

## **Comparison of Power System Transient Stability in PV Farm By PID And Fuzzy Gain Scheduling of PID Controller**

D.Priyanka, A.Parimala

*PG Scholar, Power Systems Engineering, Arunai College of Engineering, Tiruvannamalai, Tamilnadu.  
Assistant Professor, Power Systems Engineering, Arunai College of Engineering, Tiruvannamalai, Tamilnadu.*

---

**Abstract:** *The extensive expansion of large photovoltaic (PV) farms in power systems diminishes both system inertia and synchronizing coupling. Due to the occurrence of several faults, the power system transient stability may be damaged. However the transient stability is improved by the fast power controlling ability of the PV inverter. This paper focuses on the new application of large PV farms equipped with PID and Fuzzy Gain Scheduling of Proportional–Integral–Derivative (FGS-PID) controller to achieve transient stability of a multimachine power system. The FGS-PID and PID controllers are basically employed to control the PV inverter, such that the PV power output can be modulated to stabilize the transient power swing when the faults take place. The FGS-PID with PID controllers is compared and among those the most efficient controller to achieve transient stability is analyzed.*

**Keywords:** *fuzzy gain scheduling (FGS), transient stability, photovoltaic(PV) generator, proportional–integral–derivative (PID) controller.*

---

### **I. Introduction**

Nowadays, the power generation from renewable energy sources highly escalates due to the increasing such as carbon emission reduction and lack of conventional fossil fuel. Among renewable sources, the photovoltaic (PV) generator, which is inexhaustible, clean, environmentally friendly, etc., gets a lot of attention. Many large PV farms have been operated around the world.

At the end of 2012, the total capacity of PV farms is almost 100 GW. Among PV systems; the grid-connected PV systems have been extensively applied. Nevertheless, the large penetration of grid-connected systems of PV farms diminishes both system inertia and synchronizing coupling. This may be harmful to the system transient stability. The impacts of PV farms on power system transient stability reveal that high PV penetration levels, system topologies, disturbance types, and fault locations are main factors. In the effect of PV penetration levels on the system response under the critical contingency in the transmission system. It is found that the transient stability improvement by distributed PV generators is superior to the centralized PV generators.

In the transient stability assessment of power system with high penetration of PV generators is carried out under various conditions such as levels of PV penetration, variety of power sources (inverter or synchronous machine), and existence of low-voltage-ride-through capability. The results signify that an appropriate penetration of the PV generators enhances the transient stability. However, the large penetration of PV sources deteriorates the transient stability, under the occurrence of disturbance. On the other hand, with the large amount of PV generators in the future, they are highly anticipated to contribute ancillary services to the future power grids. With the ability of inverter control, the decoupled active and reactive power control of PV can be performed.

This leads to sophisticated applications of PV generator, such as frequency control, voltage control, reactive power control, power oscillation damping, wide area stabilization, etc. This paper proposes the new application of the PV farm to a transient stabilization of a multimachine power system. Depending upon the control ability of the PV inverter, the active power output of PV can be modulated, so that the transient power swing can be stabilized. In the control part, it is well known that the proportional–integral–derivative (PID) controller is widely used due to its simple and practical structures. However, the conventional PID controller with fixed gains cannot provide the satisfactory control performance over a wide range of operating conditions. To overcome this problem, a fuzzy gain scheduling of PID (FGS-PID) controller is used to adapt the PID gains.

This paper is organized as follows: Section II describes the system description. Next, the modeling of photovoltaic is explained in Section III. Subsequently control design of FGS-PID and PID is provided in Section IV. Simulation and results are given in Section V. Finally, the conclusion is provided in Section VI.

## II. System Description

A two-area four-generator interconnected power system in Figure 1 is used as the study system. Two areas are connected through an AC tie-line which exhibits a weak inter-area oscillation damping systems. Here, each area has two generators, i.e., Area 1 has G1 and G2, and area 2 has G3 and G4. Each generator is represented by the fourth-order model and is equipped with a simplified exciter and governor. In which the active power ( $P_{T12}$ ) is transferred from areas 1 to 2. The photovoltaic is installed at bus 8 in area 2. Here the  $\Delta P$  is an active power flow deviation from bus 8 to bus 7 and the fault is connected at bus 6.

