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Development Of A Fuzzy Logic-Based Mechanism For Enhancement Of Power Generation System Stability

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Abstract— **This paper presented the development of a fuzzy logic-based mechanism for enhancement of power generation system stability. The fuzzy logic controller is used for damping low frequency electro-mechanical oscillations in power generation systems. Then the fuzzy logic controller-based power system stabilizer is introduced by taking speed deviation and acceleration of synchronous generator as the input signals to the fuzzy controller and voltage as the output signal. The power system stabilizer was simulated in Mathlab software for three different cases, one, without a controller , two with a fussy logic controller (FLC) and three, with a proportional integral derivative (PID) controller. The results showed that the system was stabilized better with FLC (with peak time of 0.32secs) than with PID controller (with peak time value of 0.38secs) and without the fuzzy controller (with peak time value of 0.41secs. In comparison, the results obtained in this dissertation are in good agreement with existing study where the Static Var Compensator (SVC) system was used n the power system stabiliser. In that study, the results showed a good performance with higher settling time criterion of 0.5s at the firing angle of 180o. Again, with the FLC presented in this work, the settling time was 0.38s which was the lowest settling time among the various systems with different controllers considered in this study.**

Keywords — Fuzzy Logic, Fussy Logic Controller, Power Generation, Proportional Integral Derivative (PID) Controller, Power System Stability, Static Var Compensator

1. Introduction

Power system generations are subjected to low frequency disturbance that might cause loss of synchronism and an eventual break down of the entire power generation system [1,2]. The oscillations, which are typically in the frequency range of 0.2 to 3.0 Hz, might be excited by the disturbance in the system or in some cases might even build up spontaneously [3]. Some of the earliest power system stability problems included spontaneous power system oscillations at low frequencies [4,5,6]. These low frequency oscillations (LFOs) are related to the small signal stability of a power system and are detrimental to the goals of maximum power transfer and power system security [7,8,9,10]. Once the solution of using damper windings on the generator rotors and turbines to control these oscillations was found to be satisfactory, the stability problem was thereby disregarded for some time. However, as power systems began to be operated closer to their stability limits, the weakness of a synchronizing torque among the generators was recognized as a major cause of system instability. Automatic voltage regulators (AVRs) helped to improve the steady-state stability of the power systems [11,12,13,14,15]. But with the creation of large, interconnected power systems, another concern was the transfer of large amounts of power across extremely long transmission lines. The addition of a supplementary controller into the control loop, such as the introduction of conventional power system stabilizers (CPSS) [16,17] and the Automatic voltage regulators (AVRs) [11,12,13,14,15]on the generators provides the means to reduce the inhibiting effects of low frequency oscillations. The conventional power system stabilizers work well at the particular network configuration and steady state conditions for which they were designed. Once conditions change the performance degrades. The conventional power system stabilizer such as lead-lag, proportional integral (PI) power system stabilizer and proportional integral derivative (PID) power system stabilizer operates at a certain point. So, the disadvantage of these types of stabilizer is that they cannot operate under different disturbances. This can be overcomed by introducing a power system stabilizers (PSS) that is based on the fuzzy logic technique. So, there is a need to understudy power system generation stability using the Fuzzy Logic Controller (FLC) for enhancement of the system stability. Hence, this study seeks to enhance power generation system stability using the fuzzy logic technique.

2. Methodology

The case study is a 175MVA electrical power generation plant located at phase II Geregu, Ajoakuta, Kogi State. Then base on the empirical data, fuzzy logic model was developed for the power system stability. Also, MATHLAB software was used to simulate the fuzzy logic controller model to determine the stability of the power system generation settling parameter. The performance of the system with fuzzy logic controller is compared with the system that does not employ any stabilizer.

2.1 Modelling of the Generator Systems

The block diagram of a generator excitation system is shown in Figure 1. The reference voltage (V_{ref}) sends signal to the voltage regulator and regulates it to the exciter for voltage control, then to the generator and it gets to the fuzzy logic stabilizer.

