International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Fuzzy Logic based Wind Energy Power System Stabilizer Design using H∞ Robust Technique

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Abstract: ***As the world's power supply to a very larger degree based on wind turbines, it is consequently and increasingly essential that these are as reliable and available as possible. The main objective of the most of the wind energy systems is to extract the maximum power obtainable in the wind stream. However, the wind regime changes continuously and thus to follow these variations, the system controllers should be updated. The Robust Power System Stabilizer (RPSS) is designed using enhanced Artificial Bee Colony for designing the controllers for dynamical systems in electrical engineering. In this work, a fuzzy logic controller as power system stabilizer in wind turbine for stability enhancement of a multi-machine power system is proposed. Power System Stabilizers (PSSs) are added to excitation system or control loop of the generating unit to increase the damping during low frequency oscillations. In order to achieve the stability enhancement, speed deviation and acceleration of the rotor of synchronous generator is taken as the input to the fuzzy logic controller. These variables generate significant effects on damping of the generator shaft mechanical oscillations. The simulations are tested under various operating condition and the responses of stabilizing signal were computed. Their performance is compared with the traditional PID controller. The results of fuzzy controller are quite encouraging and acceptable.***

Keywords: Wind energy, Power System Stabilizer, Enhanced Artificial Bee colony, Fuzzy logic controller, H_∞

1. Introduction

Power grids around the world depend to increasing degree on power generated by renewable source. Among these wind turbines play a very major part. It is consequently significant that these turbines are available and reliable as possible. This indicates that wind turbines should be as tolerant to faults as possible. It is consequently capable of great relevance to apply advanced Fault Tolerant Control (FTC) methods on modern wind turbines.

Power system stabilization methods have been suggested for a long period to enhance the power system damping. Traditionally, lead-lag structures have been utilized as power system stabilizers. Majority have been used on the manner to regulate the factors of the lead lag controller. These controllers in previous years have been regulated for both multiple and single operating points of the power system. The methods used for adjusting range from pole placement, to the more recent one using the heuristic optimization techniques like the Genetic Algorithms (GA)[1] and Particle Swarm Optimization (PSO) [2].

Wind energy generation has brought about numerous challenges to electrical power system engineers [7]. The problems encountered in the electrical network made up of wind energy systems are due to the continuous changes in the wind regime [8]. These variations may inflect unwanted fluctuation in the network and thus has limited the capability of the wind energy systems which can be integrated with the network to a modest penetration factor. Different techniques have been proposed to cope with the variations in the wind speed to ensure very high performance and steady output for the wind energy systems and hence contribute to permit for higher penetration factor. The effect of the variation in the wind speed may result in Change in the output voltage, Change in the output frequency, Change in the output power, Shift in the operating point.

The variation in the output voltage and frequency is solved in this work by adopting the system which employs a doubly fed induction generator connected to the network. The frequency and voltage in this case are dictated by the major network the output power variation is addressed in a companion paper by using a storage battery to smooth the changes in the output power [9]. The shift in the operating point happens due to the variation in the wind turbine characteristics at various speed and other climate variations. These variations need that the parameters of the controller should be constantly updated to know that the wind turbine operating at the optimal point. To manage with the fact the wind speed change in uncertain manner, it is proposed to use fuzzy logic controllers.

The Conventional Power System Stabilizer (CPSS) is extensively used in existing power systems and has contributed to the improvement of the dynamic stability of power systems. The parameters of CPSS are identified based on a linearized model of the power system around a nominal operating point where they can offered good performance. Because power systems are extremely nonlinear systems, with configurations and parameters that change with time, the CPSS design based on the linearized model of the power systems cannot assure its performance in a practical operating environment [10]. To enhance the performance of CPSS, several techniques have been proposed for their design, like using intelligent optimization methods. In recent years, fuzzy logic control has emerged as a very effective tool and is starting to be used in different power system applications.

This work presents a new power system stabilizer with a fuzzy controller for various operating conditions of the power system. Various simulations have been performed in order to focus it to several types of large disturbances using power system. Comparison studies have also been made between the conventional proportional integral power system stabilizers (PSS) and the fuzzy controller based power system stabilizers. The numerical simulations results obviously demonstrate the superiority of the fuzzy in comparison to the CPSS.

2. Literature of Review

Soon et al., [11] proposed a Fuzzy Logic Controller (FLC) for decentralized stabilization of multi-machine power systems. The authors offered a unique, largely analytical technique for design of robust Multi-Input–Single-Output (MISO) FLC for enhancing stability and damping of an electrical power system without affecting the voltage regulation.

