# Partial Development of SMPS based Battery Charging System for Electric Vehicle.

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**Abstract:** To avoid dependency & environmental pollution, inthe recent& upcoming years IC engine-based vehicleswill be replaced with battery operated vehicles. More research is going in E- Vehicle & its subsystemlike Battery, Motor, Motor drive, Battery Charger, etc. Major challenges of E-vehicle are minimum charging time of battery with optimum life span. SMPS based battery charger is one of the solutions for battery charging. In this paper a comprehensive review aboutfeasibility &development checks of Switch Mode Power Supply (SMPS) based charger and its subsystems. Method and topology review of different charger circuits, Selection criteria of different component used in circuitsand development of (SMPS) charger circuits. Along with that development of charger circuit which further used in charger. Elaboration about different charging method & operation of charger.

**Keywords –** IGBT, Lead acid battery, Lithium-ion battery, Micro-controller. SMPS.

## 1. Introduction

Dueto global warming problem and continuous rise in price of gasoline, electric vehicles propose to be an attractive option due to its clean &environmentally friendly operation. Vehicle is one of most used option to meet transportation requirement. Considering global warming problem there is need for shift fromconventional fuel-basedvehicle to electric vehicles(EVs)[1]. EVsare equipped with energy storage device (Battery) and charging of battery is essential for operation of e-Vehicle.

Most commontype of batteries for EV's is Lithium-ion battery, Lithium polymer as theypossess high energy density in contrast to their weight. Other types of rechargeable battery are Lead acid battery,Nickel cadmium, Nickel metal, etc. Lead acid battery is the cheapest than other type of battery[2]. Earlier this type of batterieswas used as automobile engine starter battery &now a days these are used for electrical vehicle as well wherever weight constraints are not there i.e. Two / Three-wheeler vehicle. Lithium-ion batteries are initially developed due to space constrains i.e., Laptop, Mobile, portable devices, etc.Technical details of Lead acid and Lithium-ion battery ismentioned in Table-1 [3]. In this paper detail discussion is done about Lead acid battery charger.Conventional (Iron core based transformer) type of charger are commonly used for charging purpose. This type of charger having advantages like easy to design, simple in maintain, easy to repair/troubleshoot, sample in operation, less in cost due to causes it is more popular or used charger.This type of charger having advantages like easy to design, simple in maintain, easy to repair/troubleshoot, sample in operation, less in cost due to causes it is more popular or used charger. This type of charger having many of advantages. Along with that power consumption of charger for charging is high, no control over charging of battery its result in over charging of battery/continuous monitoring required, weight of charger is high, area required for installation is high, less protection system is in charge. these disadvantages are eliminated in proposed charger.

| **Table** 1. Technical details of Lead Acid and Lithium-ion battery.Parameters | Lead-AcidBatteries | Lithium-ion |
|---|---|---|
| Energydensity Wh/kg | 30 – 50 | 100- 265 |
| Material | Toxic | Scarce |
| Safety | Moderate | Low |
| Self-Discharge capacity | High self-discharge | Negligible self-discharge |

| | | |
|---|---|---|
| Temperature Range in Degree Celsius | -40 to 60 | -25 to 40 |
| Efficiency at low C rate | 75 % | Near to 100 % |
| Cost | Low | High |
| Weight | 3 time less then Li-ion | 3 time more than Lead acid |
| Life cycle Depth of discharge (DOD) | 500 cycle | 2000le @ 80 % DOD |

## 2. Need of SMPS Based Battery Charger

2.1. Improve efficiency of charger -Efficiency of SMPS Charger is higher compared to conventional charger. It should be above 90 % [4].

2.2. Weight of charger- Vehicles are dynamic in operation wherever they get suitable energy source as input, charger should be able to charge. In case of conventional charger weight of charger is much high. Weight of SMPS based charger is 4 – 5 Kg and it isa portable device.

2.3. Reduce monitoring & Operation time – For SMPS charger there is no need to monitor charging. It followspre-defined(Programmed) charging pattern.Thus, it becomes convenient to monitor.

2.4. Suitable for Dead battery/Deep Discharged battery- In charger design to generate current pulse, in which pulse helps to remove the sulfation plate (Remove accumulated Sulphur from plate) [5].

2.5. Reverse battery protection – User may connect the battery in reverse manner where charger internal circuit may get short circuit and damage the charger. In system it checks the availability of battery &correct polarity based on that it allows to initiate charging.

