix must be set up and stored in computer memory. A set of decision rules relating inputs to the output are first compiled.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

These decision rules are expressed using linguistic variables such as large positive (LP), medium positive (MP), small positive (SP), very small (VS), small negative (SN), medium negative (MN), and large negative (LN).

For example, a typical rule reads as follows:

Rule1:If $error_1$ is LP and $error_3$ is LN, then $error_{res}$ should be VS. (5.1)

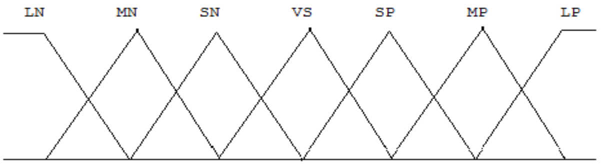

Fig. 9: Membership function for 7 variables

Through the combination of the two input signals $error_3$ and $error_1$, there will be 49 decision rules in all. The most convenient way to present these decision rules is to use a decision table as shown in Table1. It is observed from Table1 that each entry represents a particular rule.

B. Specify The Membership Functions For Fuzzy Inputs

To express the error inputs in linguistic variables LP, MP, SP, VS, SN, MN, and LN, the measured stabilizer inputs $error_3$ and $error_1$ are first normalized based on the previous experience.Here, from the conventional PID method it is found that the $error_3$ is varying from -25 to 25 and $error_1$ is varying from -4 to 4.

TABLE I
DECISION TABLE FOR 7 MEMBERSHIP VARIABLES

$error_1$	$error_3$						
	LN	MN	SN	VS	SP	MP	LP
LP	VS	SP	MP	LP	LP	LP	LP
MP	SN	VS	SP	MP	MP	LP	LP
SP	MN	SN	VS	SP	SP	MP	LP
VS	MN	MN	SN	VS	SP	MP	MP
SN	LN	MN	SN	SN	VS	SP	MP
MN	LN	LN	MN	MN	SN	VS	SP
LN	LN	LN	LN	LN	MN	SN	VS

So for normalizing the values, $error_3$ is divided by 25 and $error_1$ is divided by 4, i.e.,

$$error_1 = error_1/4 \qquad (5.2)$$
$$error_3 = error_3/25 \qquad (5.3)$$

C. Determine The Membership Function For Output Error

As, there are 7 linguistic variables for the given input, so, it is obvious that there are 49 rules which can be used to generate the desired output. Consider Rule 1 in eqn. 5.1. The 'Then' part of the rule has been represented in fuzzy set notations using membership functions but the 'If' part is still to be represented using the fuzzy set notation. An observation of Rule 1 reveals that the condition part consists of two predicates '$error_1$ is LP' and '$error_3$ is LN' combined together by an 'AND' operator. So, the membership value of the condition part is,

$\mu(x) = \mu$ ('$error_1$ is LP' and '$error_3$ is LN')

$= min\ (\mu($'$error_1$ is LP'$)\ \ \mu($'$error_3$ is LN'$))$ (5.4)

Let,

μ ('$error_1$ is LP') = 1, and

μ ('$error_3$ is LN') =0.8,

thus the membership value of the condition part is

$\mu(x_1) = min\ (1, 0.8)$

$= 0.8$ (5.5)

Given the membership values of the 'If' part and the fuzzy relation matrix, the membership values for the output characterized by the seven linguistic variables LN, MN, SN, VS, SP, MP, LP can be obtained using eqn. 4.1.

For example, the membership value for the linguistic variable LN can be computed as follows:

$\mu_{errorres}(LN) = min\ (\mu_R(x_1, LN)\ \mu(x_1))$

$= min\ (0, 0.8)$

$= 0$ (5.6)

Note that this is the membership value of the output 'LN' if only Rule 1 exists. To take the 49 rules in Table into account, the membership values of the 'If' part of all the other 48 rules $\mu(x_i)$, i=2,3,4…….49, must be determined in the same way as we did in eqn. 4.6 for $\mu(x_1)$. Thus, the final value for resultant error output ' LN' can be evaluated using eqn. 4.1.

