Design & Fabrication of 1KW Pure Sine Wave Inverter

A Community Solutions Initiative of IEEE Power and Energy Society

Dr. Shahidul Islam Khan
Professor,EEE,BUET.
Team Leader

Dr. Md. Ziaur Rahman Khan
Professor,EEE,BUET.
Deputy Team Leader

Shammya Shananda Saha
Research Assitant,
Arizona State University.
Initiator

Shuvangkar Chandra Das
Undergradute Student,
EEE,BUET.
Student Leader

Chondon Roy
Undergradute Student,
EEE,BUET.
Deputy Student Leader

Sums Uz Zaman
Undergradute Student,
EEE,BUET.
Student Volunteer

Department of Electrical & Electronic Engineering(EEE),
Bangladesh University of Engineering & Technology(BUET)

IEEE PES
Power & Energy Society®

IEEE

1KW Pure Sine Wave Inverter fabrication process

System Specification:

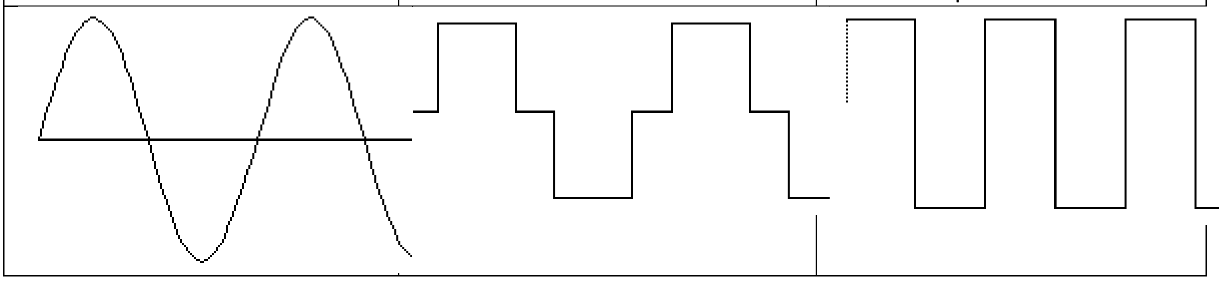
Nominal input voltage	24 V
Output voltage	220 V rms, 50 Hz
Output Power	1 kW
Efficiency(max)	80%
DC-DC Switching frequency	100 kHz (DC-DC)
DC-AC Switching frequency	16 kHz
No of layer in PCB	Single Layer
THD(minimum)	2.8
Protections	Input over-current, Output short-circuit, Input battery low voltage, Heat sink over-heating

Introduction:

There are 3 types of Inverters available in the market.

1. Pure Sine Wave Inverter
2. Modified Sine Wave Inverter
3. Square Wave Inverter

Pure sine wave	Modified Sine Wave	Square Wave



From the above wave shapes we can clearly observe that pure sine wave inverter generates similar wave shape like generators/power grid-company.

We have developed a pure sine wave inverter which is completely open source. Our project is designed for 1KW DC-AC Converter which is suitable for Battery Powered UPS system or Photo-voltaic standalone system.

We have included all the necessary files needed to fabricate our design. In this report, step by step, we will describe the fabrication process of 1KW Pure Sine Wave Inverter. If you face any problems fabricating our design please let us know through email. For any constructive discussion, queries, feedback regarding the project feel free to contact with us through email.

Name	Contribution	Email

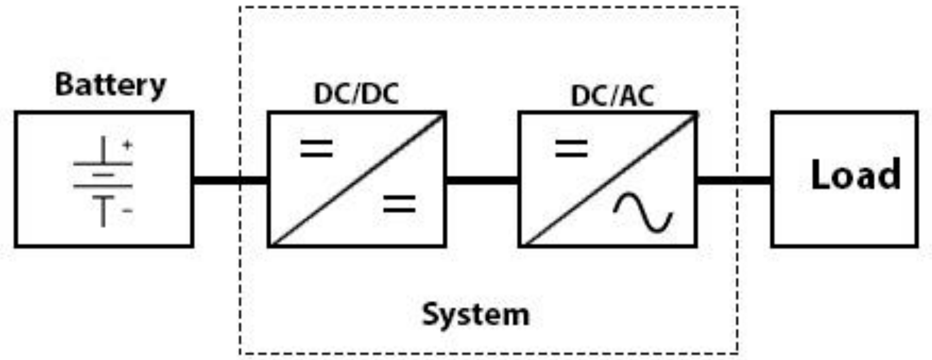
Dr. Shahidul Islam Khan	Team Leader	shahidul@eee.buet.ac.bd
Dr. Md. Ziaur Rahman Khan	Deputy Team Leader	zrkhan@eee.buet.ac.bd
Shuvangkar Chandra Das	Student Leader	s.c.das@ieee.org
Chondon Roy	Deputy Student Leader	c.roy.bd@iee.org

Advantage of pure sine wave

The most important advantage of pure sine wave inverter is that each appliance sold in the market is manufactured for pure sine wave. Many sensitive devices like medical instruments do not work perfectly without pure sine wave.

How the system works:

The system is fed up from low DC voltage varying from 21 to 28 voltage and output is single phase 220 V AC (RMS) voltage.

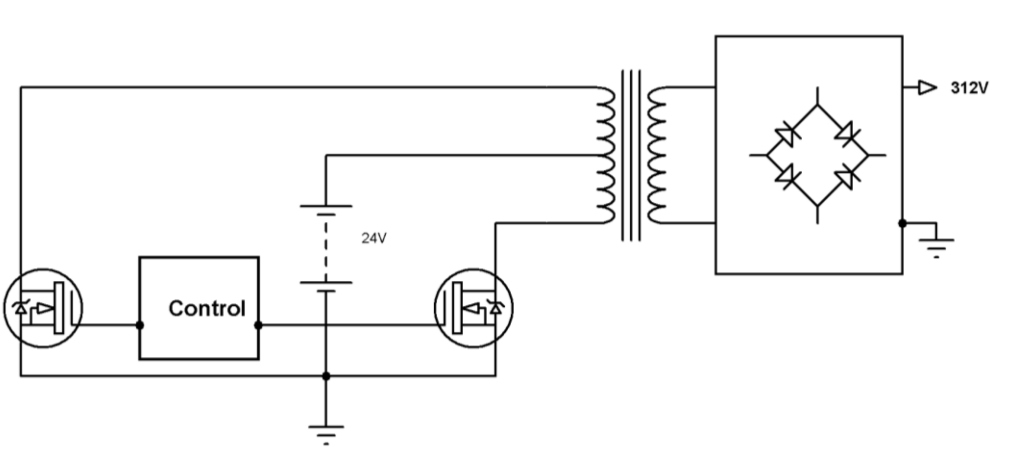


There are two main building blocks of the system.

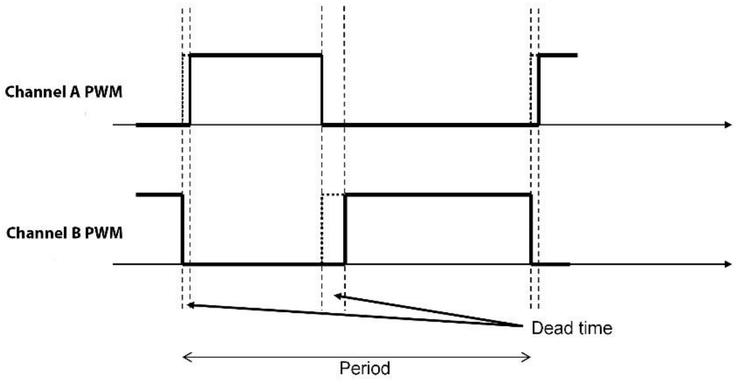
1. DC-DC converter
2. DC-AC Converter

DC-DC Converter

In this portion there is a boost converter which converts 24V (nominal) into 312V. As a boost converter we used push-pull topology. In the following image you see the basic block diagram of the push-pull topology.



Control circuit generates two complementary PWM signals. These signals drive the both side MOSFETs and Transformer steps up the battery 24V into 312V.



In the secondary side of the transformer we get -312V to +312V, high frequency square wave power signal. After rectification & filtering we get 312V HVDC output.