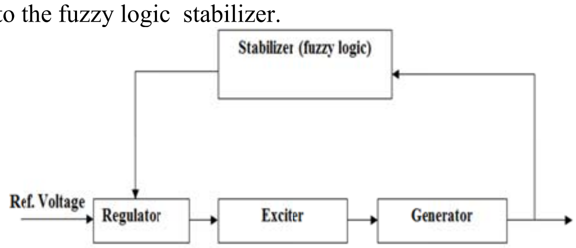

Figure 1: The block diagram of the generator excitation system

The exciter output voltage, E_{fd} of the generator system in Laplace domain is given as;

$$E_{fd} = \frac{K_A}{1+sT_A}(V_{ref} - V_c) \quad (1)$$

Where E_{fd} is the exciter output voltage, T_A is the armature torque, K_A is the armature constant parameter, V_{ref} is the reference voltage and V_c is the critical voltage of the generator. Linearlizing Equation 1 with respect to steady state gives;

$$\Delta E_{fd} = \frac{K_A}{1+sT_A}(-\Delta V_c) \quad (2)$$

The converting ΔE_{fd} to time domain, gives;

$$\frac{d}{dt}\Delta E_{fd} = -\frac{K_A}{T_A}\Delta V_c - \frac{1}{T_A}\Delta E_{fd} \quad (3)$$

The critical voltage, V_c in Laplace domain is given as;

$$\Delta V_c = \frac{1}{1+sT_A}\Delta V_t \quad (4)$$

In time domain V_c becomes;

$$\frac{d}{dt}\Delta V_c = \frac{1}{T_R}(\Delta V_t - \Delta V_c) \quad (5)$$

The effect of field flux on the generator is given as;

$$\frac{d}{dt}\Delta w_r = \frac{1}{2H}(\Delta T_m - \Delta T_e - K_D \Delta w_r) \quad (6)$$

Where H is the inertia constant, K_D is the damping torque coefficient, T_m is the mechanical torque, ΔT_e is the electrical (air-gap) torque and Δw_r is the change in speed of the rotor. The Laplace transformation of Equation 6 is given as;

$$\Delta w_r = \frac{1}{2Hs+K_D}(\Delta T_m - \Delta T_e) \quad (7)$$

The Laplace transform of the variation of the field dynamic equation is given as;

$$\Delta \mu_{fd} = \frac{K_3}{1+sT_3}(\Delta E_{fd} - K_4 \Delta \delta) \quad (8)$$

The Laplace transform of the power system stabilizer, V_c is given as;

$$V_c = \frac{1}{1+sT_R}V_t \quad (9)$$

Where T_R is the terminal voltage reducer time constant of the generator system. The block diagram of the entire power system is shown in Figure 2. The Simulink block diagram of the system with fuzzy logic controller that encapsulates the whole processes from the reference voltage to the transfer functions into the inputs of the fuzzy logic controller is shown in Figure 3.

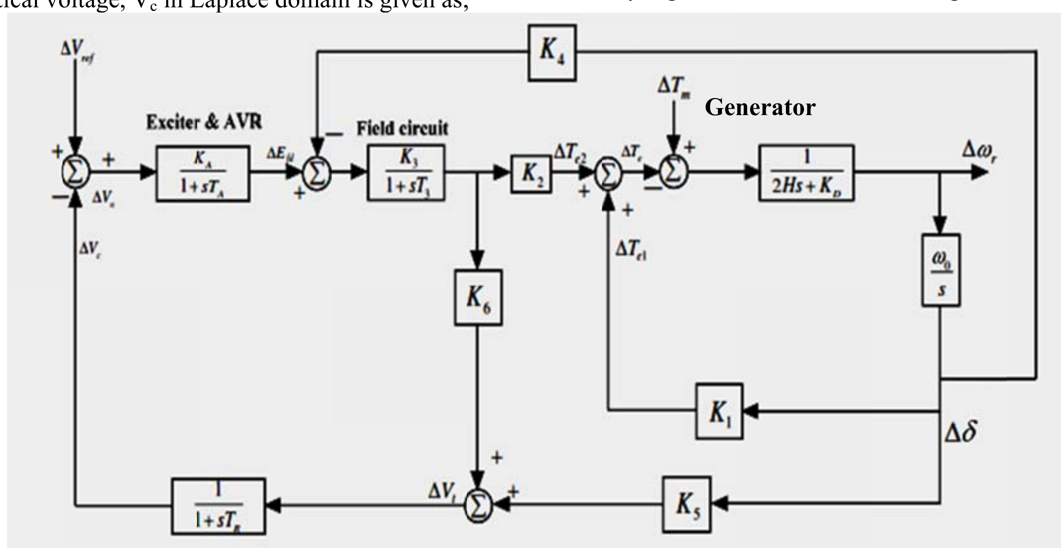

Figure 2: Block diagram of the generating system.

