VOL. 12, NO. 5, MARCH 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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STABILITY STUDIES OF FUZZY LOGIC BASED POWER SYSTEM STABILIZER IN ENHANCING DYNAMIC STABILITY OF A TWO GENERATORS TIE-LINE SYSTEM

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ABSTRACT
Electro-mechanical oscillations are created, in the machines of an interrelated power network, followed by a trouble or due to high power transfer through weak tie lines. These oscillations should be damped as quickly as possible to guarantee the reliable and stable operation of the network. This research presents the analysis of change of speed, change of angle position and tie - line power flow, fuzzy logic controller (FLC) two area symmetrical systems connected via tie-line are measured to show via performance of these controllers using Simulink/MATLAB. Simulation results described by fuzzy logic based controller having dual inputs of rotor speed deviation and generator's accelerating power there shown better solutions for damping the inter area (tie-line) oscillations.

Keywords: fuzzy logic controller, tie-line oscillations, multi-machine stability, two area power system.

1. INTRODUCTION
Low frequency oscillations have been detected with the progress of power network, through weak tie lines, in the form of long interrelated network. These oscillations convert important as the network remains to amplify and the damping of these oscillations becomes more important and critical to retain stable and reliable operation. These oscillations may occur between two synchronous generators (inter machine oscillations) or between the generators in distant areas oscillations [1]. The fuzzy logic method is much additional particular and lets knowledge and experienced increased of the system, to be used in such a way so as to provide acceptable control for the system, even when the system shape and settings change [2]. Power systems are gradually growing with ever larger capacity. Previously parted systems are interrelated to each other, while modern power systems have developed into systems of very large size. With mounting generation capacity, different areas in a power system are often additional with even large inertia. Power systems are known as weighty nonlinear and often have low frequency oscillations, particularly in weakly tie line [3]. Transient stability is the capability of a power system to recover its stability in case of sudden and stark defect, in the system. The time interest for the transient stability is 0 s to 10 s [4]. The fuzzy logic is actually interesting, because it does not need mathematical method to give control solution. The huge popular of the fuzzy logic controllers (FLC) that have been used to date were based on the old-style type fuzzy logic [5]. With the growth of the economy, the development of the request for electricity, the study of multi-machine power system has concerned great care due to their capabilities to guarantee the capabilities of power system in latest years.

Nevertheless, with a fast growth in the size and complication of power system, it is essential to design an active controller so as to continue power system stability [6]. Though, a large number of performances have been working in power systems, intellectual fuzzy logic is a powerful tool in conference challenging problems for stability of power systems. Because fuzzy logic is a skill which can handle inaccurate problems without seeing complication [7].Stability of power systems is one of the most important features in electric system operation. This get up from the fact that the power system must continue frequency and voltage levels in the favourite level, under any trouble, like a sudden rise in the load, loss of one generator or switching out of a transmission line, during a fault [8]. With the increase of power system size and volume together with the establishment of interconnections, irregular occurrences have been recurrently saw such as overly large tie-line power deviations and/or continued power oscillations under sudden system load changes [9]. In operation, the electrical power system is frequently reduced short circuit, either enduring or temporary. The short circuit can reason a deviation in the variables of the electric power system, such as voltage, frequency, and others. This deviation may affect the stability of the power system. Stability in the electric power system is definite as the capability of the power system to continue management at the time of disruption and after disruption happens [10].

2. SYSTEM MODEL

2.1 Tie-Line control
After two services interrelate their systems, they do so for several details. One is to be able to buy and sell power with neighbouring systems whose operating costs make such transactions gainful. More, even if no power is being transmitted over ties to neighbouring systems, if one system has a sudden loss of a generating unit, the units throughout the interconnection will experience a frequency change and can help in restoring frequency. Interconnections present a very motivating control problem with admiration to allocation of generation to

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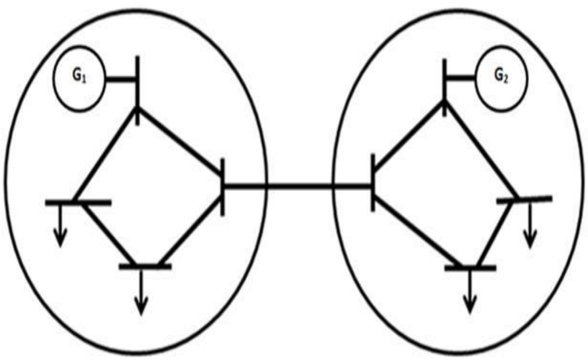
see load. The hypothetical situation in Figure-1 will be used to show this problem. Assume both systems in Figure-1 have equal generation and load characteristics.