Why push-pull topology:

There are two ways to invert a 24V DC input to a 220V AC output.

- One method is first creating a sine wave output of 24V amplitude and then stepping up the sinusoidal 24 V peak voltage to the desired output using an iron core transformer.
- The second method is first stepping up the DC voltage to $220 \times \sqrt{2} = 311\ V$ DC and then inverting this DC voltage to sinusoidal output voltage.

The power loss in iron core transformers is much larger than the power loss in ferrite core transformer (used in DC-DC converter). For this reason we chose the second method for this project.

We can divide the DC-DC converters into two classes:

1. Forward (energy transfers through the magnetic field)
2. Flyback (energy is stored in the magnetic field)

We can also categorize DC-DC converters into two classes from another point of view:

1. Isolated
2. Non-isolated.

For better performance we chose isolated converter.

There are a few isolated step up forward converter topologies. Some popular topologies are given below:

- Half Bridge
- Full Bridge
- Push-Pull

In a half bridge converter the observed input voltage becomes half of the actual input voltage. For this reason we left this topology from our list.

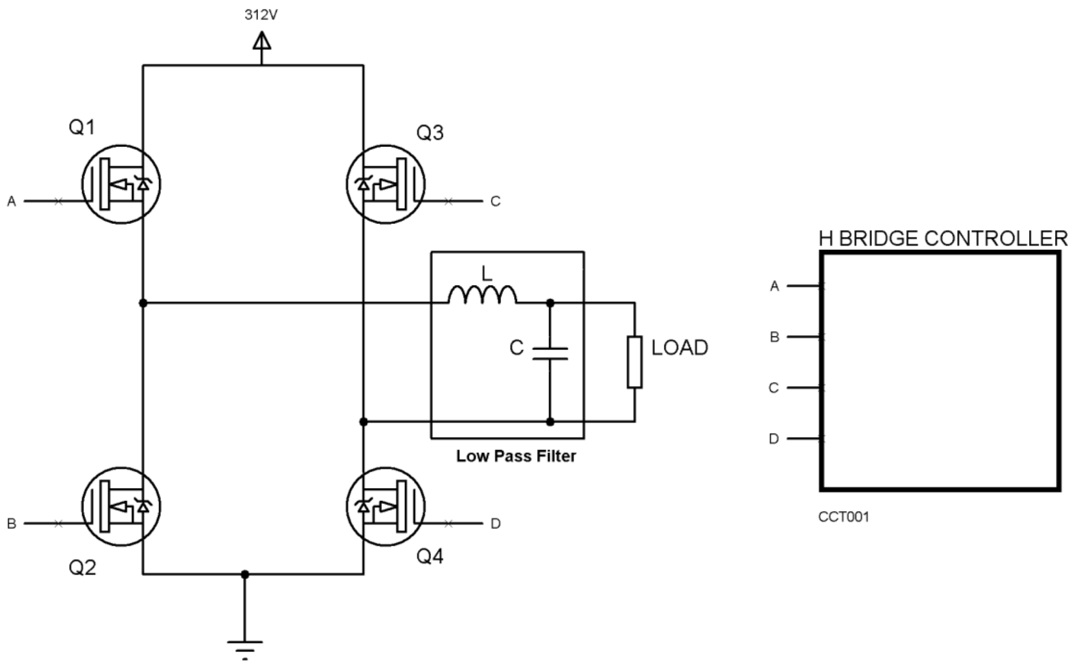
In a Full Bridge converter there are four control switches. Reference voltage (source voltage) of two of them is floating. For this reason the control system is a little bit complex.

In a Push-Pull converter there are only two control switches and both are ground referenced. So the control system is much easier than Full Bridge converter.

Considering all the above facts we chose Push-Pull topology for our design.

DC-AC Inverter:

In this portion the High voltage DC is inverted into AC voltage. We used Sinusoidal Pulse Width Method (SPWM). In this method the popular H-bridge Circuit is required. The controller circuit generates the high frequency SPWM signals and drive the four MOSFET switches (Q1, Q2, Q3, and Q4). After filtering the high frequency SPWM power signal using low pass filter we get the desired Sine wave.



Parts of the final board:

The project consists of 4 PCBs

1. **Main Board :**
   All the power line connections
2. **Push-Pull Controller:**
   Generates Push-Pull control signals
3. **H-Bridge Controller:**
   Generates SPWM control signals
4. **Protection Circuit:**
   Detects Faults like input over current, output short-circuit, battery low voltage, heat sink over-heating etc. and generates necessary protection signals then sends the signals to Push-Pull controller circuit

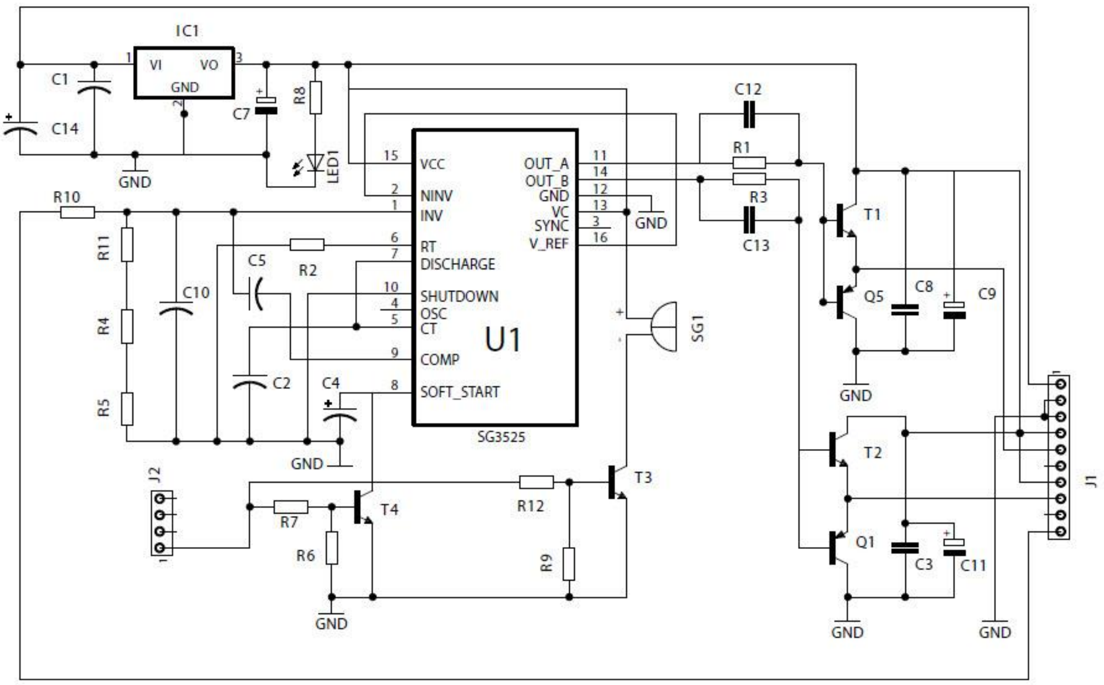
Push-Pull Controller:

So to drive push-pull MOSFETs we need a control circuitry which will generate necessary control signals. Control circuit output rail (J1) pinout description is given below.