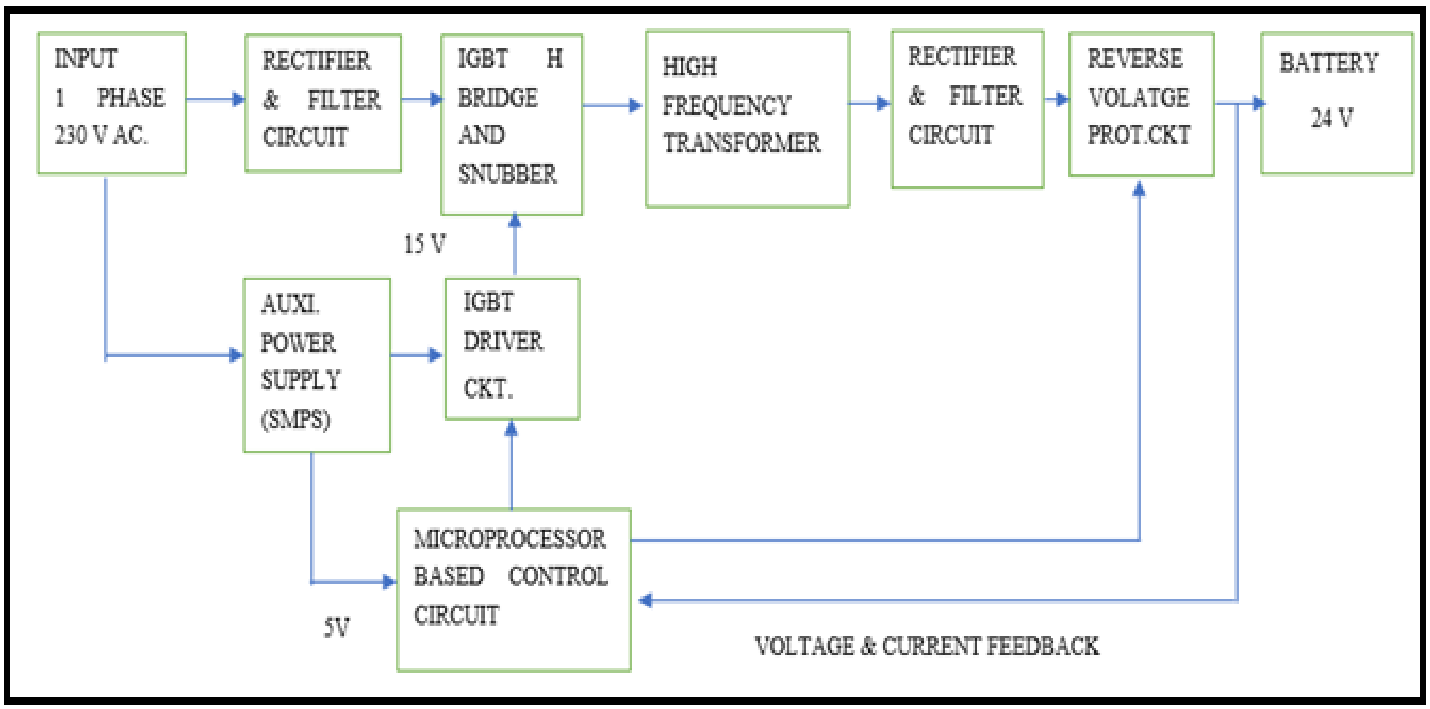


**Figure**1.Block Diagram of Charger

## 3. CHARGER CIRCUIT & ITs COMPONENT SELECTION.

Following is proposed circuit for charger.

**3.1. Source**
**3.2. Line filter & rectifier circuit.**
**3.3. Switching devices & its driver circuit.**
**3.4. Step-down transformer.**
**3.5. Rectifier & Filter circuit.**
**3.6. Voltage & current sense circuit.**

**3.7. System Protection.**
**3.8. Micro-controller circuit.**
**3.9. Auxiliary power supply.**

**3.1. Power Supply Source.**
In charger row power supply is essential for working of charger. Power source shall be easily available. Considering more availability of Grid alternating current AC supply (1 Phase, 230 V, 50 Hz) with tolerable limit set by utility selected for system. This input helps in selection of circuit & its component.

