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Design and Simulation of Single Phase PV Grid-Tie Inverter with Net Metering

Muhammad Imran Akbar*, **Madiha Chaudhary and Rida Rasheed**

Department of Engineering and Technology, Bahauddin Zakariya Univeristy, Multan, Pakistan

Abstract

The ever increasing demand for electricity and the shortcomings of finite sources is making the world to move towards renewable energy sources. In this report, the detailed analysis of the system comprising of single phase photovoltaic grid-tie inverter with net metering is deliberated. To inject solar generated waveform into the grid, one has to synchronize both waveforms of solar output and utility grid. The electronic device which synchronizes two waveforms of different power resources is called grid-tie inverter. Net meter senses the current from both sides i.e. from grid and inverter and gives a display of either the power is drawn from the grid or it is injected into the grid. The whole circuit was simulated at first then it was successfully implemented as a prototype.

Keywords: Consumption • Grid tie inverter • Net meter • Proteus software • PV panel • Single phase • Timer

Introduction

This topic is related to the concept of solar systems connected to the utility grid. These systems continue to extract power from the utility grid when the solar energy generation is falling below their usage. But it sold or sends power back to the grid when the load demand is falling below the generated electricity. Generation through solar panels is becoming more popular than other sources because it gives profit to the users by selling extra wattage to the grid.

Coming innovations are brought about to try a grid built up from the plurality of the solar panels so that the generated electricity can be injected into the utility grid. All this is achieved by an electronic device known as a grid-tie inverter which makes both electrical signals to synchronize in terms of phase, frequency and voltage level [1]. When synchronized, then it is injected into the grid and all this transfer of electricity is measured by net meter and display is shown on the LCD.

Literature Review

The world is facing an energy crisis rapidly and is moving towards renewable energy. The exhaustion of fossil fuel capitals on a worldwide basis made the researchers to do a serious search about unconventional energy sources to encounter the energy and power loads all over the world. All the renewable energies are sun dependent like tidal energy, wind energy, geothermal, etc. The most abundant form of energy existing in this world is solar energy and now the people are going to make its effective use in the generation of electricity by making different types of systems.

But neither form of energy either photovoltaic cells or wind energy is sufficient to fulfill the declining sources and increasing demand. Although, all the renewable energies are not available at all times due to temperature and weather variations so the most trending way of meeting the demands is to use the solar energy with the grid-connected systems. Such systems combine both the solar and conventional conversion units [2]. The increase in concern of customers about photovoltaic cells has been compelled amalgamation of deteriorating costs and compassionate policies about finance and economics. Among those policies, there exists a policy of net metering.

Discussion

Grid connected PV system

On the top of these installation types is Grid Tied Solar System. This is becoming very popular and common now a day in order to improve feeder voltage, decline the loading level of lines and provides environment friendly source by excluding toxin emissions. Benefits of this system also contains loss reduction, less cost of energy production, generation capacity and fuel prices that all are cost factors for fossil fuels system. The coming trend of this technique is to increase the number of panels on distribution systems and it could become analogous with the power abounding by the central source. A grid-connected system provides an opportunity for the user to save money through PV panels in a better way and getting more efficiency with lower rates (Figure 1).

***Address for Correspondence:** Dr. Muhammad Imran Akbar, Department of Engineering and Technology, Bahauddin Zakariya Univeristy, Multan, Pakistan; Tel: 92-342-2725237; Email: imran.akbar2011@gmail.com*

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Components required for grid-tied PV system are:

- PV panels
- Grid Tie inverter
- Net meter
- Load

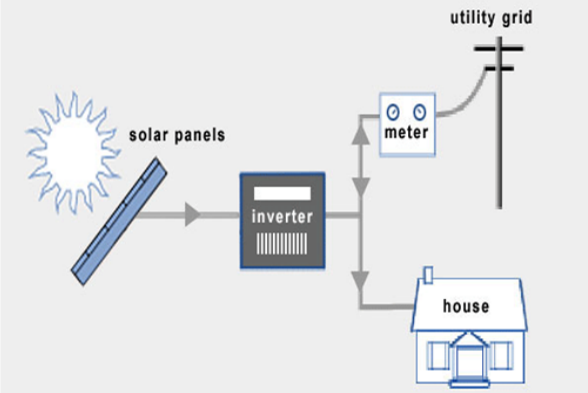

Figure 1. Grid tie PV system.