Pin No	Pin Description
1	Control Circuit power input(Minimum 14V)
2	GND
3	GND
4	+12V
5	PWM Out(Channel A)
6	NC
7	+12V
8	PWM Out(Channel B)
9	NC
10	HVDC(312V) Feedback input

There is another output rail (J2) of control circuit. Pinout of output rail J2 is given below

Pin No	Pin Description
1	NC
2	NC
3	NC
4	Fault protection input



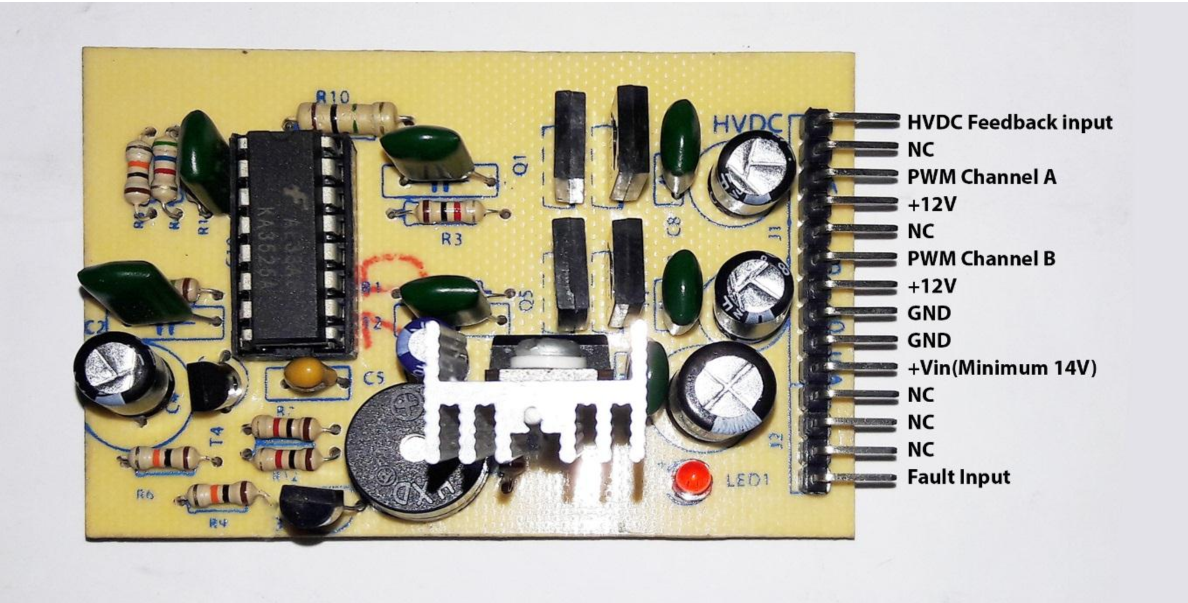
You will find PCB design of all the sub-circuits in the project file folder. After printing all the PCBs follow the steps.

First, solder the control circuit PCB. The component values are listed below.

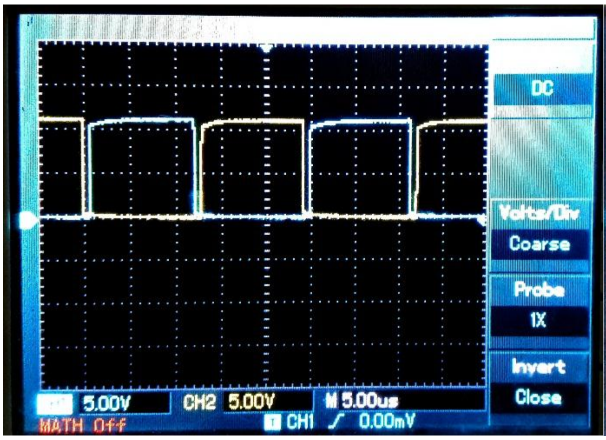
Push-Pull Control elements			
Component name	value	type	description
R1, R3	1k, 0.25W		Totem pole Base Resistor
R2	1.5k, 0.25W		3525 oscillator resistor RT
R10	1M, 0.25 W		Feedback resistor
R7	1k, 0.25W		Shutdown BJT Base Resistor
R6	10k, 0.25W		Shutdown BJT Pull Down Resistor
R12	1K, 0.25W		Buzzer BJT Base Resistor
R9	10k, 0.25W		Buzzer BJT Pull Down Resistor
R11	10k, 0.25W		Feedback Resistor
R5	5.6k, 0.25W		Feedback Resistor
R4	680R,0.25W		Feedback Resistor
R8	5.6k, 0.25W		Power LED
C1	10 nF	Polyester	7812 input Capacitor
C14	100 uF	Electrolyte	7812 input Capacitor
C7	10 uF	Electrolyte	7812 output Capacitor
C2	10nF, 100 V	polyester	3525 Oscillator capacitor, CT
C12, C13	10nF, 100 V	polyester	Totem Pole Base Capacitor
C3,C8	10nF, 100 V	polyester	Totem Pole Bypass capacitor
C9,C11	100 uF,25V	Electrolyte	Totem Pole Power Capacitor
C10	10nF, 100 V	polyester	Feedback input capacitor
C5	1 uF, 100 V	Tantalum	Compensation Capacitor

C4	220 uF	Electrolyte	Soft Start Capacitor
SG1	Buzzer		Fault alarm
IC1	LM7812		Linear Voltage Regulator IC
U1	SG3525		PWM IC
Q1,Q5	BD136	PNP	Totem Pole PNP BJT
T1,T2	BD135	NPN	Totem Pole NPN BJT
T3,T4	BC547	NPN	Protection and Buzzer activating NPN BJT
J1,J2	Male connector		Connecting rail to main board

After soldering all the components of the push-pull control circuit the board looks like this:



It’s time to check the two channels signal of the push pull control circuit. So power on the control circuit using +Vin & GND pin. There is on-board 7812 linear regulator. So while testing, Vin should be minimum +14V. It will generate two PWM signals. The two signals are complement of one another and there is minimum of 5% dead time between the signals. Left side image yellow one is channel A signal & blue one is channel B signal. Two signals are complementary. In the 2nd image we can clearly observe the dead time between the signals.

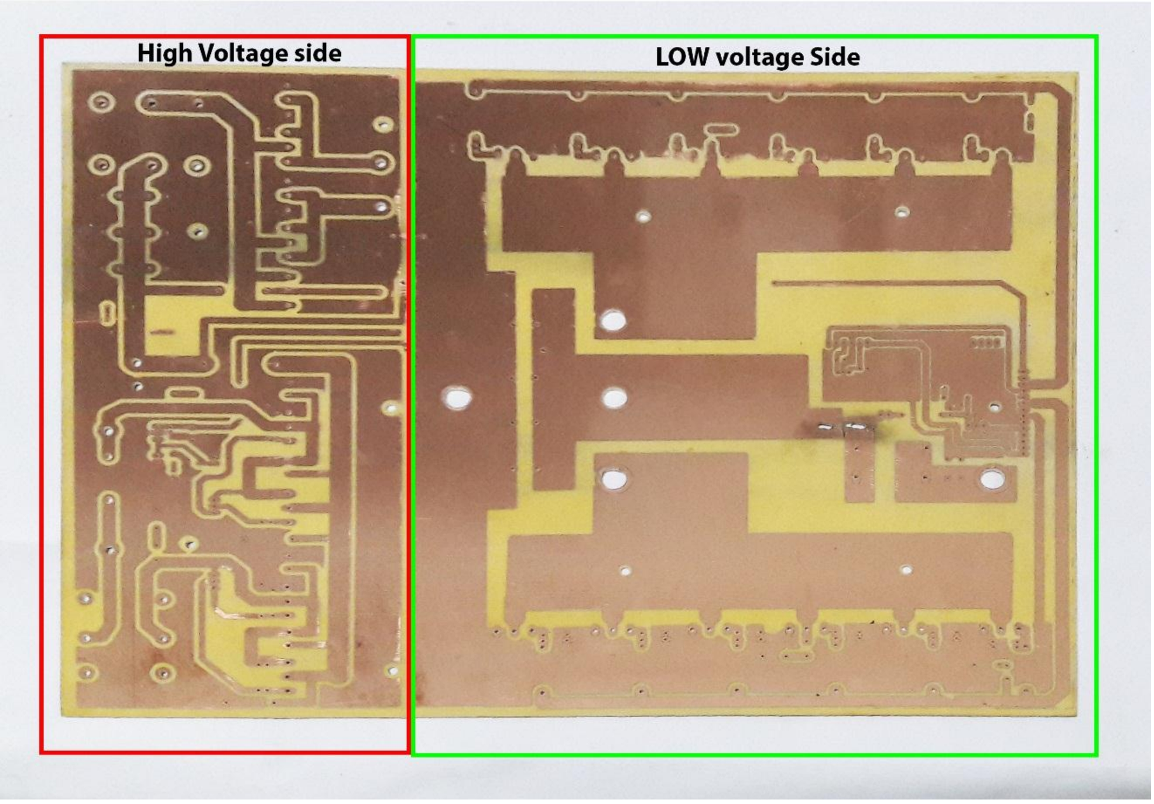


Push-pull Converter:

When we get the push pull control signals perfectly, next step is to fabricate the main board. In the main board PCB layout, there are two side.

