Design and Implementation of One kilowatt Capacity Single Phase Grid Tie Photovoltaic Inverter

Saurav Das
School of Engineering & Computer Science
Independent University Bangladesh
Dhaka, Bangladesh
E-mail:saurav.iubian@gmail.com

Khosru M Salim
School of Engineering & Computer Science
Independent University Bangladesh
Dhaka, Bangladesh
E-mail:khosrumdsalim@yahoo.com

Abstract—**This Paper is aimed to present the design and implementation of a one kilowatt capacity single phase grid tie photovoltaic inverter. The proposed design and simulation process of this system is in PSIM simulation environment. The reason for choosing the software PSIM is that it provides the solar module facilities. For single phase grid tie inverter design some special types of consideration, like reference voltage creation to synchronise the inverter's output with grid, PWM (Pulse Width Modulation) signal creation by comparing the reference and triangular wave, is designed and simulated precisely. According to the PWM pulses, the solar module provided DC voltage is switched by using single phase bridge inverter circuit. After filtering and matching the inverter's AC output wave's amplitude and frequency with grid, this AC power is given to the grid by using isolation transformer. All of these fundamental criteria of an inverter are met in this inverter design. After analysing the simulated output a hardware prototype is also implemented. In hardware prototype, according to the reference signal, PIC18F4431 microcontroller is used for generating the PWM pulses. These PWM pulses act as the switching controlling pulses for IGBT (Insulated Gate Bipolar Transistor).**

Keywords: **Grid Tie, Photovoltaic, Inverter, PWM, MPPT.**

I. INTRODUCTION

Now we are living in a modern age where almost everything is run by Electrical Energy. For greater industrialization and population growth the Energy demand rate is now increasing day by day. In International Energy Outlook 2009 by the U.S Energy Information Administration, predicted that the rate of generation of global electricity will be increased to 23.2 trillion kWh in 2015, and for the next five years it will increase to 31.8 trillion kWh. The conventional electricity generation by burning fossil fuels like coal, gas, oil is unable to meet up this rapidly increasing electricity demand. The reason is that these fossil fuels are treated as natural resources whose amount is very much limited and is decreasing day by day. On the other side burning the fossil fuel emits toxic gas like carbon dioxide which is harmful for our health and environment. The economically and environmentally suitable solution to fulfil the energy demand is the Renewable Energy [1].Among all forms of Renewable Energy such as solar energy, wind energy, biomass energy, tidal energy, energy from the rice husk, the popularity of solar energy is increasing. To fulfil the Energy demand and to ensure proper utilization of Energy, the photovoltaic inverter is a good solution. The word "Photovoltaic" means converting light energy to electrical energy. For getting electrical energy from the solar energy, the PV (Photovoltaic) module is used. The energy produced in this way is DC power. But to convert the DC power to AC power, Inverters are used. There are two types of inverters. One is stand-alone and the other type is grid-connected. Stand-alone inverter is mainly used in rural areas or in those areas where the electricity is not available. Large capacity batteries are used for storing the energy produced by the solar panel. On the other hand the grid connected inverter is installed in that type of areas where the grid is available and is able to accept the energy from the photovoltaic system [2].Grid connected inverter converts the DC power into that type of AC power whose voltage's magnitude, phase and frequency is exactly same as the grid's provided AC power. In this gird tie photovoltaic system the cost of PV module plays an important part .According to the survey report presented by the IEA-PVPS, in 2011 the average price per watt of PV module was 1.38 USD. In 2012 the average price per watt of PV module was reduced to 1.16 USD, which indicates the reduction cost is about 15.9%. In some countries, at the end of the year 2012 the average price per watt of PV module went below 0.6 USD [3]. Due to the decreasing price of PV modules, availability of sun shine, no cost for fuel, low maintenance cost, reliability, providing noise and pollution free environment in 2010 above 78% of world market was for that type of applications which are related with Grid Connected Photovoltaic Inverter system [4].

II. OVERVIEW OF THE SYSTEM

The system overview of the Grid tie photovoltaic inverter is shown in Fig.1.