A robust decentralized controller depend on optimal sequential design is proposed by Yoshitaka et al., [12]. The inter-area oscillation mode on design phase can be openly considered by the proposed controller. Moreover, the sequential process is applied to model for robust controllers. The best design sequence of the controller is examined by using the condition number. The performance of the proposed controller is illustrated by comparing it with conventional controllers. Damping of several oscillations for a multi-machine power system is illustrated through simulations, which regard as a three line to-ground fault for power system disturbance.

Yagami et al., [13] offers a power system stability improvement technique with the help of grouping of thyristor controlled braking resistor and fault current limiter. The fault current limiter functions for restriction of fault currents, enhancement of the power system stability and containment of turbine shaft torsional oscillations. Next, the thyristor controlled braking resistor functions with the intent of quick managing of generator disturbances. The achievement of both devices has been illustrated with the help of 3LG fault in a two-machine infinite bus system. Simulation results signify a better power system stability improvement and also the damping turbine shaft torsional oscillations with allowed level of temperature rise.

Zhengguo et al., [14] applied the concept of switched controller to inspect a single machine-infinite bus power system when a symmetrical 3-phase short circuit fault occurs on one of the transmission lines. Usually, linear controller cannot offer a good transient performance for such a power system with a large fault. The proposed switched controller manages both temporary and permanent faults. The performance and the efficiency of the proposed approach have been obtained using simulation results. It should be noted that this approach provides a solution to stabilization problem when a fault occurs. The future extension of this approach is to examine on achieving a good post fault performance.

P.S. Bhati et al.,[15] presents a robust fuzzy logic power system stabilizer (FLPSS) depend on evolution and learning is proposed in this work. A hybrid algorithm that combines evolution and learning is developed whereby each one complements other‟s potency. Parameters of FLPSS are encoded in chromosome of genetic algorithm (GA) population. FLPSS Population in GA learns to alleviate electromechanical power system oscillations at an operating point, as the best fitness becomes large steady value during successive generations. Operating region of FLPSS is extended by learning more operating points over the operating domain. Best FLPSS drawn from past generation is saved as designed FLPSS. Effectiveness of the proposed method is validated on a Single Machine Infinite Bus (SMIB) power system. Promising optimal stabilizing performance with modeled FLPSS for considered power system is obtained at wide range of operating points.

Eldamaty et al presents a new control method based on fuzzy logic technique to control the operation of a Unified Power Flow Controller (UPFC) installed in a SMIB power system. The aim of the fuzzy logic based UPFC controller is to damp the oscillations in power system. Phillips-Herffron model of a single-machine power system equipped with a UPFC is used to design the system. The fuzzy logic based UPFC controller is designed by selecting appropriate controller parameters based on the idea of the power system performance. Simple fuzzy logic controller using mamdani-type inference system is used. The performance of the new controller is demonstrated through time-domain simulation studies. The performance results of these studies show that the designed controller has an excellent capability in damping power system oscillations.

3. H∞ Robust Design Technique based on Enhance ABC Optimal Power System Stabilizer with Fuzzy Controller

3.1 H∞

H_∞ methods are used in control theory to make controllers attaining stabilization with guaranteed performance. To utilize H_∞ methods, a control designer expresses the control problem as a mathematical optimization problem and then identifies the controller that resolves this optimization. H_∞ techniques have the advantage over classical control techniques in that they are easily applicable to problems involving multivariate systems with cross-coupling between channels. But non-linear difficulties such as saturation are generally not well-handled.

3.2 Artificial Bee Colony (ABC)

Artificial Bee Colony is a new swarm intelligence algorithm proposed by Karaboga in 2005, which is inspired by the behavior of honey bees. In ABC algorithm, the colony of artificial bees contains three groups of bees such as employed bees, onlookers and scouts. The colony‟s first half consists of employed artificial bees and the remaining half includes the onlookers. For every food source, there is only one employed bee that is the number of employed bees is same as number of food sources. The employed bee of an abandoned food source becomes a scout.

The search done by the artificial bees can be summarized as follows:

- Employed bees find out a food source within the neighborhood of the food source in their memory.
- Employed bees share their information by onlookers within the hive and then the onlookers pick one of the food sources.
- Onlookers pick a food source within the neighborhood of the food sources selected by themselves.
- An employed bee of which the source has been discarded becomes a scout and starts to search a new food source randomly.

3.3 Enhanced Artificial Bee Colony Algorithm

The A B C algorithm is developed by analyzing the attitudes of the real bees on finding food source, which is called the nectar, and distribute the food sources information to the bees in the nest. In the ABC, the artificial agents are defined and classified into three types, which are the employed bee, the onlooker bee, and the scout. Each of them plays diverse role in the process, the employed bee stays on a food source and offers the neighborhood of the source in its memory the onlooker gets the information of food sources from the employed bees in the hive and choose one of the food source to gather the nectar and the scout is responsible for obtaining new food, the new nectar, sources.