Such a control system must use two pieces of information; the system frequency and the net power flowing in or out over the tie lines. Such a control scheme would, of requirement, have to know the following [11].

a) If frequency decreased and net interchange power leaving the system increased, a load increased has occurred outside the system.
b) If frequency decreased and net interchange power leaving the system decreased, a load increased has occurred inside the system.



Area 1 Area 2

Figure-1. Two - area system connected via tie-line.

Electrically the machines are modeled as a voltage behind a sub transient reactance. These machines have usually wound rotors and are signified with two damper windings on the **q-** axis and one on the **d**- axis. The d- and **q-** axes are attached to the major and minor reluctance axes of the rotor respectively. Figure-2 is a schematic diagram of a machine model with fuzzy logic based PSS [12].

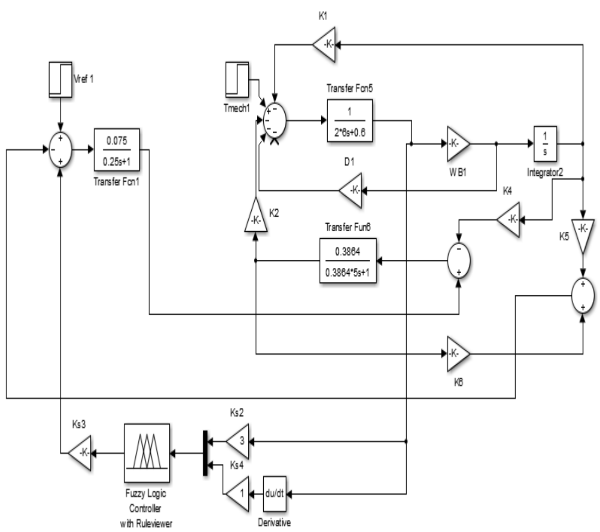


Figure-2. Schematic diagram of a machine model with FLC.

The differential equations used to model the sub transient machine. The model assumes that [2]:

a) The synchronous machines have sinusoidal air-gap mmfs and linear magnetic circuits.
b) The system is balanced.
c) Zero sub transient saliency ie. Xd″ =Xq″ = X″.
d) Effects of the $p\Psi_d$ and $p\Psi_q$, terms are neglected.

2.2 Tie-Line model

The flowing mathematical modeling are taken from references [11].

$$P_{tie\ flow}=\frac{1}{X_{tie}}(\theta_1-\theta_2) \quad (1)$$

where X_{tie} is represented reactance tie- line two generators
θ_1 is represented phase angle for generator 1
θ_2 is represented phase angle for generator 2

This tie flow is a steady-state quantity. For purpose of analysis here, we perturb Equation (1) to obtain deviations from nominal flow as a function of deviations in phase angle from nominal.

$$P_{tie\ flow}+\Delta P_{tie\ flow}=\frac{1}{X_{tie}}[(\theta_1+\Delta\theta_1)-(\theta_2+\Delta\theta_2)]$$
$$=\frac{1}{X_{tie}}(\theta_1-\theta_2)+\frac{1}{X_{tie}}(\Delta\theta_1-\Delta\theta_2) \quad (2)$$

Then
$$\Delta P_{tie\ flow}=\frac{1}{X_{tie}}(\Delta\theta_1-\Delta\theta_2) \quad (3)$$

where $\Delta\theta_1$, and $\Delta\theta_2$ are equivalent to $\Delta\delta_1$, and $\Delta\delta_2$, as defined in Equation (4). Then, using the relationship of Equation (4).

$$\Delta\omega=\alpha t=\frac{d}{dt}(\Delta\delta) \quad (4)$$
$$\Delta p_{tie\ flow}=\frac{T}{S}(\Delta\omega_1-\Delta\,\omega_2) \quad (5)$$
where $T = 377 \times \frac{1}{X_{tie}}$ for a 60 – Hz system.

