BAT Fuzzy Synergetic approach Based on Ackermann's Formula for Multi-machine Power System

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Abstract: *A fuzzy synergetic control design for stabilization of multi synchronuous machine power system is suggested within this work based on Ackermann's formula and Bat algorithm for optimisation. The design procedure is divided into three steps. First, synergetic approach is used to specific operating point-based models of a power sub-systems independently and we used the Ackermann's formula method to calculate the macro-variable gain. Second, fuzzy technique is employed to generate a global model of synchronuous machine power system that includes all of the subsystems, hence resulting in a fuzzy synergetic power system stabilizer. Third, the rate of the attractor's convergence of macro-variable is optimized by BAT method. Stability is insured by second theorem of Lyapunov. In a simulation research, severe operating conditions are employed of multi synchronuous machine model to test the validity of the optimised fuzzy synergetic approach method over optimised conventional power system stabilizer and synergetic control, indicating better performance.*

Keywords: **Ackermann's formula, bat fuzzy synergetic control, PSS, Lyapunov stability.**

1. INTRODUCTION

Power system must continue to be reliable and resilient over wide range of disturbances. In power systems, the active power is determined by the angle at which the sending and receiving ends are led, but the reactive power is influenced by the voltage magnitudes. A dynamic model uses the active and reactive powers at any moment of time is expressed as functions of frequency and the voltage of bus [1].

The synchronous generators in a stable synchronuous machine power system either quickly revert to their initial states when perturbed

The disturbances cause an oscillatory system then the damping of this is necessary [2]. Effectively, due to insufficient damping, power systems are complex and nonlinear display low frequency oscillations produced by unfavourable operational conditions which may cause lose synchronism with the underlying machine [3].

The synchronuous machine power system stabilizer design, approachs of joining combined the supplementary control with the excitation system (AVR). Synchronuous machine power system stabilizers are employed to damp oscillations and maintain the general stability [4].

The conventional stabilizer model, containing cascade interconnected lead lag bloc compensator's obtained from a linear simple model to representing the synchronuous machine power system at a fixed operating point, have been employed for a long time to reduce oscillations in any case of the varying load point conditions or disturbances. But, under a variety of operating conditions, these linear model-based control approaches often fail of objectives [5].

In [4] and [5] the authors have presented a comprehensive method for conventional adapting PSS effect and its parameters on the performance dynamic's of the single machine model. The stabilizers designed to damp one oscillation mode and il is negatively influence the other modes.

Several method of stabilization of power system are explained in literature [6][7].

Placement of poles or eigenvalues methods are used in [8][9][10][11]. Techniques of optimization failed to provide the optimum values parameters of PSS [12] as CDCARLA method [13]. Genetic algorithms are examples of heuristic approaches have been used earlier to power system control design [14]. The algorithm of particle swarm optimization (PSO) has been applied in [15] for power system stabilizer parameter's. The optimale parameters of PSS using BAT, called the BAT PSS, are reported in [16] and [17].

Remarkable research has been done in the last years [18][19][20], a global system is created using fuzzy logic to combine many linear sub-system models that were acquired for specific operating points.

In the present study, a novel approach as optimal fuzzy synergetic power system stabilizer is proposed. The synergetic gain of macro-variable function is determined used the Ackermann's formula [21]. Utilizing fuzzy logic, a global model integrating the many subsystems is created. Optimum of the rate of convergence of the macro-variable is obtained by BAT algorithm.

The following section of this study introduces the synergetic approach based in Ackermann's formula, then the second section thus global Takagi-Sugeno fuzzy synergetic technique and stability issue addressed. In section three the algorithm of BAT is discussed. The next section presents the power system model, then a presentation and the simulation of results for nominal and strong cases over conventional PSS [22] and synergetic control.

2. SYNERGETIC CONTROL BASED ON ACKERMANN'S FORMULA

Synergetic technique is a method that state space for designing control for intricate, several interconnected nonlinear systems that is due to the combined regulators analytical approach theory [23][24][25][26]. The synergistic control requires the state variables to evolve on an invariant manifold of the system state selected by the designer, allowing for desired performance to be completed despite disturbances and uncertainties without destructive chattering basic to sliding mode control [23].

Consider a system described by:

$$\dot{x} = Ax + Bu \tag{1}$$

where x is the vector of state variable, $A \in R^{nxn}$, $B \in R^{nxq}$ and u is the proposed synergetic input.