To meet the power shortages, developing countries are encouraging renewable resources electricity generation. A grid-connected system can be successfully installed if the produced is must following the précised guidelines. It includes the methods and processes to be considered for the design and simulation of single phase PV grid-tie inverter with net metering. The block diagram shown in figure includes the following components.

- PV panels
- Grid Tie inverter
- Net meter

The method comprises two aspects

- Software Design
- Hardware Design

Software design

For the simulation purposes, Proteus software has been used for the design of electrical circuit because of its capability of changing the parameters. Proteus 8 is one of the finest simulation software for numerous plans. It is most common because of the convenience of practically completely microcontrollers in it. So, to test programs and entrenched designs it is considered as a handy tool for users [3]. One can simulate the programming of microcontroller in Proteus 8 simulation software. When simulating is done in Proteus 8, a direct design can be implemented with it. So, one can attain all in one package using Proteus. Its main features are:

- Friendly user interface
- Wealth of investigational resources
- Powerful simulated instrument
- Easy to understand and work
- Easy commands
- Unique simulation approach
- A big library

Grid tie inverter

An electric power device used for conversion of rare generated power from various sources into controlled AC power and supplied it into the national grid in a control and synchronized manner.

Working: Inverters take DC power from any source like PV panels and convert it into the regulated AC power do that it can be injected to the national grid like WAPDA. The grid-tie inverter must match its frequency with a national grid (eg., 50 Hz or 60 Hz) by a local simulator and to control the voltage in a specified limit so that it may not cause any destruction. Commonly, this match of frequency is called synchronization. A well operating GTI has a unity power factor, which shows that the output voltage and current are perfectly lined up, and its phase angle also perfectly matches with the AC or national grid source. The GTI has onboard computer or controllers which sanities the AC grid waveform and output voltage to parallel with grid. Grid-tie inverter works only when it is connected to the grid but it is designed in a way to get disconnected from the grid when the utility goes down. In this project, the GTI will take 12V DC as an input and synchronizes with 220V national grid WAPDA and will provide 220V on output for AC application. It guarantees that in case of any blackout, the grid-tie inverter will be disconnected to prevent the transfer of energy. Otherwise, the sudden blackout can cause serious injury and short-circuiting. Grid-tie inverters make us able to inject the synchronized waveform with the utility grid into the utility grid so that the total generated voltages from the solar panels after inversion can be used for the user load and extra voltages and hence extra units can be given to the utility grid. For this purpose, grid-tie inverter is built up. By making use of grid-tie inverter user can save extra generated units which would get destroyed. In case if these are not injected into the grid although generation was greater than load demand.

Grid-tie inverter is also beneficial for those users who want to extend their load on solar panels in the future in a sense that when they enhance their load they don't have to install more solar plates to fulfill their load demand. In such a situation the only difference or change which will happen in their whole solar to grid-tie system is that their units that were being injected into the grid will get less [4]. So on the whole, the total net amount will decrease but they don't have to install more plates to fulfill their load demand. Another case is here that if a user wants to increase loads on solar plates and also doesn't want to lose total net amount then obviously he has to install more plates to fulfill both demands along with the load demand. Grid-tie inverter in all these cases helps the user to synchronize the solar-generated inverted waveform into the utility grid. The synchronization is done in all the three requirements i.e. in terms of voltage level, phase angle and finally, the frequency should be the same exactly to that of the grid. When all these requirements are fulfilled then the extra units can be given to the grid otherwise if any of these conditions are not fulfilled then the synchronization is not happening and the user should not expect the injection of his waveform into the grid.

Grid tie inverter circuit on proteus

The IC 556 takes the center position in the complete presentation. In fact, because of this IC arrangement could become extensively very

very simple. Referring to the circuit diagram, the IC1 and IC2 are mainly wired up as a voltage synthesizer or in most well-known term a pulse position modulator. In pulse position modulation the amplitude and width of pulses are reversed constant but the position of each pulse is changed by the amplitude of the sampled value of modulating signal. A 12V AC signal given to the bridge rectifier. A bridge rectifier is a prearrangement of four or more diode in a bridge circuit arrangement which delivers the same output polarity for either input. It is used for altering an alternating current in to direct current output (Figure 2).

