Power System Transient Stability Robust control using Fuzzy Logic PSS and Genetic Algorithm

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Abstract- This paper describes the implementation of fuzzy logic power System Stabilizer (FLPSS) to enhance transient stability of multimachines power systems. Genetic Algorithms (GA) are used to search for optimal settings of FLPSS parameters. The performance of the proposed FLPSS, under different disturbances and loading conditions, is investigated for the IEEE 3-machines 9-bus test system. The obtained results show the capability of FLPSS to enhance power system transient stability over a wide range of loading conditions.

Keywords-Transient Stability, Robust Control, Power System Stabiliser, Fuzzy Logic, Genetic Algorithm

1. INTRODUCTION

Due to growing interconnections between networks, deregulated electrical markets and rising complexity of electrical power systems, there has been increasing interest in the stabilization of such large-scale power systems. PSS are used to generate a supplementary stabilizing signal, which is applied to the excitation system or control loop of the generation.

In the past, stabilizers were effectively used for damping out the low frequency oscillation [1, 2]. The gain settings of these stabilizers are determined based on the linearized model of the power system around a nominal operating point to provide optimal performance at this point. Generally, the power systems are highly nonlinear and the operating conditions can vary over a wide range. Also the network topology can change with contingencies. Therefore, PSS performances degraded whenever the operating point changes from one to another witch is the case in transient stability studies.

Recently, alternative control schemes based on fuzzy logic have been proposed [3-7]. They used several approaches to design the PSS, namely: the rule-based stabilizer, adaptive stabilizers, robust control and fuzzy logic control. Out of these schemes, fuzzy control appears to be the most suitable one, due to the fact that it could easily be constructed using A/D and D/A converters [8].

The operating conditions of the generators are expressed by the quantities of speeds deviations and accelerations in the phase plan [4].

The supplementary stabilising signal is determined using fuzzy membership function. A continuous nonlinear function is considered to be more suitable for power system transient stability improvement. The choice of scaling factors is done either iteratively or by trial-and-error [6].

Genetic Algorithms are search algorithms based on the mechanism of natural selection and survival of the fittest. They are powerful optimisation techniques which have, recently, been applied to power system problems with promising results [5].

In this paper, we use genetic algorithms to find the optimal setting parameters of fuzzy logic power system stabilizers in order to enhance the multi-machine power system transient stability. A generalised software tool is elaborated and the simulations performed through the IEEE 3-machine 9-bus test system give promised results.

2. FUZZY LOGIC CONTROL SCHEME

The IEEE 3-machine 9-bus system [1] is considered. The system model is given in Appendix. FLPSS are implemented in parallel with excitation loops of generators. These FLPSS produce signals $u_i(t)$ witch is added to the excitation loop at time t, $u_i(t)$ is given by:

$$u_i(t) = U_{ci}(k), \quad kT_s < t < (k+1)T_s \qquad (1)$$

The value of $u_i(t)$ is determined at each sampling time based on fuzzy logic through the following Steps:

Step 1: Speeds deviations, $\Delta\omega_i(k)$ are measured at every sampling time, and machines' accelerations $A_i(k)$, are calculated by:

$$A_i(k) = (\Delta\omega_i(k) - \Delta\omega_i(k-1))/T_s \quad i=1,2\,..n \qquad (2)$$

n : is the number of generator

Step 2: Compute the scaled acceleration, $As_i(k)$ using:

$$As_i(k) = As_i(k)\,F_{ai} \qquad (3)$$

F_{ai} : is FLPSSi tuning parameter

Step 3: Generators conditions are given by points $C_i(k)$, where:

$$C_i(k) = (\Delta\omega_i(k), As_i(k)) \qquad (4)$$

Step 4: Calculate $R_i(k)$ and $\theta_i(k)$ by:

$$R_i(k) = |C_i(k)| \qquad (5)$$

$$\theta_i(k) = tag^{-1}(As_i(k)/\Delta\omega_i(k)) \qquad (6)$$

Step 5: Compute the values of the membership functions $Ns_i(\theta_i)$ and $Ps_i(\theta_i)$ defined as [5]:

$$Ns_i(\theta_i) = \begin{cases} 1-\phi_i(\theta_i;\theta_{ji};\theta_{m1i};\theta_{mi})\forall\theta_i \le \theta_{mi} \\ \phi_i(\theta_i;\theta_{mi};\theta_{m2i},2\pi)\forall\theta_i > \theta_{mi} \end{cases} \qquad (7)$$

