IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 9, Issue 1 Ver. IV (Feb. 2014), PP 91-99
www.iosrjournals.org

Closed Loop Control of Full Bridge LLC Resonant Converter for Battery Charging Application

J.Hepsy Joseph[1], R.M.Sekar[2,] J.Velmurugan[3]
[1,2,3]*Anna University Chennai, 600 025, India*
[1,2,3]*Department of Electrical & Electronics Engineering,*
[1,2,3]*PSNA College of Engineering & Technology,Dindigul india– 624 622.*

Abstract :*The Basic requirements of battery chargers with switching regulators are small sized and high efficiency. High switching frequency is necessary to achieve a small size. However, the switching loss will increase as the switching frequency is increased. This condition, in turn, decreases the efficiency. To solve this problem, some kinds of soft-switching techniques need to be used to operate under high switching frequency. One simple solution to a soft-switching converter is loaded resonant converters. By adopting these topologies, either voltage or current is zero during switching transition, which largely reduce the switching loss and also increase the reliability for the battery charger. It eliminates both low- and high frequency current ripple on the battery, thus maximizing battery life without penalizing the volume of the charger.*

*The proposed work will be LLC resonant converter with closed loop control for battery charger applications.***

Keywords: Battery, Diode bridge rectifier, Full bridge inverter ,PI Controller ,Resonant tank,.

I. INTRODUCTION

Secondary batteries are widely used in the application of residential, industrial, and commercial energy storage systems to store electricity and supply the load for various types of electronic equipment [1]–[7]. If the dc source is directly connected to the secondary battery, the output voltage of the dc source is fixed to the voltage of the secondary battery; therefore, the system cannot always operate at each optimum operating point. Therefore, it is necessary to install a dc–dc interface between the dc source and the secondary battery to make the energy storage system always operates at the optimum operating points. This dc–dc interface is also called the battery charger. The traditional battery charger, which extracts power from an ac-line source, requires a thyristor ac/dc converter rectifier with an equivalent series resistance to control the power flow to charge the battery system. Such a charging circuit necessarily draws a high-ripple charging current. Accordingly, as the concern about the quality of a charger grows, a charging circuit for reducing the ripple and extending the battery life becomes more important in designing the battery storage systems. Several charging circuits have been proposed to overcome the disadvantages of the traditional battery charger. Unlike linear regulators, switching regulators use active power switches to operate in either the saturation region or the cutoff region. Because either region will lead to low switching voltage or low switching current, it is possible to convert a dc voltage to a different level with greater efficiency, as well as with low cost, relatively small size, and light weight between the two columns. The life and capacity of the secondary batteries depend on several factors e.g., charge mode, maintenance, temperature and age. Among these factors, the charge mode has a great impact on battery life and capacity. The secondary batteries should be charged with current and voltage levels with low ripple. Therefore, a high-performance battery charger is necessary in a battery energy storage system. In addition, the basic requirements of battery chargers with switching regulators are small sized and high efficiency [8]–[10]. High switching frequency is necessary to achieve a small size. However, the switching loss will increase as the switching frequency is increased. This condition, in turn, decreases the efficiency of the battery chargers. To solve this problem, some kinds of soft-switching techniques need to be used to operate switching frequency [11]-[15].One simple solution to a soft- switching converter is loaded under high resonant converters. By adopting these topologies, either voltage or current is zero during switching transition, which largely reduce the switching loss and also increase the reliability for the battery chargers. To minimize the power losses, it is essential not to waste energy in the conversion process. In relation to the power electronics and associated control schemes, the main requirement is to guarantee that the charging system is efficient. Therefore, topologies with high frequencies and soft-switching technique are used to reduce the charging current ripple and extend battery life. Among these existing soft-switching converters, Resonant converters are the most popular ones because of their simplicity of circuit configuration, low switching losses, and high flexibility for charging current regulation. Resonant converters can be classified, depending on the manner by which energy is extracted from the resonant tank, into the following three types: 1) series resonant converters; 2) parallel resonant converters; and 3) series–parallel converters. The series resonant converter is inherently short circuit and protected by the impedance resonant tank. However, the drawback of the series resonant converter is that the charging voltage cannot be regulated at no load and light-load conditions. The disadvantage of the parallel converter is that the current in the resonant components is relatively independent of the load. The conduction losses are fixed, and the efficiency of the converter is relatively poor for light loads. On the other hand, the series–parallel converter combines the advantages of the series and parallel converters. The output is controllable for no load or light load, and the light load efficiency is relatively high. Accordingly, a series–parallel dc–dc converter is installed between the ac input source and the storage batteries to control the operating points of the dc source.

