Fuzzy Logic Controller for Modern Power Systems

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Abstract - *The main objective of this work is to design a fuzzy logic controller for the modern power system. In this paper we deal with 2 different simulations that could be designed to study the fuzzy logic controller design a). to simulate the control of automatic voltage regulator for a single synchronous generator during different load conditions and b).to develop a linearized Heffron-Philips model of a Single Machine Infinite Bus (SMIB) power system with a Fuzzy Logic Power System Stabilizer (FPSS) for different membership functions[2]. In AVR modelling the work has been achieved on a main generator, which is mechanically coupled with a small synchronous generator as an exciting system for the main generator. The result for the fuzzy logic controller has been compared with a MATLAB demo system using NO controller with the same load conditions. The proposed fuzzy controller enhanced the performance of the generator in terms of response and performance. Where as in FPSS, speed deviation and acceleration deviation are taken as inputs. Further this paper investigates the design and implementation of a Reduced Rule Fuzzy Logic Power System Stabilizer (RLFPSS). A Reduced Rule Fuzzy Logic Power System Stabilizer for different membership functions is proposed. The effectiveness of the RLFPSS for different membership functions is illustrated with simulation carried out in MATLAB*

Key Words: **AVR, Fuzzy logic controller (FLC), Fuzzy sets and membership functions, Heffron-Philips Single Machine Infinite Bus model.**

1. INTRODUCTION

The two types of power system stability are steady state and transient stability. Here we will be dealing with transient stability, i.e., ability of the power system to return to its normal conditions after a large disturbance[2][7]. The large disturbance occurs in the system due to the sudden removal of the load, line switching operations; fault occurs in the system, sudden outage of a line, etc.

The transient stability of a system was conventionally suppressed using AVR (Automatic voltage regulator), but the electric system has been seen with oscillations of frequencies ranging from 0.1 to 2 Hz. These regulators have high gain leading to destabilizing effect on power system.

Thus, we use Fuzzy logic controller. Fuzzy Logic has the features of simple concept, easy implementation, and computational efficiency. This provides an easy method to draw the definite conclusion from hazy, uncertain or inexact information.

Synchronous Generators play a very important role in the stability of power systems. Electric power system stability requirement is increasing along with the growth of load. Thus, a robust reliable AVR system is needed to enhance the voltage stability. Here, the AVR system used is Fuzzy logic control system.

1.1 Fuzzy Logic Control System

Fuzzy control is an appealing alternative to conventional control methods when systems follow some general operating characteristics and a detailed process understanding is unknown or traditional system models become overly complex [7-8]. Fuzzy logic control is a range-to-point or range-to-range control. The output of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions.[2] A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller (FLC) is based on its memberships of the different membership functions, which can be considered as a range of inputs.[10].A fuzzy controller comprises of three stages: fuzzification, fuzzy rule and defuzzification as shown in Fig 1.

1.2 Fuzzification

A fuzzy set is an expansion of standard sets and

can be comprehended as a membership degree of a set [6]. For example, a classic set can be written as { 1, 2, 3, 4 } whereas a ,Fuzzy Set can be written as { (1,0.4), (2,0.7), (3,0.1), (4,0.2)} wherein every pair (X,Y), X represents the value of the element whereas Y represents the degree of membership of the element in the set.

Fuzzification is the process of converting a crisp input value to a fuzzy value that is performed by the use of the information in the knowledge base [4]. This is done by the help of fuzzifiers (membership functions).

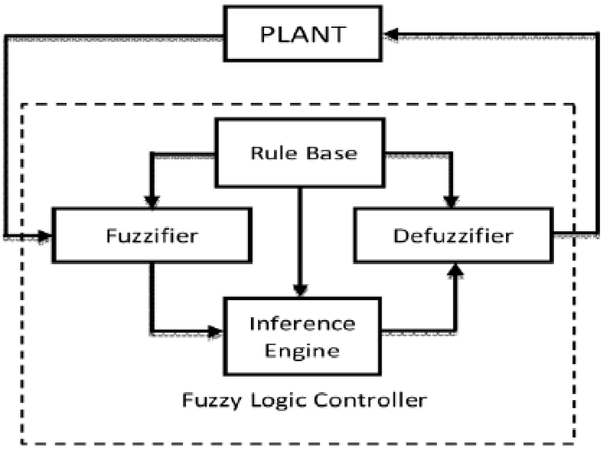

Fig-1: Fuzzy Logic Control System

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. In this system there are two inputs, speed and acceleration which is converting into fuzzy value. Each of the input and output fuzzy variables is assigned seven linguistic labels. Seven membership functions are generating better result proved by some testing are defined as NH (Negative High), NM (Negative Medium), NS (Negative-Small), ZR (Zero), PS (Positive-Small), PM (Positive-Medium), PH (Positive High) membership functions are used to convert the fuzzy values between 0 and 1 for both input and output values.

