Power System Dynamic Stability Enhancement based on Facts Device and Fuzzy Logic Controller based Stabilizer

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Abstract - *The main purpose or objective of this paper is to enhance the dynamic power system stability by minimizing the oscillation through classical controllers ,fuzzy logic controller and static synchronous compensator (STATCOM) . Fuzzy logic controller has been designed as STATCOM and power system stabilizer (PSS) for power system stability improvement. The application of fuzzy logic controller is investigated by means of simulation studies on a model of single machine infinite bus (SMIB)with its linearized equations using mat-lab simulink. Speed deviation ($\Delta\omega$) and acceleration ($d\omega/dt$) of the synchronous machine are chosen as the input signals to the fuzzy controller in order to achieve a better dynamic performance. Results show that the fuzzy logic controller has excellent and comparatively better potential in damping power system oscillation and the STATCOM also have been studied and its effectiveness has been compared to the conventional stabilizer and STATCOM with fuzzy logic controller and it has excellent results, the over shoot and the settling time are decreased compared to conventional PSS lead lag stabilizer. The simulation results proved and showed the superior performance of the proposed controller.*

Key Words: synchronous generator, PSS stabilizer, fuzzy logic control ,STATCOM ,dynamic perturbations

1. INTRODUCTION

The primary sources of electrical energy are the synchronous generators. They are electromechanical energy conversion devices that are driven at synchronous speed by steam, hydro and gas turbines, depending on the source of mechanical energy. A brief description of the modeling of various components in power systems including FACTS-devices is given. and it is also include the dynamic model of FACTS-devices as their steady state power flow models with fuzzy logic stabilizers.

1.1 power system stabilizer

The power system stabilizer (PSS) is used to generate supplementary control signals for the excitation system in order to damp out the low frequency oscillations. The conventional power system stabilizer is widely used in existing power systems and has contributed to the enhancement of the dynamic stability of power systems. The parameters of CPSS (Conventional Power System Stabilizer) are determined based on a linearized model of the power system around a nominal operating point where they can provided good performance. Because power systems are highly nonlinear systems, with configurations and parameters that change with time, the CPSS design based on the linearized model of the power systems cannot guarantee its performance in a practical operating environment [5].

To improve the performance of CPSS, numerous techniques have been proposed for their design, such us using intelligent optimization methods (genetic algorithms, neural networks, fuzzy and many other nonlinear control techniques).In recent years, fuzzy logic control has emerged as a powerful tool and is starting to be used in various power system applications [6], [8], [9].

1.2 Fuzzy logic controller and statcom

The application of fuzzy logic control techniques appears to be most suitable one whenever a well-defined control objective cannot specified, the system to be controlled is a complex one, or its exact mathematical model is not available. Recent research indicates that more emphasis has been placed on the combined usage of fuzzy systems and neural networks [8],[9] and [10].This paper presents power system stabilizer with an lead lag fuzzy controller for different operating conditions of the power system. Various simulations have been performed in order to subject it to different type of large disturbances using a single-machine infinite bus power system. Comparison studies have also been performed between the conventional power stabilizers (PSS) and the fuzzy logic controller. The numerical simulations results clearly demonstrate the superiority of the fuzzy in comparison to the CPSS and as well the STATCOM is more demonstrating stability of the system.

2. MODEL OF POWER SYSTEM ELEMENTS 2

2.1. Generator model

The generator is represented by the differential equation model consisting of the swing equation and the generator internal voltage equation. The linearized swing equation can be written as [1]

$$p\delta = \omega o\Delta\omega r \qquad\qquad 1$$

$$p\Delta\omega r = \frac{[\Delta Tm - ks\Delta\delta - kD\delta\omega r]}{2H} \qquad 2$$

$$\frac{d}{dt}\begin{bmatrix} \Delta\omega r \\ \Delta\delta \end{bmatrix} = \begin{bmatrix} \frac{-KD}{2H} & -\frac{KS}{2H} \\ \omega O & 0 \end{bmatrix} \begin{bmatrix} \Delta\omega r \\ \Delta\delta \end{bmatrix} + \begin{bmatrix} \left(\frac{1}{2H}\right) \\ 0 \end{bmatrix} \Delta Tm \qquad 3$$

Where, the speed deviation of generator rotor (in per unit) is denoted by $\Delta\omega r$ and the inertia constant is H . Also, Tm is applied mechanical torque ,KD is the damping torque coefficient

internal voltage equation is given by

$$\dot{E}q = (Efd - (xd - xd')id - Eq')/Td0' \qquad 4$$

$$Efd' = (KA(vref - v + u) - Efd)/TA \qquad 5$$

The single machine infinite bus power system (SMIB) model used to evaluate the power system stabilizer ,fuzzy controller is presented in figure 1.