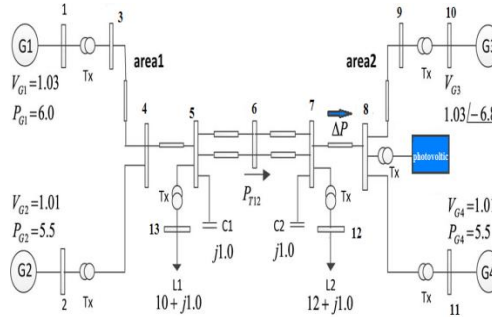


Fig.1. PV farm with Two-area interconnected power system

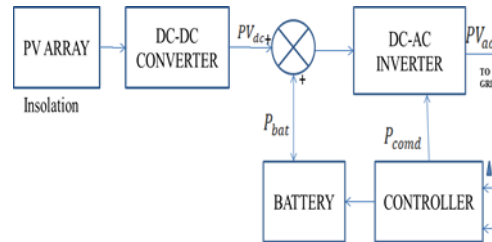


Fig. 2. Inverter control of PV model

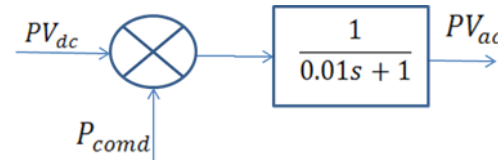


Fig.3. Output power control of Inverter model

The inverter control of PV model is illustrated in fig. 2. It's equipped with DC-DC converter, a battery, and a bidirectional inverter.  $PV_{ac}$  and  $PV_{dc}$  are ac and dc powers of PV respectively;  $P_{bat}$  is the active power of battery;  $P_{comd}$  is the command output power;  $V_{dc}$  and  $I_{dc}$  are the dc voltage and current respectively. The PV cells are wired together in series and parallel. The voltage output of the panel depends on the total cell number connected in series and parallel. Common nominal output voltages are 12, 18, and 24 volts DC. Battery is generally denoted as an electrochemical device which stores energy and then supplies it as electricity to a load circuit. They are usually prearranged in strings and can be connected in series or parallel or a combination of both, to provide the operating voltage and current. It impacts the overall reliability of the battery solution. The DC- DC converter regulates the output voltage. It also performs several functions such as a battery charge regulator and a boost converter to deliver energy from the battery to inverter. The controller used in this paper is FGS-PID and PID which directly adjusts the output power of the PV inverter. To achieve the stabilizing effects and also the maximum output power generation during system stabilization.

## III. Modelling of Photovoltaic

Solar cell is basically a p-n junction fabricate in a thin wafer or layer of semiconductors. Photovoltaic is a phenomenon in which the electromagnetic radiation of solar energy can be converted to electricity directly. Under exposure to sunlight, photons with energy superior than the band-gap energy of the semiconductor are absorbed and create some electron-hole pair which is proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, the carriers are swept to one side and create a photocurrent which is directly proportional to solar irradiation. Physically, PV system exhibit a nonlinear

current-voltage (I-V) and power-voltage (P-V) characteristics which vary with the radiant intensity and cell temperature. Fig. 4. Indicates the single solar cell consists of three terminals. This block models a solar cell as parallel combination of a current source, two exponential diodes and a parallel resistor, that are connected in series with a resistance. The output current  $I$ , is given by

$$I = I_{ph} - I_{s1} * (e^{\frac{v+I*R_s}{N} * V_t} - 1) - I_{s2} * (e^{\frac{v+I*R_s}{N2} * V_t} - 1) - (v + I * R_s) / R_p$$

Where  $I_{s1}$  and  $I_{s2}$  are the diode saturation current,  $V_t$  is the thermal voltage,  $N$  and  $N2$  are the quality factor and  $I_{ph}$  is the solar generated current. Models of reduced complexity can be specified in the mask. The quality factor varies for amorphous cells, and typically has a value in the range of 1 to 2. the physical signal input  $I_r$  is the irradiance in  $w/m^2$  falling of the cell. The solar generated current  $I_{ph}$  is given by  $I_r * (I_{ph0} / I_{r0})$  where  $I_{ph0}$  is the measured solar generated current for irradiance  $I_{r0}$ .