Not that $\Delta\theta$ must be in radians for Δp_{tie} to be in per unit megawatts, but $\Delta\omega$ is in per unit speed changes.therefor, we must multiply $\Delta\omega$ by 377 rad/sec (the base frequency in rad/ sec at 60 Hz). T may be thought of as the “tie-line stiffness” cofficient [11].

3. DESIGN OF FUZZY LOGIC CONTROLLER

The fuzzy control systems are rule based systems in which a set of fuzzy rules represent a control decision mechanism to adjust the effects of certain system stimuli. With the help of effective rule base, fuzzy control systems can replace a skilled human operator. The fuzzy logic controller provides an algorithm which can convert the linguistic control strategy based on expert knowledge into an automatic control strategy. The Figure-3 illustrates the schematic design of a fuzzy logic controller which consists of a fuzzification interface, a knowledge base, control

VOL. 12, NO. 5, MARCH 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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system (process), decision making logic and a defuzzification interface [13].

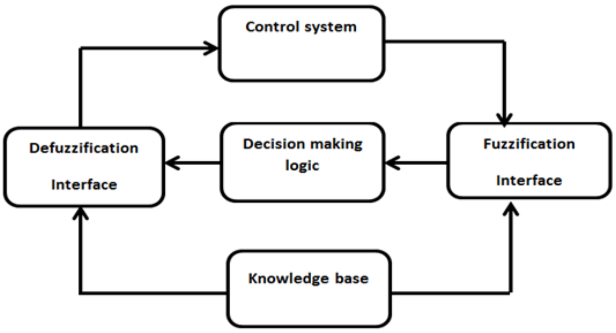

Figure-3. Principle design of fuzzy logic controller.

The fuzzy logic controller block consists of fuzzy logic block and scaling factors. Scaling factors inputs are two and one for each input and one scaling factor for output which determine the extent to which controlling effect is produced by the Fuzzy Logic Controller shown in Figure-4. Performance of Fuzzy Logic Controller is studied for the scaling factors having the values of Kin_1 = 1, Kin_2 = 3 and Kout = 0.001, as obtained from (1) the piecewise linear method (2) the linear approximate technique [14].

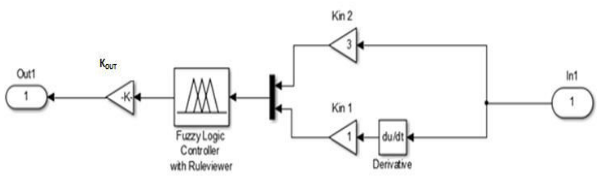

Figure-4. Fuzzy logic controller based PSS.

3.1 Fuzzy inference system

Fuzzy logic block is prepared using Fuzzy Inference System file in Matlab (R2013a) and the basic structure of this FIS editor file as shown in Figure-5. This is implemented using following FIS (Fuzzy Inference System) properties as shown in Figure-5, 6 [13]. Table-1 presents 16 rules base for fuzzy logic controller. Figure-7 shows Rule Viewer of Fuzzy Logic Controller.

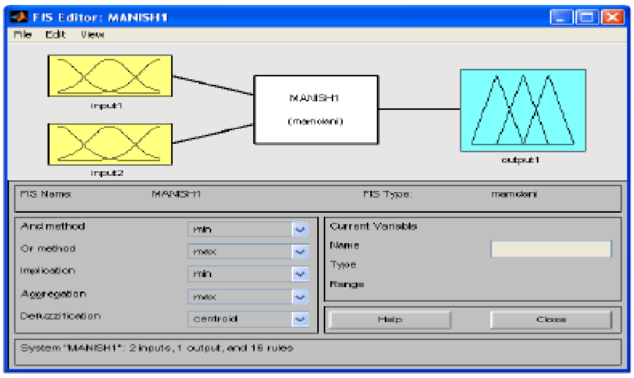

Figure-5. Fuzzy inference system.

