Analytical structure of three input fuzzy PID power system stabilizer with decoupled rules

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Abstract:

Power system stabilizer must be capable of providing appropriate stabilization signals over a broad range of operating conditions and disturbances. Traditional power system stabilizers rely on linear design methods. To cover a wider range of operating conditions, fuzzy logic power system stabilizers are proposed. Design of fuzzy logic power system stabilizer (FLPSS) is not an easy task. It is very important to appropriately tune the parameters used in FLPSS. These parameters are commonly determined by trail and error method, which is rather time consuming. Hence deriving an analytical structure for the fuzzy controller is very important as it gives the mathematical structure to the FLPSS rather than the 'black-box' approach. In the present paper a systematic approach through analytical structure of PID FLPSS is proposed to approximately tune the parameters. Structurally, a FLPSS is similar to a conventional PID controller, but is nonlinear and adaptive controller in nature whose gains change automatically and continuously with its inputs. This special structure preserves the efficiency of the conventional PID controller while enhances the capability of the controller, particularly for the control of nonlinear and complex processes .The FLPSS can be implemented either by using a three input fuzzy controller with coupled rules or by using three input fuzzy controller with decoupled rules. The advantage of the second type is the number of rules required to implement the FLPSS reduces. In the present paper a FLPSS is implemented using a three input fuzzy controller with decoupled rules. The dynamic response of FLPSS following perturbation in excitation for a single machine connected to infinite bus bar is observed. The robustness of the controller is emphasized.

***Key words**: Power system stabilizer, Fuzzy PID, Analytical structure, multi operating, nonlinear, decoupled rules*

1.Introduction:

The basic function of a PSS is to extend stability limits which are characterized by lightly damped or spontaneously growing oscillations in the 0.2 to 2.5 Hz frequency range [1]. This is accomplished via excitation control to contribute damping to the system modes of oscillation. Consequently, it is the stabilizer's ability to enhance damping under least stable condition. A PSS can be most effectively applied if it is tuned with the understanding of the characteristics of the power system associated. Considerable efforts have been directed towards developing an adaptive PSS. In an attempt to cover a wide range of operating conditions, expert or rule-based fuzzy logic controllers have been proposed for PSS. The major advantage of the FLPSS is its model independency. However the disadvantage of FLPSS mainly comes from the heuristic knowledge or expertise of human experts. This sought of knowledge is sometimes difficult to acquire and represent in the required form. Secondly, the parameters of FLPSS are determined by trail and error method. This method is time consuming and does not guarantee an optimal controller. In order to analyze and design a FLC, analytical structure of FLC in relation to classical controllers is essential. Several authors have discussed about the structure of P and PI controller [2] [3] [4] [5] [6]. In the present paper a technique to systematically tune the fuzzy PID controller with decouples rules based on the analytical structure is presented. The proposed FLPSS uses δ , $\dot{\delta}$, $\ddot{\delta}$ as input signals to obtain the required output. The dynamic responses following perturbation in excitation and perturbation in torque for a single machine connected to infinite bus bar are observed.

2.System Model

The small perturbation block diagram of a synchronous machine connected to infinite bus system [7] is considered. The exciter is assumed to be of the thyristor type. Amortisseur effects, armature resistance, armature pψ terms and saturation are neglected. The linearized model parameters K1 to K6 vary with operating conditions with the exception of. K3.

3.Fuzzy PID Power system stabilizer:

For the proposed PID FLPSS δ , $\dot{\delta}$, $\ddot{\delta}$ are the inputs to the controller. The idea of knowledge base decoupling is to formulate a set of rules for the fuzzy controllers. The structure of the fuzzy PID controller using decoupled rules is implemented using three single input fuzzy components corresponding to the decoupled rules for generating the fuzzy incremental control signal. The structure of the fuzzy PID controller is as shown in fig1

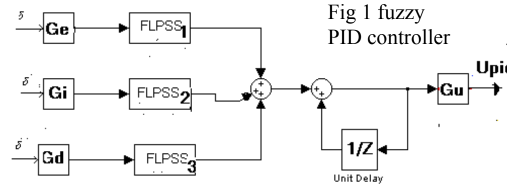


Fig 1 fuzzy PID controller

The output of FLPSS 1 is Δu_i ,the output of FLPSS2 is Δu_p and for FLPSS3 the out put is Δu_d

