3-Phase Inverter with Buck-Boost Regulator

Junaid Akhter, Masood Ahmed Rafay, Mohammad Daniyal Badar
Pakistan Air Force Karachi Institute of Economics and Technology (PAFKIET)
Department of Power Electronics and Drives
College of Engineering, PAF Base Korangi Creek, Karachi, Pakistan
rafayqureshi2010@gmail.com, junyd1993@gmail.com, mohammaddaniyal_danny@hotmail.com

***Abstract*—This Final Year report is based on solar power 3-Phase inverter with Buck-Boost Regulator. The aim of our project is to provide constant High Voltage DC supply required to run huge machinery in industries. Generating electricity using solar energy is cheap and renewable and highly efficient. This whole system requires just a one-time setup then it provides output continuously and requires no extra investment other than maintenance over the years which is not too costly either compared to the output. Nowadays, producing and providing electricity is a major problem and there is always a risk of breakdown even after that. In huge industries, losing electricity for even a few minutes means a loss of millions of Rupees and this is where Solar energy can prove beneficial. By setting up this system, we can have an alternate energy source in case of a breakdown and this system is more than efficient enough to run for hours, provided the conditions are met.**

Keywords— ***HIN: High Input, LIN: Low Input, VF: Diode Forward Biased Voltage, VFAULT: FAULT Terminal Voltage, SIP: Single In-Line Package, I (SAT): Saturation Current, VCE: Collector-Emitter Voltage, IGBT: Insulated Gate Bipolar Transistor***

I. INTRODUCTION

(1), Motivation: Our interest in Solar Energy Generation and increasing Energy crisis in Pakistan led us to choose this project as it can prove to be an alternative. (2), Applications: Since solar energy is Renewable, it can serve a wide variety of purposes. The most common use would be to power machinery in industries and to conserve electricity. Since this is a renewable energy source, the environment also benefits and there are less chances of working hazards as well. Smaller and low power versions of the same system can be used to provide power to urban areas since solar panels can be set up almost anywhere easily. (3), Limitations: The only downside of having Solar panels is the predictability of weather. The solar panels require a decent amount of sunlight in order to produce the required power. If there are clouds of smoke in the vicinity, the efficiency of the solar panels is greatly affected.

II. PROBLEM DISCUSSION

The demand for electricity in Pakistan is increasing day by day and a lot of pressure is being put on the power plants to generate more. Furthermore, there is also Load-shedding to ease the pressure on power-plants due to which people face a lot of troubles and everyday lives are disturbed hence a backup or an alternative is needed. Solar energy is renewable energy and requires one time to setup and can provide output for years after that. It only requires to change the solar panels once they are worn out over the years.

III. LIMITATIONS

A. Transformers:

We are making a transformer-less three phase inverter, here are a few limitations of Transformers:

1. Transformers are usually costly and thus they make circuits more expensive and more bulky.
2. They, like batteries, are heavier and make it difficult for us to handle the operation sometimes.
3. In three-phase transformers, there is a greater cost of stand by units.
4. Inconvenience of repairs is also a main disadvantage of transformers.
5. In case of 3-phase transformer, if one of three phases goes out of order, other two also stop working properly.
6. A transformer less system requires less space so it is more easy to use.
7. Hysteresis Power loss that arises from magnetic poles in the core material being aligned causes a lot of power wastage.
8. Instrument transformers cannot be used for DC measurements.

B. Batteries:

Here are a few points why batteries cannot be counted upon too much because they have certain limitations:

- Non-rechargeable batteries (primary, dry cell) are the most commonly used domestic batteries. They are frequently used in torches, toys, smoke detectors, watches, calculators, hearing aids, radios and remote controls and a lot of other appliances of same sort. This type of battery cannot be recharged after use and, although they can be recycled, battery recycling programmes and facilities are still developing and they still need a lot of efforts along with modification to maintain all the stuff that is simply dumped and thrown out as a trash, so maximum primary batteries are just thrown away when they become 'flat'.
- Batteries have a limited life. They constantly need to be recharged or replaced. Even rechargeable batteries have a limited life and must eventually be replaced.
- Usage of batteries makes the equipment heavier and thus it becomes very difficult to use them. This usually happens with high power consuming equipment. So we prefer a system that doesn't have a battery.
- Usage of batteries needs a lot of maintenance and continuous watch. They also need to be checked periodically. It could also cause the wastage of a lot of our precious time.
- Some batteries are very dangerous to human beings and they pose danger to almost everything around them.
- Explosion of eruption cases of batteries have already a lot of damage to the common people as well as researchers.
- Batteries can also catch fire because of chemical and electrical changes going on in them as well because of the fuel or acid inside them.

IV. SOLAR PANELS AND THEIR TYPES

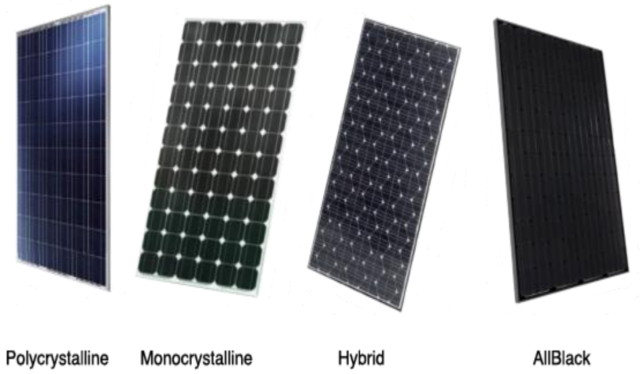
A. Solar Panels:

Solar panels contain many photovoltaic cells inside them and produce electricity by absorbing the sun's rays and converting the light energy into electrical energy and heat.