**3.2. Line Filter &RectifierFilter Circuit**.

***Line Filter*** – To protects from grid noise, spikes& avoid interference with other system line filter is used. Metal Oxide Varistor (MOV)is used to protect the system from high voltage spikes. It is one type of surge arrestor. Capacitor-Inductor-Capacitor pie(π) filteris proposed. This filter protectsfrom unwanted noise from grid. This is passive low pass filter it avoids the high frequency noise from grid.

***Rectifier & filter circuit*** [6]- As source selected, This AC supply need to convert in DC supply for SMSPS operation. Different types of rectifier with its technical details are given in Table-2.

Table 2. Type of Rectifier and its technical details.

| Parameter | Half wave Rectifier | Full Wave Rectifier | Bridge Rectifier |
|---|---|---|---|
| DC or average load current. | Im / π | 2 Im/ π | 2 Im/ π |
| Max. average load voltage | Vm / π | 2Vm/π | 2 Vm / π |
| RMS load current | Im / 2 | Im /√2 | Im / √2 |
| RMS load voltage | Vm / 2 | Vm//√2 | Vm/√2 |
| Max efficiency | 40 % | 81.2 % | 81.2 % |
| No of Diode | One | Two | Four |
| Ripple Factor | 1.21 | 0.482 | 0.483 |
| Transformer Required | No | Yes | No |

Consideringefficiency, Ripple factor, Bridge diodes are proposed for rectifier unit.Diode Bridge should with min voltage 400V & current 35 A requirement., Heat sink mountable Bridge rectifier is selected. (400V for peak voltage & 35 A for 2.5 times of normal current) [7].Varioustype of capacitors are available i.e. Filter capacitor- Ceramic, Film, electrolytic. Out of that Electrolytic capacitor is selected due to very thin dielectric oxide layer and enlarge anode surface. Capacitance voltage product per unit volume is high due to this they can achieve large capacitance value.
Capacitance calculation-

$$C = \frac{1}{2 \times f \times V_{pp}} \quad (1)$$

Where C= Capacitance, I= load current, f= Frequency,
Vpp= Ripple
Considered Vpp is 10 %.
**C= 1320 µF**
Hence, Capacitance selected – 3 Nosof 400V, 470 µF.

Output of the rectifier & filter circuit is DC power.This power is provided to switching devices to generate highfrequency pulsating DC from DC supply.

**3.3. Switching device & its driver circuit**.
Switching devices are used to convert DC supply to high frequency pulsating AC supply. Different types of Switching devices with its technical details are given in Table-3.

Table3. Type of Switching Devices & Technical Details.

| Parameter | Thyristor | MOSFET | IGBT |
|---|---|---|---|
| Type of Devices | Minority carrier | Majority carrier | Minority carrier |
| Rating | VeryHighvoltageVery High Current | Mediumvoltage High current | High voltage High current |
| Switching frequency | Low | Very high ( MHz) | High (100 KHz) |
| On state Drop | Low | Higher | Low |
| On state losses | Low | Considerable | Less then MOSFET |
| Gate drive | Current drive | Voltage drive | Voltage drive |
| Driven by | Single pulse | Continuous voltage & large gate current (Ig)at switching transition | Continuous voltage & large gate current (Ig)at switching transition. Negative voltage required for turn Off |
| Turn off | Line or forced commutation | Gate commutation | Gate commutation |
| Reliability | Most Robust | Less Robust | Robust |
| Sensitivity to temp | Less sensitive | sensitive | More sensitive |
| Heat Sink required | Yes | No | Yes |

Charger System Requires - Operating frequency 20 KHz, High Voltage, High current, less on state losses, robust in operation [8]. Considering requirement H-bridge Insulated gate bipolar transistor (IGBT) is suitable. SGF60N40SFD IGBT is (600V,40A) [9] selected. To protect the IGBT from switching impulse snubber RC combination are used. It protects IGBT during fast switching turn ON & Turn OFF transient operation.

IGBT driver circuit- To turn ON IGBT it is required to provide min 15 V so it will be in operating region. To tune OFF IGBT's it is required to provide negative voltage at gate. H bridge driver is not easily available and electrical isolator with Micro-controller is also required. Consideringabove conditionstwo stage driver circuit to be developed.In this, first Pulse Width Modulated Pulse gets from Micro-controller. This pulse is provided to half bridge driver Integrated circuit (IC)[10] . Further this pulse is provided to pulse transformer which is having four winding 1:1 ratio in which 4 winding output is connected to IGBT gate emitter. Where this transformer provides the electrical isolator and negative pulse to gate for turn OFF. Waveform of gate drive is shown in figure 1. Generated high AC square voltage are further provided to transformer for step down voltage level to 28.8V.

