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Comparative Study of Frequency Control Method of MGP System using Convectional PI and Fuzzy Logic Controller

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Abstract: ***The paper here states, the comparative study of frequency control of MGP system with convectional PI and fuzzy logic controller is done. The electrical power generation has done by non renewable energy sources in most parts of the world. The carbon emissions during the production of electricity challenge the environmental issues which lead to pollution. So, there is a necessity for the interconnection of renewable energy sources with grid for the reduction in usage of non renewable energy sources. But, interfacing of renewable sources to the grid is not an easy task. The reduction of inertia in the power system, the frequency instability problems may limit the usage of renewable sources in the interfacing with the grid. The motor generator pair can deal with all the above problems very effectively. The source grid characteristics are analyzed by simulation using convectional PI controller and fuzzy logic controller. The fuzzy logic PI controller gives better results when compared with convectional PI controller. The results were compared by simulation whether the fuzzy PI controller gives best results or convectional PI controller.***

Keywords: Frequency converter, sine pulse width modulation, motor generator pair, convectional PI controller, fuzzy logic PI controller.

I. INTRODUCTION

The transmission of the electric power is done mainly by the non renewable energy sources. This production of the electric power causes carbon emissions results in the environmental pollution. The interconnection of the power grid with renewable sources reduces this environmental pollution. The interconnection of the renewable energy sources to the power grid gives rise to instability problems in power system.

The renewable sources like wind, solar and other sources have random fluctuations and the power load will not be constant at all times. Research has been developing in this area to avoid the instability problems in power system with interconnection of renewable sources to grid. The power system does not run stably due to source load fluctuations and can be solved by high power penetration. At a particular point of time, a wind farm or a photo voltaic cell power generation is not constant but the all day generation is constant. The problems of interconnection with renewable sources with grid are

A. Inertia will be greatly reduced ad frequency stability problems arise due to the usage of the power electronic equipment.
B. The faults caused in the power system directly affect the renewable sources that are connected to the grid.
C. When renewable energy sources are located in barren lands then the power export is difficult to the grid as it as weak support terminal.

In order to solve the above problems, Motor Generator pair is proposed. The renewable sources are not directly interconnected with the grid. The renewable sources are connected to the synchronous machines and these are connected to the power grid.

Before the introduction of MGP virtual synchronous generator (VSG) is used. But, the MGP system is better than VSG as there will be increase in the penetration energy. To provide the required inertia to the system VSG needs a large scale storage system for the energy for which more space is required. MGP can compensate for reactive power without any other usage of the compensated equipment. Moreover, for a MGP system there is no requirement of expensive battery storage systems for providing the required inertia to the system.

This paper describes the mathematical model of MGP. The analysis of the results with both convectional PI controller and fuzzy logic PI controllers are done. The comparison of the results is done to know about the better controller.

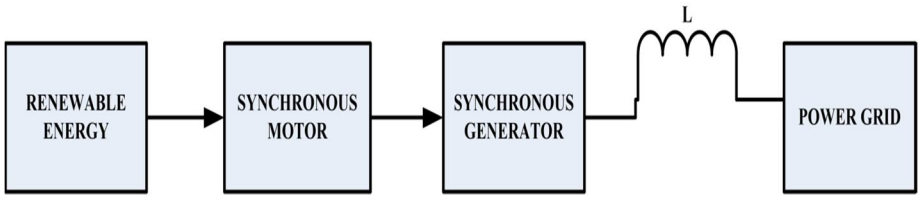
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II. THE PROPOSED MOTOR GENERATOR PAIR MODEL

A. Mathematical Model

The motor generator pair (MGP) are designed by synchronous machines. The grid capacity is considered to be in MW scale. The designed MGP system is now connected to renewable source and power grid for the configuration.



