PAPER • OPEN ACCESS

Design of Bidirectional Battery Charger for Electric Vehicle

To cite this article: M Srinivasan *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1055** 012141

Design of Bidirectional Battery Charger for Electric Vehicle

M Srinivasan[1*], Albert Alexander Stonier[2], G Visalaxi[3], M Revanth[4], K Sanjeevkumar[4], B Sinduja[4] and S Subiksha[4]

[1]Assistant Professor, Department of EEE, Kongu Engineering College, Perundurai-638060, India.

[2] Associate Professor, Department of EEE, Kongu Engineering College, Perundurai-638060, India.

[3] Assistant Professor, Department of CSE, Bharath Institute of Higher Education and Research, Chennai, India.

[4]UG Students, Department of EEE, Kongu Engineering College, Perundurai-638060, India.

*Corresponding Author: srinieee@kongu.ac.in

Abstract- This paper proposes a design for the Bidirectional electric vehicle charger which is capable of doing both the Grid to Vehicle and Vehicle to Grid power transfer, and the interaction will be made through an automatic smart energy management system(EMS). A simple power electronics topology is used. The user can adjust the output of this charger by using the control signal provided by the controller. The simulation result obtained shows that it has an interaction between the charger and an Energy Management System(EMS) in a residence.

Keywords: Energy management system, energy storage, bidirectional charger, grid to vehicle, vehicle to grid, vehicle to vehicle.

1. Introduction

The promotion of ultimate consumer resource efficiency policies along with the reduction of technical based remedies to manifest them exhibit a basic step influencing for sustainable building, which should be also joined with a higher penetration of endless resources in the generation mix. The current growth of the existing grids to smart grids, bestowed with data and communicating technologies (ICT), provides the technologies basic for the advancement of more sustainable, brilliant and elevated resource management systems (RMS), such as the resource box (RB) as proposed already[1],[2]. The RB makes use of the usual elasticity that end user have in load operating condition allotted to obtain craved necessity response action and obtain ideal global control of energy resources. RB characteristics are price signals obtained from the grid in the active tariff setting, user comfort demand

and limitation, atmospheric conditions, local generation forecast etc..., that could be used by a set of rules for optimized control game plans production . These game plans have an advantage of ultimate consumers, by putting down their electric power invoice by not lowering the hallmark of the energy service given, and system operator, by guiding network management in terms of a significant entering of intermittent endless generation[3]. The RB can also exhibit modifying outline, capture and learn the consumer's resource expenditures profile and usual habit for more ahead resource management choices predictability.
In these circumstances, the accomplishment of this type of RMS faces some technological hindrance for instance the one said in this paper: the outlook of systems for interface amidst the grid and stationery and vehicular energy vault. The plug in electric vehicle (PEV) that is a vehicle that can be bounced back through an electric plug (grid to vehicle, G to V), can be seen as a unique urban load with the inbuilt power to giveback resource to the grid (vehicle to grid V to G)

In reality, current development in PEV and urban RMS notice the control of PEV charging and discharging operation as appropriate matters on the growth of defendable mobility and universal optimization of resource consumption. The RB is trustworthy for limiting G to V/ V to G operations modes in a way of command signals acting as a footnote to the charger controllers. In addition to load management, photovoltaic and wind micro-production, the management of G to V /V to G operation modes has the ability to transform a residence. The problem in the available charger systems are listed. They are unidirectional so that only grid to vehicle charging is possible. No control strategy is integrated within the charger control algorithm and also there is no screen for monitoring the power variation. Instead of more complex architecture being given in the literature, the approach can achieve through wanted principles of operation for the operational architecture of bidirectional charger RMS. The design of power electronics controllers and sizing of some submissive elements have been designed to sustain the current and voltage levels within the limits, accomplishing power quality (PQ) requirements. Minor sample is set up for evaluating the desired architecture and control. The design efficiency has been tested in various performing areas. Final outcomes are quite worthy and visionary.

2. Power electronics charger topology

The most relatable elements of the grid are plug in electrical vehicles and their chargers. The well-known an optimized interface between the PEV and the grid are permitted by chargers, main factors for PEV to become more driven compared with Internal Combustion Engine (ICE) vehicles are chargers and their associated intelligent management systems. In regarding the control of active power, reactive power and voltage in this type of power converters research has been worked out. With the reference of topology structure in figure 1. block diagram, our model displays some resemblances as well as in the approach of the controller[4]. A proper and firm operation through a reduced-scale experimental setup have been displayed in this paper model. For completing the end outcome, power switches selection, controllers, filters, and the corresponding mechanical assembly of all components are essential.