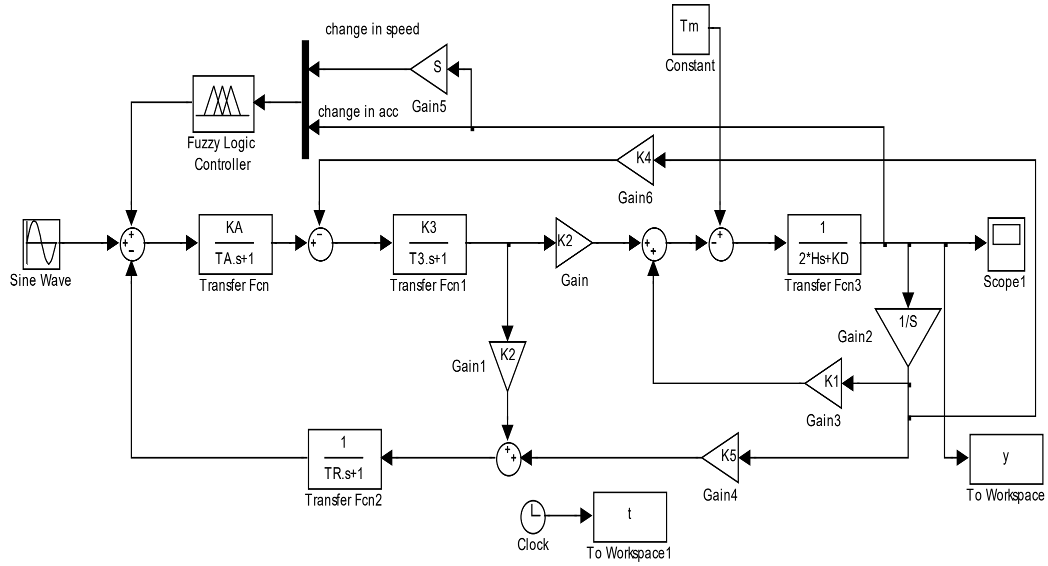

Figure 3: SIMULINK block diagram with the controller.

2.2 The Fuzzy Logic Controller

MATLAB's fuzzy logic toolbox was used to model the fuzzy logic controller (FLC) for stabilizing the power system. The block diagram in Figure 4 illustrates the procedures of modelling the fuzzy logic controller with MATLAB.

The design starts with assigning the mapped variables inputs/output of the FLC. The first input variable to the FLC is the generator speed deviation and the second is the acceleration while the output variable is the voltage, as shown in **Figure 5**.

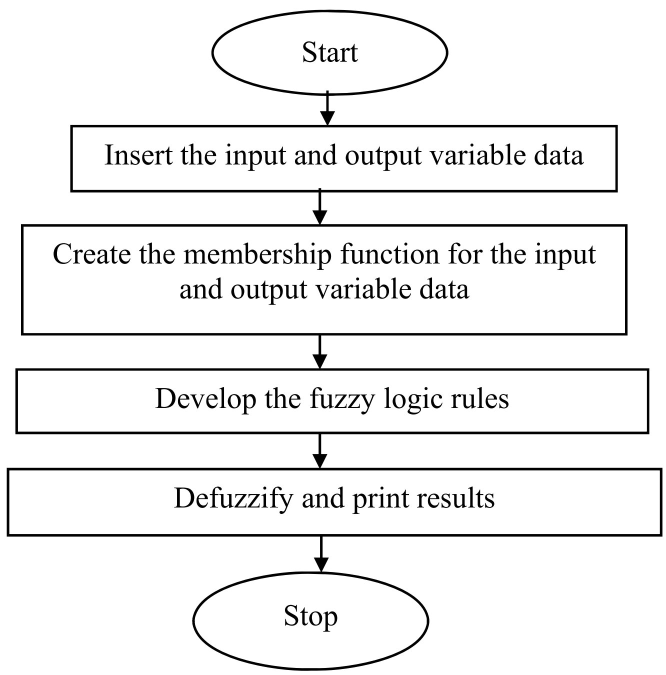

Figure 4: The **flowchart** used to model the fuzzy logic controller with MATLAB

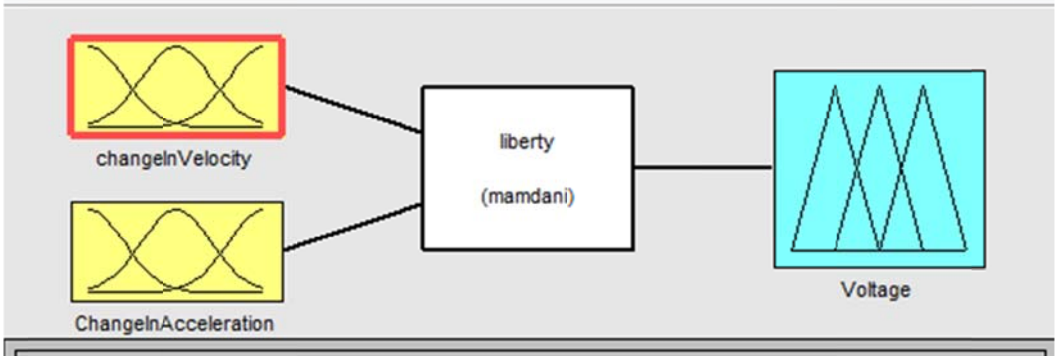

Figure 5: Fuzzy tool showing the input and output variables.