The electrical model of the MGP system can be determined by taking the individual unit of the synchronous machine.
ua, ub, uc, uf : stator voltage(3 phases), field voltage
ia, ib, ic: stator current (3 phases), field winding current
ikd , ikq: d-axis and q-axis damper winding current
ifd : field current
ψa, ψb, ψc, ψf : stator winding flux(3 phases), field winding flux
θ: rotor position
From the basic voltage equations and flux linkage equations, we get

$$\begin{pmatrix} ua \\ ub \\ uc \\ uf \\ uD \\ uQ \end{pmatrix} = \begin{pmatrix} rs & 0 & 0 & 0 & 0 & 0 \\ 0 & rs & 0 & 0 & 0 & 0 \\ 0 & 0 & rs & 0 & 0 & 0 \\ 0 & 0 & 0 & rf & 0 & 0 \\ 0 & 0 & 0 & 0 & rD & 0 \\ 0 & 0 & 0 & 0 & 0 & rQ \end{pmatrix} \begin{pmatrix} -ia \\ -ib \\ -ic \\ if \\ iD \\ iQ \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Psi a \\ \Psi b \\ \Psi c \\ \Psi f \\ \Psi D \\ \Psi Q \end{pmatrix}$$

When the mutual inductance is considered, then

$$\begin{pmatrix} \Psi a \\ \Psi b \\ \Psi c \\ \Psi f \\ \Psi D \\ \Psi Q \end{pmatrix} = \begin{pmatrix} Iaa & mab & mac & maf & maD & maQ \\ mba & Ibb & mbc & mbf & mbD & mbQ \\ mca & mcb & Icc & mcf & mcD & mcQ \\ mfa & mfb & mfc & Iff & mfD & mfQ \\ mDa & mDb & mDc & mDf & IDD & mDQ \\ mQa & mQb & mQc & mQf & mQD & IQQ \end{pmatrix} \begin{pmatrix} -ia \\ -ib \\ -ic \\ if \\ iD \\ iQ \end{pmatrix}$$

By parks transformation method, we obtain

$$\begin{pmatrix} ud \\ uq \\ u0 \end{pmatrix} = C \begin{pmatrix} ua \\ ub \\ uc \end{pmatrix}$$

Where,

$$C = \begin{pmatrix} \cos\theta & \cos(\theta - \frac{2\Pi}{3}) & \cos(\theta + \frac{2\Pi}{3}) \\ -\sin\theta & -\sin(\theta - \frac{2\Pi}{3}) & -\sin(\theta + \frac{2\Pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{pmatrix}$$

Now, the votage and flux equations of dq axis is given by

$$\begin{pmatrix} ud \\ uq \\ u0 \\ ufd \\ uDd \\ uQq \end{pmatrix} = \begin{pmatrix} rs & 0 & 0 & 0 & 0 & 0 \\ 0 & rs & 0 & 0 & 0 & 0 \\ 0 & 0 & rs & 0 & 0 & 0 \\ 0 & 0 & 0 & rf & 0 & 0 \\ 0 & 0 & 0 & 0 & rD & 0 \\ 0 & 0 & 0 & 0 & 0 & rQ \end{pmatrix} \begin{pmatrix} -id \\ -iq \\ -i0 \\ ifd \\ iDd \\ iQq \end{pmatrix} + \frac{d}{dt} \begin{pmatrix} \Psi d \\ \Psi q \\ \Psi 0 \\ \Psi fd \\ \Psi Dd \\ \Psi Qq \end{pmatrix} + \begin{pmatrix} -\omega\Psi q \\ -\omega\Psi d \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

Here, u0=uDd=uQq=0

As the generator and motor are two forms of synchronous machine, the equivalent motor can be obtained by changing the current reference direction