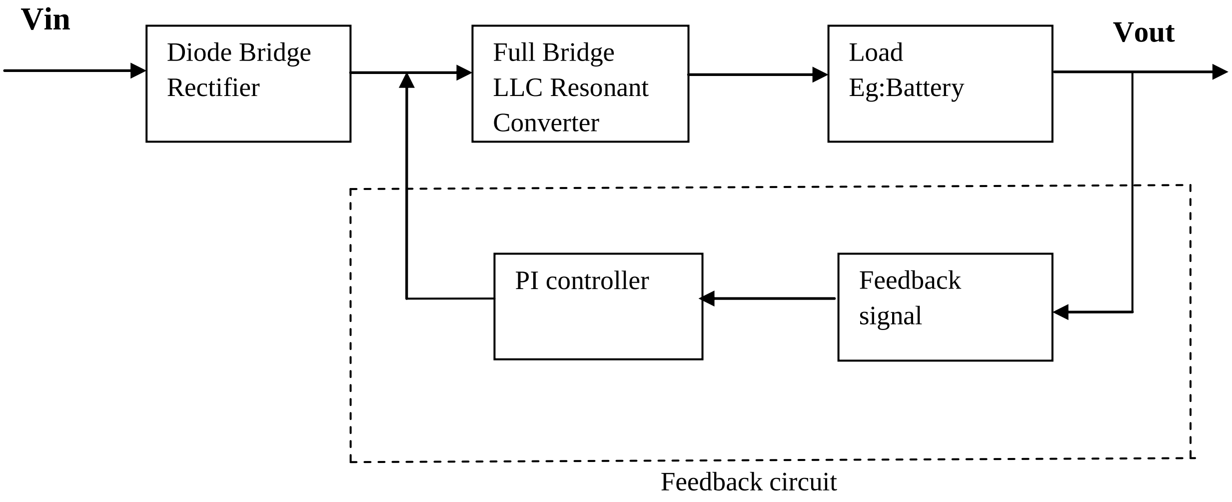


Fig1:Block Diagram Of Full Bridge LLC Resonant Converter For Battery Charging Application.

II. Circuit Description

2.1 Circuit Description

The life and capacity of Batteries depend on several factors, such as cycle count, charge mode, maintenance, temperature, and age. Among these factors, the charge mode has a significant impact on battery life and capacity. EV batteries should be charged with current and voltage levels with low ripple. In addition, the basic requirements for battery chargers are small size and high efficiency, which can be achieved using soft switching techniques. To reduce the switching losses that result from high-frequency operation, resonant power conversion can be used

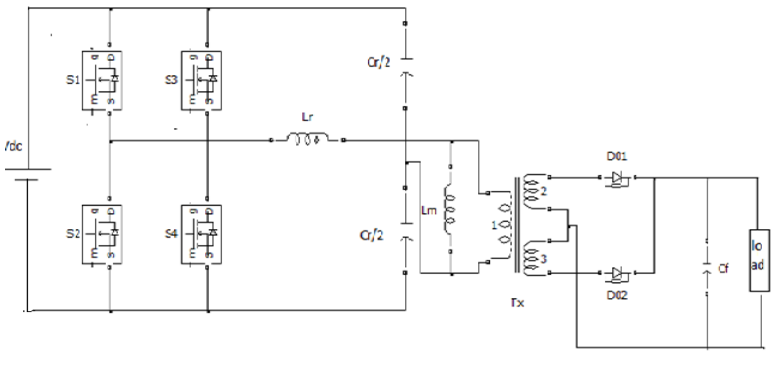


Fig2: Full Bridge LLC Resonant Converter Circuit Diagram

The proposed battery charger power architecture includes an ac–dc converter, followed by an isolated dc–dc converter, with closed loop control as shown in Fig. 1 . This architecture virtually eliminates the low- and high-frequency current ripple charging the battery without using a bulky filter capacitor. Instead, it uses a high-frequency transformer. The architecture maximizes battery life without penalizing the charger volume. The first stage is ac-dc converter .The second-stage dc–dc converter is a full-bridge multi resonant LLC converter with closed loop control [16]-[18]. The criteria for choosing these topologies include high reliability, high efficiency. The full-bridge resonant LLC converter is widely used in the telecom industry for its high efficiency at the resonant frequency and its ability to regulate the output voltage during the hold-up time, where the output voltage is constant and the input voltage might drop significantly [19]–[*22*].