Next, the linguistic variables that are used to transform the numerical values of the input of the fuzzy controller to fuzzy quantities are selected. In this study, seven linguistic variables for each of the input and output variables are used. The rule base for the fuzzy logic controller are shown in Table 1. The knowledge base involves defining the rules represented as IF-THEN statements that govern the relationship between the input and the output variables in terms of membership functions. At this stage, the input variables, namely, the speed deviation and the acceleration are process by the inference engine that executes 7×7 rules represented in rule Table 1. Each entity shown in Table 1 represents a rule.
The antecedent of each rule conjuncts speed deviation ($\Delta\omega$) and acceleration (Δa) fuzzy set values. The knowledge required to generate the fuzzy rules can be derived from an offline simulation.
The membership function maps the crisp values into fuzzy variables. The variables are normalized by multiplying with respective to gains Ke, Kce, Ko so that their values lie between -1 and +1. The membership function models and ranges for change in velocity input variable are presented in Table 2 and Figure 6 respectively.
The membership function models and ranges for change in acceleration input variable are presented in Table 3 and Figure 7respectively.
The membership function models and ranges for voltage output variable are presented in Table 4 and Figure 8 respectively.
The fuzzy rules used in this model are presented in Table 5. The IF – THEN computation of the fuzzy rules using Mandani method in Matlab tool is shown in Figure 9.

Table 1: The rule base for the fuzzy logic controller

Acceleration / Speed deviation	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NS	ZE	ZE	PS
NM	NB	NB	NM	NS	ZE	PS	PM
NS	NB	NB	NM	ZE	PS	PM	PB
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NB	NM	NS	ZE	PM	PB	PB
PM	NM	NS	ZE	PS	PM	PB	PB
PB	NS	ZE	ZE	PS	PB	PB	PB

Table 2: Membership functions condition

Membership function	Membership Function model	Ranges
Negatively Big (NB)	Trapezoidal	-1.72 to -0.5
Negatively Medium (NM)	Triangular	-1.0 to -0.25
Negatively Small (NS)	Triangular	-0.5 to 0
Zero (ZE)	Triangular	-0.25 to 0.25
Positively Small (PS)	Triangular	0 to 0.5
Positively Medium (PM)	Triangular	0.25 to 1
Positively Big (PB)	Trapezoidal	0.5 to 1.72

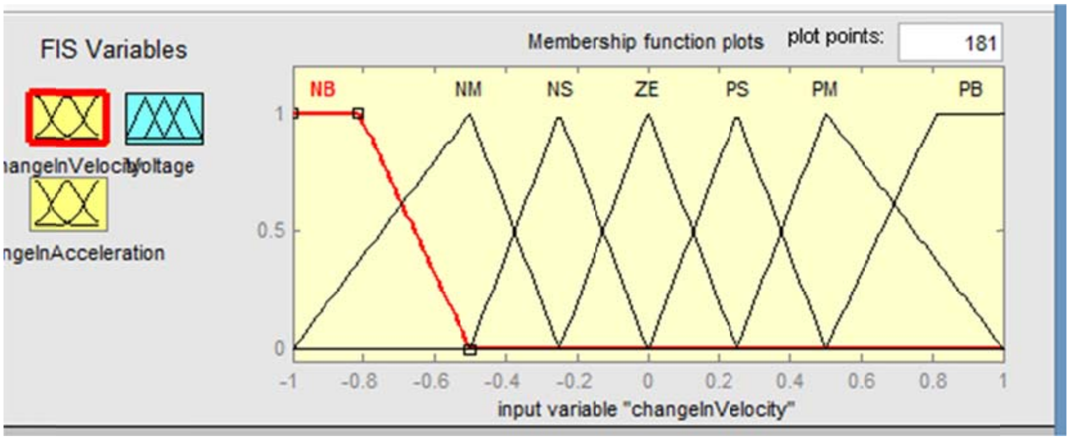

Figure 6: Membership functions for the change in velocity input variables.

