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Design of 7 level Cascaded H Bridge Inverter for Photovoltaic Application

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ABSTRACT

Renewable energy is a purest form of energy available on earth complete utilization of these energies leads to many advantages since it is an inexhaustible source it can be used most of the time. The different types of renewable sources are hydal wind and solar. Solar energy is the energy obtained by converting radiation from the sun to electrical energy using solar panels. The electrical energy obtained from the panel will be in DC and the voltage values will be low and for household purposes high voltage AC is required to convert DC to AC an inverter is required. Since solar energy is a variable voltage source a converter is required to control the voltage and if there is excess of energy that has to be stored in battery for back up. Here both simulation and hardware of a seven level inverter using a simple technique of pulse generation by using MATLAB tool and is used for programming and dumped inside a PIC Microcontroller.

Keywords: Amorphous silicon solar panel, Cascaded H bridge inverter, Closed loop buck converter, MATLAB, PID Controller

I. INTRODUCTION

These days solar energy utilization has gained high interest has it is low cost ,high energy,[1] and a flexible kind of a source which can be installed easily wherever required. Solar energy can provide mega watts of energy when it is properly utilized. Many solar farms are installed which provide huge amount of energy so that the utilization of energy from grid or through from any non renewable energy sources can be limited.

There are different types of solar panels such as Amorphous silicon (a-Si) Cadmium telluride (CdTe) Copper indium gallium selenide (CIS/CIGS),Organic photovoltaic cells (OPC), Amorphous silicon solar panels are different when compared to others because the cells are connected in series the voltage ratings of these panels will be very high when compared to other panels. And the current value will be less then one Amps these panels are used to capture the radiation of the sun.

Since the voltage is higher the required value and is fluctuating a closed loop buck converter is designed to reduce as well as to maintain constant voltage i.e required to charge batteries. The energy stored in the batteries are sent to the inverters.

There are two types of inverter two level and multilevel. Multilevel has more advantages then two level as it mainly reduces the harmonics and provides waveform nearer to sinusoidal can be obtained[2]. There are different types of multilevel inverters such as diode clamped , capacitor clamped and cascaded H bridge inverter[8].

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Out of these Cascaded H bridge inverter is low cost, high efficient inverter .The voltage levels can be increased by increasing the level of the bridges and individual bridges will have their own protection [4]. The energy from the battery is converter from AC to DC but the inverter output will be less to boost that voltage a step up transformer has to be designed and used. Since the inverter designed is a 7 level inverter the output voltage waveform will have 7 steps of different voltage levels[3] varying from 3Vdc ,2Vdc ,Vdc, 0, -Vdc, -2Vdc, -3Vdc, where Vdc is the battery voltage.

To turn on and off the switches a pulse has to be generated there are many pulse generation techniques such as space vector modulation and multicarrier pulse width modulation these techniques are complex and requires lot of time to generate a pulse. The technique used here is a simple and different kind of pulse generation which can be done using MATLAB and SIMULINK tool.

Multilevel inverter can also be used for ac drives because of its improved low harmonic output and also the switches have less dv/dt stress[6]-[7].As the switching devices increases the control of these switches will be complicated.

This paper consists of six sections 1. Introduction ,2.Literature survey, 3. System Model, 4. Scope of research 5. Proposed system and discussions 6. Results and graphs 7. Conclusion;

II. LITERATURE SURVEY

From paper [9] the design and development of cascaded H bridge inverter was analyzed. Its advantages when compared to other multilevel inverters and its disadvantages was studied and designed according to the requirement.

From Paper [10] the design of the maximum power point tracker which is also a converter was studied and a sccording to that a closed loop buck converter was designed and tested.

From paper [11] the control technique used to control converter circuit using DSP processor was studied and the modifications were made and PID controller was designed using PIC microcontroller.

From paper [12] the simulation and design of step up transformer was completely obtained and according to that design a step up transformer was developed and was tested.

From paper [13] the capacity of the battery that has to be installed to get required backup by knowing the state of charge was obtained and according to that the battery arrangements were made

And referred L umanand text book for the design of transformer and inductors and for obtaining the standard values for the calculation of inductor and selection of core and wire for winding

III. BLOCK DIAGRAM AND MATERIALS & METHODS USED

In this section the complete picture of the proposed work is shown in the form of a block diagram and the list of materials and methods used are explained here. From the above Fig.1 shown below we can see that the solar energy from the panel is reduced using converter and it is stored in battery using battery charge [5]controller as a charging, discharging and protection unit the DC energy from the battery is converted to AC through inverter and boosted using transformer.