The member function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency. A classical set might be expressed as $A = \{x \mid x > 6\}$
A fuzzy set is an extension of a classical set. If X is the sample space and its elements are denoted by x, then a fuzzy set A in X is defined as a set of ordered pairs. $A = \{x, \mu A(x) \mid x \in X\}$
μA(x) is called the membership function (or MF) of x in A. The membership function maps each element of X to a membership value between 0 and 1.

1.3 Fuzzy Rule based system

Fuzzy Rule based system is a rule-based system where fuzzy sets and fuzzy logics which constitute an extension of classical rule-based systems, considering IF–THEN rules whose antecedents and consequents are composed of fuzzy logic (FL) statements, instead of classical logic ones are used as tools for representing different forms of knowledge about the problem at hand, as well as for modelling the interactions and relationships existing between its variables.

Conventional approaches to knowledge representation are based on bivalent logic, which has associated a serious shortcoming: the inability to reason in situations of uncertainty and imprecision. As a consequence, conventional approaches do not provide an adequate framework for this mode of reasoning familiar to humans, and most common-sense reasoning falls into this category.

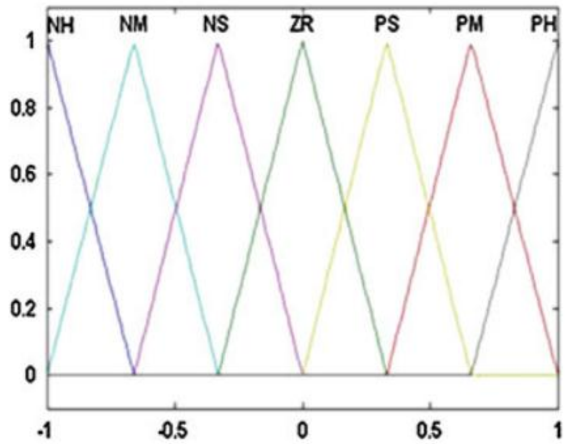

Fig-2: Membership functions for Fuzzy controller for input and output variables

Table-1: Design Parameters of FLC [1]

Speed deviation↓	ACCELERATION						
	NB	NM	NS	ZR	PS	PM	PB
NB	NB	NB	NB	NB	NM	NM	NS
NM	NB	NM	NM	NM	NS	NS	ZR
NS	NB	NM	NM	NM	NS	NS	ZR
ZR	NM	NS	NS	ZR	PS	PS	PM
PS	NS	ZR	ZR	PS	PS	PM	PM
PM	ZR	PS	PS	PM	PM	PM	PB
PB	PS	PM	PM	PB	PB	PB	PB

1.4 Defuzzification

Defuzzification is the process of converting the fuzzy output into crisp values to be applied to the system, by the degree of membership values[3]. There are several heuristic defuzzification methods. For instance, some methods produce an integral output considering all the elements of the resulting fuzzy set with the corresponding weights. One of the widely used methods is the center-of-area method that takes the center of gravity of the fuzzy set[6].

2. Reduced Rule Fuzzy Based Power System Stabilizer

In previous section for a two input fuzzy controller 7 membership functions for each input were used. Due to the need for a large rule-base, the design of such a PSS is a tedious task. In the proposed fuzzy PSS, only two fuzzy membership functions are used for the two inputs angular speed and acceleration and three membership functions for the output parameter are shown in Fig 3. Depending upon whether the output is increasing or decreasing, 4 rules were derived for the fuzzy logic controller. These four rules sufficient to cover all possible situations.

