International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 4, December 2017, pp. 1622~1630
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i4.pp1622-1630

Hardware Implementation of Solar Photovoltaic System based Half Bridge Series Parallel Resonant Converter for Battery Charger

Rakhi K[1], Ilango K[2], Manjula G Nair[3]
[1] Department of Electrical and Electronics Engineering, College of Engineering and Technology Payyanur, India
[2,3] Department of Electrical and Electronics Engineering, Amrita School of Engineering, Amrita University, India

Article Info

Article history:

Received Oct 18, 2017
Revised Nov 10, 2017
Accepted Nov 24, 2017

Keyword:

Battery charger
Current ripple
HBSPRC
SPV system
Zero Current Switching
Zero Voltage Switching

ABSTRACT

The long established battery chargers are having many drawbacks such as prominent ripple charging current, less efficiency and bulky in size. To overcome these drawbacks of conventional battery charger, several charging circuits have been proposed and inevitability force to design a high-performance battery charger with small in size and improved efficiency. In this paper solar photovoltaic system based half-bridge series–parallel resonant converter (HBSPRC) charger is proposed for battery interface. The converter is designed to abolish low and high-frequency ripple currents and thus take full advantage of the life of secondary battery circuit. This is achieved by designing converter switches turn on at zero current and zero voltage with switching frequency greater than that of resonance frequency which leads to freewheeling diodes need not have very fast reverse-recovery characteristics. The performance of the power converters depends upon the control method adopted; in this work fuzzy logic controller is used for controlling the output voltage of HBSPRC. The fuzzy control scheme for the HBSPR converter has been designed and validated in hardware implementation of HBSPRC switching technique. From the results, it is found that the proposed battery charging system which reduces the switching loss and voltage stress across the power switches which increases the efficiency of the converter.

Corresponding Author:

Ilango Karuppasamy,
Departement of Electrical and Electronics Engineering,
Amrita School of Engineering, Amritapuri, Amrita Vishwa Vidyapeetham, Amrita University, Kollam, Kerala, India.
Email: ilangok@am.amrita.edu

1. INTRODUCTION

Advancement in power electronic switches and technical revolution has made power electronic products are very important for daily life, in particular energy storage equipments. Battery Energy Storage (BES) is one of the widely accepted device in various applications, including telecommunication, power supply, electric vehicles, uninterruptible power supplies, photovoltaic systems, portable electronics products etc.,[10].To charge battery, charger is an essential device used to charge a secondary cell, rechargeable battery by forcing an electric current through it. The traditional battery charger, which extracts power from an AC-line source, requires an AC/DC converter rectifier with series resistance to control the power flow for charging the battery system. But the conventional battery charger has many disadvantages like high ripple charging current, low efficiency and large size. In literature, several charging circuits have been proposed to overcome these disadvantages of the conventional battery charger to improve the performance with high-performance battery charger which is small in size and high efficiency [10].

The operation of designed converter at higher frequencies considerably reduces the size of passive components, such as transformers and filters. However, the switching loss will increase as the switching frequency is increased. This condition, in turn, decreases the efficiency of the battery chargers. To reduce the switching losses and to allow high frequency operations, resonant switching techniques have been developed [10]. These resonant converters are basically series, parallel and series-parallel resonant converters. In series resonant converter the output load appears in series with the resonant tank. Unlike the SLR converter, where the output stage or the load appears in series with the resonant tank, here the output stage is connected in parallel with the resonant-tank capacitor. The series and parallel resonant converters have various drawbacks. In series resonant converter the charging voltage cannot be regulated at no-load and light-load conditions. In case of parallel resonant converter, current through resonant components is relatively independent of the load. On the other hand, the series–parallel resonant converter overcomes drawbacks of series, parallel resonant converters which combine the advantages of the series and parallel converters [10].

This paper presents the hardware implementation of solar photovoltaic system based half bridge series-parallel resonant converter for battery charger with fuzzy logic controller which has been designed, implemented in proto-type hardware model of Half Bridge Series-Parallel Resonant Converter (HBSPRC) topology and it's performances have been reported in detail.

