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Performance and Implementation of Grid Connected Single Phase Photovoltaic System and FPGA-Design Based MPPT

B. Pragathi1, Deepak Kumar Nayak, Polaiah Bojja

Abstract— ***Solar Photo Voltaic system are used for power generation by the process of photovoltaic effect. The solar power is varying continuously on a particular day due the variations in the temperature and irradiances. To overcome the power loss of PV system maximum power point tracking techniques are used to generate maximum solar power . Generally digital signal processors are used for implementing maximum power point tracking algorithms, but the performance is limited. The high degree of flexibility is achieved by the use of field-programmable gate arrays (FPGA) chips. The PV systems are used to provide stable and reliable power. The paper presents the single-phase implementation of the grid connected PV system and FPGS based P&O MPPT algorithm. The proposed system consists of P&O MPPT algorithm for maximum solar power extraction, bi-directional DC-DC converter for is used for controlling the battery. The solar power is used to serve the connected load and the excess power is used for serving grid utility. The single-phase inverter is used for DC-AC conversion. The Xilinx ISE is used for simulation of MPPT algorithm. The grid connected PV system is simulated using MATLAB/SIMULINK.***

Keywords: Solar PV system, DC Converter, Inverter, MPPT technique, FPGA.

I. INTRODUCTION

Mostly non-renewable energy resources such as natural gas, oil and coal are used for generating electricity but many environmental issues such as green gas effect, global warming are increases rapidly. However, the demand for renewable energy resources are increases to reduce the green gas effect [1]. The available renewable energy resources are water, wind, sunlight, biomass, sea-waves and geothermal heat, which are used to generate electricity. Photovoltaic effect is used for generation of DC output power by converting light energy into electricity. since the solar power depends on the irradiances and temperature, on a particular day the available solar power is varying to track the maximum power maximum power point algorithm are used by sensing the current and voltage of the solar panels [2], [3], [4].

Several MPPT algorithms have been developed for tracking the maximum power point [5], [6]. The generated DC power from the solar panels is converted into AC power by inverter section to feed the utility grid [7], [8]. The AC output of the inverter section depends on the switching pulses of the switching devices (BJT, MOSFET, IGBT etc.). Pulse width modulating technique is used for generating the pulses for the switching devices of the inverter section [9], [10]. The general PV system is shown in figure.1. The system consists of the solar PV module; photovoltaic effect is used for DC power generation. Maximum power point tracking algorithms are used for tracking maximum power point. The generated DC power is boost up by the DC converter. Inverter section is used DC-AC conversion. The generated solar power is delivered to the load and the excess power is transferred to the utility grid.

II. SYSTEM AND MODELLING

The proposed system block diagram is shown in fig.1 consists of solar panels which generates DC power by the process of photovoltaic effect. Incremental conductance maximum power point tracking algorithm is used for generating maximum power from the modules by sensing the current and voltage and are given to the PIC16F876A microcontroller. The operation of DC converter is controlled by adjusting the duty cycle of gating pulses applied to the IGBT. Moreover, the inverter section is used to generate the required AC signal to drive the load. The converted AC power is delivered to the load and the excess is delivered to the utility grid. The Proposed Photo Voltaic system is shown in figure.2.

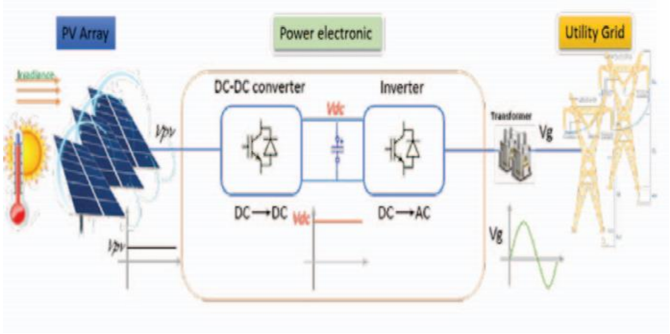

Figure.1 General PV System

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* Correspondence Author
B. Pragathi, Research Scholar, Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India
Deepak Kumar Nayak, Associate Professor, Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram,Guntur, India
Polaiah Bojja, Professor, Department of ECE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, India

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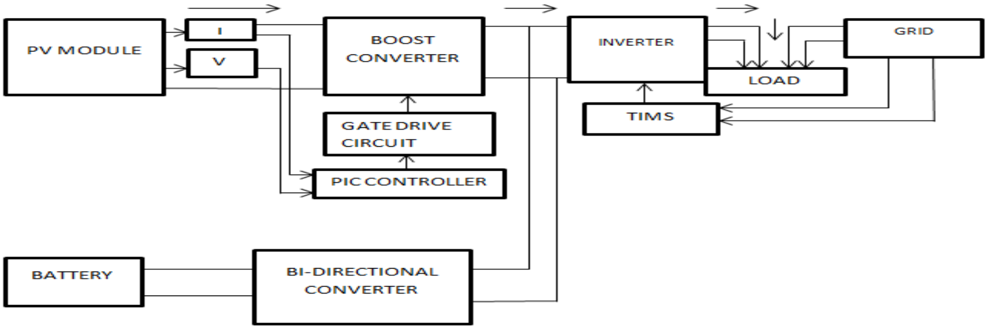

Figure.2 Block diagram of Proposed Photo Voltaic system

III. PV SYSTEM MODES OF OPERATION

PV Power Mode of operation: Maximum power is generated from the solar modules by MPPT techniques and is delivered to the load.

