Design and Generation of Control Pulses by Microcontroller Based Controller for Grid Connected Solar Photovoltaic System

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***Abstract*- In modern contest the world is moving from conventional energy sources to the renewable one. It is due to its greater abundance and environment friendly characteristics. Solar energy is one of the most reliable and never ending renewable energy sources. This paper presents a method to transfer the peak power of solar photovoltaic module to grid. A unique relationship between open circuit voltage and voltage corresponding to maximum power for the solar module ELDORA40 is developed by simulation in Matlab/simulink. Single Phase Fully Controlled Converter with RLE load is used in inversion mode to convert the solar dc into ac power. Inverter thyristers are triggered by pulse generated by microcontroller. Microcontroller programmed to generate pulse such that peak power of solar module is transferred to grid. Result obtained by experimental setup is satisfactory. The use of microcontroller based control circuit provides us large number of advantages. It reduces size and cost of controller significantly. The efficient control of delay angle is the main advantage. Besides this it provide more versality and greater scope for further improvement just by changing the program but not hardware configuration. The performance of controller is found satisfactory. In general switching control mode as well as specific application mode for solar photovoltaic grid interactive inverter.**

Keywords*- *MPPT, Photovoltaic, control pulse, grid-connected and inverter.

I. INTRODUCTION

Contribution of renewable energy is increasing and playing an important role in economic development of a country. Solar energy is one of the most reliable renewable energy resources can never be exhausted.

Power electronic devices used as interface between renewable power and its user. It makes the power generated by renewable sources suitable for utilization.

Solar power contribution in power generation has been increasing very fast and cost of power generated by solar photovoltaic is falling rapidly. Solar photovoltaic cell converts solar energy directly into dc power. Power is mostly transmitted and utilized in ac form because of advantages associated with it. To convert the dc power into ac, a highly efficient converter is required for optimum utilization of energy. Power electronic devices can be used for this purpose, because they are highly efficient, light weight, small size, very fast and most reliable. Power electronic devices used as a switch [1]-[3].

Power electronics devices required control signal for its operation. These signals may require continuously or at the time of switching. There are many controllers which generate control signal and has its own advantages and disadvantages.

The main idea of the proposed method is to use fully controlled converter with RLE load in inversion mode. When negative polarity of dc source (battery, solar photovoltaic cell or array, etc.) is connected with cathode of thyristors 1 and 3 it act as a line commutated inverter.

The convertor operates in inversion mode only when triggering pulse is greater than 90 degree and there is an inductive load in the output circuit [4].

The heart of this system is microcontroller based advanced triggering circuit. Microcontroller is programmed to generate triggering pulses such that maximum power of solar photovoltaic cell or array is supplying to grid. I-V characteristic of solar photovoltaic cell is such that there is a peak power point on the characteristic. The voltage corresponding to peak power is called maximum power point voltage. As solar photovoltaic cell is a current source. Current varies almost directly proportional to solar irradiation while open circuit voltage has a weak link with solar insolation and cell temperature. So To extract the maximum power, peak power point voltage is being tracked.

This work demonstrates a new method that can be used for transferring solar energy into the grid [5]-[11]. This consists of designing of line commutated inverter and microcontroller based control circuit. The microcontroller has been used to design the control circuit because of its greater reliability, flexibility and versality. Besides the delay angle can be controlled according to requirement by just changing the program not the hardware setup.

II. METHODOLOGY

The inverter used in this work is fully controlled bridge converter with RLE load (where E is solar photovoltaic). When thyristers are triggered after 90 degree it works as a line commutated inverter and feed SPV power to grid. Thyristers are triggered by pulse generated by microcontroller based advanced controller. The current and voltage characteristics of solar cell are non- linear. Maximum power changes with change in solar insolation and cell temperature.

Methodology adopted to transfer the peak power to grid is depicted as flowchart in Fig. 1 and 2.