The membership values for all the other six variables: $\mu_{errorres}(LN)$, $\mu_{errorres}(MN)$, $\mu_{errorres}(SN)$, $\mu_{errorres}(VS)$, $\mu_{errorres}(SP)$, $\mu_{errorres}(MP)$, $\mu_{errorres}(LP)$ can be computed in exactly the same way. For example.,

$$\mu_{errorres}(LN) = 0.5$$
$$\mu_{errorres}(MN) = 0.7$$
$$\mu_{errorres}(SN) = 0.8$$
$$\mu_{errorres}(VS) = 0.9 \qquad (5.7)$$
$$\mu_{errorres}(SP) = 1.0$$
$$\mu_{errorres}(MP) = 0.9$$
$$\mu_{errorres}(LP) = 0.7$$

D. Determine the Resultant Error Output

Once the membership values for output have been computed, a suitable algorithm must be employed to determine the resultant error output signal. The algorithm adopted in this work is the 'maximum algorithm' in which the signal with largest membership value is chosen as the resultant error output signal. Using eqn. (5.7), the resultant error output for our example is SP. The resultant error output expressed in linguistic terms must be converted back to numerical values before it can be fed into the controller. The conversion table as shown in the Table II has been compiled base on the stabilizer signals obtained in our previous work on the controller design. A different set of numerical values can be selected and different dynamic responses will be obtained. The difference will however be insignificant since the error signal must be within the narrow range from -7.5 to 7. The table is stored in computer memory as a look-up table. It is observed from Table II that the numerical value of the stabilizing signal for our example is 1.8

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

TABLE II

CONVERSION TABLE FROM 7 LINGUISTIC VARIABLES TO NUMERICAL VALUES

$error_{res}$	LN	MN	SN	VS	SP	MP	LP
	-7.5	-5	-2	0.5	1.8	4.5	7

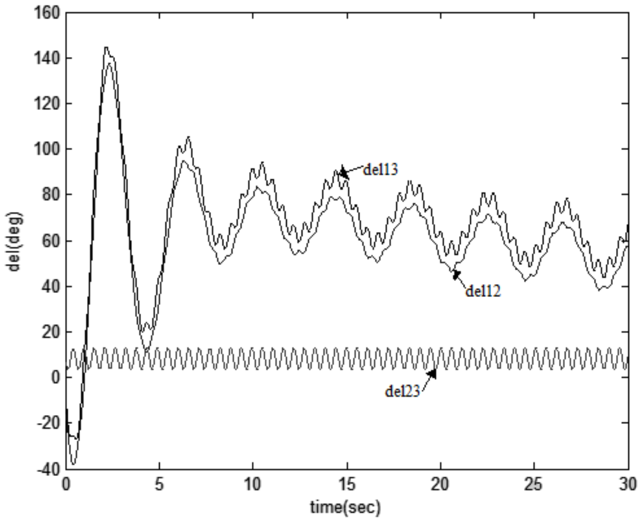

Fig. 10: Plot of relative angles with Fuzzy controller (7 membership variables)

E. Using 5 Fuzzy Variables

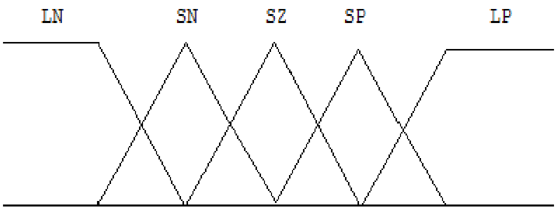

Fig. 11: Membership function for 5 variables

TABLE III Decision Table For 5 Membership Variables

$error_1$	$error_3$				
	LN	SN	SZ	SP	LP
LN	LN	LN	LN	SN	SZ
SN	LN	LN	SN	SZ	SP
SZ	LN	SN	SZ	SP	LP
SP	SN	SZ	SP	LP	LP
LP	SZ	SP	LP	LP	LP

TABLE IV

Conversion table from 5 linguistic variables to numerical values

$error_{res}$	LN	VS	SZ	MP	LP
	-7.5	-3	0.5	2.25	7

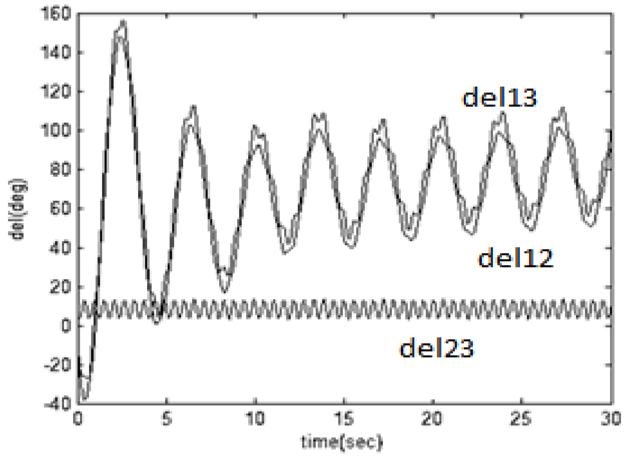

Fig.12: Plot of relative angles with Fuzzy logic controller (5 membership variables)

