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FUZZY GAIN SCHEDULING OF PID CONTROLLERS FOR PV FARMS TO IMPROVE THE TRANSIENT STABILITY OF POWER SYSTEMS

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ABSTRACT
The broad multiplication of expansive photovoltaic farms in power systems crumbles both system inertia and synchronizing coupling. Under the event of extreme faults the power system transient stability may be endangered. By using the fast active power control ability of the PV inverter the transient stability can be improved. This paper proposes the new utilization of extensive PV farms equipped with a Fuzzy Gain Scheduling of PID (FGS-PID) controller for transient stabilization of multi machine power system. The FGS-PID controller is used to control the PV inverter so that the inverter output can be modulated to stabilize the transient power swing when the fault takes place. To enhance the performance the control rules, membership functions, scale factors of FGS-PID controller are defined by a Bee Colony Optimization. Simulation study in a two area interconnected four machine system exhibits the stabilizing effect and robustness of the PV with FGS-PID controller over the PV with maximum power point tracking (MPPT) technique, Zeigler-Nichols PID (ZN-PID) controller, under different operating conditions. In addition, without losing the fundamental function of power generation, the PV with FGS-PID can supply energy to the system equivalent to PV with MPPT, during stabilization.

KEYWORDS: Transient Stability, Fuzzy Gain Scheduling, Photo Voltaic Farm, Bee Colony Optimization (BCO).

INTRODUCTION
Transient stability is defined as the ability of a power system to maintain synchronism when faults, large disturbances are occurred. Now-a-days renewable energy source plays an important role in electrical power systems [1]. Renewable energy sources are one which can be regained in a short duration of time and have low carbon emissions, environment friendly. Our country India has vast availability of Non conventional energy sources among them PV systems has been extensively used [2]. At the end of 2015 the capacity of PV farm is up to 200GW.There are two types of PV systems: one is stand alone PV system and other is grid connected PV system.

Now-a-days grid connected PV systems are widely used [3]. The large scale Grid-connected PV systems can cause problems on the grid, such as injecting more harmonics or reducing the stability level or margin by exciting the resonant mode of the power system. This affects the system transient stability. When any fault occurs in the power system some parts of the PV systems may be disconnected due to voltage sag. Increasing of PV capacity in the power system, the capacity of conventional synchronous generator needs to be reduced moderately. This gives rise to system poorer inertia, the greater generator reactance and fewer frequency control generators. So, the study of the influence of the more penetration of PV on transient stability is become an important issue. So, [4] system topologies, fault locations, disturbance types are the main factors in defining the nature of impact of high PV penetration on the system.

This paper proposes the new utilization of Photovoltaic farm for transient stability improvement of a multi machine Power System. The active power output of PV can be modulated and stabilized by the fast power control ability of PV inverter which stabilizes the transient power swings in the system. In the control part, PID

controllers are using widely because of its simple design and practical structures [5]. The conventional PID controllers have fixed gains and cannot provide satisfactory performance over a wide range of operative conditions. So Fuzzy Logic systems are used to overcome this problem, a Fuzzy based gain scheduler i.e., (FGS-PID) controller is used to adapt PID gains. But FGS-PID Controller finds difficulty in selecting suitable Membership Functions which requires more fine tuning and simulation in two area interconnected power systems. To overcome this problem in this paper bee colony optimization (BCO) is proposed. Simulation study is conducted on a two area interconnected four machine system. The effect of stability of PV with the MPPT technique, Zeigler Nichols PID controls are compared with the stability of PV with Fuzzy gain scheduling of PID (FGS-PID) control.

Table1.Details Of PV Module Simulation

Parameter	Setting Value
Rated Output Power	100W
Short Circuit Current(I_{sc})	5.75A
Open Circuit Voltage(V_{oc})	22.5V
Current At Maximum Power(I_{max})	4.6A
Voltage At Maximum Power(V_{max})	18V