θ_{ji} : FLPSSi tuning parameter

and

$$Ps_i(\theta_i) = \Psi(\theta_i, 2\pi - \theta_i, \theta_{mi}) \qquad (8)$$

where:

$$\phi(x,a,b,c) = \begin{cases} 0.0 \forall x \le a \\ 2\,[\frac{x-a}{c-a}]^2 \;\forall x \in \,]a,b] \\ 1-2[\frac{x-c}{c-a}]^2 \;\forall x \in \,]b,c[\\ 1.0 \forall x \ge c \end{cases} \qquad (9)$$

$$\Psi(x,b,c) = \begin{cases} \phi(x; c-b, c-b/2, c) \,\forall x \le c \\ 1-\phi(x; c, c+b/2, c+b) \;\forall x > c \end{cases} \qquad (10)$$

$$\theta_{mi} = (2\pi + \theta_{ji}/2) \qquad (11)$$

$$\theta_{m1i} = (\theta_{ji} + \theta_{mi}/2) \qquad (12)$$

$$\theta_{m2i} = (2\pi + \theta_{mi}/2) \qquad (13)$$

$$G_{ci}(k) = \begin{cases} R_i(k)/D_{ri} \;\; \forall R_i(k) \le D_{ri} \\ 1.0 \;\forall R_i(k) > D_{ri} \end{cases} \qquad (14)$$

D_{ri} : FLPSSi tuning parameter

Step 7: Compute the stabilising signal $U_{ci}(k)$ using:

$$U_{ci}(k) = G_{ci}(k)[N_{si}(\theta_i) - P_{si}(\theta_i)]U_{\max i} \qquad (15)$$

Step 8: Increase k by 1 and return to step 1.

3. OPTIMISATION OF FLPSS TUNING PARAMETERS

The main tuning parameters of FLPSS are θ_{ji}, F_{ai} and D_{ri}. For the optimal setting of these parameters, a quadratic performance index J is considered:

$$J = \sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{k=1}^{l}[kT_s\Delta\omega_{ji}(k)]^2 \qquad (16)$$

m: number of operating points

n: number of generator

l: total sampling number

In the above index, the speed deviation $\Delta\omega_{ij}(k)$ is weighted by the respective time kT_s. The index J is selected because it reflects small setting time, small steady state error, and small overshoots. The FLPSS tuning parameters are adjusted so as to minimize the index J. A MATLAB optimisation program is elaborated. We can neglect in this program the FLPSS effect on one or more generator and we can optimize with different contingencies and a lot of operating points.

4. SIMULATION RESULTS

An IEEE 3-generator and 9-bus system has been simulated (Fig.1). The GA is used for the optimization of FLPSS tuning parameters: θ_{ji}, F_{ai} and D_{ri}. The basic operators in GA are reproduction, crossover and mutation. The FLPSS tuning parameters, θ_{ji}, F_{ai} and D_{ri} taken as individuals in GA are represented by a binary string of length 6x9. The first population is generated randomly. The crossover and mutation probabilities are taken as 0.6 and 0.001 respectively. Population size and maximum number of generation are chosen to be 20 and 20 respectively.

The above index is minimised under three different operating conditions (m=3), system with nominal charge (SWNC), loaded system (LS) (+25% of nominal charge) and unloaded system (ULS) (-25% of nominal charge).