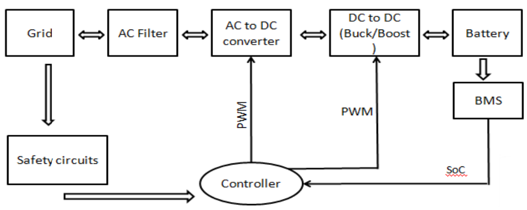

Figure 1. Block diagram.

3. Electric vehicle charger topology

The desirable features for the charger are power bi directionality (V to G and G to V), power factor equal to one, capability of performing power control, low PQ impact, construction and topology simplicity, and regular 16 A single-phase plug compatibility. This charger does not allow performing fast charge, being 2.3 kW (10 A, 230 V) the advisable maximum power for a single-phase household-type plug. This power range is categorized based on EU values and power grid limitations, as more power ranges could present a counter impact on the less voltage (LV) grid in areas of PQ and RMS requirements. In terms of the voltage level of the battery setup, the suggested design is worked on L-category vehicles (two-, three- and four-wheel vehicles such as motorcycles, mopeds, scooters, auto sand mini cars) still could be taken further to another voltage levels. The topology presented in Figure is formed by three legs of two Insulated Gate Bipolar Transistors (IGBT), The IGBTs are used due to their good compromise characteristics associated with voltage, switching frequency and current limits[5]. These power switches are used for an AC/DC converter that operates as a controlled rectifier or as an inverter for G to V or V to G operation modes, respectively, and for a DC/DC converter (C class chopper) in which the power used for both modes is limited. The characteristics of converters meet the required bi-directionality, where the chopper works as buck and boost for G to V and V to G performance modes, respectively. Some complementary elements for filtering and energy storage purposes are also designed and worked, that are related for wished proper system dynamics, stability and power quality.

4. AC/DC

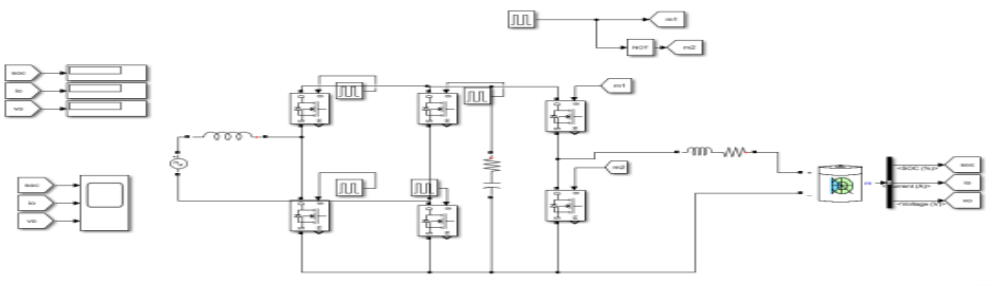

Figure 2. AC to DC converter.

It works as a both rectifier and inverter mode of operation and in each mode of operation it is controllable. Here apply unipolar switching methods and at a same time the same leg switches are not turned on as[6]. The output voltages is taken from the upper and lower part of the circuit. In the figure 2 Fourier series is used to approximate the switching function equal to 1/2 (1+Ci), where Ci is control signal which is used to control the convertor. Each IGBT is turned on and off by using the control signal by a comparison with the carrier signal. The same principal is used for the inverter in figure 3 and the output is shown in figure 4.

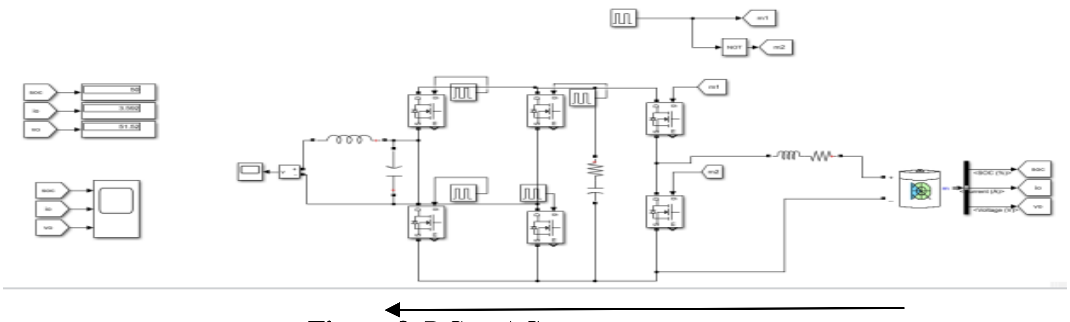

Figure 3. DC to AC converter.

The power factor is improved by adding a L capacitor in the start of this circuit. It is the minimum cost solution. The size of the inductor here used is 7.6mH with a power of 2.3KW.

$$L = \frac{2(Vac)^2(5.2 \times 10^{-2})}{wp}$$

Where Vac = 230V, W= 2πf, P=2.3KW

Here used PI controller for AC to DC and DC to AC conversion. The pole placement approach is used to tune this PI controller[7]. During this inverter mode this is based on unipolar switching method.