STUDY AND MODELING OF A SYSTEM

In this paper the study system is a two area interconnected four machine system has shown in Fig.1. It consists of two areas area1 and area2 which are interconnected by an ac tie-line. Here each area consists of two generators i.e., G_1, G_2 in area 1 and G_3, G_4 in area 2. Each generator is represented by simple exciter and governor. Active power (P_{T12}) is transferred from area1 to area2 through ac tie line.
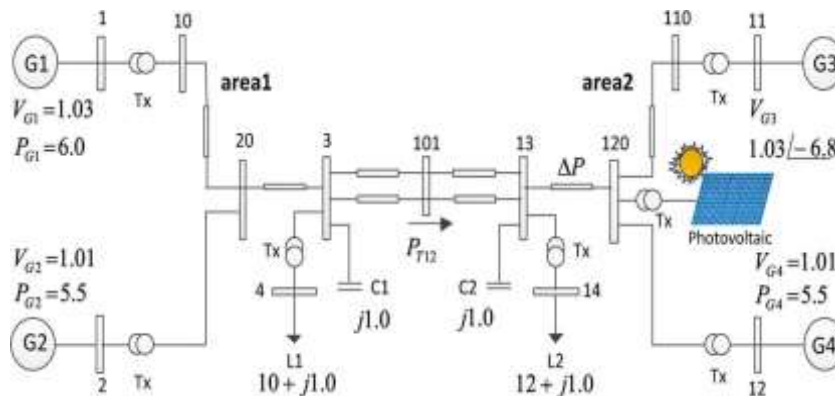

Fig. 1. Two area interconnected power system with PV farm

A PV model with inverter control is shown in Fig.2. It consists of PV equipped with MPPT technique [6], a battery and a bidirectional inverter. Here PV_{dc} and PV_{ac} are the dc and ac powers of photovoltaic farm respectively; P_{Batt} is the battery active power; P_{comd} is the output power command; I_{dc} and V_{dc} are the dc current and voltages respectively; ΔP is an active power flow deviation from bus 120 to bus 13.

In Fig.2 PV array is the combination of both series and parallel connection of PV modules. Equivalent circuit of PV module is shown in Fig.3. PV module is represented by a current source, diode, shunt resistor and series resistor. Here shunt resistance represents resistance of leakage current, series resistance represents internal resistance of PV cells.
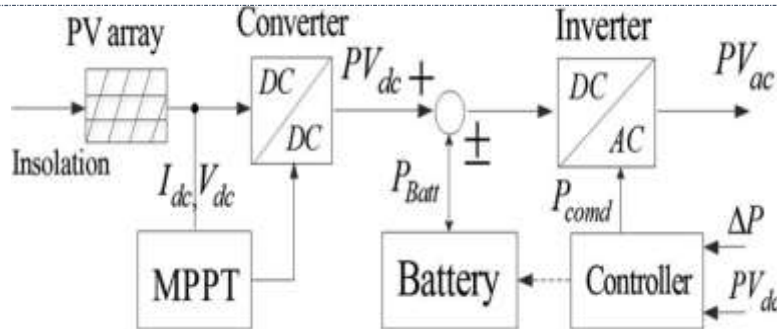
Fig. 2. PV model with inverter control

From KCL and KVL the I_{dc} and V_{dc} are given by

$$I_{dc} = I_g - I_D - V_D/R_p \qquad (1)$$
$$V_{dc} = V_D - R_sI_{dc} \qquad (2)$$

In above equations I_g is the generated current from insolation, I_D, V_D are the diode current and voltage respectively. R_p, R_s are the shunt and series resistance respectively.

From diode characteristics I_D is given by

$$I_D = I_0(e^{V_D/V_T} - 1) \qquad (3)$$

Above I_0 is the reverse saturation current of the diode, V_T is the threshold voltage of the diode

Then the output power of inverter is given by

$$PV_{dc} = V_{dc} . I_{dc}. \qquad (4)$$
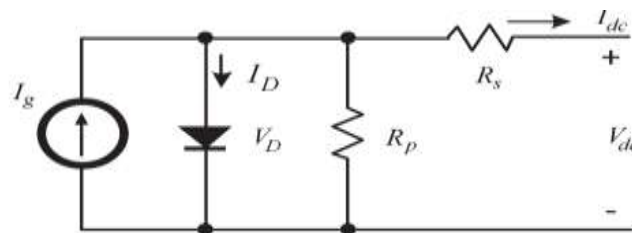
Fig. 3. Equivalent circuit of PV module

In this paper PV equipped with maximum power point tracking (MPPT) method. So, the maximum power track from PV and again fed to the dc-dc converter. The dc-dc converters step up the power and fed to inverter. Here inverter is a bidirectional one. It Converts dc to ac power supply to the load and absorb ac power from the system.