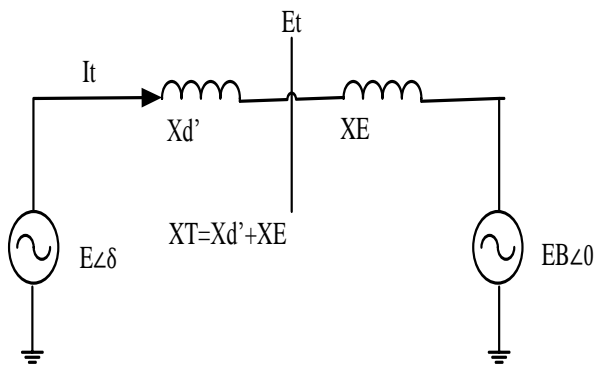The SMIB consists of a synchronous generator, a turbine, a

Figure 1 single machine infinite bus system

In Figure 1, here the infinite bus voltage is shown by EB, XT is the transfer reactance which combination of direct axis reactance(may be transient) of generator ,transmission line reactance and external circuit reactance. The pre-disturbance value E remains constant it is a assumption. Here, E always lead to infinite bus voltage δ is a factor by which it leads.

2.2 power system stabilizer

The basic function of power system stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signals. For provide damping signal the stabilizer must produce a component of electrical torque in phase with rotor speed deviation. The Power System Stabilizer with the aid of block diagram as shown in Fig. 2
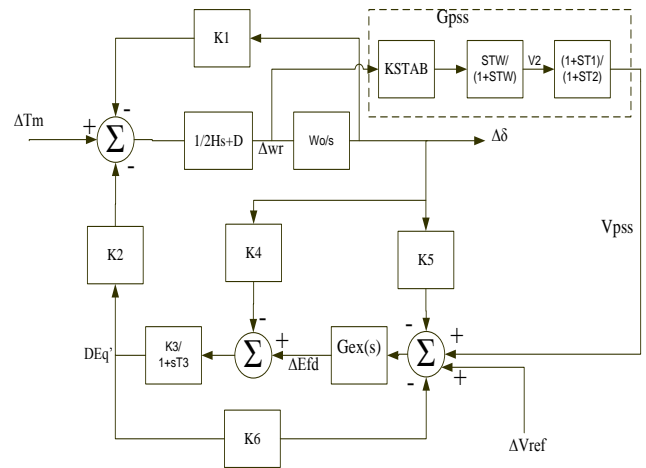

Figure 2.block diagram representation with AVR and pss

According to the well-known design method which uses CPSS, the electromechanical oscillations are damped by implementing the PSS as shown in figure 3.

Automatic devices control the generator output in voltage and frequency, in order to keep them constant according to pre established values .these devices are listed below.

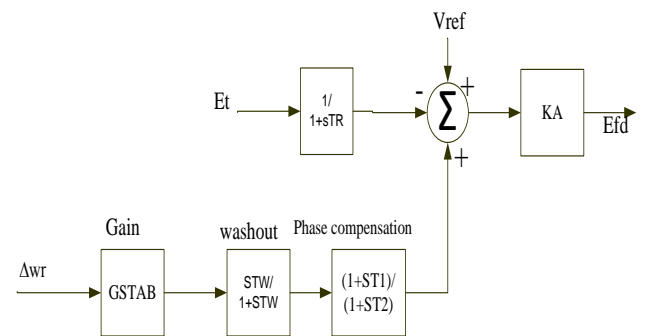- ✓ automatic voltage
- ✓ regulator

Figure.3. Block diagram of the conventional power system stabilizer

The main objective of the automatic voltage regulator AVR is to control the terminal voltage by adjusting the generators exciter voltage. The AVR must keep track of the generator terminal voltage all the time and under any load condition, working in order to keep the voltage within pre-established limits. Based on this, it can be said that the AVR also controls the reactive power generated and the power factor of the machine once these variables are related to the generator excitation level [11].

The AVR quality influences the voltage level during steady state operation, and also reduce the voltage oscillations during transient periods, affecting the overall system stability. The parameters for the generator, AVR, excitation system, are given in the appendix below.

2.3 Fuzzy logic structure

The content of control is determined in relation to a number of data inputs using a set of equations to express the whole control process in conventional and non linear control systems.