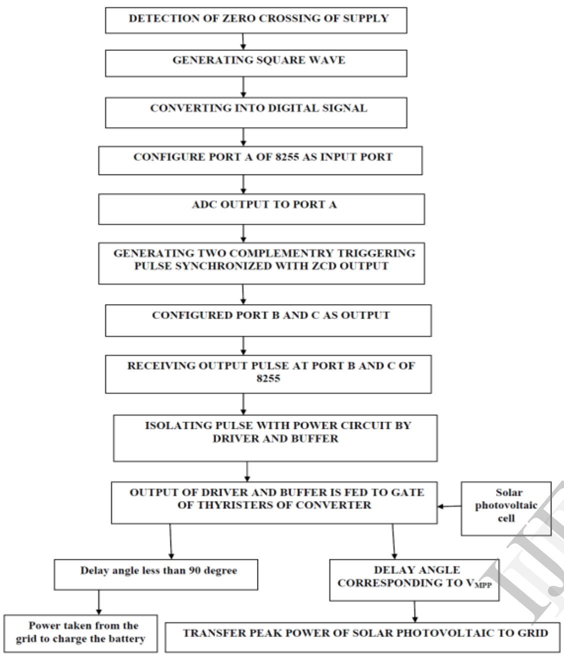

Fig. 1: Flow chart of the proposed method

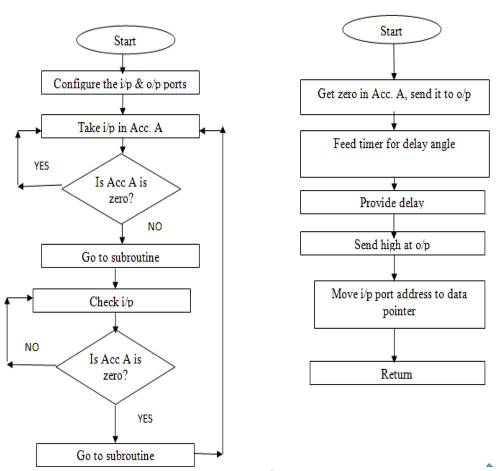

Fig.2: Flowchart of Triggering pulses

III. SOFTWARE MODEL

A. Mathematical Model of the SPV Cell/Module

Incident solar radiation produces current so it becomes effectively a current source. Current depends on solar radiation incident. It has a PN junction so there must be a diode. When current flow through material it encounter a resistance in its path. This resistance is a series resistance. There will be a resistance between material and metal. This shunt resistance is due to recombination of electron hole pairs. So the electrical equivalent circuit can be represented as shown in figure3.

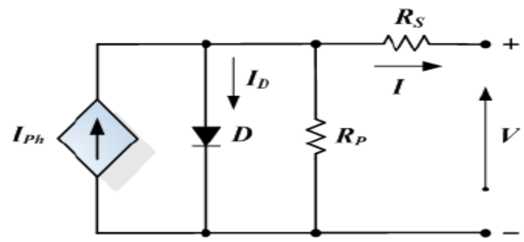

Fig.3: Electrical equivalent circuit of PV cell [12]

From Figure 3 output current is derived as given in equation (1).

$$I=N_PI_{PH}-N_PI_S[\exp\{q(V/N_S+IR_S)/(N_PKT_CN)\}-1]-(N_PV/N_S+IR_S)/R_{SH} \quad (1)$$

Where:
I: PV array output current
V: PV array output voltage
I_{ph}: Solar cell photocurrent
I_{RS}: Solar cell reverses saturation current (aka dark current)
q: Electron charge, $1.60217733e^{-19}$ C
N: P–N junction ideality factor, between 1 and 5
k: Boltzmann's constant, $1.380658e^{-23}$ J/K
R_S: Cell intrinsic series resistance
R_P: Cell intrinsic shunt or parallel resistance

The current generated photon by Iph is in fact related with solar insolation S as:

$$I_{ph}=[I_{SC}+K_I(T_C-T_{ref})]S \quad (2)$$

Where
K_I: Cells short-circuit current temperature coefficient
I_{SC}: short circuit current at 25 °C
T_{cell}: cell's temperature
S: solar insolation in W/m^2

PV Cell under Varying Temperature

$$I_S=I_{RS}(T_{Cell}/T_r)^3\exp[qE_G(1/T_r-1/T_{Cell})/KN] \quad (3)$$

Where
I_S : cell's saturation current
I_{RS}: reverse saturation current
E_G: band-gap energy

$$I_{RS}=I_{SC}/[\exp(qv_{OC}/KNN_ST_C)-1] \quad (4)$$

V_{OC}: PV open-circuit voltage.

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B. Matlab Simulink Model

The equations (1), (2), (3) and (4) have been used to develop a Matlab simulink model of solar photovoltaic cell/module/array as given in Figure 4[12].