To reduce the switching losses that result from higher frequency operation of battery chargers, resonant power conversion receives renewed interest. These converters usually operate at high frequency employing natural commutation. As a result, the resonant converters have several advantages over traditional thyristor converters. Lower size and weight, reduced switching losses, lower harmonic content, and step-up or step-down capability are some of the advantages. In view of the increasing importance and application of resonant converters, several efforts have recently been made in the modeling and analysis of resonant converters.

The FBSPRC consists of a full bridge inverter, Resonant tank(LLC), Transformer and a Half bridge Diode rectifier with capacitive filter as shown in the fig2.The Full bridge inverter employs a pair of bi directional *S*1 ,*S*2,S_3 and S_4 MOSFET Switches. A half-bridge would have twice the current of what a full-bridge would have, the squared rms current in the half-bridge case four times, the number of switches in a half bridge is half of that in a full-bridge, therefore, the total FETs conduction losses of a half-bridge is twice compared to the full bridge as shown in fig2**.**

2.2. Switches

An important part of any power electronic converter is its semiconductor devices. The semiconductor devices that are typically used in switch-mode power converter are diodes, MOSFETs (Metal Oxide Semiconductor Field Effect Transistors) and IGBTs (Insulated Gate Bipolar Transistors). Diodes can be considered to be uncontrolled switches as they are on and conduct current when they are forward-biased and are off when they are reverse-biased. Current cannot be interrupted in a diode and some external action must be taken to the diode in order to divert current away from it and make it reverse biased. MOSFETs and IGBTs are controllable switches as they can be turned on and off by feeding a signal to their gate then removing it.

For MOSFET selection, consideration must be given to practical dv/dt turn-on limits, body diode reverse recovery [28], and losses. A power MOSFET is a specific type of metal oxide semiconductor field-effect transistor (MOSFET) designed to handle significant power levels and is typically depicted as shown in Fig4. It has three terminals - a gate, a drain, and a source. The switch is on when current is fed to the gate and its gate-source capacitance is charged to a threshold voltage(Vth) , which creates a field that opens the drain-source channel and allows current to flow from drain to source. It has an isolated gate and current does not have to be continuously fed to the gate to keep the device on; the device is on as long as the voltage across the gate-source capacitance Vgs is greater than Vth and the field that keeps the drain-source channel open exists. A MOSFET has an intrinsic parallel body diode and can conduct reverse current even when the switch is off.

The MOSFET has three main regions of operation: triode, saturation, and cut-off. Since controllable semiconductor devices in almost all power electronics applications function as switches that are either fully on or fully off, a MOSFET in a power converter operates either in the triode region (fully on) or in the cut-off region (fully off). When the power MOSFET is in the on-state, however, it is not an ideal switch; it acts as if there is a resistor, Rds (on) (drain to source on-state resistance), between its drain and source terminals.

Compared to other power semiconductor devices such as the IGBT, the MOSFET’s main advantage is its high switching speed. MOSFETs can be turned on and off very quickly and are the fastest semiconductor devices in terms of switching because they are majority carrier devices and their operation is based on the generation and removal of an electric field,. They are the devices of choice in low power applications as their fast switching characteristics allows them to be implemented in converters that operate with high switching frequencies (>100kHz) to reduce the size of their magnetic elements (inductors, transformers). They are not suitable for higher power applications due to their Rds (on) and the conduction losses created by this parameter.

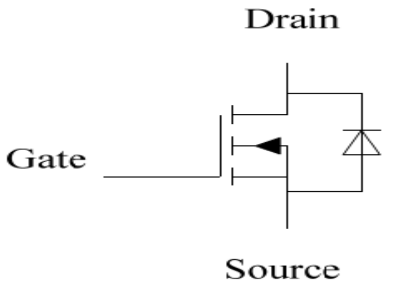


Fig3:An N-Channel Power MOSFET Symbol

2.3 .High Switching Frequency Operation

A power electronic converter has energy storage elements such as inductors, capacitors and transformers that account for much of its overall size. These components are used to store and transfer energy as part of the power conversion process converter's switching frequency is increased, the component values of its energy storage elements decrease, as do their physical size and weight, due to the shorter time they are required to store voltage or current.