1. Low voltage side or transformer primary side
2. High voltage side or transformer secondary side & DC-AC inverter portion

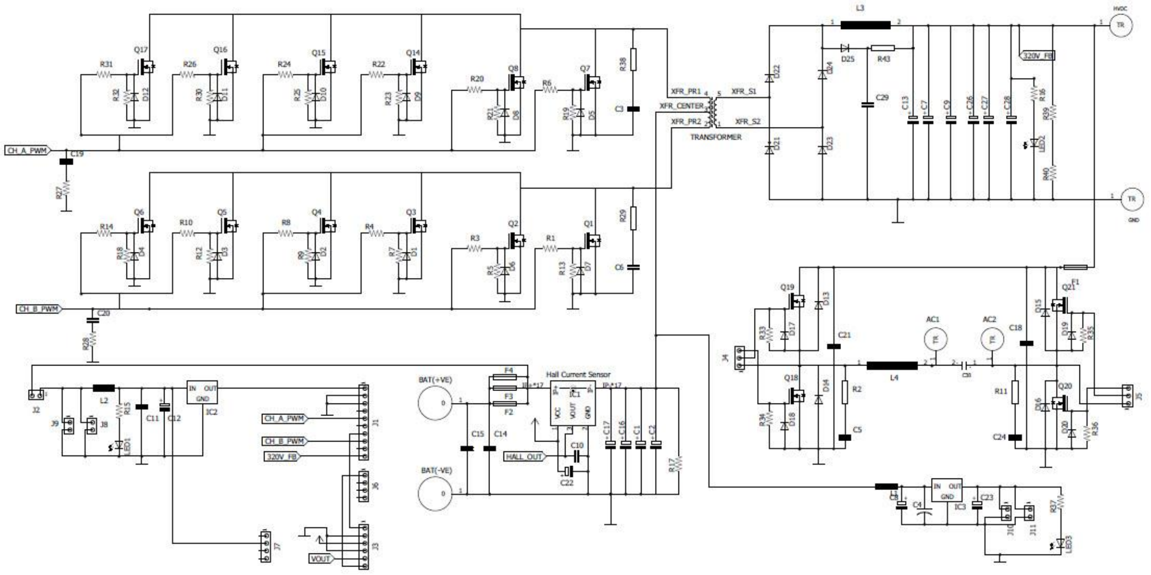
Both side are kept isolated except reference voltage connection for the feedback line.



Low Voltage side assembling:

In the low voltage side basically push-pull transformer primary side. In the main board, first we solder the low voltage side and then test it.

Here is the schematic. For better view please open the pdf file of this design.



Main board Input pin description:

- **J1 & J6:** Push-Pull control circuit input rail
- **J3 & J7:** Protection Circuit Input rail
- **J4, J5 & J10:** H-Bridge Controller input Rail
- **J8 & J9:** cooling fan power up rail
- **J2:** System Power up switch connection rail

Low voltage side components description is given below.
The main concern of this side is Heat Sink and Transformer design. These are most important parts of pure sine wave inverter.

Name	Value	Type	Description
Q1,Q2,Q3,Q4,Q5,Q6,Q7, Q8,Q14,Q15,Q16,Q17	IRF P150N		Push Pull MOSFET
R1,R3,R4,R6,R8,R10,R14, R20,R22,R24,R26,R31	10R, 0.5 W		MOSFET gate Resistor
R5,R7,R9,R12,R13,R18,R19, R21,R23,R25,R30,R32	10K, 0.25 w		MOSFET gate Pull Down Resistor
D1,D2,D3,D4,D5,D6,D7, D8,D9,D10,D11,D12	15V ZENER		MOSFET gate Zener Diode
XFR PR 1		Connector	Transformer Primary terminal 1
XFR PR 2		Connector	Transformer Primary terminal 2
XFR CENTER		Connector	Transformer center terminal
XFR S1		Connector	Transformer Secondary terminal 1
XFR S2		Connector	Transformer Secondary terminal 2
F2,F3	30A	Fuse	Input Protection Fuse (30+30)=60A
BAT(+VE)		Connector	Battery positive terminal
BAT(-VE)		Connector	Battery negative terminal
IC1	ACS758	Hall effect sensor	Input Current sensor

C10	100 nF	Ceramic	
C22	1uF, 25 V	Electrolyte	Hall effect sensor power capacitor
J3			Control rail
J2			Power ON/OFF switch connector
IC2	7818	Linear Regulator	Step down for control unit
L2	100mH		Control power inductor
C12	100uF,100V	Electrolyte	7818 regulator input capacitor
C11	10nF	Ceramic	7818 regulator input bypass capacitor
R15	10K, 0.25 w		Power LED series Resistor
LED 1	3mm	Red	Power LED
C14	10nF,100V	Polyester	Battery bypass capacitor
C15	100nF,100V	Polyester	Battery bypass capacitor
J7			Supporting rail to protection circuit
J1			Push Pull Control circuit rail

Transformer parameters:

Ferrite core transformer is used for high frequency Switched Mode Power Supply (SMPS). In our design switching frequency is 100 KHz. So to avoid skin effect, few thin wires are combined to make thick wire.

No. of primary turns, Np= 2
No. of Secondary turns, Ns= 38
Wire gauge number (AWG) = 26
Number of wires in the primary winding = 64
Number of wires in the secondary winding= 5
Ferrite core number = E65/32/27.

For push-pull topology, the primary side of the transformer is **center-tapped.** Special attention should be given to make the two windings of the transformer primary side symmetric.

One important point is to reduce skin effect litz wire is highly recommended. So basically what we had to do is combined 64 primary wires and then wounded the primary side. The scenario same is for the secondary side

Heat sink parameters and assembling:

For 1KW Pure Sine Wave Inverter input current is more than 50A. So Heat sinks should be large enough to keep the MOSFETs in allowable temperature range. It is highly recommended to use thermal paste between the casings of MOSFETs & Heat sinks to reduce thermal resistance.

Cooling Fan:

In the main board there is room for two cooling fans to keep the Push-Pull two side MOSFTs in the allowable temperature range.
As Cooling Fan power rail is directly connected with battery, we used **24V** rating cooling fan for this purpose.

Testing low voltage side:

After assembling low voltage side we will test the secondary side output of the transformer. Before that

- ✓ Make sure that heat sinks are installed with the MOSFETs properly.
- ✓ Transformer primary windings are connected properly.
- ✓ Battery positive and Negative wire size should be enough thick to conduct 55A current.
- ✓ Plug the Push-pull control board vertically on J1 rail of main board (Check twice the pin sequence).
- ✓ Connect a small load like 100W bulb with secondary side of the transformer.
- ✓ Connect oscilloscope with the secondary side of the transformer. Transformer probe should be 10x, otherwise waveform cannot be seen properly.
- ✓ Main board power switch is connected the J2 rail (Check twice the pin sequence).
- ✓ Test the pads connections of MOSFETs and other components carefully.
- ✓ Connect cooling fan properly

Power on the switch. If everything is ok, transformer secondary output will be like below.

The ideal waveform is 100 KHz, square wave, -350V to +350V peak to peak. Voltage may vary depending on load as there is no feedback connection right now. In the oscilloscope output the waveform is slightly distorted because inductive effects of transformer and PCB trace.

Then increase load and observe the input current and heat sink temperature. We used resistive load for testing purpose. The temperature of the heat sink will increase slightly in full load. IF you observe unusual increase in the temperature, there is problem in heat sink or heat sink assembling.

After debugging is complete & if the transformer secondary waveform & heat sinks are okay, we proceed to the High voltage section.

High voltage side assembling:

High voltage side is risky and hazardous. So take necessary high voltage protection measures before proceeding this section.

High voltage side comprises of two sections

1. DC-DC Rectifier & filter
2. DC-AC inverter H bridge Circuit

DC-DC rectifier &Filter:

Now just assemble Push-pull transformer secondary section. Full bridge rectifier diodes, Rectifier, Snubber and Low pass LC- Filter. There are two output pins of DC-DC Converter named HVDC and GND. DC-Dc output can be easily checked connecting a Green connector here.

- ✓ Connect the **JUMPER II** because feedback won't work without this connection.
- ✓ Connect the transformer secondary wires.
- ✓ You can check output without attaching heat sink with the Diodes. Because output current is below 5A, so diodes will not be heated much.

