©gopalax -International Journal of Technology And Engineering System(IJTES):
Jan –March 2011- Vol.2.No.3.

Efficient Voltage Regulation for Standalone Photovoltaic system using PI and Fuzzy Controller for AC Voltage Application

A.Y. Thiagarajan[1] and B.S.Kavitha[2]

[1] *Sri Manakula Vinayagar Engineering College/Department of Electrical and Electronics, Pondicherry, India*
Email: thiagu2517@gmail.com
[2,] *Mailam Engineering College/Department of Electrical and Electronics, Mailam, India*
Email: {kavitha.sethu@yahoo.com}

Abstract **- This paper focuses on the renewable energy PV (Photo Voltaic) system in standalone model. The system consisting of PV module, DC-DC Boost converter, and inverter coupled to the load system. An 18V photovoltaic system and a DC-DC boost converter is designed for the purpose of boosting the PV system output voltage. The advantage of using the proposed DC-DC converter is only one sensor is required, high power density, more efficient with reduced complexity of control. An inverter is used to convert DC to AC for application purposes. A PI controller is designed for controlling the entire converter system using standard Ziegler-Nicholz technique. The performance of the system is analyzed under both variations in temperature of PV system and load parameter for the feasibility of controller. The proposed work is also analyzed using Fuzzy logic controller for good transient and steady state performance improvement.**

Keywords **- PV system, DC-DC Boost Converter, Inverter, PI Controller, Fuzzy Logic controller.**

I. INTRODUCTION

One of the major issues confronting users and designers of [1] solar energy system is the random, fluctuating nature of the energy sources. This makes them unpredictable' are even 'unreliable' in the eyes of some compared to traditional supplies of electric energy. In reality, the load on electric network supplied is itself random, being subject to seasonal and environmental influences such as the weather. All plant, whether, renewable or not, suffers from occasional breakdown, which also impacts on supply availability. This gives a basis of designing renewable energy system – not on the basis of an unachievable 100% reliability but to a reliability (are more strictly 'availability') approaching that of a traditional sub urban grid supply. The solar distributions were used to obtain a net system availability using convolution processes. This paper presents a different approach one based on designing of PV cell, modeling of DC-DC boost converter and Inverter. A PI controller is designed to ensure regulation of system, under supply and load disturbances. Finally the system is also analyzed using Fuzzy Logic controller to verify the performance, using MATLAB Semolina tool box.

II.A STAND ALONE PV SYSTEM

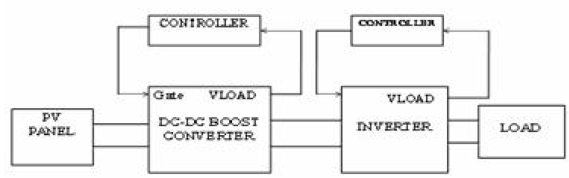


Figure1. Block diagram of Photovoltaic system with controllers.

Figure 1 shows the block diagram of controllers for a standalone PV system. The power from Photovoltaic module is given to the DC-DC boost converter where the input voltage is boosted up to the required DC voltage, then given to the DC-AC converter. This arrangement is controlled through controllers. The actual parameter, which has to be controlled, is compared with the reference parameter and this error is fed as an input to the controller. The controller takes the error as input and generates a corresponding control signal. This is investigated in this thesis for better control algorithm.

A .PV Cell:

Solar cells have many applications [2]-[3]. They have long been used in situations where electrical power from the grid is unavailable, such as in remote area power systems, Earth-orbiting satellites and space probes, consumer systems, e.g. handheld calculators or wrist watches, remote radiotelephones and water pumping applications. More recently, they are starting to be used in assemblies of solar modules (photovoltaic arrays) connected to the electricity grid through an inverter, often in combination with a net metering arrangement. Solar cells are often electrically connected and encapsulated as a module. PV modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from the elements (rain, hail, etc.). Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current. Modules are then interconnected, in series or parallel, or both, to create an array with the desired peak dc voltage and current. The power output of a solar array is measured in watts or kilowatts.

