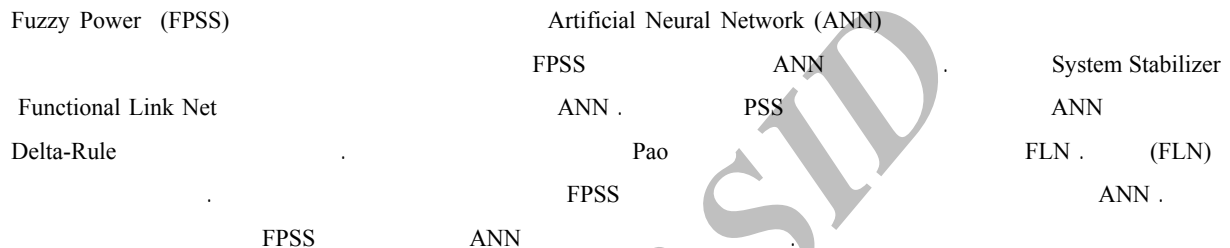


FLN



Generator Excitation Control Using FLN Artificial Neural Network Controller

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Abstract

A new methodology based on a functional link net (FLN) artificial neural network (ANN) is introduced for excitation control of a synchronous generator based on fuzzy power system stabilizer (FPSS). This method combines the advantages of the fuzzy controller along with the independence from model identification and fast processing ANN and proposes a new form of excitation controller for a synchronous generator. Delta-rule is used for training of ANN. ANN is trained for different load patterns which are produced by FPSS, and is continued until the total error was smaller than certain value. The analysis of a three-phase short circuit fault condition under various loading conditions of a single machine infinite bus system is presented to illustrate the application of the developed methodology. The obtained results show that the proposed FLN artificial neural network, based on fuzzy controller for power system stabilizer (PSS), can provide very good damping characteristic through wide range of operating conditions for power system and it has smoother control for system variables; hence it improves dynamic operating of the system considerably.

Key words: Power system stabilizer, Fuzzy control, Artificial neural network, Functional link net, Excitation controller.

[]

[]

ANN

[-]

ANN

ANN

FPSS

ANN

FPSS ANN

ANN

PSS

FLN

[]

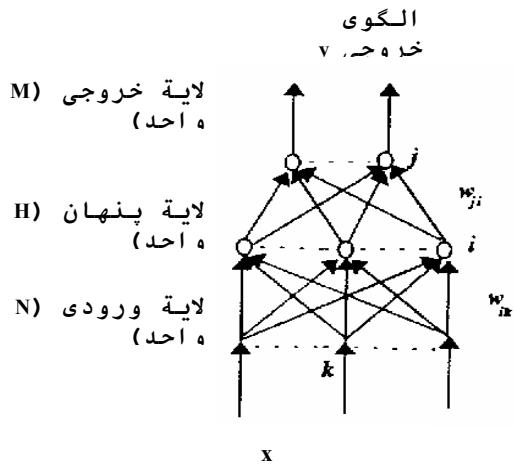
ANN

(Delta Rule or Back Propagation)

FPSS

ANN

ANN



ω

$$net_j = \sum_{i=1}^n W_{ji} O_i$$

$$f = \frac{1}{1 + \exp[-(net_j + \theta_j) / \theta_0]} \quad ()$$

(threshold) θ
 θ_0

Pao

FLN

[]

Archive of SID

[]

ANN

(Robust)

ANN :

ANN

ANN :

ANN

ANN

VLSI

IC

ANN

ANN

ANN

()

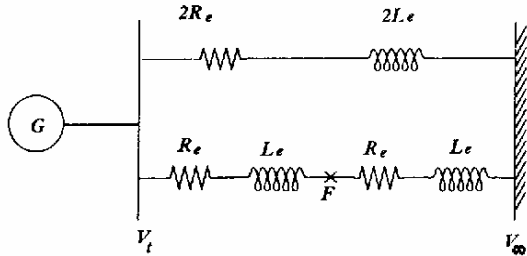
ANN ()

Carpenter/Grossbrg,

() . Hopfield, Perceptron , ...