F. Using 9 Fuzzy Variables

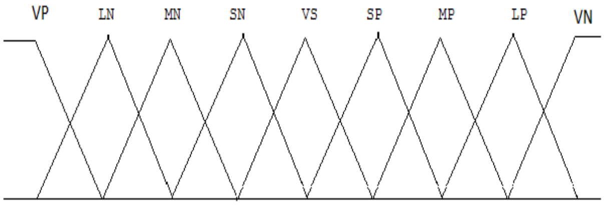

Fig.13: Membership function for 9 variables

TABLE V Decision Table For 9 Membership Variables

$erro_1$	$error_3$								
	VN	LN	MN	SN	VS	SP	MP	LP	VP
VP	VS	SP	MP	LP	LP	LP	LP	LP	LP
LP	SN	VS	SP	MP	LP	LP	LP	LP	LP
MP	MN	SN	VS	SP	MP	MP	LP	LP	LP
SP	MN	MN	SN	VS	SP	SP	MP	LP	MP
VS	LN	MN	MN	SN	VS	SP	MP	MP	MP
SN	LN	LN	MN	SN	SN	VS	SP	MP	SP
MN	LN	LN	LN	MN	MN	SN	VS	SP	VS
LN	LN	LN	LN	LN	LN	MN	SN	VS	VS
VN	LN	LN	LN	LN	LN	LN	MN	SN	VS

TABLE VI

Conversion table from 9 linguistic variables to numerical values

$error_{res}$	VN	LN	MN	SN	VS	SP	MP	LP	VP
	-7.5	-5.7	-3.8	-2	0.26	1.55	3.36	5.17	7

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

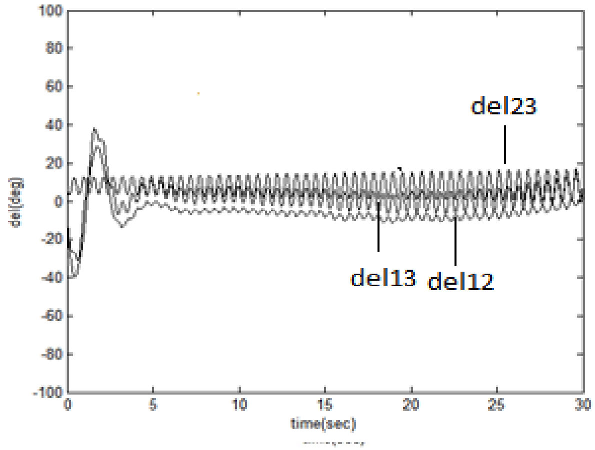

Fig.14: Plot of relative angles with Fuzzy logic controller (9 membership variables)

From above discussion we can conclude that if number of fuzzy variables increased the transient behavior of system will improve.

VI. FUZZY LOGIC CONTROLLER FOR HVDC BETWEEN BUS 4 AND 5 AND FAULT BETWEEN BUS 4 AND 6 NEAR TO BUS 6

A. Using 9 Fuzzy Variable

Here from conventional PID method it is found that the $error_3$ is varying from -38 to 38 and $error_1$ is varying from -8 to 8.So for normalizing the values error3 isdivided by 38 and error1 is divided by 8.

$$error_1 = error_1/8$$

$$error_3 = error_3/38$$

TABLE VII Conversion table from 9 linguistic variables to numerical values

$error_{res}$	VN	LN	MN	SN	VS	SP	MP	LP	VP
	-12	-8.5	-6.7	2.4	-0.1	3.6	5.6	8	10

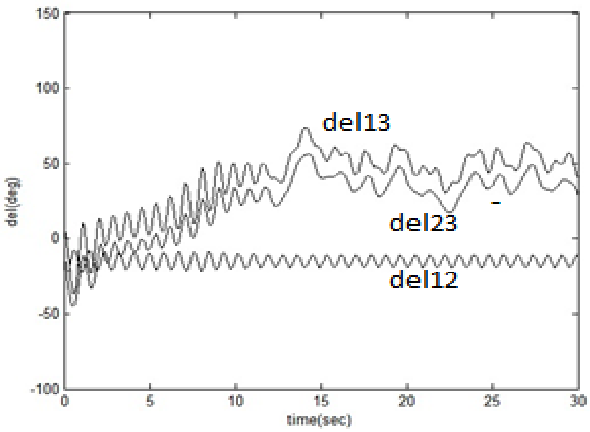

Fig.15: Plot of relative angles with Fuzzy logic controller (9 membership variables)

VII. CONCLUSIONS

The paper presents the design of a very simple form of fuzzy controller which is equivalent to a nonlinear PI controller for a DC transmission link in AC-DC power systems. The fuzzy controller introduces nonlinearities by using a nonlinear de-fuzzification algorithm and is thus suitable for a controlling a highly nonlinear plant like the AC-DC system.