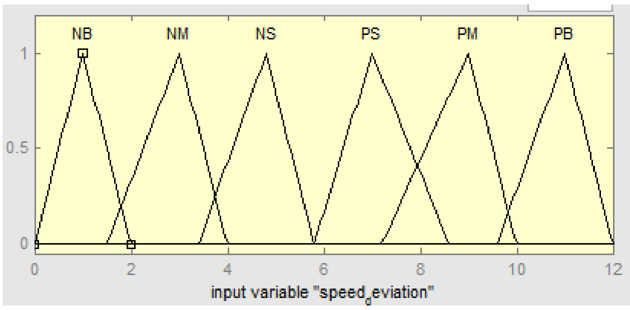

Figure-6(a). Membership functions for speed deviation.

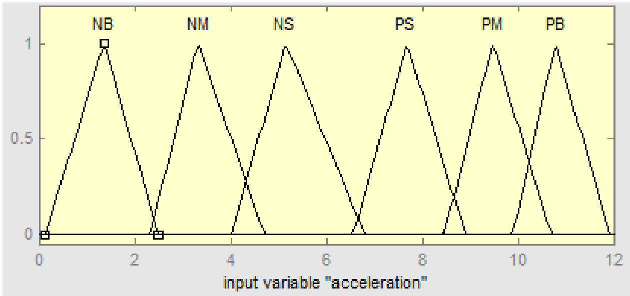

Figure-6(b). Membership functions for acceleration.

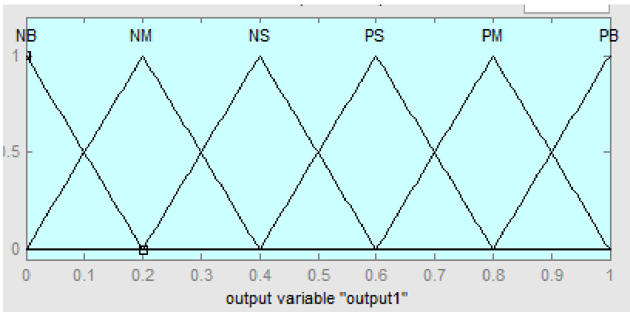

Figure-6(c). Membership functions for voltage.

Table-1. 16 Rule base for fuzzy logic controller.

	Acceleration					
Speed deviation	**NB**	**NM**	**NS**	**PS**	**PM**	**PB**
NB	NB	0	0	0	0	0
NM	0	0	0	0	0	0
NS	0	0	0	0	0	0
PS	NM	NS	0	PM	PB	PB
PM	NS	0	PS	PB	PB	PB
PB	0	PS	PM	PB	PB	PB

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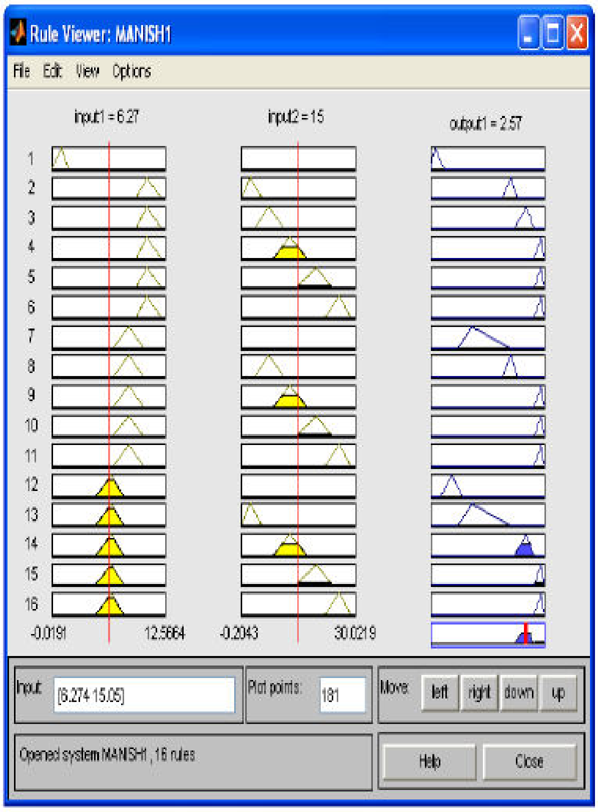

Figure-7. Rule viewer of fuzzy logic controller.

4. RESULTS AND DISCUSSIONS

The studies were implemented using MATLAB/SIMULINK based on the system shown Figure-8. Performance of a-two generator system has been studied using 16 rules fuzzy logic controller (FLC). Machine data is taken from references [15] in Table-2 and Table-3 present the change of input torque.