()

FLN



FLN

FLN

$$\dot{\delta} = \omega - 1 \quad ()$$

FLN

$$\tau_j \dot{\omega} = T_m - T_e - D\omega \quad ()$$

.[[sin kπx, cos kπx, k=1, 2, ...]

$$T_e = \frac{L_d i_q \dot{i}_d + kM_F i_q i_F + kM_D i_q i_D - L_q i_q \dot{i}_d - kM_Q i_d i_Q}{3} \quad ()$$

{x_i} ⇒ {x_i, x_ix_j}_{j≥i} ⇒ {x_i, x_ix_j, x_ix_jx_k}_{k≥j≥i} ⇒ ...

$$V_d = -r_i \dot{i}_d - \omega L_q i_q - \omega kM_Q i_Q - L_d \dot{i}_d - kM_F i_F - kM_D \dot{i}_D \quad ()$$

FLN

$$-V_F = -r_F i_F - kM_F i_d - L_F \dot{i}_F - M_R \dot{i}_D \quad ()$$

$$V_D = 0 = -r_D i_D - kM_D i_d - M_R i_F - L_D \dot{i}_D \quad ()$$

Sobajic

FLN

(Flat)

$$V_q = \omega L_d i_d + \omega kM_F i_F - r_i \dot{i}_q - L_q \dot{i}_q - kM_Q i_Q \quad ()$$

[]

FLN

$$V_Q = 0 = -r_Q i_Q - kM_Q i_q - L_Q \dot{i}_Q \quad ()$$

(Hidden)

: L_e R_e

[]

Delta-Rule

() R

$$V_d = -\sqrt{3}V_\infty \sin(\delta - \alpha) + R_e i_d + L_e \dot{i}_d + \omega L_e i_q \quad ()$$

$$V_q = \sqrt{3}V_\infty \cos(\delta - \alpha) + R_e i_q - \omega L_e i_d \quad ()$$

$$\Delta \dot{\omega} \quad \Delta \omega \quad [] \quad ()$$

U_c

$$T_A \dot{E}_{FD} = -E_{FD} - k_A V_{ST} + k_A (V_{REF} - V_t + U_c) \quad ()$$

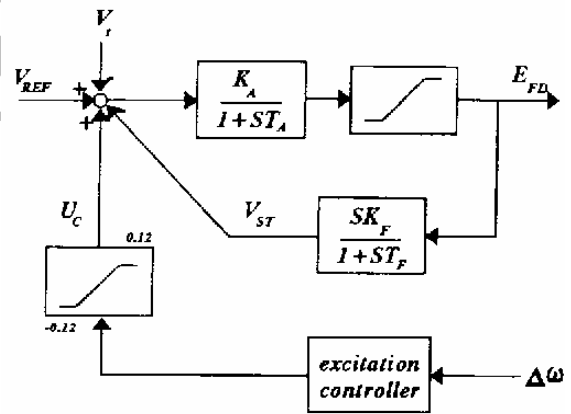
[]

$$T_F \dot{V}_{ST} = -V_{ST} + k_F \dot{E}_{FD} \quad ()$$

PI

P=1.5 pu

PI



() U_c

FLN ANN

FLN ANN

FLN

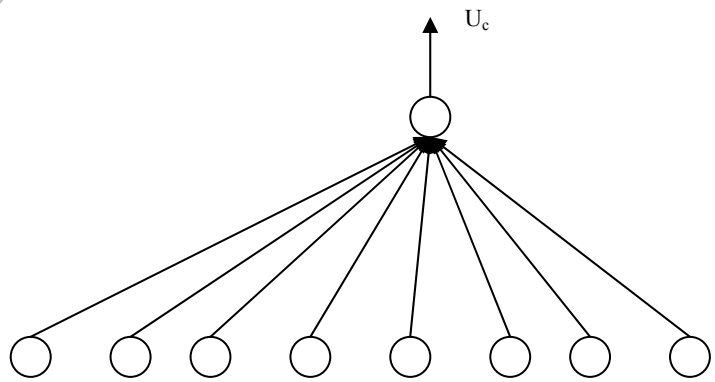
Δω

[]

Δω̇

FLN (Generalized Delta-Rule Delta-Rule)
PSS ω
P=1.5 pu ω(n- ω(n-1) ω
FLN ω(n-3) 2)
() F U_c ANN
ANN [] Pao
()
FLN sinπω(n-1) cosπω(n-1) sinπω(n) cosπω(n)
sinπω(n-2) cosπω(n-3) sinπω(n-2) cosπω(n-2)
ω(n)ω(n-3) ω(n-1)ω(n-3) ω(n)ω(n-2)
[]
ANN ()
ANN ANN
ANN PSS FPSS
X_{norm} X_a ANN
X_{max} ANN
X_{min} - PSS -
U_L L_L ANN
L_L U_L ANN
/ / ANN
FPSS
(clustering)