Table 3: Membership function conditions for change in acceleration variables

Membership Function	Membership Function model	Ranges
Negatively Big (NB)	Trapezoidal	-1.72 to -0.5
Negatively Medium (NM)	Triangular	-1.0 to -0.25
Negatively Small (NS)	Triangular	-0.5 to 0
Zero (ZE)	Triangular	-0.25 to 0.25
Positively Small (PS)	Triangular	0 to 0.5
Positively Medium (PM)	Triangular	0.25 to 1
Positively Big (PB)	Trapezoidal	0.5 to 1.72

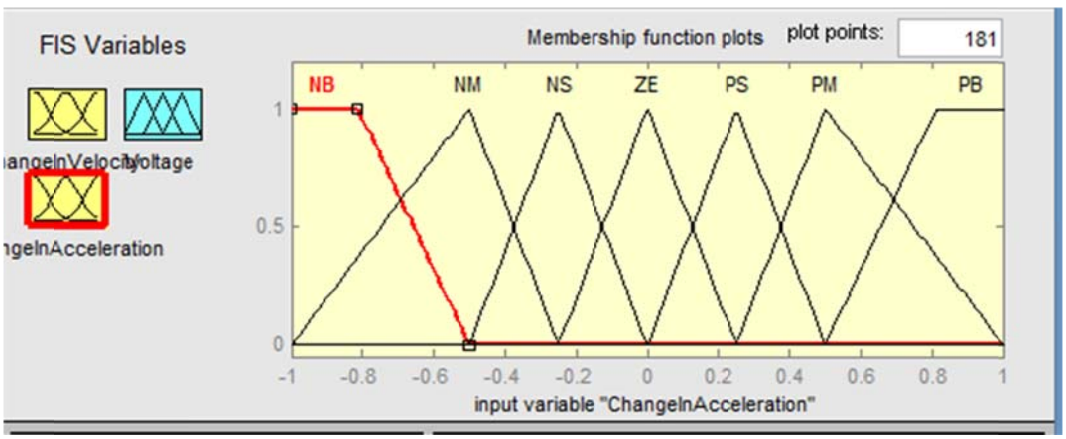

Figure 7: Membership functions for the change in acceleration input variables

Table 4: Membership function conditions for output voltage variables.

Membership function	Membership Function model	Ranges
Negatively Big (NB)	Trapezoidal	-1.72 to -0.5
Negatively Medium (NM)	Triangular	-1.0 to -0.25
Negatively Small (NS)	Triangular	-0.5 to 0
Zero (ZE)	Triangular	-0.25 to 0.25
Positively Small (PS)	Triangular	0 to 0.5
Positively Medium (PM)	Triangular	0.25 to 1
Positively Big (PB)	Trapezoidal	0.5 to 1.72

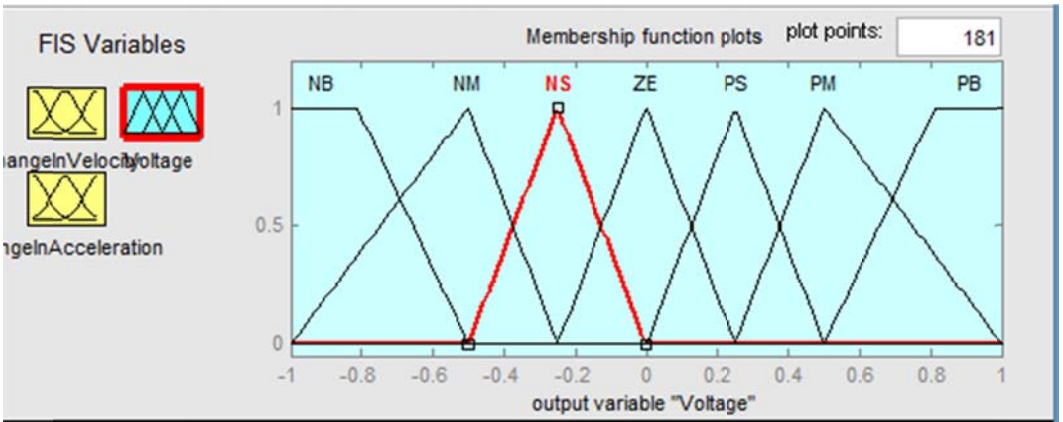

Figure 8: Membership functions for the voltage output variables.

The membership function ranges and model for the inputs and output are presented in Table 3.5

Table 3.5: Membership function conditions for input and output variables.