Therefore ac power is given by,

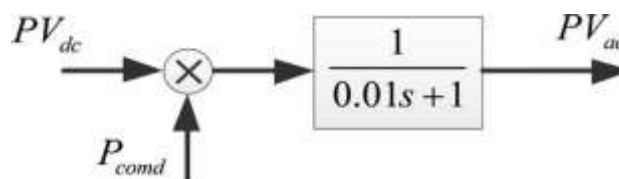$$PV_{ac} = PV_{dc} \qquad (5)$$

Fig. 4. Inverter with output power control

In Fig.4 the inverter is represented by a first order transfer function with the output power control. So the output power can be controlled by the power command (P_{comd}). Based on the power command the battery may be charging or discharging.

FGS-PID CONTROLLER DESIGN

Fuzzy logic is a popular method of handling systems associated with uncertainty, unmodeled dynamics and where human experience is required. It provides a simple way to arrive a definite solution based upon vague, imprecise, noise, or missing information [7]. This approach to control problems mimics how a person would make a decision such faster. The main application of fuzzy gain scheduler is the tuning of PID controller gains. By the collection of IF-THEN rules the fuzzy gain scheduler adjusts the gains of controller over different

operating conditions. However the PID controllers are used due to its simple and practical structures. But these are not giving any satisfactory performance over a wide range of operating conditions. In this paper the fuzzy system is used to tune the PID controller gains as FGS-PID gains.
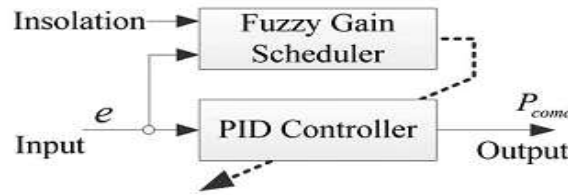

Fig. 5. Schematic diagram of fuzzy gain scheduler

Schematic diagram of fuzzy gain scheduler is as shown in Fig. 5. The control signal of a PID controller is given by

$$P_{comd} = K_P \, e(t) + K_I \int e(t) \, dt + K_D \, de(t)/dt \qquad (6)$$

Where K_P, K_I, K_D are the proportional, integral, derivative gains of PID controller respectively .and $e(t)$ is the control signal.

By adjusting the power command (P_{comd}) of the inverter the control signal of a classical PID controller is generated.
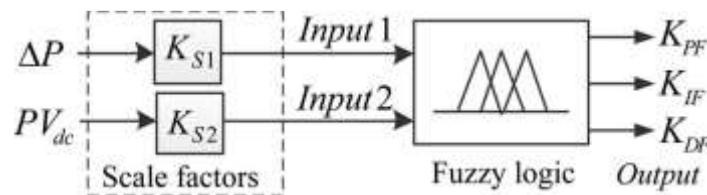

Fig. 6. Block diagram of FGS-PID controller

In Fig.6 ΔP and PV_{dc} are the inputs of the fuzzy inference system and K_{s1} and K_{s2} are the scale factors, K_{PF}, K_{DF}, K_{IF} are the outputs. Here PV_{dc} is error and ΔP is the change in error, K_{PF}, K_{DF}, K_{IF} are the proportional, integral, derivative operations of normalized values.

$$Input1 = K_{s1}\Delta P \qquad (7)$$
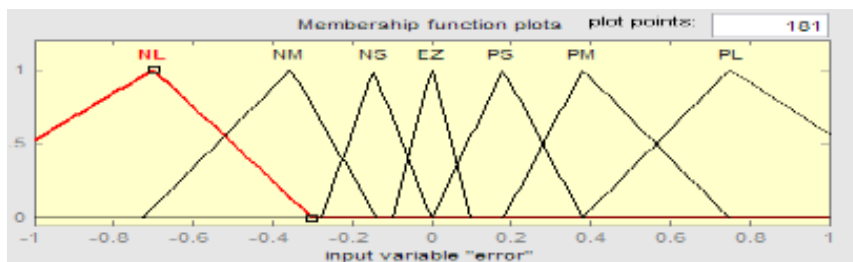$$Input2 = K_{s2}PV_{dc} \qquad (8)$$