B. MODELLING OF A PV CELL

A solar cell, which is basically a *p-n* semiconductor junction directly, converts light energy into electricity. PV cells are grouped in larger units called PV modules, which are further interconnected in a parallel-series configuration to form PV arrays or generators. The photovoltaic cell considered can be modeled mathematically using the following procedure [4]-[5]:

Output voltage of PV Cell:

$$V_{pv} = \left(\frac{N_s ATK}{q}\right) \ln\left[\frac{N_p \times I_{ph} - I_{pv} + N_p \times I_o}{I_o}\right] - I_{pv} R_s \quad (1)$$

Output current of PV Cell:

$$I_{pv} = N_p \times I_{ph} - N_p \times I_o \left[\exp\left\{\frac{q \times (Vpv + Ipv \times Rs)}{NsATK}\right\}_{-1}\right] (2)$$

$$I_{ph} = \left[I_{scr} + K_i (T - 298)\right] \times \lambda/100 \qquad (3)$$

$$I_o = I_{or}\left[\frac{T}{T_r}\right] \exp\left[\frac{q \times E_{go}}{BK}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] (4)$$

The PV array power P can be calculated using the following equation:

$$P_{pv} = I_{pv} \times Vpv$$

$$= Vpv \times N_p \times I_{ph} - V_{pv} \times N_p \times I_o \left[\exp\left\{\frac{q \times (Vpv + Ipv \times Rs)}{NsATK}\right\}_{-1}\right] (5)$$

Where,

Vpv	is output voltage of a P V cell (V)
Ipv	is output current of a PV cell (A)
T	is the cell temperature in Kelvin = 298K
Tr	is the reference temperature =301.18K
I_{pa}	is the light generated current in a PV cell (A)
Io	is the PV cell saturation current (A)
A=B	is an ideality factor =1.6
K	is Boltzman constant = 1.3 805e-2 3Nni/K
q	Is Electron charge =1.6e-l 9Coulomb

TABLE-I : SIMULATION PARAMETERS OF PV SYSTEM

Output Voltage from PV System	18V
Output power from PV System	83watts
Temperature Variation	25,100,25°C
Rated Current	4.6 Amps

III. POWER CONVERTER FOR PV SYSTEM VOLTAGE REGULATION

A. DC-DC BOOST CONVERTER

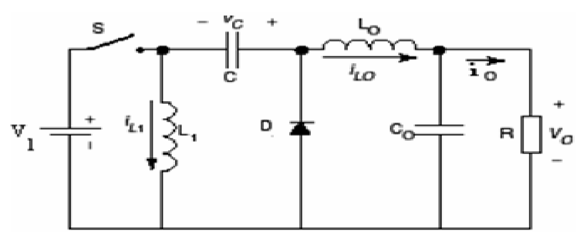


Figure 2. Equivalent circuit of DC-DC boost converter with voltage lift technique.

Figure 2.Illustrates the proposed Boost Converter which is derived from Cuk or Zeta Converter and Luo-converter of previous topology [6]-[10]. The new series of DC-DC boost converter provides better voltage transfer ratio compared to the previous topologies. The circuit essentially consists of a P-channel MOSFET switch triggered using the PWM switching pulse with variable frequency and duty ratio k. The switch is operated in two modes with the incorporated passive components C and L at the input side. The purpose of capacitor C is to lift the voltage of the C_o during the switch ON time. The voltage across C_o will be the voltage across the load under steady condition. Purpose of providing L is to lift the voltage across C. During the charging period the voltage across C_o will be V_1+V_c and this voltage is maintained even when switch is off. The switching equivalent circuit of the figure 1 is shown in figure 3 and 4.

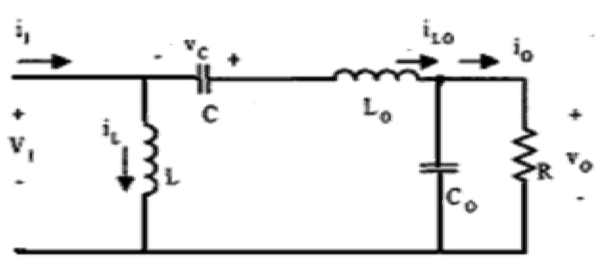


Figure 3. Equivalent Circuit when Switch ON Condition.

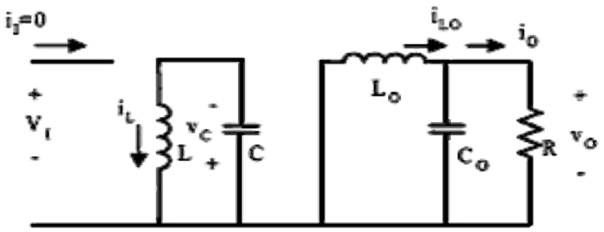


Figure 4. Equivalent Circuit when Switch OFF Condition.