When the motor and generator pair is running steadily, then

$$T_{eM} = -T_{eG}$$

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When the torque acting on the rotor is unbalanced then, the unbalanced torque

$$\Delta T = Tm - Te$$

The rotor speed changes the unbalanced torque equation. The equation of rotor motion

$$J\frac{d\omega m}{dt} = Tm - Te$$

When we use inertia time constant

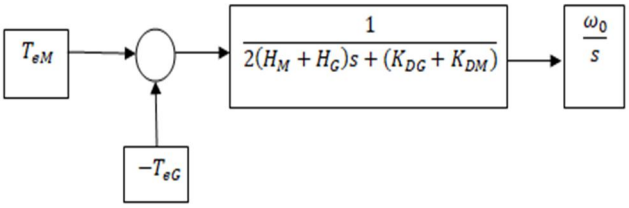
$$\frac{2H}{\omega_0{}^2} S_B \frac{d\omega m}{dt} = Tm - Te$$

The motor power angle can be expressed as

$$\delta = \omega mt - \omega_0 t + \delta_0$$

By solving the above equations, we get

$$\frac{d\delta_M}{dt} = \frac{d\delta_G}{dt} = \omega_0 \Delta\omega m$$



Mechanical Model of Motor Generator Pair System

Where,

$\Delta\theta$ = phase adjustment amount

θ_g = phase of power grid voltage

ω_g = angular frequency of power grid voltage

f_{ref} = frequency reference value of the frequency converter output voltage

P_{ref} = output active power reference value of MGP system

U_g = generator terminal voltage

I_g = generator output current

P = output active power of MGP system

H_M, H_G = inertia time constants

δ_M, δ_G = rotor angles

T_{eM}, T_{eG} = electromagnetic torque

K_{DM}, K_{DG} = damping coefficients

The active power transmitted by synchronous motor can be simplified to

$$P_M = \frac{-U_m{}^2}{X_{Md}} \sin\delta_M$$

The active power transmitted by synchronous generator can be simplified to

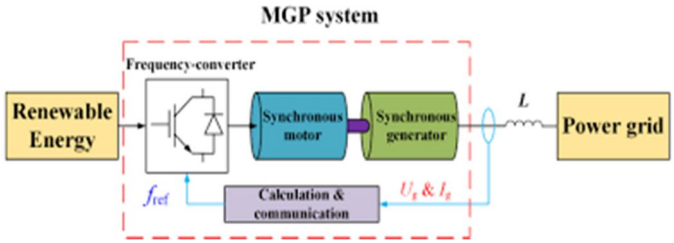
$$P_G = \frac{-U_G{}^2}{X_{Gd}} \sin\delta_G$$

The power and the rotor angles of the synchronous machine are determined for the MGP systemby the above equation analysis.

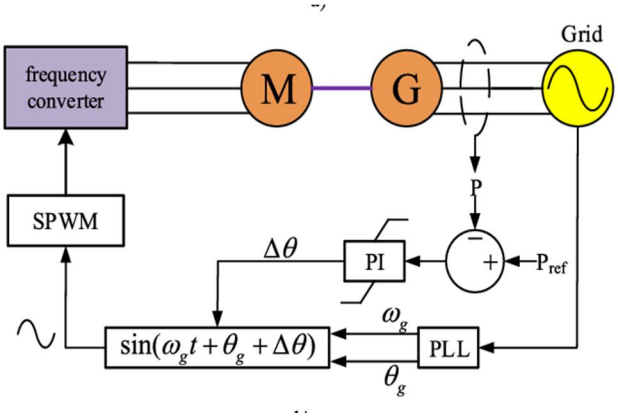
B. Control method by Convectional PI Controller

The transmission of power can be controlled by collecting the frequency of the grid as the reference to voltage output frequency of the frequency converter. Then, by changing the phase difference between the motor and generator power can be controlled. By adjusting the values of the terminal voltages of the generator and terminal voltage of the motor phase differences, the transmission of the power is regulated. The other method is rotor angle stability method used for small signal stability analysis.