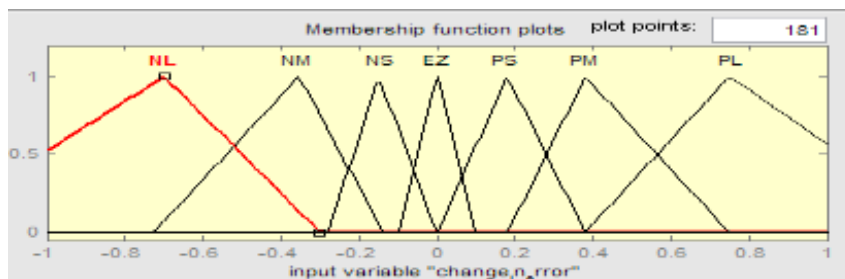*Fig. 7 Membership function of error e(t)*

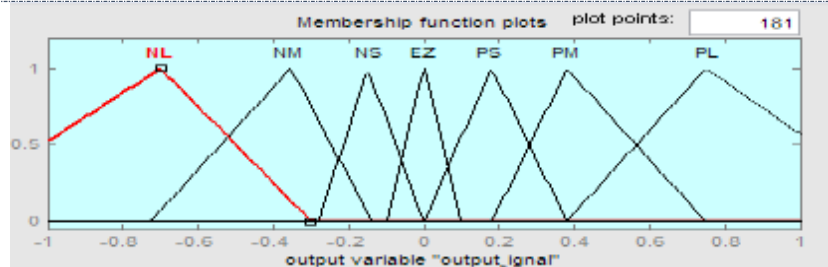*Fig. 8 Membership function of change in error de(t)/dt*

Fig. 9. Membership function of output

The inputs of FIS system are error and change in error. All inputs and output have seven linguistic variables with membership function as triangular. Here NL is negative large, NM is negative medium, NS is negative small, EZ is equivalent zero,PS is positive small, PM is positive medium, PL is positive large. By using different set of control rules of fuzzy gain scheduler, defuzzification rule K_{PF}, K_{DF}, K_{IF} are to be determined.
By using FGS-PID controller the parameters of PID are tuned online.

$K_P = K_{PC} . K_{PF}$ (9)
$K_I = K_{IC} . K_{IF}$ (10)
$K_D = K_{DC} . K_{DF}$ (11)

Where K_{PC}, K_{IC} and K_{DC} are proportional, integral, derivative gains of classical PID controller respectively.
In the design of FGS-PID controller, to define the control rules, MFs and scale factors BCO is used.

BEE COLONY OPTIMIZATION (BCO)
BCO is an optimization algorithm that inspired by decision making process of honey bees [8]. This process can be mimicked for finding out solutions of optimization problem. This process used by the honey bees for searching out the best food resources like swarm based decision method.

Honey Bees use waggle dance to communicate other bees [9]. It is a communication method used by bees to inform other bees about food resources and location of next site.
The algorithm steps of BCO are as follows:
1) Initialize with population of ns scouts bees with random solutions. Set NC=0.
2) Calculate the fitness of population.
3) Select m sites for neighborhood search.
4) Determine the size of neighborhood (ngh).
5) Recruit bees for selected best sites.
6) Select fittest bee from each site.
7) Check the stopping condition. If satisfied stop the search, else set NC=NC+1.
8) Assign the (n-m) remaining scout bees to random search and go to step2.
Where ns is the number of scout bees, NC is the number of iterations, m is the number of selection bees for neighborhood search.

SIMULATION   RESULTS
The performance of proposed fuzzy gain scheduling of PID (FGS-PID) controller is compared with the following controllers.
- "MPPT technique" means PV equipped with MPPT then, output power command   (P_{commd}) is constant.
- "ZN-PID control" means PV equipped with MPPT and PID controller for adjusting output power command (P_{commd}). In this control the gains of PID controller are adjusted by the Zeigler-Nichols method.

"FGS-PID control" means PV equipped with MPPT and PID controller for adjusting output power command (P_{commd}). In this control the gains of PID controller are adjusted by the fuzzy gain scheduler. In this three operating conditions are set for supervised learning. In each operating condition, it is considered that the three-phase to ground fault occurs at different buses and various solar insolations of PV.
The parameters of BCO are set to be n=50, m=2, eb=1 and NC=50.
After the optimization the scale factors are given in (12).while the control rules are given in table 3.

K_{s1}=0.03 K_{s2}=2.3   (12)

The simulation in a two area four machine system is carried out under different operating scenarios in table2.