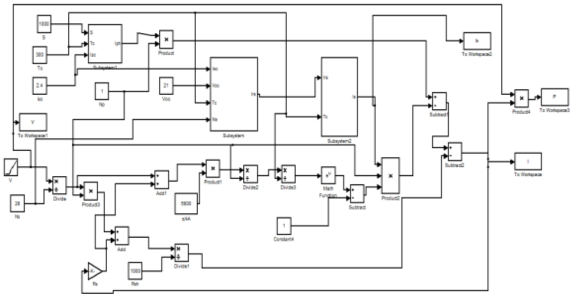


Fig.4: Model of solar photovoltaic module [14]

C. Model of Proposed Setup

Model shown in Fig.5 has complete circuitry of proposed work.

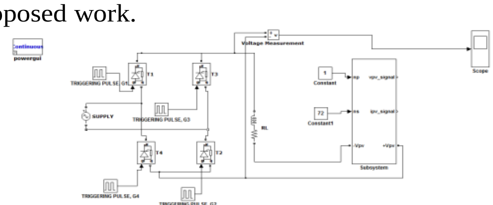


Fig.5: complete circuitry of proposed work

D. Maximum Power Point Tracking

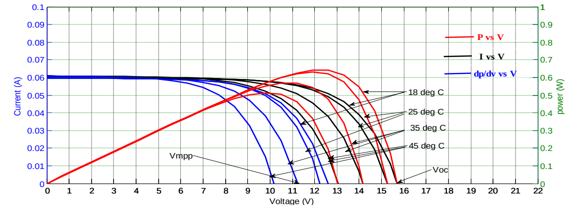
The current and voltage characteristics of solar cell are non- linear. Maximum power changes with change in solar insolation and cell temperature.

In this study, a relation between open circuit voltage and voltage corresponding to maximum power has been developed. For developing relationship between Vmpp and Voc, parameters of the solar PV module ELDORA40 as given in Table 1 have been used.

Table 1: Parameters of ELDORA40 Solar Module

PARAMETER	VALUE
Maximum power (Pmax)	37 W
Voltage at Pmax (Vmax)	17.2V
Current at Pmax (Imax)	2.2A
Short circuit current (Isc)	2.4A
Open circuit voltage (Voc)	21V

The model given in Figure 4 is simulated for various values of solar insolations (0-1100 W/m2) and cell temperatures and obtained results are shown in Figures 6. Open circuit voltage (Voc) and corresponding maximum power point voltage is read from the graphs.



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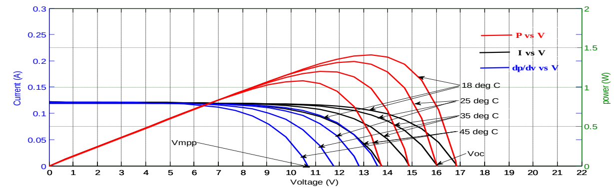

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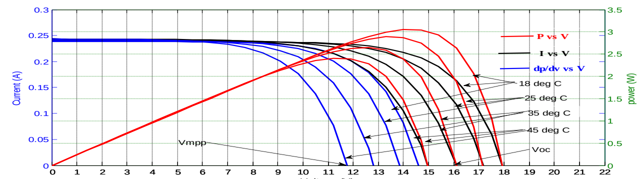

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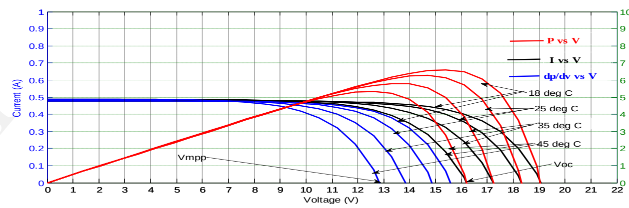

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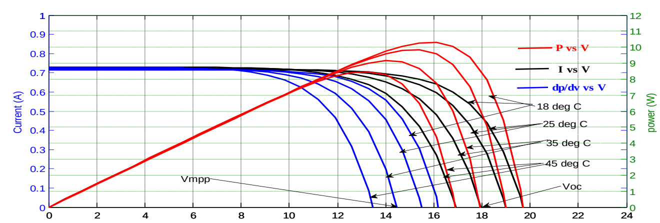