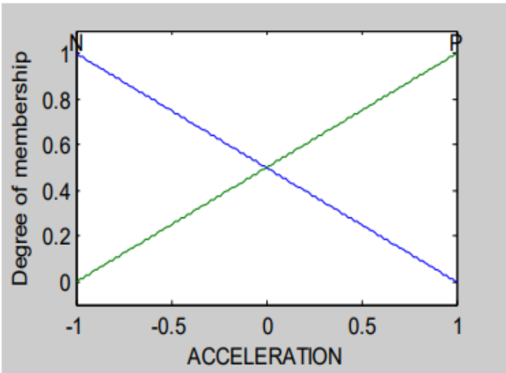

Fig-3: New Reduced MFs for inputs angular speed and acceleration. N: Negative, P: Positive

Table-2: Reduced rule base of a fuzzy Power System Stabilizer

OUTPUT		ACCELERATION	
		N	P
SPEED	N	N	Z
	P	Z	P

3. AUTOMATIC VOLTAGE REGULATOR FOR SYNCHRONOUS GENERATOR

The AVR is a device to control the reactive power and hold the terminal voltage of the synchronous generator at safer limits. The AVR is a circuitry that holds the terminal voltage of synchronous generators at safer limits[5]. AVR is used wherever a voltage level is not stable and fluctuations is more on the system loads. The AVR system provides the control action to the exciter voltage for maintaining the generator terminal.

The simple function of the AVR is to compute the difference between a desired voltage and the output voltage of the generator. The result of this difference is the error signal that is used in the control inside the AVR itself, the output of the AVR will be high or low depending to the degree of the error signal, as the error is high the AVR output voltage will be high and vice versa. The excitation coils of the generator will receive this voltage from the AVR and change the terminal voltage (Vt) of the main generator according to Equation due to the change of the flux density for every pole (ϕ) in Tesla.

$$Vt = K \times Ns \times \phi$$

Where K is a constant, compute the number of the number of winding in the armature of the generator and is the synchronous speed of the rotor in revolution per minutes (rpm).

Steady state Response:

$$V_{tss}(s) = \lim_{s\to 0} s * V(s)_t = \frac{K_A}{1+k_A} = \frac{10}{1+10} = 0.909$$

$$V_{ess} = 1.0 - 0.909 = 0.091$$

Steady State Actual response:

$$V_{Actual} = V_{p.u} * V_{base}$$

$$V_{Actual} = 1.0 * 11kV = 11kV$$

4. SIMULATION RESULTS

4.1Simulation Results for SMIB

The system that is used in SMIB, Single machine infinite bus, meaning that there in neither voltage or frequency change in the system. The inputs are speed and acceleration. The outputs of SMIB systems with conventional PSS (a) Speed Deviation (Dx) (b) Power angle Deviation (Dd) of generator. With Fuzzy power system stability as a triangular membership, it can be seen that, system has smaller overshoot (Mp-maximum peak), smaller settling time (ts-time taken to reach steady state) and error steady state is 0 and 2 for Speed Deviation and Power angle respectively[4]. So, performance improved by using Fuzzy PSS. This can be further improved by fine tuning of controller parameters. Further studies show that, Fuzzy Power system stability is better when trapezoidal membership is used, where the system has much smaller overshoot (Mp) and much smaller settling time (ts) [4].

We use the Fuzzy Rule base system, but the number of iterations would take a lot of time, thus using the reduced rule base system would be sufficient.

Parameter Values

M = 7.0 s.,

D = 0,

Xd = 1.8,

Xq = 1.76,

X0 d = 0.3,

T0 do = 7.2940,

xb = 314

Exciter: (IEEE Type ST1): KA = 200,

TA = 0.02 s.