Begin by designing a macro variable that depends on the state variables vector.

$$\Psi = \psi(x,t) \tag{2}$$

Control will oblige the system to work on the manifold $\Psi = 0$. The designer can choose the characteristics parameters of the macro variable based on specifications control. This macro variable may be a linear simple combination of all state variables. You can repeat the procedure in an identical manner, defining as just many macro variables as approach of control. Giving a standard constraint (3), the selected macro variable is chosen to adapt in a preferred manner despite the disturbances and/or uncertainties.

$$T_c\dot{\Psi} + \Psi = 0, \quad T_c > 0 \tag{3}$$

T_c: The designer's choice influences the attractor's rate of convergence, and it can be arbitrarily small when taking simply the eventual control constraint.

The macro-variable in this study is defined as:

$$\Psi = \boldsymbol{C}^T \boldsymbol{x} \tag{4}$$

C is the synergetic vector, which Ackermann's method can be used to determine [21].

An excellent choice of macro variables allows the designer to develop an extensive number of attractive characteristic for the best synchronization, parameter insensitivity, suppression of noise and stability. It is important to note that global stability is guaranteed by the synergetic control law on the manifold indicating that after the manifold is attained, with large-signal variances, the system is not intended to abandon it.

The ideal dynamic proprieties may be provided by a proper selection of the vector C. In this paper, we show how found the macro-variable gain vector utilizing Ackermann's formula, concerning the task of eigenvalue placement.

The optimal eigenvalues $\lambda_1, \lambda_2, ..., \lambda_n$ of the system (1) may be assigned utilizing Ackermann's formula [21].

$$C = e^T P(A) \tag{5}$$

where

$$e^T = (0, ..., 0, 1)(B, AB, ..., A^{n-1}B)^{-1} \tag{6}$$

$$P(\lambda) = (\lambda - \lambda_1)(\lambda - \lambda_2)\cdots(\lambda - \lambda_{n-1})(\lambda - \lambda_n) \tag{7}$$

The following is a summary of the design algorithm: Step 1) The desired value of the synergetic approach $\lambda_1, \lambda_2, ..., \lambda_{n-1}$ is selected.

Step 2) The macro-variable equation $\Psi = Cx = 0$ is found as: $C^T = e^T(A - \lambda_1 I)(A - \lambda_2 I)\cdots(A - \lambda_{n-1} I)$.

Step 3) The synergetic control is obtained.

$$u = -(C^T B)^{-1}\left(C^T A x + \frac{1}{T_c}\Psi\right) \tag{8}$$

this control law enabling satisfaction of the constraint (3) assuming *(CB)* is non-singular.

3. FUZZY SYNERGETIC CONTROL DESIGN

In this technique control procedure, a Takagi-Sugeno fuzzy model is employed in order to serve as representation a global system model of the under nonlinear plant. Fuzzy model explained by fuzzy ''IF-THEN'' rules signifies local linear input output relations of the nonlinear system under study. The primary characteristic of a Takagi Sugeno fuzzy model is expressing the local dynamics of all fuzzy rules by a linear subsystem model.

Global fuzzy system model is done by fuzzy "blending" the operating point based linear subsystem models [18][19][20].

The i[th] rule of the Takagi Sugeno fuzzy model is of the next structure:

IF z_1 is F_1^i AND … z_p is F_p^i THEN $\dot{x} = A_i x + B_i u, \quad \Psi = C_i^T x, \quad i = 1, 2, ..., m$ (9)

where

$F_j^i (j = 1, 2, \cdots, p)$: fuzzy sets,

m: number of inference rules,

x, u: state and the input vectors respectively,

A_i, B_i, C_i are respectively the matrices and synergetic vector of the i[th] system and $z_1, ..., z_p$ are some of the system's measurable variables.

For example, the active and reactive power's in our work (P and Q).

By using a conventional fuzzy inference technique, that is, using singleton method for fuzzifer, product fuzzy for inference, center average defuzzifer and let $\mu_i(z)$ the normalized fuzzy membership function satisfying

$$F^i = \prod_{j=1}^{p} F_j^i(z_j) \quad \text{and} \quad \sum_{i=1}^{m} \mu_i = 1 \tag{10}$$

where $F_j^i(z_j)$ is the grade membership of z_j in the fuzzy set F^i.

The global fuzzy state space model and the macro-variable proposed in this paper, is given by (11), where

$$A = \sum_{i=1}^{m} \mu_i A_i, \quad B = \sum_{i=1}^{m} \mu_i B_i, \quad C = \sum_{i=1}^{m} \mu_i C_i \tag{11}$$

Assuming that each subsystem is controllable, let's assume that the couple (A, B) is

completely controllable.
Theorem 1: All subsystems of the fuzzy presentation (9) and if we choose the next control u_i

$$u_i = -\left(C_i^T B_i\right)^{-1}\left(C_i^T A_i x + \frac{1}{T_c}\Psi_i\right) \tag{12}$$

then the subsystem is stable.