2.4 Soft Switching

Hard switching refers to the stressful switching behaviour of the power electronic devices. During the turn-on and turn-off processes, the power device has to withstand high voltage and current simultaneously, resulting in high switching losses and stress. Dissipative passive snubbers are usually added to the power circuits so that the dv/dt and di/dt of the power devices could be reduced, and the switching loss and stress be diverted to the passive snubber circuits. However, the switching loss is proportional to the switching frequency, thus limiting the maximum switching frequency of the power converter. Because the switching loss and stress have been reduced, soft-switched converter can be operated at the very high frequency (typically 500kHz to a few Mega-Hertz). Soft-switching converters also provide an effective solution to suppress EMI and have been applied to DC-DC, AC-DC and DC-AC converters.

The stray inductive and capacitive components in the power circuits and power devices still cause considerable transient effects, which in turn give rise to electromagnetic interference (EMI) problems. Shows ideal switching waveforms and typical practical waveforms of the switch voltage. The transient ringing effects are major causes of EMI. The concept was to incorporate resonant tanks in the converters to create oscillatory (usually sinusoidal) voltage and/or current waveforms so that zero voltage switching (ZVS) or zero current switching (ZCS) conditions can be created for the power switches. The reduction of switching loss and the continual improvement of power switches allow the switching frequency of the resonant converters to reach hundreds of kilo-Hertz (typically 100kHz to 500kHz). Consequently, magnetic sizes can be reduced and the power density of the converters increased. Various forms of resonant converters have been proposed and developed. However, most of the resonant converters suffer several problems. **.**

As shown in the Fig2 converter combining the series and parallel configurations, called a series-parallel resonant converter (SPRC), has been proposed. One version of this structure uses two inductor and two capacitors, or (LLC) configuration, Although this combination overcomes the drawbacks of a simple SRC or PRC by embedding more resonant frequencies, The LLC resonant converter has many additional benefits over conventional resonant converter For example, it can regulate the output over wide line and load variations with a relatively small variation of switching frequency, while maintaining excellent efficiency. It can also achieve zero voltage switching (ZVS) and zero current switching (ZCS) over the entire operating range.

2.5 Battery Charge Algorithm

Battery are energy storage devices ,that are particularly useful for powering small portable devices like phones ,laptop ,and entertainment devices as well a mobility devices that travel over a earth's surface through water and in the air.

The battery charger controls the voltage that is applied to the battery, the amount of charge current that is supplied to the battery, and depending on the level of sophistication in the charger technology[2]-[4], the timing associated with what may be multiple voltage and current levels. The following paragraphs provide an overview with some significant detail of the different charging modes, or stages that may be included in a charging algorithm. Basically, a charge algorithm is a collection of all of the software controls over electrical parameters and timing that are applied sequentially to the charging system hardware for the express purpose of recharging a discharged battery. Stated a little more directly, the charging algorithm is what controls the battery charger behavior as measured at its electrical output terminals

A constant voltage charger is basically a DC power supply which in its simplest form may consist of a step down transformer from the mains with a rectifier to provide the DC voltage to charge the battery. Such simple designs are often found in cheap car battery chargers. The lead-acid cells used for cars and backup power systems typically use constant voltage chargers.

Selecting Transformer Turns Ratio, Nn

The transformer turns ratio should be selected at the resonant frequency where the gain is unity and can be calculated using (1), where Vd represents the diode voltage drop of the output rectifier

$$Nn = \frac{Vin(nom)}{2(Vo(min) + Vd)}. \qquad (1)$$

Calculating Resonant Inductor, Lr

The minimum resonant inductor must be selected to limit the maximum output current in the short circuit condition and limit the converter to its maximum switching frequency. The minimum inductance is given by (2)

$$Lr(SCC) = \frac{Nn \cdot Vin(nom) \cdot Vo(nom)}{8fsmax \cdot} \qquad (2)$$

Calculating Resonant Capacitor, Cr

Once the value of the resonant inductor is determined, the resonant capacitor value can be calculated using (3)

$$Cr(res) = \frac{1}{(2 \cdot \pi \cdot fo)2 \cdot Lr(scc)} \qquad (3)$$

III. Matlab Simulation

Closed Loop Controlled Converter

The closed-loop circuit model of the LLC Series- parallel Resonant full-Bridge DC-DC Converter is shown in Fig.2. The closed loop system consists of comparator and PI controller. The output voltage is sensed and it is compared with the reference voltage. The error signal is sent to the PI controller. The output of the PI controller is given to the MOSFET. The output of the PI controller controls the dependent source. The steady state error signal is reduced by properly turning the PI controller. Scopes and displays are connected to measure the input voltage, output voltage.