The mathematical formula for a system cannot able to express human experience, if not it is an impossible one. Fuzzy logic gives a simple interpretation for this experience in to the practical world. Fuzzy logic controller are rule based controllers that are depending on the inference rules. The basic configuration of the fuzzy logic controller has four parts shown below**.**
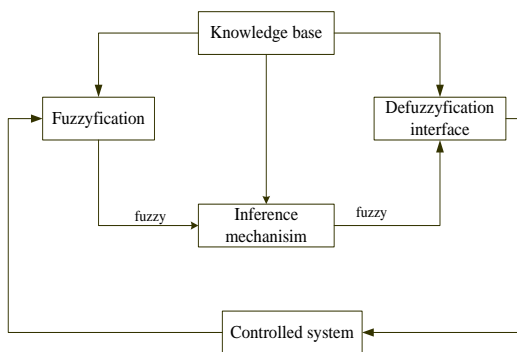

Fig. 4 Schematic diagram of the FLC building block

1.Fuzzification – first, it is a process that read, measure, and scale the control variable (speed, acceleration) and, second, to transform the measured numerical values to the corresponding linguistic (fuzzy variables with appropriate membership values);

2.Knowledge base - this includes the definitions of the fuzzy membership functions defined for each control variables and the necessary rules that specify the control goals using linguistic variables

3.Inference mechanism – it should be capable of simulating human decision making and influencing the control actions based on fuzzy logic

4.Defuzzufication module – which converts the inferred decision from the linguistic variables back the numerical values

2.3.1.Fuzzy logic design

The fuzzy logic controller (FLC) design consists of the following five steps

1. Identification of input and output variables.
2. Construction of control rules.
3. Establishing the approach for describing system state in terms of fuzzy sets, i.e., establishing fuzzification method and fuzzy membership functions.
4. Selection of the compositional rule of inference.
5. Defuzzification method, i.e., transformation of the fuzzy control statement into specific control actions.

Selection of proper linguistic variables formulating the fuzzy control rules is very important factor in the performance of fuzzy controllers. For the present investigations generator speed deviation $\Delta\omega$ and Acceleration $\Delta.\omega$ are chosen as input signals to FLPSS.

$\Delta\omega=\omega(k)-\omega(k-1)=(1-z^{-1})\omega(k)$

$(\Delta\omega(k))/(\omega(k))=(1-z^{-1})$

observe that the output is

$\Delta u=u(k)-u(k-1)$ by taking the z-transform of this equation results in:

$=u(k)-z^{-1}u(k)$

$=(1-z^{-1})u(k)$ then

$u/\Delta u=1/((1-z^{-1}))$,it is a discrete filter

Membership function: Each of the FLC input signal and output signal, fuzzy variables ($X_j=\{\Delta\omega, d\Delta\omega, u\}$), has the real line R as the universe of discourse. In any practical study, the universe of discourse is restricted to a comparatively small interval of [Xminj, Xmaxj]. The number of fuzzy sets are stated for each fuzzy variables varies according to the application. The reasonable number is an odd numbers starting from 3,5,7. Increasing the number of fuzzy sets will result in a corresponding increase in the number of rules.

$$A = \{(x, \mu(x))/x \in X\}$$

where $\mu A(x)$ is called the membership function for the set A. There are existing different shapes of membership functions 1.The first and most important is the triangular function or the triangular curve is a function of a vector X, and depends on the three scalar parameters like a,b, and c as given as follows

$$f(X:a,b,c) = \begin{cases} 0, & X \leq a \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ \dfrac{c-x}{c-b}, & b \leq x \leq c \\ 0, & c \leq x \end{cases}$$

or more compactly. by

f(X:a,b,c)=max(min((x-a)/(b-a),(c-x)/(c-b)),0)

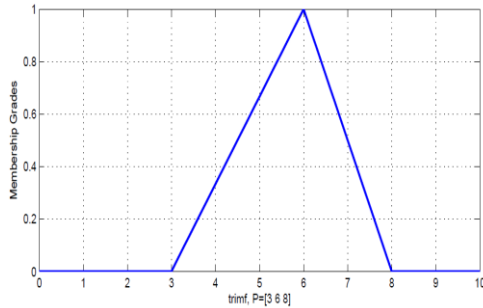Figure5: Triangular Membership Function

2. The Trapezoidal function

The trapezoidal curve is a function of a vector, x, and depends on four scalar parameters a, b, c, and d, as given by

$$f(x, a, b, c, d) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \dfrac{d-x}{d-c}, & c \leq x \leq d \\ 0, & d \leq x \end{cases}$$

or more compactly. by

$$f(x, a, b, c, d) = \max\left(\min\left(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}\right), 0\right)$$
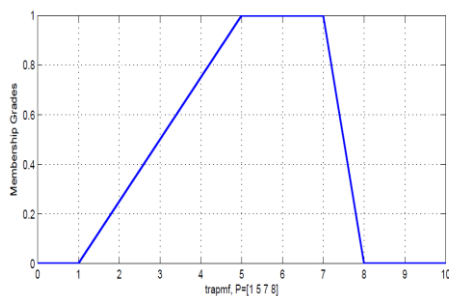
Figure 6: Trapezoidal Membership Function