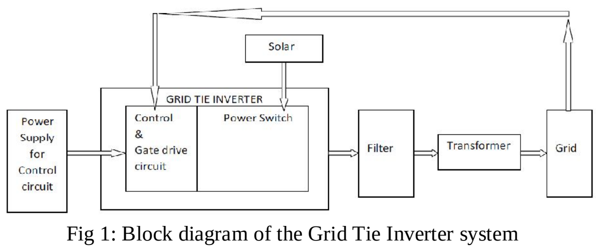

Fig 1: Block diagram of the Grid Tie Inverter system

The aim of this system is to convert the DC input voltage which is collected from the solar panel, into the AC output voltage where the magnitude and frequency must be the same as the National Grid's supply of AC voltage. To get the desired magnitude and frequency of AC output voltage, this system uses SPWM (Sinusoidal Pulse Width Modulation) technique. It is shown in Fig.1 that since the system is grid tie photovoltaic inverter, the grid's provided sinusoidal voltage should be taken continuously as a reference signal while a triangular signal is also produced by the "Control & Gate drive circuit". Here the triangular signal acts like carrier signal. For single phase inverter four switching PWM signals is needed. "Control & Gate drive circuit" produces the four required switching PWM pulses by comparing the reference and carrier signal. "Power switch" unit consists of four IGBT (Insulated Gate Bipolar Transistor), which switches the DC input voltage coming from solar panel according to the four switching PWM pulses. After switching, the inverter's output voltage frequency is higher than the required frequency level, so it needs filtering. Low pass LC filter must be designed in such a way, that the output AC sinusoidal wave will be of the same magnitude and same frequency as the grid's provided AC wave. This inverter's output power will then be given to the grid by using an isolation transformer. Isolation transformer is used to protect the circuit by providing isolation between grid and inverter. Since the solar panel which gives the DC power is weather dependent, the inverter's output voltage level may fluctuate. So if the output voltage level of the inverter is lower than the grid's provided voltage level, isolation transformer will step up the inverter's output voltage and then will give power to the grid. In this way it is possible to keep the inverter's output AC voltage level fixed.

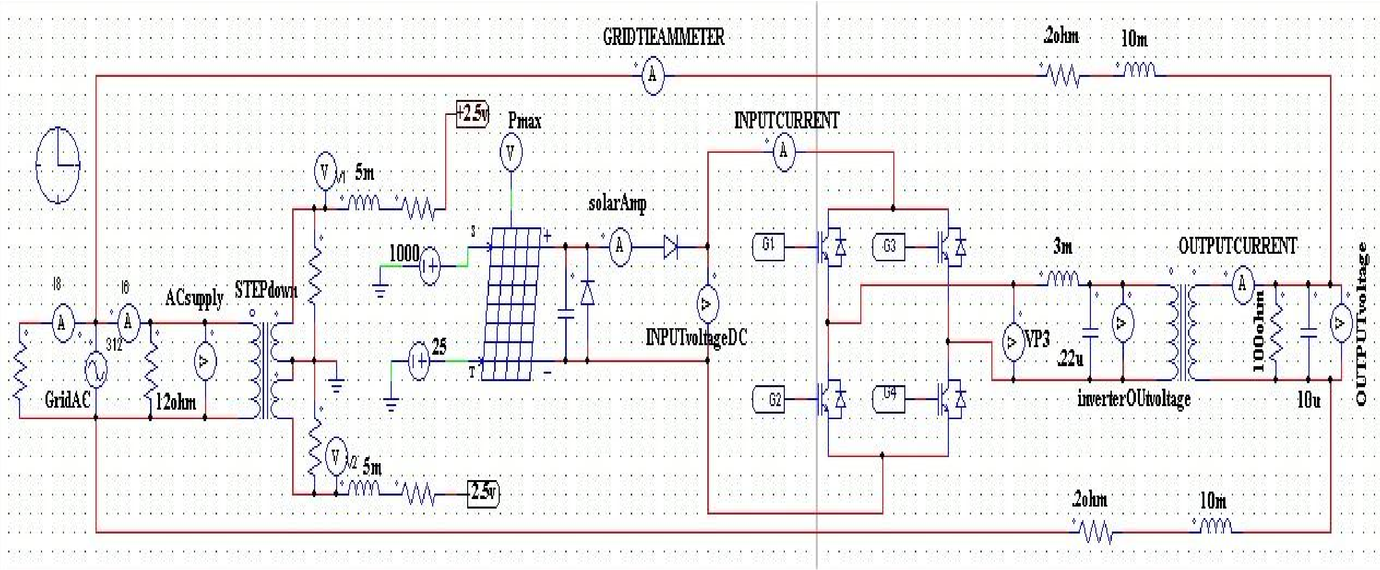

Fig.2 Proposed circuit designed in PSIM simulation software

III. Grid Tie Inverter Design

The proposed system design for 1kw capacity Grid tie Photovoltaic Inverter is shown in Fig.2. The description of this system is given below:

A. Reference Signal Creation

For SPWM signal creation it needs two signals. One is reference signal and other is carrier signal. The aim of this project is to supply the power to the grid, so the reference signal which is needed is the National grid's provided sinusoidal AC signal. Though the grid's provided AC voltage level is very much higher (220Vrms) so a step down transformer is used to step down the grid's provided voltage. This step down transformer converts the 220Vrms AC sinusoidal wave to 0 degree and 180 degree phase shifted 2.5V AC sinusoidal waves which act as the reference signals of SPWM signal generating circuit.