The maximum control effort is U_{max} = 0.15 and

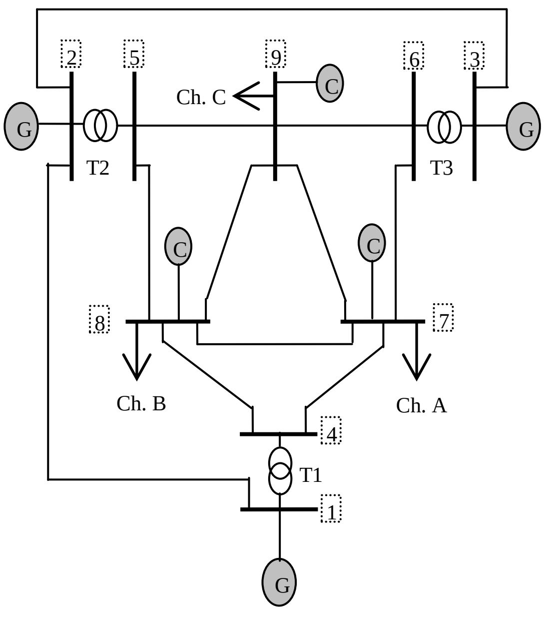

Fig.1: IEEE 3-generator 9-bus test system

time simulation for transient stability evaluation is t=2s. We consider a three line-to-ground fault between bus 1 and bus 2 for 0.3 s and eliminated by opening the default line.

The obtained optimal parameters of FLPSS are shown in table 1.

Table 1 : Optimal FLPSS setting parameters			
Generator FLPSS	θ_{ji}	F_{ai}	D_{ri}
$i=1$	2.6	7.3	10.3
$i=2$	2.3	14.0	1.2
$i=3$	2.5	3.4	16.6

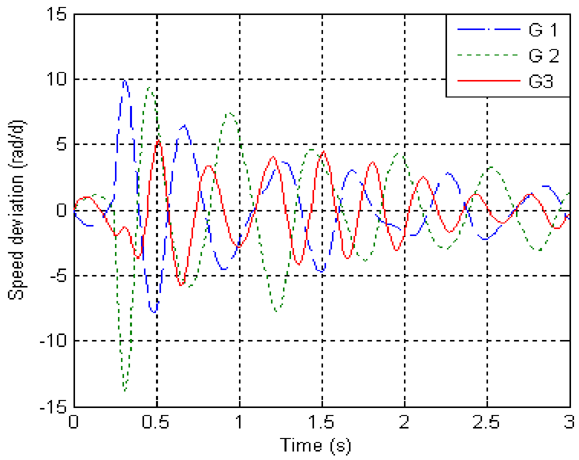

Fig.2: Speed deviation for system without FLPSS, tcl=0.3s, default line: 1-2

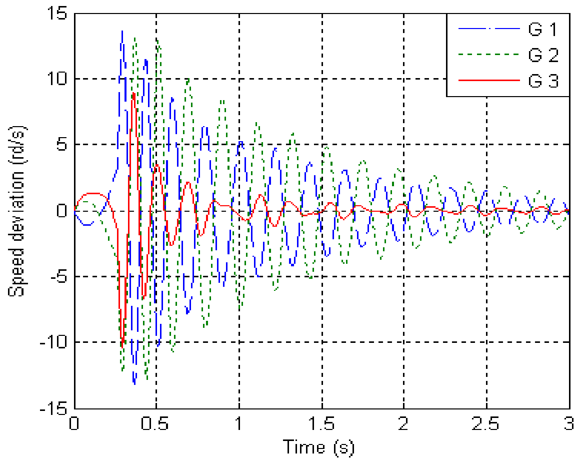

Fig.3: Speed deviation (rd/s) for system without FLPSS, tcl=0.3s, default line: 1-2

Figures 2 and 3 show the ability of the proposed FLPSS to damp out speed deviation after fault elimination.