The main parts of the FLC is the rule base and the inference mechanism

The ith linguistic control rule

Ri: if $\Delta\omega$ is Ai and $d\Delta\omega$ is Bi THEN Ui is Ci

where Ai and Bi (antecedent) Ci(consequent) are fuzzy variables characterized by membership functions and the composition operation can be expressed as

µB(U)=Sup[MIN(UA(x),µB(x,0))]

where A is the known fuzzy set for the input X and B is for the inferred fuzzy set for the output.

defuzzification: converts the fuzzy output of the inference engine to crisp using membership functions similar to the ones used by the fuzzier. The performance of the FLC depends very much on the deffuzzification process. This is because the overall performance of the system under control is determined by the controlling signal (the defuzzified output of the FLC) that the system universe. From the literature there are defuzzification methods that has been proposed[12]

1.The centroid of area method(COA) : it is given by the algebraic expression.

$$UcoA = \frac{\int_u^n \mu A(0) * u du}{\int_U^n \mu A(U)}$$

where U is the output variable and $\mu A(U)$ is the membership function of the aggregated fuzzy set A with respect to U. For a continuous membership function and

$$UcoA = \frac{\sum_{i=1}^n Ui\mu(ui)}{\sum_{i=1}^n \mu(ui)}$$

for a discrete membership function .where $\mu A(U)$ the aggregate output MF

2.Means of maximum (Mom) method: it is the average of the maximizing U at which the MF reach maximum U.

$$U = \frac{\sum_{ui \in m} Ui}{|M|}$$

where M={Ui/ μ (ui) the height of the fuzzy set } and $|M|$ is the cardinality of the set M

3.Centre of sums (COS) method: cos builds the result and membership function by taking the algebraic sum of outputs from each of the contributing fuzzy sets A1,A2,A3,etc. The defuzzied value Ucos is given by

$$Ucos = \frac{\sum_{i=1}^N Ui \sum_{k=1}^n \mu k(Ui)}{\sum_{i=1}^N \sum_{k=1}^n \mu Ak(Ui)}$$

where n is the number of fuzzy sets and N is the number of fuzzy variables.

The inputs of FLC are defined as the change of rotor speed and the derivative of change of speed of the rotor (Δw and d/dtΔw) respectively. The fuzzy sets are defined for each input and output variables, are seven fuzzy levels.

NB: negative big, NM negative medium, NS negative small , ZE zero, PS positive small , PM positive medium and PB positive big. The membership functions for input and output variables are triangular. The min-max method inference engine is used; the deffuzzify method used in this FLC is centre of area. The complete set of control rule is shown below.

Table -1: Fuzzy controller rules

Change of speed acceleration	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NM	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PM	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PM	PB	PB	PB

Each of the 49 control rules represents the desired controller response to a particular situation. The block diagram of FLC shown in matlab simulation (ANFS edit),and in figure the simulation of the surface control is presented.

3. PROPOSED SYSTEM

3.1. Modeling of STATCOM Controller
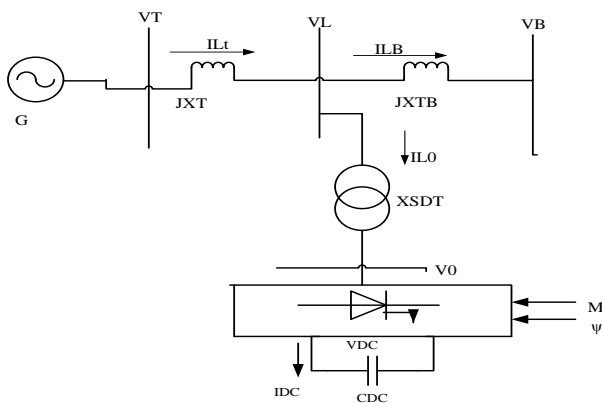
Figure 7. STATCOM connected in a single machine infinite bus power system

Figure.7 shows a single-machine infinite-bus power system installed with a FACTS device , a statcom which consists of the transformer (SDT) that connected in the low coil side with a leakage reactance xsdt, a three phase GTO-based voltage source converter (VSC) and a DC capacitor to get turn of thyrister.