B. Types of Solar cells:

There are four basic types of Solar cells:

- Mono Crystalline Solar cell
- Poly Crystalline Solar Cell
- All Black
- Hybrid

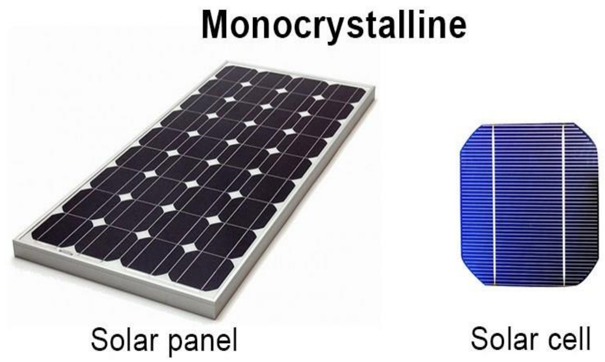


i. *Mono Crystalline Solar Cell:*

As it is obvious from its name, it is a cell composed of one continuous silicon crystal lattice. It is usually black in color. It works in dim light and is very sensitive and expensive in all solar cells. It converts 18% of the incident light into electricity.

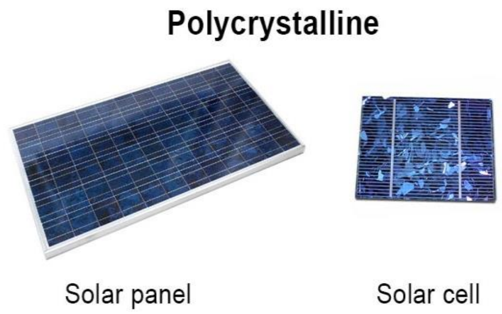
It has low beat bearing capacity and shows its complete efficiency till temperature ranges to25C. Temperature varies for different solar cells. It is written on all solar cells as N.O.T.C (Nominal Operating Cell Temperature). Mono cells have the highest lab efficiencies of 25 % in PV market.

In mono crystalline solar cell, if some of its silicon cells are exposed to light while at the same time the others are not then it may cause damage to the solar panel. Therefore, it should be kept in mind that all the cells must be exposed to light or be kept in dark at the same time to prevent damage to the panel.



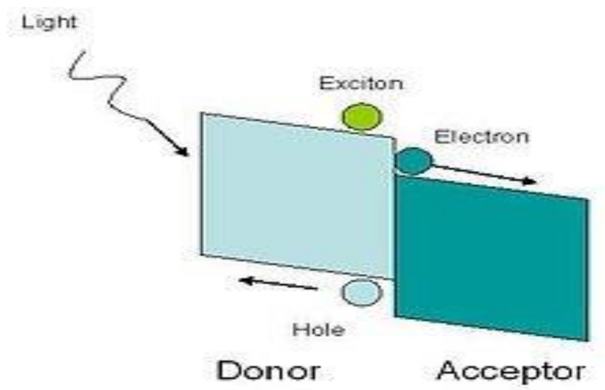
ii. Poly Crystalline Solar Cell:

It is a solar cell consisting of multiple small silicon crystals called crystallites. Each of these crystals is larger than 1mm. These cells are usually blue in color and there may be spots or lines of other colors seen in the cell.It converts 15% of the incident light into electricity. If we compare it with a Mono crystalline solar cell of the same size, then its efficiency is slightly lower as compared to the mono crystalline cell.It is less sensitive and less expensive than mono crystalline solar cell and its heat bearing capacity is more than mono crystalline cell. It usually works under the temperature ranges to 45 degrees Centigrade but it also varies for different solar panels. Similarly to the mono crystalline cell though, if all of its cells are not kept in light or in the dark at one time, it might cause damage to the solar panel.



iii. Hybrid Solar Cells:

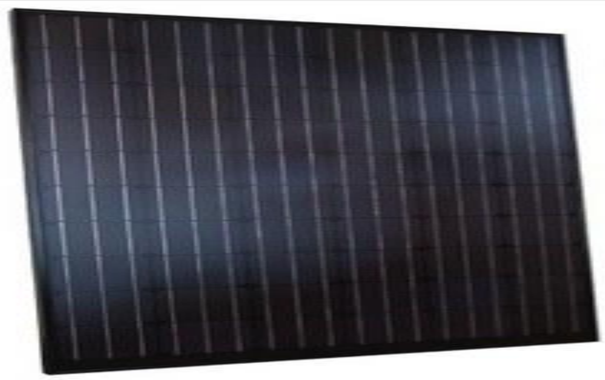
Hybrid solar cells are made by combining organic and inorganic materials together to form a photoactive layer. This combination of two different materials provides greater power conversion efficiency than a single material would. One material acts as exciton donor and the other promotes exciton dissociation.



iv. Black Frames and Black Backed Solar Panels

These panels are so called because not only do they have black frames but also black backs. But being completely black is a disadvantage since none of the light is reflected back to the cells and is absorbed by the back, which reduces efficiency.