2. CONVERTER TOPOLOGY

In conventional system, the rectified supply is directly connected to the battery charger circuit which is a combination of HBSPRC and rectifier. The rectified output is filtered then it is given to a battery charger circuit. But in the proposed system, DC source is replaced by a solar photovoltaic system which has constant output voltage with voltage regulation controller. The circuit diagram of battery charger with HBSPRC consists of a Half bridge inverter, a resonant tank circuit, a voltage-driven rectifier and a LC filter is shown in Figure 1.

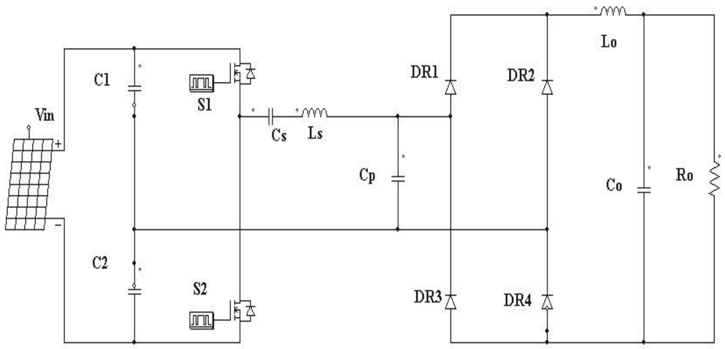

Figure 1. Proposed Battery Charger Circuit Topology

Where L_S, C_S, C_P represent resonant inductor, series resonant capacitor and parallel resonant capacitor respectively. The two capacitors, C_1 and C_2, split the input voltage of the SPV system voltage and its value should be large. The half bridge inverter consists of two bidirectional switches S_1 and S_2. .Each bidirectional power switch consists of a MOSFET and its body diode[10]. These two active power switches are driven by non overlapping rectangular-wave trigger signals V_{GS1} and V_{GS2} with dead time. Capacitor Cs is connected in series with inductor Ls as in the series resonant inverter, and the full-bridge rectifier is connected in parallel with capacitor C_P as in the parallel resonant converter[1]. Hence it is called series-parallel resonant converter. The applied supply voltage to resonant tank circuit is $+V_A$ or $–V_A$ depending on whether S_1 is on or S_2 is on. L_O, C_O represents filter inductor and filter capacitor respectively which perform as a low pass filter for smoother output voltage and current and R_O represents resistive load.

2.1 Modes of Operation

The steady state operation of HBSPR converter charging circuit in one switching periods are divided into four modes and it had been reported in detail [1] and [10].

2.2. Design of Half bridge Series-Parallel Resonant Converter

The design procedure of the half bridge series-parallel resonant converter had been reported in detail [1] and [10]. In this application HBSPRC has been designed with following requirements, input voltage V_{in} = 40V, output voltage V_o = 12V (Equivalent to battery voltage), output current I_o= 2.4A, quality factor Q =1, resonant frequency w_o = 83kHz and switching frequency w_s = 87kHz[10].

3. SIMUATIUON RESULTS AND ANALYSIS

The open loop simulation study of Half bridge series parallel resonant converter had been simulated using Matlab/ Simulink and the results were discussed and presented in [10],From the results, it was found that when the switching frequency decreases the efficiency of the converter increases. When switching frequency equals the resonant frequency, efficiency is maximum of 90%. And also found that, output power is maximum when switching frequency is equal to resonant frequency (83 kHz) and as the switching frequency increases output power decreases [10].

3.1. Fuzzy Logic Controller Implementation

The closed loop control of HBSPRC has been done by sensing voltage and comparator circuit. The control circuit and power circuits are isolated with help of isolation circuit. The controller generated switching pulses are amplified with use of driver circuit to meet required magnitude of switching device .In this section closed loop fuzzy controller design and implementation has been discussed. Two input fuzzy logic controller is designed with error and change in error to control the output current of HBSPRC.