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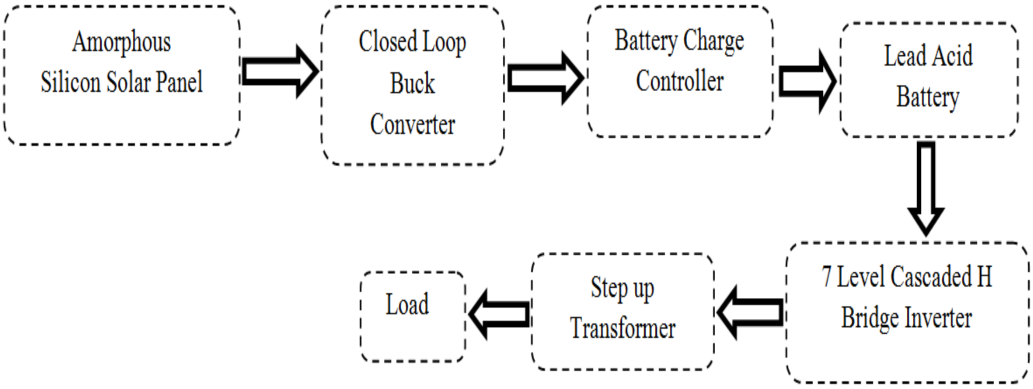

Fig.1 Block diagram of the complete system

The materials mainly used in the proposed system are listed in the Table.1 below

Table 1 System specifications and quantity

Material used	Ratings or Specification	Quantity
Amorphous silicon solar panels	72Voc and 35W	18
Closed loop buck converter	90 to 35V output 6A	3
Battery charge controller	12/24V 50Vmax 10A	3
Step up transformer	72-230V 2KVA	1

The methods used in the proposed system are PID control technique and pulse generating technique by using MATLAB and SIMULINK module and programming and controlling using PIC16F877A microcontroller.

IV. SCOPE OF REASEARCH

This proposed solar PV multilevel inverter was basically designed to utilize the renewable energy and it was basically designed for rural electrification purpose. The scope is to implement a new and a simple technique for pulse generation.

And design a PID controller for closed loop buck converter. Since the proposed work has many sub systems assembling them and obtaining accurate result is a high task. This system works as a backup and it also reduces the utilization of power from grid.

V. PROPOSED WORK AND DISCUSSION

The proposed work is first simulated and after getting exact values of the components that has to be used for hardware will be obtained using that the hardware part is designed and tested

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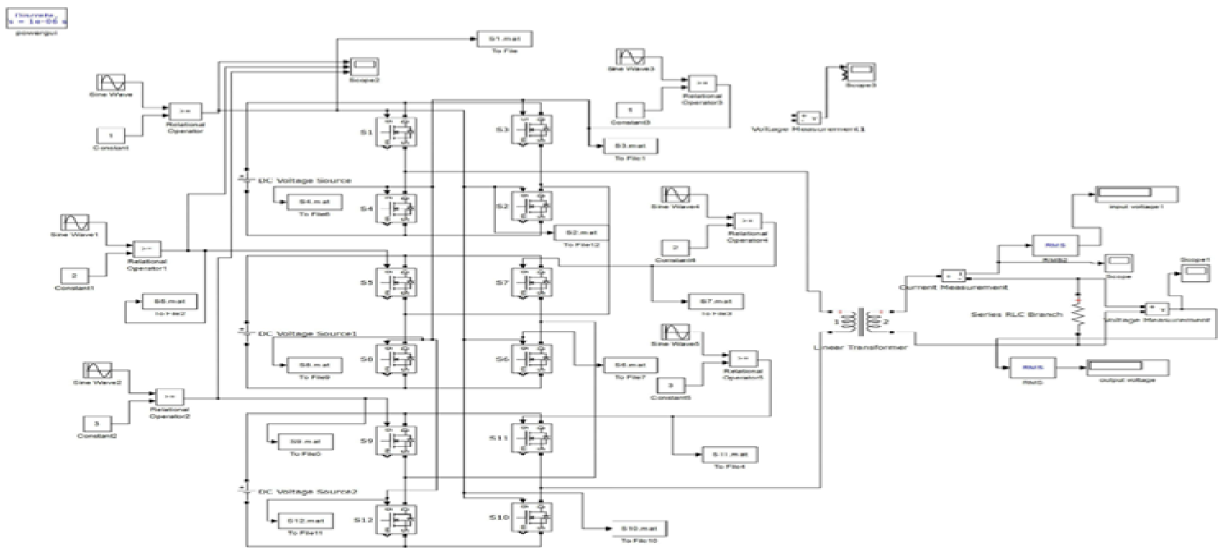

Fig.2 Simulation circuit of cascaded H bridge inverter

Simulation of the complete 7 level cascaded H bridge inverter is as shown in fig.2 above there are 3 cascaded H bridges connected in series on the secondary side and total number of switches used are 12 (MOSFET IRF3205) and the switching sequence is divided into 6 Mode of operations .