Because of absorbing more sunlight as compared to other types, these panels heat quickly too which further reduces their efficiency.

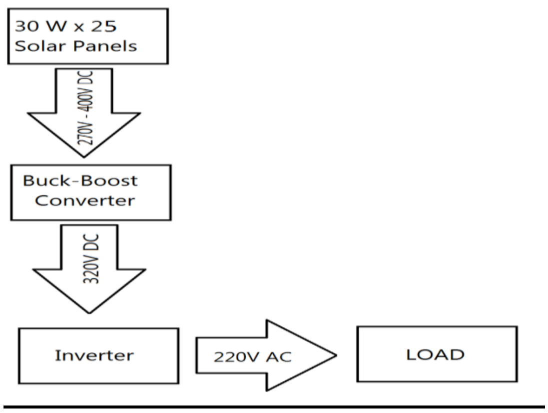


C. Limitations of Solar Panels:

The only downside of having Solar panels is the predictability of weather. The solar panels require a decent amount of sunlight in order to produce the required power. If there are clouds or smoke in the vicinity, the efficiency of the solar panels is greatly affected.

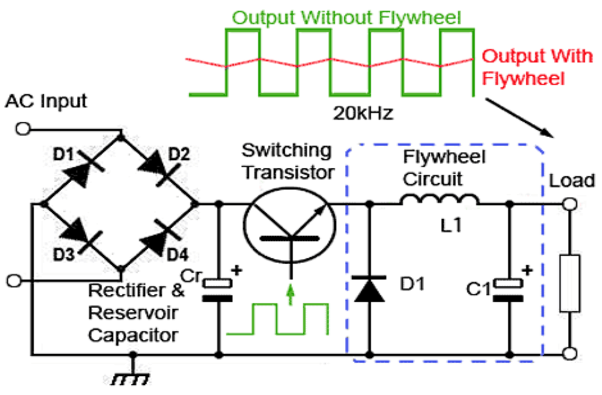
v.

V. Block/System Flow Diagram:



VI. Voltage Regulator:

A. *Buck regulator:*



The above figure illustrates a buck converter, also known as a step down converter. The input supply Vs is converted from AC to DC via the Bridge rectifier. When the positive cycle comes, the Switch S conducts (ON-time) and the Diode D1 becomes reverse biased. The current charges the inductor and goes to the load. When the negative cycle comes the Switch S does not conduct and becomes an open circuit (OFF-time), hence the diode becomes reversed biased and current flows in the opposite direction from the inductor to the load. It should be noted that the current never becomes zero in either condition hence this is called Continuous Conduction Mode (CCM).Since the current shows a linear behavior, inductor-volt second balance equation can be applied on it to calculate the average inductor current. It is given by:

$$L = VD / f \Delta I V_s$$

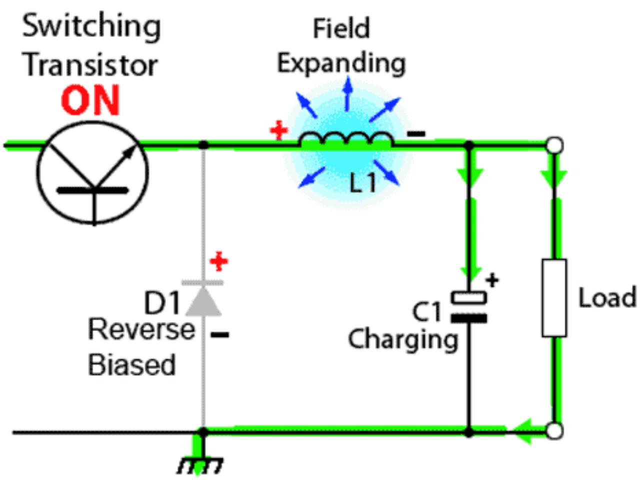
Where, L=Value of Inductor, V = Voltage across load, D=Duty Cycle, f=Frequency, ΔI = Ripples in inductor current, Vs = Supply Voltage.

Similarly, Capacitor Charge Balance equation can be applied on the Buck convertor to find out the Capacitor current (Ic) .When the positive cycle comes, the Switch S conducts (ON-time) and the Diode D1 becomes reverse biased. The current is divided between the Capacitor and the load accordingly and the capacitor charges. When the negative cycle comes the Switch S does not conduct and becomes an open circuit (OFF-time), hence the diode becomes reversed biased and current flows in the opposite direction. In this way, the charged capacitor discharges through the resistor.

$$C = \Delta I / 8f \Delta V_c$$

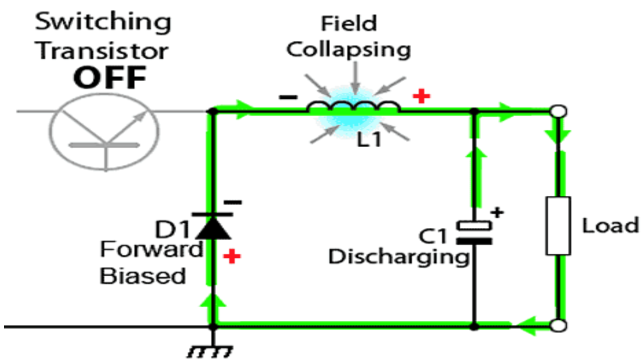
Where, C = Value of Capacitor, ΔI = Ripple current, F=Frequency, ΔV_c = Voltage Ripples across Capacitor.