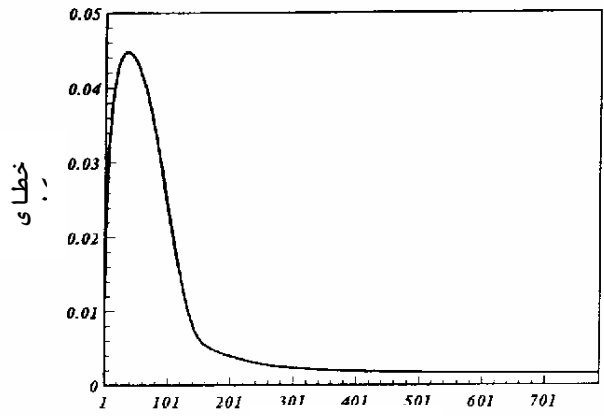
$$X_{norm} = \frac{X_a - X_{max}}{X_{max} - X_{min}} (U_L - L_L) + L_L$$



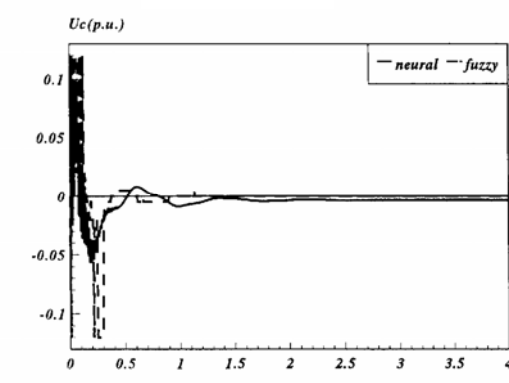
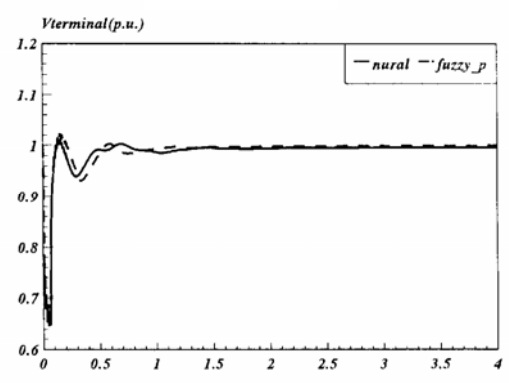
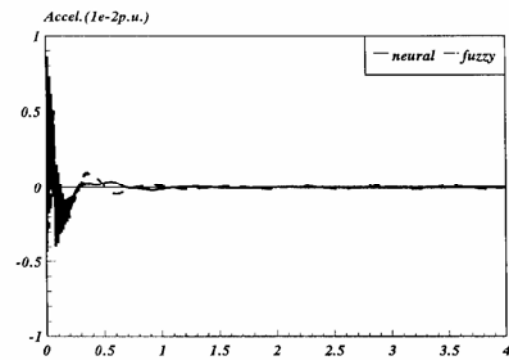
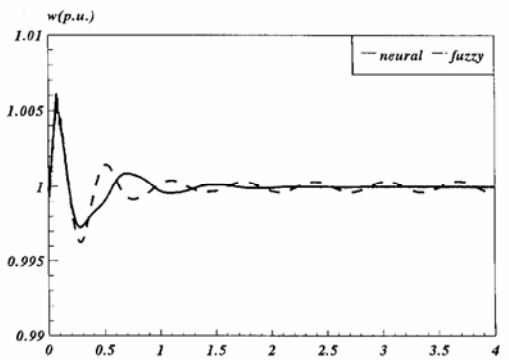
ω, ω(n-1), ω(n-2), ω(n-3), cosπω(n), sinπω(n), ..., ω(n)ω(n-2), ω(n)ω(n-3)

FLN

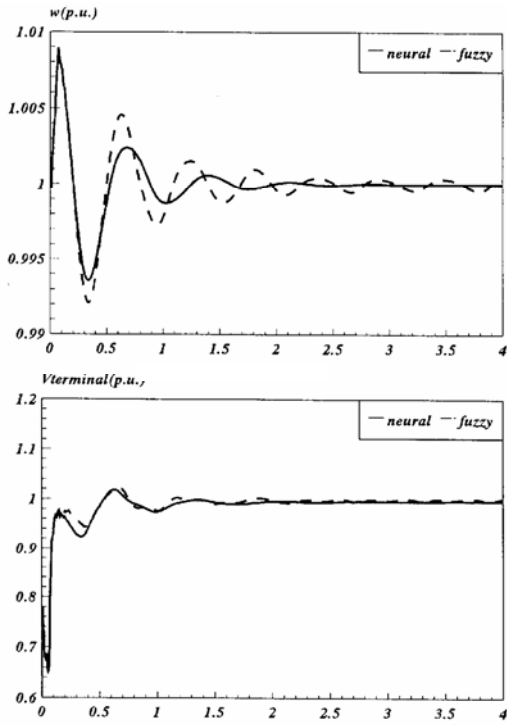
P=1.5 pu P=1 pu ()
 P=1, 1.3, 1.4, ANN ANN
 () 1.5 pu FPSS