Proof Lyapunov candidate function was selected as

$$V_i = \frac{1}{2}\Psi_i^T \Psi_i \tag{13}$$

Therefore

$$\dot{V}_i = \Psi_i^T \dot{\Psi}_i \tag{14}$$

$$= \Psi_i C_i^T \left(A_i x + B_i u_i\right) \tag{15}$$

$$= -\frac{1}{T_c}\Psi_i^2 \tag{16}$$

then :

$$\dot{V}_i \le 0 \tag{17}$$

Based on second theorem of Lyapunov, stabilization of the subsystem is ensured by the control law (12).
Theorem 2: If we apply the following synergetic control for the global fuzzy system (11),

$$u = -\left(\sum_{i=1}^{m}\mu_i C_i \sum_{i=1}^{m}\mu_i B_i\right)^{-1}\left(\sum_{i=1}^{m}\mu_i C_i \sum_{i=1}^{m}\mu_i A_i x + \frac{1}{T_c}\Psi\right) \tag{18}$$

then the global system is stable.

Proof: Choosing the Lyapunov candidate function to be

$$V = \frac{1}{2}\Psi^T \Psi \tag{19}$$

Therefore

$$\dot{V} = \Psi^T \dot{\Psi} \tag{20}$$

$$= \Psi C^T \left(Ax + Bu\right) \tag{21}$$

$$= \Psi\left(\sum_{i=1}^{m}\mu_i C_i \sum_{i=1}^{m}\mu_i A_i x + \sum_{i=1}^{m}\mu_i C_i \sum_{i=1}^{m}\mu_i B_i u\right) \tag{22}$$

$$= -\frac{1}{T_c}\Psi^2 \tag{23}$$

thus:

$$\dot{V} \le 0 \tag{24}$$

To optimize the synergetic parameter T_c an optimisation method is selected. This study focuses on the best possible tuning of fuzzy synergetic control approach using bat optimisation algorithm. The optimized parameter's typical values are considered as $\left[0.004 - 0.2\right]$ for T_c.

4. BAT ALGORITHM

The BAT algorithm is new optimization method based metaheuristic technique recommended by Xin-She Yang [27]. The algorithm requires use of the bats' so-called echolocation. Sonar echoes are used by the bats to identify and steer clear of obstacles. It is well known that resonances are converted into a frequency that reflects off of objects. Bats use the time delay between emission and reflection to navigate. Following impact and reflection, the bats convert their own pulse into information that can be used to determine the distance to the prey. It is easy to calculate the pulse rate in the range of 0 to 1. where 0 indicates no emission and 1 indicates the bat's maximal output [28][29].

The following principles have been idealized by Yang [30] in order to model this algorithm:

1) Echolocation is used by all bats to detect distance, and they also "know" the difference between background boundaries and food/prey in a magical sense;

2) A bat fly at random with velocity v_i at position y_i with a fixed frequency $f_{\min}$, varying wavelength τ and loudness Λ_0 to scan for prey. They are adept at autonomously

varying the pulse emission rate and the frequency (or wavelength) of their pulses $r \in [0,1]$, depending on the proximity of their target;

3) Although the loudness can vary in a wide range of ways, According to Yang, the loudness ranges from a positive large Λ_0 to a minimum value $\Lambda_{\min}$.

First, the initial position y_i, frequency f_i velocity v_i and velocity v_i are initialized for each bat. For each time step t, being T the maximum number of iterations, the movement of the bats is provided by updating their position and velocity using Equations :

$$f_i = f_{\min} + (f_{\min} - f_{\max})\beta \tag{25}$$

$$v_i^j(t) = v_i^j(t-1) + [y_i^j(t-1) - \hat{y}^j]f_i \tag{26}$$

$$y_i^j(t) = y_i^j(t-1) + v_i^j(t) \tag{27}$$

where β indicates a randomly generated number within the interval *[0, 1]*. Recall that $y_i^j(t)$ indicates the value of decision variable j for bat i at time step t. The variable $\hat{y}^j$ signifies the best current global solution for decision variable j, which is achieved by comparing each bat's solution.