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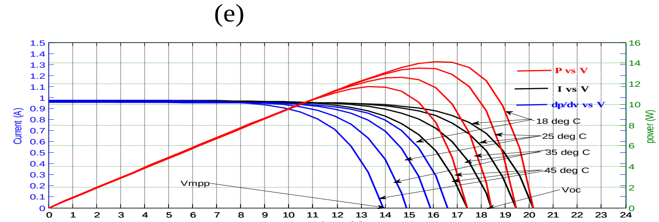

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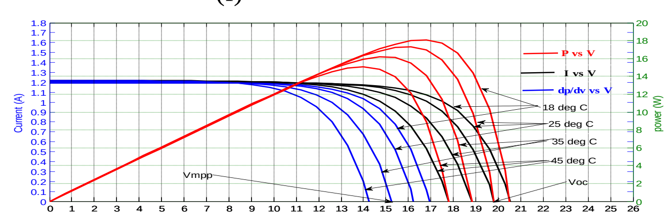

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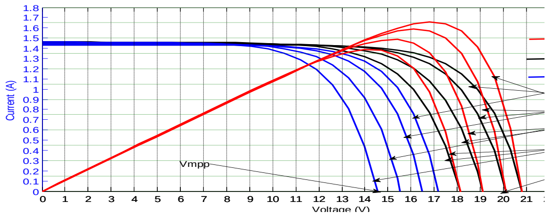

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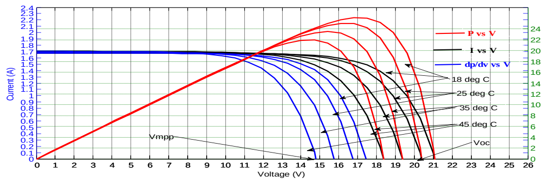
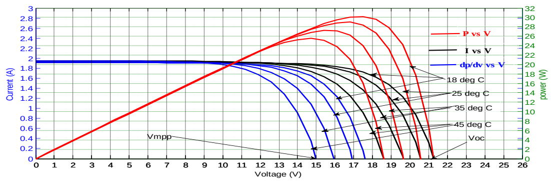


(i)



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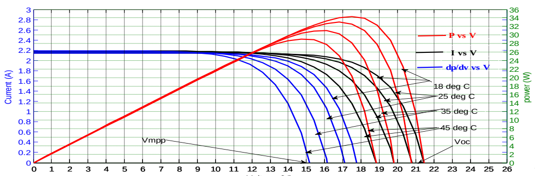

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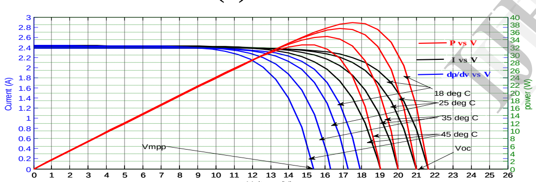

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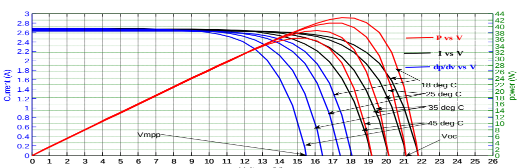


(m)

Fig.6: I-V, P-V and dp/dv-V characteristics curves at (a) 25 W/m^2 (b) 50 W/m^2 (c) 100 W/m^2 (d)200 W/m^2 (e) 300W/m^2 (f) 400 W/m^2 (g)500 W/m^2 (h)600 W/m^2 (i)700 W/m^2 (j)800 W/m^2 (k)900 W/m^2 (l) 1000 W/m^2 (m) 1100 W/m^2 [14]

As it is clear from the above characteristic curves that Voc and Vmpp depends on solar insolations and cell temperatures.

The values of Voc and Vmpp are read from the above curves and plotted to develop a relation as given in Figure 7.

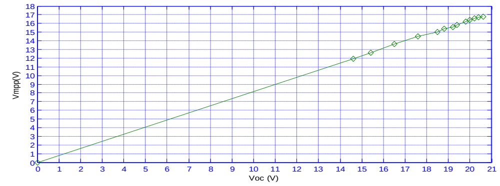


Fig.7: Voc vs. Vmpp

The Figure 7 shows a linear relation between Voc and Vmpp that can be represented by a linear equation as given in equation (5).

$$\mathbf{Vmpp=0.817Voc+0.0055} \quad (5)$$

Can be approximated as,

$$\mathbf{Vmpp=0.817Voc} \quad (6)$$

To implement this by using microcontroller two modules of similar characteristics are required. Open circuit voltage of one module is multiplied by the factor 0.817 and given to reference of the ADC. Now the voltage of the module whose maximum power is being tracked is sensed and feed to one of the channel of ADC.adc compare the voltages and sends an error signal to microcontroller. Programming is done such that when the sensed voltage is equal to the reference voltage a control pulse is generated.