Membership function	Membership Function model	Ranges
Negatively Big (NB)	Trapezoidal	-1.72 to -0.5
Negatively Medium (NM)	Triangular	-1.0 to -0.25
Negatively Small (NS)	Triangular	-0.5 to 0
Zero (ZE)	Triangular	-0.25 to 0.25
Positively Small (PS)	Triangular	0 to 0.5
Positively Medium (PM)	Triangular	0.25 to 1
Positively Big (PB)	Trapezoidal	0.5 to 1.72

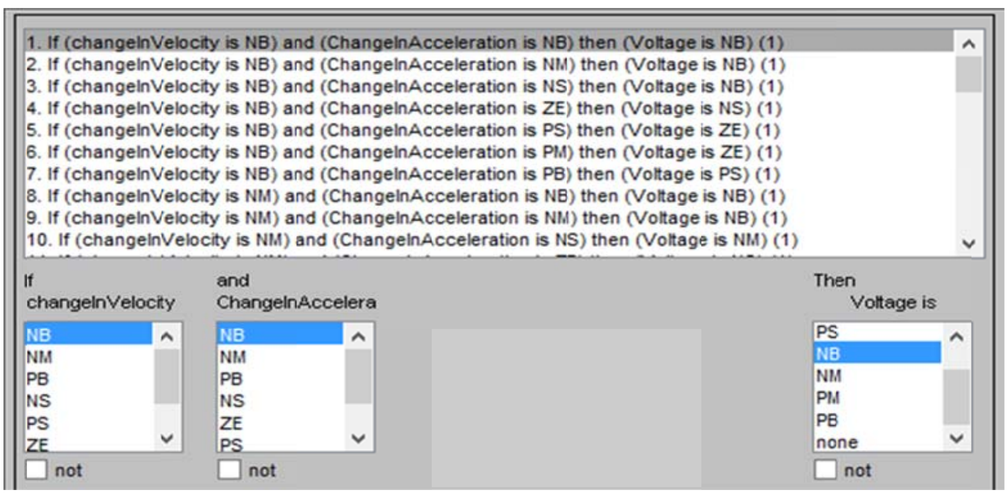

Figure 9: Mandani fuzzy logic rules.

3. Results and discussion

The two inputs , namely, the change in velocity and the change in acceleration along with the system output , which is the voltage when there is variation in the two input signals are shown in Figure 10.

From Figure 10, when the change in velocity and change in acceleration were zero, the output voltage of the fuzzy logic was 8.04x10^{-18}. Again, the fuzzy rule view when the two inputs variables velocity and acceleration are varied to 0.734m/s and 0.4m/s^2 respectively is shown in Figure 11. From Figure 11 when the change in velocity and change in acceleration were 0.734m/s and 0.4m/s^2 respectively, the output voltage of the fuzzy logic was 0.69KV.

Similarly, when the change in velocity and change in acceleration were 0.5m/s and 1m/ s^2 respectively, the output voltage of the fuzzy logic was 0.822KV. The surface interaction of the input variables (change in velocity, and the change in acceleration) and the output (voltage) is shown in Figure 12.

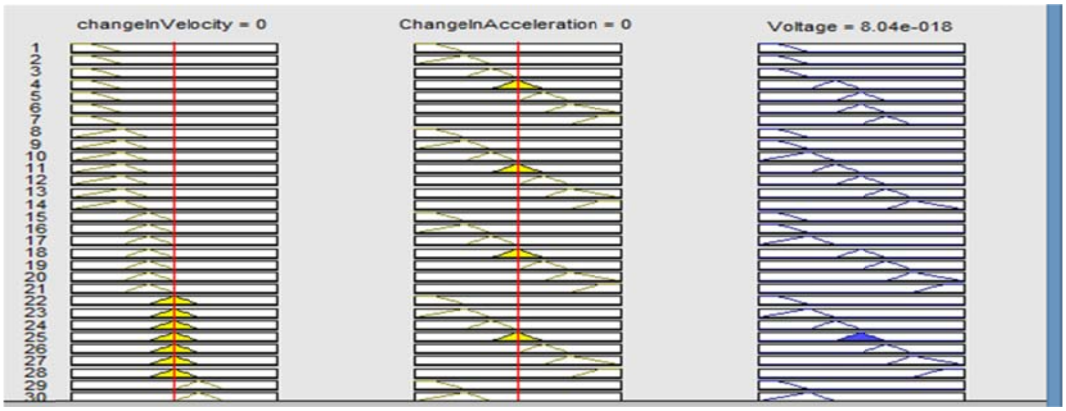

Figure 10: Rule view when the change in velocity and change in acceleration equals to 0