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a) MGP system with control of frequency



b) System for calculation and communication

Table 1
Simulation parameters

Parameters for simulation	value
Voltage on Ac side	380 V
Inverter capacity	30 KW
Generator capacity	3 KW
Motor capacity	3 KW
Power frequency	50 Hz
Inductance (L_g)	1.3 H

Table 2
Synchronous machine parameters in simulink model

Machine parameter	p.u value
R_s	1.98 ohm
theta	5.6
Moment of inertia	84435 Kg.M^2
No of poles	2
Damping factor	32.15

The values of PI controller are determined by the trial and error method. The values are K_P =0.14, K_I = 0.01.
In simulation, the power transmission value of reference of the MGP system is 5MW at the starting point. The reference value of power is set to be 10 MW during initial condition. The results of the simulation depicts that the transmission of power is done stably in accordance with given power reference value. When the reference value of the MGP system is changed, the inverter adjusts the output voltage phase based on the grid voltage by the control system. In the results of simulation power angle (delta) varies in accordance with the power reference value of the MGP system, which indicates that the power transmission is adjusted by phase angle difference method.

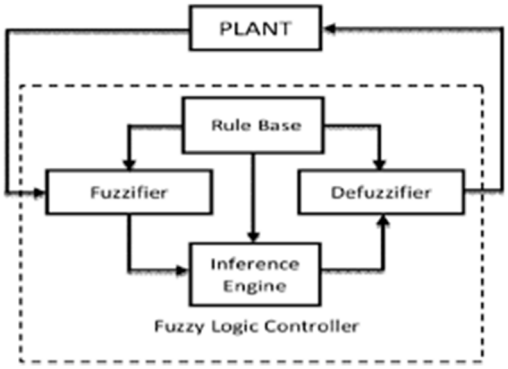
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C. Fuzzy Logic Controller

The recent technique in control applications used now a day is fuzzy logic. The use of fuzzy logic controller has growing and became prominence in many control system applications. The following illustrates the examples of the fuzzy control usage like regulating temperature in air conditioners, controlling of traffic lights etc..,

The different components of the Fuzzy Logic Controller are shown in below figure.

1) Fuzzifier: The main function of fuzzifier is to convert crisp values to fuzzy values.
2) *Fuzzy Knowledge Base:* The fuzzy input output relations storage is done here. The membership functions which define input variables and output variables are present here.
3) *Fuzzy Rule Base:* The knowledge based on the domain operation is stored here.
4) *Inference Engine:* By appropriate reasoning it simulates the human results and thus it is an essential part of the fuzzy logic controller
5) *Defuzzifier:* The main function of defuzzifier is to convert the fuzzy values to crisp values based on the output from the inference engine.



D. The Proposed FGPI Controller

The real life data is converted into linguistic values by the fuzzy controller. Analysis is done according to user defined variations by membership functions during fuzzification for a fuzzy variable. The input always be the set of crisp values. The membership functions help in taking the inputs according to the output values. By the linguistic set qualification to degree of correspondence membership, the fuzzification process of the output starts. The two inputs that are taken by the fuzzy controller are control area error and change in control area error. There are 7 membership functions which convert the inputs into fuzzy in the fuzzifier. The membership functions are negative large (NL), negative medium (NM), negative small (NS), zero (Z), positive small (PS), positive medium (PM), positive large (PL). The input variables ranges from -0.25 to 0.25. The output variables ranges from 0 to 0.002

Rule base and inference engine is second part of the fuzzy logic controller. Decision making logic is given by rule base. For input membership functions we get the output values in terms of membership functions by various combinations. Here we have e (k) and ce (k) as the linguistic input and delPc as the linguistic output. The controller here is designed with 7 membership functions which has 49 rules. The table below illustrates the rules for the design of fuzzy logic controller. For the area control error e (k) and change in error ce (k) the rules are interpreted as if e(k) is NB and ce(k) is NS then delPc is S. Triangular membership functions are used for the input and output variables.