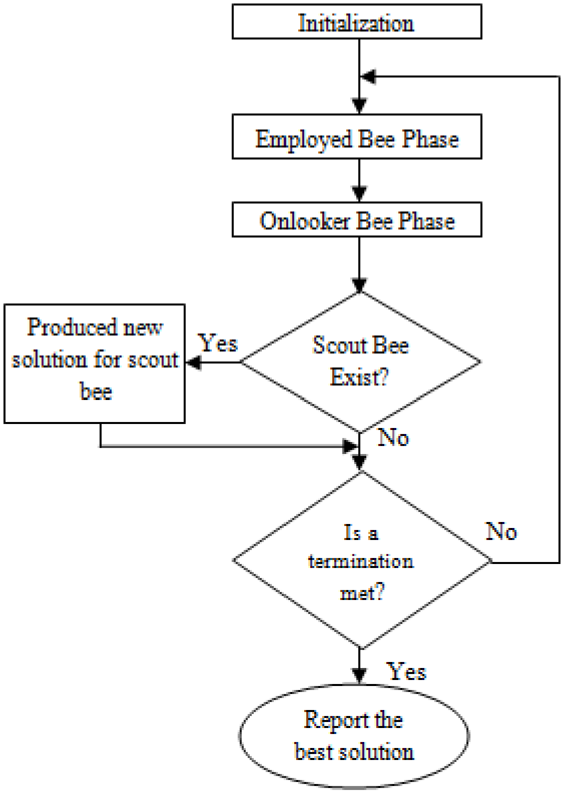


Figure1: Flow chart for Enhanced Artificial Bee Colony algorithm

Algorithm

Initialize all parameters; Repeat while termination criteria is not meet
Step 1: Employed bee phase for computing new food sources.
Step 2: Onlooker bees phase for updating location the food sources based on their amount of nectar.
Step 3: Scout bee phase for searching new food sources in place of rejected food sources.
Step 4: Memorize the best food source identified so far.
End of while
Output: The best solution identified so far.

3.4 PID Controller

A proportional–integral–derivative(PID) controller is a control loop feedback mechanism generally used in industrial control systems. A PID controller constantly calculates an error value as the difference between a measured process variable and a desired set point. The fundamental complexity with PID control is that it is a feedback system with constant parameters, and don‟t have direct knowledge of the process, and thus the whole performance is reactive and a compromise. Other problems faced with PID controllers is that they are linear, and in particular symmetric.

3.5 Fuzzy Controller

Fuzzy logic is a logic is using graded and quantified statement rather than once that are firmly true or false. The outputs of fuzzy reasoning are not definite as those derived by strict logic. The fuzzy sets allow objects to have membership grades from 0 to 1. These sets are represented by linguistic variables, which are ordinary language terms. They are used to define a particular fuzzy set in a given problem, such as “large”, “medium” and “small”.

Fuzzy Logic Controls are very useful when an exact mathematical model of the plant is not obtainable yet experienced human operators are available for offering qualitative rules to control. The necessary part of the fuzzy logic controller is a set of rules of linguistic controls related by dual concepts of fuzzy implication and the compositional rule of inference. The fuzzy logic controller is simpler and top methodology. It does not require any exact system mathematical model and it can manage nonlinearity of arbitrary complexity. It depends on the linguistic rules with an IF-THEN general structure, which is the basis of human logic. It consists of fuzzification inference engine and defuzzification blocks. In this the, input variables are change in speed deviation (dω) and change in acceleration (da) and the output variable is stabilizing voltage (Vstab). The basic configuration of the FLC can be simply defined in four parts, as shown in following figure

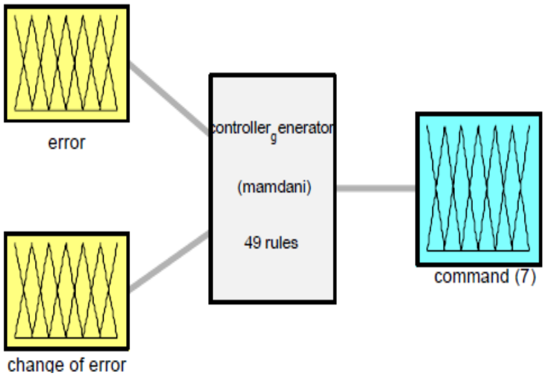


Figure 2: Fuzzy Block

4. Modeling of Power System with PSS

The single machine infinite bus system performance has been studied with conventional PSS and with fuzzy logic based PSS. The fuzzy stabilizer has been modeled in fis editor of MATLAB. The dynamic models of synchronous machine and conventional PSS are described.