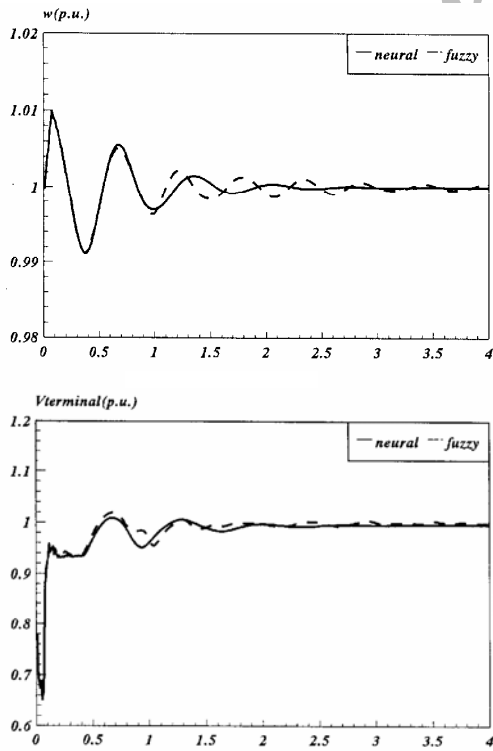
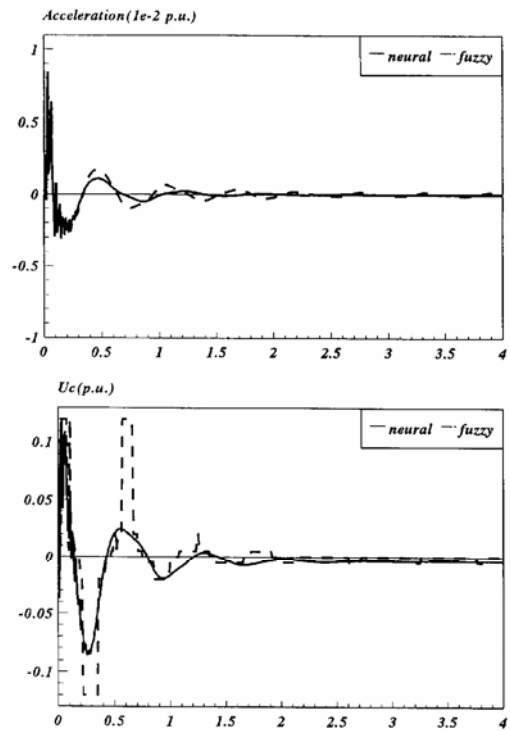
تعداد
 FLN