Fig. 5. Indicates the PV panels which convert the light reaching them into DC power. The amount of power they produce is roughly proportional to the intensity and the angle of the light reaching them. They are therefore positioned to take maximum advantage of available sunlight within siting constraints. Maximum power is obtained when the panels are able to 'track' the sun's movements during the day and the various seasons. However, these tracking mechanisms tend to add a fair bit to the cost of the system, so a lot of people either have fixed panels or compromise by incorporating some limited manual adjustments, which take into account the different 'elevations' of the sun at various times of the year.

Fig. 6. Shows that PV module Equivalent circuit. Based on Kirchoff's circuit and voltage laws,  $I_{DC}$  and  $V_{DC}$  of the PV module can be expressed by

$$I_{DC} = I_G - I_D - V_D / R_P$$

$$V_{DC} = V_D - R_S I_{DC}$$

where  $I_G$  is the generated current from insolation,  $R_P$  is the internal parallel resistance,  $R_S$  is the internal series resistance and  $I_D$  and  $V_D$  are the current and voltage of the diode, respectively. From the diode characteristic,  $I_D$  can be calculated by

$$I_D = I_0 (e^{\frac{V_D}{V_T}} - 1)$$

$$I_{DC} = I_G - I_0 (e^{\frac{V_D}{V_T}} - 1) - V_D / R_P$$

where  $I_0$  is the reverse saturation current of diode, and  $V_T$  is the thermal voltage of diode.

Consequently, the output power of PV module is given by

$$PV_{DC} = V_{DC} I_{DC}$$

For the bidirectional inverter of PV, it is used to supply the ac power to the load and absorb the ac power from the system. When the power generation from PV exceeds the load power demand, the surplus power is charged to the battery.

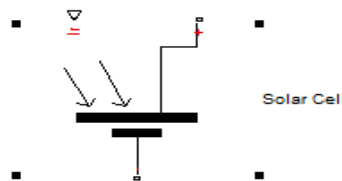


Fig. 4. Structure of solar cell

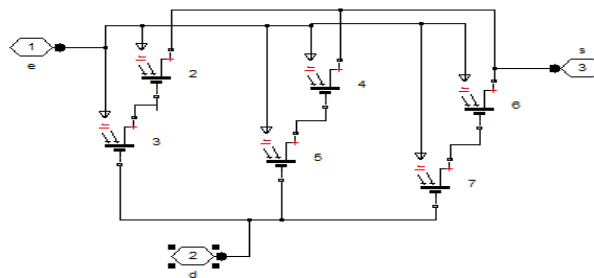


Fig. 5. Solar panel

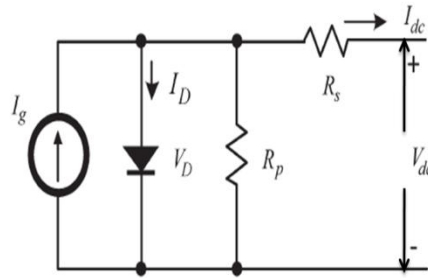


Fig. 6. PV module Equivalent circuit

#### IV. Control Design of FGS-PID and PID

The control signal of a classical PID controller can be expressed in the time domain by

$$P_{com.d} = K_p e(t) + K_i \int e(t) dt + K_D \frac{de(t)}{dt}$$

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

However, the conventional PID controller cannot provide the reasonable performance in case of a wide range of operating conditions due to fixed gains. Accordingly, the fuzzy gain scheduler is utilized for tuning the PID parameters. the coefficients  $K_P$ ,  $K_I$ , and  $K_D$  are tuned by the knowledge base and fuzzy interface of the fuzzy gain scheduler. Then, the control signal is generated by the classical PID controller to adjust  $P_{com.d}$  of the PV inverter.