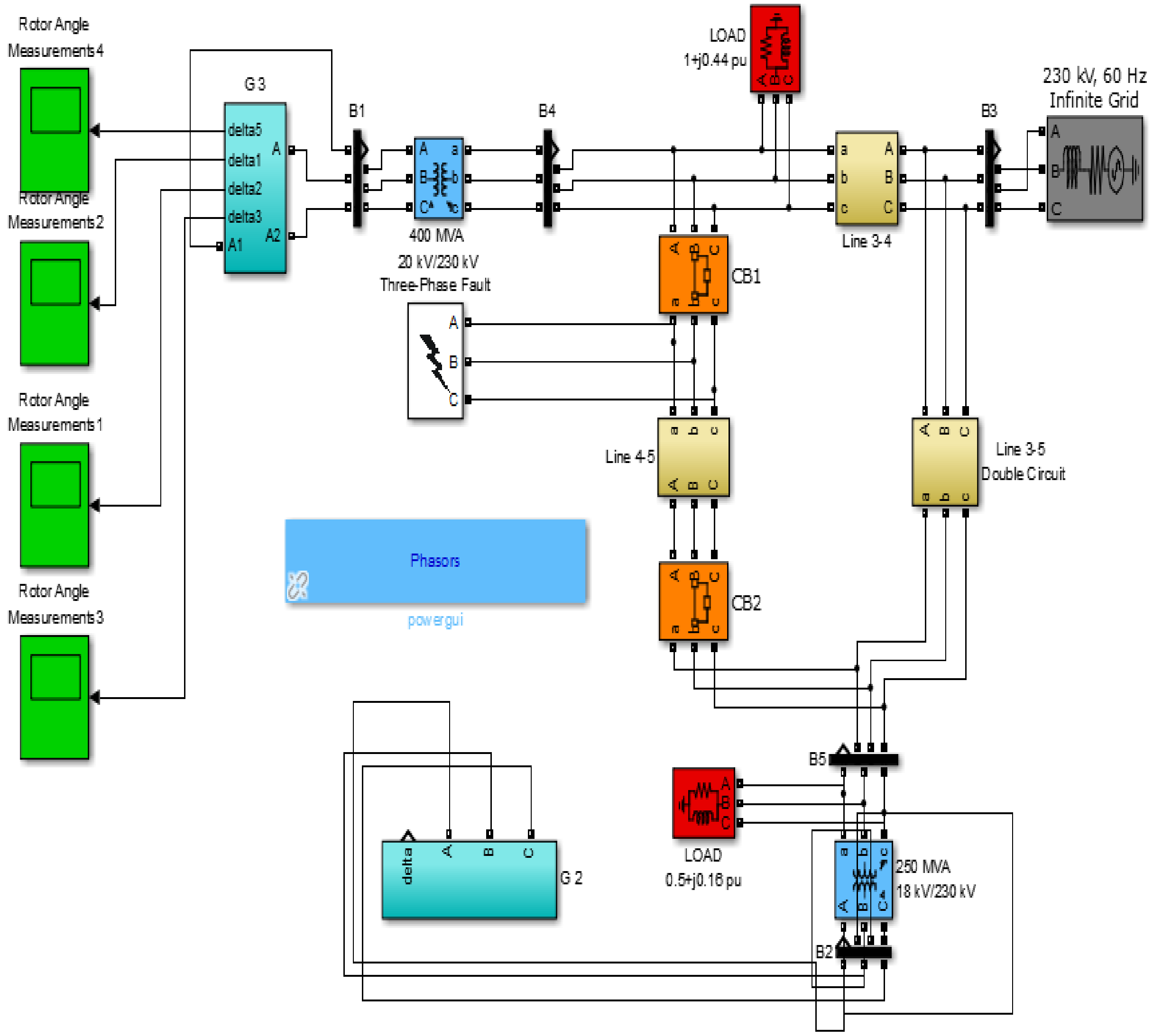


Figure 3: Simulink model

5. Simulation Results

In this work, the simulation algorithm of the proposed fuzzy controller is discussed. For each time step in the system simulation, a computation of the generator speed deviation signal and generator speed deviation change in signal is made. This is attained by getting the value of the state variable in the state matrix which equal to the generator speed deviation. The value of generator speed deviation signal from the preceding generator speed deviation signal. The associated membership values for every normalization input are calculated. Then applying the max-min method inference method to obtain the control output in fuzzy values. These fuzzy values can be converted to a crisp value by COG method. The signal of the controller is the damping signal that is fed into the reference voltage summing point to obtain the next state values.

Various performances such as terminal voltage (Vt), speed deviation (dω), active power (Pa) and stator angle voltage of the proposed fuzzy logic power system stabilizer (FLPSS) is compared with conventional power system stabilizer.

5.1 Comparison of Conventional PSS and PSS with Enhanced ABC Optimization Technique

5.1.1 Active Power

Active (Real or True) Power is measured in watts (W) and is the power drawn by the electrical resistance of a system doing useful work.

