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# Design and Implementation of Quazi-Z-Source Inverter for AC Microgrid using Renewable Energy Source

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***Abstract: This paper presents quasi Z source inverter (qZSI) with battery energy management system can utilize the power from renewable source injected to the load or AC microgrid. The voltage fed qZSI is similar to the impedance source inverter (ZSI). The qZSI is a single stage converter with one controllable dc port. The battery are connected in the one DC port of qZSI utilizes an LC network and uses active & shoot-through states which is reduces the number of power switches, switching losses, lower component ratings, reduced source stress, reduced component count, simplified control strategies and reduced cost. In this paper presents the hardware implementation of the nenewable energy based qZSI for AC microgrid using dsPIC30F2010 microcontroller. In this system a suitable active and reactive power control for injecting or recovering the power between the AC microgrid and PV system. The PV panel and energy-stored qZSI based experimental setup is developed and demonstrates in different operating modes that make in suitable for AC microgrid applications.***
***Index Terms: Quazi Z Source Inverter, Renewable Energy Source, Battery, dsPIC30F2010 Microcontroller, Pulse Width Modulation (PWM), IRF 840 MOSFET, IR2110 Driver Circuit & Opto Isolator.***

## I. INTRODUCTION

The cost of electricity produced by renewable energy sources and probabilistic nature of the generation are the major concerns that limit its wider usage. Storage technologies have big potential for smoothing out the electricity supply from these sources and ensuring that the supply of generation matches the demand. Especially, storage can be important in rural areas with a weak grid or even without connection to the utility AC grid. With the decrease of conventional energy sources and the growing problem of environmental pollution, the research and utilization of the renewable energy, such as solar energy, wind energy as so on, has been concerned with more and more attention [1]. The rapidly increasing environmental degradation across the globe is posing a major challenge to develop commercially feasible alternative sources of electrical energy generation. Thus, a huge research effort is being conducted worldwide to come up with a solution in developing an environmentally benign and long-term sustainable solution in electric power generation. The major players in renewable energy generation are photovoltaic (PV), wind farms, fuel cell, and biomass. These distributed power generation sources are widely accepted for micro grid applications. However, the reliability of the micro grid relies upon the interfacing power converter. Thus the proper power regulation from the interfacing power converter will ensure a stable and reliable micro grid system. Thus this paper focuses on the proposal of a new class of interfacing inverter, the quasi-Z-source inverter (qZSI) for off-grid applications. Transformer less topology is deserving attention because of its increased efficiency, reduced size, weight and price for the PV system. The Z-source inverter (ZSI), as a single-stage power converter with a step-up/down function, allows a wide range of PV voltages, and has been reported in applications in PV systems. It can handle the PV dc voltage variation in a wide range without overrating the inverter, at the same time it can carry out voltage boost and inversion simultaneously in a single power conversion stage, thus minimizing system cost and reducing component count and cost, and improving the reliability. The power conversion stage is an important stage in microgrid to regulate the DC voltage to a desirable value, the qZSI intriguing the gain of the shoot-through duty cycle [2]. This feature of qZSI has provided the advantage of using BESS in parallel arrangement and also incorporating the features of renewable sources [3-4]. The qZSI has all the features of ZSI and in addition it has an advantage of lower voltage rating components as compared to ZSI. The power conversion stage is an important stage in microgrid to control the DC voltage to a desirable level. The quasi Z-source inverter (qZSI) is a double-port converter in its DC side taking the advantage of the shoot-through duty cycle [5]. This feature of qZSI has made the advantage of using BESS in parallel arrangement and also incorporating the features of renewable sources [6-7]. The parameters of qZSI are

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important criteria for proper operation of batteries, hence the battery parameters are chosen in such a way to decrease the ripple component of battery current in microgrid applications [8-10].

## II. PROPOSED SYSTEM

### A. *Photovoltaic System*

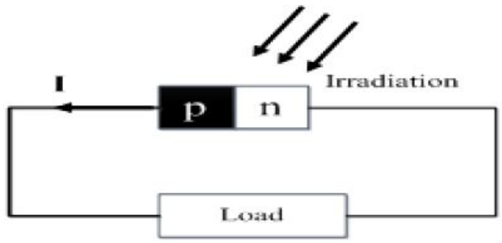


Fig.1: Solar Cell

The outp ut of one crystalline silicon photovoltaic cell is approximately 0.5V. In order to produce a specific output voltage solar cells are connected in series. They are electrically connected and mechanically mounted in a frame to form a panel. When panels are wired in series or parallel the form an array. The solar panels are also equipped with necessary protective devices, such as bypass and blocking diodes in order to protect cells from the temperature rise under shady condition or to prevent it from reverse current owing back during night.