The linearzed model of the power system installed with the STATCOM is derived [13] are

$$\Delta\frac{d\delta}{dt} = \omega b\Delta\omega \qquad\qquad 1$$

$$\Delta\frac{d\omega}{dt} = \frac{\Delta pe - D\Delta\omega}{m} \qquad\qquad 2$$

$$\Delta\frac{dEq}{dt} = (-\Delta Eq + \Delta Efd)/Tdo' \qquad\qquad 3$$

$$\Delta\frac{dEfd}{dt} = \frac{-1}{TA}\Delta Efd - \frac{KA}{TA}\Delta Vt \qquad\qquad 4$$

where

$$\Delta pe = \Delta Eq'ItLq + \Delta ItLqEq' + (Xq - Xd')\Delta ItLdItLq + (Xq - Xd')\Delta ItLqItLd \qquad 5$$

by substituting the linearzied currents and equation 3 in to equation5.

$$\Delta pe = k1\Delta\delta + K2\Delta Eq' + KpDc\Delta VDc + Kpc\Delta c + Kp\varphi\Delta\varphi \qquad 6$$
$$Eq = Eq' + (Xq - Xd')ItL$$
$$\Delta Eq = \Delta Eq' + (Xq - Xd')\Delta ItLd$$
$$\Delta Eq' = \Delta Eq - (Xq - Xd')\Delta ItLd \qquad\qquad 7$$

or by substitution deviation of d-axis current in this equation we can get

$$\Delta Eq' = K4\Delta\delta + K3\Delta Eq' + Kqdc\Delta Vdc + Kqc\Delta c + Kq\varphi\Delta\varphi \qquad 8$$

$$\Delta Eq' = K4\Delta\delta + K3\Delta Eq' + Kqdc\Delta Vdc + Kqc\Delta c + Kq\varphi\Delta\varphi \qquad 9$$

substituting equations 5-8 in to equation 4, we get

$$\frac{d}{dt}\begin{bmatrix}\Delta\delta\\\Delta\omega\\\Delta Eq\\\Delta Efd\end{bmatrix} = \begin{bmatrix}0 & \omega o & 0 & 0\\-\frac{K1}{m} & \frac{-D}{m} & \frac{-K2}{m} & 0\\-\frac{K4}{Td0'} & 0 & -\frac{K3}{Td0'} & \frac{1}{Td0'}\\-\frac{KAK5}{TA} & 0 & -\frac{KAK6}{TA} & \frac{-1}{TA}\end{bmatrix}\begin{bmatrix}\Delta\delta\\\Delta\omega\\\Delta Eq'\\\Delta Efd\end{bmatrix} + \begin{bmatrix}0\\-\frac{Kpdc}{m}\\-\frac{Kqdc}{Td0'}\\-\frac{KAKvdc}{TA}\end{bmatrix}\Delta Vdc$$

$$+ \begin{bmatrix}0 & 0\\\frac{-Kpc}{m} & \frac{-Kp\varphi}{m}\\\frac{-Kqc}{Td0'} & \frac{-Kq\varphi}{Td0'}\\\frac{-KAKvc}{TA} & \frac{-KAKv\varphi}{TA}\end{bmatrix}\begin{bmatrix}\Delta c\\\Delta\varphi\end{bmatrix}$$

$$\qquad\qquad 10$$

denoting $\quad \Delta f* = [\Delta Vdc \quad \Delta c \quad \Delta\varphi]$

where

$$Kp = \begin{bmatrix}\frac{Kpdc}{m}\\\frac{Kpc}{m}\\\frac{Kp\varphi}{m}\end{bmatrix} \qquad Kq = \begin{bmatrix}\frac{Kqdc}{Td0'}\\\frac{Kqc}{Td0'}\\\frac{Kq\varphi}{Td0'}\end{bmatrix} \qquad Kv = \begin{bmatrix}\frac{KAKvdc}{TA}\\\frac{KAKVv}{TA}\\\frac{KAKv\varphi}{TA}\end{bmatrix}$$

The linearized model of dc side voltage is from the above figure and equation

$$\frac{d\Delta Vdc}{dt} = K7\Delta\delta + K8\Delta Eq' + K9\Delta Vdc + Kdc\Delta c + Kd\varphi\Delta\varphi$$
$$11$$

where K1-K9 calculated in the linearized current equations .