Figure 2.shows the fuzzy surface controller and Table.1 provides the rule base of designed controller. The steady/transient state performance of designed fuzzy controller has been tested in simulation as well as hardware implementation. It offers good response for both conditions.

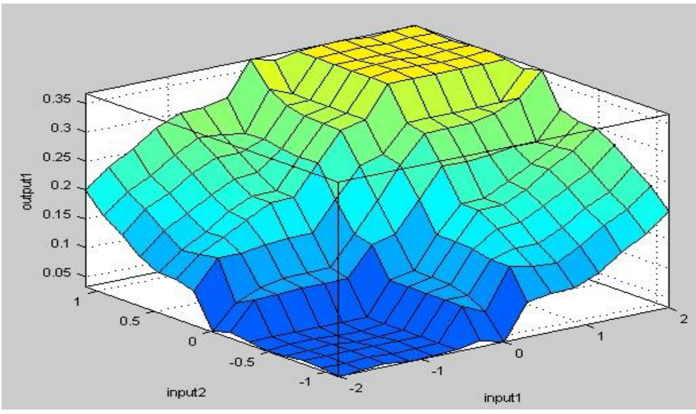

Figure 2. Fuzzy Controlling Surface

Table 1.Fuzzy Rule Base

Error / Change in Error	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	PS	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

NB: Negative big NS: Negative small Z: Zero PS: Positive big PB: Positive small

The transient/dynamic state performance of designed fuzzy controller is tested with introducing load change after 0.04sec. Figure 3 shows the output current waveform when a resistive load is used to introduced for load change. It is found that, output current is 2.4A up to 0.04sec, after that it current reaches to 4A with load change.

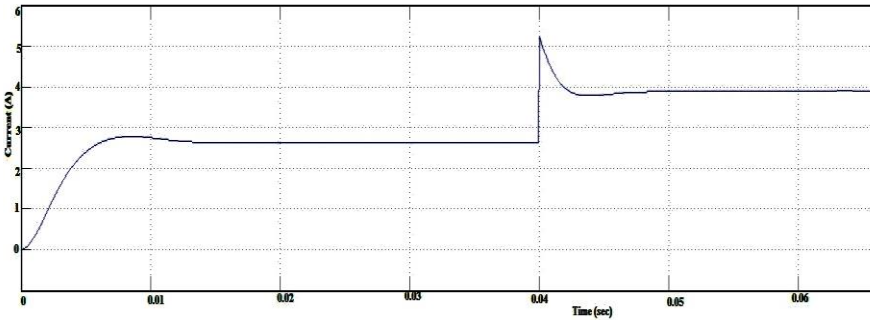

Figure 3. Output current without controller

Figure 4 illustrates the output voltage and current of the designed converter with fuzzy logic controller. It is clear that, when the load change is introduced at 0. 04 sec output voltage is dropping from 12 V to 6.4 V. But the load current is regulated by designed fuzzy controller and it has been maintained constant current of 2.4 A for entire simulation period .The designed fuzzy controller provides better current regulation even under load varying conditions which is most suitable characteristic required for battery charger.