During the switch OFF condition voltage across C_o, $V_o=V_1+V_c$ will appear across R for short duration of time. The inductor L_o maintains the current direction even during switch OFF. Elementary equations of conventional DC-DC converter are given below for the performance comparison of the proposed topology.

$$\text{Output Voltage } V_O = \frac{K}{1-K} V_1$$

$$\text{Output Current } I_O = \frac{1-K}{K} I_1$$

$$\text{Voltage Transfer Gain } M = \frac{K}{1-K}$$

$$\text{Average Voltage } V_C = V_O$$

$$\text{Average Current } I_{LO} = I_O$$

$$I_{LO} = \frac{K}{1-K} I_O$$

B. ANALYSIS OF PROPOSED CONVERTER

Under Steady state the average inductor voltage over a period is zero hence,

$$V_{C1} = V_{CO} = V_O \tag{6}$$

I_L – increases when switch is ON-corresponding Voltage across L $=V_1$

I_L – decreases when switch is OFF-corresponding Voltage across L $= -V_C$

Therefore $KV_1 = (1-K)\, V_C$ (7)

$$V_C = \frac{K}{1-K} V_1 \tag{8}$$

During switch ON period the voltage across C_O is equal to the source voltage V_1 plus the voltage across C

$$V_{CO} = V_1 + V_C \tag{9}$$

$$V_{VO} = V_1 + \frac{K}{1-k} V_1$$

$$V_{CO} = \frac{1}{1-K} V_1 \tag{10}$$

Voltage transfer gain of Continuous Conduction Mode

$$M = \frac{V_O}{V_1} = \frac{V_{CO}}{V_1} = \frac{1}{1-K}\frac{V_1}{V_1} = \frac{1}{1-K} \tag{11}$$

TABLE-II : SIMULATION PARAMETERS FOR DC-DC CONVERTER

Input Voltage	18V
Output Voltage	54V
Frequency	50Hz
Inductance L_1, L_2	100µH
Capacitance C_1, C_2	5µF

IV. INVERTER

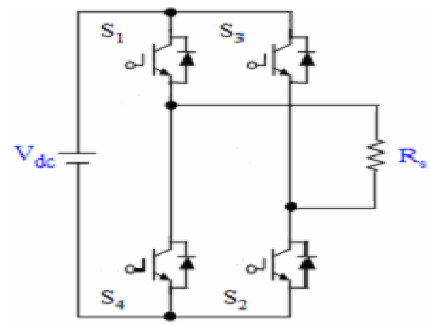


Figure5. Equivalent circuit of inverter.

Inverter is designed to provide power at a fixed frequency. A resonant filter can be used shown in figure 5. For an adjustable frequency inverter, the filter must be tuned to a frequency that is above the maximum fundamental frequency. Since most loads contain inductance, feedback rectifiers or anti parallel diodes are often connected across each semiconductor switch to provide a path for the peak inductive load current when the switch is turned off. The anti parallel diodes are somewhat similar to the freewheeling diodes used in AC/DC converter circuits.

TABLE-III SIMULATION PARAMETERS FOR INVERTER

DC Source voltage	54 v
Rated output voltage	24 v
Rated output frequency	50 Hz
Filter inductor , L_f	250 mH
Filter resistor, R_f	0.2 Ohms
Filter capacitor , C_f	30 µF

IV. IMPLEMENTING CONTROLLERS FOR THE STAND ALONE PHOTOVOLTAIC SYSTEM

A. PI CONTROLLER

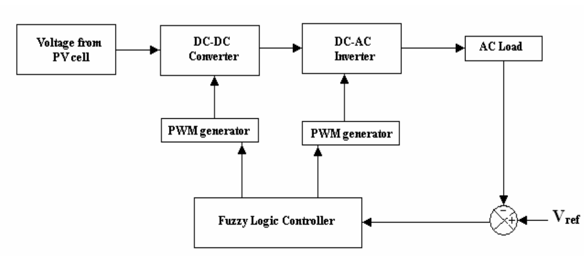


Figure 6. Block diagram of PI controller for standalone PV system.