B. SPWM Signal Creation Circuit

Fig.3 shows the circuit design for creating four SPWM signals. The step down transformer outputs (0 degree & 180 degree phase shifted sinusoidal waves) are one of the input signals of the two comparators. Triangular wave of 20 kHz frequency, acts as the carrier wave which is the common input for these two comparators. Comparators will create the SPWM signal by comparing these two input signals.

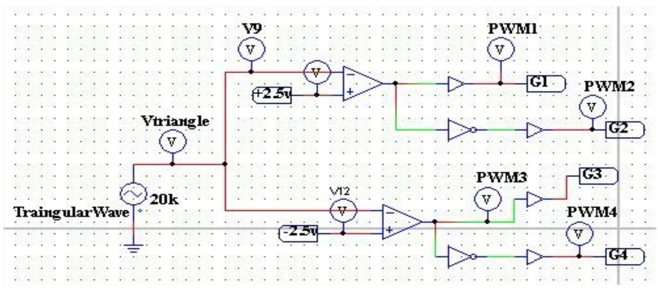

Fig.3 SPWM Signal creation circuit

C. Full Bridge Inverter Circuit

Fig.4 shows the circuit design of single phase full bridge inverter. It consists of four IGBT. The input voltage appears across the load when IGBT1 and IGBT2 are simultaneously turned on. In the same way if IGBT3 and IGBT4 are turned on the voltage across the load will be reversed [5].Here these four IGBT switches act as choppers. The reason for choosing IGBT as the chopper is, it has the capability of chopping maximum 600V DC.

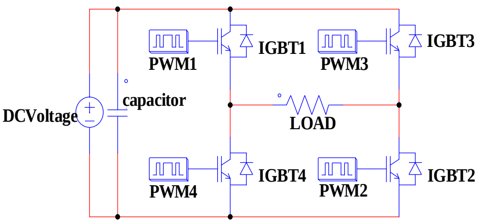

Fig.4 Full Bridge Inverter Circuit

D. Output Power of Solar Module

The objective of this project is to give 1KW AC power to the grid. To provide 1KW AC power, the input power of the inverter must also have to be 1KW DC power. By using the Solar Module (physical model) utilities provided by PSIM software, one can easily measure the maximum output power of the designed solar system, which is also known as MPPT system. The default parameter for solar module which is provided by PSIM exactly follows the configuration of solar module MSX-60 from BP Solar. The Light Intensity & the Temperature reference is in Standard Test Condition [6]. Considered Parameter for solar module which provides the 1KW DC power to the proposed inverter is shown in Table I.

TABLE I: Considered Parameters for Solar Module

Parameters	Magnitude
Solar cell number	595
Maximum Power	1000.51W
Voltage at Maximum Power	281.60V
Current at Maximum Power	3.55A
Open-Circuit Voltage	21.1V
Short-Circuit Current	3.8A
Standard Light Intensity	1000 W/m²
Temperature Reference	25° C
Series Resistance	0.0133Ω

E. Low pass Filter Design

The advantage of SPWM technique is, by using this technique the harmonics (unwanted frequencies wave) which are below from the switching frequency level, can be removed. Switching frequency is mainly the frequency of the carrier wave. The higher rate of switching frequency indicates that higher rate of PWM pulses will be created. Thus it removes the harmonics which are below the switching frequency level. The remaining harmonics which are greater than the switching frequency can be easily removed by using a Low pass L-C filter. This low pass L-C filter is inserted between the inverter output and the load. Where the capacitor(C) remains in parallel and the inductor (L) remains in series connection with the load. Dominant harmonics are blocked by the inductor and the capacitor acts as the easy path for the n^{th} order harmonic ripple current [7].In this proposed system the considered value for the carrier wave is 20 KHz. The considered capacitance value is 0.22µF. The value of the inductance is calculated by following this formula:

$$fc = \frac{1}{2\pi\sqrt{LC}} \qquad (1)$$

In (1) the "fc" indicates the cut-off frequency which is 20 kHz for this proposed system. After putting all these values the calculated value for inductance is 0.2878mH which is approximately 0.3mH. In software simulation it is found that increasing the inductance value gives harmonics free output. For considering 3mH there remains no harmonics at all. Table II shows the considered parameter for inductance and capacitance and the corresponding THD (Total Harmonic Distortion) rate.