T1 = 0.154,

T2 = 0.033,

KS = 9.5,

TW = 1.4

K1 = 0.7636,

K2 = 0.8644,

K3 = 0.3231,

K4 = 1.4189,

K5 = 0.1463,

K6 = 0.4167

Input1 = 1.8,

Input2 = 29.56,

Output = 1.06

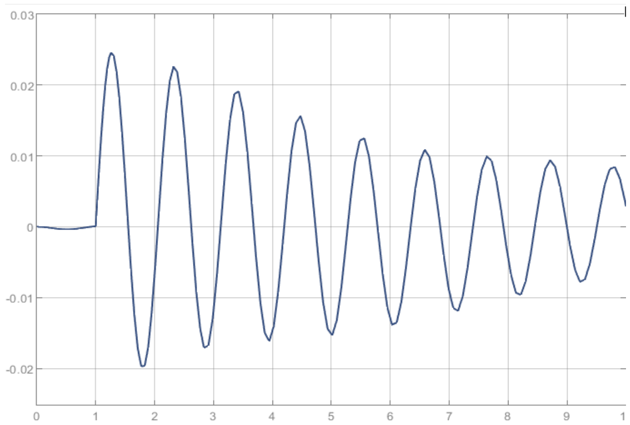

Fig-5: Speed deviation vs time

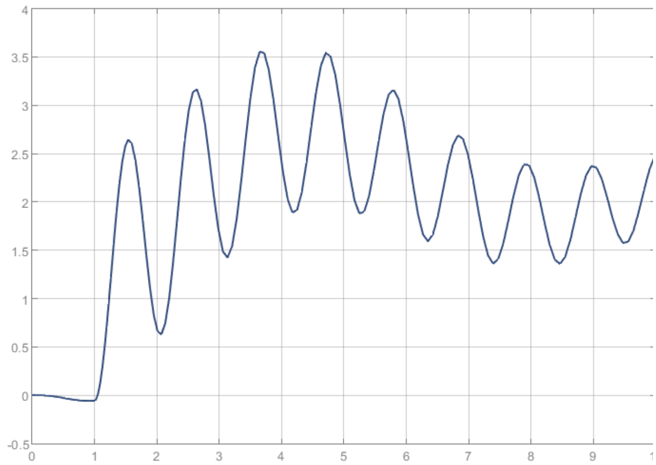

Fig-6: Power deviation vs time

4.2 Simulation results for fuzzy logic controller based AVR

Simulation is carried out with the help of MATLAB Simulink. The voltage response of the Simulink based SG model without a fuzzy logic controller is shown in fig 7 [11].

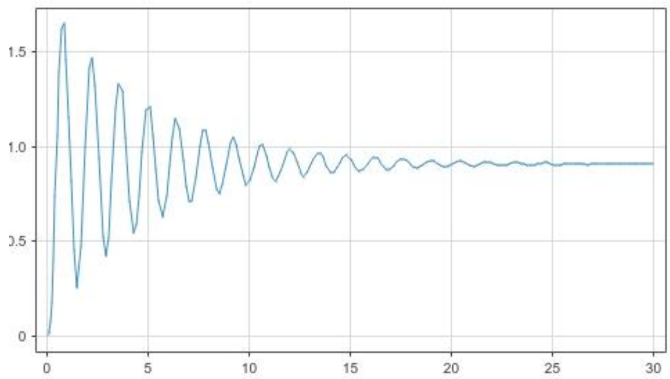

Fig-7: Voltage response without FLC

We can observe that the AVR response presents a ripple and some oscillations before reaching the steady state operation point.

The voltage response of the Simulink based SG model with a fuzzy logic controller is shown in fig 8. We can observe that the ripples in the waveform are removed when we use a fuzzy logic controller. So, by using a fuzzy logic controller, we can prevent the 'large overshoot' and 'very long settling time' of the voltage response of the synchronous generator thus enhancing the system performance and stability.

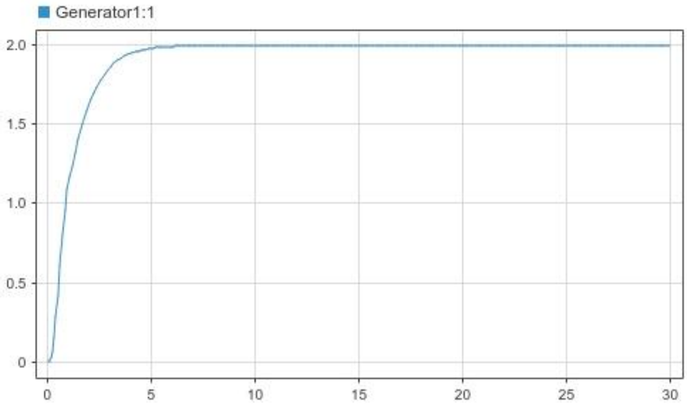

Fig-8: Voltage response with FLC

CONCLUSION

In this paper, initially the effect of system stabilizer is reviewed. The simulation results showed that in the presence of small disturbances in the system, fuzzy controller is more effective as compared to the conventional controller. We also showed that the fuzzy controllers as compared to the no controller system enhanced the system performance and stability since the settling time value using fuzzy controller is much lesser and the speed of the synchronous generator is also enhanced. Further, the Reduced Rule Fuzzy PSS is tested for Triangular, Trapezoidal and Gaussian membership functions for input and output. The Reduced Rule Fuzzy power system stability with Trapezoidal membership function provide best performance. The future scope of work would be implementing this in microgrid systems.

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