(a) (b)

Fig.2: (a) PV Array & (b) I-V & P-V Characteristics of PV Cell

Photovoltaic cells uses the "photovoltaic effect" phenomenon to produce the electricity. The physics of PV cell is similar to conventional PN junction diode. Whenever the light falls on the junction, the energy of it is transferred to the electron-hole pair, thus the free charge carriers are generated. These charge carriers creates the potential gradient and gets accelerated under the electric field. This will cause the current to flow through the external circuit.

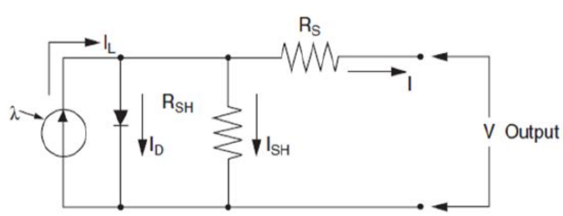


Fig.3: Basic Model of Solar Cell

### B. *Renewable Energy*

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides and geothermal heat. Renewable energy replaces conventional fuels in four distinct areas: electricity generation hot water/space heating, motor fuels and rural energy services. Renewable energy can be recycled and it will not shed in particular season like non renewable energy the process will be repeated continuously. Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries.

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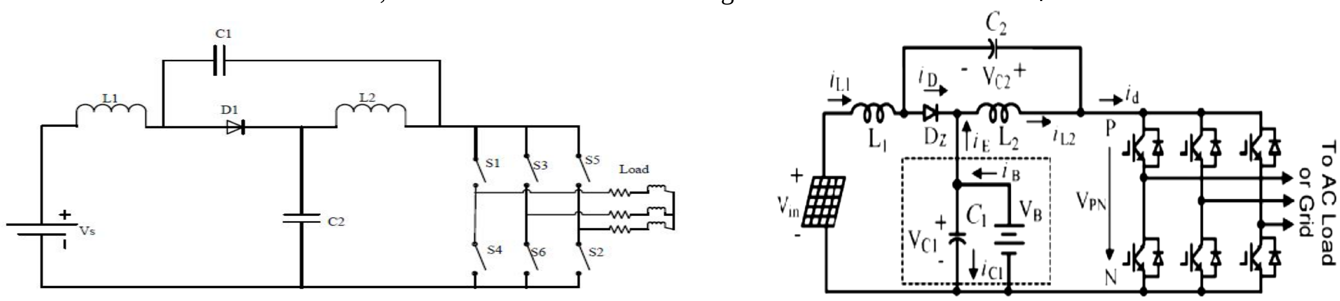
Rapid development of renewable energy and energy efficiency is resulting insignificant energy security, climate change mitigation, and economic benefits.

### *C. Principle of Quazi Z Source Inverter*

The quasi Z source inverter can be used for ac-to-dc , dc-to-ac , ac-to-ac , dc-to-dc power conversion. The general quasi Z source inverter structure. Its internal impedance network connects the converter main circuit to the power source or load. The qZSI inverter consists of two inductors $L_1$ and $L_2$ and two capacitors $C_1$ and $C_2$. The inductor present in the quasi Z source inverter reduces the source current. The capacitor voltage is lower than in case of Z source inverter. The quasi Z source network connected the converter to the dc source and load. The dc source can be a battery, fuel cell, photovoltaic cell and load can be inductor, capacitor, resistor, or a combination of these. The six switches are a combination of switching devices like insulated gate bipolar transistor (IGBTs) and an anti-parallel diode. The continuous quasi Z source inverter provides an earthing between the dc – link and input source, by which there is a reduction in common mode, noise can occur. The low voltage stress is obtained on the capacitors.




(a)

Fig.4: (a) Basic qZSI & (b) Solar Based qZSI (b)

### *D. Operating modes of qZSI*

The two modes of operation of a quasi z-source inverter are:

1) *Active mode:* In the non-shoot through mode or active mode, the switching pattern for the qZSI is similar to that of voltage source inverter (VSI). The input dc voltage is available as DC link voltage input to the inverter, which makes the QZSI behave similar to a VSI in this mode.