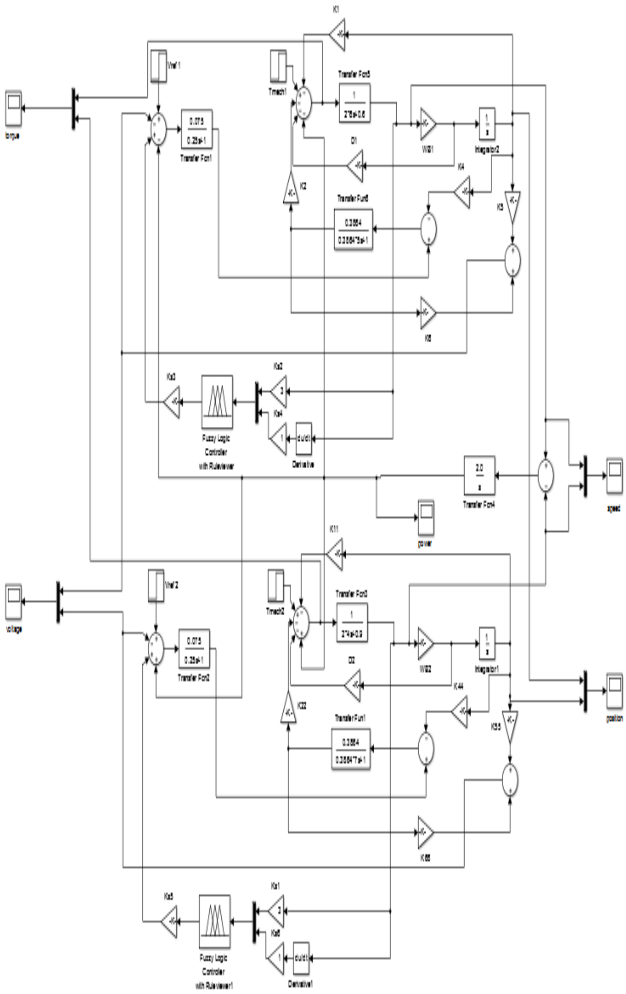

Figure-8. Simulation model of a 2- Generator connected via tie-line.

Table-2. Machine data.

Parameters	Numerical value
K1	0.9831
K2	1.0923
K3	0.3864
K4	1.4746
K5	- 0.1103
K6	0.4477
K_E	0.075
T_E	0.25
K_D	0
H_1	6
H_2	4
D_1	0.6
D_2	0.9
V_{ref}	1

Table-3. Change of input torque.

	$T_{mech\ 1}$	$T_{mech\ 2}$
Case 1	**0.2**	**0**
Case 2	0	0.2
Case 3	0.2	0.2
Case 4	0.2	0.1

Case 1: $T_{L1} = 0.2$ pu and $T_{L2} = 0$ pu.

The variations of angular speed, angular position (angle rotor) and tie – line power flow ($P_{1\text{-}2}$) are displayed in Figure-9(a),(b) and (c)for the systems with 20% change of input torque for generator 1 and 0% for generator 2. Time is 120 sec using 16 rules in fuzzy logic controller.

Figure-9(a), (b) and (c) show angular speed variations, angular position (angle rotor) variations and power flow ($P_{1\text{-}2}$) variations of a 2-generators connected via tie-line.

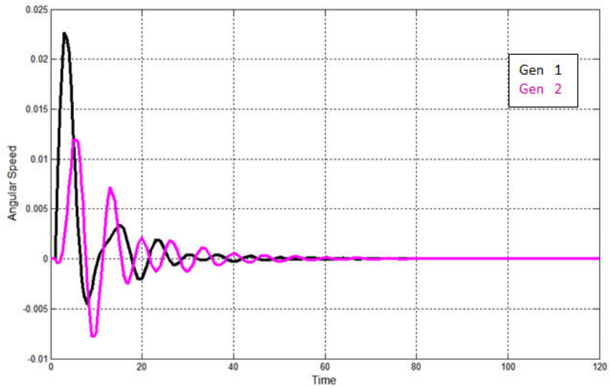

Figure-9(a). Angular speed.