5.1.2 Terminal Voltage

Terminal voltage is the voltage output of a device is measured across its terminals. Terminal voltage is calculated by V = emf - Ir.

5.1.3 Stator Angle Voltage

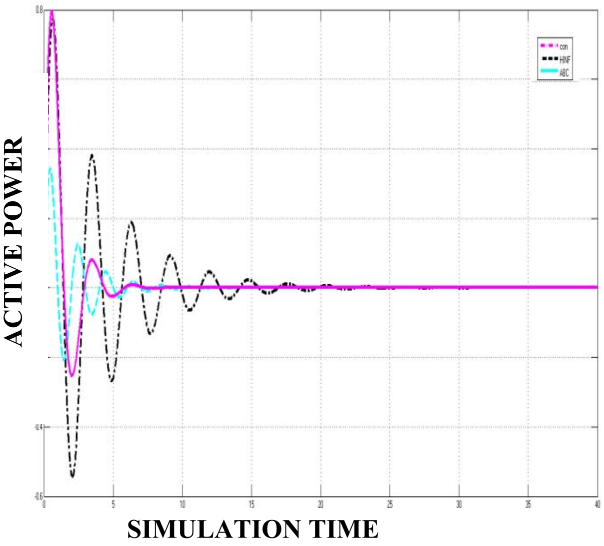
Voltage measured at the stator side.

5.1.4 Speed Deviation

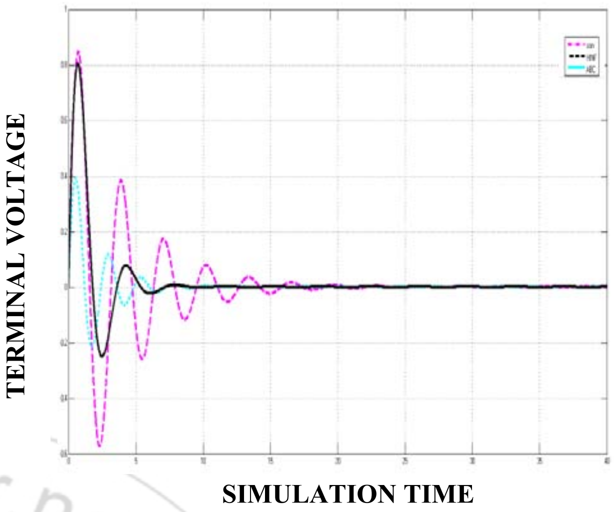
The difference between the value of a set speed and the rotation speed of a motor.