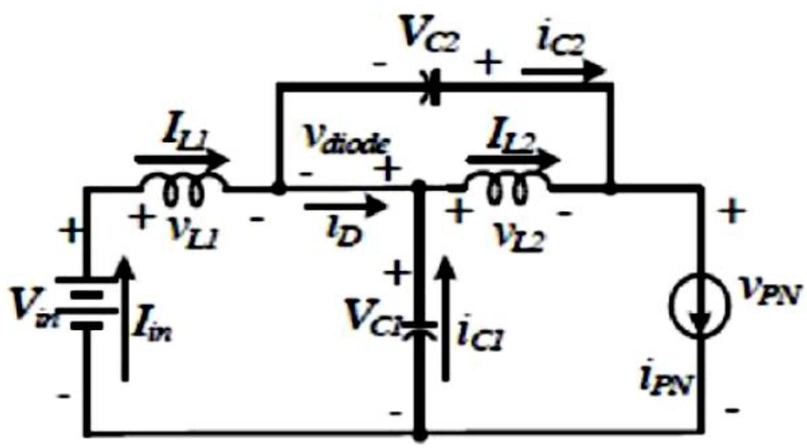



Fig.5: Active Mode

2) *Shoot Through Mode* In this mode, switches of the same phase in the inverter bridge are switched on simultaneously for a veryshort duration. The source however isn't short circuited when attempted to do so because of the presence of LC network (quasi), that boosts the output voltage. The DC link voltage during the shoot through states, is boosted bya boost factor, whose value depends on the shoot through duty ratio for a given modulation index.

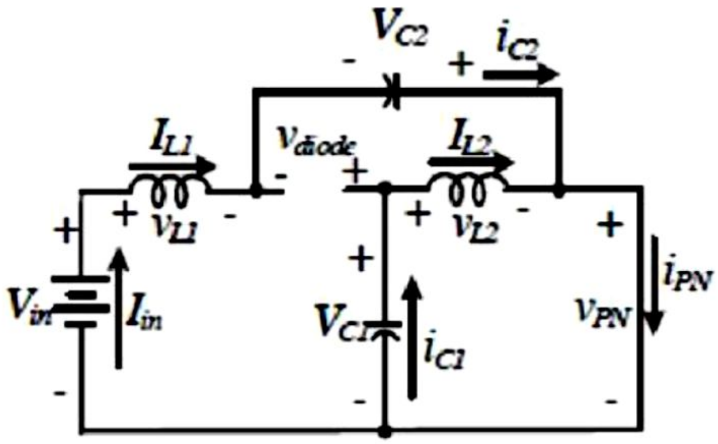



Fig.6: Shoot Through Mode

### *E. Control Strategy*

The qZSI configuration has six active vectors when the DC voltage is impressed across the load and two zero vectors when the load terminals are shorted through either lower or upper two switches. These switching states and their combinations have been spawned many PWM control schemes. Sinusoidal PWM is the most commonly used PWM technique in the VSI. On the other hand, qZSI has additional zero vectors or shoot through switching states that are forbidden in traditional VSI. In order to boost the output voltage, the shoot through state should always be followed by active state. This requirement may be met by the complimentary operations of the switches within a leg. The simple boost control method used here employs two constantvoltage envelopes which are compared with the sine carrier wave. Whenever the magnitude of sine carrier wave becomes greater than or equal to the positive constant magnitude envelope (or) lesser than or equal to the negative constant magnitude envelope, pulses are generated which control the shoot through duty ratio *D*. These serve as the firing signals for the switches in the inverter. This control technique has shoot through states spread uniformly which makes output free of frequency ripples.

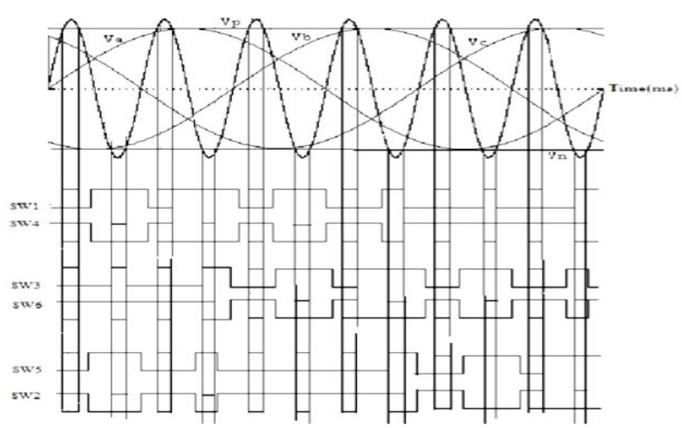



Fig.7: Waveform of Sine PWM

### *F. Pulse Width Modulation (PWM)*

Pulse-width modulation (PWM) is a commonly used technique for controlling power to an electrical device, made practical by modern electronic power switches. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load is PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. Typically switching have to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies The term duty cycle describes the proportion of on time to the regular interval or period of time; a low duty cycle