Battery Charge-up Mode of operation: The battery is charged by the bidirectional converter. Bidirectional converter is used for charging battery, controlled by the duty cycle of IGBT.

Battery Powered Mode of operation: When the power from the panel is unavailable, the battery supplies power to the load.

Grid Connected Mode of operation: The excess power from solar panel after serving the load is delivered to the grid and in the absence of solar power, grid power is delivered to the load.

IV. COMPONENT MODELLING

The solar panels required for the hardware implementation system as shown in figure.4, experimental solar Photo Voltaic panel specifications are given in table.1.

Figure.4 Solar panels

By Applying KVL to the PV cell electrical equivalent model in Fig.3, the total current is derived as given in eq.1.

$$\mathrm{I} = \mathrm{I_L} - \mathrm{I_D} - \mathrm{I_{sh}}$$

(1)

I=Total current , $\mathrm{I_L} = Photon\ current$, $\mathrm{I_D} = Diode\ current$, $\mathrm{I_{sh}} = shunt\ current$

.

$$\mathrm{I_D} = \mathrm{I_O}\left[\mathrm{e}^{\left(\frac{\mathrm{V+IR_s}}{\eta \mathrm{V_T}}\right)} - 1\right]$$

(2)

η-diode ideality factor (1 or 2)

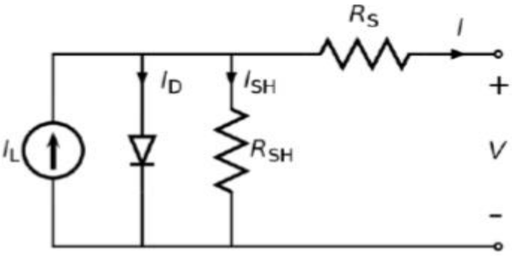

Figure.3 PV cell electrical equivalent model

$$V_T = \frac{KT_C}{q}\ , K = 1.381 * 10^{-23}\frac{J}{K}$$

(3)

$$q = 1.602 * 10^{-19} C$$

$$I_{sh} = \frac{(V+IR_s)}{R_{sh}}$$

(4)

$$I = \mathrm{I_L} - \mathrm{I_O}\left[\mathrm{e}^{\left(\frac{\mathrm{V+IR_s}}{\eta \mathrm{V_T}}\right)} - 1\right] - \frac{(V+IR_s)}{R_{sh}}$$

(5)

$\mathrm{I_L} = photon\ current(A), \mathrm{I_O} = reverse\ saturation\ current(A) of diode$

$$I_O = KT^m e^{\frac{-V_{GO}}{\eta V_T}}$$

(6)

$m = 1.5\ for\ Si, V_{GO} = 1.16V\ to\ 1.21V\ for\ Si, K = constant$

$$I_{ph} = [I_{scr} + K_i(T - T_{ref})] * \frac{\lambda}{1000}$$

(7)

$T_{ref} = (25^o + 273^o), I_{scr} = short\ circuit\ current\ at\ 25^o C$

,

$K_i = short\ circuit\ current\ coefficient(0.0017\frac{A}{C^o})$

Table.1 Experimental solar panel specifications

No of panels used:250W*4	1000W
Panels connected	parallel
Panel voltage	36V
Battery two	24V
(P_{max})-PV panel Maximum power	250W
(V_{mp})- PV panel Maximum voltage	36.8V
(I_{mp})- PV panel Maximum current	6.79A
(V_{oc})- PV panel Open circuit voltage	45.2V
(I_{sc})- PV panel Short circuit current	6.79A

V. MAXIMUM POWER POINT TRACKING ALGORITHM WITH DC-DC CONVERTER

To generate the maximum solar power maximum power point techniques are used. Incremental conductance MPPT technique is used to generate maximum power. The flow chart for Incremental conductance MPPT is given in figurr.5. To increase the power of the DC signal, DC converter is used. The circuit diagram of DC converter is given in fig.6. obtain the required RMS voltage, the DC voltage from PV module is fed to the DC-DC converter. Switching of the IGBT in the DC-DC converter is controlled by the pulses from the MPPT module. The selection of capacitor and inductor value are obtained by the equations given below. The DC-DC parameters are given in table.2. The MPPT DC Converter circuit diagram is as shown in figure.7 The hardware implementation of MPPT along with converter is as shown in figure.8.