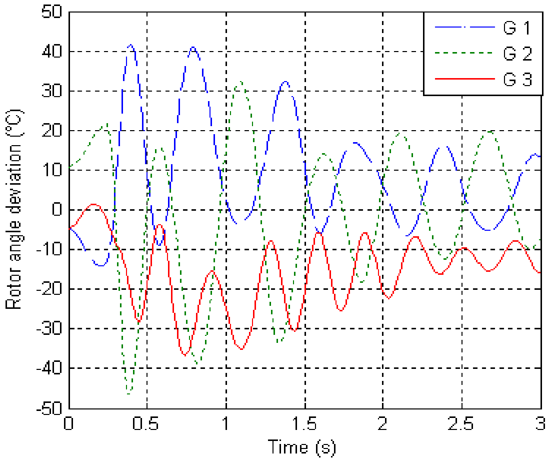

Fig.4: Rotor angle deviation for system without FLPSS, tcl=0.3s, default line: 1-2

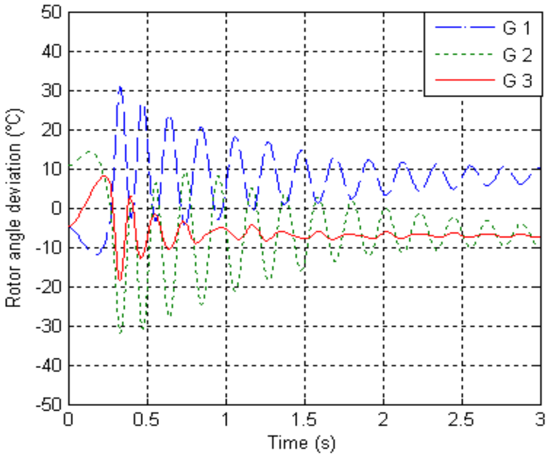

Fig.5: Rotor angle deviation for system without FLPSS, tcl=0.3s, default line: 1-2

Figures 4 and 5 show the ability of FLPSS to enhance transient stability of power system. Number of simulations were performed to demonstrate the robustness of the proposed Genetic Algorithm FLPSS. The results are shown in Table 2.

Table 2: Default Critical Clearing Time (s)

Default line	Default Bus	System	Operating Point		
			ULS	SWNC	LS
1-2	1	*WFLPSS*	0,52	0,25	0,19
		WOFLPSS	0,50	0,23	0,18
5-9	5	*WFLPSS*	0,44	0,34	0,28
		WOFLPSS	0,40	0,31	0,26
6-7	6	*WOFLPSS*	0,49	0,33	0,30
		WFLPSS	0,45	0,31	0,26
8-9	9	*WOFLPSS*	0,55	0,36	0,32
		WFLPSS	0,47	0,32	0,26

where:

WFLPSS: With FLPSS

WOFLPSS: Without FLPSS

Results in table 2 demonstrate the ability of Genetic Algorithms FLPSS to enhance power system transient stability, under a wide rang of operating conditions and for different nature of contingencies. Better critical clearing times are obtained.

5. CONCLUSION

In this study, FLPSS controllers are implemented in parallel with excitation loop at each generator to enhance power system transient stability. AG are used to determine optimal parameters of fuzzy logic under a wide range of operating conditions. Results show the ability of these controllers to provide good damping characteristic during transient conditions. Moreover, the robustness of the proposed FLPSS is demonstrated for different contingencies.

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7. APPENDIX

MODEL

System model for the i^{th} machine is:

$$\frac{d\delta_i}{dt} = \omega_i \quad \text{(A.1)}$$

$$\frac{d\omega_i}{dt} = \frac{1}{M_i}\left(p_{mi} - p_{ei}\right) \quad \text{(A.2)}$$

$$\frac{de'_{di}}{dt} = \frac{1}{T'_{d0i}}\left(-e'_{di} + \left(x'_{qi} - x_{qi}\right)i_{qi}\right) \quad \text{(A.3)}$$

$$\frac{de'_{qi}}{dt} = \frac{1}{T'_{d0i}}\left(-e'_{qi} + e'_{exi} - \left(x'_{di} - x_{di}\right)i_{di}\right) \quad \text{(A.4)}$$

$$\frac{dp_{mi}}{dt} = \frac{1}{T_{vi}}\left(-p_{mi} + p_{mrefi} - K_{vi}\left(\omega_i + \sigma_i \frac{d\omega_i}{dt}\right)\right) \quad \text{(A.5)}$$