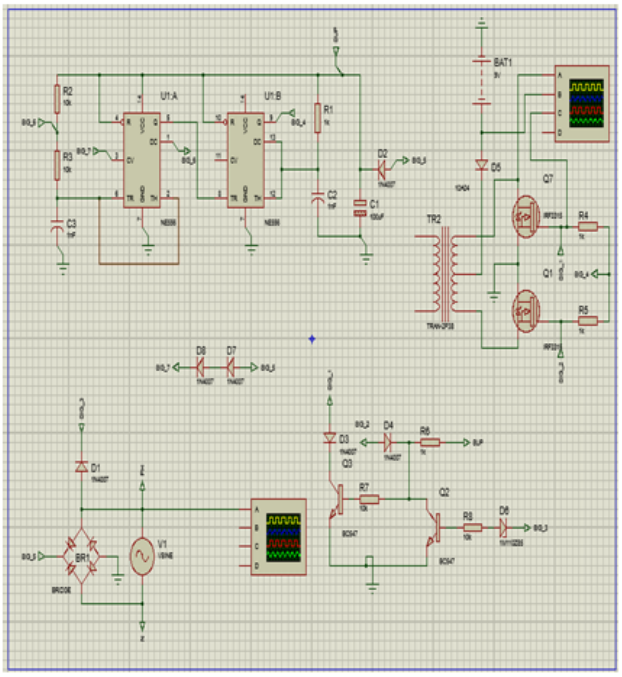

Figure 2. Grid-tie inverter on proteus.

A 12V sinusoidal signal is rectified by a bridge rectifier. The bridge rectifier consists of four diodes, two diodes work for a positive-half cycle and the other two work for a negative half cycle. The SIG_5 (rectified signal) is fed to the U1: B or the IC2. It is delivering the necessary voltage to the IC circuit, and as well as for providing the synchronization data to IC, so that IC can process according to the national grid WAPDA waveform (Figure 3) [5].

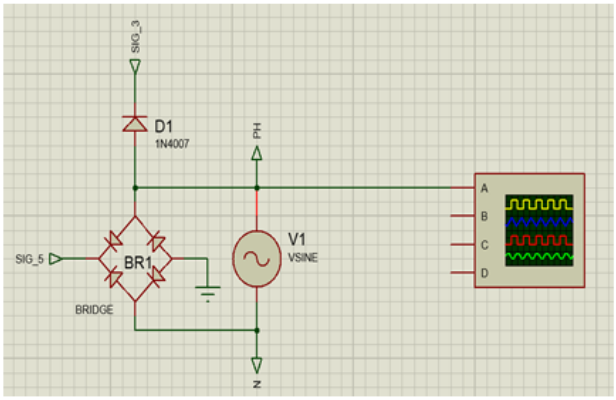

Figure 3. Rectifier circuit.

SIG_3 which is 12V AC signal is fed to the transistor BC547 through diode. A BC547 transistor is a Negative-Positive-Negative (NPN) transistor. Two BC 547 transistors when connected as shown in the diagram, provides the beneficial features of controlling the quantity of current drawn by the load. This arrangement makes sure that current to the load never goes beyond a certain set limit, as calculated through a limiting resistor. One transistor (Q3) generates the signal SIG_3 through diode D3, and the transistor (Q2) generate signal SIG_2 through diode and resistor combination as shown in Figure 4. SIG_1 and SIG2 are fed to the Q1 and Q7. A 12V DC voltage source from a charge controller is given to the center tap transformer. When an additional wire is wired up transversely a particular middle plug of the secondary winding of the transformer, it is known as center-tapped transformer [6].