Mode 1 during this mode switches M1 ,M12 ,M8,M4 , and internal diodes of mosfet M7 and M11 will conduct including only one voltage source V1 so the voltage will be Vdc

Mode 2 during this mode switches M1 M12 M8 M4 M5 and internal diode of mosfet M11 will be on including two voltage sources V1 and V2 so the voltage will be 2Vdc

Mode 3 During this mode switches M1 M12 M8 M4 M5 M9 will be on including all the three voltage sources V1 V2 and V3 so the total voltage will be 3Vdc

Mode 4 this is for negative half cycle which is after 180 degree phase shift so the diodes will be in reverse bias condition during this mode the current will start flowing from the negative terminal of the source V1 through switches M2,M11,M7,M3 and internal diodes M12 ,M8 and reaches the positive terminal of the source. The voltage will be

–Vdc

Mode 5 during this mode switches M2,M11,M7,M6,M3 including internal diode M12 here two sources gets added up giving output voltage as -2Vdc

Mode 6 during this mode switches M2 M11 M7 M6 M3 M10 will be on including all the three voltage sources giving output voltage as -3Vdc the switching cycle of inverter is given in the table below.

The switching Table.2 is as shown below

Table.2 Switching table of cascaded H bridge inverter

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M1	M4	M3	M2	M5	M8	M6	M7	M9	M12	M10	M11	V
0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	1	0	1	0	1	0	1	Vdc
1	1	0	0	1	1	0	0	0	1	0	1	2Vdc
1	1	0	0	1	1	0	0	1	1	0	0	3Vdc
0	0	1	1	0	1	0	1	0	1	0	1	-Vdc
0	0	1	1	0	0	1	1	0	1	0	1	-2Vdc
0	0	1	1	0	0	1	1	0	0	1	1	-3Vdc

The value of Vdc is the battery voltage which is 24V (12V batteries are connected in series) so the maximum voltage output of the inverter is 3Vdc which will be 72V which is converted to72V AC using inverter. In the simulation circuit instead of PWM block a new comparative analysis box is used which compares a sine wave and a constant value and provides a pulse which is as shown in as shown in fig 3 below.

The main advantages of cascaded H bridge inverter is that it is easy to design a cascaded H bridge inverter when compared to other multilevel inverters because it consumes less components and low cost there is no need of adding any filters because each H bridge will be having its own filter circuits and it is easy to add levels when compared to other inverters the harmonics will be less in these inverters. The main disadvantage of the cascaded H bridge inverter is that each bridges requires separate sources. So as the level increases the source also increases.

In this proposed work each H bridge is connected to separate batteries and solar panels which makes it three sets. If one bridge fails it will not affect the other two bridges attached to it as a matter of safety MCB and fuses are used for the protection of the system as well as the batteries which prevents from drawing excess of current from the source due to faults.

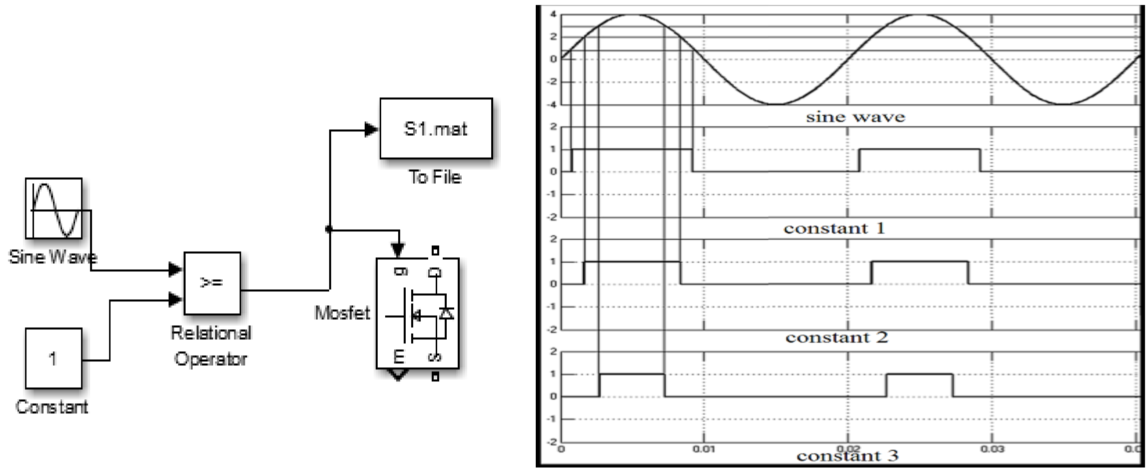

Fig.3 Proposed method for pulse generation

The output pulse obtained by comparing a sine wave of magnitude 4 with constant (1,2,3) is as shown in fig.3 above. The TO FILE block used in the simulation block will provide time scale value of the pulse in an excel sheet format this value shows at what time the switch is on and off

The obtained values are programmed using MPLAB software and is dumped in PIC16F877A controller and the output of it is sent to the gate driver circuit which controls the turn on and off of the MOSFET this gate driver circuit is called as a push pull gate driver unit which uses PNP NPN transistor , and a optocoupler.