Transistor Switch ON period (ON Time)



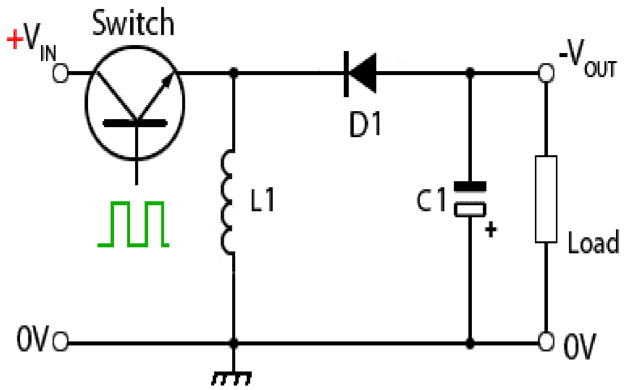
When the switch is ON, Diode D1 is reverse biased and current flows through the inductor charging it and also across the capacitor developing voltage on it.

Transistor Switch OFF period (OFF Time):



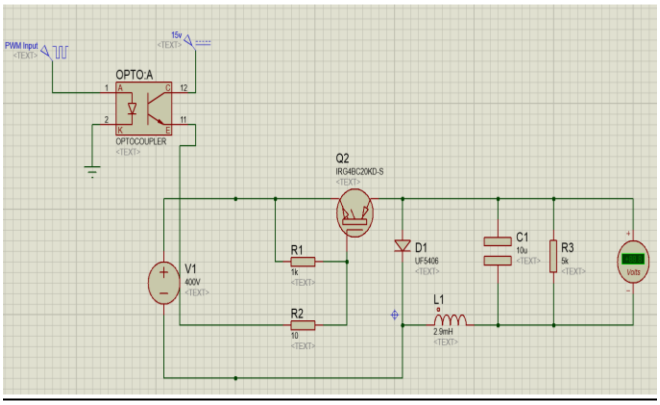
When the switch is off, current flows from the charged inductor, which now acts as an energy source. Similarly, the charged Capacitor also discharges through the Load during OFF time.

Buck Converter for Negative Supplies:

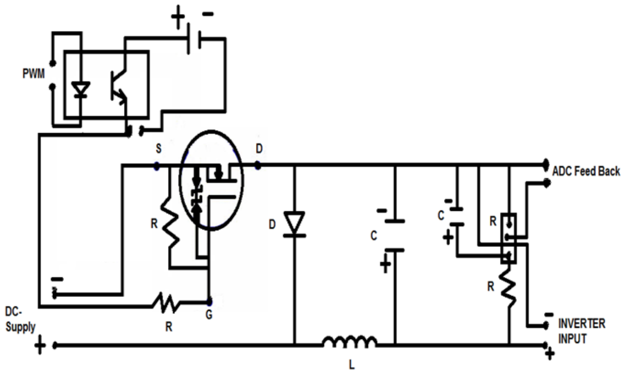


In case of negative supplies, we can utilize the circuitry provided above. The position of inductor and Diode are reversed and the direction of the diode is also matched accordingly. This circuit then converts a positive supply and gives us an output from 0v to –Vi. The polarity of the Capacitor also has to be adjusted.

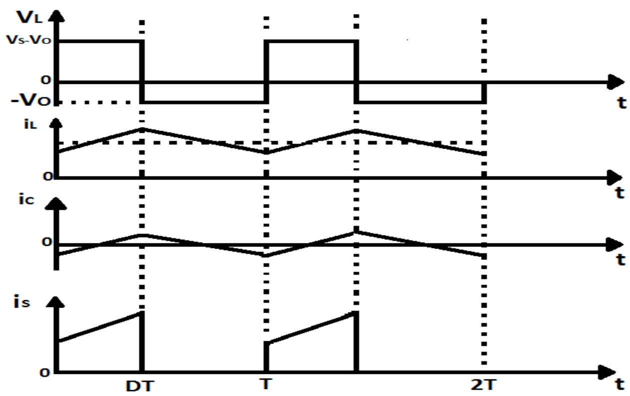
Schematic Diagram:



Circuit Diagram:



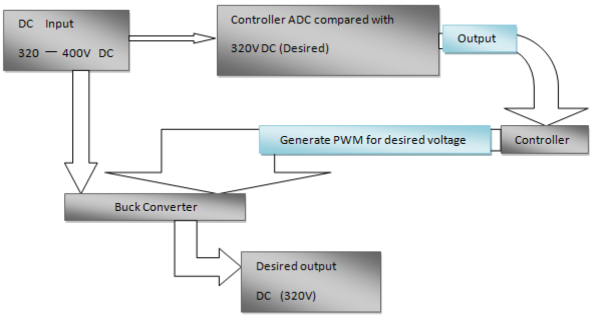
Waveforms:



It can be seen from all the waveforms that the inductor voltage and the Capacitor current never become 0, hence we are operating in Continuous Conduction Mode (CCM).

The waveforms of switch and diode are mirror images of one another since they both work alternatively, i.e. when switch is conducting, diode does not conduct and when diode is conducting, the switch acts as an open circuit.

Buck Regulator Flow Chart:



Calculations for Buck Regulator:

Input voltage: V_s = 400v, Output voltage:

Vo= 320v, Ripple Voltage: ΔV_c= 20v, Frequency:f =43.2 kHz,

Change in current: ΔI =36A, Duty cycle: D =0.8.