In literature there is a fixed voltage method to track the maximum power. In this study mp has been tracked by this method also. The Vmpp has been fixed by using equation (6) by multiplying the average value of Voc.

Actual maximum power, maximum power actually tracked and maximum power obtained by fixed Vmpp method have been shown in Figure 8.

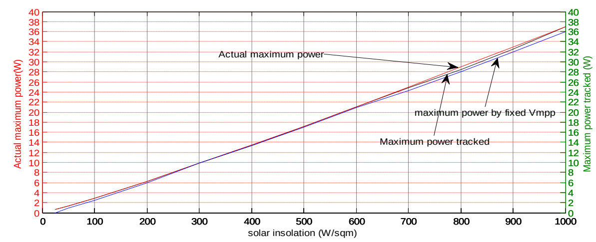


Fig.8: Actual Pmax and Pmax tracked

Loss of power when these two methods are used is given in Figure 9. It can be seen that power loss is minimum when power is tracked by implementing equation (6).

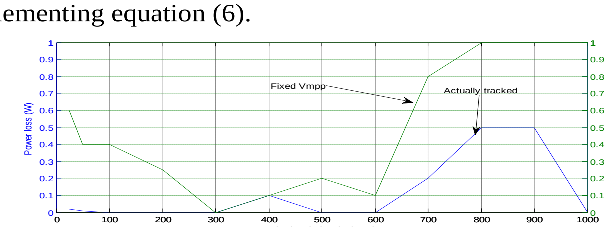


Fig. 9: Power loss in fixed Vmpp and actually tracking of Vmpp

IV. EXPERIMENTAL SETUP

The whole setup is divided into two units. The one unit which is of low power and control the power flow is called control unit and the other unit is of high power which contains power electronic devices thyristers is known as power unit.

The experimental setup comprises of the following components:

1. 8051 advanced microcontroller kit
2. Analog to digital converter
3. Zero crossing detectors
5. Driver and buffer circuit
6. Single phase fully controlled converter
7. Solar module

The control unit which generates control pulses of desired delay to control the flow of power are comprised of the following components:

(i) 8051 advanced microcontroller kit
(ii) Analog to digital converter
(iii) Zero crossing detectors
(iv) Driver and buffer circuit

The complete circuit diagram and photograph of the experimental setup are shown in figures 10,11 and 12.