Unlike, in the conventional controller, Gain constants are not used in fuzzy controller. Also there is a improvement in the stability of the Power system, using Fuzzy controller. Neuro-Fuzzy Technique can be used to tune the rules which will improve the system performance.

VIII. APPENDIX

Nine bus system data.

A. Generator Data

Generator	X_d' (pu)	H (MJ/MVA)
1	0.0608	23.64
2	0.1198	6.4
3	0.1813	3.01

B. Transformer Data

Transformer	X(pu)
1	0.0576
2	0.0625
3	0.0586

C. Transmission Network Data

Bus		R(pu)	X(pu)	y'/2`(pu)
p	q			
1	4	0.0	0.0576	0.0
2	7	0.0	0.0625	0.0
3	9	0.0 (2.15)	0.0586	0.0
4	6	0.017	0.092	0.079
5	7	0.032	0.161	0.153
6	9	0.039	0.17	0.179
7	8	0.0085	0.072	0.0745
8	9	0.0119	0.1008	0.1045

D. Bus Data

Bus no.	P_{gen}	P_D	Q_d	V_{sp}
1	0.0	0.0	0.0	1.04
2	1.63	0.0	0.0	1.025
3	0.85	0.0	0.0	1.025
4	0.0	0.0	0.0	--
5	0.0	1.25	0.5	--
6	0.0	0.9	0.5	--
7	0.0	0.0	0.0	--
8	0.0	1.0	0.35	--
9	0.0	0.0	0.0	--

E. DC line Data

r_d= 0.017(pu), x_c = 0.6(pu), L_d = 0.05(pu)

alphamin = 5^0, alphamax = 80^0

taprmin = 0.96, taprmax = 1.06

tapimin = 0.99, tapimax = 1.09

F. Initial Conditions

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

alpha = 0.2094	gama = 0.3142	
I_d = 0.3691	P_{di} = 0.406	V_{di} = 1.1
$P_{m(1)}$ = 0.756646	$P_{m(2)}$ = 1.63	$P_{m(3)}$ = 0.85
$\delta_{M[1]} = 2.388448^0$	$\delta_{M[2]} = 18.603189^0$	$\delta_{M[3]} = 12.314856^0$

IX. ACKNOWLEDGMENT

The authors would like to express their most sincere gratitude to those people, listed in the References, who in the past years have greatly contributed to the advancement of the technique applied in this paper.

REFERENCE

[1] P. Kundur, “Power System Stability and Control”, McGraw-Hill, Inc., 1994

[2] Garng M. Huang, Vikram Krishnaswamy, “HVDC Controls for Power System Stability”, IEEE Power Engineering Society, pp 597- 602, 2002.

[3] T. Smed, G. Anderson, “A New Approach to AC/DC Power Flow”, IEEE Trans. on Power Systems., Vol. 6, No. 3, pp 1238- 1244, Aug. 1991.

[4] K. R. Padiyar, “HVDC Power Transmission Systems”, New Age International (P) Ltd., 2004.

[5] Stagg and El- Abiad, “Computer Methods in Power System Analysis”, International Student Edition, McGraw- Hill, Book Company, 1968.

[6] P.M.Anderson and A.A.Fouad, Power System Control and Stability, 1st ed.,Iowa State University Press, 1977.

[7] V.S. Reddy, P.V.R Rao, “ Supplementary HVDC Controls for Multi-machine System Stability Improvement? IEEE (India) June 2008 vol.89

[8] Y.-Y. Hsu, C.-H. Cheng, “Design of fuzzy power system stabilizers for multi-machine power systems”, IEE Proceedings, Vol. 137, Pt. C, No. 3, May 1990

Nagu B was born in India, on Auguest 06, 1980. He obtained his B.Tech Degree in Electrical and Electronics Engineering from kakatiya University, Kothagudem, Andhra Pradesh, India in 2002 and M.Tech degree in Power Systems from National Institute of Technology, Warangal, Andhra Pradesh, India in 2005. Currently he is an Assistant Professor in the department of Electrical Engineering and pursuing Ph.D in the same department at National Institute of Technology, Warangal, Andhra Pradesh, India. His present areas of interest are Power System stability, HVDC and Artificial Intelligence applications in Power Systems.

Prof. Maheswarapu Sydulu obtained his B.Tech (Electrical Engineering, 1978), M.Tech (Power Systems, 1980), Ph.D (Electrical Engineering – Power Systems, 1993), all degrees from Regional Engineering College, Warangal, Andhra Pradesh, India. His areas of interest include Real Time power system operation and control, ANN, fuzzy logic and Genetic Algorithm applications in Power Systems, Distribution system studies, Economic operation, Reactive power planning and management. Presently he is Professor of Electrical Engineering, at National Institute of Technology, Warangal (formerly RECW).