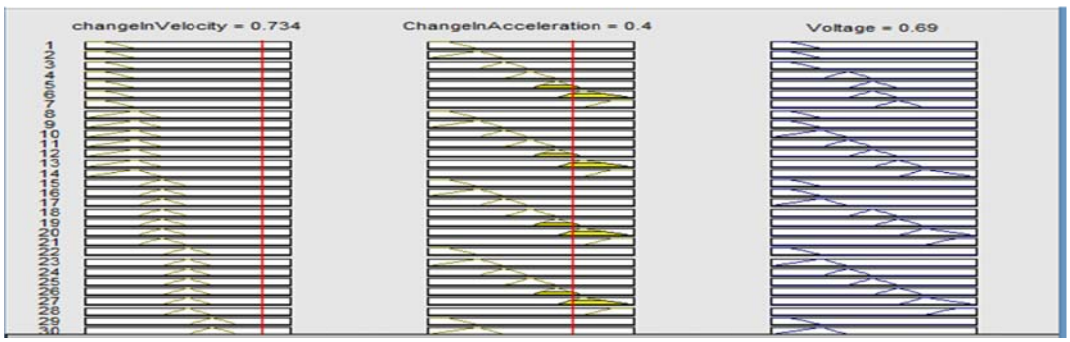

Figure 11: Rule view when the change in velocity and change in acceleration are 0.734m/s and 0.4m/s^2 respectively

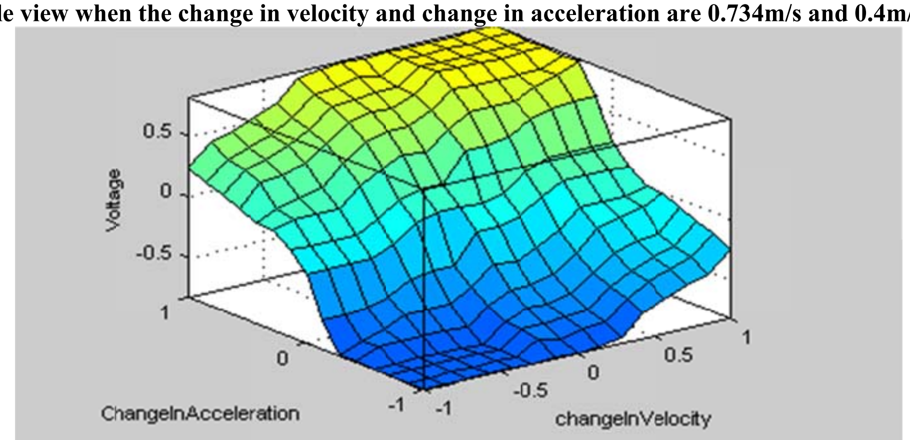

Figure 12: The surface plot of the interaction of change in velocity and change in acceleration and voltage

From the trend in Figure 12, the higher the values of the inputs, the higher the values of the voltages, that is, as the change in velocity and change in acceleration increases, the voltage also increases. Essentially, Figure 10, Figure 11 and Figure 12 indicate that the fuzzy logic is very much functional in stabilizing the generation system.

The graphical representation of the power generating system with the fuzzy logic controller and also without the fuzzy logic controller is shown in Figure 13. The result in Figure 13 shows that without the fuzzy controller, the peak time was at 0.41sec and the peak time was less because the system modelled contained an AVR. On the other hand, the system with fuzzy logic intelligent controller has a peak time of 0.32sec. This was an improvement when compared with the system without the fussy controller. Specifically, the results in Figure 13 shows that the settling time criterion without the fussy controller was at 0.42m/s which made the system damping condition higher than normal thereby making the system unstable, but when the fuzzy controller was introduced into the system, the damping time reduced to 0.33m/s and the oscillation dropped to a controllable working point which made system stable.

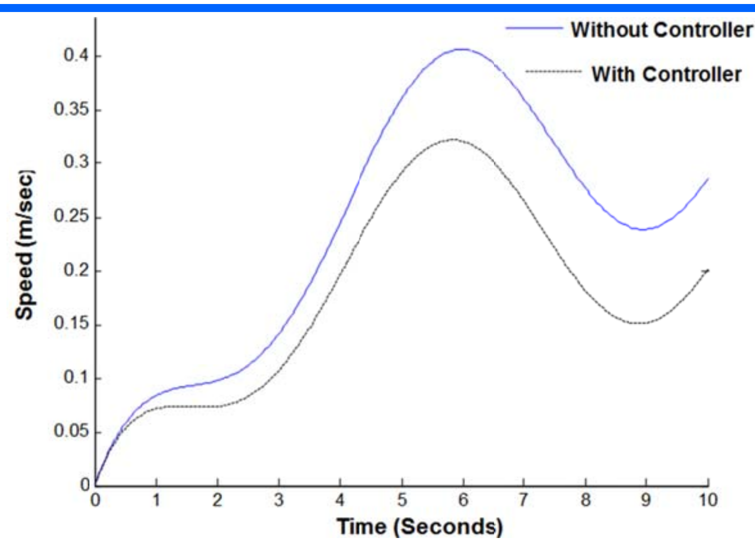

Figure 13: Stability of the system with the fuzzy logic controller and the system without the fuzzy logic controller

The response of the system for the following three cases (i) without the fussy controller , (ii) with the fuzzy logic (iii) with a proportional integral derivative (PID) controllers are shown in Figure 14.

