# Fast and Efficient Inter-Area Power Oscillation Damping in Two Area Four Machine Power System using Sugeno Type Fuzzy-PID Controller at different fault by using MATLAB

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*Abstract* - Power systems are steadily growing with ever larger capacity. Formerly separated systems are interconnected to each other. Modern power systems have evolved into systems of very large size. With growing generation capacity, different areas in a power system are added with even large inertia. As a consequence in large interconnected power systems, low frequency oscillations have an increasing importance. Low frequency oscillations include local area modes and inter-area modes. Inter-area modes of oscillations may be caused by the either high gain exciters or heavy power transfer across weak tie line. The occurrence of the inter-area power oscillations depends on various reasons such as weak ties between interconnected areas, voltage level, transmitted power and load. At time, the oscillations may continue to grow causing the instability of the power system. lots of power system stabilizers have been developed by the researchers in the past few years, but the area is still open for the efficient power stabilizer development which can efficiently able to handle the power oscillations without increasing the system controller system complexity. This paper presents recent developments in power system stabilizers for two area four machine system transmission lines power stabilization.

*Index term* - PID Controller, Power System Stabilizer (PSS), Multi area machine system, Power oscillation Damping, Sugeno type Fuzzy-PID hybrid controller, PID-PSS.

#### I. INTRODUCTION

Throughout the world, the electric industry is undergoing a transformation of how the industry is organized and operated. The goal is to disassemble the traditionally vertically integrated system to form an open market system. Although the specific approach of restructuring can be quite different in different countries, in different regions and in different networks, most of implementations involve the following components;

- Power generation components will be operating in an open competitive environment with many players.
- Non-utility entities will have the right to sell the energy to any load.
- The transmission system will be an open access system. All market participants will be allowed to access the transmission system and transmit energy across the system provided the reliability criteria are met.
- To ensure the impartiality of access to transmission system, transmission system operation may need to be operated by an impartial organization.
- Traditional Utilities will no longer be the single entity to control the production, quality, and delivery of the service. It
  implies a shift of some reliability responsibility along with the transition.

Fig.1 illustrates the relations of a typical restructured power system. Under this structure, an impartial organization called the Regional Transmission Operator (RTO) or Independent System Operator (ISO) plays a vital role in ensuring the reliable and impartial operation of power systems.



Fig.1 Restructured Power System

Oscillation instability is one such kind of problems. It has become one of the major concerns in system operation and planning today. The initial occurrences of oscillation instability accompanied the wide use of fast responding and high-response exciters, which are used to limit first-swing transient instability as well as increase steady-state transfer limits. However, high-response exciters in some cases result in decreased damping of power swings and as a result may cause oscillatory instability. Another source of oscillatory instability problems comes from the growth in interconnections among power systems. With heavy power transfers on inter-area tie line, such systems are easy to have low frequency inter-area modes, of oscillation. In many situations, electro-mechanical oscillation instability has become an operational constraint, which limits the transfer or generation capacities of a power system.

This paper presents a novel way to achieve fast and efficient damping of Inter-area oscillations and improve the dynamic stability of interconnected power systems by designing of an Sugeno type Fuzzy-PID hybrid controller for efficient Inter-area power oscillation damping in two area four machine power system.

#### II. FOUR MACHINE TWO AREA SYST<mark>EM</mark>

The test system present in MATLAB 2012(b) consists of two fully symmetrical areas linked together by two tie 230 KV lines of 220 Km length as shown in Fig.2. It was specifically designed to study low frequency electromechanical oscillations in large interconnected power systems. Despite its small size, it mimics very closely the behavior of typical system in actual operation. Each area is equipped with two identical round rotor generators rated 20 KV/900 MVA. The synchronous machines have identical parameters except for the inertias which are H = 6.5s in area 1 and H is = 6.175s in area 2. Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciter with a 200 gain. The load is represented as constant impedance and spilt between the areas [1, 11, and 12].



Fig. 2 Four-Machine Two Area power system for Stability Analysis

Now the actual simulation model implemented for analysis of the PID-PSS and proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) for Inter-area power oscillation stability is shown in fig.3. Fig.4. Shows the internal structure of area-1 of the implemented power study testing system and fig. 5 Depicts the Internal configuration of Turbine and regular consisting the conventional PID controller and proposed sugeno type fuzzy PID hybrid controller.Fig.6 shows the internal configuration of output signals. Fig. 7 shows the internal configuration of system data.