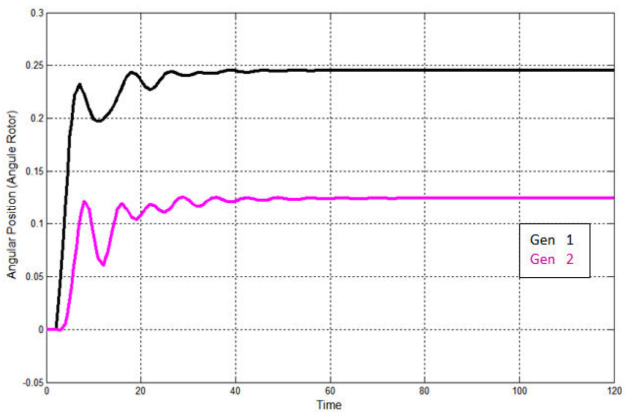

Figure-9(b). Angular position (Angle rotor).

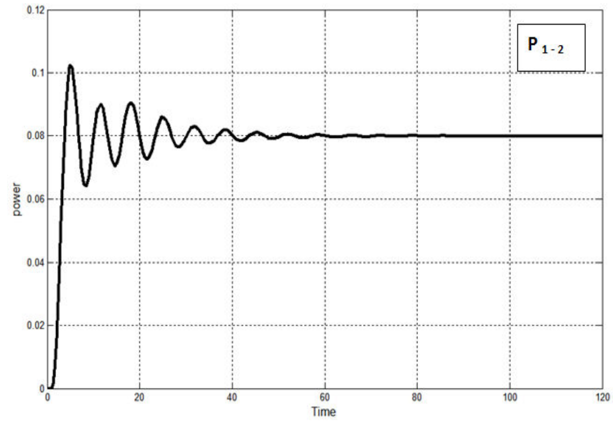

Figure-9(c). Tie - Line power flow.

Case 2: $T_{L1} = 0$ pu and $T_{L2} = 0.2$ pu.

The variations of angular speed, angular position (angle rotor) and tie – line power flow ($P_{1\text{-}2}$) are displayed in Figure 10 (a), (b) and (c)for the systems with 0% change of input torque for generator 1 and 20% for generator 2. Time is 120 sec using 16 rules in fuzzy logic controller. Figure-10 (a), (b) and (c) show angular speed variations, angular position (angle rotor) variations and power flow ($P_{1\text{-}2}$) variations of a 2-generators connected via tie-line.

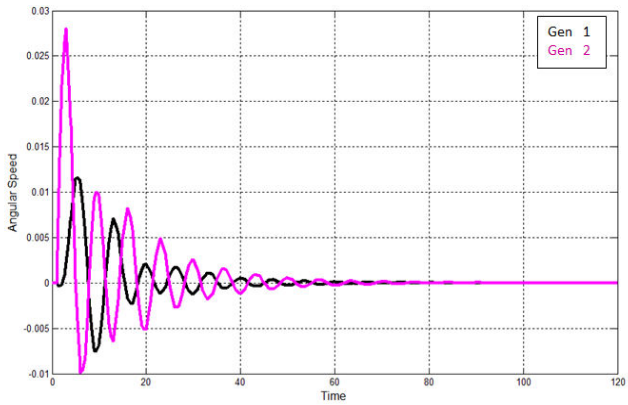

Figure-10(a). Angular speed.

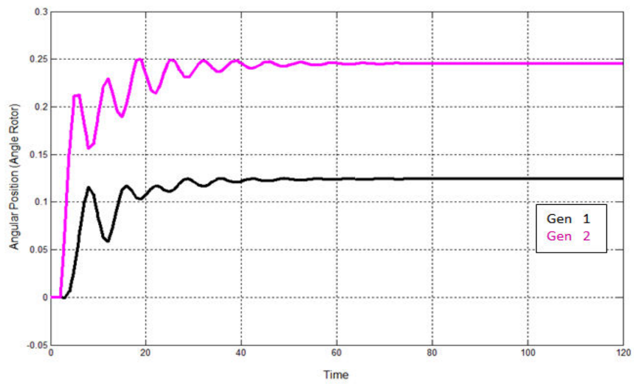

Figure-10(b). Angular position (Angle rotor).