The full state system model can be obtained as follows

$$\frac{d}{dt}\begin{bmatrix}\Delta\delta\\\Delta\omega\\\Delta Eq\\\Delta Efd\\\Delta Vdc\end{bmatrix}=\begin{bmatrix}0 & \omega0 & 0 & 0 & 0\\\frac{-K1}{m} & \frac{-D}{m} & \frac{K2}{m} & 0 & \frac{-Kpdc}{m}\\\frac{-K4}{Td0} & 0 & \frac{-K3}{Td0} & \frac{1}{Td0} & \frac{-Kqdc}{Td0}\\\frac{-KAK5}{TA} & 0 & \frac{KAK6}{TA} & \frac{1}{TA} & \frac{KAKVdc}{TA}\\K7 & 0 & K8 & 0 & K9\end{bmatrix}\begin{bmatrix}\Delta\delta\\\Delta\omega\\\Delta Eq'\\\Delta Efd\\\Delta Vdc\end{bmatrix}+\begin{bmatrix}0 & 0\\\frac{kpc}{m} & \frac{Kp\varphi}{m}\\\frac{Kqc}{Td0} & \frac{Kq\varphi}{Td0}\\\frac{KAKvc}{TA} & \frac{KAKv\varphi}{TA}\\Kdc & KD\varphi\end{bmatrix}\begin{bmatrix}\Delta c\\\Delta\varphi\end{bmatrix}$$
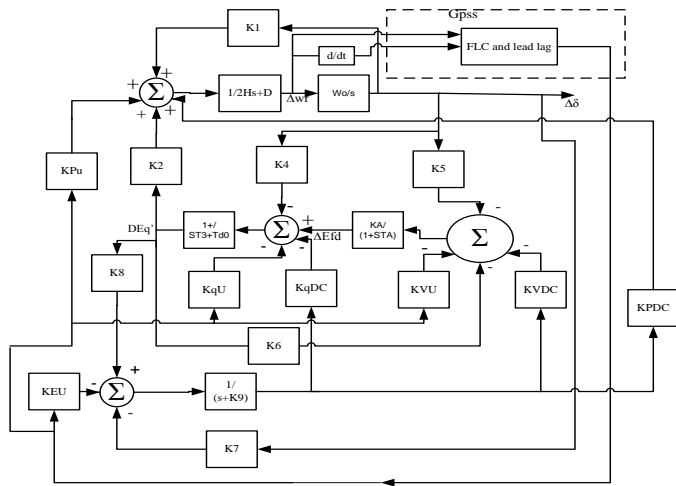
Figure 8. SIMB with STATCOM block diagram

The block diagram shown in figure 11 shows a synchronous applied to its excitation system in the Matlab simulation machine for which the output voltage is controlled by a PSS.
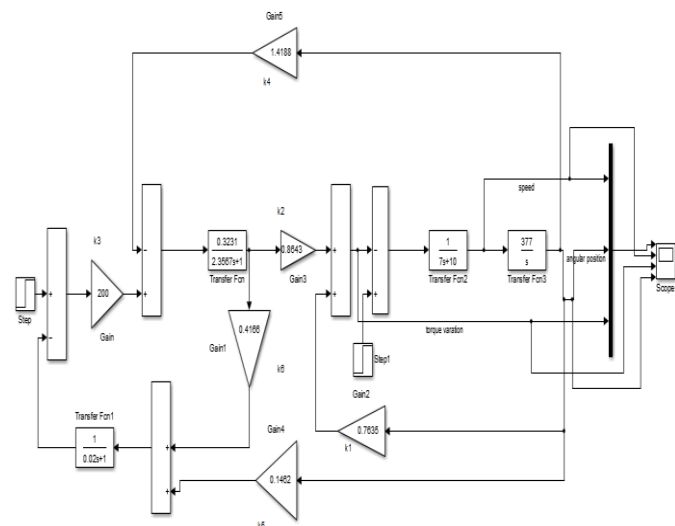
Figure 9. Excitation system simulink diagram