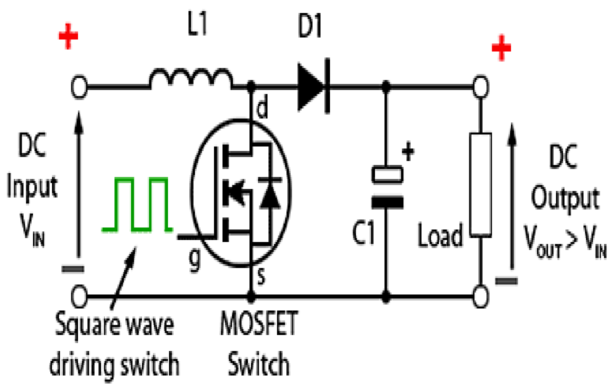
For Inductor:

$L = V_a D / f \Delta I V_s$, $L = 320(0.8) / (43.2k \times 36 \times 400)$, **L = 4.93mH**

For Capacitor:

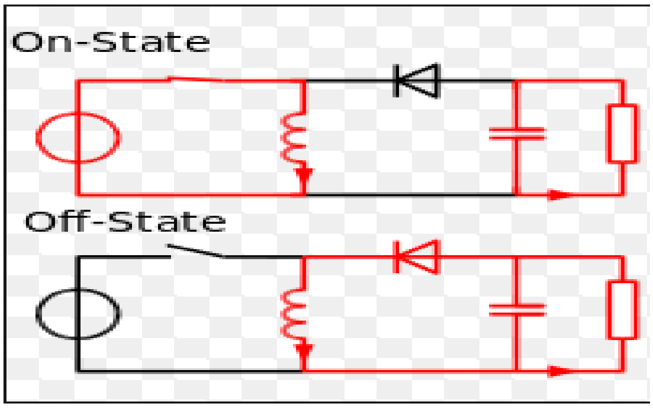
$C = \Delta I / 8f \Delta V_c$, $C = 36 / (8 \times 43.2k \times 20)$, **C = 5.2 uF**

Boost Converter:

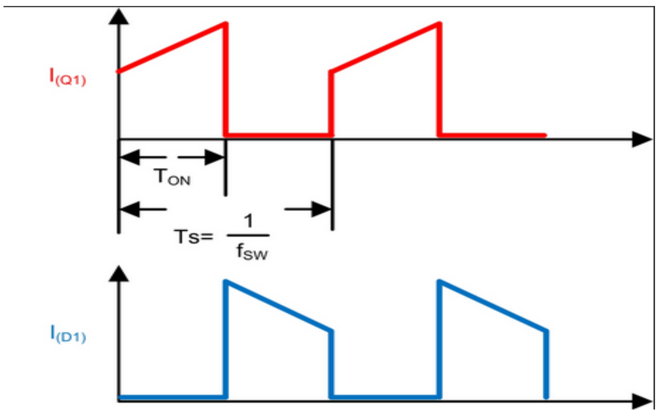


The Boost Converter is basically a step-up converter that boosts the output to the desired value. The output of a Boost Converter is always greater than the input. During the ON-time, the inductor charges and during the OFF-time it comes in series with the input and charges the output capacitor and drives the load. It should be noted that similarly like the buck converter, the switch and diode in the Boost circuit operate alternatively as well.

Boost Converter ON-Time and OFF-Time:



Boost Converter Switch and Diode Waveforms:



The Switch Q1 operates during the ON-time allowing the Inductor to charge and then remains open during OFF-time. Similarly, Diode D1 is reverse biased during ON-Time and does not conduct but it becomes forward biased in OFF-time and allow the inductor to come in series with the input and increase the value of output.

VII. Inverter:

A. Introduction:

The inverter is a device that converts DC voltage to AC. The input voltage, output yield and frequency and overall power all depend on the design of the hardware. The inverter cannot generate any power itself so the power has to be provided from a DC supply. A commonplace power inverter device or circuit entails a comparatively stable DC power source accomplished of providing enough current for the planned power demands of the system. The data voltage depends on the scheme and purpose of the inverter. Examples include:

- *12 Volts DC for small commercial use. Can easily be driven from 12 volt lead batteries.*
- *24 and 48 VDC, for domestic energy systems. Power here can be generated using 24 volt batteries.*
- *200 to 400 VDC for industrial uses and for driving heavy machinery. The power here is generated using photovoltaic solar panels.*
- *300 to 450 VDC for high voltage and current applications like power plants. The power is generated from car batteries.*

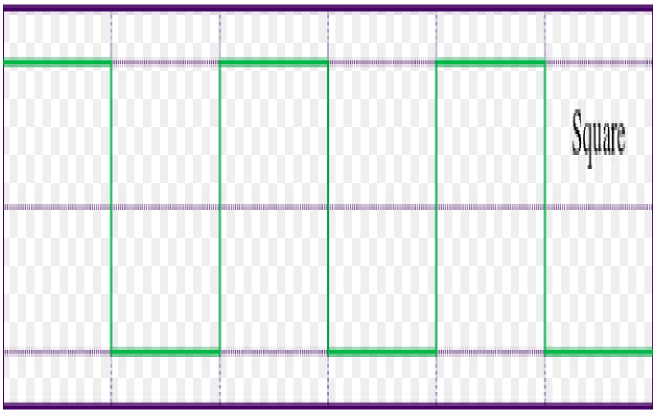
i. Output Waveform:

An inverter can provide a variety of waveforms as output. Some examples are Sine wave, Altered Sine wave, Square wave or beat sine wave. The type of wave generated depends upon the circuitry greatly.