Closed Loop control scheme [11] for the proposed DC-DC Boost converter and Inverter topology is shown in the above figure 6. The control scheme essentially consisting of only one voltage sensor with simple control structure when compared with conventional DC-DC boost converter which requires both voltage and current sensors. In this paper for the above model of the converter [11] the Ziegler-Nichols method 1 is (S-shaped curve technique) applied to design the PI controller. Using [11] Ziegler-Nichols chart the value of the K_p and T_i are calculated. Closed control scheme for the both converter are the same and the parameter of K_p and K_i are different. The standalone PV model is tested under following conditions to check the effectiveness of the designed PI controller and the results presented.

A. tested under normal condition.

B. tested with input voltage variation.

C. tested under load resistance variation.

B. DESIGN OF FUZZY LOGIC CONTROLLER

The Fuzzy Logic Controller (FLC) provides an adaptive control for better system performance. Fuzzy logic is aimed to provide solution for controlling non-linear processes and to handle ambiguous and uncertain situations. Fuzzy control is based on the fundamental of fuzzy sets. The fuzzy control for the chosen converter is developed using input membership functions for error 'e' and change in error 'ce' and the output membership function for D, the duty ratio of converter.

For instance, if the output voltage continues to increase gradually while the current is low during the charging process, the fuzzy controller will maintain the increase in voltage to reach the set point. A drop in the output voltage level triggers the fuzzy controller to increase the output voltage of the converter by modifying the duty cycle of the converter. Fuzzy control involves three stages: fuzzification, inference or rule evaluation and defuzzification. Seven triangular membership functions are chosen for simplicity and Table IV shows the fuzzy rule base created in the present work based on intuitive reasoning and experience. The block diagram for fuzzy logic controller for chosen converter/ inverter is shown in Fig.7.

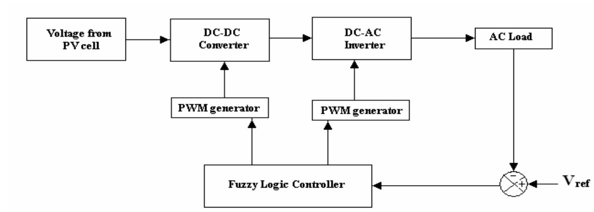


Figure. 7. Block diagram of fuzzy controller for a standalone PV system.

TABLE-IV : FUZZY RULE BASE

ce / e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

TABLE-V
PERFORMANCE ANALYSIS FOR BOTH THE CONTROLLERS

Controller	Rise Time	Peak Overshoot	Settling time	Steady state Error
PI	0.005	0.8 %	0.01 sec	2%
FUZZY LOGIC	0.003	0.3%	0.007 sec	1.2%