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The output of the controller will be in analog that is high or low pulse the voltage value of this pulse will be 5V and the gate driver unit requires 12V to turn on the MOSFET which is taken from the grid by steping down using transformer and converting the AC voltage to DC using capacitor and diode and is sent to the gate driver unit which is as shown in Fig 4 below.

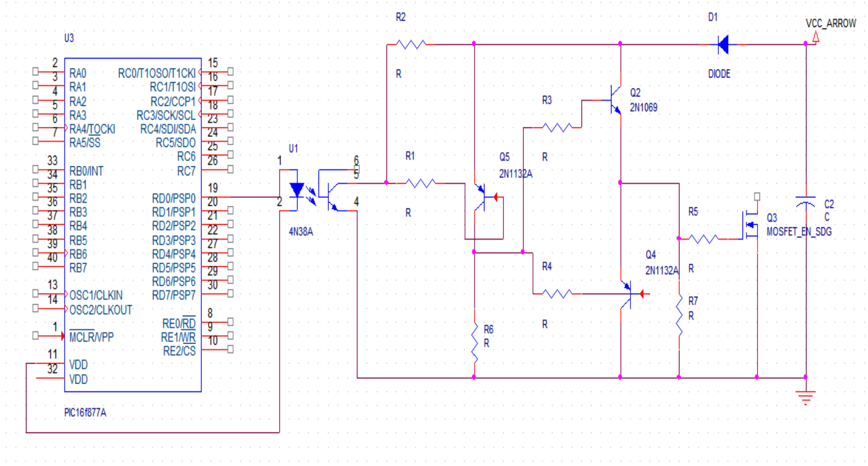

Fig.4 Push pull gate driver unit

During high pulse PNP and NPN transistor will turn on and transmits the 12V to the gate of the MOSFET which will turn it on. During low pulse both PNP transistor turns on connecting gate and source forming a closed loop discharging charges stored in MOSFET and turning it off. Since there are 12 switches there are 12 gate driver units.

The closed loop buck converter is used basically because the output of the solar panel is fluctuating and varies according to the radiation. Amorphous silicon panel provides the voltage rating from 50-75V and the battery charging voltage for a 24V battery should be slightly more then the rated voltage. The closed loop buck converter reduces the voltage from solar panel to 35V which is sent through battery charge controller to the battery so that the battery can be protected. The buck converter basically consists of resistance inductor and capacitors. The design of converter basically consist calculating the values of RLC and using simulation it is verified.

The design of inductor basically consist of choosing the type of core and the number of turns, as well as the material used for turns which can be obtained from the datasheets.

There are different control techniques like Linear quadratic regulator (LQR), PID, Fuzzy tuned PID, sliding mode and error compensation method out of these simplest control technique which is widely used is PID control technique

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5.1 Design of closed loop buck converter

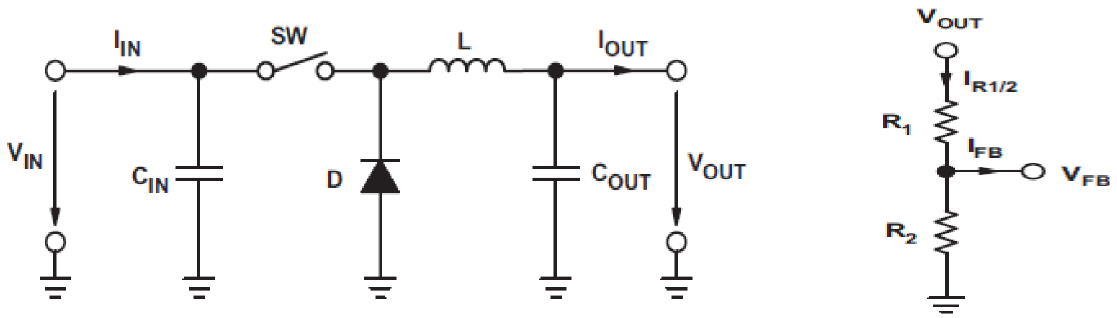

Fig.5 Buck converter with feedback circuit

The maximum input voltage Vin is 90V and it is a variable input and it has to be reduced to 35V because the charge controller capacity is only 50V it cannot withstand voltage above that,Vin is 50-90V, Frequency is 20KHz and Vout is 35V and current is 6A.Since the input and the output is known the duty cycle can be calculated using the equation given below duty cycle is expressed as D

$$D=\frac{Vout}{Vin}=\frac{35V}{90V}=0.388 \qquad (3.1)$$

To calculate the ripple current 20-40% of the maximum current is considered.