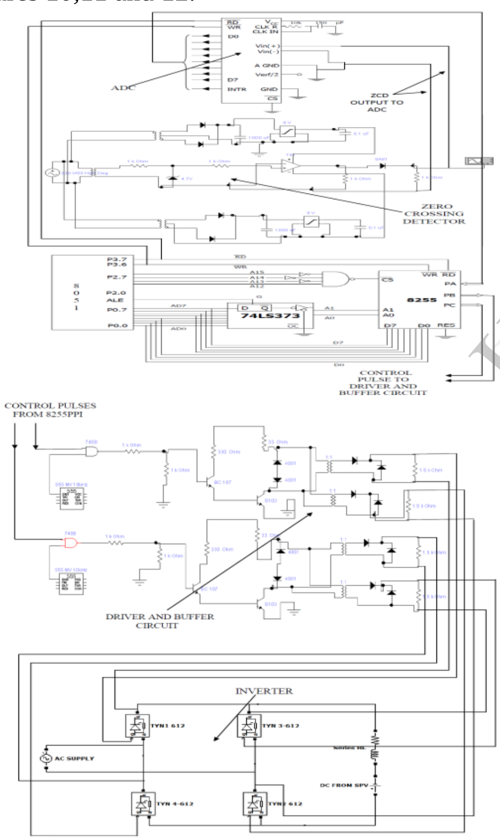


Fig.10: complete circuit diagram of proposed work

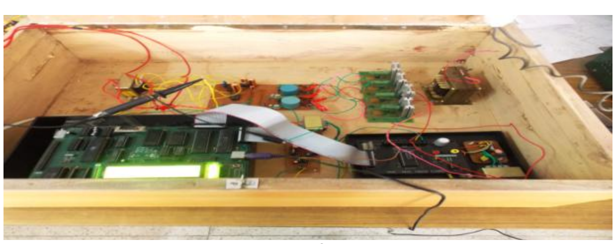


Fig.11: Developed model of the proposed work


Fig.12: Solar module used in experiment

V. RESULTS AND DISCUSSION

A. SYNCHRONIZATION

Control pulse generated by the microcontroller must be synchronized with supply. If control pulse is not synchronized with supply frequency the power circuit triggered wrongly. It is clear from the output shown in figure 12 that pulse generated by microcontroller is synchronized with supply frequency.

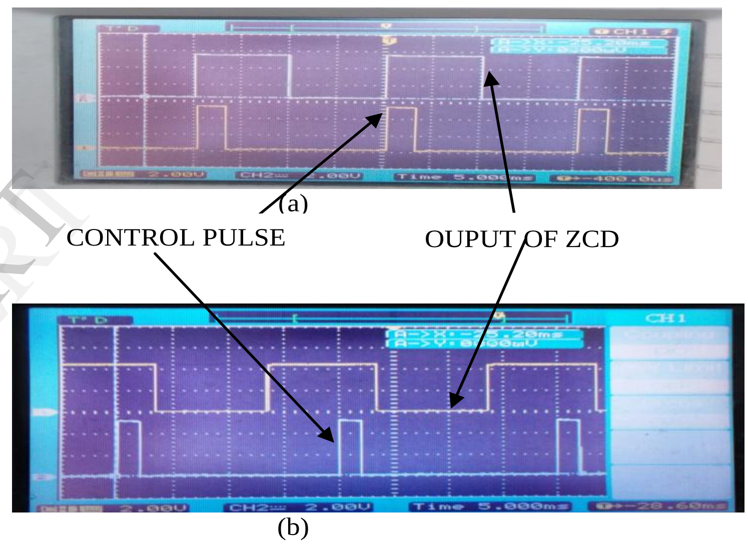


Fig.12: synchronized pulse (a) synchronized with +ve cycle (b) synchronized with -ve cycle

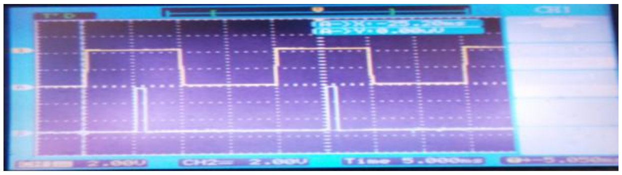
B. TRIGGERING PULSES

The topology of inverter used in the proposed work is fully controlled full wave inverter. This topology of inverter has bridge of four thyristers. Four triggering pulses are required to trigger the thyristors of this topology. The thyristers T1 and T2 are triggered simultaneously with same type of gate pulse G1 and G2 and other two thyristers T13 and T4 required gate pulse G3 and G4 complementary to the gate pulses of thyristers T1 and T2.

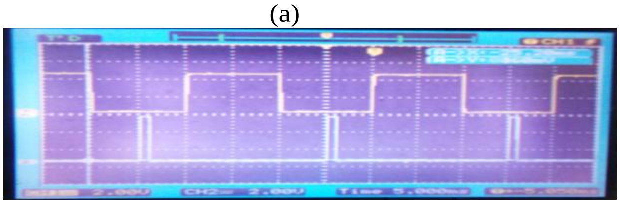
The control or triggering pulses generated experimentally as well as by Matlab simulink block for various delay time is being depicted below.

The converter circuit work as an inverter only when thyristers are trigger after 90 degree and there is an inductive load connected to circuit.

Triggering pulse of any delay can be generated by microcontroller by feeding suitable value to timer just by changing the program without any change in hardware. The waveform record of control pluses generated by controller and by Matlab simulation for various time delays is given in Fig. 13 and 14.



