

## Efficient Control Design for the Single Phase Grid Tie Inverter Using Wave Shape Coping Pulse Width Modulation Technique

A.B. Taj<sup>1\*</sup> and M. Ahmad<sup>2</sup>

<sup>1</sup>National University of Technology (NUTECH), Sector I-12, IJP Road, Islamabad, Pakistan

<sup>2</sup>Preston University, Kohat (Islamabad Campus), Pakistan

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### ABSTRACT

The aim of this paper is to achieve the efficient control design for a single phase grid tie inverter (GTI) using PROTEUS Professional software and its practical implementation. Unique thought is given to the way that, dissimilar to customary standalone inverters, GTI are required to satisfy the demands associated with each phase of the grid. Photovoltaic module and single-phase GTI both are tied together using an inverter. In this paper we have got the reference voltage from the main grid using operational amplifier, Wave Shape Coping Pulse Width Modulation (WSPWM) technique is applied with PIC16F877A microcontroller and IR2110 gate driver which drive the MOSFET IRF840 after appropriate filtering and control the power supply to the grid with appropriate isolation. The functional testing of the single phase GTI has been performed successfully when DC-AC conversion occurs. Beside the ability of GTI, its frequency and output voltage had consistent fluctuations due to the change in frequency and grid voltage. Another feature of the GTI is that if the power from electrical grid is zero, the inverter will stop the process of inversion and just supply zero voltage output at that time. Accordingly, quick shut down of DC-AC process of inversion happens if there arises a sudden dark out period. It is worth mentioning that the designed GTI cannot be operated without reference voltage of the grid and connected directly to PV solar panels.

### 1. Introduction

The regular increase in word population is resulting in increasing energy demand. This increase in energy demand translates in requirement to install more electrical devices and energy production sources. The requirement of energy demand is pressing researchers, engineers, and scientists to develop and apply economical options to overcome the energy crises / demand instead of fossils fuels. Pakistan is facing population growth and short fall of fossil fuel sources as well as hike in fossil fuel prices due to the import of petrol, coal etc. The burning of fossil fuel increases the pollutants in the environment which are very harmful for the human beings and they are a cause of increasing temperature on earth. This increase in temperature along with the large quantity of pollutants are resulting in worldwide climate change [1-3].

Pakistan is rich in solar energy which can be utilized for producing electrical energy by using Photovoltaic (PV) solar panels. This energy source is very cheap and has minimum effect on nature. PV solar panels are already being used throughout the world to generate electricity [4]. The energy produced by the solar panels without GTI ends up being very expensive since any extra energy produced above the local demand need to be stored and the installation of storage devices for the surplus energy is expensive. Therefore, the need of GTI for the supply of surplus power to the local grid to achieve the better efficiency to the main grid is quite evident [5].

GTI is presently considered as an appropriate technique to tie up solar panels to the electrical grid [6] and feed surplus power to the grid. In this technique it is necessary that GTI

must be synchronized with the main grid. The main task of GTI is not only convert the DC to AC but also to synchronize it with the main grid supply, that permits the system to interface with the grid [7]. These inverters are being attached directly with PV solar panels for smooth and proper delivery to the grid.

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### 2. Simulation and Experimentation

For the design of the GTI, two main requirements must be considered. Firstly, PV solar panels must operate at maximum power point tracking (MPPT) [8] and the other one is the conversion of DC to AC inverter must be synchronized to the grid [9]. There is a difference between conventional independent inverter or inverter utilizing as a part of variable speed controller and the GTI have the conditions in which output must be synchronized with the main grid [10].

The GTI is used to synchronize the PV signal with the main grid, the advantage of our design using WSPWM technique is proper formatting and synchronizing PV solar panels with the main grid. Our design of GTI satisfies the criteria given below:

\* Corresponding author: [abdulbasittaj@nutech.edu.pk](mailto:abdulbasittaj@nutech.edu.pk)

1. The output of the inverter (phase and amplitude) must be synchronized with the main grid.
2. Inverter output frequency must be synchronized with the single phase main grid.
3. If the system detects the blackout situation the inverter must shut down automatically and disconnect the link with the main grid.