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy to use environment where problems and solutions are expressed in familiar mathematical notation .SIMULINK is a software package for modeling, SIMULINK, and analyzing Dynamic system. It supports linear and nonlinear systems, modeled in continuous Time, sample time, or a hybrid of the two .System can also be multi rate, i.e., have Different parts that are sampled or updated at different rates. SIMULINK encourages us to try things out. We can easily build models from scratch, or take an existing model and add to it. Simulations are interactive, so we can change parameters on the fly and immediately see what happens.

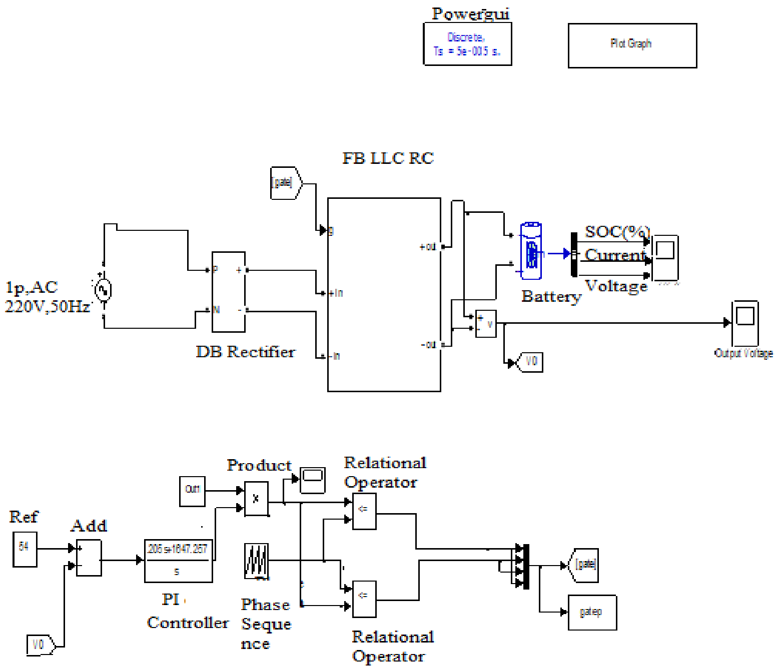


Fig4:Simulation Diagram Of Closed Loop Control Battery Charging Application

The Full bridge LLC series-parrell resonant DC to DC converter with closed loop control is simulated using Matlab are presented as shown in the fig4.

SIMULINK model of a proposed Full bridge LLC resonant converter is shown in the fig 5.The proposed model include Full Bridge inverter ,Resonant tank(LLC),center tap Transformer ,Diode bridge rectifier and capacitive filter .The 4 switches connected to the gate signal.

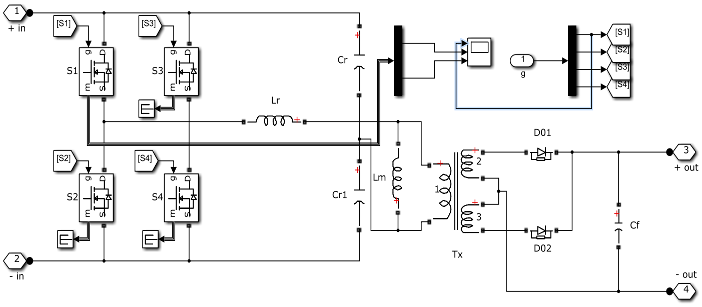


Fig5: MATLAB/Simulink Simulation Diagram for LLC Resonant Converter

The dc voltage converted into ac by use of full bridge inverter. The resonant tank connected to inverter . Usage soft switching technique. either voltage or current is zero during switching transition, which largely reduce the switching loss and also increase the reliability for the battery charger. Using proposed system virtually eliminates the low- and high-frequency current ripple charging the battery without using a bulky filter capacitor.

IV. Simulation Result

The gate pulses of 4 switches(S1,S2,S3 & S4) for LLC Resonant Converter as shown in the fig6.The switches S1,S4 triggered at one half cycle and another half cycle S2 & S3 are triggered .So the gate pulses of S1,S4 same and opposite to the gate pulses of S2,S3 in each switching cycle.