Name	Value	Type	Description
D21,D22,D23,D24	MUR3060		Rectifier Diode
D25	MUR3060		Snubber Diode
R43	1K, 20W		Snubber Resistor
L3			DC Filter Inductor
C7,C9,C13,C26,C27,C28	10uF,450V	Electrolyte	DC Filter Capacitor
R16	1M,0.25W		DC-DC output indicator LED series resistor
LED2	3mm	Red	DC-DC output indicator LED
R39,R40	1M,2W		DC-DC output capacitor discharge Resistor
JUMPER II			Connecting wire of feedback signal.
XFR_S1 & XFR_S2		PCB hole	Transformer secondary connections

When you power up the circuit you see pure dc voltage is increasing gradually and it will stop when reaches 312V. It ensures you that feedback is working perfectly. If the dc voltage does not stop within 320V then turn off power, if voltage crosses the capacitors rating (450V), capacitors may get damaged.

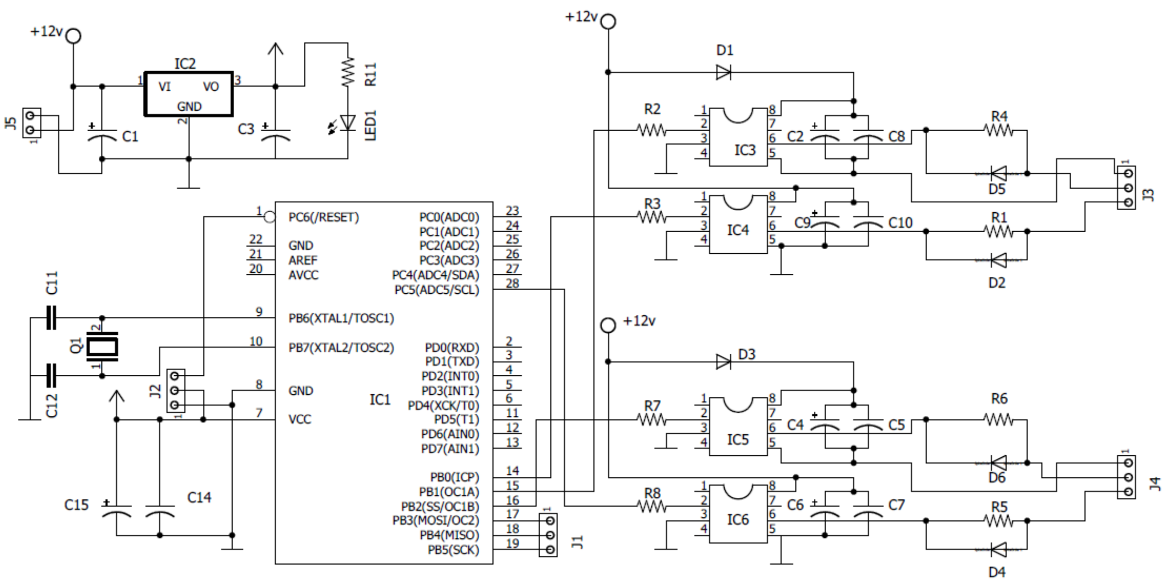
AC-DC inverter H-bridge Circuit

We have already produced the High DC voltage. Now using SPWM method & H-Bridge we will invert the HVDC into 220AC rms voltage. We need an H-bridge driver circuit which will generate the SPWM pulses.

H-Bridge Driver Circuit:

In this circuit we used atmega8A to generate the sinusoidal pulse width modulation (SPWM) signals. Atmega8A is a microcontroller of Atmel AVR series. Then the microcontroller signals are passed to optocouplers TLP250. Optocouplers drive the H-Bridge MOSFETs.

R1,R4,R5,R6	10R, 0.25W		Optocoupler output resistor
R2,R3,R7	220R, 0.25W		Optocoupler Input Resistor
R11	1K, 0.25W		Power indicator LED
D2,D4,D5,D6	FR 107		Optocoupler output diode
D1,D3	FR 107		Bootstrap diode
C5,C6,C8,C10	10 nF	ceramic	Optocoupler output capacitor
C11,C12	22pF	ceramic	Crystal capacitor
C1	100uF, 50V	Electrolytic	7805 Input
C3	0.1uF,25V	Electrolytic	7805 Output
C14	10 nF	ceramic	Atmega Bypass capacitor
C15	100uF,25V	Electrolytic	Atmega power capacitor
C2,C9,C6,C4	100uF,25V	Electrolytic	Optocoupler output capacitor
J1, J2	3 pin rails		Programmer rails
J3,J4	3 pin rails		Control signal rails
J5	2 pin rail		Power rail
IC3,IC4,IC5,IC6	TIP250		Optocoupler
IC2	7805		Power regulator
IC1	ATmega8		Microcontroller
LED1	3mm	Red	Power indicator LED



So there are 5 jumper rails. Pinout of these rails are given below.

J1 for uploading program

Pin No	Pin Description
1	MOSI
2	MISO
3	SCK

J2 is also for uploading program

Pin No	Pin Description
1	GND
2	VCC
3	RESET

J3 is one side MOSFET gate drive pinout

Pin No	Pin Description
1	High side reference input
2	High Side MOSFET gate drive signal
3	Low Side MOSFET Gate drive Signal

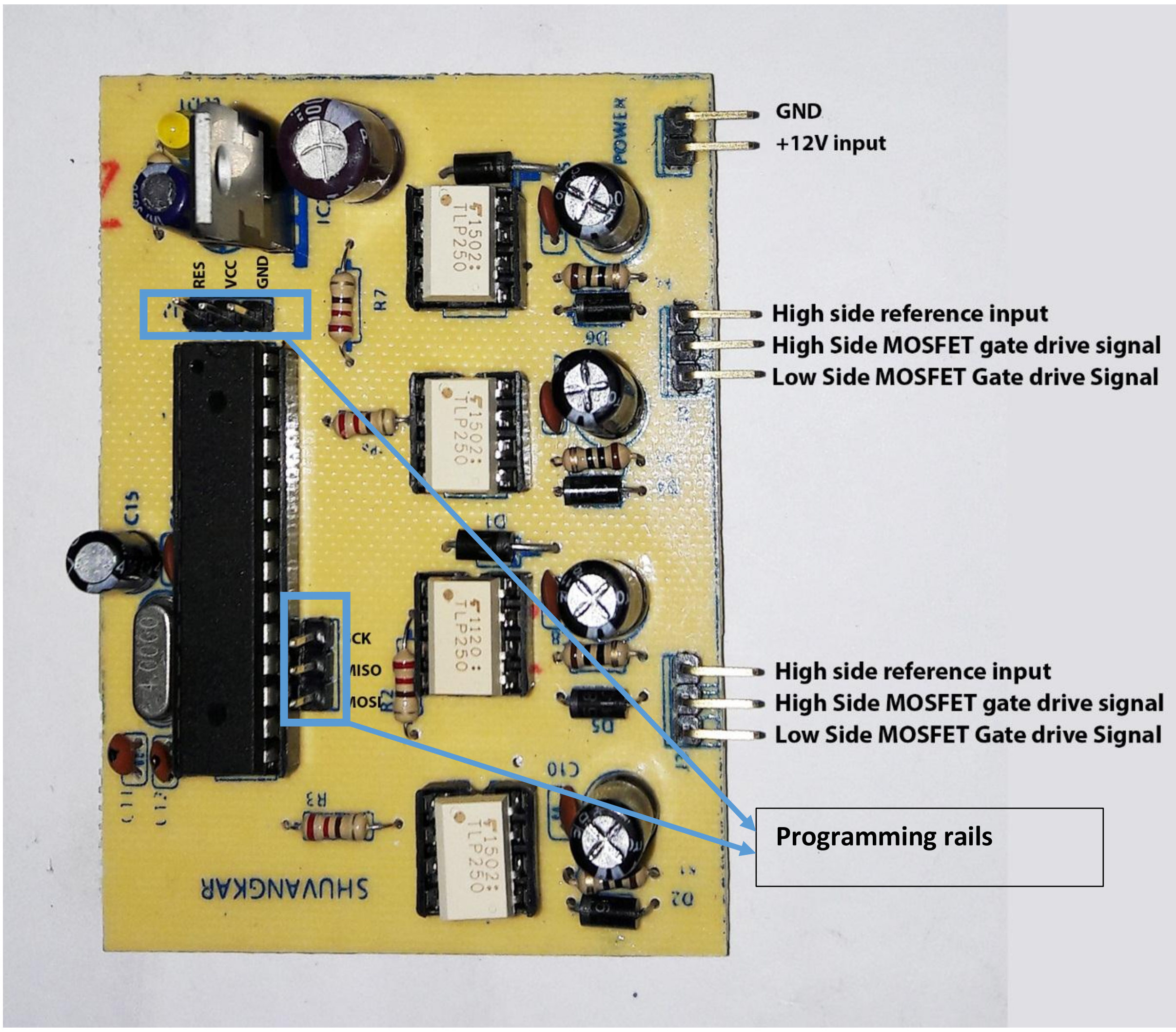
J4 is another side MOSFET gate drive pinout

Pin No	Pin Description
1	High side reference input
2	High Side MOSFET gate drive signal
3	Low Side MOSFET Gate drive Signal

and finally J5 is control power input rail.