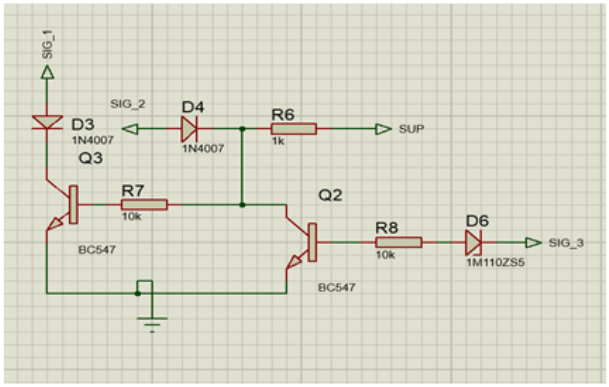

Figure 4. Transistor circuit.

There are three wires for output. One is for neutral. The wire is attuned such that it falls in the exact middle point of the secondary winding and it thus at zero volt, forming the neutral point of winding. This is called “center tap” and this thing permits the transformer to supply two isolated output voltages which are identical in magnitude but differing in polarity to each other [7]. Two transistors cumulatively make it confirm that the MOSFETs never conduct electricity at once rather only one at a time, as per the mains national grid frequency 50 Hz or 60 Hz (Figure 5).

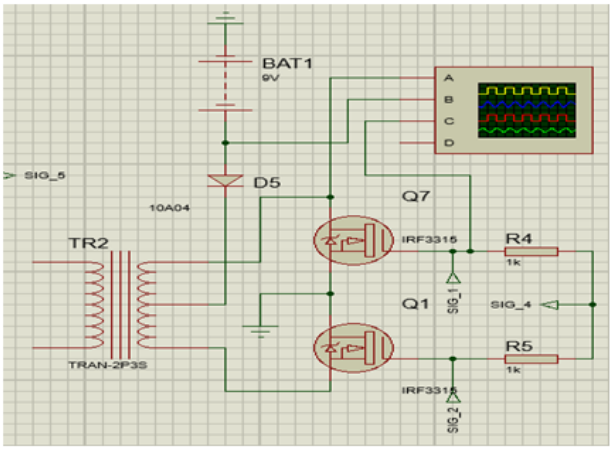

Figure 5. MOSFETs circuit.

SIG_4 is given to the Pin 9 of U1: B (IC) and the DC signal SIG7 is fed to the pin 3 of U1:A (IC), which supplies the frequency count and amplitude data of the national grid AC to the ICs correspondingly. IC 556 has been inserted for creating the pulse width modulation. One half of the IC has been arranged as a high-frequency generator for

feeding the other half IC which is connected as a pulse width modulator [8]. The information provided to the IC prompts the ICs to maintain their output at the relevant pin according to this data. The results from output interpret this data well-improved pulse width modulation that's why very much synchronized with the national grid WAPDA voltage.

IC 556 is creating PWM pulses for permitting the detection of both positive and negative half cycles, the control input of IC must be tended with both positive and negative half cycles AC. This can be obtained by using a bridge rectifier arrangement (Figure 6).

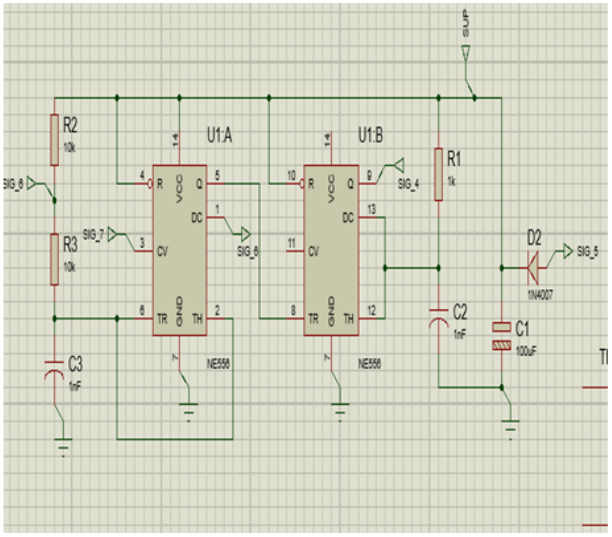

Figure 6. ICs circuit.