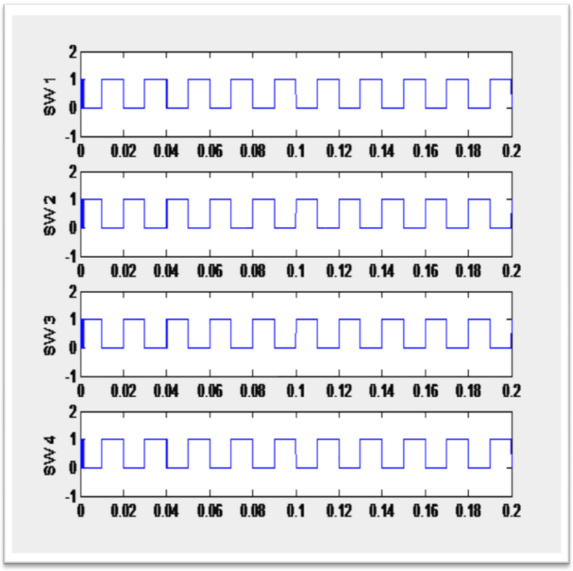


Fig6:Gate pulses (S1,S2,S3 & S4) for LLC Resonant Converter

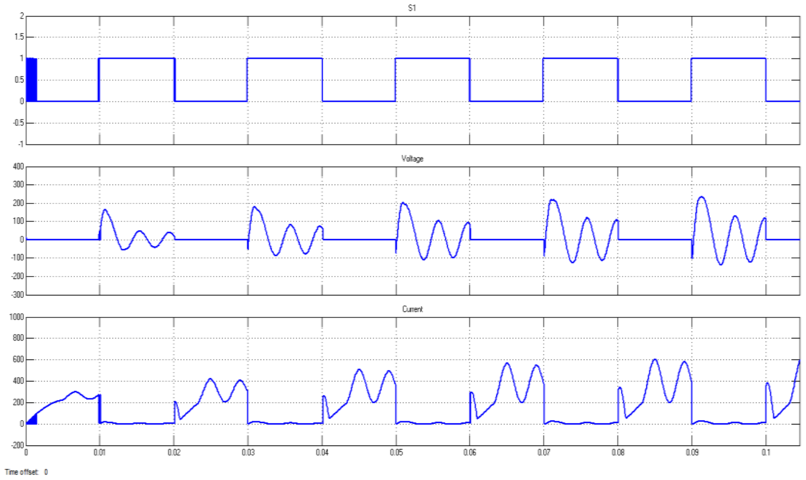


Fig7:Simulated Response of ZVS of S1 of LLC Resonant Converter

Usage soft switching(ZVS or ZCS►)technique. either voltage or current is zero during switching transition, which largely reduce the switching loss. The Full bridge LLC resonant converter simulate by using MATLAB/SIMULINK. and the output voltage results are presented as shown in the fig8. The output voltage increase from zero and reach to constant value(60v).

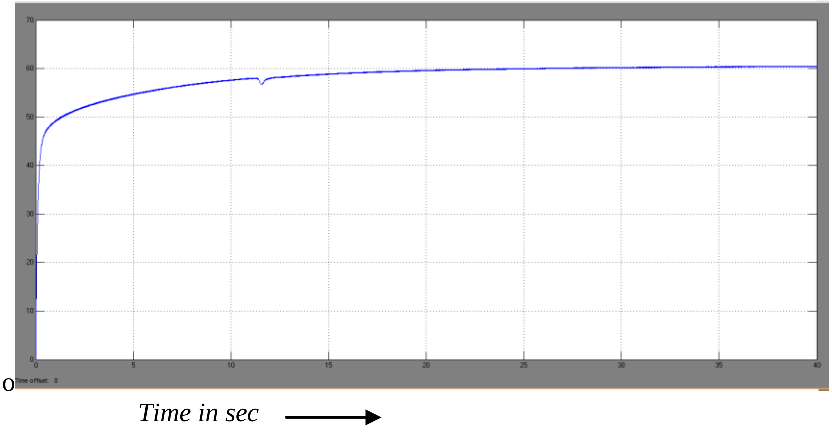
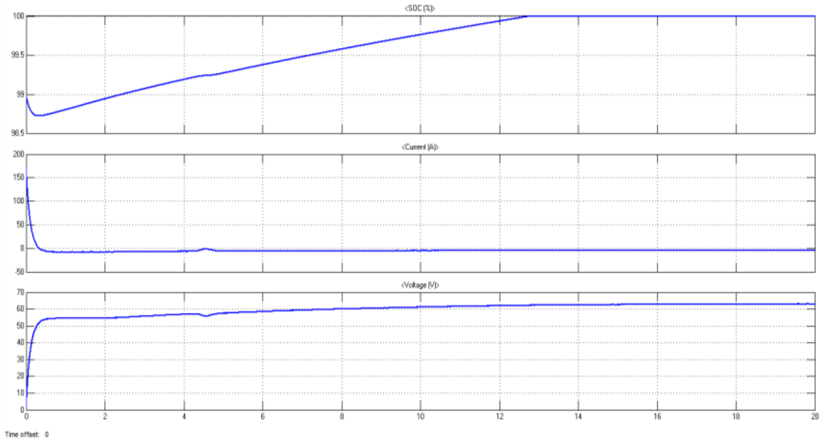