Pin No	Pin Description
1	+12V input
2	GND

So in the PCB all these pins look like below:

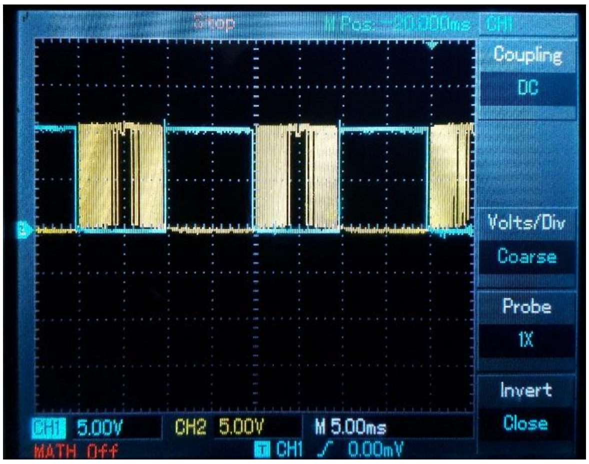


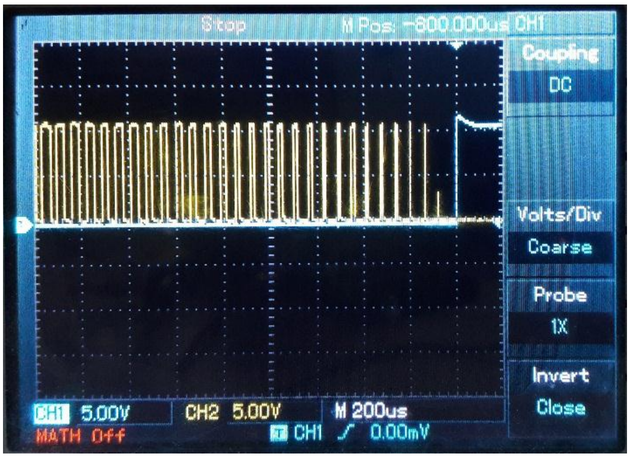
SPWM code is included in the project files. So upload the H-Bridge SPWM code. After uploading check the signal using an oscilloscope.

N.B: While checking the high side MOSFET Gate drive signals, you have to connect the High side reference input with the GND pin of the Control board. Otherwise the high side cannot find reference point.

Checking the H-Bridge control signal:

Output of J3 rail (High side reference input is connected to ground)





In the image the blue signal is the low side MOSFET signal and the yellow signal is high side MOSFET signal. The frequency of the signals is 50Hz. In the second image, we clearly see that there is a dead time between the low side and high side signals. We can also see in the second image that pulse width is increasing from right to left and maximum at center just as think about sine wave: Voltage is maximum at 90° and then voltage decreases (pulse width decreases). So pulse width is proportional to the voltage of sine wave.

We get same type of result for the j4 rail.

From the graph we find that.

- ✓ Low side MOSFETs are running at 50Hz and complementary.
- ✓ Microcontroller passes SPWM signals only to the High side MOSFETs which are running at 16 KHz.

Assembling H-Bridge:

Then it is time to connect the H-bridge components, as H-Bridge Driver circuit is completely ready.

Components list of the H-Bridge Side is given below

Name	Value	Type	Description
F1	10A		Inverter input Fuse
D13,D14,D15,D16	MUR1560		H-Bridge Freewheeling diode
Q18,Q19,Q20,Q21	IRFP460		H-Bridge MOSFET
R33,R34,R35,R36	10k,0.25W		H-Bridge MOSFET Pull Down Resistor
D17,D18,D19,D20	15V zener	Zener	H-Bridge MOSFET Gate Protection
R37,R15	10k, 0.25W		Power LED Resistor
IC3	7812		Linear regulator to powe H-Bridge control
C4	10nF	Ceramic	7812 input bypass capacitor
C8	100uF,25V	Electrolyte	7812 input Capacitor

L1	680uF		7812 series input inductor
R11,R2	Not tested		Snubber
C24,C5	No tested	Polyster	Snubber
C23	10uF,25V	Electrolyte	7812 output capacitor
C18,C21	100nF	Polyster	Snubber
C30	10uF,450V	Polyster*******	Output Filter

N.B: R11,R2, C24,C5 can be omitted.

After assembling the H bridge components you can test it individually for low voltage.

Test H-Bridge for low voltage:

- Plug the H-bridge Control circuit
- There is fuse F1 for H-Bridge protection. Connect low voltage like 30V-60V with the fuse terminal close to heat sink.
- Connect GND of power supply with the GND of H-Bridge
- Short the H-Bridge output inductor connection with a wire.
- Separately power up the H-Bridge Driver circuit. Voltage should be exactly +12V
- Connect oscilloscope with output AC1 & AC2
- Connect a 100W bulb load with output.

Now power up the H-Bride Driver circuit. You will get waveform like below

The signal indicates the SPWM signal in positive and negative side. So H -Bridge circuit is working properly. Now if you connect Low pass filter (Inductor & capacitor) you will get sine wave.

After testing H-Bridge connect rest of the components like filter capacitor, inductor etc. **JUMPER I** is the power input connection of H-Bridge Driver which is directly connected to the battery.

High Voltage Side Heat Sink Assembling:

While assembling the high voltage side heat sink few precaution should be maintained.