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corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on the main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM works also well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel.

## III. BLOCK DIAGRAM

The block diagrm consists of PV array, Battery, dsPIC30F2010 Microcontroller, MOSFET (IRF840), Opto Isolator, MOSFET driver circuit IR2110, qZSI and AC microgrid. The output voltage of PV array is fed to the battery. The battery output voltage is flow to AC microgrid through qZSI. The switching operation of qZSI inverter is operated by dsPIC30F2010 Microcontroller with suitable PWM techniques. The opto isolator is used to isolating the MOSFET switches. The driver circuit is used to drive from microcontroller with MOSFET switching operations. The input of qZSI inverter is dc from battery is inverterted to ac is fed to the AC microgrid.

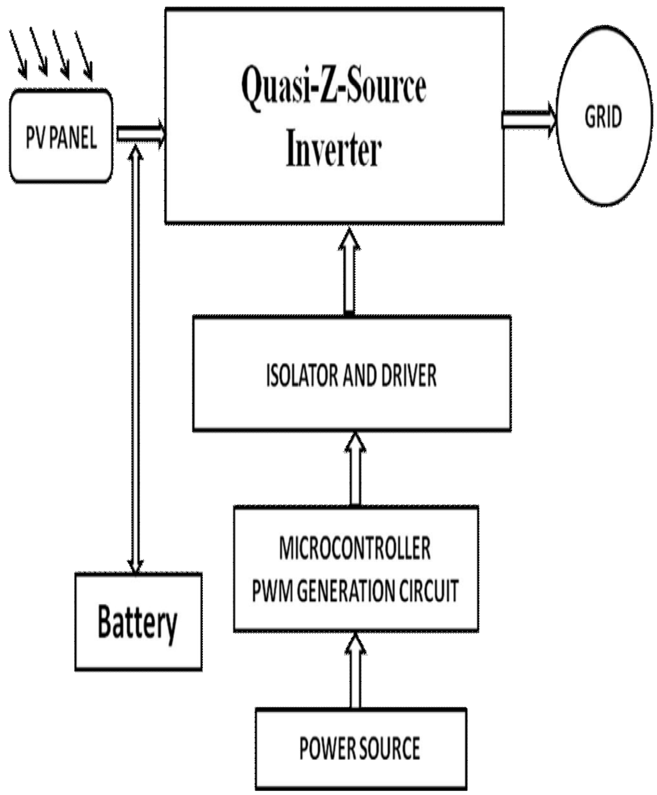


Fig.8: Block Diagram of qZSI with PV Panel

## IV. HARDWARE IMPLEMENTATION

### *A. Power Supply Unit*

The first building block in the dc power supply is the full wave rectifier. The purpose of the Full Wave Rectifier (FWR) is to create a rectified ac output from a sinusoidal ac input signal. It does this by using the nonlinear conductivity characteristics of diodes to direct the path of the current. The operation of power supply circuits built using filters, rectifiers and then voltage regulators. Starting with an ac voltage, a steady dc voltage is obtained by rectifying the ac voltage then filtering to a dc level and finally, regulating to obtain a desired fixed dc voltage. The regulation is usually obtained from an IC voltage regulator unit, which takes a dc voltage and provides a somewhat lower dc voltage which remains the same even if the input dc voltage varies, or the output load connected to the dc voltage changes.