V. SIMULATION RESULTS

A. NO DISTURBANCE

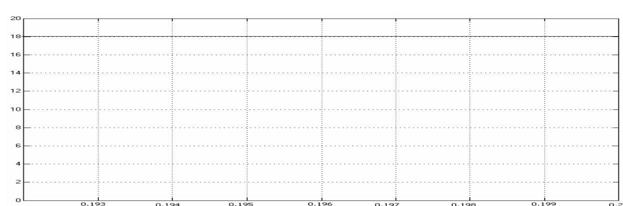


Figure 8.Output voltage from PV system with PI controller

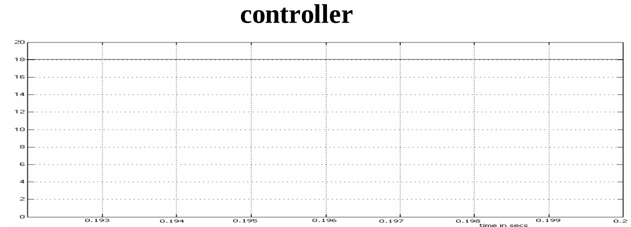


Figure 9.Output voltage from PV system with Fuzzy logic controller

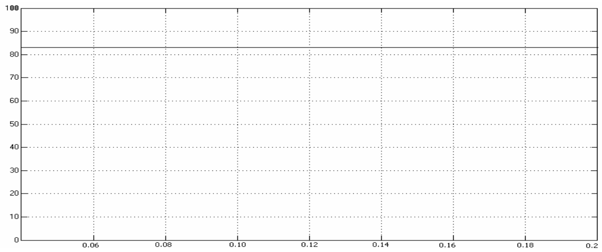


Figure 10.Output power from PV system with PI controller

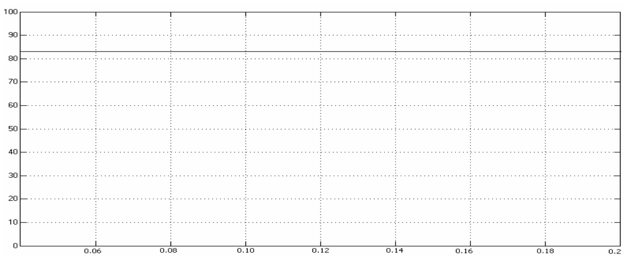


Figure 11.Output power from PV system with Fuzzl logic controller

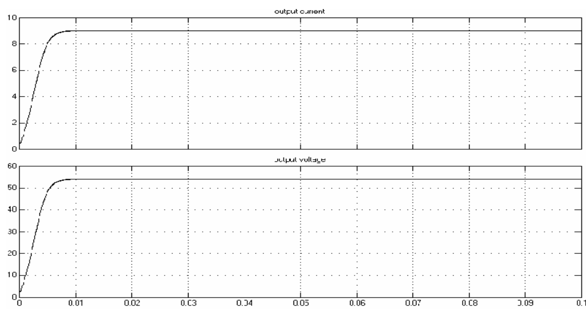


Figure12. Output current and voltage waveform of dc-dc converter when using PI controller

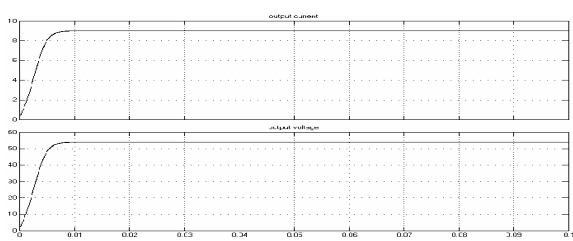


Figure13. Output current and voltage waveform of dc-dc converter when using Fuzzy logic controller

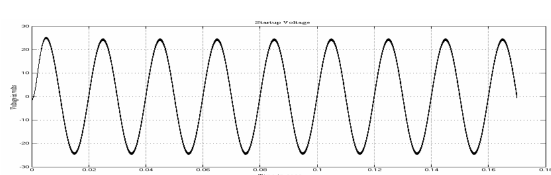


Figure14. Simulated start-up of the output voltage of inverter using PI controller.

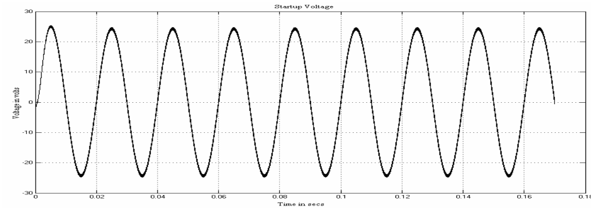


Figure15 Simulated start-up of the output voltage of inverter using Fuzzy logic controller.

B.LINE DISTURBANCES

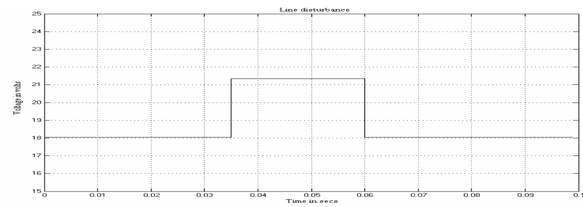


Figure16. Simulated output voltage of PV system with line disturbances using PI Controller.

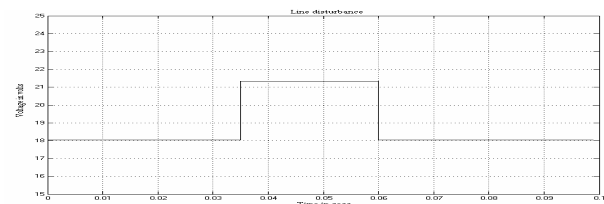


Figure17. Simulated output voltage of PV system with line disturbances using Fuzzy logic Controller

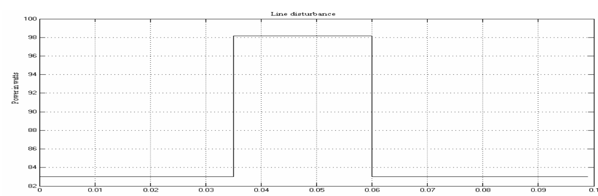


Figure18. Simulated output power of PV system with line disturbances using PI controller

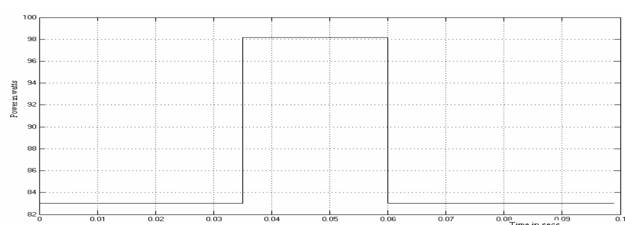


Figure19. Simulated output power of PV system with line disturbances using Fuzzy logic controller.