The block diagram given in Fig. 1 below represents the high-level functional block diagram of single phase GTI. DC power from PV solar panels is fed to the GTI through MPPT. In GTI we are using WSPWM technique for the proper formatting and synchronizing the signals to tie with the main grid. The primary side of the isolation transformer is connected with the output of the inverter to isolate the inverter from the single phase main grid and the secondary side of the isolation transformer is connected to the grid. This type of connection will help to deliver the power from inverter to the main grid.

For the verification of simulation results along with the hardware results, an exploratory setup was established. In our design we have used 500-watt solar panels to check the design of GTI.

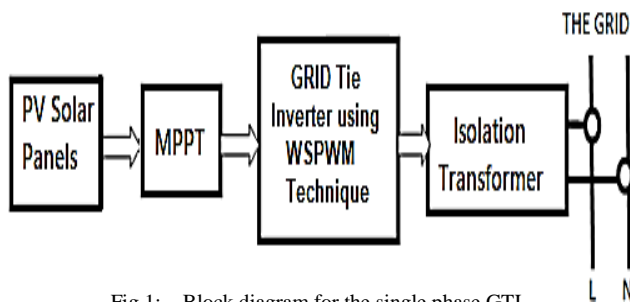


Fig.1: Block diagram for the single phase GTI.

### 3. Design Consideration

#### 3.1. Switching Technique

Wave Shape Coping Pulse Width Modulation (WSPWM) technique has been used to operate the gate driver IR2110 for designing the inverter. PWM is dependent on the main grid, produced from PIC16F877A microcontroller. To achieve proper sine wave from the output of the inverter, LC filter has been used to remove the harmonics. In WSPWM the width of every pulse is directly proportional to the amplitude of the incoming wave. For generating PWM, PIC16F877A microcontroller is used [11]. The main purpose of this microcontroller is to read pulsating DC waveform which we have produced from main grid that has been inserted in the ADC of microcontroller and to generate PWM. The output of microcontroller is given to the PWM, where these pulses will be the input of H-bridge. Now we are going to separate out the 1<sup>st</sup> and 2<sup>nd</sup> input of H-bridge using gates. The pulses we got from microcontroller will be the AND using AND gate with the output of the zero crossing as shown in Fig. 2. This is the 1<sup>st</sup> input of the H-Bridge. Now we inverted the output of the zero crossing using NOT gate and feed it to AND gate

with the same pulses generated with the controller that is the 2<sup>nd</sup>

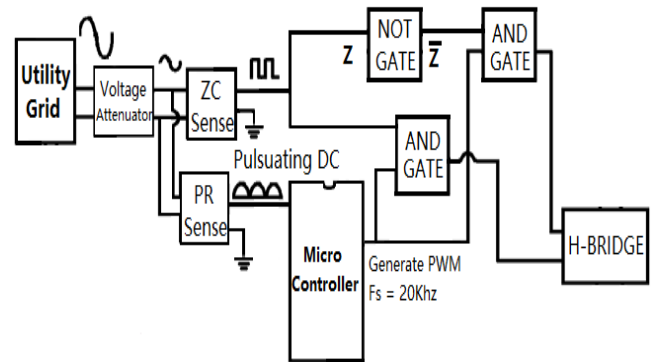


Fig.2: Grid reference and phase detection circuit for PWM signal generation.

input of the H-Bridge. As we know from NYQUIST criteria [12] sampling frequency should always greater than or at least two times of the maximum frequency contents otherwise aliasing occurs. In our case we take 20 kHz sampling frequency of the PWM to obtain necessary precision, as in this case we would like to achieve maximum frequency content at 10 kHz to avoid the aliasing effect [13].