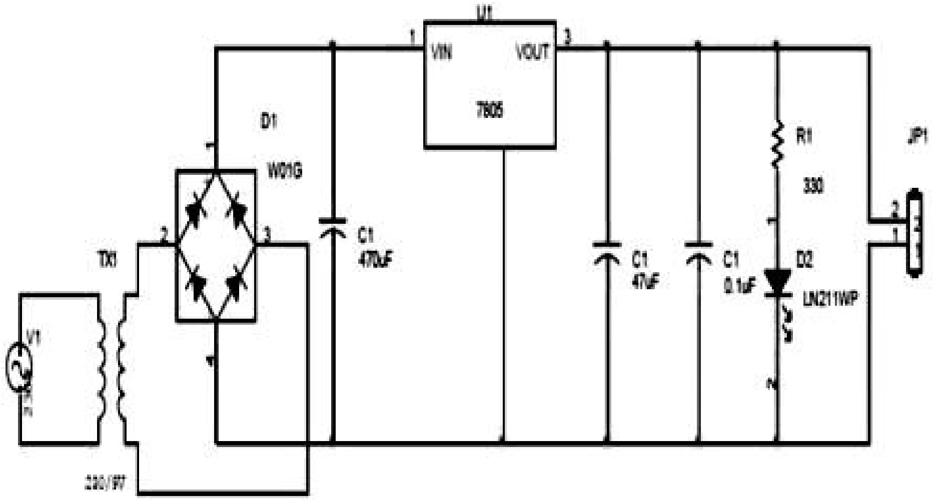


Fig.9: Power Circuit for Microcontroller

*B. dsPIC30F2010 Microcontroller*

The dsPIC30F2010 Microcontroller is a highly integrated chip that contains all the components comprising a controller. Typically it includes a CPU, RAM, ROM, I/O ports, Timers and UARTs. Unlike a general-purpose computer, this also includes all of these components. Typically microcontroller is called a dedicated processor that is designed for a very specific task to control a particular system. As a result the parts can be simplified and reduced, which cuts down on production costs. The dsPIC30F2010 microcontroller is power-off timer and oscillator start-up timer, watchdog timer with its own on-chip RC, oscillator for reliable operation, programmable code protection, power saving sleep mode selectable oscillator options, low power, high speed CMOS FLASH/EEPROM technology.

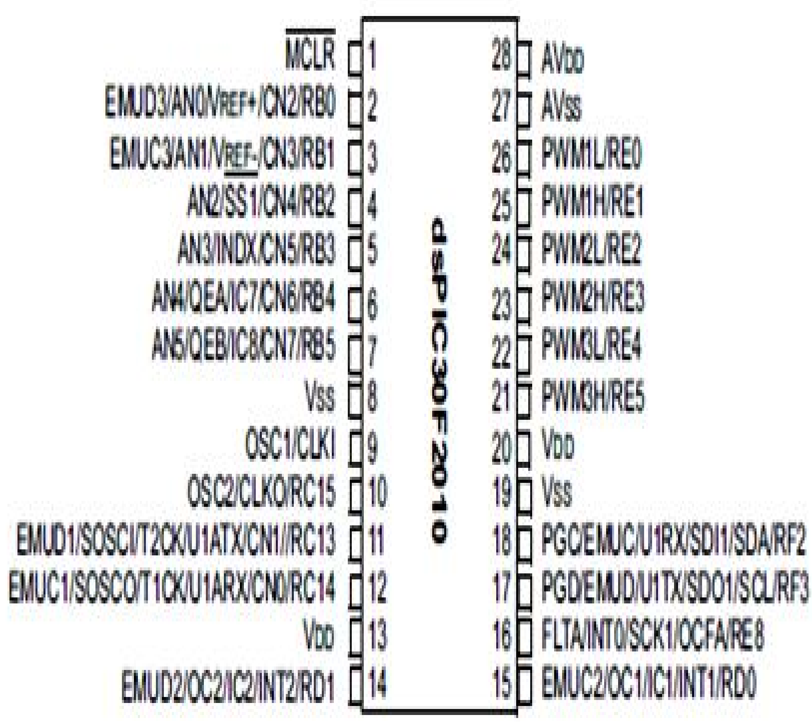


Fig.10: Pin Diagram of dsPIC30F2010

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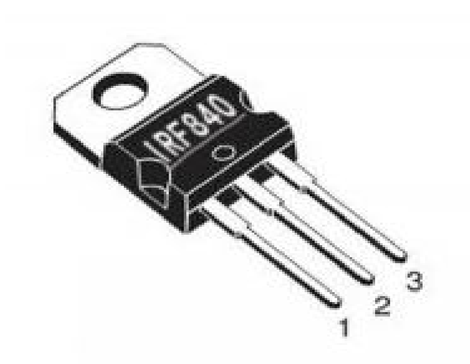
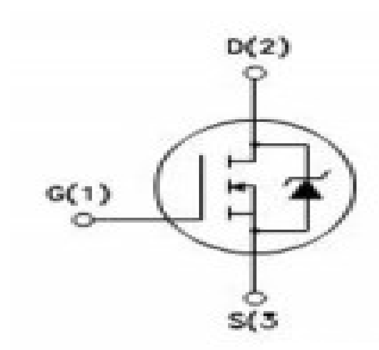
Table –1: Key features of dsPIC30F2010 Microcontroller