$$P_{mi} = P_{mmai} \qquad pour: \qquad P_{mi} \geq P_{mmai}$$

$$P_{mi} = P_{mmii} \qquad pour: \qquad P_{mmii} \geq P_{mi}$$

$$\frac{de_{exi}}{dt} = \frac{1}{T_{ei}}\left(-e_{exi} + e_{ex0i} + K_{vi}\left(v_{refi} - v_i + u_i(t)\right)\right) \quad \text{(A.6)}$$

$$e_{exi} = E_{xmai} \qquad pour: \quad e_{exi} \geq E_{xmai}$$

$$e_{exi} = E_{xmii} \qquad pour: \quad E_{xmii} \geq e_{exi}$$

algebraic interconnections equations are:

$$i_{di} = G_{ij}e'_{di} + B_{ij}e'_{qi} + \sum_{j=1(\neq i)}^{n}\left(e'_{dj}F_{G+B}\left(\delta_{ij}\right) + e'_{qj}F_{G-B}\left(\delta_{ij}\right)\right) \quad \text{(A.7)}$$

$$i_{qi} = G_{ij}e'_{qi} - B_{ij}e'_{di} + \sum_{j=1(\neq i)}^{n}\left(e'_{qj}F_{G-B}\left(\delta_{ij}\right) - e'_{dj}F_{G+B}\left(\delta_{ij}\right)\right) \quad \text{(A.8)}$$

$$v_{di} = e'_{di} - x'_{qi}i_{qi} \quad \text{(A.9)}$$

$$v_{qi} = e'_{qi} + x'_{di}i_{di} \quad \text{(A.10)}$$

$$v_i = \sqrt{v_{di}^2 + v_{qi}^2} \quad \text{(A.11)}$$

$$p_{ei} = G_{ii}\left(e'^{2}_{di} + e'^{2}_{qi}\right) + \sum_{j=1(\neq i)}^{n}\left(C_{ij}F_{G+B}\left(\delta_{ij}\right) - D_{ij}F_{G-B}\left(\delta_{ij}\right)\right) \quad \text{(A.12)}$$

with:

$$F_{G+B}\left(\delta_{ij}\right) = G_{ij}\cos\left(\delta_{ij}\right) + B_{ij}\sin\left(\delta_{ij}\right) \quad \text{(A.13)}$$

$$F_{G-B}\left(\delta_{ij}\right) = B_{ij}\cos\left(\delta_{ij}\right) - G_{ij}\sin\left(\delta_{ij}\right) \quad \text{(A.14)}$$

$$C_{ij} = e_{qi}e_{qj}B_{ij} \quad \text{(A.15)}$$

$$F_{ij} = e_{qi}e_{qj}G_{ij} \quad \text{(A.16)}$$

G_{ij} and B_{ij} are the real and imaginary part of reduced matrix admittance elements *ij*.

NOMENCLATURE

ω , $\Delta\omega$	speed and speed deviation respectively
δ	torque angle
M	inertia constant
P_m	turbine mechanical power
P_e	generator electric power
i_d , i_q	d-axis and q-axis component of stator currents
v_d , v_q	d-axis and q-axis component of terminal voltage
v	terminal voltage
x_d , x_q	direct and quadratic synchronous reactance
x'_d , x'_q	direct and quadratic transient reactance
T'_{d0}	direct transient time constant
T'_{q0}	transversal transient time constant
e'_d , e'_q	direct and transversal transient *f.e.m*
e_{ex}	excitation voltage
e_{ex0}	Excitation voltage initial value
e_q	Permanent *f.e.m*
K_e , T_e	voltage regulator gain and time constant respectively
E_{xma} E_{xmi}	maximal and minimal excitation voltage
K_v , T_v	speed regulator gain and time constant respectively
σ	accelerometer dosage
P_{mma} , P_{mmi}	maximal and minimal mechanic power
$P_{mréf}$	reference mechanic power
T_s	sampling time
$U_{\max}$	maximum control effort