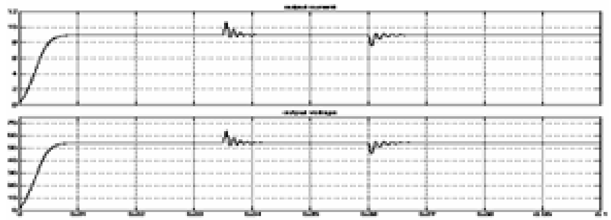


Figure20.Simulated output current and voltage from DC-DC converter with line disturbance under nominal load with PI controller

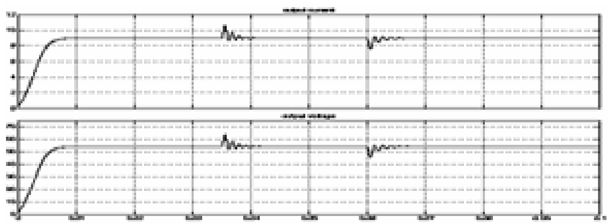


Figure21.Simulated output current and voltage from DC-DC converter with line disturbance under nominal load with fuzzy logic controller

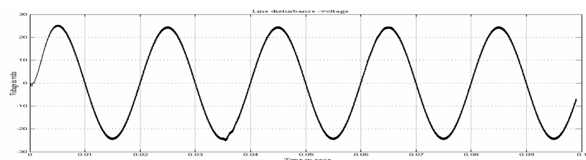


Figure22.Simulated output voltage of inverter with line disturbance under nominal load with PI controller

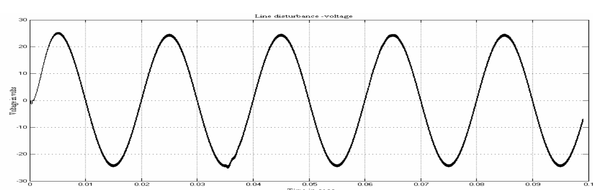


Figure23.Simulated output voltage of inverter with line disturbance under nominal load with fuzzy logic controller.

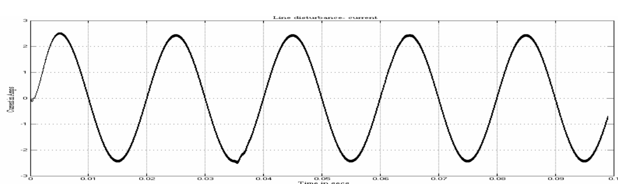


Figure24.Simulated output current of dc-ac inverter with line disturbance under nominal load using PI controller

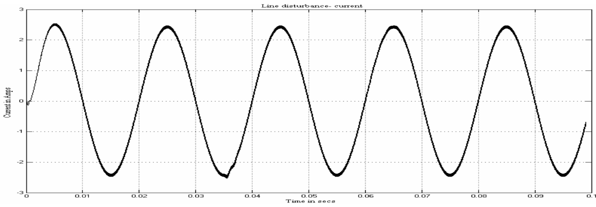


Figure25.Simulated output current of inverter with line disturbance under nominal load using fuzzy logic controller.

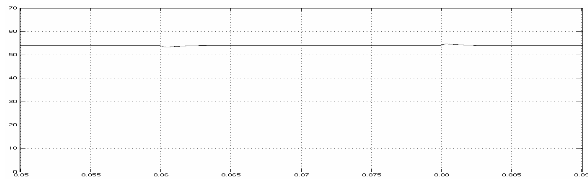


Figure26.Simulated output voltage of inverter with load disturbance under nominal load using PI controller.

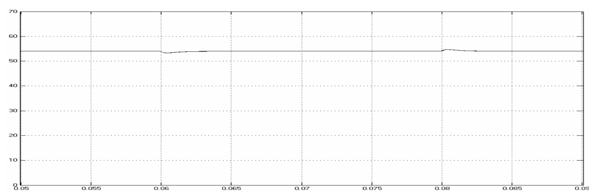


Figure27.Simulated output voltage of inverter with load disturbance under nominal load using fuzzy logic controller.