| Serial No. | Key Features | dsPIC30f2010 |
|---|---|---|
| 1 | Operating Frequency | 20MHz |
| 2 | Flash Program Memory | 8K |
| 3 | Data memory | 368 bytes |
| 4 | EEPROM Data Memory | 15 |
| 5 | Interrupts | 14 |
| 6 | I/O Ports | PORTS (A,B,C,D,E) |
| 7 | Timers | 3 |
| 8 | PWM Modules | 2 |
| 9 | Serial Communications | MSSP, USART |
| 10 | Parallel Communication | PSP |
| 11 | 10-bit A/D Module | 8 Input |
| 12 | Instruction Set | 35 |

### *C. Mosfet Irf840*




(a)




(b)

Fig.11: (a) Pin Diagram of IRF840 & (b) Schematic of IRF840

The MOSFET (Metal Oxide Semiconductor Field Effect Transistor) transistor is a semiconductor device which is widely used for switching and amplifying electronic signals in the electronic devices. The MOSFET is a core of integrated circuit and it can be

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designed and fabricated in a single chip because of these very small sizes. The MOSFET is a three terminal device with source (S), gate (G), drain (D) terminals. The body of the MOSFET is frequently connected to the source terminal so making it a three terminal device like field effect transistor. The MOSFET is very far the most common transistor and can be used in both analog and digital circuits. The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain. It is insulated from the channel near an extremely thin layer of metal oxide.

*D. MOSFET Driver Circuit IR2110*

The IR2110 is a high voltage, high speed power MOSFET and IGBT driver with independent high and low side referenced output channels. Proprietary HVIC and latch immune CMOS technologies enable ruggedized monolithic construction. Logic inputs are compatible with standard CMOS or LSTTL outputs down to 3.3V logic propagation delays are matched to simplify use in high frequency applications. The floating channel can be used to drive an N-channel power MOSFET or IGBT in the high side configuration which operates upto 6000V.