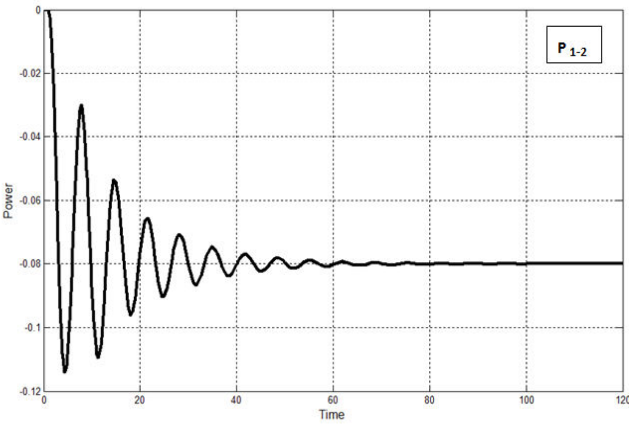

Figure-10(c). Tie - Line power flow.

Case 3: $T_{L1} = 0.2$ pu and $T_{L2} = 0.2$ pu.

The variations of angular speed, angular position (angle rotor) and tie - line power flow (P_{1-2}) are displayed in Figure-11 (a), (b) and (c)for the systems with 20% change of input torque for generator 1 and 20% for generator 2. Time is 120 sec using 16 rules in fuzzy logic controller.

Figure-11 (a), (b) and (c) show angular speed variations, angular position (angle rotor) variations and power flow (P_{1-2}) variations of a 2-generators connected via tie-line.

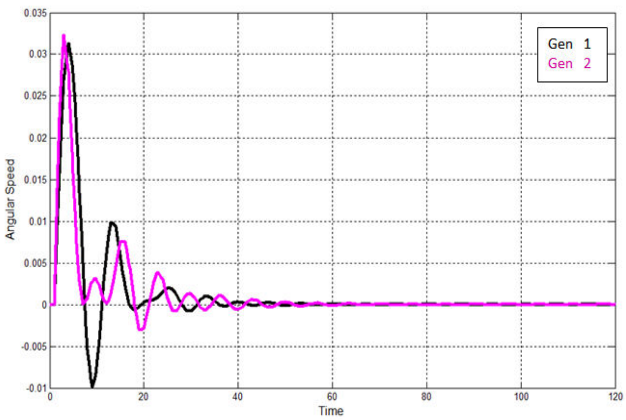

Figure-11(a). Angular speed.

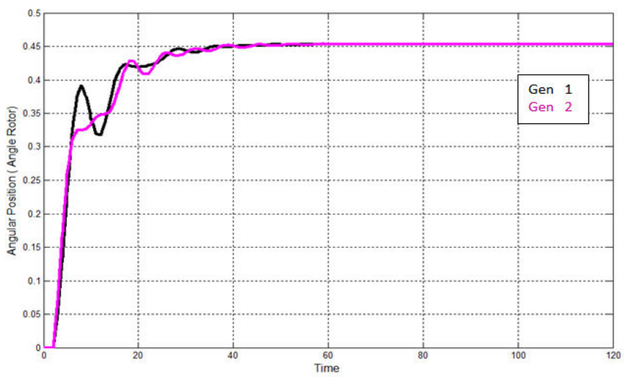

Figure-11(b). Angular position (Angle rotor).

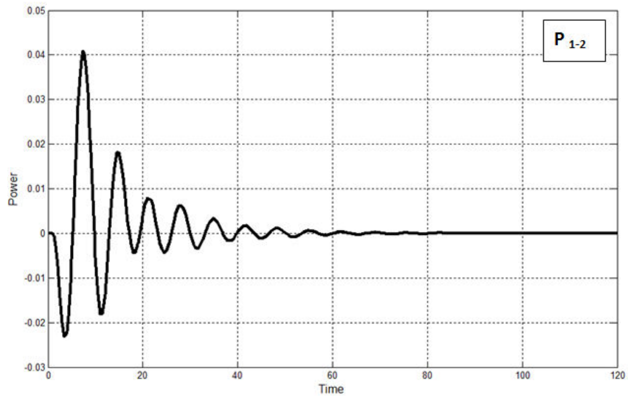

Figure-11(c). Tie - Line power flow.