Here,  $\Delta P$  and  $PV_{dc}$  are used for the inputs of the fuzzy gain scheduler, as shown in Fig. 7. The outputs are the normalized value of proportional (KPF), integral (KIF), and derivative (KDF) operations. Thus, there are two inputs and three outputs for the fuzzy gain scheduler.  $Input1$  and  $Input2$  are given by

$$Input1 = \Delta P K_{S1}$$

$$Input2 = PV_{dc} K_{S2}$$

Where  $K_{S1}$  and  $K_{S2}$  are the scale factors of FGS-PID controller. By using the fuzzy knowledge, the new PID parameters of the FGS-PID controller, which are tuned online, can be established by the following equations:

$$K_P = K_{PC} K_{PF}$$

$$K_I = K_{IC} K_{IF}$$

$$K_D = K_{DC} K_{DF}$$

where  $K_{PC}$ ,  $K_{IC}$ , and  $K_{DC}$  are the proportional, integral, and derivative gains of the classical PID controller, respectively. As shown in Fig. 8,  $Input1$  has two trapezoidal and five triangular memberships, whereas  $Input2$  has two trapezoidal and two triangular memberships. The outputs of the fuzzy gain scheduler are a constant membership.

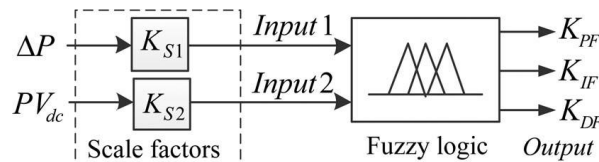


Fig. 7. Block diagram of FGS.

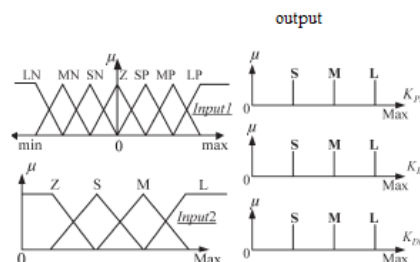


Fig. 8. Membership functions for inputs and output of FGS-PID.

### V. Simulation and Results

To compare the FGS-PID and PID controller efficiency of the systems based on FFT analysis. In the design of FGS-PID and PID controller, the operating condition, it is assumed that a three-phase fault to ground occurs at bus 6 at time  $t = 0.5$  s to  $0.7$  s and is cleared naturally. Fig. 9. Indicate the simulation diagram and results of without any controller and fault where as Fig. 11. is about the fault take place in bus 6 at time period of 0.5s to 0.7s without controller. The simulation diagram and result of PV with FGS-PID controller and PID is given in Fig. 12. The output of PV is dc voltage which fed input to the dc-dc boost convertor which boosts the output voltage and given to inverter where inverter convert dc into ac voltage and interconnect to the system. The output voltage of PV inverter is directly controlled using a controller i.e., FGS-PID and PID to stabilize the transient stability in the power system. The output voltage of PV with FGS-PID is compared with PID on the basis of FFT analysis on Fig. 13.