Fig.3 Definite simulation model implemented with PID-PSS and proposed Sugeno PID-PSS for Inter-area power oscillation stability Analysis.



Fig.4 Internal configuration of area-1(subsystem) & Fig.5 Internal configuration of Turbine and regulator With PID-controller and proposed sugeno type fuzzy PID Controller



Fig.6 Internal configuration of Output signals (sub system) & Fig.7 Internal configuration of System data (sub system)

### III. PROPOSED SUGENO TYPE FUZZY PID CONTROLLER

#### The PID Controller

Due to their simple structure and robust performance, proportional-integral-derivative (PID) controllers are the most commonly used controllers in industrial process control. The transfer function of **a** PID controller has following form:

$$G(s) = K_p + \frac{\kappa_i}{s} + K_d s \qquad \dots (3.1)$$

Where  $K_p$ ,  $K_i$  and  $K_d$  are called the proportional, integral, and derivative gains, respectively.

#### Analysis of a Fuzzy Controller

Consider a product-sum type fuzzy controller with two inputs and one crisp output (MISO). Let the inputs to the fuzzy controller be the error e and the rate of change of the error e, and the output of the fuzzy controller (that is the input to the controlled process) be u. If an analysis of this controller is made, it can be seen that it behaves approximately like a PD controller. We can therefore consider it as a time-varying parameter PD controller. Such a controller is named as a PD type fuzzy controller (PDFC) in the literature. It is well known that if the controlled system is type "0", a P or PD type controller cannot eliminate the steady-state error. Although the use of an integral term in the controller (such as PI controller) can take care of the steady-state error, it can deteriorate the transient characteristics by slowing the response. However, with a PID-type fuzzy controller fast rise times and small overshoots as well as short settling times can be achieved with no steady-state error.

#### **PID Type Fuzzy Control**

In order to design a PID type fuzzy controller (PIDFC), one can design a fuzzy controller with three inputs, error, and the change rate of error and the integration of the error. Handling the three variables is however, in practice, quite difficult. Besides, adding another input to the controller will increase the number of rules exponentially. This requires more computational effort, leading to larger execution time. Because of the drawbacks mentioned above, a PID type fuzzy controller consisting of only the error and the rate of change of error is used in the proposed method. This allows PD and PI type fuzzy controllers to work in parallel. An equivalent structure is shown in Fig. 8, where  $\beta$  and  $\alpha$  are the weights of PI and PD type controllers, respectively. Similarly, K and Kd are the scaling factors for e and e', respectively. As the  $\alpha/\beta$  ratio becomes larger, the effect of the derivative control increases with respect to the integral control.



Fig. 8 Block diagram of the PID type fuzzy control system

... (3.2)

The output of the controller can be expressed as,

 $u_c = \propto u + \beta \int u dt$ 

This controller is called as PID type fuzzy controller (PIDFC).

#### Development of Proposed Sugeno Type Fuzzy PID Type Controller

During the development of fuzzy controller two variables, error (e) which is the rotor speed deviation (in pu) has been used as first input variable for designing of fuzzy controller. On the same time the rate of change of error signal ( $\dot{e}$ ) has been taken as the second input variable for the fuzzy controller. The membership functions of error (e), change rate of error ( $\dot{e}$ ) are shown in Fig.9 and Fig.10, are chosen as triangular membership functions. On the other hand, since the proposed fuzzy-PID controller uses Sugeno type fuzzy inference the control signal (u) is selected as linear as shown in figure 11.