Case 4: $T_{L1} = 0.2$ pu and $T_{L2} = 0.1$ pu.

The variations of angular speed, angular position (angle rotor) and tie - line power flow (P_{1-2}) are displayed in Figure-12 (a), (b) and (c)for the systems with 20% change of input torque for generator 1 and 10% for generator 2. Time is 120 sec using 16 rules in fuzzy logic controller. Figures 12 (a), (b) and (c) show angular speed variations, angular position (angle rotor) variations and power flow (P_{1-2}) variations of a 2-generators connected via tie-line.

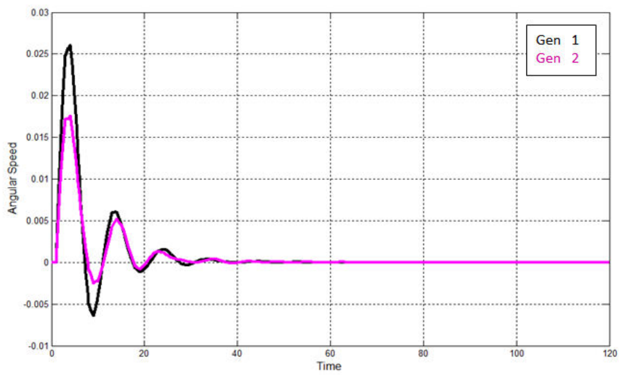

Figure-12(a). Angular speed.

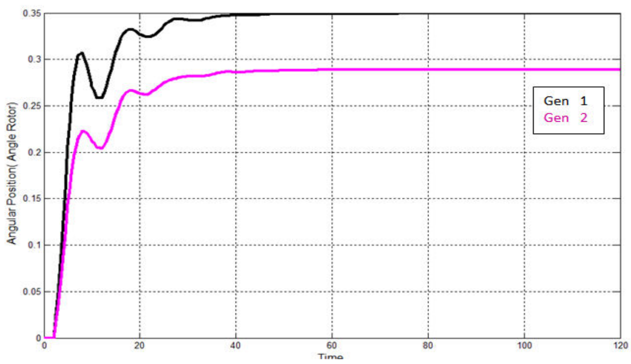

Figure-12(b). Angular position (Angle rotor).

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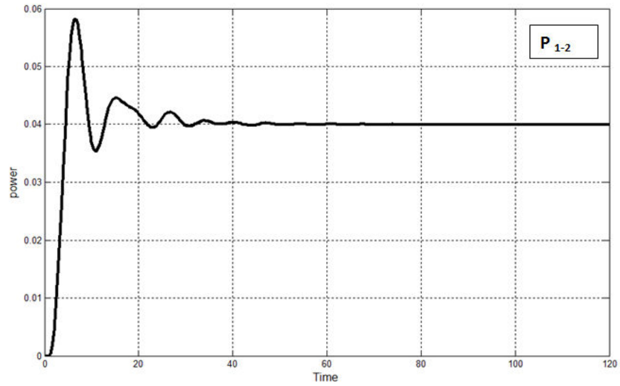

Figure-12(c). Tie - Line power flow.

CONCLUSIONS

For the load torque disturbances investigated between two areas connected via tie - line, the fuzzy logichas increased the damping of the speed Δω angle rotor Δδ causing it to settle down to steady state in much less time. The fuzzy logichas also confirmed to be strong and independent of point of operation the machine. Therefore, it has a greater effect on the multi- machine system. When the input torque of generator 1 is greater than generator 2, it leads to larger speed Δω and angle rotor Δδ for generator 1 compared to the generator 2; therefore the power flow via tie - line (P_{1-2}) becomes positive value. One the other hand, power flow via tie - line, (P_{1-2}) becomes negative value if the input torque of generator 1is smaller than generator 2.But if the two values are of input torque of both generators are equal, then power flow via tie - line, (P_{1-2}) becomes zero. The fuzzy logic controller though rather basic in its control, however, it proves that it is indeed a good controller due to its simplicity. With careful tuning of scaling factors much better response can be succeeded from the fuzzy logic controller.

ACKNOWLEDGEMENT

This authors are grateful to University Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education Malaysia for supporting this research in parts through the grant FRGS/2/2014/TK03/FKE/01/F00238.

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