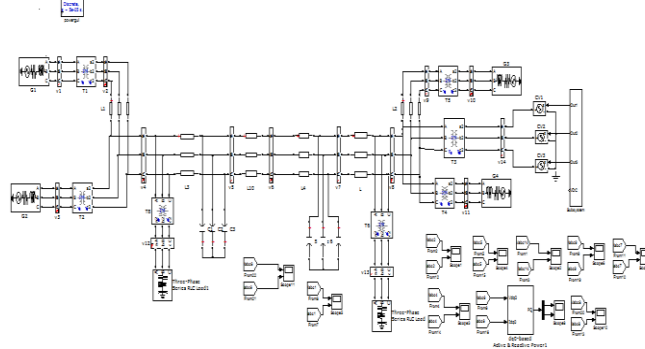


Fig. 9. Simulation diagram for open loop system without fault

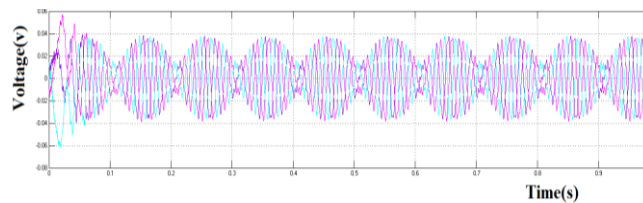


Fig. 10. Simulation results for output voltage of open loop system without fault

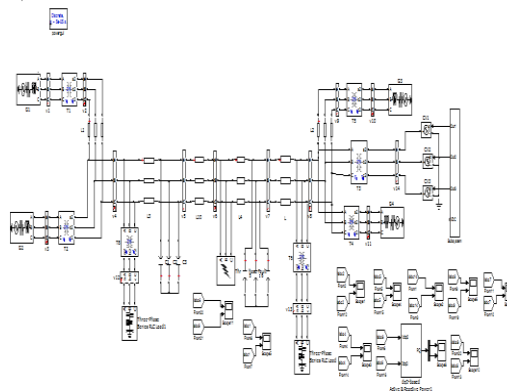


Fig. 11. Simulation diagram for open loop system with fault

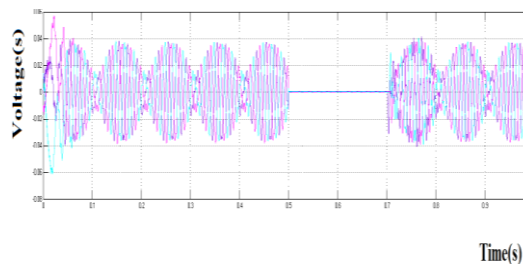


Fig. 12. Simulation results for output voltage of open loop system with fault

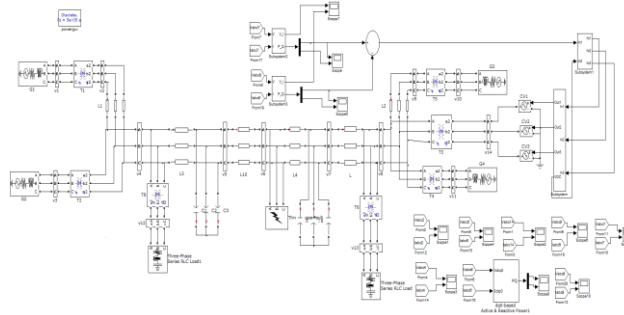


Fig.13. Simulation diagram of PV with FGS-PID controller

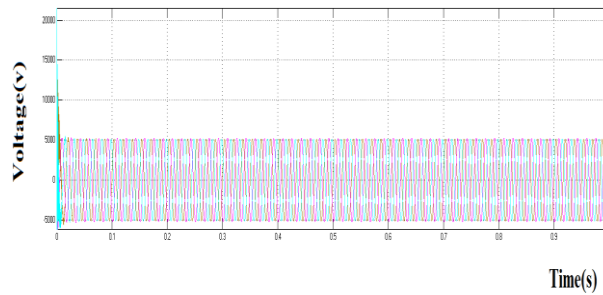


Fig. 14. simulation result for output voltage of PV with FGS-PID controller

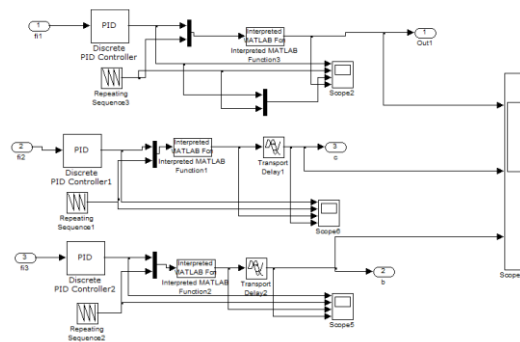


Fig. 15. Simulation diagram of PV with PID controller

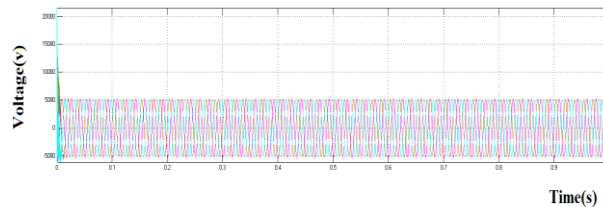


Fig. 16. Simulation result for PV with PID controller

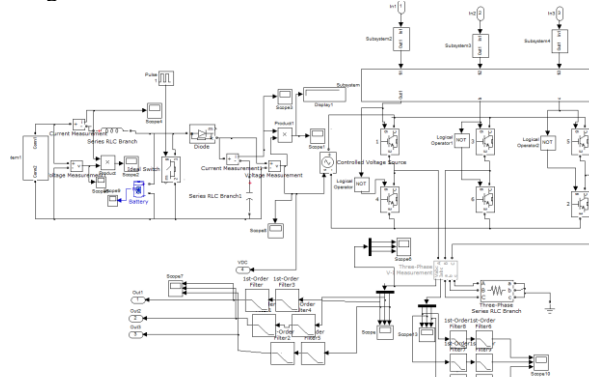


Fig. 17. Simulation diagram of PV, converter and inverter

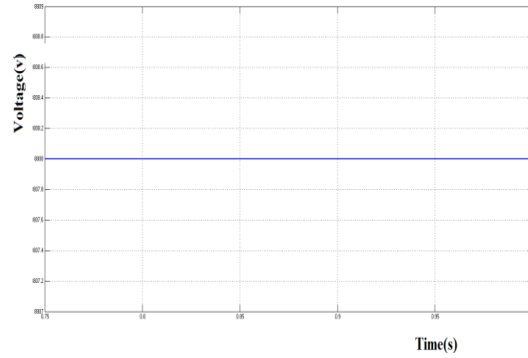


Fig. 18. Simulation result for output voltage of PV

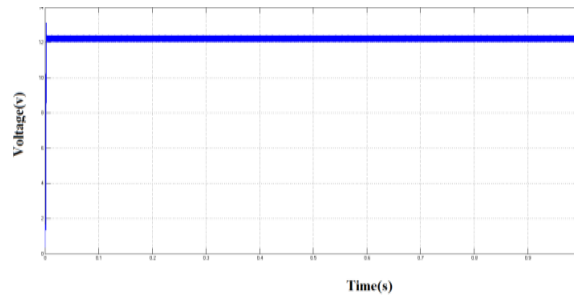


Fig. 19. Simulation result for output voltage of DC-DC converter

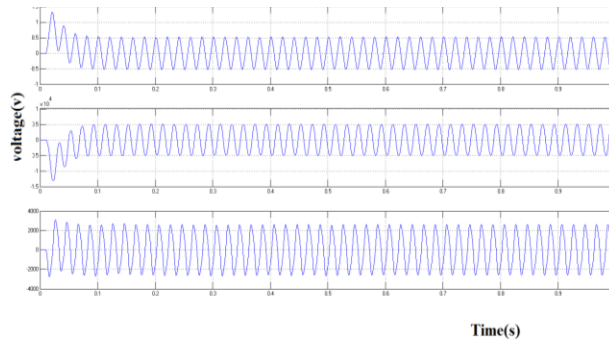


Fig. 20. Simulation result for output voltage of inverter

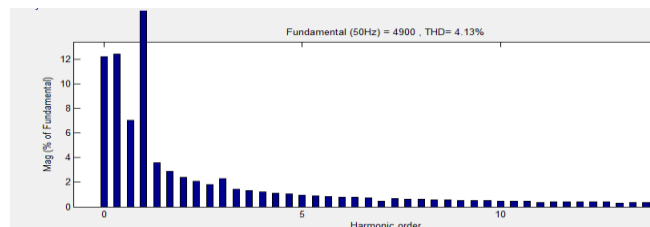


Fig. 21. FFT analysis for output voltage ( $v_{abc}$ ) of PID controller