TABLE II: Considered Parameters for Inductance & Capacitance

Inductance Value	Capacitance Value	THD Rate (%)
0.3 mH	0.22µF	0.08
3 mH	0.22µF	0.05

F. Isolation Transformer

An isolation transformer is also used in this proposed system design. For ensuring safety, it provides isolation between the Inverter and the Grid. Another important consideration is though the solar system depends on the sunshine, which is weather dependent so the inverter's output voltage will fluctuate. But to give power supply in grid the inverter's output voltage level must have to be higher than the grid's provided voltage level. In this proposed system, the inverter output voltage level is stepped up at 225Vrms by using this step up transformer. By which it is ensured that, the inverter output power will be given to the Grid.

IV. Simulated Output

The simulated output of this proposed inverter design is now giving below:

A. SPWM Signals Creation

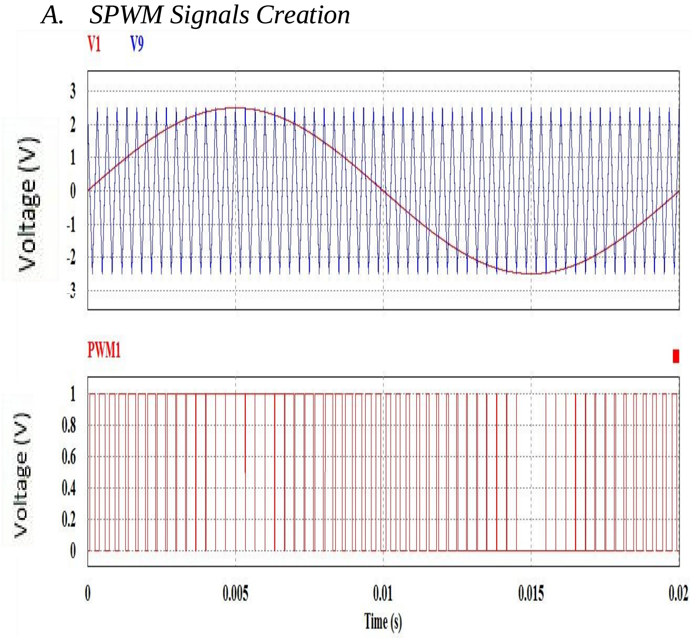

Fig. 5 SPWM signal creation by compeering sinusoidal & triangular wave

B. DC Output Voltage and DC Output Current of Solar Module

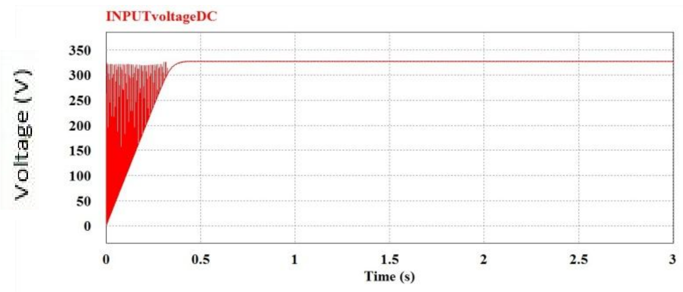

Fig.6 Output DC voltage of Solar Module

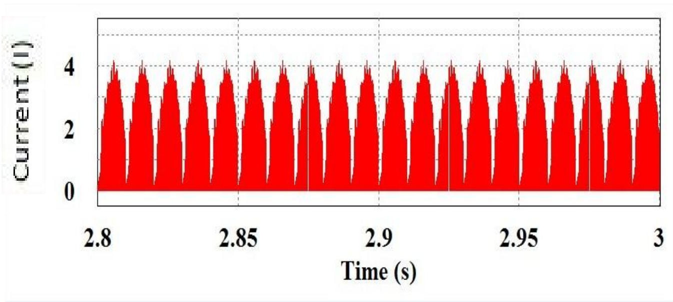

Fig. 7 Output DC current of solar module

Fig. 6 shows the output DC voltage of solar module. This simulated output shows approximately after 0.3 second the output voltage level becomes stable. Fig.7 shows the output DC current of solar module.