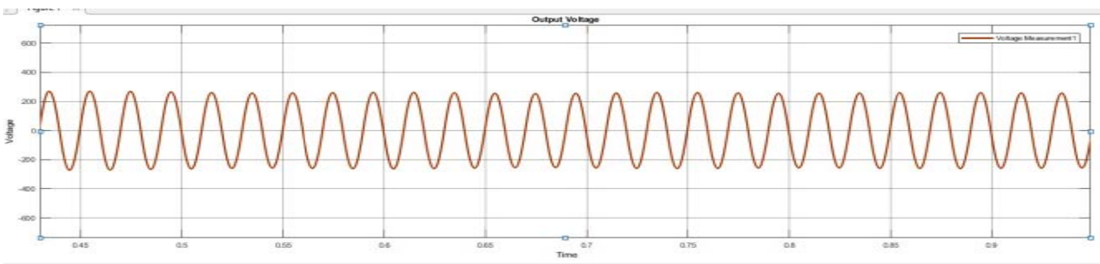

Figure 4. DC to AC converter Output.

5. DC to DC converter

Class C chopper is used for this DC to DC conversion. It operates in first two quadrants. It is a bidirectional one which operates in both buck mode and boost modes respectively which is shown in figure 5. The PWM signals to these controller is provided by the controller. The important element of this converter are the inductor and a capacitor. The inductor should be sized and it work as an energy gauge. The source current ripple is controlled by this inductor. Stabilization of DC voltage is provided by the capacitor.

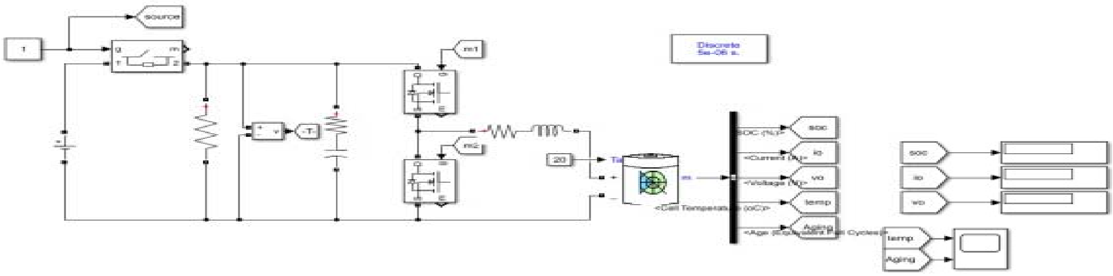

Figure 5. DC to DC converter.

6. Controller for DC to DC Converter

This is the most important part of this circuit. It have two operating cases. One is charging and another one is discharging. The controllers are designed for both the operations.

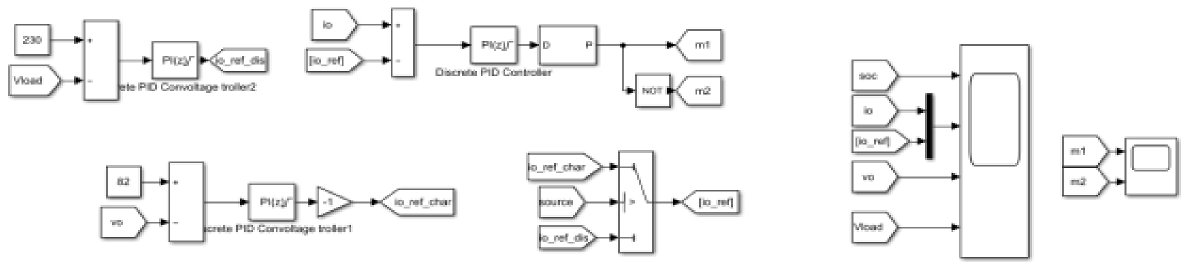

Figure 6. DC to DC converter controller.

It uses PI controller for this control operation and stimulated the entire design in MATLAB software. It is known that the charging is done in two modes of operation. One is constant current and another one is constant voltage. Some battery companies separate the constant current and constant voltage sides at 80% SoC levels[8]. For the current control PI controllers fix P as 40 and I as 5000 based on Ziegler Nichols method in figure 6. It can also vary according to our requirement. Here used a separate PI controller for constant voltage control. For this voltage control PI controller the proportional constant as 1 and integral constant as 50 are fixed by using the same method. The output of this controller is shown in figure 7. The battery parameters while charging is shown in figure 8.