$$\Delta IL=(0.2\text{-}0.4)\times I \qquad (3.2)$$

$$\Delta IL=0.4\times 6= 2.4$$

The value of inductor is calculated by using the equation given below

$$L=\frac{Vout\,(Vin-Vout)}{\Delta IL\,fs\,Vin} \qquad (3.3)$$

By substituting the values in equation 3.3 we get the value of inductor as

$$L=\frac{35(90-35)}{2.4\times 20000\times 90}= 0.4mH$$

The value of capacitor can be calculated using the formulae given below.

$$C=\frac{\Delta IL}{8f\,\Delta Vout} \qquad (3.4)$$

The value of ΔVout is equal to ΔIL by substituting all values in equation 3.16 the value of capacitor can be obtained as.

$$C=\frac{2.4}{8\times 20000\times 2.4}= 6.5\mu F$$

The output of the buck converter is given to the controller so the voltage has to be below 5V the output has to be reduced using resistance divider circuit has shown in Fig below. The resistance R1 and R2 has to be designed such that the voltage ranging from 50-90V has to be reduced to 0-5V to calculate the value of R2 we have to assume the value of R1 to some value. Let the value of R1 is assumed as 43KΩ the formulae to find out R2 is given below.

$$\frac{Vout}{Vin}=\frac{R2}{R2+R1} \qquad (3.5)$$

Here the value of Vout is 5V the maximum voltage a controller can withstand substituting all the values in equation 3.5 the value of R2 can be obtained

$$\frac{5}{90} = \frac{R2}{43K+R2} \qquad R2=820K\Omega$$

The inductor used is a torroidal inductor and it is designed and tested.

Step-1 before calculating the area product the energy that has to be stored by the inductor is calculated by using the below formulae.

$$El=\frac{1}{2}LIm^2 \qquad (3.6)$$

Where Im = Io+ΔIl/2 and ΔIl is 10% of Io which is 6A the value of Im is obtained as 6.3

By substituting the value of Im and the value of L as calculated from equation 3.6

$$El=\frac{1}{2}0.14mh\times 6.3^2 = 0.2122mJ$$

By using the value of energy the area product is calculated by using the equation given below

$$Ap = \frac{2El}{Kw\times Kc\ J\ Bm} \qquad (3.7)$$

Where Kw,J,Bm are the design parameters that has to be chosen by the designer. The default value is selected as Kw is 0.6 , J is 3×10^6 , Bm is 0.25T , Kc is 1.05 by substituting these values in above equation we obtain the value of area product.

$$Ap = \frac{2\ 0.2122mJ}{0.6\times 3\times 10^6\times 0.25\times 1.05} = 8928\ mm^4$$

The area of product value higher than the above value is selected as a core from the table mentioned in appendix Ap value is closer to the value T32 but here the core is chosen as T31.5. the toroidal core T31.5 dimension are A=31.5,B=19,C=12 which is as shown in Fig 6 below. The nominal inductance value of the core is taken from the table present in appendix

Which will be denoted as Al=3825.

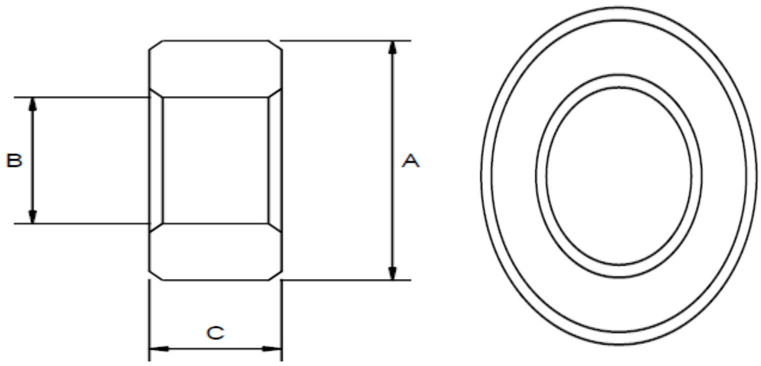

Fig 6 Torroidal core design

The next step is to find out the number of turns that has to be wounded around the core.

$$N=10^3\sqrt{(L/AL)}= 10^3\sqrt{(0.14mH/3825)}=11turns \qquad (3.8)$$

Where L is in miliheneries

Gauge of wire a=Iavg/J = 3.816/3×10^6 =1.272mm² which is nearer to the value of 18swg