**3.4. Step Down Transformer**

Major losses in conventional charger are due to iron core transformer. To increase the over all efficiency ferrite core are proposed. Ferrite cores have very high magnetic permeability, very high degree of magnetization, low amount of eddy current losses and lower switching losses.Ferrite core transformer is used for voltage conversion. Transformer input is 230 V output is 30 V frequency 20 KHz. Primary winding is single winding & secondary winding is centre tap winding to increase current capacity.

Core selection is carried out based on M/S magnetics power handling [11]-[12].

Following results are-

Core size = 2 X (EE65X27X32.8 mm) which can handle 4000 W at 20 KHz.

Primary turns & Conductor area. - 26 turns. 2.5 sq. mm.

Secondary turns & Conductor area – 2 X 3 no's (centre tap winding) 10 sq. mm.

**3.5. Rectifier & Filter circuit**

Output of transformer is 30 V AC square wave form. Thisneed to rectify for pure DC supply. So rectifier units are used. Rectifier type selection based on Table 3. Diode shall be suitable for high frequency operation. Freewheeling diode used to protect flyback energy, bypass the spikes. D92-02[13] feature of diode ultrafast recovery diode, low recovery loss, high surge current capability, low leakage current. voltage rating 220 V & RMSforward Current rating 28A per unit. Such 6 unit are used for system. enquired snubber is used for saving diode form over voltage spikes. Output of diode are provided to different circuits.

First - Filter circuit (Normal CC/CV operation, no bypasscapacitor)further to Voltage & current sensor. Second for Deep discharged charging. In This operation capacitor will be bypass and pulse will provide to battery for chargingFilter –Positive Square wave form are generating from Diode unit. This wave needs to be filtered before providing to battery. Filter capacitor are filter the wave form convert into pure DC supply. Eliminate the ripple form supply for this operation LC type of filter. Capacitor type selection based on table- 3. Benefits for LC filter as follow –

a. No direct loading on Transform or diode.
b. High output DC voltage
c. Diode not required to carry the surge current.
d. Very low ripple factor.
e. Very good for load regulation.
f. Better voltage regulation.

Capacitance of filter circuit = 4000 micro farad. (ESR=0.46)
Inductor inductance = 5micro-H.
Ripple calculation -

$$Attenuation = \frac{2\,\pi\,f\,L}{ESR} \tag{2}$$

Where,
ESR= Equivalent Series resistance of output capacitor.
L= Inductance of Inductor.
F= Frequency (20 KHz X 2) full wave rectification.
Attenuation = 109.56 %

% Ripple = (1/ attenuation) * 100.
% Ripple =1.09 %

**3.6. Voltage & current sensor circuit**

Feedback for charger is essential to appropriate operation and control over charging. This sensor isproviding the actualfeedback (output value)of voltage& current to micro-controller. Sensor circuit directly senses actual values which is not suitable for micro-controller. It shall be isolated from main supply(high voltage more than 5 V) and provide output suitable for micro-controller.
Voltage sensor –4N35[14] it has high isolation voltage 5000V.
Current sensor- WCS 1500(Hall effect based liner current sensor) [15] used feature are suitable for AC & DC, have wide current sensing range up to 200 A, isolation voltage 4000V, high sensitivity 11mV/A, Low operating current equal to 3 mA.

**3.7. System Protection**

Protection system from abnormal condition due to internal fault and external fault are essential. Protection system as below.

3.7.1. Failure of system due to external signal/noise/spike - This type of fault will be clear by line filter unit.

3.7.2. Failure of system due to internal circuit – Internal circuit can fail due to over loading, failure of cooling, decertation of component, leakage in component. In such cases overcurrent take place. To protect the system from internal short circuit miniature circuit breaker (MCB) is used.