C. After switching the inverter output

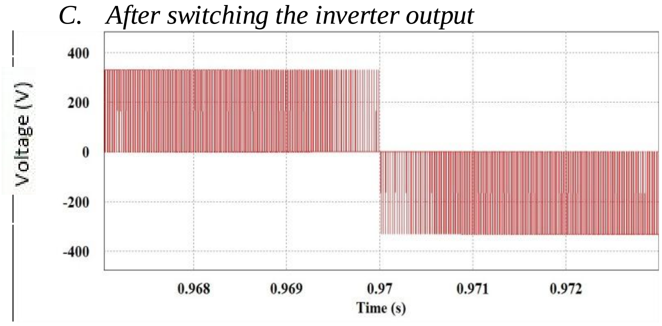

Fig. 8 without filtering the inverter output

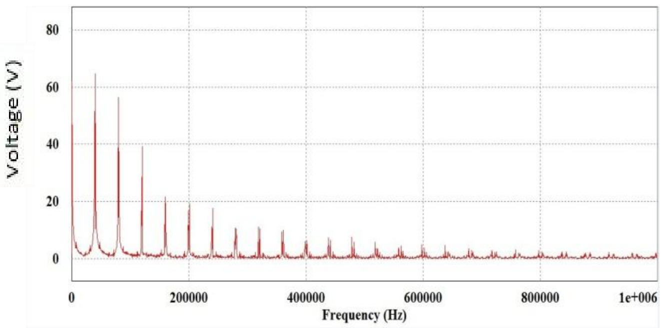

Fig. 9 FFT (Fast Fourier Transform) analysis, of inverter's without filtering output.

Fig.8 shows the output of the inverter after switching stage. FFT analysis shown in Fig.9 indicates that after switching the inverter's output consists of harmonics, which are higher than the switching frequency.

D. Inverter Output after filtering

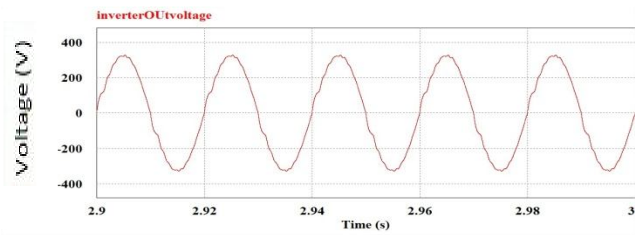

Fig. 10 The inverter output voltage after filtering

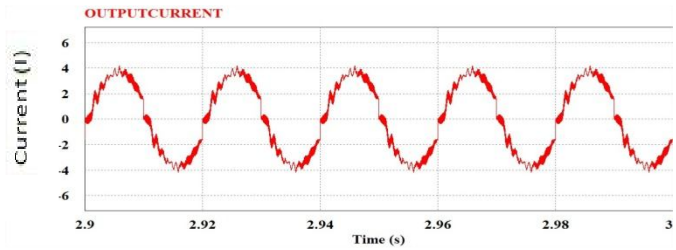

Fig. 11 The inverter output current after filtering

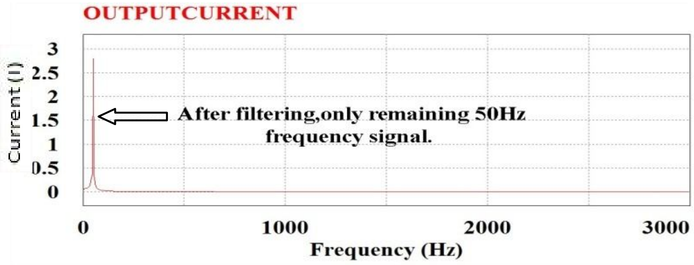

Fig. 12 FFT analysis after filtering the inverter output current

Fig.12 shows that the low pass LC filter removes all harmonics. Only the expected 50Hz frequency is remaining.

E. After Connecting with Grid

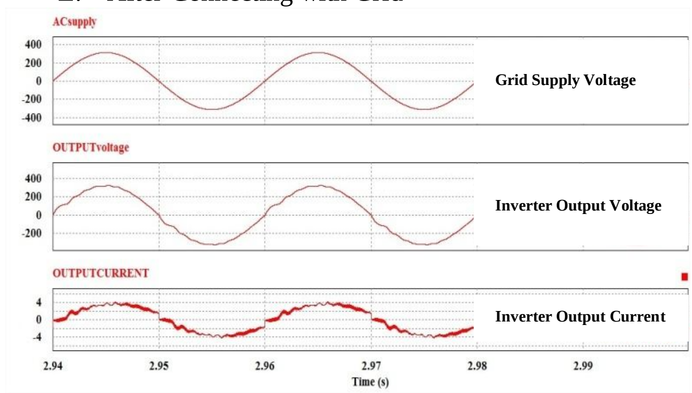

Fig. 13 The Grid's supply voltage, inverter's output voltage and current are in same phase.