Square Wave:

The square wave is the least complex wave the inverter can generate. It has a variety of applications. Square waves are normally used in timing/synchronous circuits to provide clock signals. They are generated using binary logic devices. But if we use the frequency domain to analyze them, instead of time domain, we see that they have a wide range of harmonics which cannot be removed easily. These harmonics tend to generate electromagnetic radiations or pulses of current that act as noise for nearby circuitry and disrupt output. Hence we avoid using square waves in sensitive circuits where precision is needed. The Fourier Analysis equation of a Square wave is given below:

$$x_{\text{square}}(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin\left(2\pi(2k-1)ft\right)}{(2k-1)}$$
$$= \frac{4}{\pi}\left(\sin(2\pi ft) + \frac{1}{3}\sin(6\pi ft) + \frac{1}{5}\sin(10\pi ft) + \cdots\right)$$

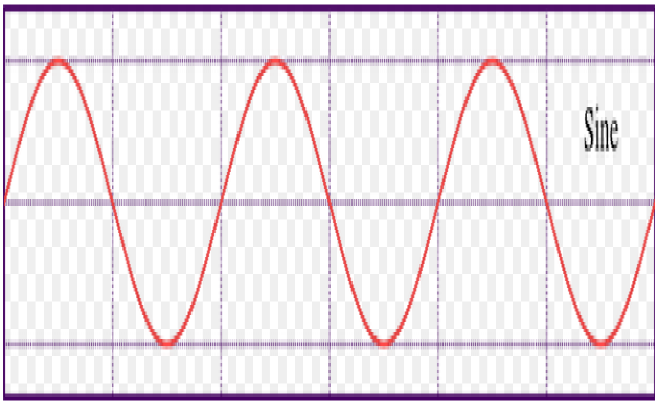


Sine Wave:

The simple mathematical representation of Sine wave is:

$$y(t) = A\sin(2\pi ft + \varphi) = A\sin(\omega t + \varphi)$$

Where: A= Amplitude of the Signal, f = Frequency of the signal, ω = Angular Frequency (in radians per second), φ= Phase (in radians).

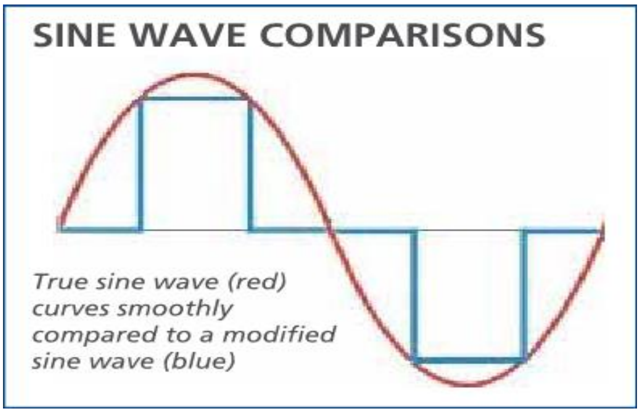


The Sine wave is one of the most widely used waveforms because it retains its shape after being added to or being subtracted from another sine wave.

Some applications of sine waves include Power supplies, everyday electronics like Television, Refrigerator, iron, etc and many more.

Modified Sine Wave:

A modified Sine Wave can provide all the functionalities of a Pure since Wave (sometimes called True Sine Wave) with the exception of a few. The only difference between these two is that Pure Sine wave can cater to high power applications whereas the Modified sine wave can only deal with simple moderate power demands. Therefore if you require high power output driving capability, Pure sine wave is preferred and if power is not a big issue then Modified sine wave is the better economical choice.



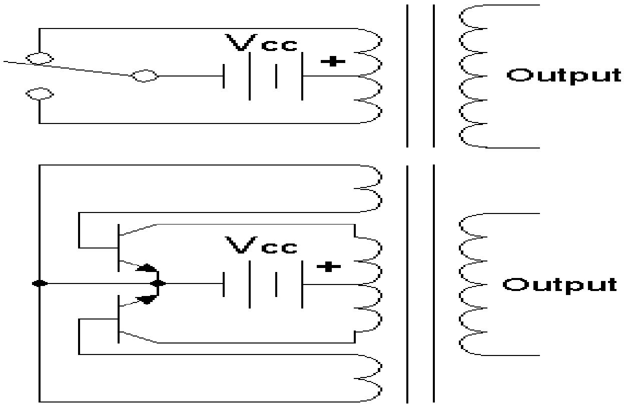
The Modified Sine wave is basically generated by varying On time and Off time by changing RMS voltages while keeping the frequency constant. A modified Sine wave can be used to operate numerous electrical devices namely resistive loads. Most AC motors will also run on Modified sine wave but with a drawback of 20% drop in efficiency due to harmonics and being a bit noisy. The noise, however, can easily be removed with the help of a series LC filter.

ii. Output Frequency:

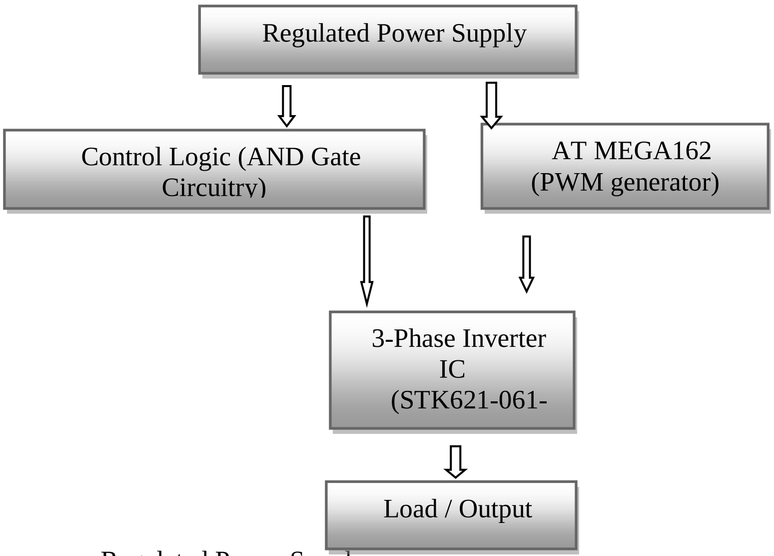
The AC output frequency of a power inverter device is usually the same as standard power line frequency, 50 or 60 hertz. If the output of the device or circuit is to be further conditioned (for example stepped up) then the frequency may be much higher for good transformer efficiency.

iii. Basic Design:

The input current and voltage are provided using a simple transformer. A switch is turned ON and OFF rapidly to change the direction of current. This change in the primary winding of the transformer induces an alternating current in the secondary winding of the transformer. At first, relays were used in such circuits and such circuits were called vibrators or buzzers. But as technology advanced and we were able to handle more power, the use of Thyristors (SCRs) and transistors increased. SCRs provide greater power handling capabilities and are used for large systems that require high power. A simple inverter gives a Square Wave as output if not connected to an output transformer due to simple ON and OFF PWM logic.



iv. Inverter Block Diagram:



v. Regulated Power Supply:

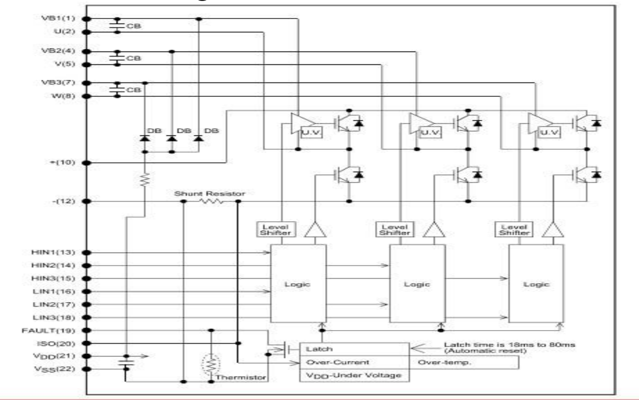
The ATMEGA162 controller and the AND Gate IC are both TTL chips hence require low voltages to work. Similarly the inverter chip also requires 15 volts DC to operate along with the usual 220 Volts AC. The simplest solution was to build a power supply that provides multiple fixed voltages, i.e. 5 volts, 15 volts and 24 volts. To do this we used different regulator ICs of LM78XXC series namely LM7805C, LM7812C and LM7824C. The reason for using the 78XXC series over the regular 7805 IC is that the C series can withstand voltage ratings upto 32 volts.

vi. Power Rating of LM7805C IC:

The chart below shows the voltage rating, current rating, and other features of LM7805C but the LM7812C and LM7824C are almost identical except for the fixed output which is 12 volts DC for LM7812C and 24 volts DC for LM7824C.

vii. Phase Inverter IC (STK621-061-E):

The STK621-061-E is a three phase inverter IC which requires AC as well as DC input to work. It also requires some control logic in order to generate PWM and compare output using output Compare Registers (OCR). Basic internal circuit of STK621-061-E is given below:



Pin Configuration details:

- Pins 1 and 2, 4 and 5, 7 and 8 either require 15V power supplies indivisually or require a bootstrap circuit to work.
- Pin 10 and 12 are the Main Supply terminals.10 is Positive terminal and 12 is negative terminal.
- Pins 13, 14 and 15 are HIGH Logic input pins and 16, 17 and 18 are LOW Logic input pins.
- Pin 19 is the FAULT pin which is 0 by default but goes high if there is any fault in the circuit.
- Pin 20 is ISO pin which is basically Current monitor pin.
- Pin 21 is VDD which is +12V.
- Pin 22 is VSS which is -12V.