1. Under-exited mode x=0.5 , y=0.85 , z=0.1802

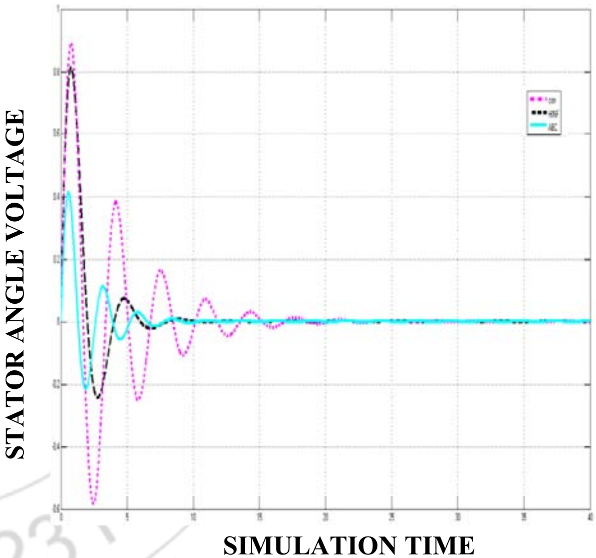
a) Active power



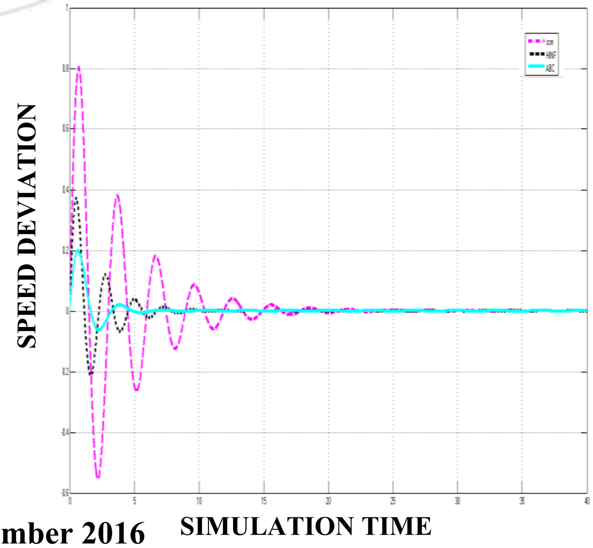
b) Terminal Voltage



c) Stator Angle Voltage

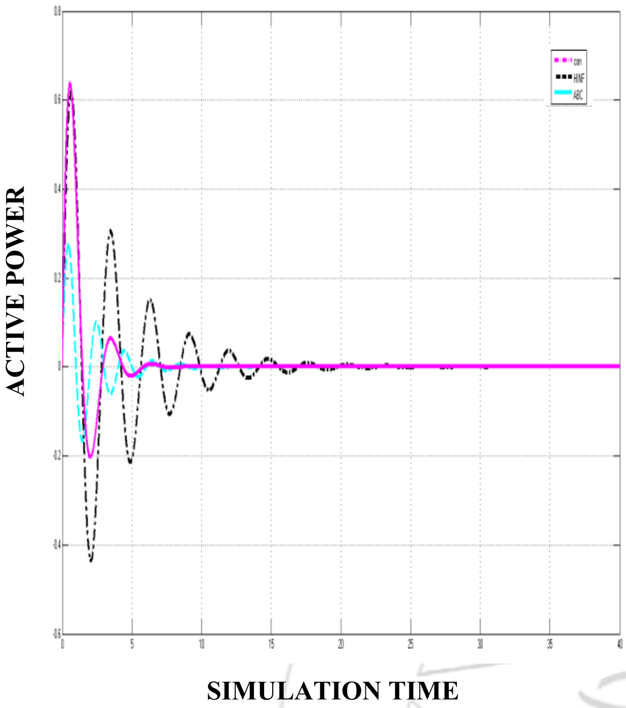


d) Speed Deviation

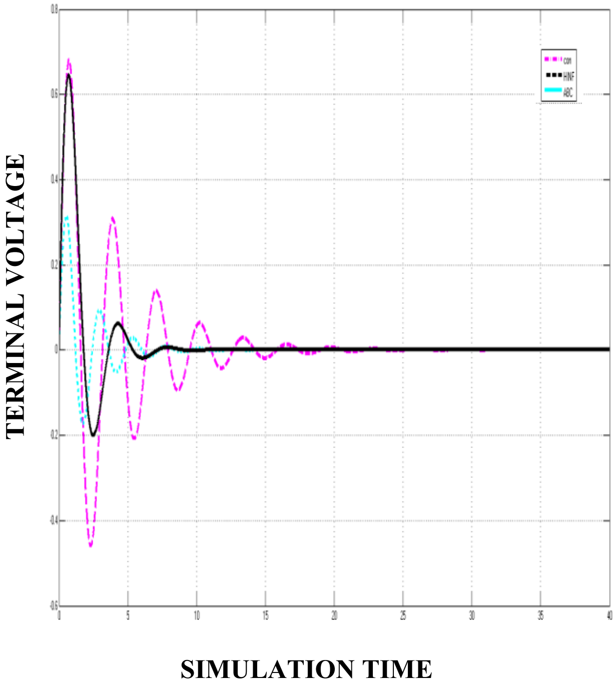


2. Nominale mode x=0.3, y=0.85, z=0.1102

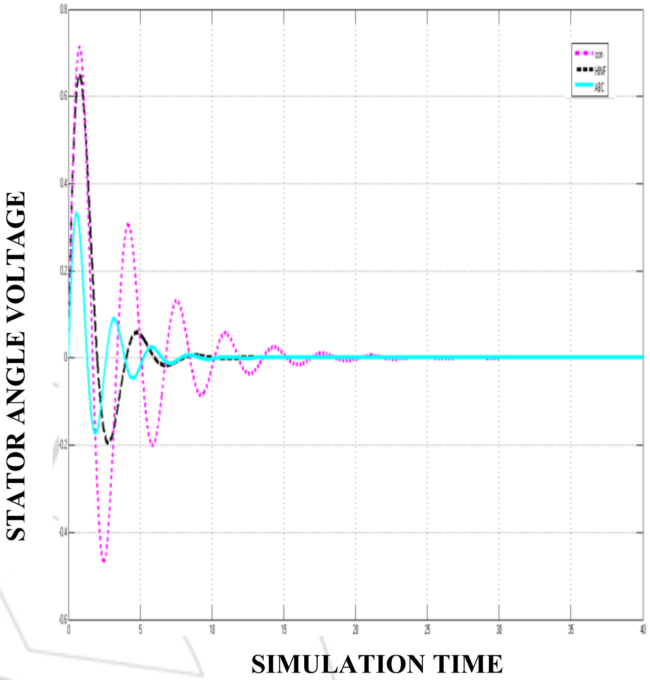
a) **Active power**



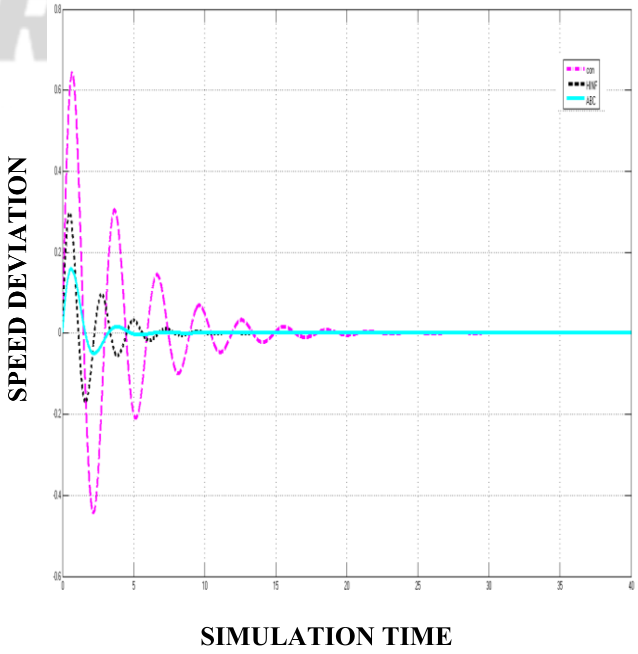
b) **Terminal Voltage**



c) **Stator Angle Voltage**

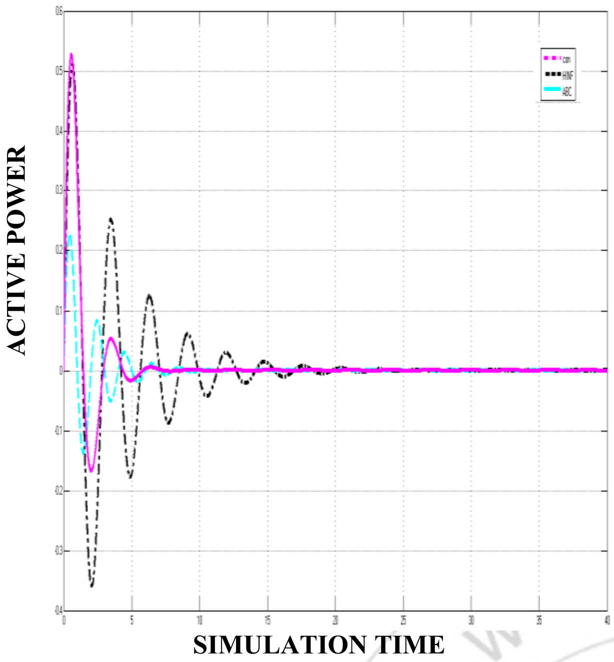


d) **Speed Deviation**

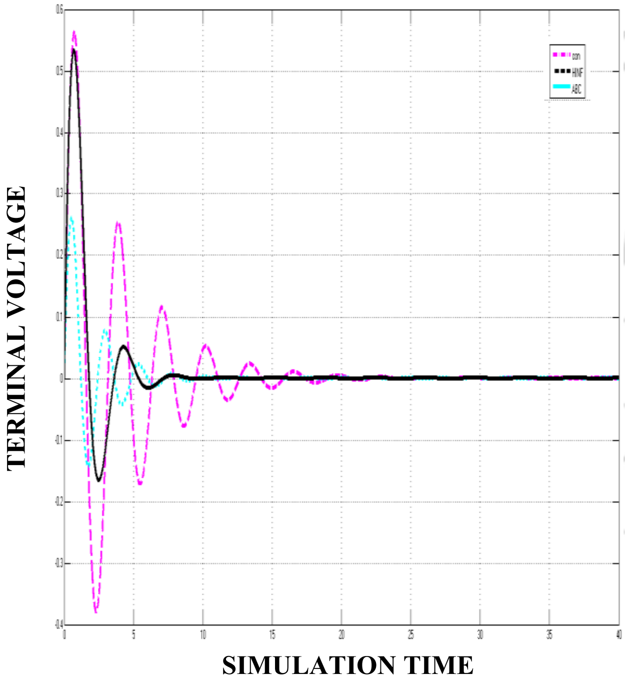


3. **Over-excited mode x=0.2, y=0.85, z=0.6760**

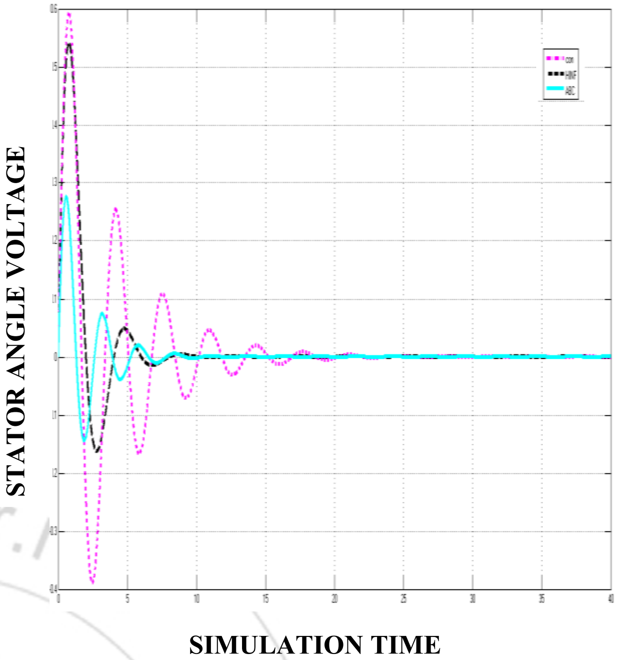
a) **Active power**



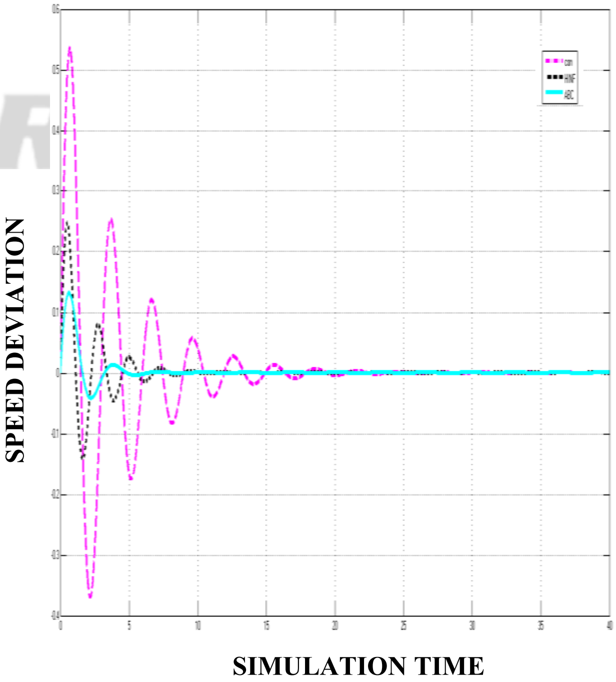
b) **Terminal Voltage**



c) **Stator Angle Voltage**



d) **Speed Deviation**



From the result, the performance of FPSS with membership function is superior in comparison to the performance with other PSS.