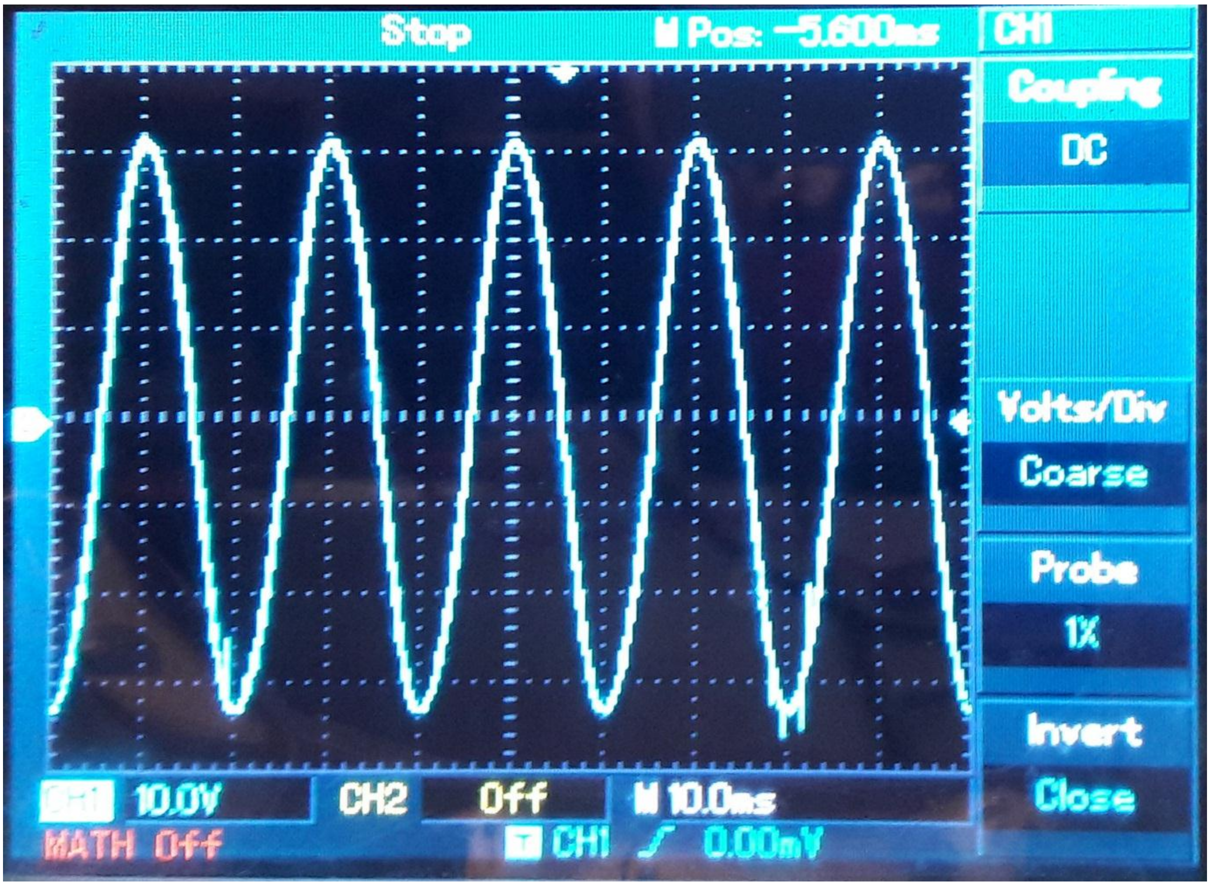
- ✓ Use mica insulator between heat sink & MOSFET or Diode Casing.
- ✓ Thermal paste will reduce thermal resistance.
- ✓ After assembling the heat sink check every pad of the MOSFETs/ Diodes whether it somehow get connected to the heat sink.
- ✓ If heat sink is connected to any pads of the component find out which component(s) is connected and change the insulator and reassemble the components until there is no connection with the heat sink and the pads.

Cooling Fan Assembling:

Primary side of the Push-pull MOSFETs will carry more than 50A currents (at full load). So to keep the MOSFETs in its safe operating temperature range, force cooling method is adopted. We use two cooling fans for the two sides of the push pull MOSFETs.

Final test:

Now our board is ready for final testing. Out final output will be pure sine wave.



Protection Circuit:

To keep the system safe and durable we have designed different types of protections.

We have taken two types of protection

I. Hardware protection
II. Software protection

Hardware protection:

We know our complete system is two stages. There are fuses before every stage to keep the system from burning because of over-current.

1. 30A three fuse (90A) are parallel after battery connection. As maximum input current is 55A
2. 10A Fuse is before the H-Bridge DC-AC converter

Software protection:

We integrated the system with a little bit intelligence using microcontroller protection. So the software protection includes

I. Input Over current Protection
II. Output Short Circuit Protection
III. Battery Low Voltage Protection
IV. High Temperature Protection for Push-Pull two side heat sink

Software protection latches the faults and turns off the system. It also turns on alarm so that user can be aware of faults and can take necessary steps.

Input Over current Protection:

In the main board there is Hall current Sensor ACS758 which can measure maximum of 200A. The accuracy is good enough to measure the input current on the system. The Output from ACS758 goes to the Protection circuit board. The microcontroller measure the actual current and when fault occurs microcontroller latches the fault and sends fault signal to the Push-Pull controller circuit. Then push-pull controller turns off the system and turn on alarm so that the user can take necessary action.

Output Short Circuit Protection:

Output AC wire goes through a current transformer so the protection circuit measures output current. When output current exceed 5A AC the microcontroller generates fault signal and sends the signal to the Push-Pull controller circuit. Then it turns-off the system and starts fault alarm.

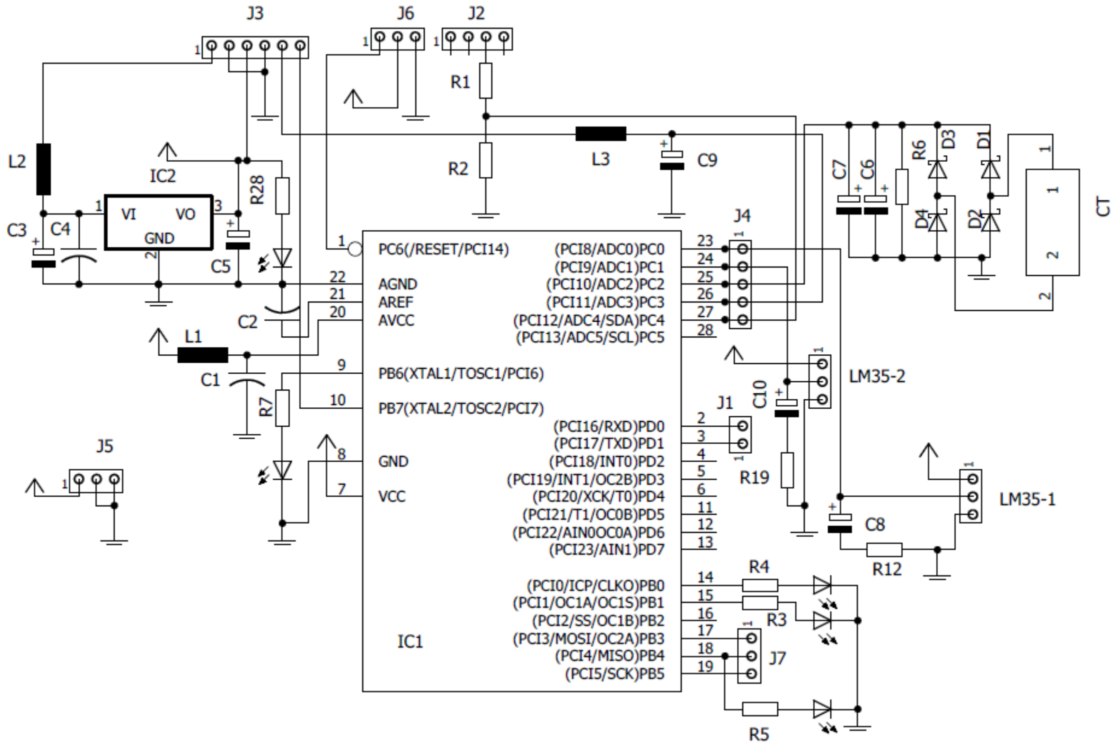
Battery Low voltage Protection:

We used a 24V lead acid battery. 24V is the nominal voltage. Fully charged the maximum voltage might be 28 voltage. Cut-off voltage is 21V. So when the voltage drops below 21V, the system automatically turns off. When battery voltage is 22V the system will automatically turn-on.

High Temperature Protection for Push-Pull two side heat sink:

The maximum input current is close to 55A. There are 6 MOSFETs are parallel each side of Push-Pull DC-DC converter. In case of faults the MOSFET will heat up and it will heat up the heat sink. The temperature sensor LM35 is closely attached with the heat sink to sense its temperature. Any type of temperature sensor like NTC thermistor will works fine. In this case microcontroller code has to be modified. We used IRFP150 in Push-Pull two sides which maximum allowable temperature is 150 degree Celsius. So cut-off temperature is kept 70 degree Celsius.

Here is the protection circuit schematic.