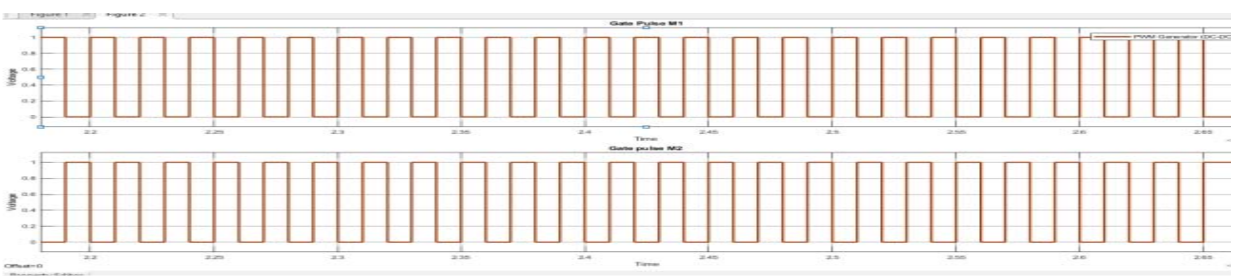

Figure 7. Control signal for DC to DC.

For discharging a separate PI controller is used which provides the load voltage. For this proportional value as 0.15 and integral value as 200 is fixed as per the same method.

IOP Conf. Series: Materials Science and Engineering 1055 (2021) 012141 doi:10.1088/1757-899X/1055/1/012141

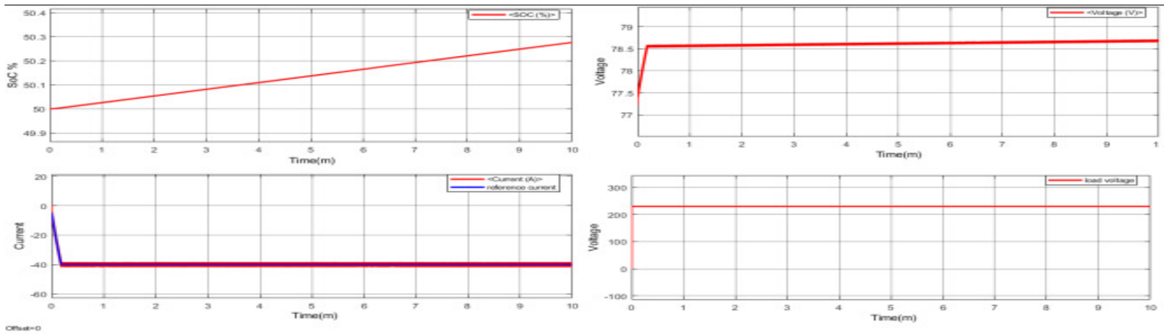

Figure 8. SoC, voltage, current output.

6.1 Formula to calculate SoC of a battery

There are four major ways for the SoC calculation of a battery. Here uses direct method of calculation. SoC by considering the voltage of the battery can be calculated as

$$SoC(t) = SoC(t-1) + \left(\frac{1}{C}\right)(int[i(t)]\,dt) \qquad (1)$$

7. Safety features

As a device with the protection against the electric shock, it is essential to install the protective measures. In the making of a Bidirectional Charger which can transfer energy to both G2V and V2G it is necessary to implement safety. These safety features can protect the charger and it also improves the life cycle of the battery and the charger.

7.1 Over voltage protection

In normal condition, the supply voltage is 180V-240V, the voltage at (pin3) of non-inverting terminal of operational amplifier U2A is lower than the 6.8V. The result of amplifier is 0 and the transistor Q1 is in off state. The circuit is completed through the normally closed relay. The opamp IC LM324 works here as a comparator. The IC LM324 consist of four op amp, here only two op amp were used. The supply is to be connected in the series connection of resistors R1 and resistor R2. The same power supply is linked to the 6.8V zener diode and resistor R3. When the input voltage is above 240V it is called as over voltage, where the voltage v is at the (pin3) of non-inverting terminal of operational amplifier U2A is maximum. Inverting terminal voltage is same as 6.8 V. Where, voltage at (pin3) of the operational amplifier is higher than the 6.8V. In these case the result of the operational amplifier is high (figure 9). So the supply is disconnected and the charger will be be protected against the over voltage.

7.2 Under voltage protection

When the supply voltage is below 180 V it is called as under voltage. In these case the voltage at (pin6) inverting terminal of the operational amplifier U2B is lower than the voltage at non-inverting terminal that is the 6V. Hence the result of the operational amplifier U2A goes maximum and it neutralized the relay across the transistor of Q1. (figure 9) where the power supply gets removed and the charger is protected against the under voltage. Here relay is used in two different conditions,the first if the voltage at the pin 3 of operational amplifier is more than 6.8V the relay gets opened, the second, the voltage at the pin 6 the operational amplifier is under the 6V the relay gets opened.