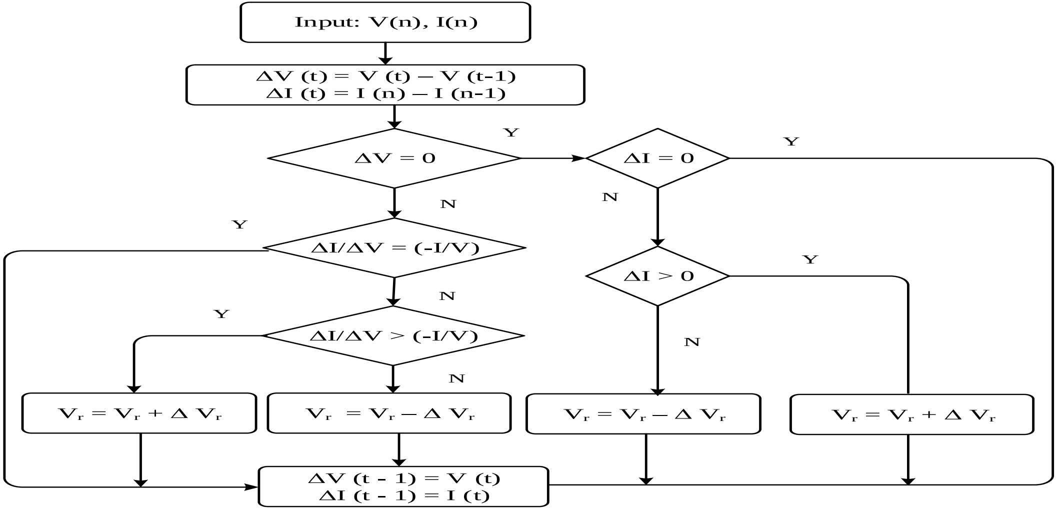

Fig.5 Incremental conductance MPPT algorithm

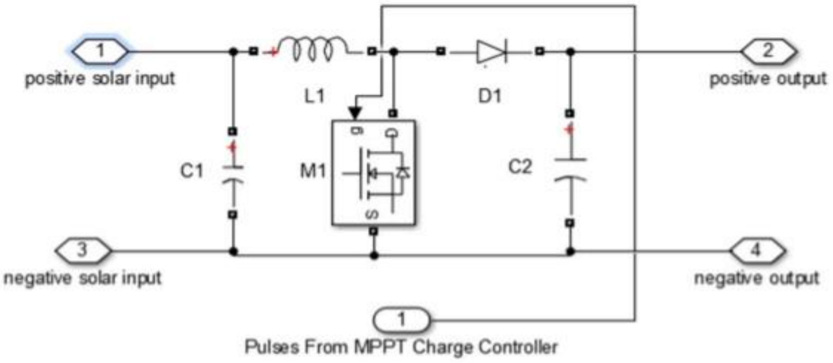

Fig.6 MPPT DC-DC Converter circuit diagram

Value of an inductor Lb and C_b for the boost converter:

$$L_1 = \left(\frac{V_{PV}D}{2\Delta i_1 f_{sw}}\right)$$

(8)

$$D = 1 - \left(\frac{V_{in}}{V_b}\right)$$

(9)

Output voltage from PV array V_{in} = V_{PV};$\Delta i_1 - output\ current\ ripple$

$$I_1 = \frac{P}{V_{in}}$$

(10)

$$C_1 = \frac{I_{ob} D}{\Delta V f_{sw}} \tag{11}$$

$where\ I_{ob} = \frac{P_{ob}}{V_b}\ output\ current$;
$P_{ob} -$ output power of DC − DC boost converter; $\Delta V -$ peak ripple in output voltage; V_b -output voltage; output current (I_{ob})

Table.2 DC-DC Converter Parameters

D	$0.375\ to\ 0.1565$
V_{in}	675V
Δi_1	$10\%\ of\ input\ current$
I_1	37.03A
Δi_1	$3.7A$
f_{sw}	$10KHz$
L_1	$1.45mH$
V_b	800V
(I_{ob})	$31.25A$
$output$ $capacitor$	$2685\mu F$

Fig.7 Hardware Implementation of MPPT with DC-DC converter

VI. GRID TIE INVERTER

The inverter section is shown in fig.8, the hardware implementation of the inverter section is shown in fig.9. Full bridge voltage source inverter is used for converting DC voltage of 360V from DC-DC boost converter to RMS AC voltage of 230V with a fundamental frequency of 50Hz.The switching pulses for IGBTS of inverter are obtained by PWM technique. The inverter section circuit diagram is shown in figure.8. The hardware implementation of inverter with transformer is as shown in figure.9. The Simulink model and hardware implementation of the proposed system is shown in figure.10 and figure.11.