4. SIMULATION RESULTS OF THE SYSTEM
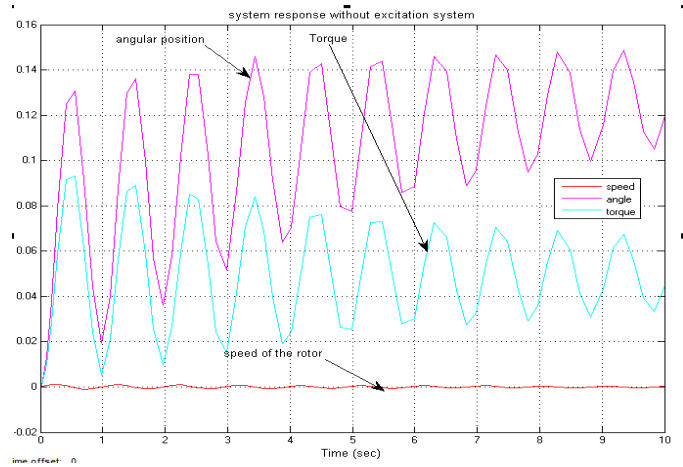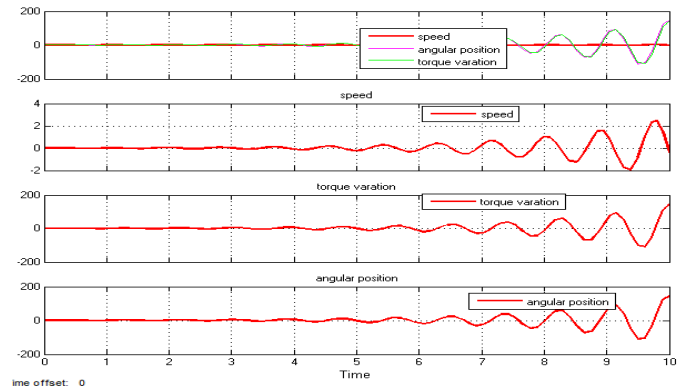

Figure 10: Response without excitation system
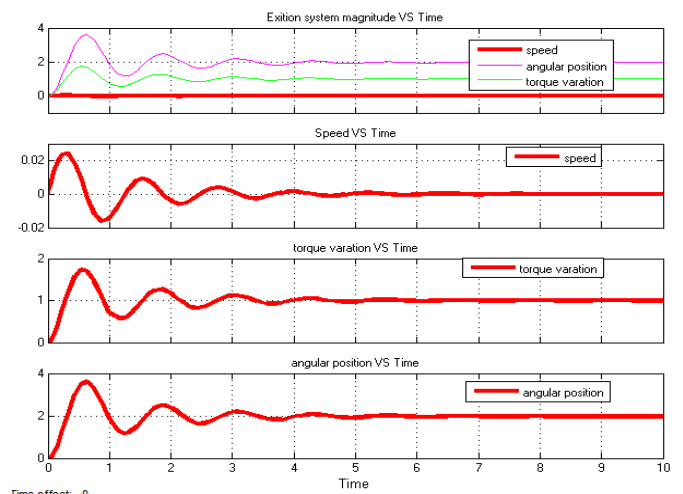

Figure 11: Response with excitation system for -ve $K5$

Figure 12 : Response with excitation system for +ve $K5$
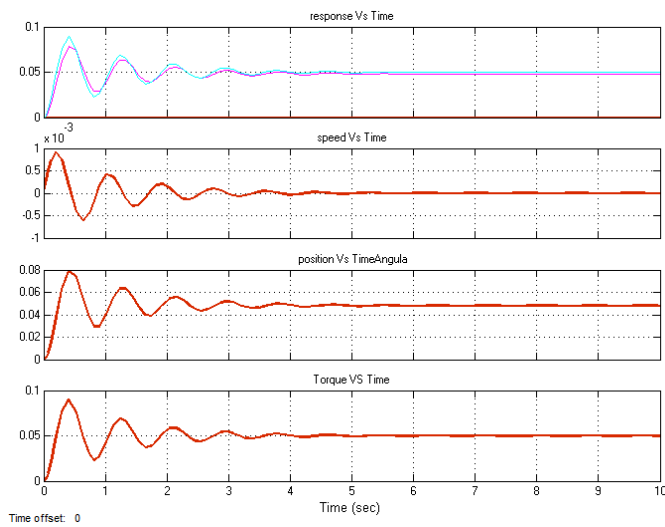
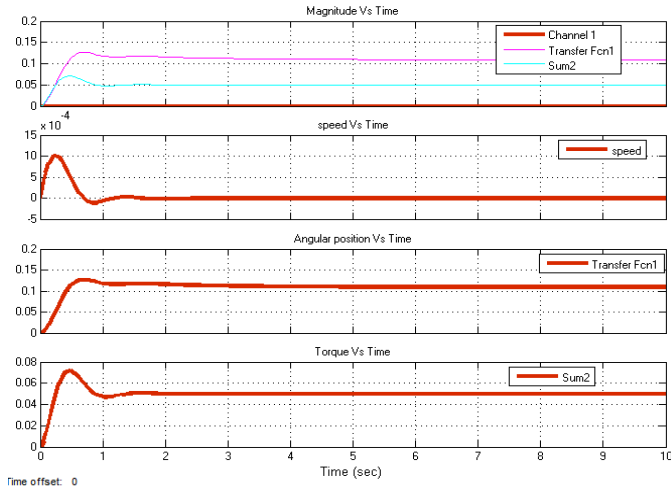Figure 13: response with pss system for -Ve K5