Amorphous silicon is a thin film panel where the cells are connected in series and the its voltage will be maximum current will be minimum so the panels are connected in panel since the battery used is 60AH battery minimum 6A current is required to charge the battery so 6 panels (1 set)are connected in parallel to get required

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current. The main disadvantage of cascaded H bridge inverter is that for each bridge a separate source is required and since there are three bridges three set of batteries and three sets of solar panels, buck converters and charge controllers are required

The required output is 230V AC and the output of the inverter is 72V AC it has to be boosted by using a step up transformer. Shell transformer of rating 72V to 230V 2KVA transformer is designed. The complete circuit diagram of the system is as shown in fig below

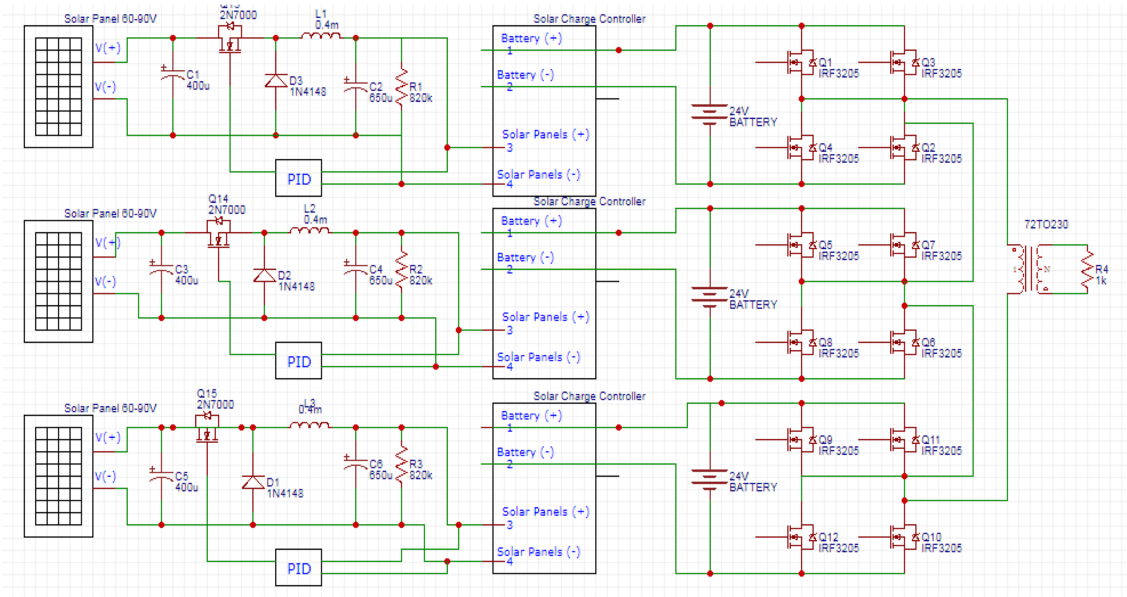

Fig.7 Complete circuit of the proposed system

The hardware implementation of the proposed system is as shown in Fig.7 below

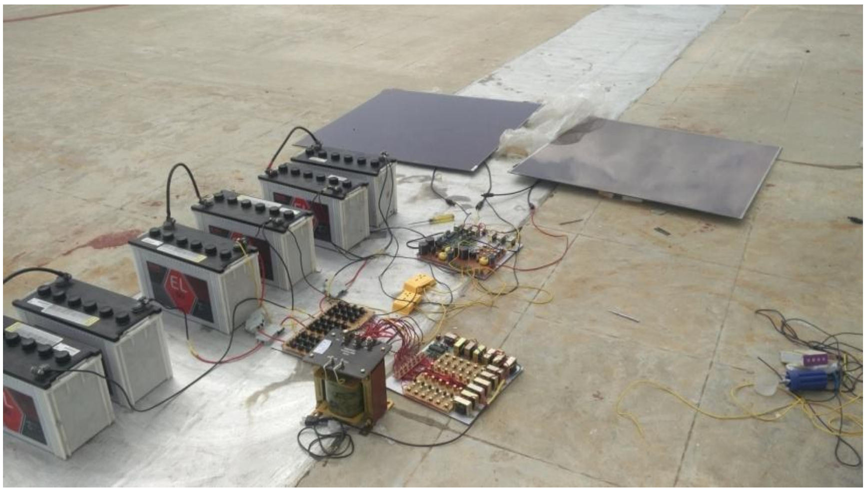

Fig.8 Hardware implementation

The solar panel output is connected to closed loop buck converter. The reduced voltage is sent to the battery charge controller which charges the battery. Two batteries are connected in series so the total voltage will be 24V which will be input to the inverter. There are 3 H bridges so for each bridge two batteries are connected as a supply. The total output voltage at the secondary side of the inverter will be 72V which will be boosted to 230V using step up transformer. The multilevel inverter consists of 36 switches (12 sets and each set as 3

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switches all are connected in parallel) .MOSFET IRF3205 is used as switches. The gating signal is provided by the push pull gate driver unit. The supply for the gate driver and controller unit is provided by using transformer which converts 230V AC to 12V AC which is later on converted to 12V DC by using capacitor and diode circuit and by using LM7805 regulator it is reduced to 5V DC for the controller.