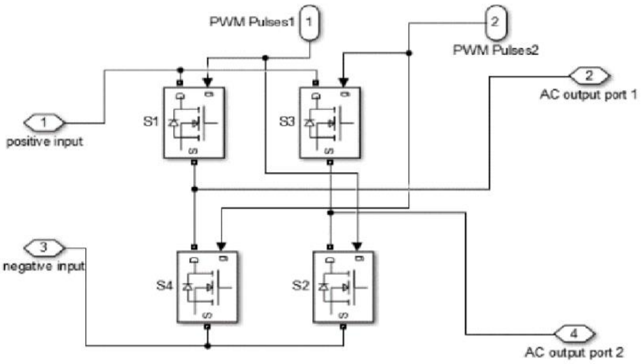

Fig.8 Inverter section circuit diagram

Fig.9 Hardware implementation of inverter with transformer

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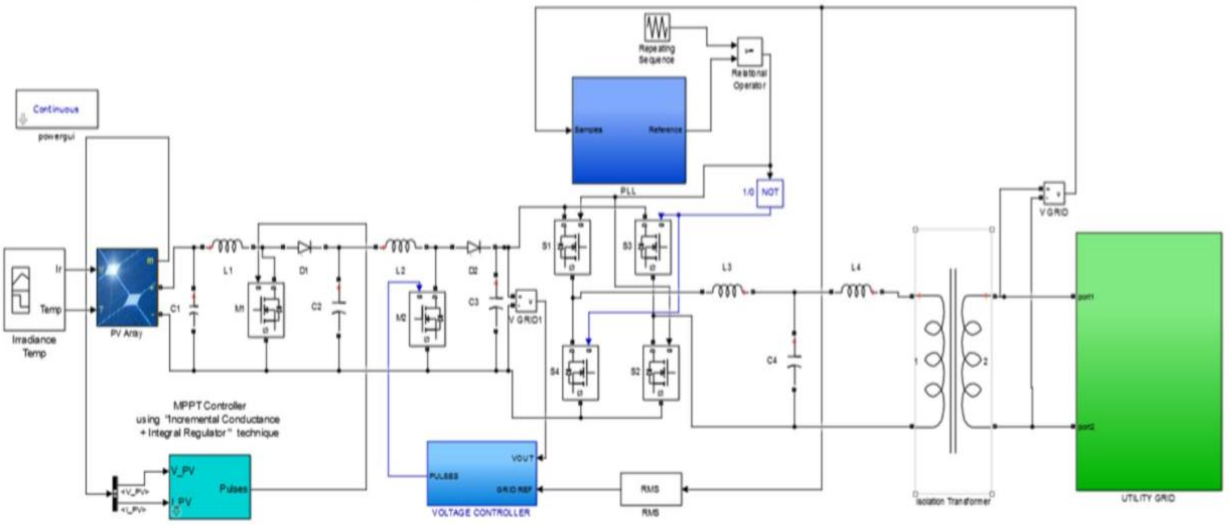


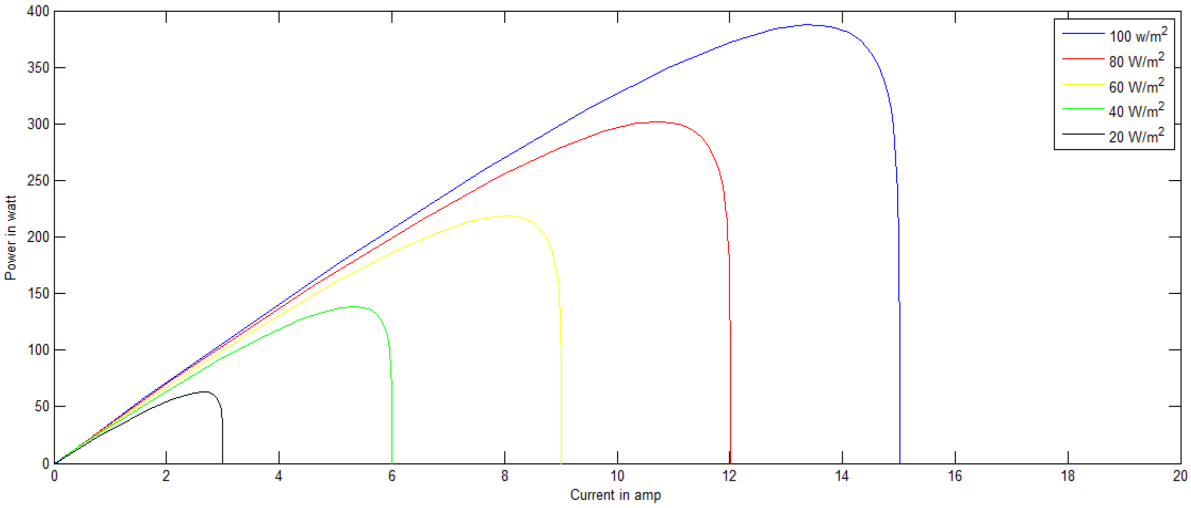
Fig.10 Overall Simulink model of the proposed system