Table 2.Case study

scenario	Solar insolation(W/m²)	Applied disturbance	P_{T12}(pu)
1	600	3 phase fault occurs at bus 6 for 20ms	3.0
2	400	Sudden loss of one line between bus 6 and 12, inertia reduced 90%.	2.0
3	600	3 phase fault occurs at bus 6 for 20ms.and P_{T12} is transferred from area 2 to area 1.	3.0

*Table 3.Tuned control rules of FGS-PID controller*

| ΔP / PV_{dc}	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	NL
NM	NL	NL	NL	NM	NS	EZ	NM
NS	NL	NL	NM	NM	EZ	PS	NS
EZ	NL	NM	NS	EZ	PS	PM	EZ
PS	NM	NS	EZ	PS	PM	PL	PS
PM	NS	EZ	PS	PM	PL	PL	PM
PL	EZ	PS	PM	PL	PL	PL	PL

Scenario 1:

After the occurrence of fault the rotor speed difference between G_1& G_3 is severely oscillates in PV with MPPT technique. The speed difference between G_1& G_3 is as shown in Fig. 10(a). In case of PV with ZN-PID and FGS-PID oscillations are damped out and the system reached to steady state quickly. But PV with FGS-PID has the more stabilizing effect. The PV power output is shown in Fig. 10(b).During the fault the output power can be adjusted by controller. The battery power is demonstrated in Fig. 10(c). Here positive power means charging and negative power means discharging.
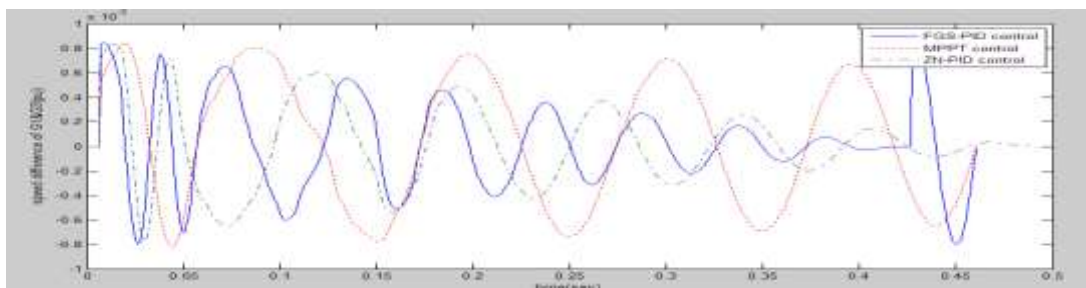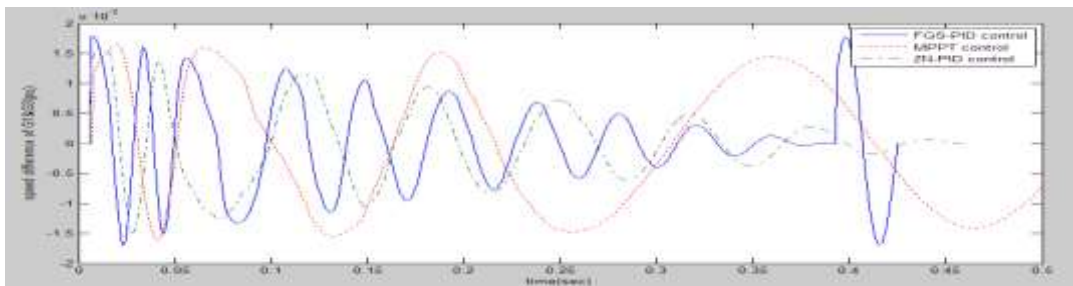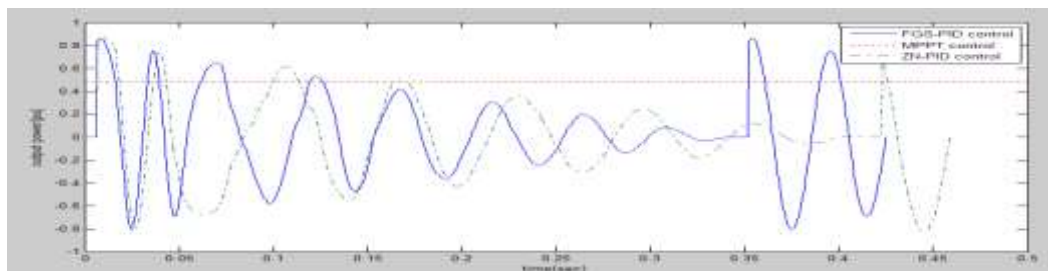