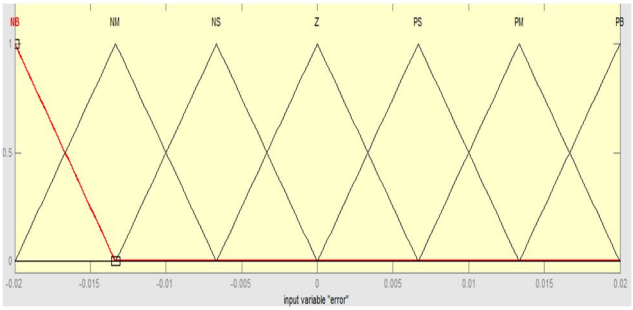
Table 3
Proportional and integral gains of the proposed FGPI controllers rules

E	de						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PM	PM	PM	PS	Z	NS
NS	PB	PM	PS	PS	Z	NS	NM
Z	PM	PM	PS	Z	NS	NM	NM
PS	PM	PS	Z	NS	NS	NM	NB
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	NS	NM	NM	NB	NB	NB

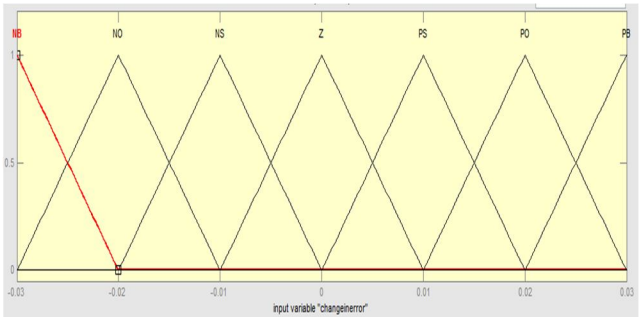
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E. Membership functions