In order to enhance the diversity of the possible solutions, Yang [27][30] has recommended using random walks. Primarily, one solution is chosen from the best solutions, and then the random walk is used for generating new solution for bat.

$$y_{new} = y_{old} + \varepsilon\overline{\Lambda}(t) \tag{28}$$

Because $\overline{\Lambda}(t)$ represents the average loudness of all the bats at time t, and $\varepsilon \in [-1, 1]$ estimates of the random walk's strength and direction. For everyone iteration of this algorithm, the emission pulse rate r_i and the loudness Λ_i are updated, as follows:

$$\Lambda_i(t+1) = \alpha\Lambda_i(t) \tag{29}$$

$$r_i(t+1) = r_i(0)[1 - e^{-\gamma t}] \tag{30}$$

where α and γ are constants. The emission rate and loudness are generally chosen at random in the first step.

We use in this study: $\alpha = \gamma = 0.9$, $\Lambda_0 = 1$, $\Lambda_{\min} = 0$, $f_{\min} = 0$, $f_{\max} = 50$.

5. POWER SYSTEM MODEL CALCUL

This work studies a calcul of linearized power system model that represents An infinite bus is connected to a single synchronous machine via a double circuit transmission line. A representation of the fourth order classic state space [4][5] is given in (31).

$$\dot{x}=\begin{bmatrix} -\frac{D}{M} & -\frac{K_1}{M} & -\frac{K_2}{M} & 0 \\ \omega_0 & 0 & 0 & 0 \\ 0 & -\frac{K_4}{T'_{d0}} & -\frac{1}{T'_{d0}K_3} & \frac{1}{T'_{d0}} \\ 0 & -\frac{K_4K_5}{T_A} & -\frac{K_AK_6}{T_A} & -\frac{1}{T_A} \end{bmatrix} x+\begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_A}{T_A} \end{bmatrix} u \tag{31}$$

where the state variables are written as follows: $x=\left[\Delta\omega(t)\,\Delta\delta(t)\,\Delta e'_q(t)\,\Delta e_{fd}(t)\right]^T$.

Note that, the calcul of six parameters constants K_1-K_6 in the linearized model of synchronous machine are as function of real power P and reactive power Q.

where

$$K_1=\frac{V^2\left(x_q-x'_d\right)\left(P/\left(P^2+\left(Q+\left(V^2/x_e+x_q\right)\right)^2\right)\right)}{\left(x_e+x_q\right)\left(x_e+x'_d\right)}+Q+\frac{V^2}{x_e+x_q} \tag{32}$$

$$K_2=\frac{V}{\left(x_e+x'_d\right)}\left(P^2\Big/\sqrt{P^2+\left(Q+\left(V^2/\left(x_e+x_q\right)\right)\right)^2}\right) \tag{33}$$

$$K_3=\frac{\left(x_e+x'_d\right)}{\left(x_e+x_d\right)} \tag{34}$$

$$K_4=V\frac{\left(x_d-x'_d\right)}{\left(x_e+x'_d\right)}\left(P\Big/\sqrt{P^2+\left(Q+\left(V^2/x_e+x_q\right)\right)^2}\right) \tag{35}$$

$$K_5=\left(x_e\frac{V}{\left(x_e+x'_d\right)}\left(P/\left(V^2+Qx_e\right)\right)\right)\left(\left(\left(\frac{V^2x_q\left(x_q-x'_d\right)}{\left(x_e+x_q\right)}\right)\left(Q+\frac{V^2}{x_e+x_q}\right)\Bigg/\left(P^2+\left(Q+\frac{V^2}{x_e+x_q}\right)^2\right)\right)-x'_d\right) \tag{36}$$

$$K_6=\frac{x_e}{\left(x_e+x'_d\right)}\left(\sqrt{P^2+\left(Q+\left(V^2/\left(x_e+x_q\right)\right)\right)^2}\Big/\left(V^2+Qx_e\right)\right)$$
$$\left(x_e+\left(\left(\frac{V^2}{x_e+x_q}x_q\left(Q+\frac{V^2}{x_e+x_q}\right)\right)\Bigg/\left(P^2+\left(Q+\frac{V^2}{x_e+x_q}\right)^2\right)\right)\right) \tag{37}$$

Where

V : voltage of infinite bus,
M : inertia moment coefficient
D : damping coefficient
e_{fd} : voltage of equivalent excitation,
e'_q : transient voltage component in q-axis,
$\Delta\omega$: deviation speed,
$\Delta\delta$: deviation angle,
K_A : gain voltage regulator,
T_A : constant time voltage regulator,
T'_{d0} : d-axis transient open circuit time constant,
M : coefficient of inertia moment,
D : coefficient system damping,
P,Q : real and reactive power's respectively
x_d : direct reactance,
x'_d : d-axis transient reactance,
x_q : q-axis synchronous reactance,
x_e : line reactance