The Zener diode is connected with the base of transistor so that would confidently allow the transistors to separate the MOSFETs conduction in a most precise manner. In this way the conduct interchangeably in answer to the 50 Hz pulses at the base of transistor Q2. Half portion of ICs operate as a high-frequency generator for supplying the further half IC which is equipped as a pulse width modulator. The sample of modulating frequency is resulting from transformer TR1 which provides the correct and precise frequency data to the IC so that pulse width modulation is perfectly directed under the main frequency of the national grid [9]. The high-frequency component ensures that the output waveform can cut the above modulation information to accuracy and deliver the MOSFET with an exact RMS value equivalent of national grid mains frequency. Finally, the two transistors IC 547 ensure that MOSFETs (IR 3315) never conduct together, only one conduct at a time, according to main frequency (50 Hz) oscillations.

Total working of the grid-tie inverter is summarized as utility grid AC is rectified by using the full bridge rectifier circuit and that rectified output pulses are counted by the IC 556. One of the IC counts the total pulses in a second and makes the second IC to trigger. One IC works for the first half cycle considering it as a positive cycle and second IC works for the second half considering it the negative cycle. These two pulses are given step by step onto the gate of MOSFETs which are made to trigger the help of transistor. Each of the two transistors works for the ON and OFF of the gate of MOSFET. At the drains of both the MOSFETs an AC voltage is obtained by using center tap transformer which having common point at the ground terminal of 12V DC battery considering it as a solar panel and other two terminals of center tap transformer has connections on Drain points of MOSFETs. Here output will be an AC signal that should be synchronized with that of input utility grid voltage signal in terms of voltage, frequency, and phase angle.

Net meter

Net meter is a device which gives the basic measurement of generated amperes, voltages and watts based on load demand and compared by the grid's amperes, voltages and watts then finally give an output which describes two conditions that either user is exporting the electricity (i.e. Watts) or importing it. Usually, what is the common trend? The Common trend is that solar power is utilized by the homes having a battery bank. Further, there are two scenarios either running DC load on the solar or running AC load by inverting DC voltage level of solar into AC. In the latter case, the system still needs a battery which stores the DC and then inverts in case of sun absence or WAPDA blackout. But net metering excludes the cost and maintenance of the battery. Net metering gives the concept of no requirement of battery as when production is less utility is connected and if production is more than demand then utility is injected with the extra productive units. That's why the world's future trend is moving towards smart digital electronic meters rather than old fashion electromechanical meters. When the utility bill is taken under consideration than by having a comparative assessment between the PV system supporting the feed-in tariff scheme and net metering supporting scheme, it is clear that the latter scheme is much profitable than the first one [10]. It is scrutinized by changing the PV capacity and retail pricing of electricity and resulted in an indication of profit in the net metering supporting scheme. A grid-tie system can consist of one or more meters depending upon the requirements. A meter can, in some embodiments, track and measure the amount of current flowing in and out of the power system. In some cases, a unidirectional meter is installed which measures only the outgoing or incoming of power system. In such grid-tie systems, one meter is configured for measuring the power outgoing the power system and other meter is installed in a way to calculate the power incoming the power system. So a variety of configurations can be used according to system and requirements. In this project the main concern is about one bidirectional net meter i.e. measures both outgoing and incoming power from the power system. This only meter measures both directional flow by using CTs and PT. Net meter senses current of both sides one from the inverter towards the utility grid and second from WAPDA towards the load. By sensing both sides current and measuring the total units flowing into the WAPDA, net meter gives the display of net units either being injected into the WAPDA or being drawn from the WAPDA (Figure 7).

Components of net meter:

- Current Transformer
- Potential Transformer
- Current sensor
- Voltage source (220 V i.e. Grid)
- AC Supply from inverter
- Microcontroller (Arduino Uno)
- Load
- Liquid crystal display (LCD)