#### 3.2. Reference Wave Selection

For interfacing the grid with the output of the inverter it must be of the same frequency and its voltage should match with the single-phase grid. Thus, take grid as a reference voltage for generating the PWM from microcontroller. As we know grid voltage is very high and microcontroller cannot read this high voltage due to its ability to read not more than +5 volts to -5 volts. In this case we first attenuate this high voltage using operational amplifier, passing this to the detection of zero crossing and then attenuated signal pass through full wave precision rectifier. The output of full wave precision rectifier is fed to the analog pin of microcontroller and generates PWM as a reference voltage of precision rectifier as shown in Fig. 2. This PWM is the output of the microcontroller, these pulses AND with the output of the zero crossing that is the 1<sup>st</sup> input of the H-Bridge. The inverted output of the zero crossing AND with the same pulses is the 2<sup>nd</sup> input of the H-Bridge.

#### 3.3 Switching Frequency Consideration

Switching frequency is taken as 20 kHz to generate 400 samples per cycle or 200 cycles per half cycle by using microcontroller as mentioned above. In this way more precision and exact match with the grid sinusoidal wave has been achieved. To achieve this frequency, it must be synchronized with the main single phase grid and the output voltage of the GTI should be same as the single phase grid voltage.

#### 3.4 Gate Drive Circuit and Dead Time Fixation

The generated PWM from microcontroller is used to operate the gate drivers IR2110, as these gate drivers drive the MOSFETS. IRF840 MOSFET which is utilized as a

switching device [14]. IRF 840 which is capable to cope the 20 kHz switching frequency as well as the ability to handle 600

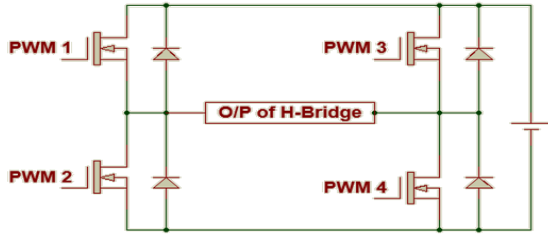


Fig. 3: Single phase full bridge MOSFET power inverter.

volts DC which fulfill the requirements. This switching device has some limitations for switching time. To overcome this limitation, we have embedded a dead time in the PWM using microcontroller. To maintain a strategic distance from the conduction of two switching devices in the common legs, PWM is the output of the microcontroller. The pulses generated by the microcontroller fed to the AND gate with the output of the zero crossing. Further these signals fed in to the PWM1 and PWM4. We have successfully inverted the output of the zero crossing AND with the same pulses that are also fed to the PWM2 and PWM3. PWM1 and PWM4 is one pair while PWM2 and PWM3 is the second pair as shown in Fig. 3. In this technique we have also followed the NYQUIST criteria for operating the H-Bridge.

### 3.5 Filtering Circuit

In GTI, it is very important issue for the designing of low pass LC filter [15, 16]. We know if the sampling frequency is greater than 3 kHz the lower frequency harmonics that is 2<sup>nd</sup>, 3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup> are rejected perfectly by the microcontroller [17]. The advantage of LC filter is to control the harmonics that cause high frequency distortion in the output voltage [16]. There are different types of filters but L, LC and LCL are mostly common in inverters for the removal of unwanted harmonics. In the present study we have used LC filter to get a pure sine wave. According to the standard of IEEE 1547 harmonic voltage distortion should not be more than 0.3%.

By using the below-mentioned formula we can calculate the value of L and C. In this study, we have used the sampling frequency of 20 kHz and the value of C is taken as 2.5μF and the calculated value of L is 25μH.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The characteristic impedance and cut-off frequency of LC filter is calculated by using the formulae given below.

$$Z = \sqrt{\frac{L}{C}}$$

$$f_c = \frac{1}{2\pi\sqrt{LC}}$$

Low pass LC filter has been used to limit the extreme current harmonics between the output of H-Bridge and

isolation transformer [17]. Isolation transformer has been used to isolate the output of H-Bridge and the main grid, as shown in Fig. 4.