The parameters of the single synchrounuous machine infinite bus system are as follows: $x_e = 0.4p.u,\ x_q = 1.55p.u,\ x_d = 1.6p.u,\quad x'_d = 0.32p.u,\ D = 0,\quad T'_{d0} = 6s,\quad H = 5s,\quad T_A = 0.05,$ $K_A = 50,\quad V = 1p.u.$

6. SIMULATION

Results of simulation are shown to confirm robustness and performance of the Bat fuzzy synergetic approach. First, we use Takagi-Sugeno fuzzy model for system description of single synchrounuous machine infinite bus. Four differential equations of the first order were used to model each synchronous generator. An infinite bus is subjected to a three-phase fault test that extends 60 ms before being cleared. The proposed power system stabilizer can be developed using several fuzzy sets for all variable state. The fuzzy sets for $P \in [0.4500, 3.5730]$ and $Q \in [-0.2668, 1.8143]$ are determined by the membership functions shown in Figure.1 and Figure.2 respectively.

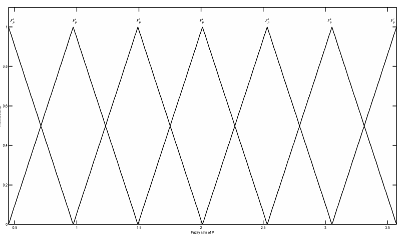

Figure.1 Active power fuzzy sets.

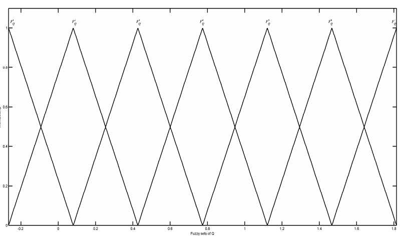

Figure.2 Reactive power fuzzy sets.

In general case, fuzzy rules are

$$\begin{aligned}&IF\ P\ is\ F_P^i\ AND\ ...\ Q\ is\ F_Q^i\ THEN\\ &\dot{x} = A_i x + B_i u \qquad\qquad i = 1, 2, ..., 49\\ &\Psi = C_i^T x\end{aligned} \tag{38}$$

therefore

$$\begin{aligned}&IF\ P\ is\ F_P^1\ AND\ ...\ Q\ is\ F_Q^1\ THEN\\ &\dot{x} = A_1 x + B_1 u\\ &\Psi = C_1^T x\\ &\quad\vdots\end{aligned} \tag{39}$$

$$\begin{aligned}&IF\ P\ is\ F_P^3\ AND\ ...\ Q\ is\ F_Q^7\ THEN\\ &\dot{x} = A_{21} x + B_{21} u\\ &\Psi = C_{21}^T x\\ &\quad\vdots\end{aligned} \tag{40}$$

$$IF\ P\ is\ F_P^7\ AND \ldots Q\ is\ F_Q^7\ THEN$$
$$\dot{x} = A_{49}x + B_{49}u$$
$$\Psi = C_{49}{}^T x \tag{41}$$

Where

$$\boldsymbol{A}_1 = \begin{bmatrix} 0 & -0.1745 & -0.0548 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.2600 & -0.4630 & 0.1667 \\ 0 & -41.6903 & -364.7271 & -20 \end{bmatrix}, \boldsymbol{B}_1 = \begin{bmatrix} 0 & 0 & 0 & 1000 \end{bmatrix}^T,$$
$$\boldsymbol{C}_1 = \begin{bmatrix} -0.8993 & 0.2500 & 0.0872 & 0.0010 \end{bmatrix}^T \tag{42}$$
$$\vdots$$

$$A_{21} = \begin{bmatrix} 0 & -0.2498 & -0.1117 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.1599 & -0.4630 & 0.1667 \\ 0 & 80.2816 & -571.3554 & -20 \end{bmatrix}, \boldsymbol{B}_{21} = \begin{bmatrix} 0 & 0 & 0 & 1000 \end{bmatrix}^T,$$
$$\boldsymbol{C}_{21} = \begin{bmatrix} 1.0831 & 0.1832 & 0.0872 & 0.0010 \end{bmatrix}^T \tag{43}$$
$$\vdots$$

$$\boldsymbol{A}_{49} = \begin{bmatrix} 0 & -0.2499 & -0.4158 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.2483 & -0.4630 & 0.1667 \\ 0 & 294.2885 & -688.7488 & -20 \end{bmatrix}, \boldsymbol{B}_{49} = \begin{bmatrix} 0 & 0 & 0 & 1000 \end{bmatrix}^T,$$
$$\boldsymbol{C}_{49} = \begin{bmatrix} 0.2916 & 0.0480 & 0.0872 & 0.0010 \end{bmatrix}^T \tag{44}$$

The proposed stabilizer is then compared with a synergetic power system stabilizer and a BAT conventional PSS in all cases. The conventional stabilizer of power system (CPSS) is given in follow Figure.3.