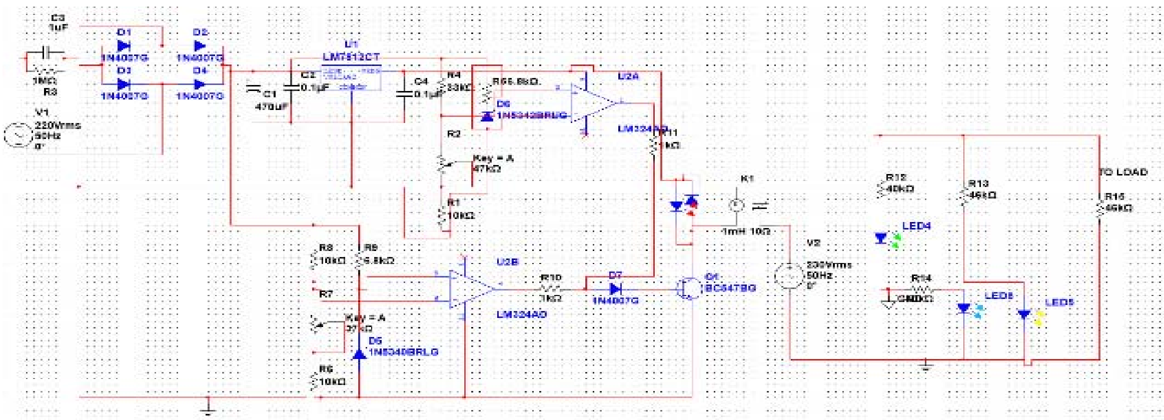

Figure 9. Over and Under voltage protection

7.2.1 Specifications of components.
LM324 op amp supply voltage 3V to 32V and the dual power supply ±1.5V to ±16V. lower supply current is about 700µA. NPN type of transistor BC547 has max power of 625mW, voltage collector (max) is about 45V and current collector (max) 100mA.

7.3 Earth leakage protection
Earth leakage protection is used to protect the charger against the earth fault. Where R2 is position as a current sensing resistor which have low value so that it act as actual earthing.T1 is a current sensing and a voltage amplifier stage. The small voltage detected across the R2 is amplified by T1 and given to the LED inside an opto coupler. If the leakage is not significant (below 20mA) the LED inside the opto coupler is not respond (figure 10) where value exceed the limit(above 20mA) the LED inside opto coupler switch ON and activate the red LED connected across collector indicate the earth leakage (figure 11). The value of R2 is calculated using R =0.2/0.02=10 ohms. Collector resistance of T1 is quite high, T1 could get trigger with low as the 0.2V to its base or emitter

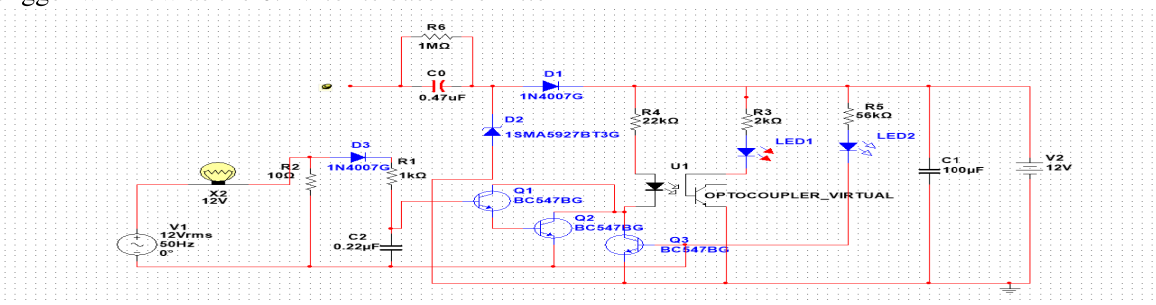

Figure 10. Earth leakage protection in normal condition.

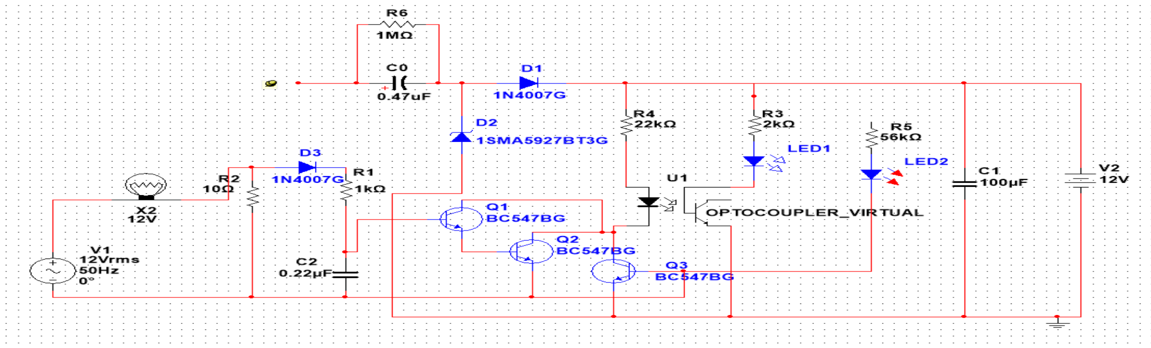

Figure 11. Earth leakage protection in fault condition.