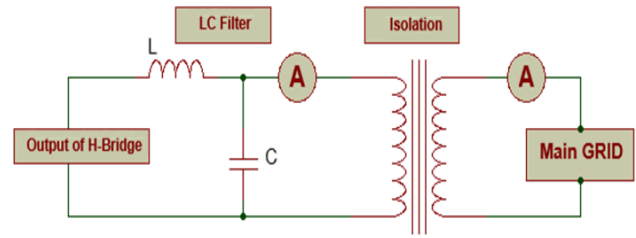


Fig. 4: LC filter circuit.

## 4. Function of Microcontroller

The utilization of PWM is very important for the switching of MOSFETs in H-Bridge to generate PWM from microcontroller PIC16f877A as shown in Fig.5. In this way, turning on the PWM module is obligatory. Taking grid sine wave as a reference signal attenuates the AC sine wave of 2.5volts using operational amplifier. Precision rectifier is used for the detection of pulsating DC and also zero crossing as both are taking the input reference signal of 2.5volts, which is dependent on the single phase grid. Hence, utilization of ADC module is obligatory that is built-in this microcontroller. Pulsating DC is the reference signal of ADC. Microcontroller generates PWM that is dependent on the pulsating DC and the sampling frequency which is 20 kHz in this case. This PWM is the output of the microcontroller and it is used to operate the H-Bridge as shown in Fig. 6.

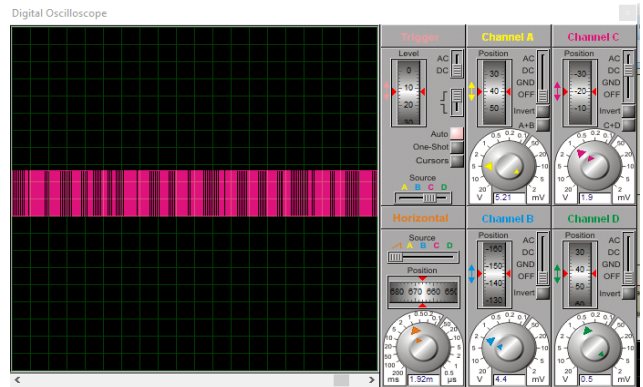


Fig. 5: Output of microcontroller.

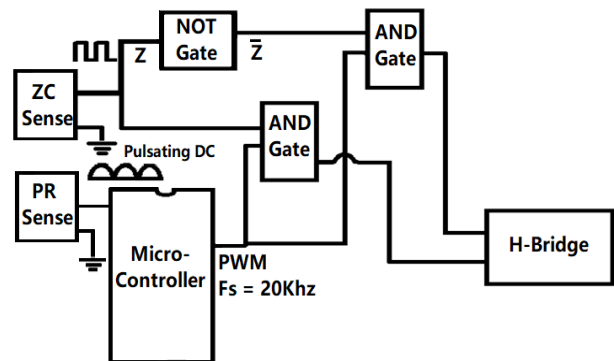


Fig. 6: Microcontroller generate PWM and its operate H-Bridge.

## 5. Simulation Results

Simulated results shown in Fig. 7 are generated using PROTEUS Professional software [18] without using LC filter. The simulated results show the waveform of the output of H-Bridge that is distorted sinusoidal wave and contain unnecessary harmonics. To reduce the unwanted harmonics [19] a low pass LC filter has been used in the experimental study which gives excellent performance.

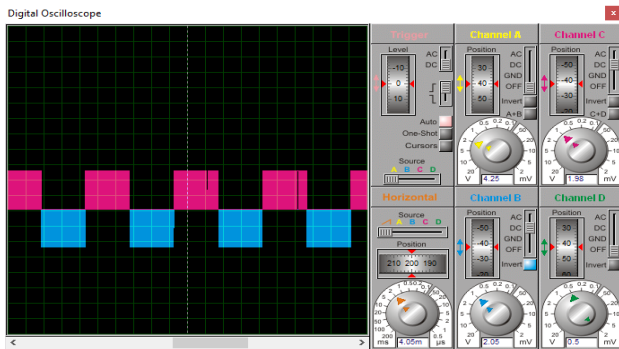


Fig. 7: Waveform of the output H-Bridge circuit without LC filter.