Fig.11 Overall hardware implementation of the proposed system

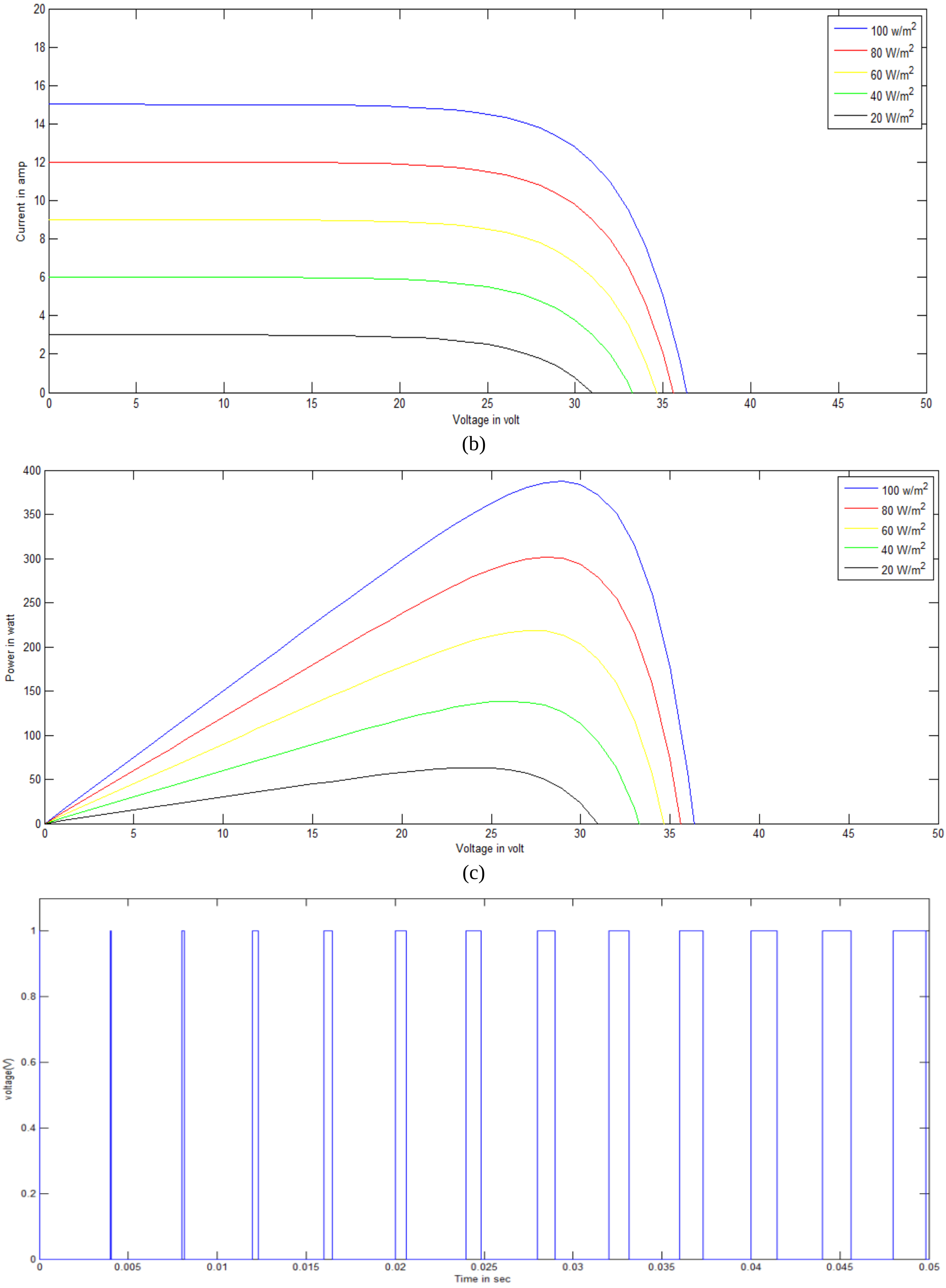
VII. RESULTS

The solar PV output power, current and voltage for various isolation levels is shown in figure12. (a), (b), (c). The output of the incremental conductance MPPT technique is shown in fig.13. The output pulse is used to adjust the duty cycle in the DC converter and the output is shown in fig.14. The output of the grid tie single phase inverter is shown in fig.15. The PV system output load voltage and current waveforms is shown in fig.16.The P&O MPPT simulation in Xilinx is shown in fig.17.a and fig.17. b. The grid connected PV system is synchronized with the inverter and stable output voltage and current are generated.