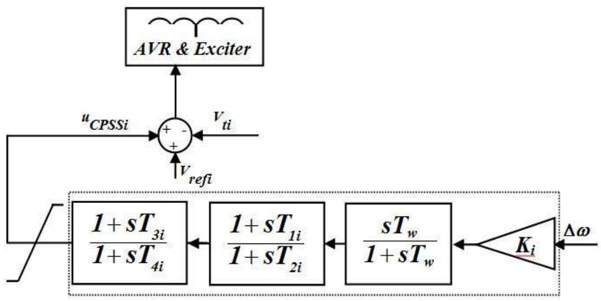

Figure.3 Conventional IEEE lead lag power system stabilizer.

where T_w is constant of the wash out time. $T_{1i} - T_{4i}$ are power system stabilizer time constants and K_i is the power system stabilizer gain of generator i. The calculate of optimal parameters of conventional power system stabilizer are given by BAT method (Table.1) in [22].

Table.1 BAT conventional power system stabilizer parameters.

	K	T1	T3
BATPSS 1	46.6588	0.4153	0.2698
BATPSS	8.4751	0.4756	0.1642

2				
3	BATPSS	4.2331	0.2513	0.1853

To prove the effectiveness of Takagi-Sugeno method we took three extreme operating points for single machine infinite bus (SMIB), the first in light load if $P = 1p.u$ and $Q = -0.1933$. Using equations (11) and (18), we find

$$A = \begin{bmatrix} 0 & -0.1113 & -0.1316 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.2804 & -0.4630 & 0.1667 \\ 0 & 110.7781 & -395.4493 & -20 \end{bmatrix},\ B = [0\ 0\ 0\ 1000]^T,\ C = [-1.4669\ 0.0614\ 0.0872\ 0.0010]^T \tag{45}$$

We run the Bat algorithm to find the optimal synergetic parameter $\boldsymbol{T_s} = 0.170$. The result of a simulation obtained is compared with the bat conventional and the synergetic power system stabilizers (Figure.4).

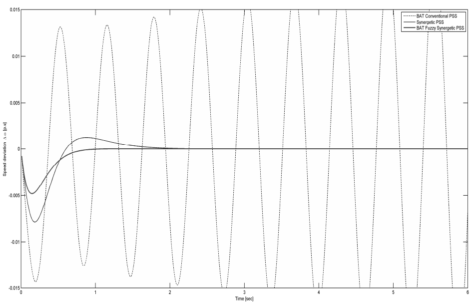

Figure.4 Speed deviation $\Delta\omega$ for light condition.

We do the same work with the case of a normal load for $\boldsymbol{P} = 1.630\boldsymbol{p.u}$ and $\boldsymbol{Q} = 0.0665\boldsymbol{p.u}$. The system becomes

$$A = \begin{bmatrix} 0 & -0.1060 & -0.2130 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.2783 & -0.4630 & 0.1667 \\ 0 & 196.6139 & -520.5710 & -20 \end{bmatrix},\quad B = [0\ 0\ 0\ 1000]^T,$$

$$C = [-0.9714 \quad 0.0352 \quad 0.0872 \quad 0.0010]^T \tag{46}$$

The simulation result is given in Figure.5 for $\boldsymbol{T_s} = 0.0125$. The performance of the proposed method in comparison to both conventional and synergetic power system stabilizers is shown in the Figure.5.

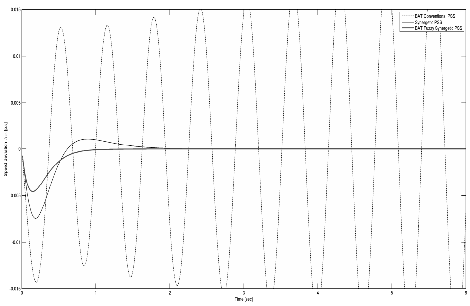

Figure.5 Speed deviation $\Delta\omega$ for nominal condition.

The last test for single machine infinite bus is during a heavy load where $\boldsymbol{P} = 2.20\boldsymbol{p.u}$ and $\boldsymbol{Q} = 0.7127\boldsymbol{p.u.}$ the synergetic vector is $T_s = 0.0100$, the global system is

$$A = \begin{bmatrix} 0 & -0.1530 & -0.2667 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.2578 & -0.4630 & 0.1667 \\ 0 & 213.3299 & -604.1566 & -20 \end{bmatrix},\ B = \begin{bmatrix} 0\ 0\ 0\ 1000 \end{bmatrix}^T,\ C = \begin{bmatrix} -0.3701\ 0.0439\ 0.0872\ 0.0010 \end{bmatrix}^T \tag{47}$$

The simulation result of the optimal control compared with a synergetic control and the conventional control is presented in Figure.6.