Component list is given below

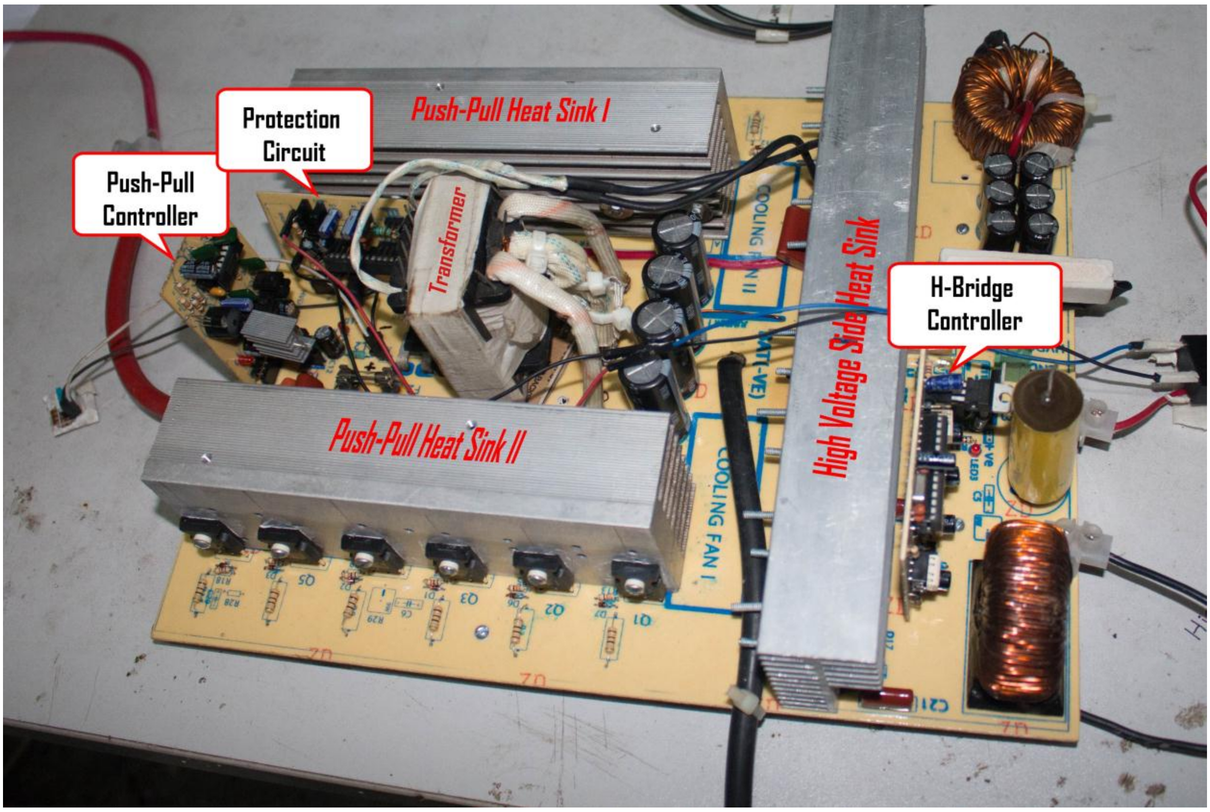
Name	**Value**	**Type**	**Description**
IC1	atmega8		Microcontroller
IC2	7805		
C3	100uf	Electrolytic	Charge Storage capaticor
C4	0.1uf	polyester	bypass capacitor
L2	680uH		Filtering inductor
C5	1uf,25V	Electrolytic	Noise filtering
R28,R7,R5,R4,R3	10K, 0.25W		Led indicator series resistor
Led1	3mm,RED		Power indicator
C2	0.1uf	Ceramic	ADC Reference noise filter cap
L1	680UH		ADC pins power filter inductor
C1	0.1uf	Ceramic	ADC pins power filter inductor
Led2,Led3,LED4,Led5	3mm,RED		Faults indicator
L3	1mH		Filter inductor for Hall sensor output
C9	100uf,16V		Filter capacitor for Hall sensor output
R1			Battery voltage sense resistor
R2			Battery voltage sense resistor

R12,R19	680,0.25W		LM35 Noise filter res
C10,C8	0.1uf	Ceramic	LM35 Noise filter cap
D1,D2,D3,D4	1n5819	Schottky	Current Transformer Rectifier
CT			Current Transformer, Turns ratio 1:2500
R6			Current to voltage transfer resistor
J7,J6			Program upload rail
J1			Serial Communication rail
J2			Battery voltage sense rail
J3			main board Communication rail
LM35-1,LM35-2	LM35		Temperature Sensor for push-pull heat sink
J5			VCC, Gnd rail
PCB			

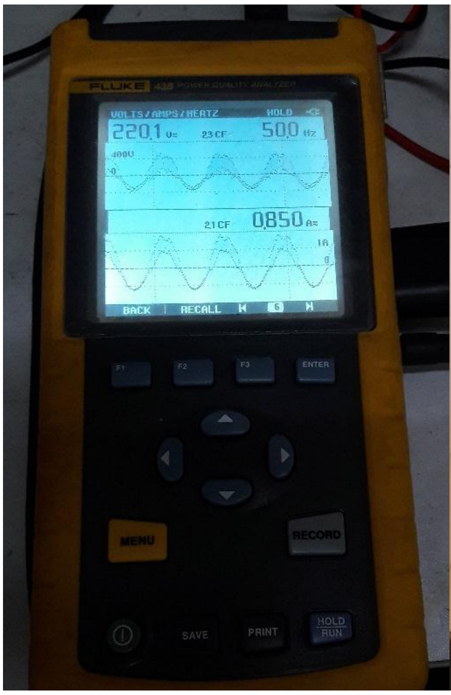
N.B: The Protection circuits is bit incomplete. Please email me at s.c.das@ieee.org to get the full and complete code.

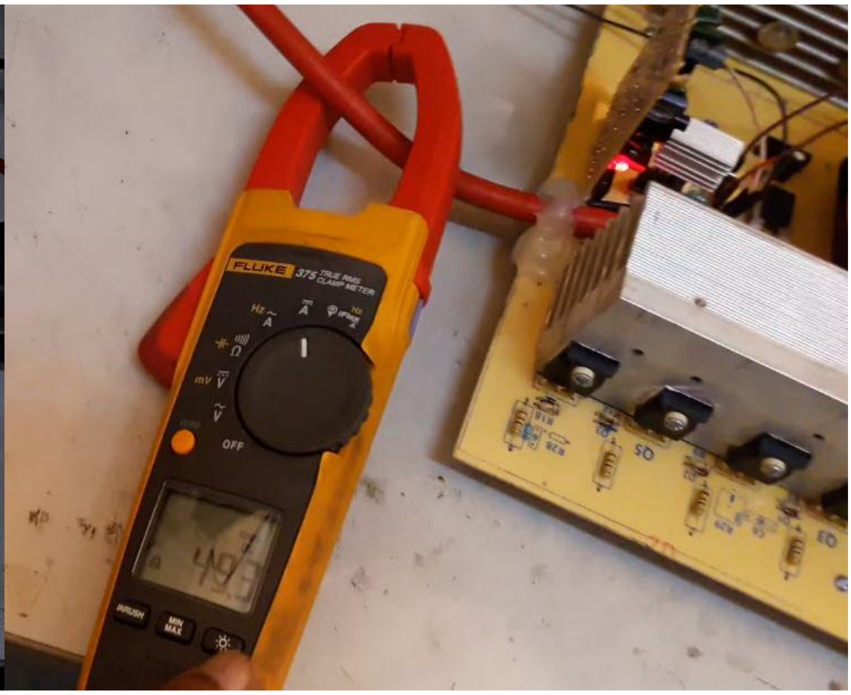
Final Board & Output Results:

Here is the image of final board. We did not used cooling fan as our board heats up a little bit.



- ❑ Output data was monitored using Fluke 43B Power Quality analyzer
- ❑ Input Current was measured using Fluke 375 True RMS Clamp Meter
- ❑ Input voltage was measured using UNI-T UT338 Multi-meter





Vin	Iin	Pin	Vout	Iout	p.f	Pout	Efficiency	THD(Voltage)	THD(current)	Frequency
26.87	9.3	249.891	220.1	0.85	1	185	74.03%		**2.8**	50
25.19	13.6	342.584	215.9	1.274	1	271	79.10%	3.4	4.5	50
25.15	17.6	442.64	211.9	1.655	1	350	79.07%	4.5	4.4	50
24.93	22.3	555.939	209.5	2.075	1	434	78.07%	5	5.5	50
23.4	33.8	790.92	203.1	3.204	1	620	78.39%		7.2	50
23.1	41.5	958.65	200.5	3.593	1	722	75.31%		8.6	50

22.7	46.8	1062.36			1	786	73.99%		9.2	50
22.7	49.3	1119.11	198.7	4.13	1	820	73.27%		9.2	50