Figure.12 (a) PV cell power versus current waveforms for various isolation levels (b) PV cell current versus voltage waveforms for various isolation levels (c) PV cell power versus voltage waveforms for various isolation levels



(a)



(b)

(c)

Fig.15 Incremental conductance MPPT Output

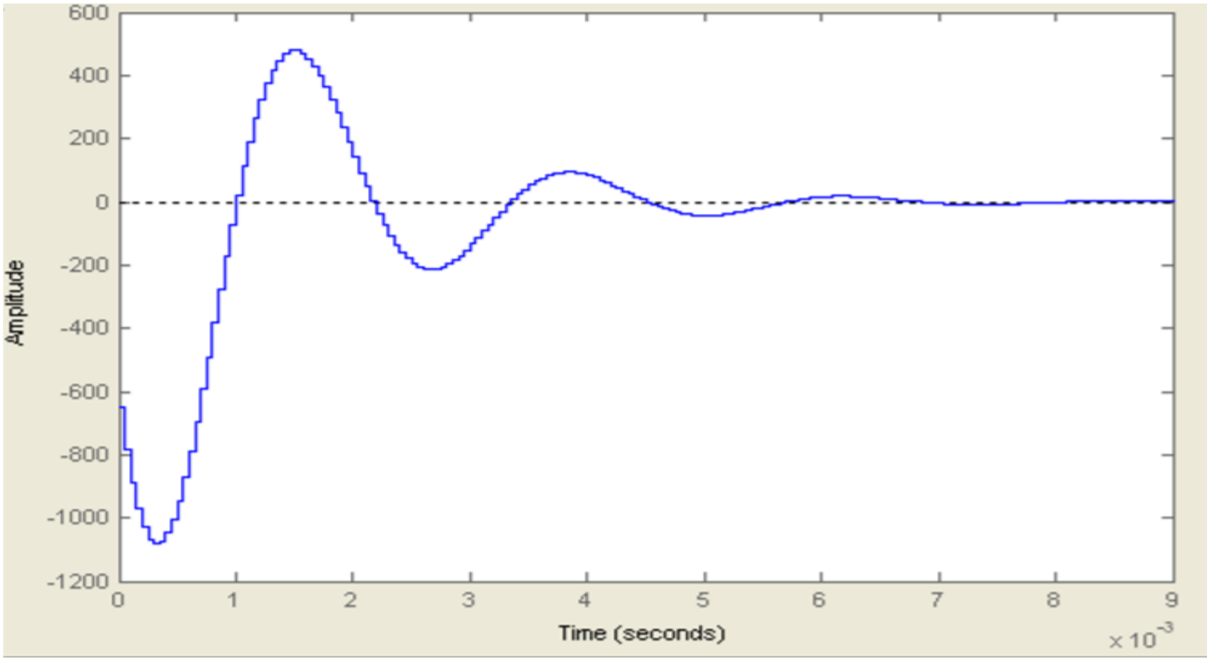


Fig.16 DC-DC Converter Output

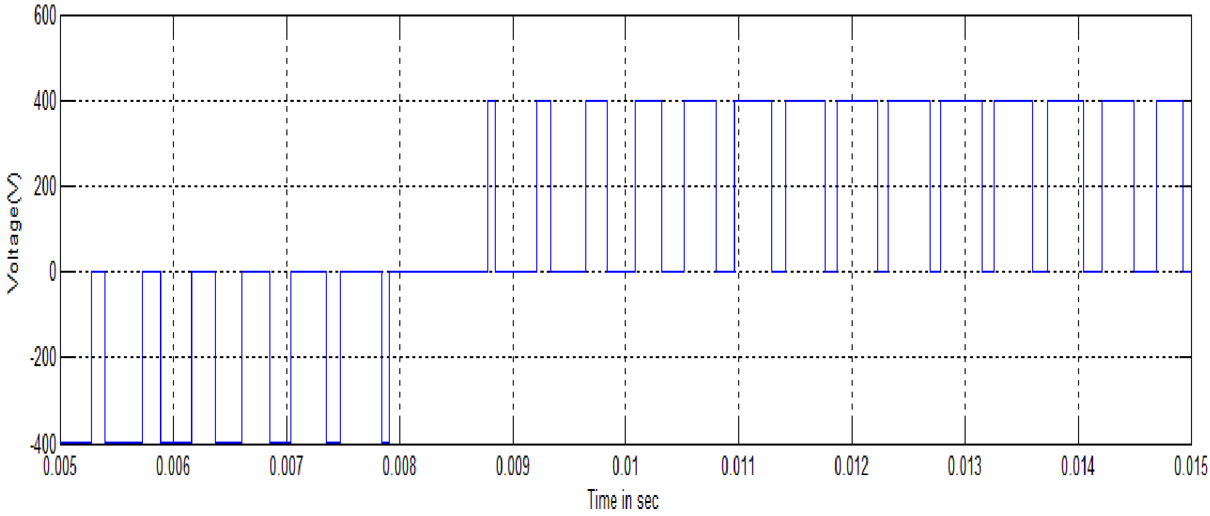


Fig.17 Grid Tie Inverter Output Waveform

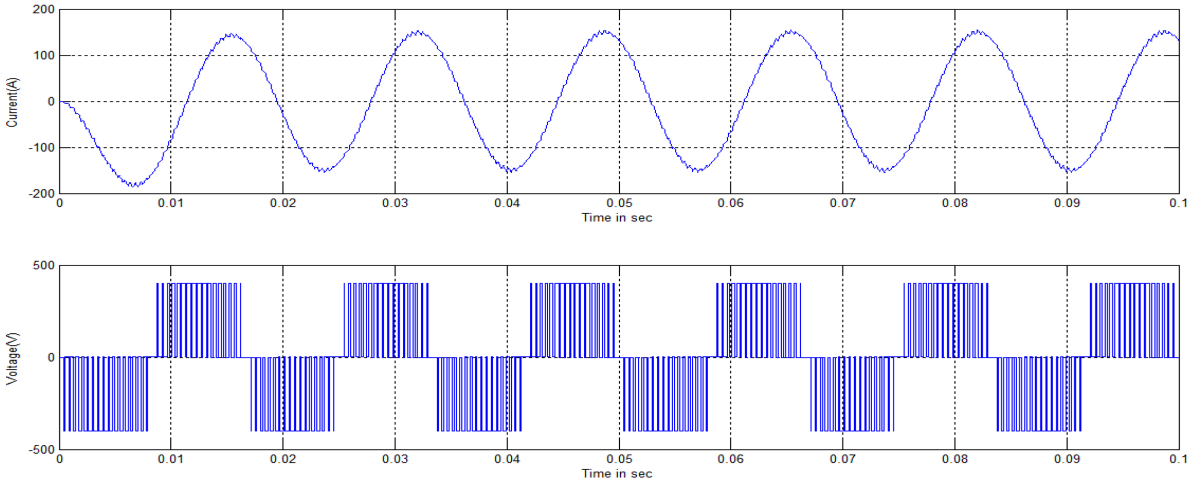
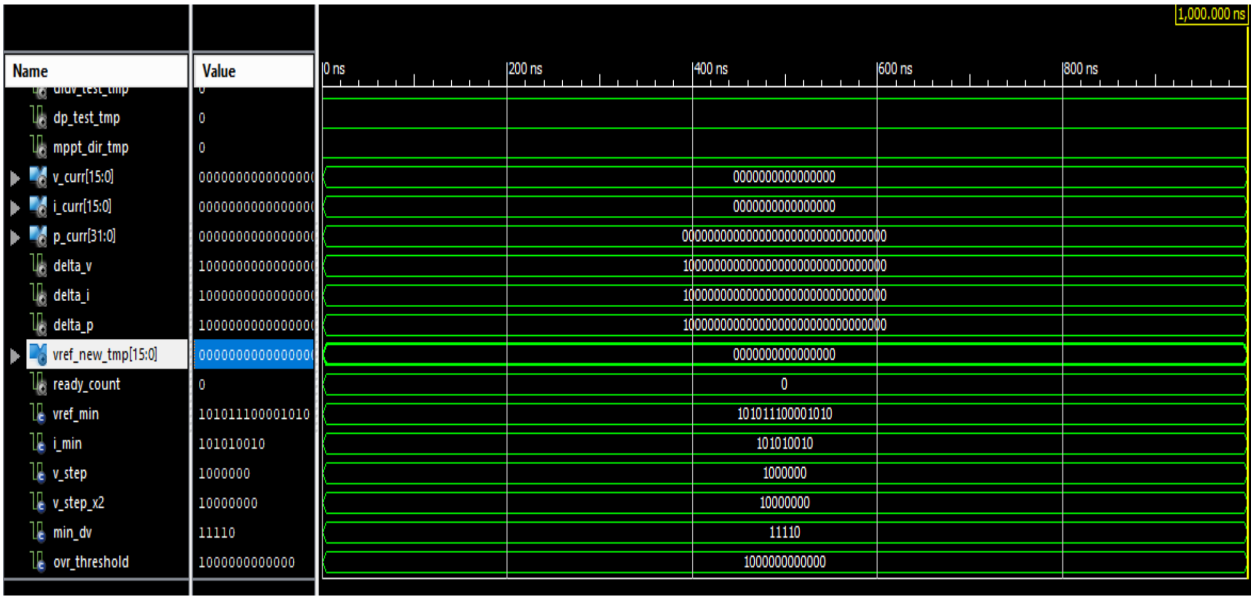
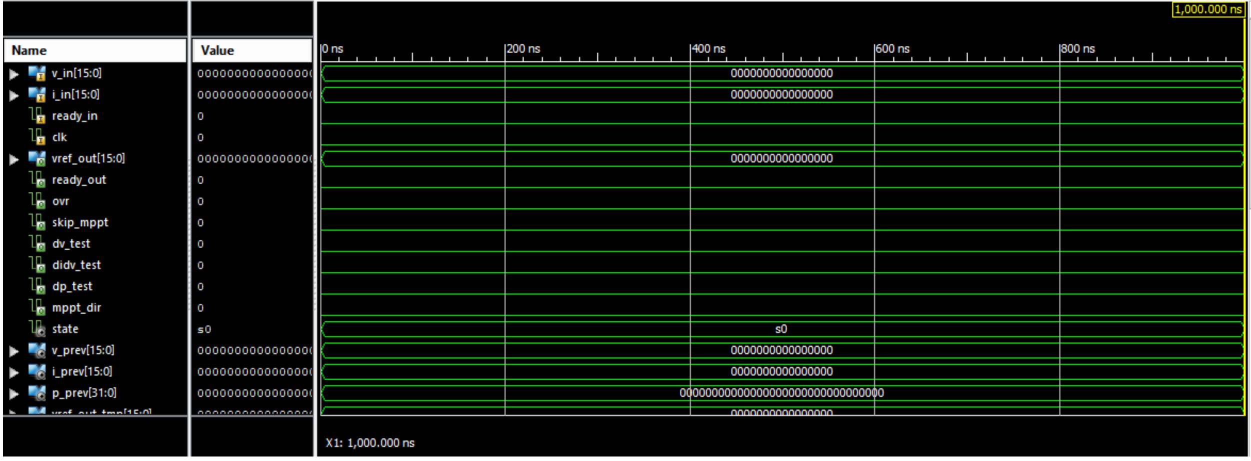