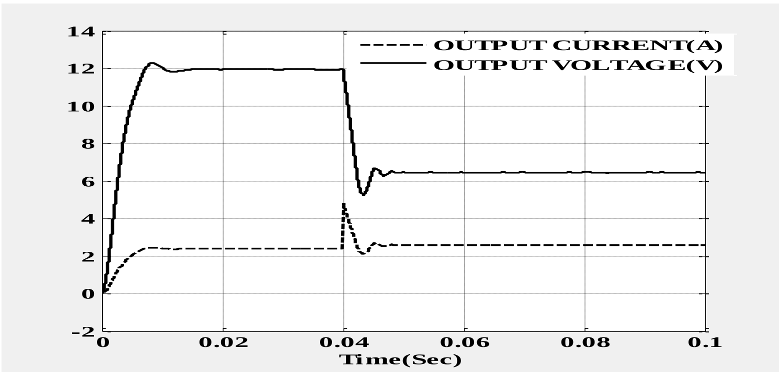

Figure 4. Output voltage and current with Fuzzy controller

3.2. Hardware Implementation of HBSPRC for Battery Charging Circuit

The developed laboratory prototype model of the HBSPRC is shown in Figure 5.The proto-type model has been tested with 40V input and output voltage of 12 V which is equivalent to the secondary battery. This model has been built with HBSPRC power circuit (IRF 540N), Arm processor based control circuit (Keil kit), Driver and Isolation circuit (TLP 250). The design parameters of experimental set-up is given in Table 3.

As discussed in section 3.1, the fuzzy logic controller has been designed to generate switching pulses for the HBSPR converter. Figure 6 shows generated pulse output using Keil kit (Arm Processor) which has peak-peak voltage of 3.8 V. It is not sufficient for driving power MOSFET switches of HBSPRC. Hence driver and isolation circuit (TLP250) has been designed and it is used for boosting the voltage level from 3.8V to 12 V which is shown in Figure 7, as a driver circuit output voltage.

In [10], modes of operation and key wave forms of HBSPR converter had been presented. Here the focus has been given to proto-type hardware implementation and its results. Figure 8 displays the voltage across the power switch of HBSPR converter circuit. The peak-peak voltage across the switch is 40V because the applied input voltage is 40V.To reduce turn off voltage stress on power switch, turn off snubber circuits can be used. Figure 9. presents output voltage of half-bridge inverter circuit which is a square wave with 40V amplitude and 87 kHz frequency.

Figure 10.presents the voltage across resonant inductor which has resonant frequency of designed 87kHz. The voltage across parallel resonant capacitor and half bridge inverter output VA is shown in Figure 11.It is clear that, voltage across capacitor Cp is a sine wave with peak-peak voltage of VCP is 58V.The VCP is rectified to obtain an output dc voltage.

Table 3.Hardware Parameters

Variable	Value
Input Voltage	40V
Output Voltage	12V
Switching Frequency	87KHz
Input Side Capacitor C_1,C_2	1000uF(electrolytic)
Switches S_1,S_2	MOSFET IRF540N
Resonant Capacitors C_P,C_R	1uF(non-electrolytic)
Resonant Inductor L_S	12uH
Rectifying Diodes	UF5408
Output Filter Inductor L_O	4.9mH
Output Filter Capacitor C_O	1000uF(electrolytic)

Figure 5. Laboratory prototype model of the HBSPRC

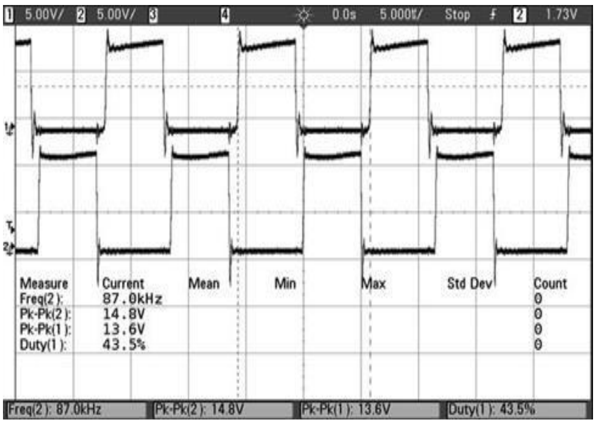

Figure 6. Generated Pulse output from Keil kit using Fuzzy Logic.