The knowledge base can be expressed using decoupled rules as

[IF δ is E_i THEN Δu_i IS $U_{m1,I}$]

[IF $\dot{\delta}$ is E_j THEN Δu_p IS $U_{m2,P}$]

[IF $\ddot{\delta}$ is E_i THEN Δu_d IS $U_{m3,D}$]

The rule base inference is independent and the output constitutes three separate non-linear functions. The number of rules required to implement the fuzzy controller are N1+N2+N3. Where N1 is the number of rules required to implement FLPSS1,N2 the number of rules required to implement FLPSS2 and N3 the number of rules required to implement FLPSS3 . The final control action is given by

$$u_{pid} = G_u \sum_{q=0}^{n} (\Delta u_p(q) + \Delta u_i(q) + \Delta u_d(q))$$

4.Analytical structure of single input single output fuzzy controller

Let us consider, a three rule fuzzy controller with symmetrical triangular membership functions. The input membership function are uniformly distributed over the universe of discourse(USD),which is defined as [-a,+a], with a 50% overlap to satisfy the rule completeness during the inference.

Let the fuzzy variables be labeled with ‘NB’,”ZE”,”PB” representing negative big, zero equal and positive big. The total number of linguistic variables are N=3 with J Mf on the positive and J on the negative and one at zero 'input'. The MF are designated as (μ_{-1} $\mu_{-0}\mu_{1-}$} in the indexed form. Generally for any fuzzy set μ_I,

$$\mu_i(\delta) + \mu_{i+1}(\delta) = 1$$

Then the center values of adjacent fuzzy sets is equal to

$$A = \frac{L}{J} = \frac{L}{1} = L \qquad \text{--4}$$

Assume there are three that is one membership functions for the negative and one for positive and one for zero 'output'. If the central value of the output MF is denoted by γ, then γ_{-1}=-H, γ_0=-0, γ_1=H

The space between the adjacent output functions is given by

$$V = \frac{H}{J} \qquad \text{--5}$$

Let the output Mf be described by {NB, ZE, PB}

The three rules for one input PID controller element can be writes as

R1: If δ is NB then Δu_i is NB

R2: If δ is ZE then Δu_i is ZE

R3: If δ is PB then Δu_i is PB

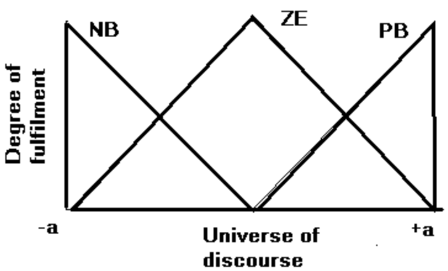


Fig 2

The input membership function for PB can be represented as μ_1.

Let the input δ at some instant be equal to 'e' as shown in fig3. 'e' should lie in the USD defined by [-a +a] at any sampling time 'T'. For

$$iA \le e \le (i+1)A$$

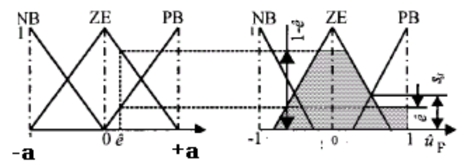
$$\mu_i(\omega) = -\frac{1}{A}\left[\omega - (i+1)A\right] \text{---6}$$

$$\mu_{i+1}(\omega) = \frac{1}{A}\left[\omega - (i)A\right] \text{---7}$$

Then 'e' can either be PB or ZE To determine the result of Zadeh AND operator, the Minimum operation is carried out. And the final output is obtained by substituting the memberships as shown in (6),(7) into the centroid defuzzification algorithm. We get

$$G_u\Delta u(nT) = -(i)\frac{G_uH}{N-1} - G_e\beta \times \frac{G_uH}{N-1}$$

Fig 3



Where the first part represents a global multi level rely and the second part represents a proportional controller with nonlinear gain β, which changes with the position from the equilibrium point.

Similarly, we can prove that the outputs of the other two fuzzy controllers can be expressed in the form of a global multi level rely and a nonlinear gain

At equilibrium point, the gains become linear and its action is equivalent to conventional PID controller.

$$K_p = G_d G_u$$

$$K_i = \frac{G_e G_u}{T}$$

$$K_d = G_e G_u T$$

5.Numerical Simulation:

To evaluate the stability of the fuzzy logic power system stabilizer over a wide range of operating conditions, we consider a typical example of a generator connected to infinite bus bar [7] with the data xd=1.6,xd'=0.32,xq=1.55,Tdo=6,H=5,xe=0.4, Te=. 05,Ke=200.