Fig.18 PV system Load Current and Voltage Waveforms



Name	Value
didv_test_tmp	0
dp_test_tmp	0
mppt_dir_tmp	0
v_curr[15:0]	0000000000000000
i_curr[15:0]	0000000000000000
p_curr[31:0]	00000000000000000000000000000000
delta_v	10000000000000000000000000000000
delta_i	10000000000000000000000000000000
delta_p	10000000000000000000000000000000
vref_new_tmp[15:0]	0000000000000000
ready_count	0
vref_min	101011100001010
i_min	101010010
v_step	1000000
v_step_x2	10000000
min_dv	11110
ovr_threshold	1000000000000

Fig 19.a P&O MPPT algorithm



Name	Value
v_in[15:0]	0000000000000000
i_in[15:0]	0000000000000000
ready_in	0
clk	0
vref_out[15:0]	0000000000000000
ready_out	0
ovr	0
skip_mppt	0
dv_test	0
didv_test	0
dp_test	0
mppt_dir	0
state	s0
v_prev[15:0]	0000000000000000
i_prev[15:0]	0000000000000000
p_prev[31:0]	00000000000000000000000000000000
vref_out_tmp[15:0]	0000000000000000

Fig 19.b P&O MPPT algorithm

VIII. CONCLUSION

The paper presents the MATLAB/SIMULINK simulated single phase and hardware implementation of the grid connected PV system. The incremental conductance MPPT algorithm had extracted maximum solar power, the battery is used to supply continuous power to the load and the excess power is supplied to the grid. The bi-directional DC-DC converter is used for controlling the battery. The grid connected PV system is synchronized with the inverter and stable output voltage and current are generated which are shown in the result section. The high degree of flexibility is achieved by the use of field-programmable gate arrays (FPGA). The control algorithms can be further implemented for generating pulses to the inverter section to mitigate the reactive power.

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AUTHOURS PROFILE

Bellamkonda Pragathi was born in kazipet, India, in 1986. She received the B.Tech degree in Electronics and Communication Engineering from the Christu Jyoti Institute of Technology and Science, Jangaon, India, in 2008, and M.Tech in VLSI from the Jayamukhi Institute of Technological Sciences, Warangal, India, in 2010 and presently working for her doctoral degree at Koneru Lakshmaiah University, India, India. Her current research interests include power electronics, renewable energy resources, VLSI and power quality.

Dr. Polaiah Bojja, K L University, Vaddeswaram, Guntur, Andhra Pradesh, IndiaVerified email at kluniversity.in