In the testing circuit setup 12V AC supply is connected in series with the lamp which act as a load R5 is kept disconnected. It should instantly switch ON the red LED indicating the current leakage through the R2. Now the load is reduced by adding a another 12V bulb serious in it. Even in this condition the LED should be able to indicate the leakage across R2. This test is used to conform proper working circuit. Now removing the load should suddenly switch OFF the LED to assuring the correct working of the circuit.

7.4 Over current protection

It is the protection circuit which protects the charger from over current damage. A simple over current circuit breaker can be used. And also the Magnetic circuit breaker, fuses and the over current relays can be used to the provide the over current protection for the circuit.

7.5 Short circuit protection

The AC short circuit protection is used to protect the charger from the fault condition. The circuit will also safeguard you house wiring against a possible overload conditions. The system consists of optocoupler, where it internally consist of LED and switching transistor arrangements. The resistor R1 is connected, the AC mains current from the house wiring passes to it and so the over load or over current is subjected over the resistor. During overload and short circuit conditions, the resistor develops the potential to it and send to optocoupler. The optocoupler suddenly switch ON the corresponding transistor connected to it. SCR is used for triggering the main supply. During the normal condition, (figure 12) the supply goes through resistor R4 and remains switched ON and allowing the load connected to it. In this condition the SCR remains in OFF state. In case of overload or short circuit the optocoupler transistor conducts and it triggers the SCR to turn ON and supply through R1 resistor to safe the load and house wiring equipment.

7.5.1 Specification of components.

Input and output of coupling capacitance is <0.5 Pf. Forward current is 60mA reverse voltage about 6V. Surge current is 2.5A, collector-emitter voltage 70V, Emitter-base voltage is 7V, collector current is 100mA for the opto-coupler MCT2E. SCR of c106 has 4A RMS and 400-600 volts.

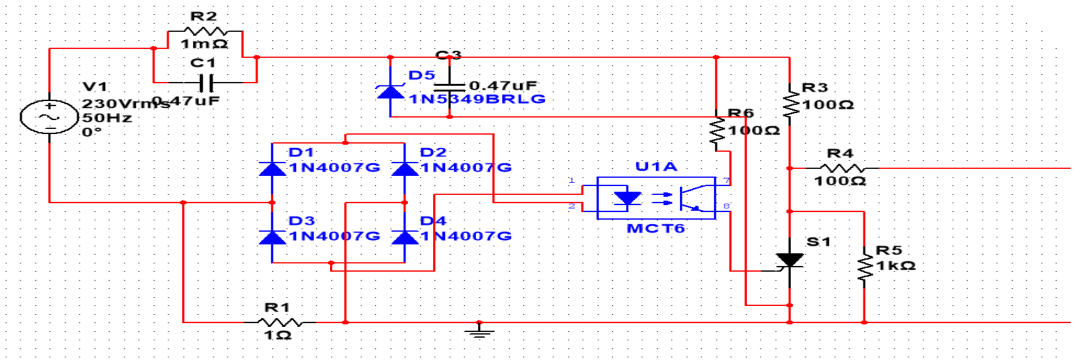

Figure 12. AC Short circuit protection.

7.6 Reverse battery protection

Reverse battery protection is used to protect the battery from reverse polarity connection. Here the MOSFET is used as a switch and resistance is considered as a load (figure 13).In normal condition the current flow through the MOSFET. If the charger is attached to the battery correctly the voltage to the gate is low so the MOSFET is in on condition. If the charger is attached to the battery incorrectly the voltage to the gate of the MOSFET is high so the switch is in off condition. It prevents the charger from damage.

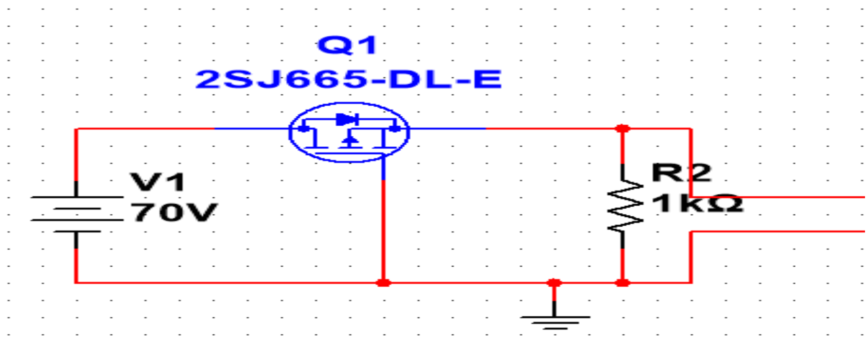

Figure 13. Reverse battery protection

7.6.1 Specification of components.

MOSFET of drain current DC is -27A, drain current pulse -108A

8. Controllers

The Proportional Integral type controller are used here and they design for accurately controlling the Insulated-gate bipolar transistor switching by references of current and voltage.