Fig. 9 The membership functions of error (e) & Fig. 10 The membership functions of rate of change of error(e)

	Membership function plots	plot points: 181					
U5							
U4		U9					
U3		US					
U2		U7					
U1		U6					
output variable "u"							

Fig. 11 Output control signal u as a linear function

Finally the rule base designed and employed for the fuzzy PID type controller are given as

- 1. If (e is Small) and (edot is Small) then (u is U1) (1)
- 2. If (e is Small) and (edot is Medium) then (u is U2) (1)
- 3. If (e is Small) and (edot is Large) then (u is U3) (1)
- 4. If (e is Medium) and (edot is Small) then (u is U4) (1)
- 5. If (e is Medium) and (edot is Medium) then (u is U5) (1)
- 6. If (e is Medium) and (edot is Large) then (u is U6) (1)
- 7. If (e is Large) and (edot is Small) then (u is U7) (1)
- 8. If (e is Large) and (edot is Medium) then (u is U8) (1)
- 9. If (e is Large) and (edot is Large) then (u is U9) (1)

#### **IV. SIMULATION RESULTS**

Performance of the PID-PSS and proposed Hybrid-PSS was evaluated by applying a large disturbance caused by various line to line(LL), line to line to ground (LLG) and line to line to line(LLL) fault applied at the middle of one tie line for 0.2 sec duration. Fault may be applied at 1 sec. and cleared after 1.2 sec by opening the breakers, with one tie-line the system can reach a stable operating point in steady state. The Parameters of PID-PSS used in test generators are given in Table 1. Each generator parameters are based on data in Table 2.

Table 1: Parameter of PID controller			Table 2:		<mark>: Para</mark> meters of the gene rator	
Parameter	Kn	K1	Kd	Parameter	Generator	/ /
G1	30	10	0.001	Xd	1.8	
G2	10.50	0.67	0.001	Xd'	0.3	
G2 G3	10.50	0.67	0.45	Xd"	0.25	0
G4	10.50	0.67	0.45	Xq	1.7	X
04	10.50	0.07	0.45	Xq'	0.55	
				Xq"	0.25	
		× .		Xt	0.2	
			Tdo	8		
		- 2		Tdo'	0.03	
				Τq	0.4	

To investigate the Inter-area power oscillation damping performance of No controller, PID controller and proposed sugeno type fuzzy PID Hybrid controller with two-area four-machine test system, the line to ground (LG) fault was considered in the simulation studies. A various line to line(LL), line to line to ground (LLG)and line to line to line(LLL) fault of 0.2sec duration is simulated at line-1. Fault may be applied at 1 sec. and cleared after 1.2 sec Fig. 12 and Fig. 13, Fig.14, Fig.15, Fig. 16, Fig. 17, Fig. 18, Fig. 19, Fig. 20, Fig. 21, Fig. 22, Fig. 23. Shows the compared system response under with Sugeno type fuzzy PID hybrid controller, with PID controller and without any controller.

0.05

Τq



Fig.12 Active power transfer from B1 to B2 at LL fault



Fig.14 Positive sequence voltage of bus1 at LL fault



Fig.16 Active Power transfer from bus-1 to bus2 at LLG fault



Fig.18 Positive sequence voltage of bus1 at LLG fault



Fig.13 System speed deviation at LL fault



Fig.15 Positive sequence voltage of bus2 at LL fault



Fig.17 System speed deviation at LLG fault



Fig.19 Positive sequence voltage of bus2 at LLG fault



Fig.20 Active Power transfer from bus-1 to bus2 at LLL fault Fig.21 System speed deviation at LLL fault



Fig.22 Positive sequence voltage of bus1 at LLL fault Fig.23 Positive sequence voltage of bus2 at LLL fault

#### **V. CONCLUSION**

This work forwarded a novel way to achieve fast and efficient damping of Inter-area power oscillations. By the development of the project work an improved dynamic stability of interconnected power systems has been achieved by designing of an Sugeno type Fuzzy-PID hybrid controller for efficient Inter-area power oscillation damping in two area four machine power system. The basic aim was to exploit unique advantage of the fuzzy based advance control structure.

After the successful implementation of the proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS), a complete testing process have been performed by generating line to ground fault. The detail description and discussion about the testing results for proposed work and conventional PID-PSS have been given separately in the results section.

This paper also presents a complete comparative analysis of Inter-area power oscillation damping capabilities of proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS), conventional PID controller based power system stabilizer (PID-PSS) and without any controller. The obtained results shows that the Inter-area power oscillation damping capability of proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) is much higher than the conventional PID-PSS.

In addition to this the results also indicates that, the proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) takes only 4 sec to completely damp the Inter-area power oscillations, whereas PID-PSS takes even more than 12 sec to control the power oscillations.

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