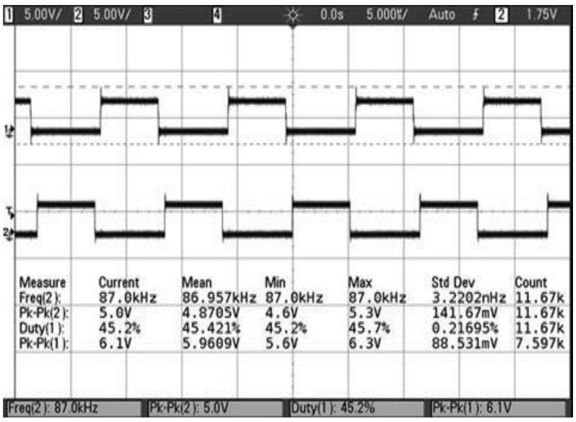

Figure 7. Pulse output from driver and isolation circuit.

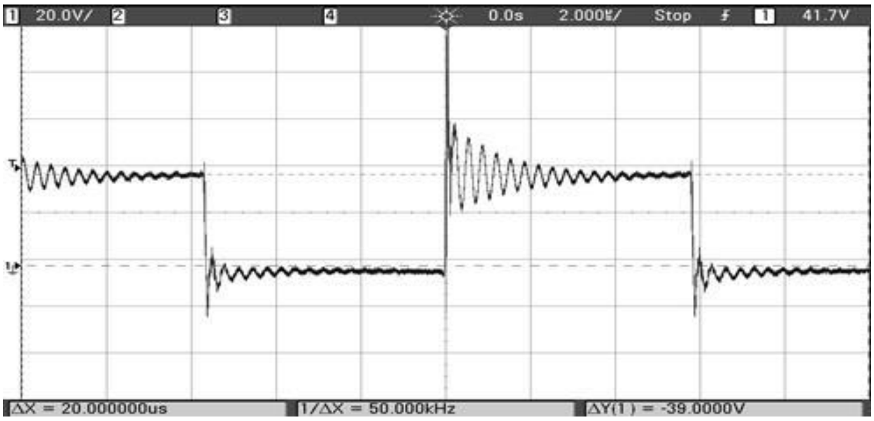

Figure 8. Voltage across switch V_{S1}

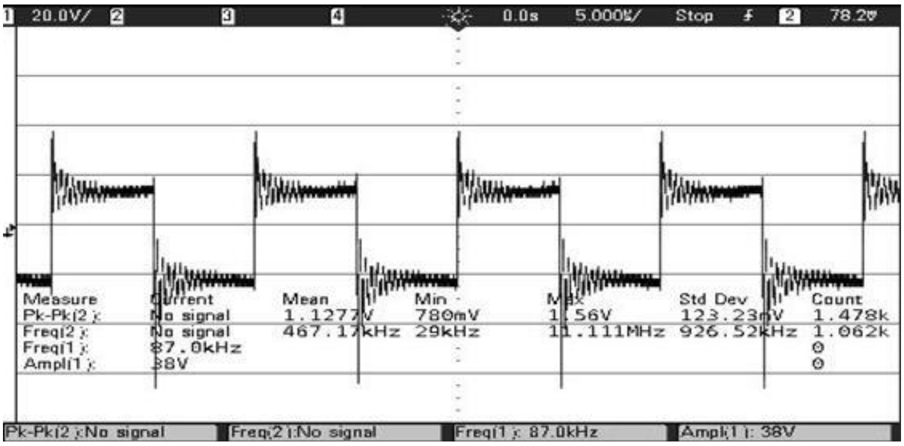

Figure 9. Half Bridge Inverter Output

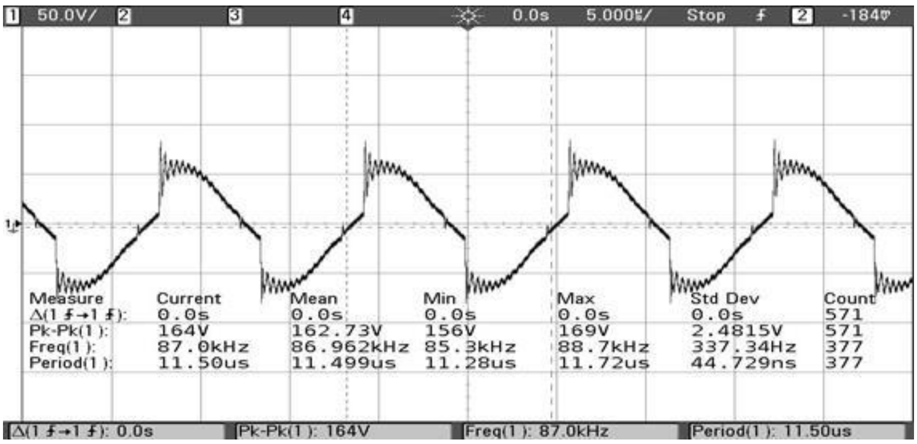

Figure 10. Voltage across resonant inductor

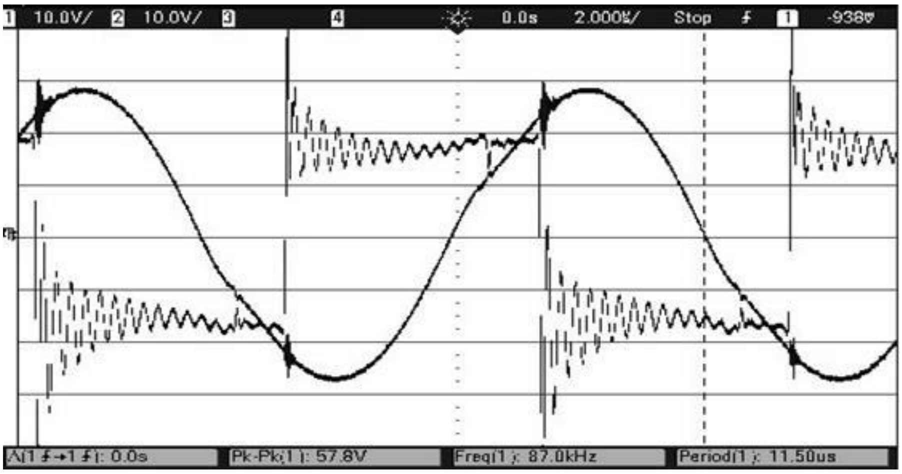

Figure 11. Voltage across parallel resonant capacitor and Half Bridge inverter output V_A and V_{CP}

The voltage across series and parallel resonant capacitor is illustrated in Figure 12. In which the voltage across series capacitor is a pure sine wave. The frequency of voltage across C_P & C_R is 87 kHz and the peak-peak voltage across $C_P(V_{CP})$ is greater than the voltage across C_R (V_{CR}). There is no phase shift between these two waveforms.