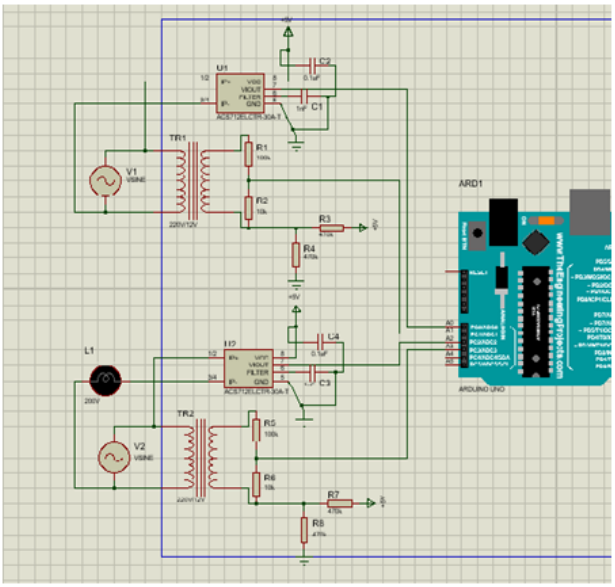

Figure 7. Net meter circuit on proteus.

Hardware

The circuit designed on the Proteus software is just software design. First of all the grid-tie inverter circuit shown in the above diagrams is connected on breadboard. It is easy to make modifications rather than on the vero board. Because the breadboard provides an experimental arrangement of electronic circuit in which components can easily be inserted. A 5Ah battery is used as a DC source. First of all transformer 220/12 AC is connected, diode bridge is connected for converting 12V AC into 12V DC, then the connection across ICs BC 547 and IC 556 are made, finally the output from drains of both MOSFETs IR3315 is connected to center tap transformer which converts the 12V AC output to 230V AC for residential application [11]. The step-down transformer was used initially which step-downs the 220VAC in 12V AC because it is easy to deal with 12VAC rather than 220V. IC 556 has been inserted for generating the PWM pulses. For permitting the detection of the negative half-cycles, the control input of the IC must be tended with both half cycles of the AC (Figure 8).

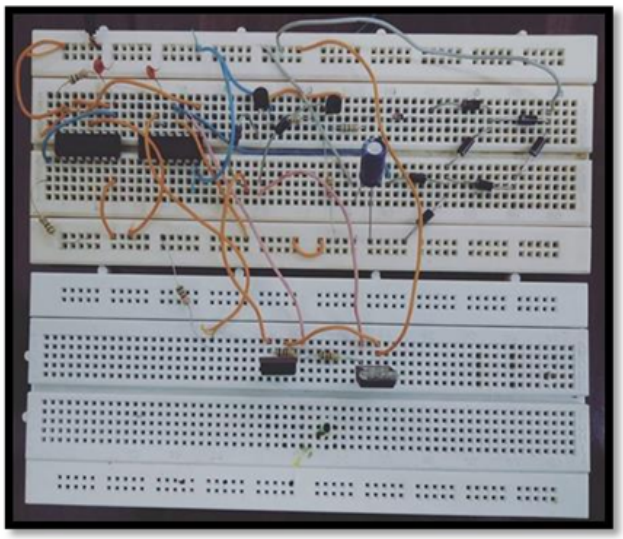

Figure 8. Grid tie inverter circuit.

A center tap transformer 6-0-6 was connected at output. There must be 12V AC input to the transformer. But initially, the voltage across the drain of MOSFETs or at center tap transformer input was not stable because of some lose connection. By rechecking the circuit the mistake was indicated and finally, 220V AC at output of 6-0-6 transformer appeared. The load (LED bulb) connected to the transformer it illuminated stably. A vero board is neatly constructed with strips of coppers dressed on a top-quality board containing a grid pattern of holes 0.1 m apart. This design allows connecting ICs, resistors, capacitors on to the vero board neatly. This board provides a tight connection of components. Due to this tight connection, there may be less chance of mishap. With the vero board, one can obtain the versatility and durability of the circuit. While soldering is must be taken into account that the joints must be neat so that is may not cause any short-circuiting. A little negligence can destroy the entire circuit and components. The following problems were faced till the completion of the circuit

- The MOSFETs IR 3315 started heating as the center tap transformer connected across the MOSFET drains.
- Transformer caused the noise.
- The voltage across ICs were not stable.