Fig8: Output Voltage Of Full Bridge LLC Resonant Converter

The closed loop control of Full bridge LLC series-parallel resonant DC to DC converter Battery charging application simulated using MATLAB/SIMULINK. and the output results are presented as shown in the fig9.

The Battery output waveform include State of charge(SOC), Current, Voltage waveform. The state of charge is increased and reach (100%) constant value. By use of constant voltage charging method voltage start to increased from zero and reach to constant value. The current was start to decreased and reach zero value. By use soft switching technique,Both low and high-frequency current ripple are eliminated on the battery, thus maximizing battery life without penalizing the volume of the charger, and also reduce the switching loss. Stability is maintained by use of closed loop control operation ,and provides more accuracy under the presence of non-linearites.



.

Fig9 :Simulated Response of Battery Load (State of Charge, Current and Voltage)

Advantages of this System

- Using Proposed Converter (Full Bridge LLC), we can expect Better Controllability than Half Bridge for wide voltage range.
- By adopting soft switching topologies, either voltage or current is zero during switching transition, which largely reduce the switching loss and also increase the reliability for the battery charger.
- It eliminates both low- and high-frequency current ripple on the battery, without using bulky filter capacitor, thus maximizing battery life without penalizing the volume of the charger.
- By use of closed loop control operation provides more accuracy and stability under the presence of nonlinearities .
- Resonant converter topologies can be used to increase circuit switching speeds, improved power factor and reduced switching losses.

V. Conclusion

The closed loop control of full bridge LLC Resonant Converter has been analyzed with help of MATLAB/SIMULINK.. By use soft switching technique, Both low- and high-frequency current ripple are eliminated on the battery, thus maximizing battery life without penalizing the volume of the charger, and also reduce the switching loss. Stability is maintained by use of closed loop control operation,and provides more accuracy under the presence of non-linearity's .The High effiency achieved with a constant output voltage .

REFERENCES

[1] W. Wongsaichua, W. J. Lee, S. Oraintara, C. Kwan, and F. Zhang, "In- tegrated high-speed intelligent utility tie unit for disbursed/renewable generation facilities," IEEE Trans. Ind. Appl., vol. 41, no. 2, pp. 507–513, Mar./Apr. 2005

[2] B. P. McGrath, D. G. Holmes, P. J. McGoldrick, and A. D. McIver, "De- sign of a soft-switched 6-kW battery charger for traction applications," IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1136–1144, Jul. 2007

[3] C. G. Kim, D. H. Seo, J. S. You, J. H. Park, and B. H. Cho, "Design of a contactless battery charger for cellular phone," IEEE Trans. Ind. Electron., , pp. 1238–1247, Dec. 2001.

[4] T. S. Mundra and A. Kumar, "An innovative battery charger for safe charging of NiMH/NiCd batteries," IEEE Trans. Consum. Electron., vol. 53, no. 3, pp. 1044–1052, Aug. 2007.

[5] F. Boico, B. Lehman, and K. Shujaee, "Solar battery chargers for NiMH batteries," IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1600–1609, Sep. 2007.

[6] X. Liu and S. Y. Hui, "Optimal design of a hybrid winding structure for planar contactless battery charging platform," IEEE Trans. Power Electron., vol. 23, no. 1, pp. 455–463, Jan. 2008.