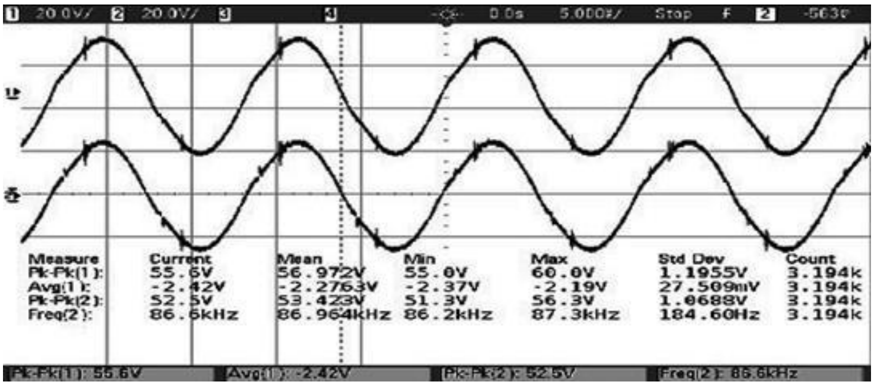

Figure 12. Voltage across series and parallel resonant capacitor

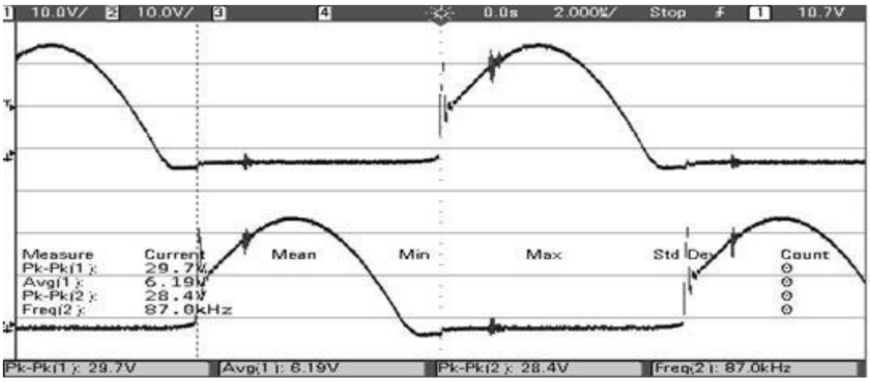

Figure 13. Voltage across diodes DR_1 and DR_2

The voltage across diodes DR_1 and DR_2 are presented in Figure13. The voltage across DR_1 is similar to DR_3 and the voltage across DR_2 is similar toDR_4.The peak voltage across the power diodes are maintained at 29.7V , thus reduces the switching stress across power switches.

Figure 14, be evidence for the output voltage across the load resistor of 5Ω is 11.93 V under load varying condition. From the results it is clear that, the designed HBSPR converter operates at desired characteristics which reduces the switching loss and voltage stress of power switches and also increase efficiency of converter.

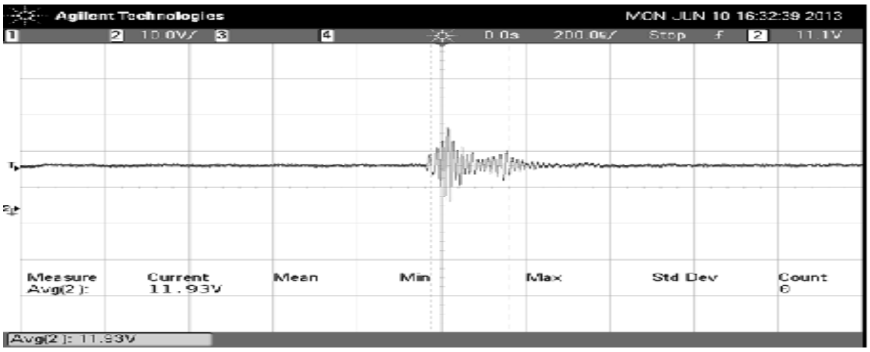

Figure 14. Output voltage across Load Resistor

4. CONCLUSION

The solar photovoltaic system based half-bridge series–parallel resonant converter (HBSPRC) charger for battery interface has been designed to eliminate both low and high-frequency current ripples on the battery charging , thus maximize the life of secondary battery. The desired characteristics of the designed converter has been achieved by turning on at zero current and zero voltage with switching frequency greater than that of resonance frequency which leads to freewheeling diodes need not have very fast reverse-recovery characteristics. Hence it reduces the switching loss and voltage stress across the power switches which increases the efficiency of the converter. The hardware implementation of Half Bridge Series Parallel Resonant Converter (HBSPRC) switching technique has been verified for battery charging system model with fuzzy logic control had been tested with Keil kit (Arm Processor). From the results, it is found that simulation and hardware results were similar under the test input voltage of 40V and output voltage of 12V even under load varying conditions.