When the output transformer 6-0-6 connected the 7.6V across MOSFETs disappear. The reason for heating the transformer maybe checking the output current by directly connecting the ammeter which may cause a temporary short circuit; it may cause the heating of the transformer. To eliminate the problems of heating across the MOSFET, heat sink was used. The heat sink will expel the heat from the generating source i.e. MOSFETs. Heat sinks are inert form of cooling as they have static parts and require no power [12]. It is thermally conducted metal device which can easily be inserted. Because the MOSFETs drains are directly connected to the center tap transformer, the voltage may be imbalance according to the transformer rating. Transformer noise is caused by a process which causes the magnetic sheet to extend when magnetized. When the transformer demagnetizes the sheet does back to the original state. This expansion and contraction of a magnetic sheet is due to imbalance voltage across the transformer input and the variation in frequency (Figure 9).

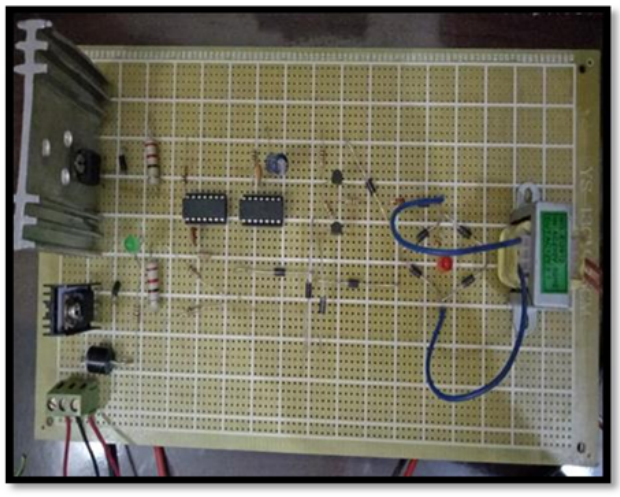

Figure 9. Single phase grid-tie inverter.

The output from the software design of the grid-tie inverter is achieved up to 100% by synchronizing the grid waveform to the inverter output waveform in voltage and frequency. The output waveform shown in results is exactly according to our demand. The output of hardware design is achieved after so many hurdles because in actual it is not easy to synchronize National Grid (WAPDA) with the solar inverter output waveform (Figure 10).

- The obtained output of grid-tie inverter is 220V which is exactly the same as that of Grid in terms of voltage, phase angle, and frequency.
- A precise synchronization to some extent is accomplished.
- The standard frequency of 50Hz is achieved at output

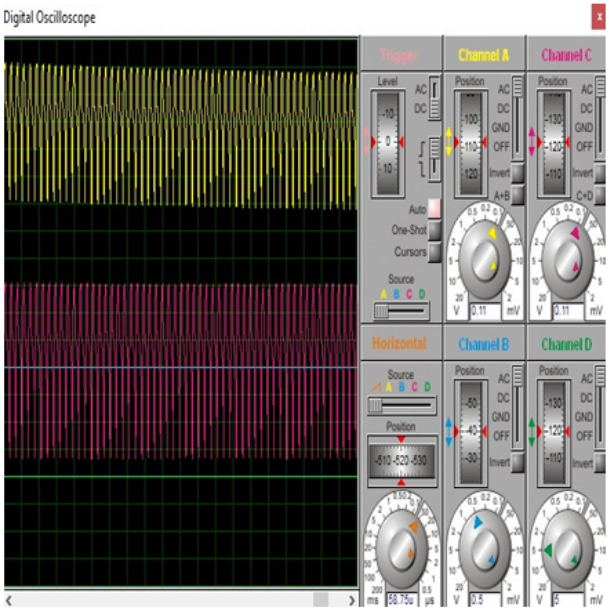

Figure 10. Synchronizing waveform.

Conclusion

The brain of this project i.e. Single Phase PV Grid Tie Inverter with Net Metering is Grid Tie Inverter itself. The net meter displays significantly shows the measured values of current, voltage and eventually power of both utility grid and inverter on LCD screen. It is injecting power into the grid up to 41.44 mW or it is withdrawing power from the utility grid up to 23.5 mW. At the end of this project, one can learn about detailed features of electronic and power components and protection measures while dealing with the National grid with the help of this research.

Appendix

Oscilloscope, Digital Multi-meter, Bread board, Variable DC supply, Clamp meter.

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