In this section we used the Ackerman's method to obtain the synergetic vector and sub-system model in different operating points, we applied the Takagi-Sugeno method to obtain the global model and the Bat algorithm for optimized synergetic vector T_c .

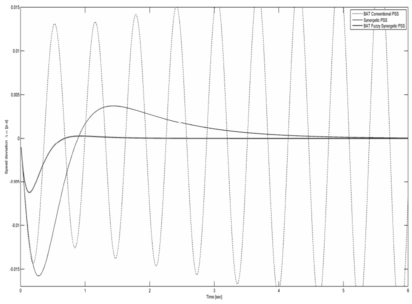

Figure.6 Speed deviation $\Delta\omega$ for heavy condition.

Secondly, to demonstrate the effectiveness and robustness of the proposed optimal fuzzy synergetic of the proposed optimal fuzzy synergetic power system stabilizer, Simulations for a multi synchronuous machine power system were carried out under a variety of operating conditions. In order to validate improvement of stability due to the optimal proposed stabilizer, a three-phase fault test is applied in bus 7 of multi–machine power system (Figure.7) with duration of 60 ms before it's cleared.

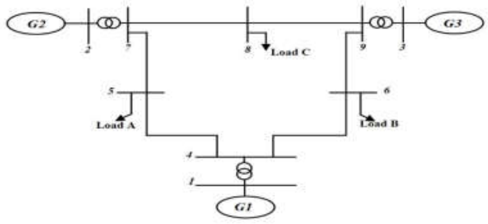

Figure.7 Multi-machine power system.

Several disturbances are employed in the simulation to test the system. For reasons of simplicity, we considered the following three cases (Table.2):

Case 1) light load;

Case 2) nominal load case;

Case 3) heavy load;

Table.2 Cases of loading conditions for the system in [p.u].

		Generator		
		G1	G2	G3
Light case	P	0.964 9	1.00	0.45
	Q	0.223	-0.1933	-0.2668
Normal	P	1.716	1.630	0.85

case	4 0.620 (5	0.0665	- 0.1086
Heavy case	3.573 I 0	2.20	1.35
	1.814 (3	0.7127	0.4313

The membership functions displayed in Figure.1 and Figure.2. are used to define the fuzzy sets for P and Q. The fault is cleared and the controller helps the system to reach a stable operating point very quickly. The inter-area oscillation control problem is studied using a three-machine test system is shown in Figure.8.1, Figure.8.2 and Figure.8.3 for light load case, in Figure.9.1, Figure.9.2 and Figure.9.3 for nominal load case and in Figure.10.1, Figure.10.2 and Figure.10.3 for heavy case respectively.

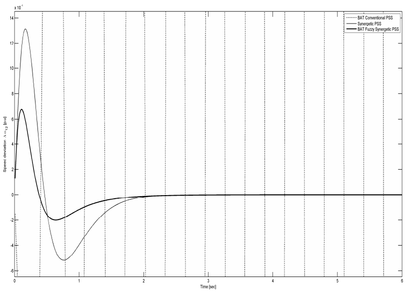

Figure.8.1 Speed deviation $\Delta\omega_{12}$ for case 1.

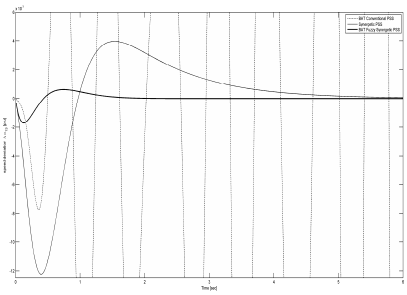

Figure.8.2 Speed deviation $\Delta\omega_{13}$ for case 1.

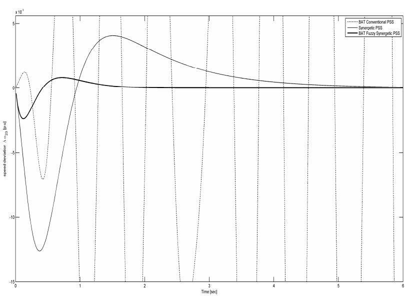

Figure.8.3 Speed deviation $\Delta\omega_{23}$ for case 1.

As shown Figure.9.1 to Figure.9.3, better control performance is demonstrated by the proposed method than conventional PSS and synergetic control regarding damping effect and settling time inter-machine.