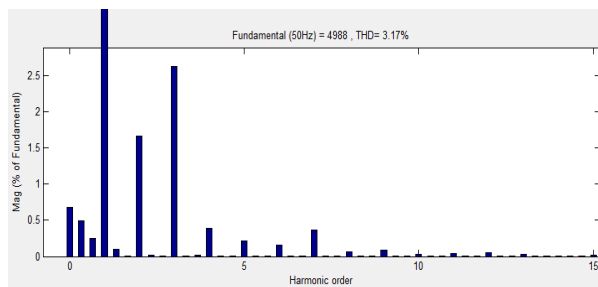


Fig. 22. FFT analysis for output voltage ( $v_{abc}$ ) of FGS- PID controller



## **VI. Conclusion**

The transient stability of power system in PV farm is achieved by using Fuzzy Gain Scheduling of Proportional–Integral–Derivative (FGS-PID) and Proportional–Integral–Derivative (PID) controllers. Both the controllers are compared on the bases of total harmonic distortion (THD) in which Fuzzy Gain Scheduling of Proportional–Integral–Derivative (FGS-PID) is best suitable controller to achieve transient stability.

## **References**

- [1]. Yuru, Jan Kleissl, and Sonia Martinez, “Storage Size Determination for Grid-Connected Photovoltaic Systems,” *IEEE Trans. Sustain. Energy*, vol. 4, no.1, Jan. 2013.
- [2]. Ch. V. Narasimha Raja, “Load Frequency Control in Four Area Power Systems Using Fuzzy Logic PI Controller,” *Buletin Teknik Elektro dan Informatika*, vol. 2, no. 2, June 2013, pp. 105~110.
- [3]. Sara Eftekharnjad, Vijay Vittal, Gerald Thomas Heydt, Brian Keel and Jeffrey Loehr, “Impact of Increased Penetration of Photovoltaicgeneration on Power Systems,”*IEEE Trans. Power Syst*, vol. 28, no. 2, May 2013.
- [4]. Dominique Bonkougou, Zacharie Koalaga, Donatien Njomo, “ Modelling and Simulation of photovoltaic module considering single diode equivalent circuit model in MATLAB,” *International Journal of Emerging Technology and Advanced Engineering* ,vol.3, no 3, March 2013.