Calculation for MCB selection as follows,
Full Load Current =(( Output power / efficiency )/ Input voltage) *safety/design factor.\
= (28.4 V * 100 A)/ 0.95 / 230 V * 1.2
=15.95A

16 A MCB selected for protection of system.

3.7.3. External battery side fault. Major two faults are in system.

Short circuit at output terminal/ battery end this fault & Reverse battery connection will be clear by internal short circuit protection & sensor circuit. Details are given as below-

3.7.3.1. Short circuit at terminal end short circuit protection is provided. In this current sensor is used. Sensor will sense this feedback, provide it to micro-controller. If sensed current is more than set value (110A) it will stop Pulse out for IGBT and will send command to electro-mechanical relay. Relay will isolate the output. No output will be at the terminal.

3.7.3.2. Reverse battery connection – Battery reverse connection is normal problem during charging service. If reverse polarity is connected tocharger, it will damage the charger internal parts and battery as well. During reverse connection of battery diode will be in forward conditioni.e it will allow to follow current from it and this conditioncan cause for battery short circuit. Controller is programmed in such a way that if there is no voltage sense or reverse(negative) voltage sense. Controller will not start the charging process. Once, correct polarity of battery connected to terminal then charging process start.

**3.8. Micro-Controller**.

Controlling & operation of charger system is carried by micro-controller. ARM Cortex M451 family 32 bits M453LE6AE is selected for system [16].Selection criteria for Micro-controller – High speed of microcontroller 72 MHz so low time for operation, easily available controller is market, low power consumption 15 micro ampere. Major criteria is it generates the dual PWM which is necessary for drive IGBT. It can be easily interfaced with liquid crystal display (LCD) or 7 segment light emitting diode display (LED). Good operating temp range -40 to 105 degree. It is suitable for high level programming language such as C, Python, Java. ''C'' language used for programming.

**3.9. Auxiliary Power Supply**.

To drive the passive circuit in system auxiliary power supply is required. Required voltage of sub system circuit is given in Table 4.

Table 4. Auxiliary Power Required with its Circuits.

| **Circuit** | **Required Voltage( Volts)** |
|---|---|
| Micro-controller | 5 |
| IGBT driver | 15 |
| Relay | 12 |
| Current & voltage sensor | 5 |

To full-fill power supply requirement of circuits auxiliary power supply is provided. SMPS converts 1 phase 230 V AC Supply in to various required DC voltage (5V, 12V, 15V). TNY268 IC is used for SMPS(Small in size, Low ripple in output voltage, Built in short circuit protection, less power consumption for conversion)