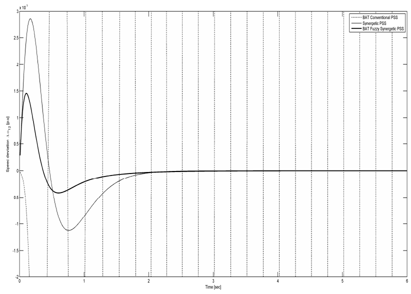

Figure.9.1 Speed deviation $\Delta\omega_{12}$ for normal condition.

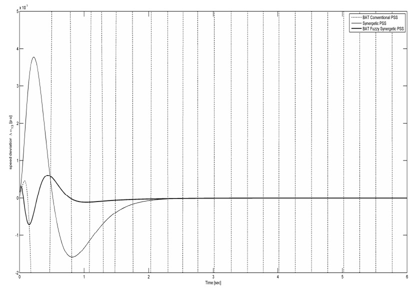

Figure.9.2 Speed deviation $\Delta\omega_{13}$ for normal condition.

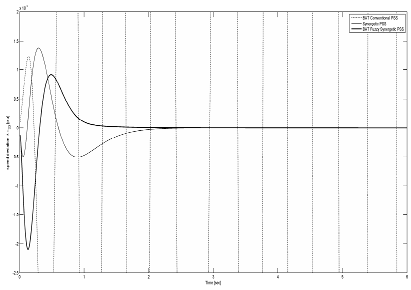

Figure.9.3 Speed deviation $\Delta\omega_{23}$ for normal condition.

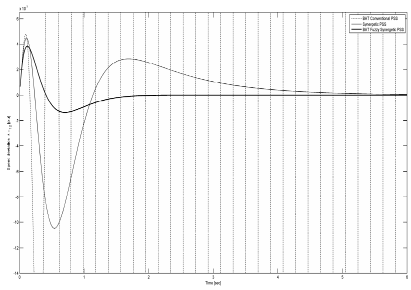

Figure.10.1 Speed deviation $\Delta\omega_{12}$ for case 3.

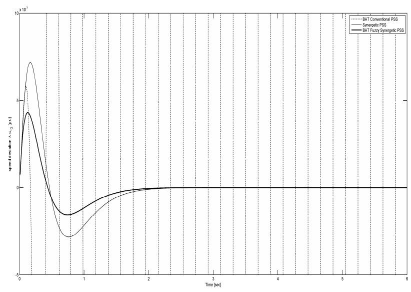

Figure.10.2 Speed deviation $\Delta\omega_{13}$ for case 3.

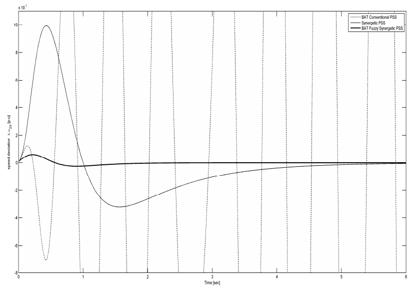

Figure.10.3 Speed deviation $\Delta\omega_{23}$ for case 3.

Light and heavy load operations are applied to the power system in order to further evaluate the stability of the proposed stabilizer, illustrating once again precisely how better the proposed controller operates in a multi synchronuous machine power system than its conventional counterpart.

Several operational points were used in this study to illustrate the effectiveness of the bat fuzzy synergetic power system stabilizer in oscillations damping after the occurrence of major disturbance over other stabilizers. The proposed stabilizer forces the generator from prevent its synchronism. Three studies were conducted to examine the impact of the proposed optimal fuzzy synergetic power system stabilizer (BATFSPSS). Results are compared with a BAT conventional power system stabilizer (BATCPSS) and synergetic power system stabilizer (SPSS). After the fault is corrected, the system rapidly reaches a stable operating point with the aid of the proposed stabilizer.

7. CONCLUSION

We introduced in this study, a global optimal fuzzy synergetic power system stabilizer based Ackermann's formula that improves your effictness to damp oscillations and thus enhances transient dynamics of multi synchronuous machine power system. Three case operating conditions as well as several perturbations were used for evaluation of the proposed BAT fuzzy synergetic power system stabilizer is robuste and quickly reducing oscillations that, if not treated, could result in synchronism loss. Simulation results proof superior performance over traditional bat power system control (CPSS), synergetic power system control (SPSS) and satisfactory transient behaviour and showing a better performance. Multi synchronuous machines power system needs further research under the proposed approach of stabilizer. Stability is proved by second theorem of Lyapunov.

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