- [5]. Ontario, Canad Behnam Tamimi, Claudio Cañizares, and Kankar Bhattacharya, “System Stability Impact of Large-Scale Anddistributed Solar Photovoltaic Generation,”*IEEE Trans. Sustain. Energy*, vol. 4, no. 3, July 2013.
- [6]. Preethi \*, D.Gifty Deborah, “Transient Stability and Cost Analysis of a System with Distributed Generation and Energy Storage Devices ,”*Int. Journal of Scientific and Research Publications*, vol. 5, no. 6, June 2015.
- [7]. Alessiacagnano, Enrico De Tuglie, Marco Liserre, and Rosa A, “Online Optimal Reactive Power Controlstrategy of PV Inverters,” *Mastromauro IEEE Trans. Indust. Electron*, vol. 58, no. 10, October 2011.
- [8]. J. Pahasa and I. Ngamroo, “ Least square support vector machine for power system stabilizer design using wide area phasor measurements,” *International Journal of Innovative Computing, Information and Control*, vol.7, no.8, pp.4487-4501, 2011.
- [9]. Theerawut Chaiyatham and Issarachai Ngamroo , “Optimal Fuzzy Gain Scheduling of Pid Controller of Superconducting Magnetic Energy Storage for Power System Stabilization,” *International Journal of Innovative Computing, Information and Control* ,vol. 9, no. 2, Feb. 2013.
- [10]. Rakibuzzaman Shah, Nadarajah Mithulananthan, and Kwang Y. Lee,“Large-Scale PV Plant with a Robust Controller Considering Power Oscillation Damping,”
- [11]. *IEEE Trans. Energy Conv*, vol. 28, no. 1, March 2013.