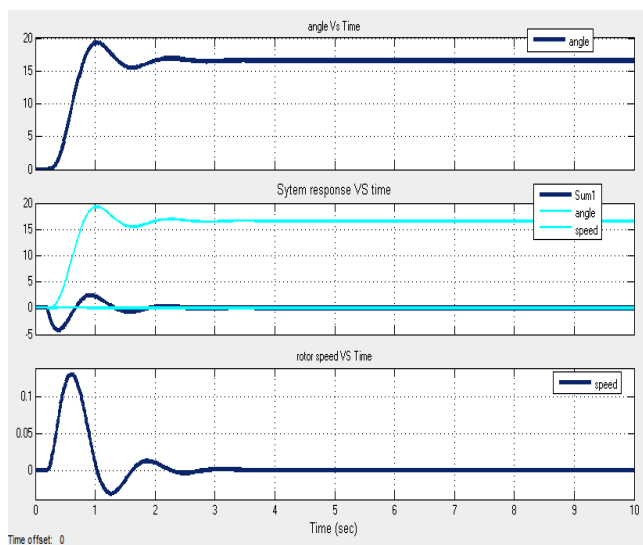Figure 14: Response with PSS system for +Ve K5

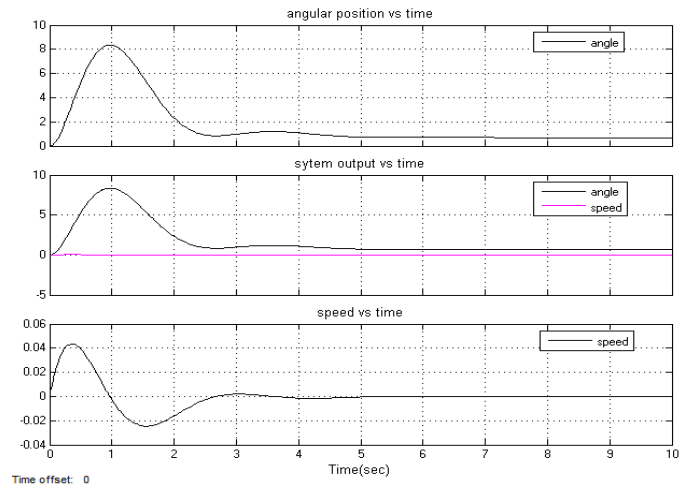Figure 15: Response with Fuzzy system for +Ve K5

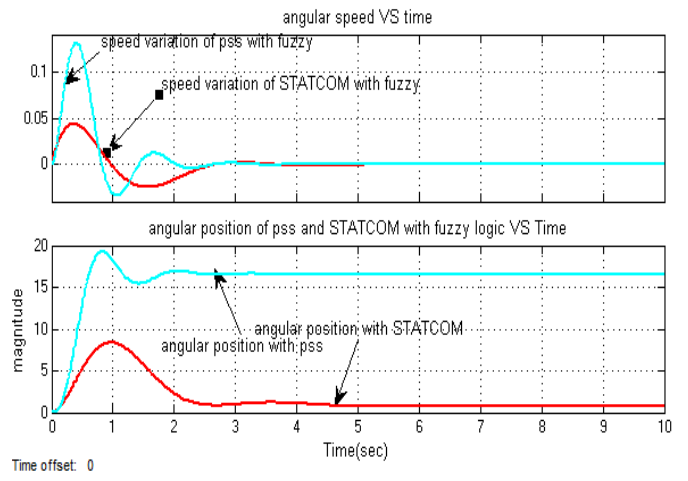Figure 16: System response of STATCOM with fuzzy controller

Figure 17: Comparisons of PSS and STATCOM controllers

5. CONCLUSIONS

It is observed in the three studies, from the Matlab/Simulink simulation, that the fuzzy controller has an excellent response with small oscillations, while the PSS response shows a ripple in both studies and some oscillations before reaching the steady state operating point but the FACTS device or STATCOM shows the better response and before steady state reached it increases the magnitude of the response. and It has been shown that an excellent performance of the fuzzy control of STATCOM in contrast to the conventional one and conventional power system stabilizer (pss) for the excitation with field current control of synchronous machines could be achieved as well as the oscillation is damped and stabilized.

ACKNOWLEDGEMENT

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