### 5.1. Designing of Proposed System

Fig. 8a shows the GTI proposed model for grid sensing used as a sensor. The simulation was done by PROTEUS Professional software.

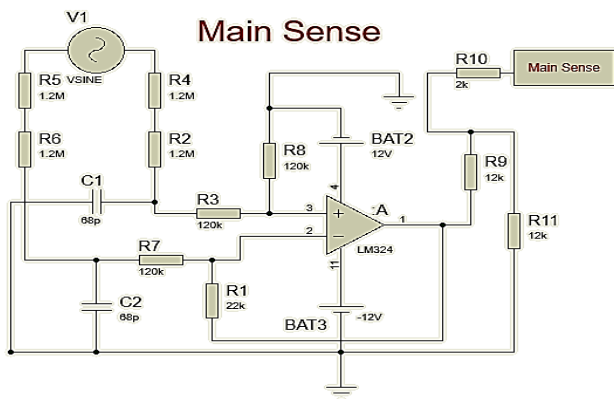


Fig. 8a: Schematic diagram of main grid sensing.

Fig. 8b shows the GTI proposed model for precision rectifier used as a sensor. The simulation was done using PROTEUS Professional software.

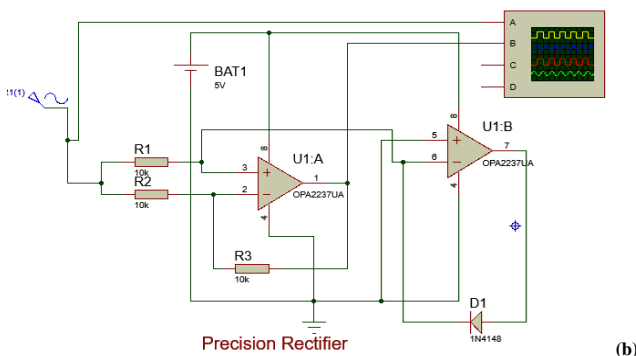


Fig. 8b: Schematic diagram of precision rectifier for sensing.

Fig. 8c shows the GTI proposed model for zero crossing used as a sensor. The simulation was done by PROTEUS Professional software.

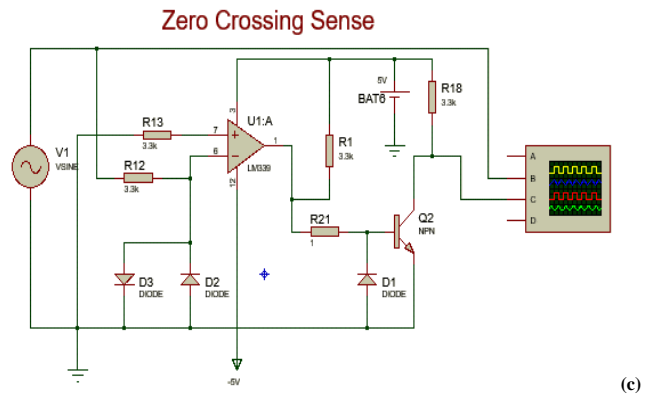


Fig. 8c: Schematic diagram of zero crossing for sensing.

Fig. 8d shows the GTI proposed model for the generation of PWM using microcontroller and operate the H-Bridge. The simulation was done by PROTEUS Professional software.