REFERENCES

[1] Ying-Chun Chuang, Yu-Lung Ke, Hung-Shiang Chuang and Yu-Min Chen Analysis and Implementation of Half Bridge series-Parallel Converter for Battery Chargers" *IEEE Industrial and Commercial Power systems Technical Conference,* May 2010, pp 1-11.
[2] Y. Jang and M. M. Jovanovi, “A contactless electrical energy transmission system for portable-telephone battery chargers”, *IEEE Trans. Ind. Electron.*, vol. 50, no. 3, Jun. 2003, pp. 520–527.
[3] 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, Jun. 2005, pp. 889–897.
[4] T. S. Mundra and A. Kumar, “An innovative battery charger for safecharging of NiMH/NiCd batteries,” *IEEE Trans. Consum. Electron.,* vol. 53, no. 3, 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, pp. 1044–1052.
[6] S. J. Chiang, H. J. Shieh, and M. C. Chen, “Modeling and control of PV charger system with SEPIC converter,” *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, Nov. 2009, pp. 4344–4353.
[7] 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, May/Jun. 2009, pp. 1052–1059.
[8] Ricardo Barrero, Joeri Van Mierlo & Philippe Lataire, “Design of Bi-directional Series Resonant Converter as Peak Power Unit in Hybrid Electric Vehicles”, *IEEE international conference on Industrial Technology(ICIT),* 2010, pp 1102 – 1107
[9] Piero P Bonissone,Pratap .S Khedkar, Michael J Shatten,” Fuzzy logic control of resonant converter for power supply”, *General Electric Cooperate Research and Development Schenectady*, New York.

[10] Rakhi K, Ilango.K, Manjunath H V and Manjula G Nair,"Simulation Analysis of Half Bridge Series Parallel Resonant Converter based Battery Charger for Photovoltaic System*", IEEE-International Conference on Power and Energy Systems: Towards Sustainable Energy Systems (PESTSE2014)*, March, 2014.
[11] Asep Nugroho , Estiko Rijanto , and Latif Rozaqi "Buck Converter Control for Lead Acid Battery Charger using Peak Current Mode" *Int. J. Power Electron. Drive Syst.*, Vol. 8, No. 2, June 2017, pp. 686-694.
[12] A. Elamathy*, G. Vijayagowri, V. Nivetha. "Bidirectional Battery Charger for PV Using Interleaved Fourport DC-DC Converter", *TELKOMNIKA Indonesian Journal of Electrical Engineering*, Vol. 14, No. 3, June 2015, pp. 428 – 433.

BIOGRAPHIES OF AUTHORS

Rakhi K currently serves as Assistant Professor in the Department of Electrical and Electronics Engineering at College of Engineering and Technology Payyannur. She received her M.Tech (Power Electronics) from Amrita School of Engineering, Bengaluru Campus, Amrita Vishwa Vidyapeetham, Amrita University in June 2014. She completed her B.Tech Degree in Electrical and Electronics Engineering at College of Engineering Trikaipur, CUSAT, Kerala .Since 2014 she is associated with College of Engineering and Technology Payyannur.

Dr. Ilango K. currently serves as Assistant Professor in the Department of Electrical and Electronics Engineering at Amrita School of Engineering, Amritapuri Campus. Dr. Ilango received his Ph.D. Degree in Electrical Engineering from Amrita Vishwa Vidyapeetham, Amrita School of Engineering, Amritapuri Campus in August 2016. He has been teaching 12 years for under graduate and post graduate courses and presently he is with Amrita School of Engineering (Amritapuri Campus), Amrita Vishwa Vidyapeetham. He is an active member of IEEE and a life member of ISTE. His research interest includes, Renewable Energy Sources & Power Quality, Power Electronics Drives and Control, Energy Conservation & Management.

Dr. Manjula G. Nair completed her PhD in Power Electronics from the Indian Institute of Technology, Delhi, in 2007. Her dissertation was on 'Shunt Active Power Filtering for Power Quality Improvement'. Dr. Manjula G Nair has guided several B.Tech and M.Tech research projects. She has also guided two Ph.D students in the area of Electric Power Quality Improvement and Renewable Energy sources. She has to her credit, a three year funded research project under the Young Scientist Fast Track Scheme sponsored by Department of Science & Technology (DST-SERC), Ministry of Human Resource Development (MHRD), Government of India, which she completed in 2012 and another project funded by Amrita, Ettimadai campus, completed in 2008.