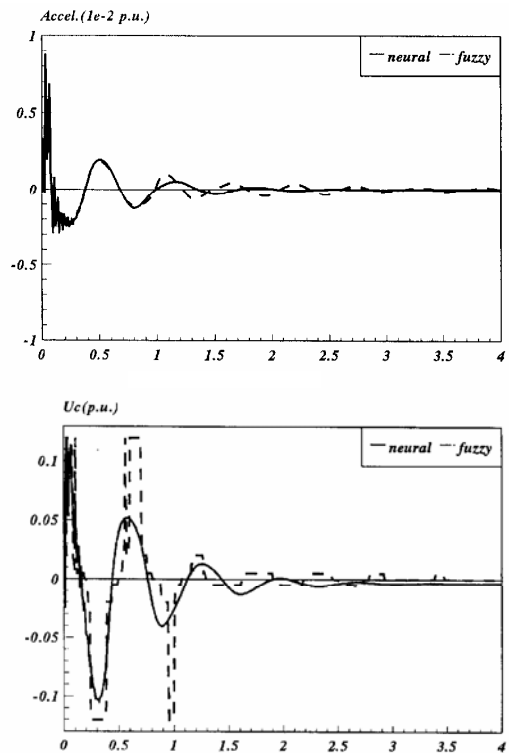
(s) P=1 pu

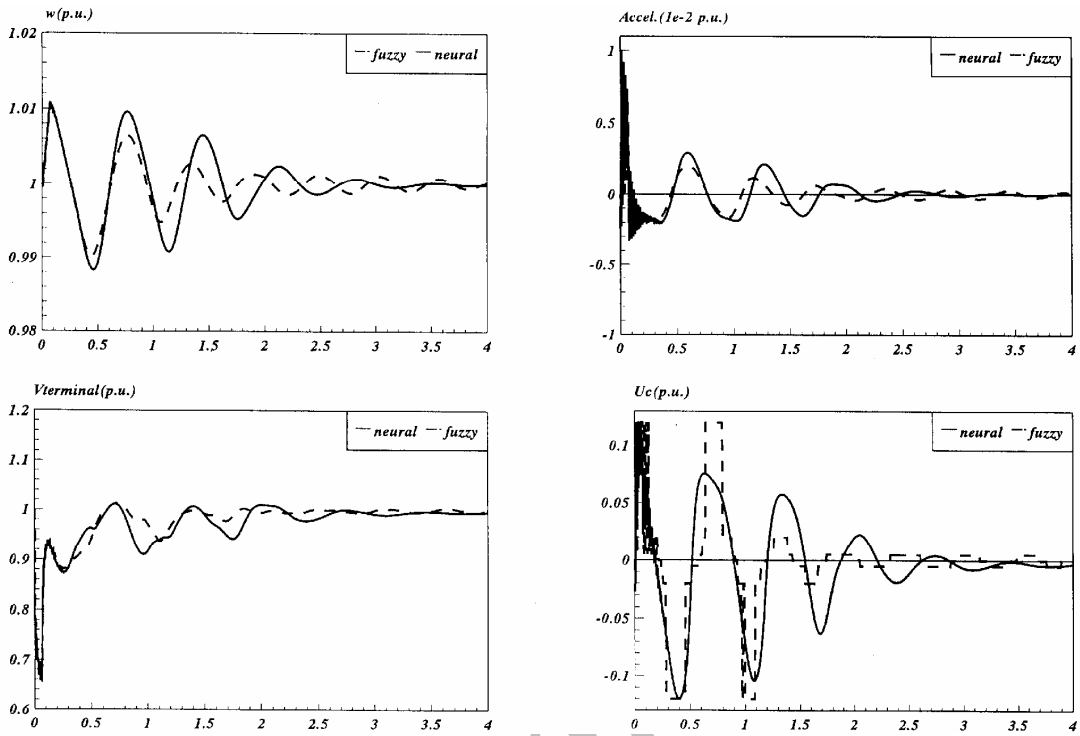


(s) P=1.3 pu



(s) P=1.4 pu





(s) P=1.5 pu

(AVR)

PSS

PI

(%)

ANN

FPSS

ANN

FPSS

ANN

ANN

FPSS

FLN

FPSS

ANN-PSS

FPSS

(P=1.5 pu)

ANN

ANN

ANN

(overshot)

P=1, 1.3, 1.4 pu

(settling time)

T_m					
E_{FD}		FLN			
R_e				ANN	Delta-Rule
L_e					
i_d	d			ANN	
i_q	q) FPSS	ANN		
V_{ST}		FPSS		(
T_e					
i_D	d				
i_Q	q				
V_D	d	ω			
V_Q	q	δ			
		L_d			d
		L_q			q
		L_F			
		L_D			d
		L_Q			q
		l_d			d
		l_q			q
					$k M_F = k M_D = L_d - l_d$
					$k M_Q = L_q - l_q$
		R			
		r_F			
		r_D			d
		r_Q			q
		D			
		T_A			
		i_F			
		V_d			d
		V_q			q
		K_A			
		T_A			
		T_F			
		K_F			
		V_∞			
		V_t			
		V_{REF}			

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ω_R	377 rad/s
L_d	1.7 pu
L_q	1.64 pu
L_F	1.65 pu
L_D	1.605 pu
L_Q	1.529 pu
$kM_F=kM_D=MR$	1.55 pu
kM_Q	1.49 pu
$I_d=I_q$	0.15 pu
r	0.001096 pu
r_F	0.00742 pu
r_D	0.0131 pu
r_Q	0.054 pu
D	0
Q	0.062 pu
P	1 pu
R_e	0.02 pu
L_e	0.02 pu
T_A	0.05 pu
K_A	400 pu
T_F	1 pu
K_F	0.025 pu
E_{FDmax}	7.3 pu
E_{FDmin}	-7.3 pu

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