VI. RESULT AND GRAPHS

This section consists of graphs and tables obtained from both simulation and hardware. The output of the cascaded H bridge inverter must be a 7 step output which is as shown in figure below.

The output of the inverter must be 72V AC and after steping it up it should be around 230V AC. Since the inverter is designed for 1500W the input current drawn from the battery will be around 20A since it is a 60 AH battery the backup will be around 3 hours. But the result obtained was slightly less then the expected output. The output voltage obtained was 200V and was tested for 1200W.

The closed loop inverter was tested using a autotransformer from 90V to 50Vand the output obtained was 35V and 6A

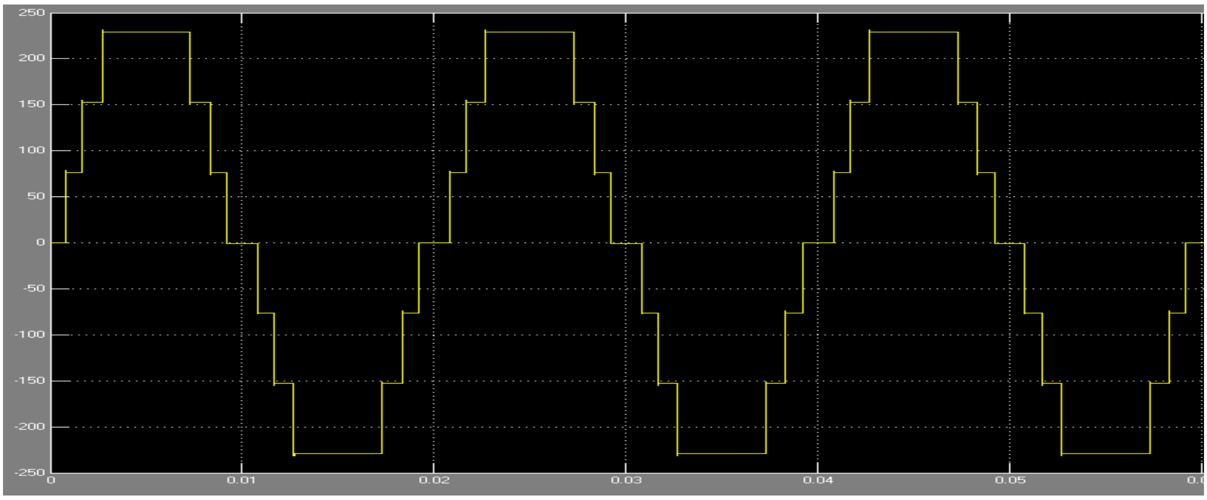

Fig.9 Simulation result of 7 level inverter

The output waveform obtained after completely setting up the hardware is as shown in the Fig below

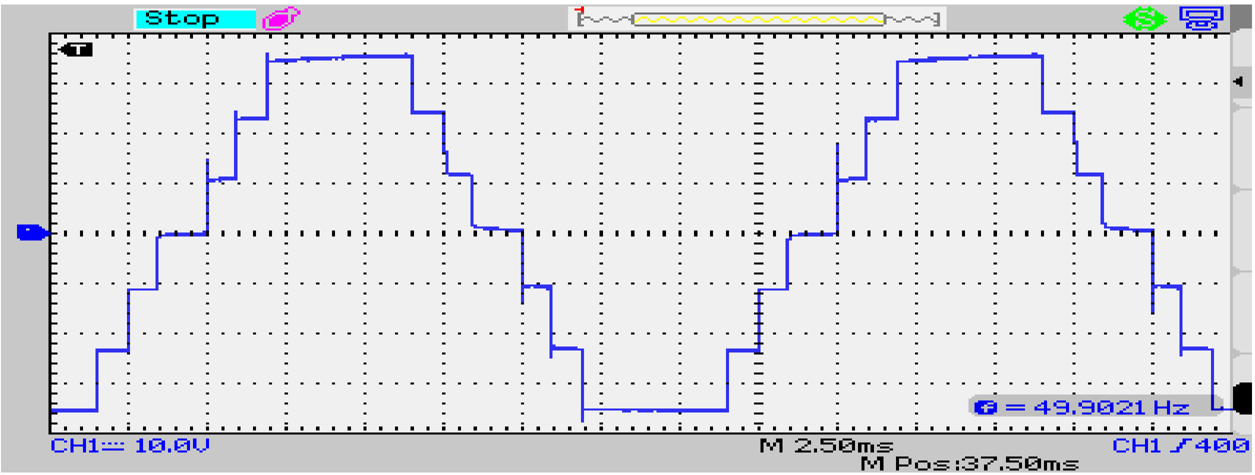

Fig 10 Hardware tested result of output waveform

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Both the simulated and the hardware outputs match each other and the frequency is reduced to standard 50hz and the voltage obtained is 200V