[7] L. Schuch, C. Rech, H. L. Hey, H. A. Gründling, H. Pinheiro, and J. R. Pinheiro, "Analysis and design of a new high-efficiency bidirec- tional integrated ZVT PWM converter for DC-bus and battery-bank interface," IEEE Trans. Ind. Appl., vol. 42, no. 5, pp. 1321–1332, Sep./Oct. 2006.

[8] Y. Jang and M. M. Jovanovi, "A contactless electrical energy transmission system for portable-telephone battery chargers," IEEE Trans. Ind. Elec- tron., vol. 50, no. 3, pp. 520–527, Jun. 2003.

[9] J. H. Choi, J. M. Kwon, J. H. Jung, and B. H. Kwon, "High-performance online UPS using three-leg-type converter," IEEE Trans. Ind. Electron., vol. 52, no. 3, pp. 889–897, Jun. 2005.

[10] Y. C. Chuang and Y. L. Ke, "High-efficiency battery charger with a buck zero-current-switching pulse-width-modulated converter," IET Power Electron., vol. 1, no. 4, pp. 433–444, Dec. 2008.

[11] Y. C. Chuang and Y. L. Ke, "High-efficiency and low-stress ZVT-PWM DC-to-DC converter for battery charger," IEEE Trans. Ind. Electron., vol. 55, no. 8, pp. 3030–3037, Aug. 2008.

[12] M. G. Egan, D. L. O'Sullivan, J. G. Hayes, M. J. Willers, and C. P. Henze, "Power-factor-corrected single-stage inductive charger for electric vehicle batteries," IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 1217–1226, Apr. 2007.

[13] Y. C. Chuang, Y. L. Ke, H. S. Chuang, and H. K. Chen, "Implementation and analysis of an improved series-loaded resonant DC–DC converter operating above resonance for battery chargers," IEEE Trans. Ind. Appl., vol. 45, no. 3, pp. 1052–1059, May/Jun. 2009.

[14] Y. C. Chuang and Y. L. Ke, “A novel high-efficiency battery charger with a buck zero-voltage-switching resonant converter,” IEEE Trans. Energy Convers., vol. 22, no. 4, pp. 848–854, Dec. 2007

[15] L. Petersen and M. Andersen, “Two-stage power factor corrected power supplies:Thelowcomponent-stressapproach,”inProc.IEEEAppl.Power Electron. Conf. Expo., 2002, vol. 2, pp. 1195–1201.

[16] B. Lu, W. Dong, S. Wang, and F. C. Lee, “High frequency investigation of single-switch CCM power factor correction converter,” in Proc. IEEE Appl. Power Electron. Conf. Expo., 2004, vol. 3, pp. 1481–1487.

[17] L. Yang, B. Lu, W. Dong, Z. Lu, M. Xu, F. C. Lee, and W. G. Odendaal, “Modeling and characterization of a 1KW CCM PFC converter for con- ductedEMIprediction,”in Proc. IEEE Appl.Power Electron. Conf.Expo., 2004, vol. 2, pp. 763–769.

[18] A. K. S. Bhat, “Analysis and design of LCL-type series resonant con- verter,” IEEE Trans. Ind. Electron., vol. 41, no. 1, pp. 118–124, Feb. 1994.

[19] B. Yang, F. C. Lee, A. J. Zhang, and G. Huang, “LLC resonant converter for front end DC/DC conversion,” in Proc. IEEE Appl. Power Electron. Conf. Expo., 2002, vol. 2, pp. 1108–1112.

[20] T. Liu, Z. Zhou, A. Xiong, J. Zeng, and J. Ying, “A novel precise design method for LLC series resonant converter,” in Proc. IEEE Telecommun. Energy Conf., INTELEC, 2006, pp. 1–6.

[21] Jee-hoon Jung and Joong-gi Kwon, “Theoretical analysis and optimal design of LLC resonant converter,” in Proc. Eur. Conf. Power Electron. Appl., 2007, pp. 1–10.

[22] J. Biela, U. Badstubner, and J. W. Kolar, “Design of a 5 kW, 1U, 10 kW/ltr resonant DC-DC converter for telecom applications,” Proc. Int. Telecom- mun. Energy Conf., INTELEC, pp. 824–831, 2007

[23] Won-sukChoi,Sung-moYoung,andDong-wookKim,“AnalysisofMOS- FET failure modes in LLC resonant converter,” in Proc. Int. Telecommun. Energy Conf., INTELEC, 2009,