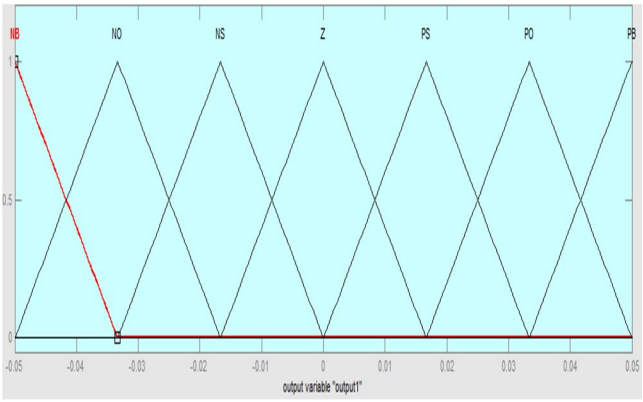
1) Error

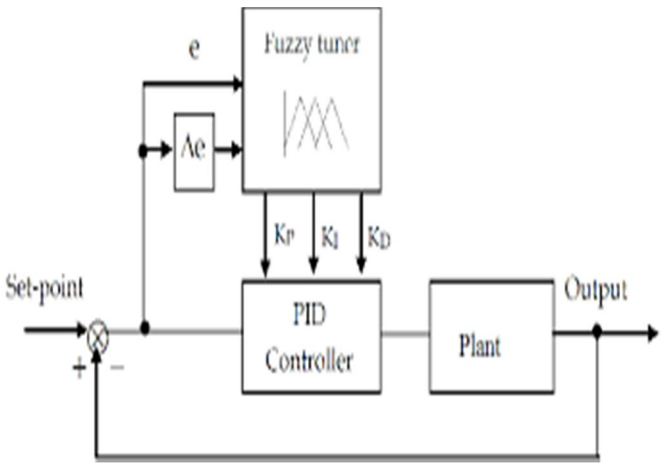


2) Change in Error



3) Output



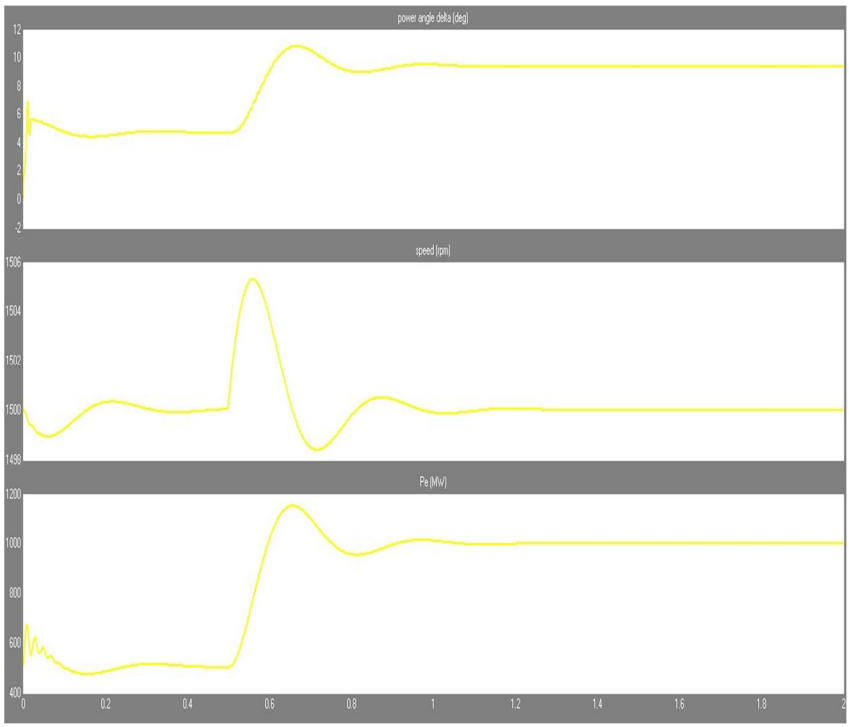


Here, Kd=0. ‘e’ is the error and ‘Ae’ is the change in error.

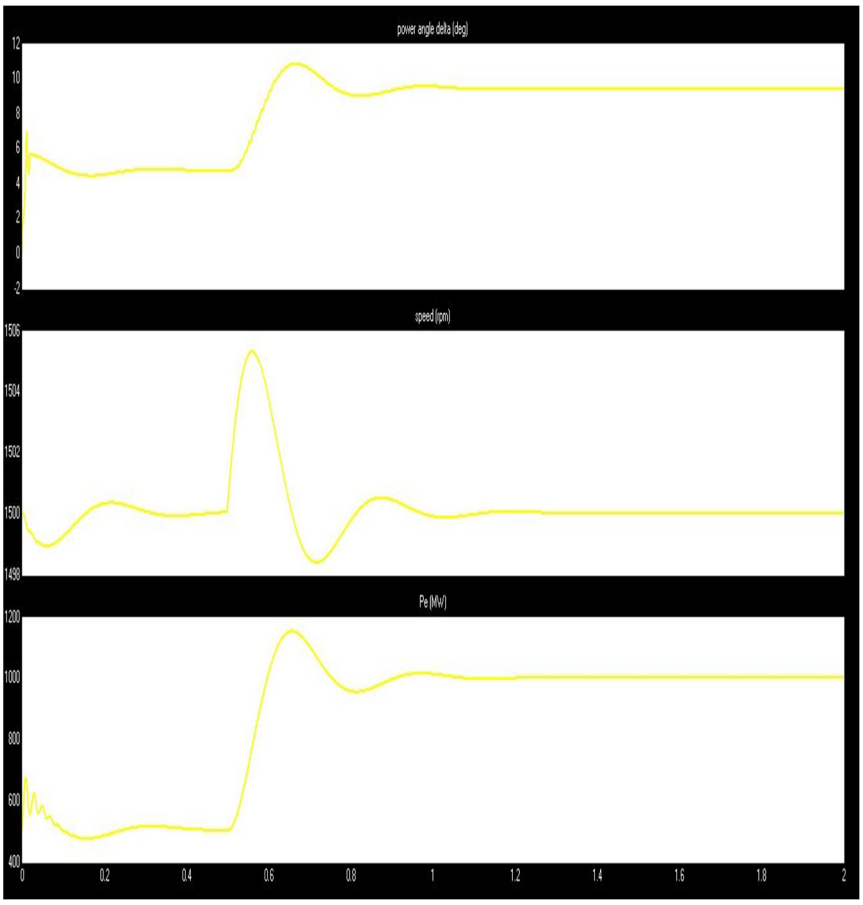
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F. Simulation Results