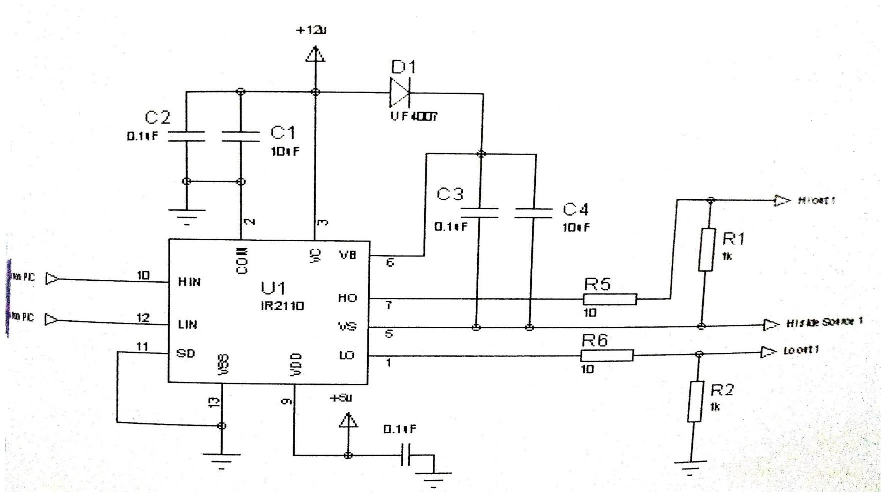


Fig.12: MOSFET Driver Circuit IR2110

*E. Opto Isolator*

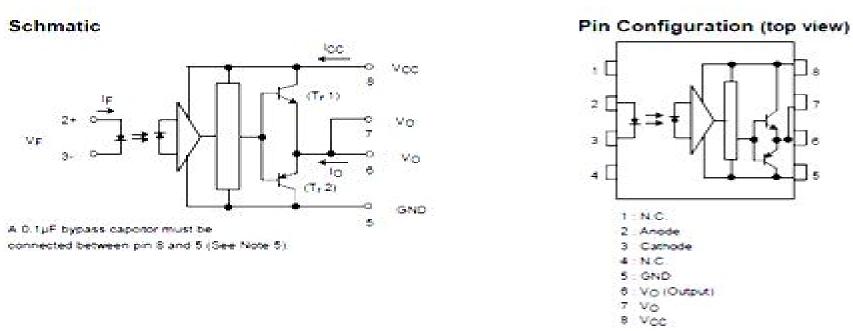


Fig.13: Opto Isolator

It is a small device that allows the transmission of a signal between parts of circuit while keeping those two parts electrically isolated. Inside a typical optocoupler there are two things – a LED and a phototransistor. When a current runs through the LED, it switches on at which point the phototransistor. Its detects the light and allows another current to flow through it. When the LED is off, current cannot flow through the phototransistor.

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*F. Battery*

The Lead acid batteries used in the RV and Marine Industries usually consist of two 6-volt batteries in series, or a single 12-volt battery. These batteries are constructed of several single cells connected in series each cell produces approximately 2.1 volts. A six-volt battery has three single cells, which when fully charged produce an output voltage of 6.3 volts. A twelve-volt battery has six single cells in series producing a fully charged output voltage of 12.6 volts.

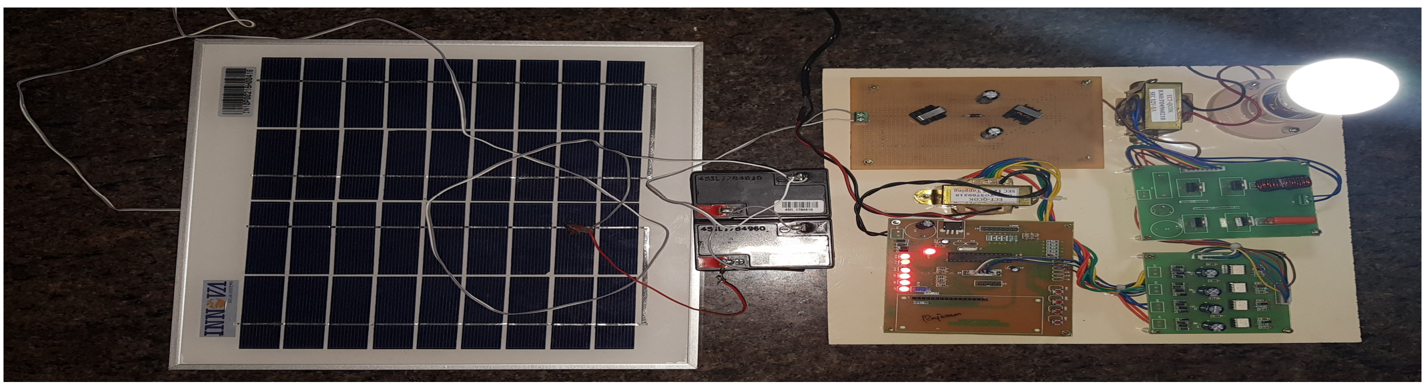

Fig.15: Photograph for Hardware Setup

Table –2: Solar Panel Specifications

| S NO. | PARAMETER | VALUES |
|---|---|---|
| 1 | Maximum Power Rating (Pmax) | 10W |
| 2 | Open Circuit Voltage (Voc) | 12V |
| 3 | Short Circuit Current (Isc) | 0.68A |
| 4 | $V_{pmax}$ / Panel | 17.5V |
| 5 | $I_{pmax}$ | 0.58A |
| 6 | Controller | dsPIC30F2010 Microcontroller |

Table –3: Component Specifications

| S.NO. | COMPONENTS | RANGES |
|---|---|---|
| 1 | Capacitor | 470µF, 50V |
| 2 | Inductor | 100mH |
| 3 | MOSFET | IRF840 |
| 4 | Transformer | 12V to 230V |
| 5 | Switching Frequency | 1 kHZ |
| 6 | Diode | 1N4007 |

## V. CONCLUSION

This paper presents complete design and implementation of an experimental prototype of single phase Quasi Z Source inverter using PV panel. A new topology for energy stored quasi Z-source inverter is more suitable for photovoltaic systems applications. The different operating modes of the proposed model make sure that the power supply to the load is uninterrupted and satisfies the load requirement. Connecting the battery in parallel to the upper capacitor allows using the low voltage battery, but the discharge mode has power limitation that limit the practical application range of this energy stored qZSI. Connecting the battery in parallel to the lower capacitor has no power limitation, but usage of the high voltage battery is less attractive in many applications. qZSI exploited for solar oriented power applications, where both refining and inconsistent should be possible in a single stage. An experimental setup has been developed and demonstrates the effectiveness of this topology for PV power systems directly connected to the load or AC microgrid applications.