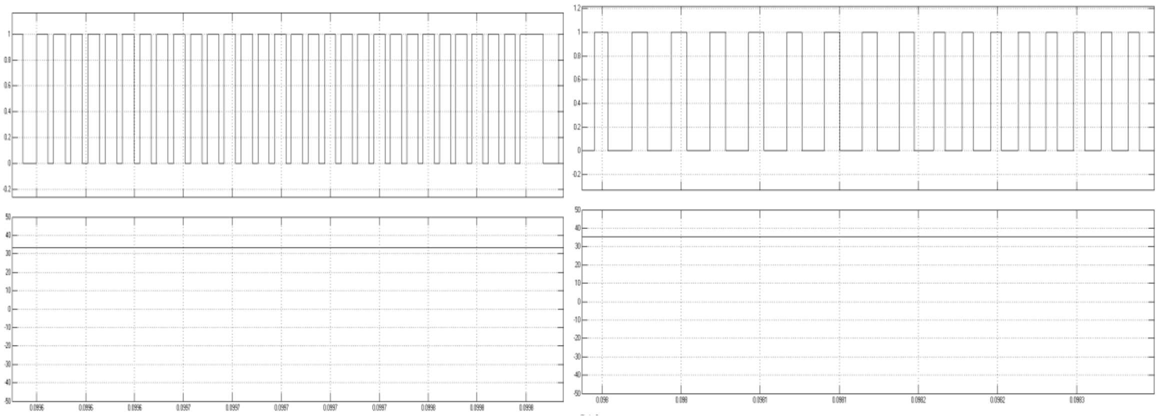

Fig 11 Simulated result of closed loop buck converter

The closed loop converter simulation results with the pulse for 78 as well as 58V is as shown in Fig above as we can see that as the value of voltage increases the pulse width decreases and vice versa even the hardware testing results matched the same which is as shown in fig below

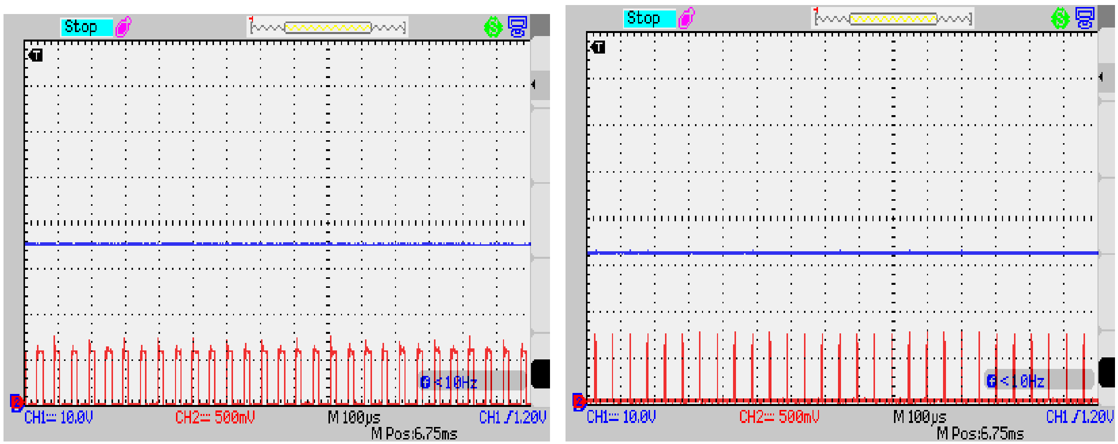

Fig 12 Hardware result of closed loop buck converter

VII. CONCLUSIONS

In the study of multilevel inverter the main important concept got to know was as the level increases the harmonics reduces. The seven level multilevel inverter was successfully designed and implemented. an appropriate scheme is proposed for the utilization of solar energy. The inverter is operated at the voltage range of 12V or 24V which gets added up to 36V or 72V which is stepped up to 230V by using 36/72V to 230V step up transformer. Here input is 24V and the output obtained is around 200V and upto 1.5KVA power. The inverter designed and operation, performance of the multilevel inverter was testified using simulation and verified experimentally and both the results closely matched for the design of closed loop buck converter which was designed to obtain 35V for the variable output range from 40-90V by using trial and error technique to obtain the correct value of P,I and D the output was verified by using both simulation and hardware and the results matched.

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