Fig.13 shows that after connecting inverter with Grid, the National Grid's provided supply voltage level and the inverter's output voltage, current level are in same phase. The frequency level of the inverter's output also matches with the grid's provided sinusoidal wave.

V. Simulation Result Analysis

Before and after connecting with grid, the performance analysis of this proposed inverter is given below:

TABLE III: Before connecting with grid the inverter performance

Parameters	Magnitude
DC Output Voltage of Solar Module	331.25V
Current of Solar Module	3.98Amp
Power Given by Solar Module	1318.38Watt
Inverter Output Voltage	327.51V
Inverter Output Current	3.98Amp
Power Given by Inverter	1303.49Watt
Total Harmonic Distortion(THD)	0.25%
Efficiency of this Proposed System	98.87%

TABLE IV: After connecting with grid the inverter performance

Parameters	Magnitude
DC Output Voltage of Solar Module	328.21V
Current of Solar Module	4.18Amp
Power Given by Solar Module	1371.92Watt
Inverter Output Voltage	325.36V
Inverter Output Current	4.20Amp
Power Given by Inverter	1366.51Watt
Total Harmonic Distortion (THD)	0.14%
Efficiency of This Proposed System	99.75%

VI. Practical Implementation

A Hardware Prototype of this system is also implemented.

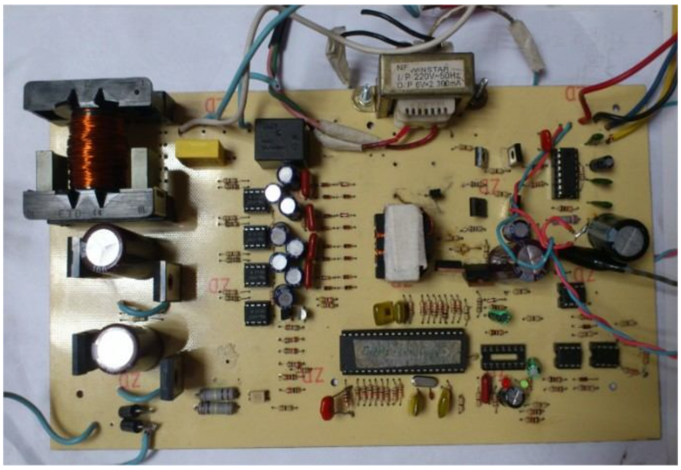

Fig. 14 Implemented Hardware Prototype of this system.

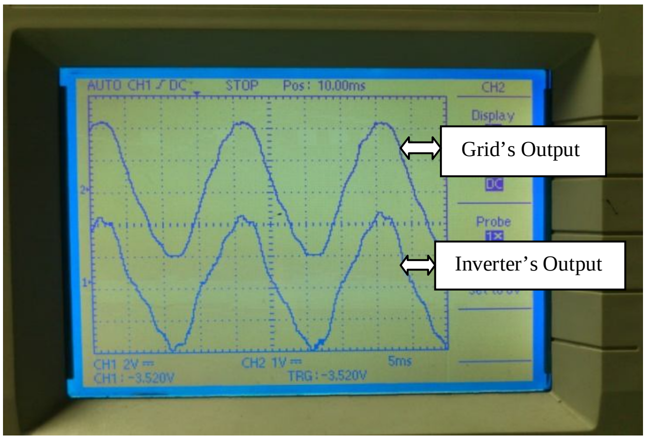

Fig. 15 The output of the implemented Hardware Prototype for this system

VII. CONCLUSIONS

The design, simulation and the implementation of 1kw capacity single phase grid tie photovoltaic inverter has been described. The simulation shows that in low pass filter design the THD rate will be decreased if the value of inductance is increased simultaneously. The magnitude, frequency and phase of the hardware prototype's sinusoidal output matched with the Grid's provided AC sinusoidal wave. In hardware prototype PIC18F4431 microcontroller is used for generating the PWM pulses. PIC16F676 microcontroller and the relay were also used for ensuring safety. But though there remains some small distortion in hardware prototype's output, the prototype of this system was not connected with the Grid. Further modification of this hardware prototype will make it capable of giving power to the grid.

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