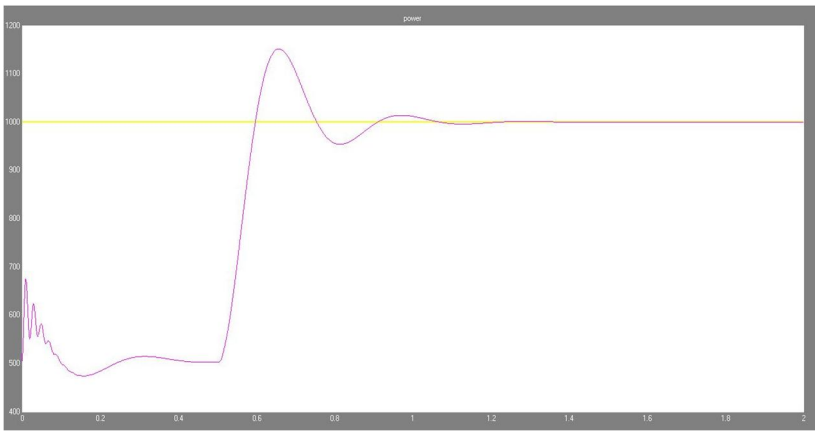


Simulation results for convectional PI controller of power angle, speed and power

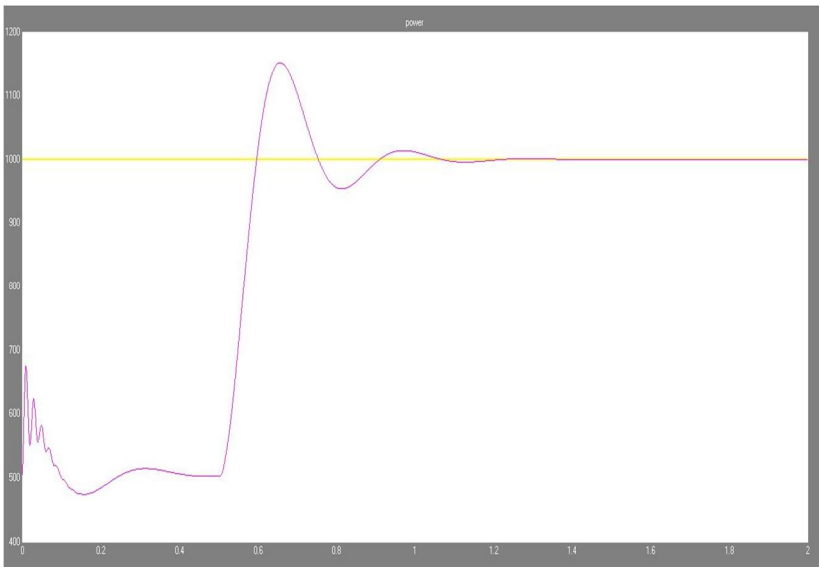


Simulation results for fuzzy logic PI controller of power angle, speed and power

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Active power by convectional PI controller



Active power by fuzzy logic controller

G. Comparison Of The Results Of The Above Three Systems

	Convectional PI controller	Fuzzy with PI controller
Over shoot values (%)	0.65	0.6
Settling time (seconds)	1.4 sec	1.2 sec

III. CONCLUSIONS

The present paper is the analysis of the present energy usage and environmental issues. The penetration advantages and the problems in power system with the interconnection of renewable sources are also stated here. The usage of the MGP system for the reduction of frequency stability problems is proposed.

The mathematical model of the MGP system is analyzed and phase difference method is determined by the source grid phase difference and active power is been established. The source grid phase difference used to control the active power is very feasible by this MGP method.