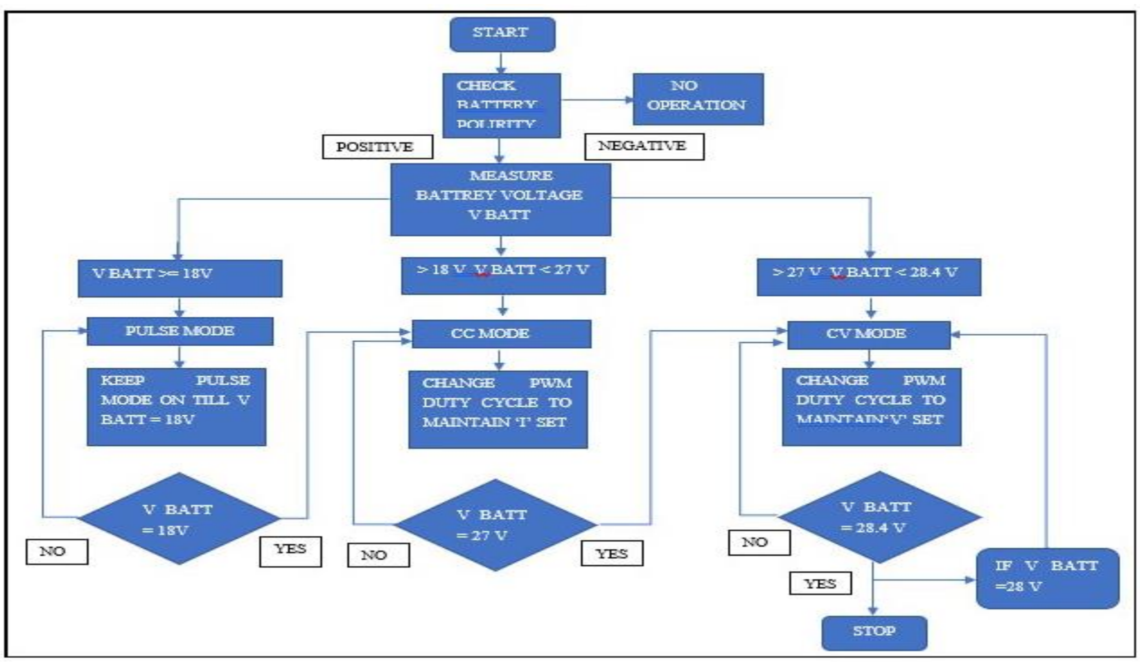


**Figure 2**.Flow chart of charger.

## 4. OPERATION OF BATTERY CHARGER WITH CHARGING TECHNICS –

In component selection we have seen all component which are used for build/ develop charger. Refer. Flowchart for charger operation step wise operation of charger. Power ON of charger (MCB). Rectifier & Filter circuit will rectify 230 V AC to 325 peak DC & filter Circuit will filler DC supply (reduce ripple). Rectified DC provided to IGBT H Bridge H bride will convert the DC supply to Square AC at 20 KHz. Generated 20 KHz power will reduced by stap down ferrite transformer it will reduce voltage to 30 V. This reduced passes to fast recovery diode they will rectify Square AC to pulsating DC. Pulsating DC supply will be filtered by LC filter. Filter power is used for battery charging purpose. To measure output voltage & current sensor circuit is provided. This sensed output will be provided to Micro-controller. Micro-controller is controlling overall charger system. Through micro-controller PWM is generated and other function such as reverse battery protection, charging mode selection are performed. Charing mode selection in given below- Following are Charging methods with combinations used for battery charging [17]-[18].

### 4.1. Constant Current (CC)

In this method continuous current is provided to battery for set period. Advantage of this method is that it requires less time to charge battery. Disadvantage of this method are overheating, decreasing in life cycle of battery.

### 4.2. Constant Voltage (CV*)*

In this technique constant voltage is applied to the battery till it reaches to battery cut off voltage. Disadvantage of this method is that in single stage operation (When battery is discharged) large current can be drawn from charger/Grid and can be provided to battery which can draw more current thus, over heating can take place. Hence, to avoid this situation control based CV can be applied for battery charging.

### 4.3. Pulse method

In this method current pulse are applied to battery. Sulfation on plate can be removed by pulse charging method high frequency during charging (superimposed method). Method can eliminate the accumulated sulphur on the electrodes which improves chemical reaction in a battery. This method helps to charge depth/deep discharged battery.

In charger system, above mentioned three methods with combination are used for battery charger. CC and CV method used for normal/ good condition battery to reduce the battery charging time. Method selection of charging are based on battery voltage. Battery voltage and charging method. (Applicable for 24 Battery system) refer. Table-5.

**4.4.** To reduce the Gas formation in battery and reverting the battery sulfation pulse. Current pulse added with constant current profile in order to increase charging acceptance, reduce the gas formation and partially increase battery life. [19]

Table 5. Battery voltage & charging method selection.

| Battery Voltage | Method of Charging |
|---|---|
| Below 18 V | Pulse method |
| 18 V to 22.2 V | Combination of Pulse & CC |
| 22.2 V to 27 V | CC |
| 27 V to 28.4 V | CV |

## 5. DETAILS OF ASSEMBLSED HARDWARE.

For charger Operation, charger circuits are finalised & this circuits are built for uses purpose. (Becauseparts need to connect to each other for formation of circuits) Following circuit boards are developed.

**5.1.** PCB (Printed circuit board) 1

This PCB is consisting of following circuits-

- Line filter – It is used protects internal circuit from grid noise, spikes & avoid interference with other system.
- Rectifier Unit – It is used to convert the AC supply to DC supply.
- Filter – used to reduce ripple in DC supply.
- Auxiliary power supply – Provides an auxiliary power to circuit for its operation.


**Figure**3. Assembled Circuit Board of Line filter, Rectifier, Filter and Auxiliary Power Supply.

**5.2.** PCB 2 -

This PCB is consisting of following circuits-

- H bridge IGBT – IGBT Generates high frequency square wave ( at 20 KHz) form DC Supply.
- IGBT Driver Circuit. For operated IGBT bridge required gate pulse provided through IGBT driver. Output wave form of driver circuit are presented in Figure no- 4
- Snubber Circuit – This protects system from internal spicks.