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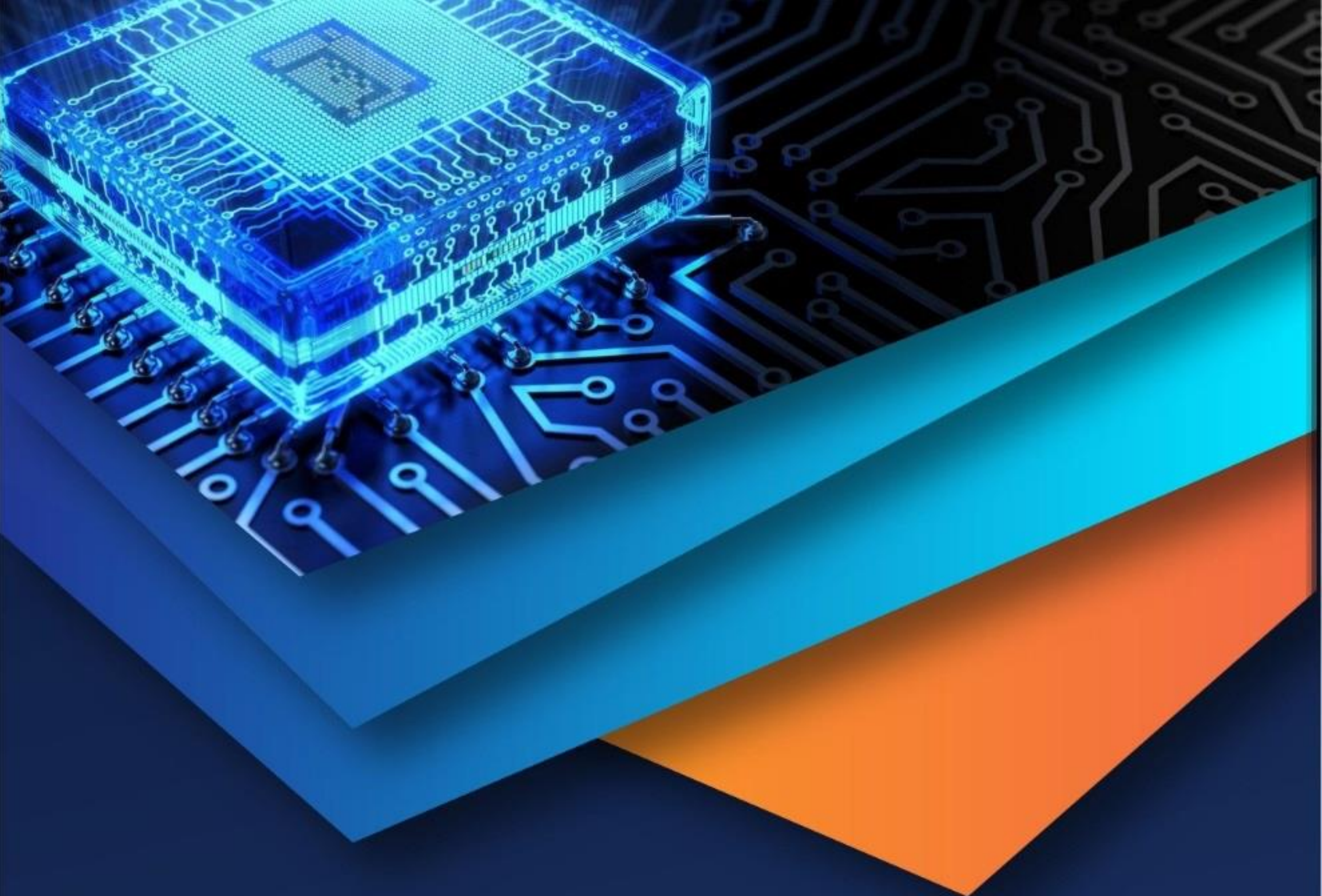


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