(a)



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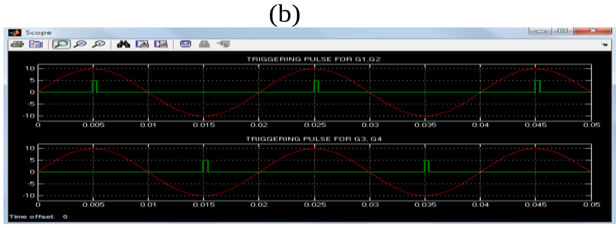
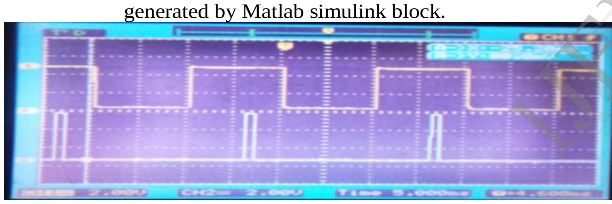
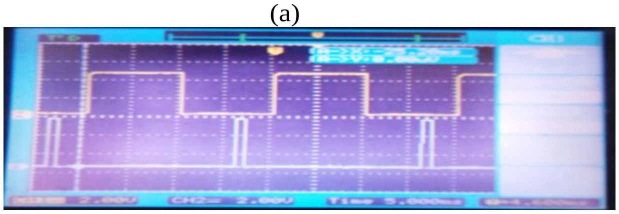


(c)

Fig.13: control pulse with 5ms delay (a) generated by controller for G1 and G2 (b) generated by controller for G3 and G4 (c) generated by Matlab simulink block.



(a)



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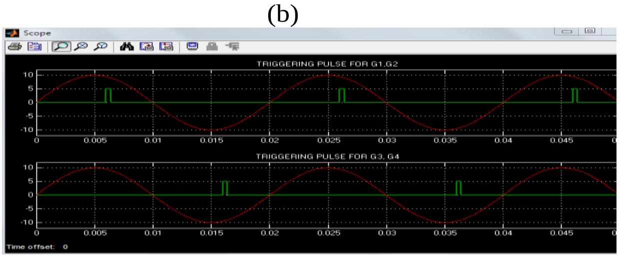


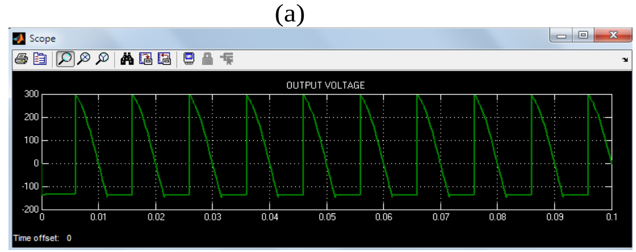
(c)

Fig.14: control pulse with 6 ms delay (a) generated by controller for G1 and G2 (b) generated by controller for G3 and G4 (c) generated by Matlab simulink block.

C. OUTPUT VOLTAGE WAVEFORM

The output wave forms obtained experimentally and by simulation are given in figure 15. It is clear from the negative value of output voltage wave form that power is being transferred to grid from dc source connected to the load side.

(a)



(b)

Fig.15: Output voltage waveform (a) experimental result (b) simulation result

VI. CONCLUSIONS

The use of microcontroller based control circuit provides us large number of advantages. It reduces size and cost of controller significantly. The efficient control of delay angle is the main advantage.

Besides this it provide more versality and greater scope for further improvement just by changing the program but not hardware configuration.

This work is carried out by breaking it into several steps for its smooth and successful completion.

The first stage consisted of generating control pulse which corresponds to peak power of solar photovoltaic module. The control pulses are generated by software model as well as by realizing microcontroller based advanced practical circuit.

The second stage was to realize Matlab simulink based circuit as well as practical circuit of grid interactive solar photovoltaic based line commutated inverter.

The first stage, a synchronized control pulse for an ac to dc converter/ inverter for the full wave was generated. After getting satisfactory results then delay program was changed to generate a control pulse whose delay angle was adjusted beyond 90 degree to operate converter in inversion mode, at this condition the converter supplies the energy from solar photovoltaic cell to grid.

The developed relation between open circuit voltage and voltage corresponding to maximum power point is unique for a module. Peak power tracked by this method is very accurate.

The control pulse waveform obtained from model and practical circuit comply each other. The performance of controller is found satisfactory.

In general switching control mode as well as specific application mode for solar photovoltaic grid interactive inverter. The wave form records shows accuracy of delay of control pulse and also show the satisfactory performance of whole setup.
Following analysis can be carried out before field implementation:
(i) Total harmonic distortion of grid power quality
(ii) Power inversion analysis
(iii) Developed method for tracking of Pmax implement experimentally

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