Program for the 3 Phase Inverter:

```
#include <mega162.h>
#include <delay.h>
#define f 50
#define spc 24
#define adj 0
#define Phase1L PORTC.0
#define Phase1H PORTC.1
flash unsigned char PWM Codes[721]=
{0,4,9,13,18,22,27,31,35,40,44,49,53,57,62,66,70,75,79,83,87
,91,96,100,104,108,112,116,120,124,127,131,135,139,143,14
6,150,153,157,160,164,167,171,174,177,180,183,186,190,192
,195,198,201,204,206,209,211,214,216,219,221,223,225,227,
229,231,233,235,236,238,240,241,243,244,245,246,247,248,2
49,250,251,252,253,253,254,254,254,255,255,255,255,255,25
5,255,254,254,254,253,253,252,251,250,249,248,247,246,245
,244,243,241,240,238,236,235,233,231,229,227,225,223,221,
219,216,214,211,209,206,204,201,198,195,192,190,186,183,1
80,177,174,171,167,164,160,157,153,150,146,143,139,135,13
1,128,124,120,116,112,108,104,100,96,91,87,83,79,75,70,66,
62,57,53,49,44,40,35,31,27,22,18,13,9,4,0,4,9,13,18,22,27,31,
35,40,44,49,53,57,62,66,70,75,79,83,87,91,96,100,104,108,11
2,116,120,124,127,131,135,139,143,146,150,153,157,160,164
,167,171,174,177,180,183,186,190,192,195,198,201,204,206,
209,211,214,216,219,221,223,225,227,229,231,233,235,236,2
38,240,241,243,244,245,246,247,248,249,250,251,252,253,25
3,254,254,254,255,255,255,255,255,255,255,254,254,254,253
,253,252,251,250,249,248,247,246,245,244,243,241,240,238,
236,235,233,231,229,227,225,223,221,219,216,214,211,209,2
06,204,201,198,195,192,190,186,183,180,177,174,171,167,16
4,160,157,153,150,146,143,139,135,131,128,124,120,116,112
,108,104,100,96,91,87,83,79,75,70,66,62,57,53,49,44,40,35,3
1,27,22,18,13,9,4};

void main(void)
{
unsigned char i=0;
DDRA=0x00;
DDRB=0x13;
DDRC=0x3F;
DDRD=0x10;

TCCR0=0x6a;

OCR0=0x00;

while (1)
    {

    For (i=0;i<spc; i++)
        {
         j=i+8;
         k=i+16;
         if(i<12)
         {
         Phase1L=0;
         Phase1H=1;
         }
         else

 {
         Phase1H=0;
         Phase1L=1;
         }
         OCR0=PWM Codes [i*(360/spc)];     // Output
Phase#1 (OCR0)
         OCR3AL=PWM Codes [(j)*(360/spc)]; // Output
Phase#2 (OCR3A)
         OCR2=PWM Codes [(k)*(360/spc)];   // Output
Phase#3 (OCR2)
         delay_us((1000000/(f*spc))-adj);
        };
    };

}
```

VIII. ACKNOWLEDGMENT

IN THE NAME OF ALLAH, THE MOST GRACIOUS AND MOST MERCIFUL .THANKS TO ALMIGHTY ALLAH FOR GIVING US THE STRENGTH, HEALTH, RESOURCES, TIME AND KNOWLEDGE TO COMPLETE OUR SENIOR DESIGN PROJECT. THIS PROJECT REACHED COMPLETION THANKS TO THE HELP AND GUIDANCE OF MANY PEOPLE, WITHOUT WHOM WE WOULD NOT HAVE BEEN ABLE TO COMPLETE IT. WHATEVER RESULTS WE HAVE ACHIEVED ARE THANKS TO THEIR HELP AND IT IS NECESSARY TO SHOW OUR GRATITUDE BY THANKING THEM.

First of all, thanks to our Project Advisor Asst. Professor Farhan Khan for suggesting us this project and allowing us to work on it. Also thanks to him for guiding us throughout the project till the end and making time for us from his busy schedule whenever we needed guidance.

Thanks to all the teachers who helped us and also thanks to the members of the Senior Design Project Committee for guiding us in making the project and the report.

Last but not the least, thanks to my fellow team members and friends without whose efforts this could not have been possible.

IX. REFERENCES

[1] Sairaj v Dhople, Jonathan L Ehlmann and Ali Davoudi," Multiple input Boost Converter to minimize power losses due to partial shading in PV modules, 978-1-4244-5287-3/10, IEEE 2010

[2] N. Chowdhury, S. E. Reza, T. A. Nitol, A. I. Mahbub, "Present Scenario of Renewable Energy in Bangladesh and a Proposed Hybrid System to Minimize Power Crisis in Remote Areas", International Journal of Renewable Energy Research-IJRER, vol. 2, no. 2, pp. 280–288, 2012

[3] F. Ahammed, D. A. Taufiq, "Applications of Solar PV On Rural Development in Bangladesh", Journal of Rural and Community Development, vol. 3, pp. 93-103, 2008

[4] Tahsina Hossain Loba, Khosru M Salim, "Design and implementation of a micro inverter for single PV panel based solar home system", 978-1-4799-0400-6/13, IEEE2013

[5] Historical Facts; AC/DC Debate, Edison vs. Tesla, circa 1900. http://www.nextekpower.com/support/ac-vs-dc-power.pdf.

[6] Cost of SolarPower.http://www.sunrunhome.com/solar-lease/cost-of-solar/.

[7] R. Haider, R. Alam, N. B. Yousuf, K. M. Salim, "Design and Construction of Single Phase Pure Sine Wave Inverter for Photovoltaic Application", International Conference on Informatics, Electronics & Vision, pp. 190-194, 2012.

[8] I. F. Crowley, H. F. Leung, S. J. Bitar, "PWM Techniques: A Pure Sine Wave Inverter", 2010-2011 Worcester Polytechnic Institute Major

[9] Qualifying Project. http://www.wpi.edu/Pubs/E-project/Available/E-project-042711-190851/unrestricted/PWM_Techniques_final.pdf.