8.1 Controller design

$$I = -IC + I\_L \tag{2}$$

$$Cbus \cdot dVCbus\,(t)dt = -I\,(t) + IL\,(t) \tag{3}$$

$$VL + VBAT - VCbus = 0 \tag{4}$$

$$LChopper \cdot di\,(t)dt = -VBAT\,(t) + VCbus\,(t) \tag{5}$$

$$VL + VBAT = 0 \tag{6}$$

$$LChopper \cdot d\,IL\,(t)\,dt = -VBAT\,(t) \tag{7}$$

$$IL = -\,VBAT\,/\,LChopper\,s + (1 - d\,(s))\,VCbus\,/\,LChopper\,s \tag{8}$$

8.2 Controller Of AC/DC Converter

The controller of the rectifier is Proportional Integral type. A linking of dual Proportional Integral controllers for AC current regulation and DC bus voltage, The method of phase locked loop is giving reference of AC current control. Above controller was tuned by a pole placement approach and then refined by test experiments, at last Insulated-gate bipolar transistor's PWM signal were generated by the PWM generator by Arduino (figure 14). When this used as inverter the controller use AC/DC converter, it is on the basis of the mode used in the charger[9]. A sinusoidal reference is given by PLL, where the voltage grid is synchronized. AC/DC converter mode, the bus voltage of DC is in a right way. Both AC/DC shape shifter controllers are connecting to the IGBT and Adriano. Information for the suggested topology of charger and the intended controllers are brief below,

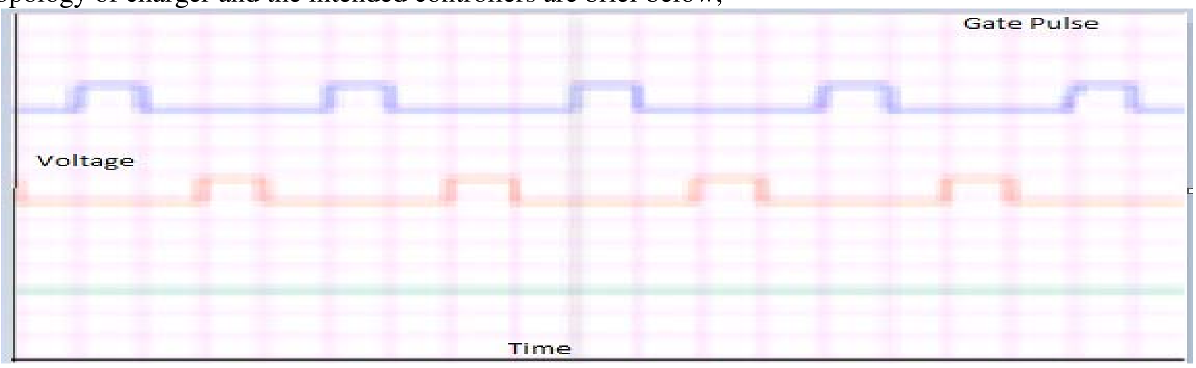

Figure 14. Voltage and Frequency value obtained in AC/DC converter controller.

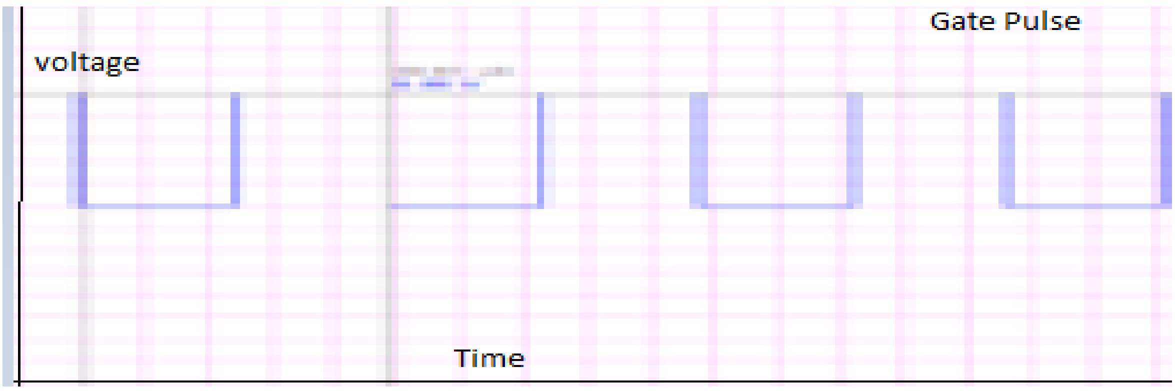

Figure 15. Voltage value obtained in DC/DC converter controller.