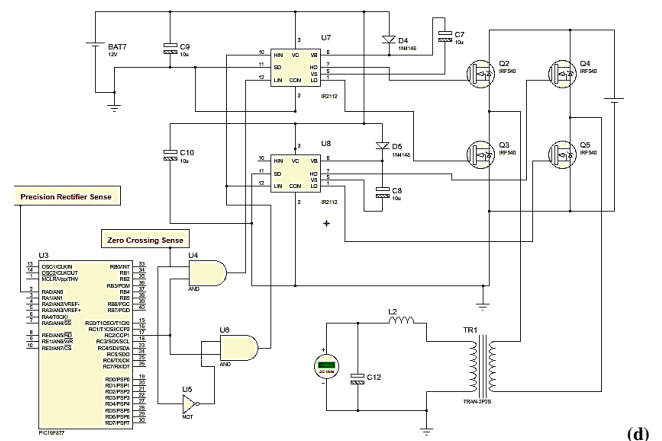


Fig. 8d: Schematic diagram for the generation of PWM using microcontroller and operate the H-Bridge.

### 5.2 Hardware of Proposed System

The Hardware of the proposed schematic by Proteus Professional software of the GTI is shown in Fig. 9.



Fig. 9: Hardware of the proposed system.



### 5.3. Power Delivery to the Grid

The isolation transformer is used to isolate the inverter and the grid. For monitoring the current we have connected two Ammeters, one is connected at the grid side and another is connected at the inverter side. The inverter and grid voltage are to be matched at 31 volts using isolation transformer. We observed that utility grid and output of GTI both are synchronized to each other as shown in Fig. 10.

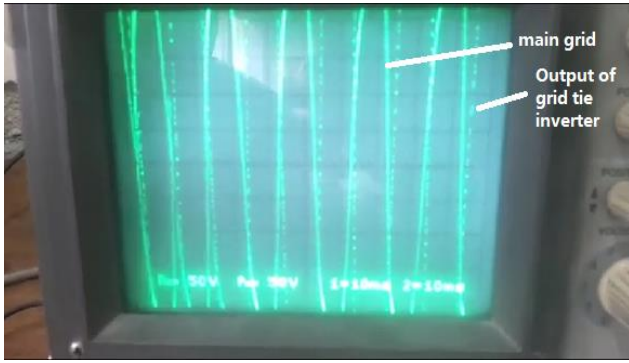


Fig. 10: Synchronization between utility grid and output of GTI.

### 5.4 Power Calculation

Power calculation is the important factor in DC to AC power conversion from PV cells to the main grid. To measure the active and reactive power of the inverter by using already specified two current samples within a single AC cycle [20]. We have assumed that the grid voltage is pure sinusoidal wave. We can calculate the output power by just injecting the sinusoidal current.

The active and reactive output power of the inverter can be calculated by using the eq. (1) and (2). By using eq. (3) and eq (4) we can calculate the value of  $V_m$  and  $I_m$ .

$$P_{out} = V_m I_m \cos \theta = V_m I_{ac}(t_p) \quad (1)$$

$$Q_{out} = V_m I_m \sin \theta = V_m I_{ac}(t_q) \quad (2)$$

$$V_{ac}(t) = V_m \sin(\omega t) \quad (3)$$

$$I_{ac}(t) = I_m \sin(\omega t - \theta) \quad (4)$$

Where,

$t_p$  = Time when the voltage goes its peak means maximum.

$t_q$  = Time when the voltage goes to zero it means when zero crossing.

## 6. Conclusions

The designed schematic diagram by PROTEUS Professional software is implemented and successfully achieved the results which are very useful for implementing the generated signal to tie up with the main grid. It is observed that the hardware tested results and simulation results are in good agreement. We are successful in making a single phase GTI with the locally available components. Therefore, it is possible to fabricate this type of GTI, which can be used to tie up available energy generated by the solar panels to the main grid, it will help the country, like Pakistan, to reduce the

energy crises and reduction in environmental pollution as well as for the improvement of economy. Additionally, the reliance on the foreign technology can be minimized. It is observed that our designed system offers good synchronization with the main grid. It is also worth mentioning that the designed and implemented system having better efficiency as well as synchronizing capability compared to the locally fabricated system available in the market.

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