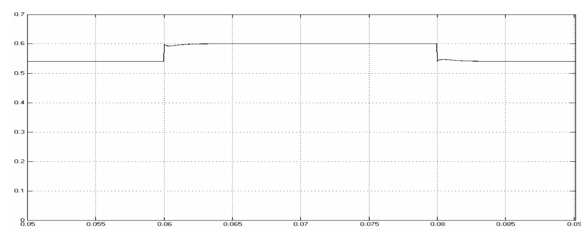


Figure28. Simulated output current of DC-DC converter with load disturbances under nominal load using PI controller.

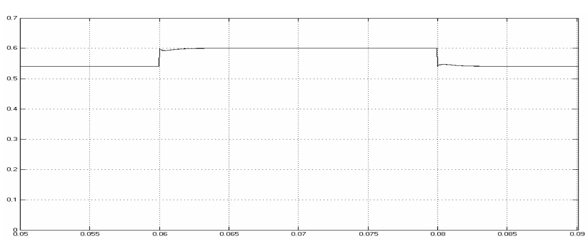


Figure29. Simulated output current of DC-DC converter with load disturbances under nominal load using Fuzzy logic controller.

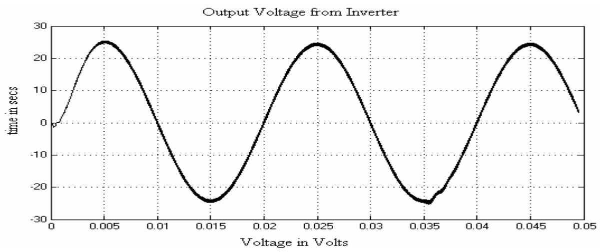
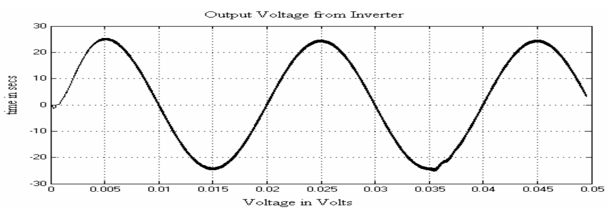


Figure30. Simulated output voltage of inverter with



load disturbances using PI controller.

Figure31. Simulated output voltage of inverter with load disturbances under nominal load using fuzzy logic controller.

VI. CONCLUSION

Renewable energy source plays a vital role in the growing economy. Here a photovoltaic cell is used in this proposal. The benefit of using predictive controllers is to maintain stand by energy import. In this work, two different controller (PI/fuzzy controllers) structures are designed, and simulated for Standalone photovoltaic system. From the performance analysis it can be concluded that Fuzzy logic controller provides better performance in terms of reduced peak overshoot, settling time and steady state error for the proposed system for its vital utilities.

VII. REFERENCES

[1] K. Mitchell, M. Nagrial, J. Rizk, Simulation and optimization of renewable energy systems,.Electrical Power and Energy Sysems 27 (2005) 177-188

[2] B. J. Masserant, student, ieee, t. A. Stuart, member IEEE, “A Maximum Power Transfer Battery Charger For Electric Vehicles”, ieee transactions on aerospace and electronic systems vol. 33, no. 3 july 1997, PP.930 – 938.

[3] ziyad M.salameh margret A. casacca, william a. lynch“A Mathematical model for lead acid batteries” IEEE transactions on energy conversion, vol. 7, No.1, 1992.

[4] “Evaluation Of Demand And Supply Control maintaining electric power quality using rechargeable electric system ”january 30, 2001, tetsuo sasaki, the kansi electric power co.

[5] M. Hirakata, T. Shimizu, and G. Kimura, “Generation control circuit forPV system,” in *Proc. ICEE’96*, vol. 2, Aug. 1996, pp. 992–996.

[6] Comparison of PI Controller for battery charger Application” March 23,2007. bikanar,Rajasthan.

[7] Browny SB, Salameh ZM. Optimum photovoltaic array size in a hybrid wind/PV system IEEE Trans Energy Convers 1999;9(3).

[8] S. C. Yip, D. Y. Qiu, Henry Shu-Hung Chung, *Member, IEEE*, and S. Y. R. Hui, *Fellow,IEEE*, A Novel Voltage Sensorless Control Technique for a Bidirectional AC/DC Converter.