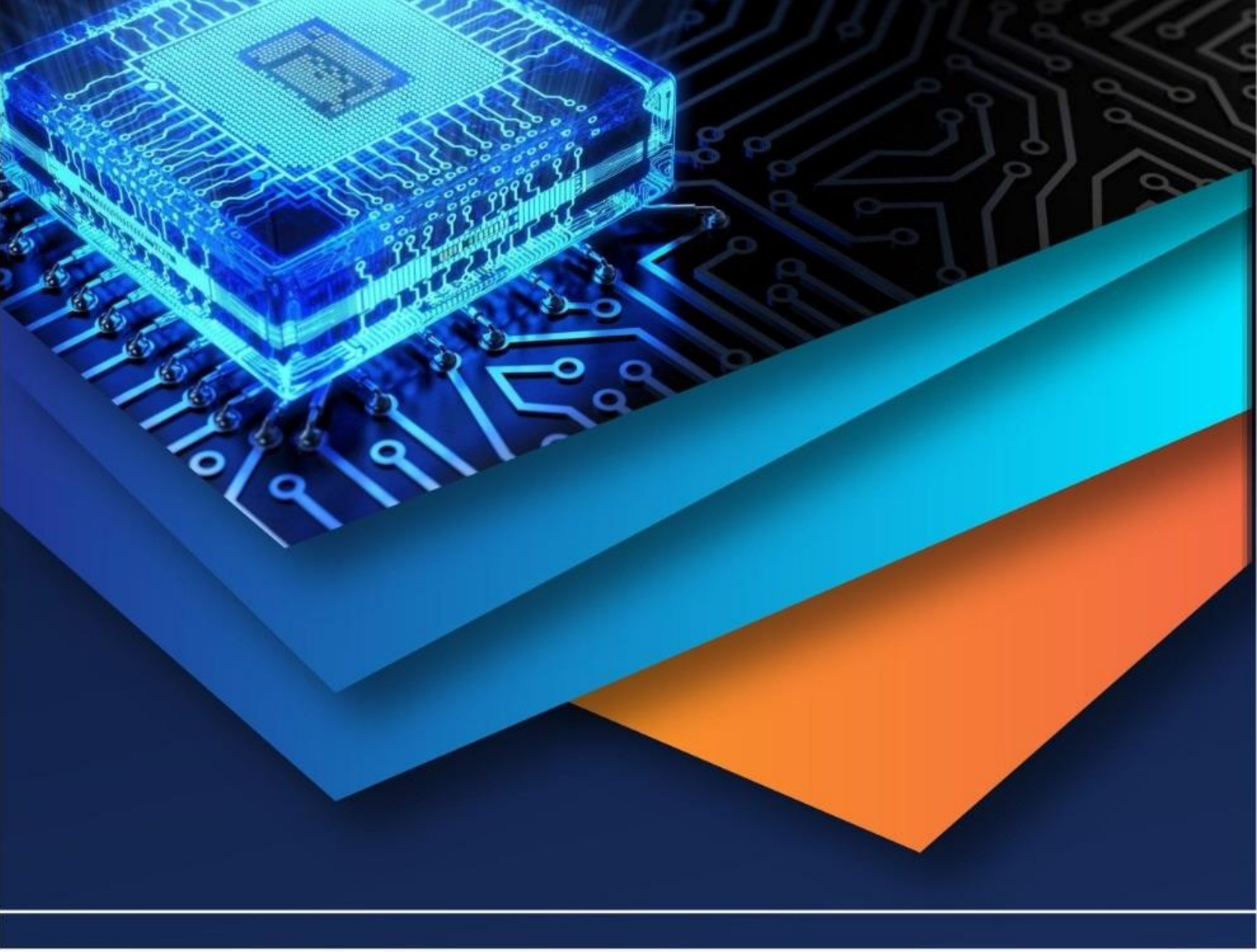
Along with the reduction of frequency stability problems, the simulations results are been compared by using both convectional PI controller and fuzzy logic PI controller. By the comparison of the results states that fuzzy logic controller yields better results when compared to convectional PI controller.

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