Table 1: Damping Coefficients „α‟ and Static Error „ξ‟ in the Closed Loop System with RPSS and CPSS in Different Operating Conditions of the Power System

Reactive Power	α_{PSS}	ξ_{PSS}	$\alpha_{PSSH\infty}$	$\xi_{PSSH\infty}$	$\alpha_{PSSEABC}$	$\xi_{PSSEABC}$	$\alpha_{PSSEABCWITHFUZZY}$	$\xi_{PSSEABCWITHFUZZY}$
-0.2033	0.6574	0.00119	0.6846	0	0.7121	0	0.8023	0
-0.2449	0.6564	0.0012	0.6853	0	0.7211	0	0.8143	0
-0.1238	0.6695	0.00112	0.6960	0	0.7321	0	0.8229	0
-0.3402	0.6671	0.00089	0.7038	0	0.7382	0	0.8237	0
-0.6840	0.6574	0.00071	0.6877	0	0.7401	0	0.8301	0

Table 2: Settling Time „T_s‟ and Peak Time „T_p‟ in the Closed Loop System with RPSS and CPSS in Different Operating Conditions of the Power System

Reactive Power	$T_{S\ PSS}$	$T_{P\ PSS}$	$T_{S\ PSSH\infty}$	$T_{P\ PSSH\infty}$	$T_{S\ PSSEABC}$	$T_{P\ PSSEABC}$	$T_{S\ PSSEABCWITH\ FUZZY}$	$T_{P\ PSSEABCWITH\ FUZZY}$
-0.2033	0.93	0.51	0.6	0.464	0.38	0.34	0.26	0.21
-0.2449	0.92	0.51	0.594	0.461	0.372	0.334	0.252	0.214
-0.1238	0.65	0.5	0.59	0.46	0.367	0.3217	0.234	0.2305
-0.3402	0.81	0.46	0.549	0.435	0.3211	0.312	0.2207	0.210
-0.6840	0.84	0.47	0.56	0.44	0.303	0.304	0.201	0.202

6. Conclusion

The goal of the developed work is damping of oscillations related to power system using a controller based on fuzzy logic theory. The proposed controller offers a more robust control over a large excursion of the various operating points. Most of the preceding control methods are either not working sufficiently under whole range of operating condition or they require complicated calculation and exact model methodology. The proposed controller doesn‟t depend on the Eigen analysis approach model which is regularly used techniques for getting the controller result. Here, the time responses of the system with different operating condition are proposed and tested.

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