The range of the machine loading [6] considered is (1) 1+j0 (2) 1+j0.5 (3) 1-j0.5 (4) 0.5+j0 (5) 0.1+j0.

The simulations were carried out for all the operating conditions and results of two cases 1-j0.5 which is the most unstable case and 0.1+j0 which is a lightly loaded and under damped case are presented in fig 5 (a-d). The simulations were carried out for a 0.05 pu step change of excitation et. The plots show speed and rotor angle response to this disturbance for the system with FLPSS designed

Fig 4(a) delta .1+j0

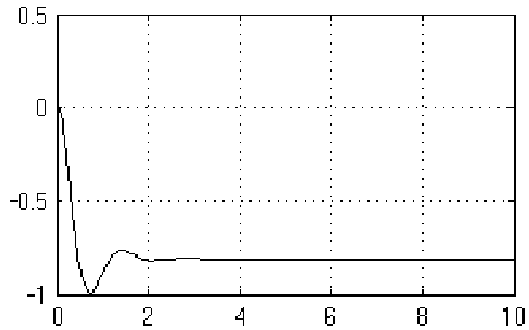


Fig 4(b) delta for 1-j0.5

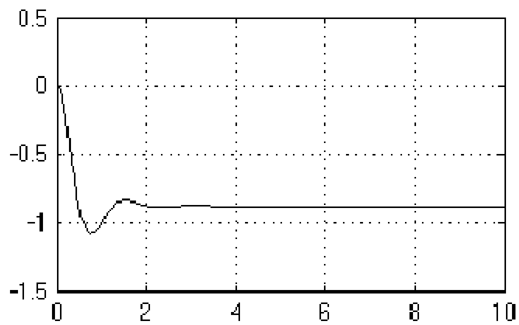
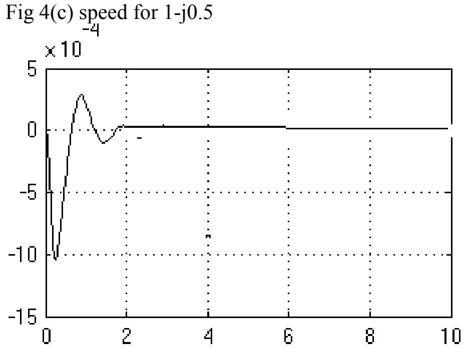


Fig 4(c) speed for 1-j0.5



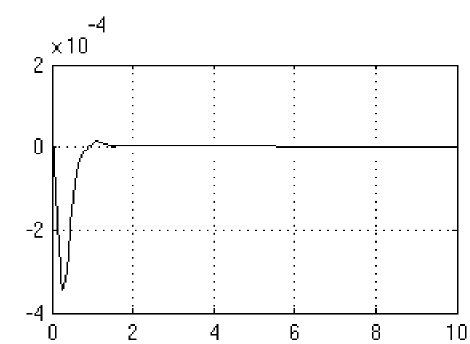


Fig 4(d) speed for .1+j0

6.Performance Analysis

6.1.SMALL SIGNAL STABILITY

For small disturbances, stability can be characterized by the system linearized about the operating point. To obtain the parameters of the FLPSS, the classical PID controller parameters designed using the phase variable model are used.
Kp=-3.6, Ki= -0.6, Kd= -0.1.

Hence the values of FLPSS with a sampling time of 0.01 s is calculated .The PID controller parameters are used as a starting point to further tune the PID controller. The results show that the performance of the FLPSS yields almost the same rise time and overshoot as the classical PID controller.

7.Conclusions

This paper proposes a general analytical structure for a fuzzy logic PID stabilizer. It is seen that a PID FLPSS is equivalent to a nonlinear PID controller and at equilibrium point it is equivalent to a PID controller. Thus the classical PID parameters can be used as a starting point for tuning the FLPSS. The advantage of this design approach is that the controller is insensitive to the precise dynamics of the system. Simulation of the response to disturbances has demonstrated the effectiveness of this design technique. Small signal stability analysis gives some evidence of the robustness of the controller.
This research is directed at developing systematic methods of design and analysis for fuzzy logic based stabilization control.

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