(a)
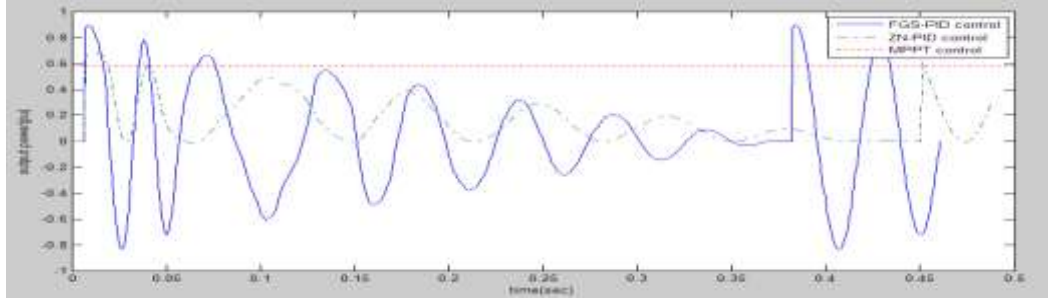
(b)
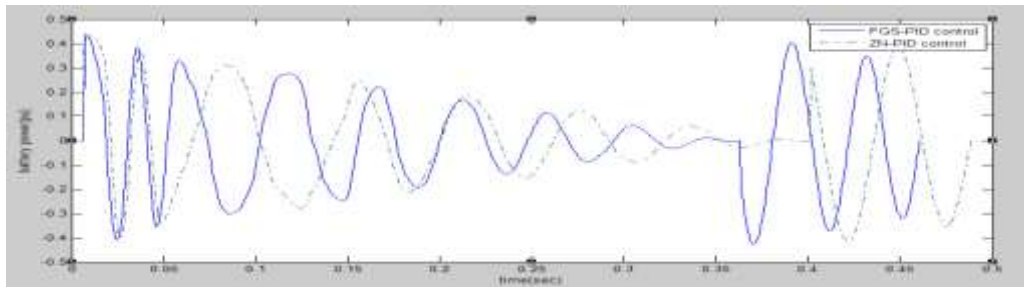
(c)

Fig.10. Simulation result of scenario 1 (a) Rotor speed difference (b) Output power of PV   (c) Battery power
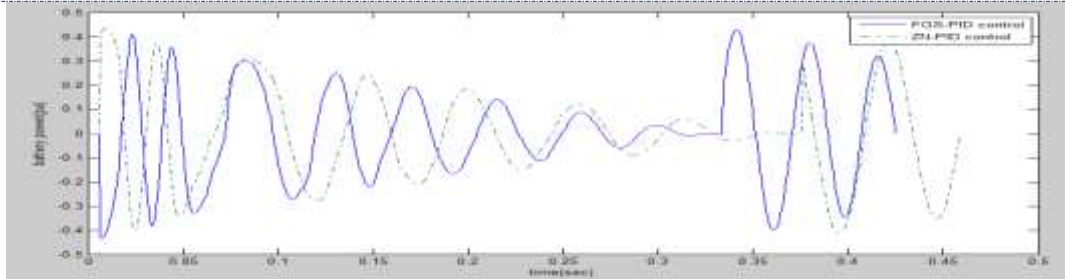
Scenario 2:

The rotor speed difference of G_1&G_3 in case of PV with MPPT technique has the more oscillations compared to PV with ZN-PID and FGS-PID controller. In MPPT technique the output power of PV is constant as shown in Fig. 11(b). Fig.11(c) represents battery power positive means battery charging, negative means battery discharging.
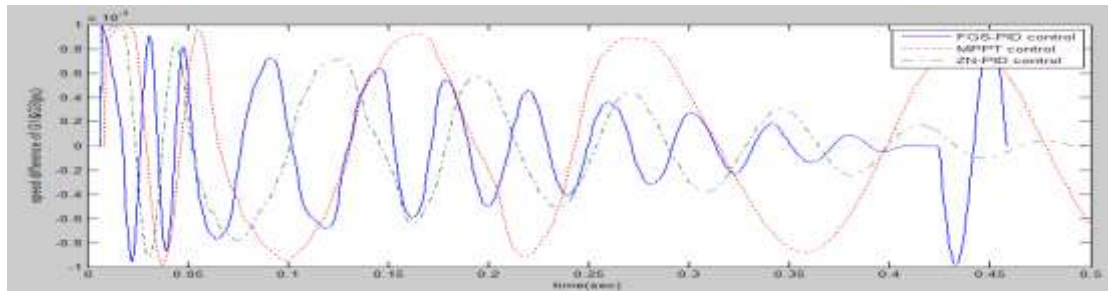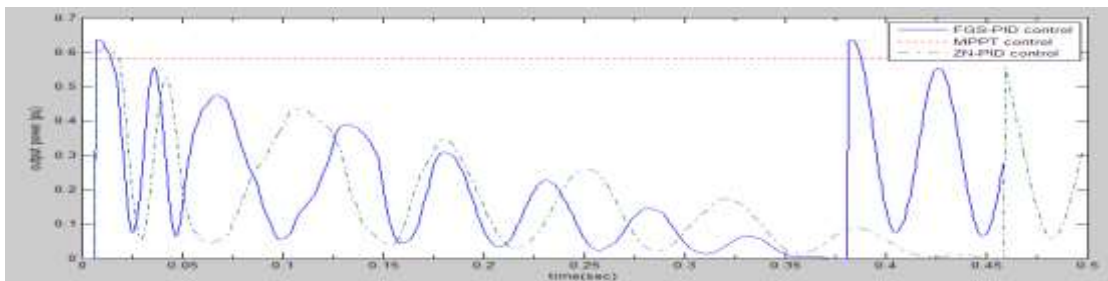

(a)

(b)

(c)

Fig.11.Simulation result of scenario 2 (a) Rotor speed difference (b) Output power (c) Battery power
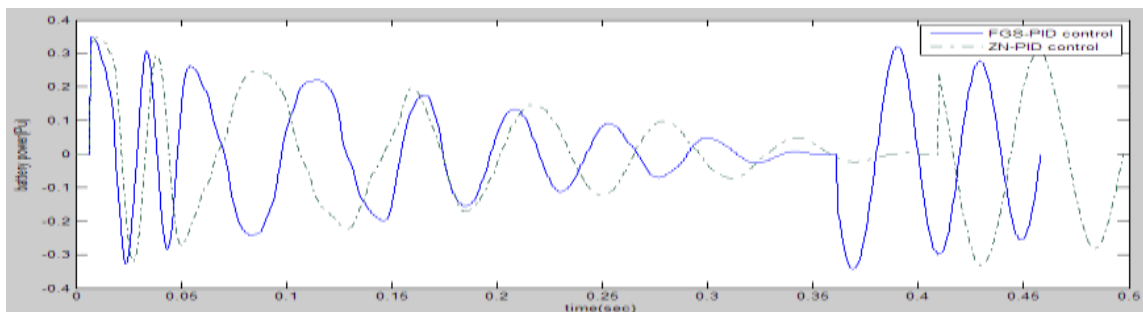
Scenario 3:

Fig. 12(a) illustrates the response of rotor speed difference of PV with MPPT, Zn-PID and FGS-PID controls. The oscillation of speed difference of FGS-PID controller is lower than that of MPPT and ZN-PID controllers. The output power of PV and battery power is as shown in Fig. 12(b) and (c).

(a)

(b)

(c)

Fig.12. Simulation result of scenario 3 (a) Rotor speed difference (b) Output power (c) Battery power

CONCLUSION

In this paper, the PV equipped with FGS-PID controller is used for enhancing the transient stability of four machine two area interconnected system has been proposed. Here the fuzzy gain scheduler is used to tune K_P, K_I, K_D of the PID controller. Then the output power of PV is controlled by FGS-PID controller. Therefore, the transient stability of the PV system is improved. In this paper, the BCO optimization is used to define MFs, control rules and scale factors. As a result of, more stabilization and maximum output power from PV attained. Simulation results shown that the stability and robustness of the PV with FGS-PID control is effective than that of PV with MPPT technique and ZN-PID control under different fault locations on 14-bus system and various solar insolations. In addition, without losing the fundamental function of power generation, the PV with FGS-PID capable to supply energy to the system is equivalent to PV with MPPT, during stabilization.

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