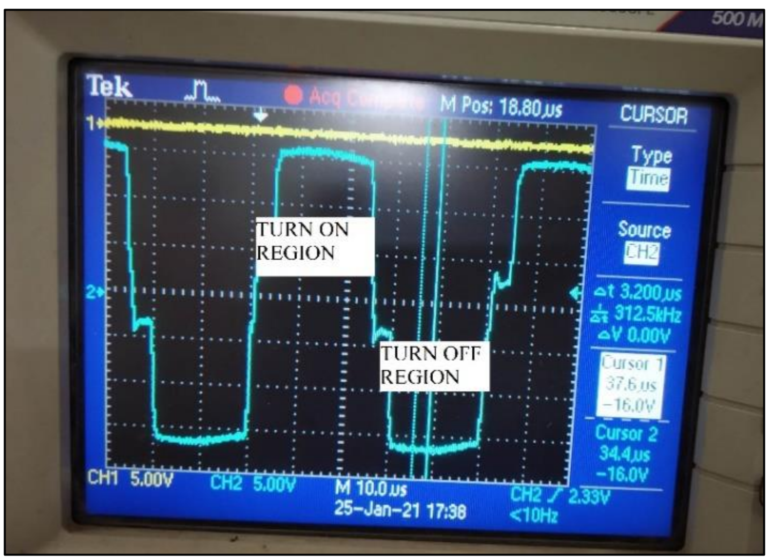


**Figure**4. IGBT Gate Wave forms.

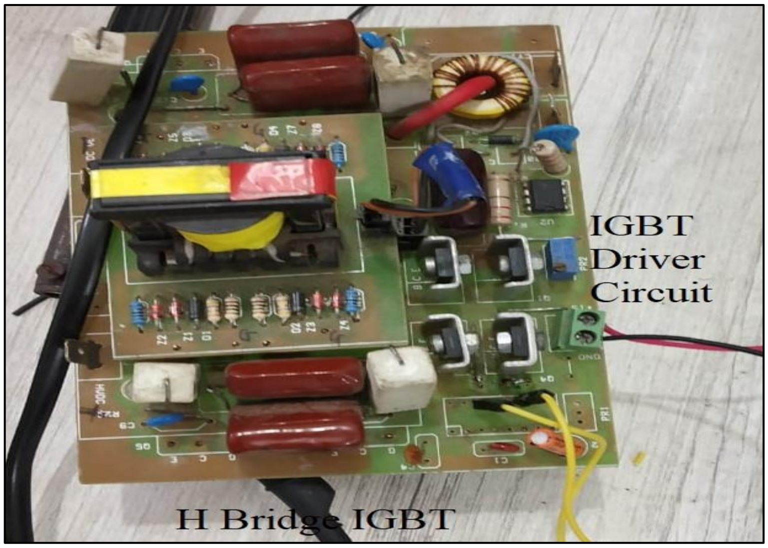

**Figure**5. Assembled Circuit Board of H bridge IGBT and its Driver Circuit.

**5.3.** PCB 3-

This PCB is consisting of following circuits-

- Ferrite Core Transformer (Step Down Transformer) – Transformer convert high voltage to required Low voltage.
- Rectifier Circuit& filter – This units used to rectify square wave to positive square wave. Filter circuit reduce ripple in supply which further feeds to battery.

**Figure**-6 Assembled Circuit Board of Ferrite Core Transformer.

## 6. Conclusions

Lead Acid battery is widely used for Two, Three-wheeler vehicle. Components are selected and Circuity of charger are finalized based on that hardware are developed. Further this circuit can used for charger development. During development of circuit & selection of component some of difficult faces i.e. failure of IGBT (Due to improper gate input & commutation between IGBTs, improper snubber circuit), Failure of Diode unit (Due to voltage spick and improper cooling ), Filter Circuit modify to reduce the ripple on output. Proposed charger circuit & components are suitable for smart battery charger. SMPS based Battery charger is suitable for lead acid battery charger. This circuit are capable of handle power rating up to 2800 Watt so medium size battery can charger. Selected topologies and component are adequate to meet the charger operation philosophy.

## 7. Acknowledgment

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## 8. Future Scope

Developed circuits can use for Battery charger &check proper operation of charger with desire function. Chargercircuits were developed to operate at 20 KHz frequency. This frequency can be changed i.e increase to reduce weight of transformer &over all weight of charger.

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