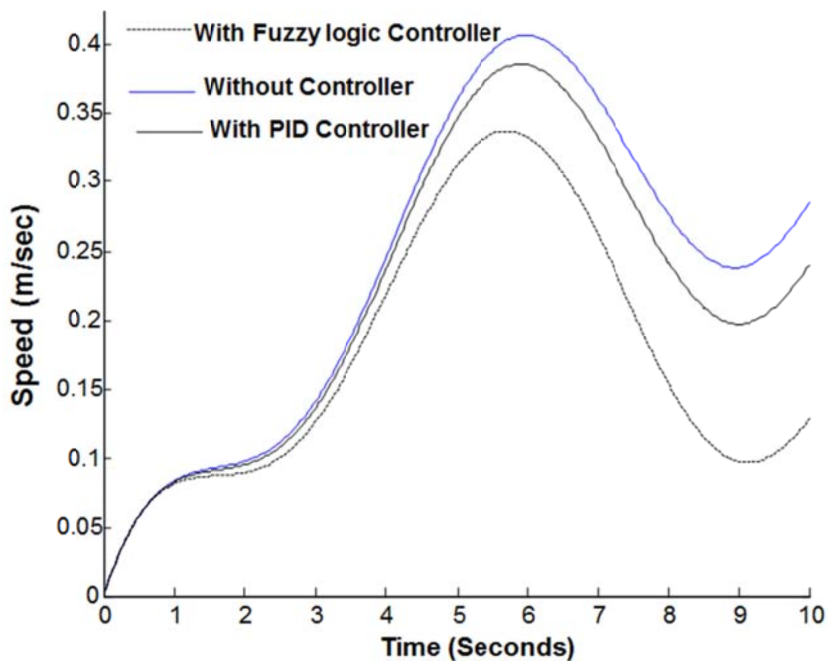

Figure 14: Comparison of the system without controller, with PID controller and with fuzzy logic controller (FLC)

From Figure 14, the system was stabilized better with FLC (with peak time of 0.32secs) than with PID controller (with peak time value of 0.38secs). This indicates that, to stabilize the voltage of the power generating system, fuzzy logic controller is the best controller to be used.

In comparison, the results obtained in this dissertation are in good agreement with Mark (2009) and Agarwal (2013) where Static Var Compensator (SVC) system was used and the results showed a good performance with higher settling time criterion of 0.5s at the firing angle of 180°. They also used the PID controller and the settling time was 1.0s . Meanwhile, in this work, with the PID controller, the settling time was 0.38s. Most importantly, the results obtained in this paper for a system with FLC had a settling time of 0.32s , which is the lowest settling time among the various systems with different controllers considered in this study.

Although the FLC had the best performance among the different controllers considered in this study, it is important to note that the choice of membership functions can significantly affect the damping of oscillations. In the simulation studies, the oscillations were more pronounced in the case of trapezoidal membership functions whereas the performance of FLC with the triangular membership functions is superior compared to other membership functions. In essence, the choices made in the design of the FLC can significantly affect the result and hence the performance of the FLC as a power system stabiliser.

4 Conclusion

In this paper the effectiveness of power system generation stabilizer in damping power system generation stabilizer is reviewed. Then the fuzzy logic controller-based power system stabilizer is introduced by taking speed deviation and acceleration of synchronous generator as the input signals to the fuzzy controller and voltage as the output signal. According to the results obtained, in terms of settling time and damping effect, the fuzzy logic based power system stabilizer (FLPSS) showed better control performance than the other power system generation stabilizers such as the PID controller and the traditional techniques that are based on linear controllers. Therefore, it can be concluded that the performance of the FLPSS presented in this study is better than conventional PSS. However, the choice of membership functions has an important bearing on the damping of oscillations. From the simulation studies, it shows that the oscillations are more pronounced in the case of trapezoidal membership functions. The response with trapezoidal membership functions is comparable to triangular membership functions. However, the performance of FLPSS with triangular membership functions is superior compared to other membership functions.

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