8.3 Controller for DC/AC Converter

During the reverse process, the DC is converted to AC. The controller used is PI-based controller. PWM signal is generate in arduino where required amount of frequency is produced. Those PWM signal were given to the IGBT to control the flow of voltage in the charger. The PLL is also used provide reference of DC current[10]. The booster were used in the circuit to improve stead flow of the voltage and current. This operation will only used when the mode is change to the inverter mode. The requirement of the frequency of both AC to DC and DC to AC are more or less same. The generated frequency is feed into the IGBT and rectifier.

8.4 Safety controller

Safety is very important in circuit to protect the charge. There are many safety circuit in this charge and each and every Safety circuit will be connected to the Arduino, if there is error in the circuit then total circuit will be disconnected or turn OFF. If there is error signal will be send to the Arduino then it will cut off the signal to the IGBT.

9. Conclusion

The bidirectional charger is developed which is to be used for the V2G and G2V power flow. It mean a charging and discharging with one unit are possible, with the design proposed. It operate in constant current, constant voltage battery charging methods are happen in unit power factor changing. The operating parameters can be adjusted by varying the control signal from the controller. This design allows the charging and discharging operation at the different power level.

10. References

[1]Livengood D and Larson R 2009 The energy box: Locally automated optimal control of residential electricity usage *Serv. Sci* vol. **1** pp. 1–16.

[2]Soares A, Gomes A, Antunes C. H and Oliveira C Apr. 2017 A customized evolutionary algorithm for multi objective management of residential energy resources IEEE *Trans. Ind. Informat.* vol. **13** pp. 492–501.

[3] Trovao J. P, Pereirinha P. G, Trovao L, and Jorge H, 2011 Electric vehicles chargers haracterization: Load demand and harmonic distortion in *Proc 11th Int. Conf. Elect. Power Qual. Utilisation* pp. 1–7.

[4] Solero L, Jan. 2001 Nonconventional on-board charger for electric vehicle propulsion Batteries *IEEE Trans. Veh. Technol.* vol. **50**, no. 1, pp. 144–149.

[5] Melo H. N, Trovao J. P, Pereirinha P. G, and Jorge H, 2013 Energy profits with controllable electric vehicle's charger under energy box decisions in *Proc. 7th Int. Conf. Energy Efficiency Domestic Appliances Lighting* Coimbra Portugal pp. 1–6.

[6] Vittorias I, Metzger M, Kunz D, Gerlich M, and Bachmaier G, 2014 A bidirectional battery charger for electric vehicles with V2G and V2H capability and active and reactive power control in *Proc. IEEE Transp. Electrific. Conf. Expo*, Dearborn, MI, USA, pp. 1–6.

[7] Tashakor N, Farjah E, and Ghanbari T, Mar. 2017 A bidirectional battery charger with modular integrated charge equalization circuit *IEEE Trans. Power Electron.*, vol. **32**, pp. 2133–2145.

[8]Pinto J. G, Monteiro V, Gonc¸alves H, and Afonso J. L, Mar. 2014 Onboard reconfigurable battery charger for electric vehicles with traction-to-auxiliary mode *IEEE Trans. Veh. Technol.* vol. **63** pp. 1104–1116.

[9]Melo H. N, Trovao J. P, Pereirinha P. G, and Jorge H, 2012 Electric vehicles intelligent charger for automated energy management system in *Proc. Int. Workshop Energy Efficiency More Sustain. World*, Azores, Portugal, pp. 1–6.

[10] Lopes M, 2012 An automated energy management system in a smart grid context in *Proc. IEEE Int. Symp. Sustain. Syst. Technol.* p. 1.
[11] A. S. Albert, and T. Manigandan, "Optimal harmonic stepped waveform technique for solar fed cascaded multilevel inverter," J Electr Eng Technol., Vol. 10, No. 10, pp. 742–751, 2015.
[12] A.A. Stonier, S. Murugesan, R. Samikannu, S. K. Venkatachary, S. Senthil Kumar and P. Arumugam, "Power Quality Improvement in Solar Fed Cascaded Multilevel Inverter With Output Voltage Regulation Techniques," in *IEEE Access*, vol. 8, pp. 178360-178371, 2020, doi: 10.1109/ACCESS.2020.3027784.
[13] Sampath Kumar Venkatachary, Ravi Samikannu , Srinivasan Murugesan ,Narasimha Rao Dasari , Ragupathy Uthandipalayam Subramaniyam , Nov. 2020, Economics and impact of recycling solar waste materials on the environment and health care, "Environmental Technology & Innovation", Vol.20, no.101130, pp. 1-14.