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A DC-DC Converter with Battery Energy Storage System for Electric Vehicles

Srinivasa Kishore Babu Y* and Tripura Pidikiti**

Abstract : We The performance of DC –DC converter with battery energy storage system is analyzed for electric vehicle applications.

Methods : Electrical vehicles energy and voltage levels vary for different stages of it like starting, accelerating, free running, coasting and braking. The DC-DC converter provides voltage regulation and it also lifts the source voltage to bus voltage. The battery energy storage system work like an intermediate block between input DC grid and output DC bus. The topology is capable of compensating power and voltage variation in supply and protects against power outages. The analysis of the circuit is clearly explained through MATLAB simulation.

Findings : The converter is capable of providing voltage regulation, peak power leveling, compensate for power variations and is adequate for applications in Electrical Vehicles. Functionally, the circuit operates like a conventional boost converter and as well as buck converter.

Applications: The converter topology presented with battery storage system widely applied in various applications such as Uninterruptible Power Supplies (UPS). These systems are standard solution when total outage or voltage sag compensation is required.

Keywords **:** VR-BESS – Voltage Regulator Battery Energy Storage system, BESS-Battery Energy Storage System, BES-Battery Energy Storage, EV – Electric Vehicle, UPS-Uninterrupted Power Supply, MATLAB/ Simulink.

1. INTRODUCTION

Automobiles constitute an integral part of our everyday life. Irrespective of the type of the industry, the transportation has become the major concern. The advent of the fuel driven combustion engine had brought a great revolution in human life. Increase in dependence on these engines made to dig out more about of crude fuel from the earth, which eventually resulting in their reduction in quantity. The fear complete removal of these fuel oils from nature made people think about alternative source. The electric power had been observed as the only efficient source which serves this purpose. The battery powered electric vehicles (EV) have been proposed as the alternative to the regular fossil fuel driven automobiles[1]. EV has unique feature of recharging the batteries for which wind and solar power can be used as a source. As the transportation also got a bigger share in a country's development, the respective government bodies are also encouraging them. Reduced moving parts in EV compared to combustion engines have made it design simple. But we can't guarantee its reliability on long runs. The voltage regulation and control of energy are major factors to be concerned about in these EV. Electrical vehicles, energy and voltage levels

* Assistant Professor, Department of Electrical and Electronics Engineering, JNTUK-University College of Engineering, Vizianagaram, Andhra Pradesh. yskbabu@gmail.com

** Assistant Professor, Department of Electrical and Electronics Engineering, K L University, Vijayawada, Andhra Pradesh. tripura.pidikiti@gmail.com.

vary for different stages of it like starting, accelerating, free running, coasting and braking[2] . To vary these voltage levels and for battery bank, a DC-DC converter is needed. The DC-DC converter provides voltage regulation and it also lifts the source voltage to bus voltage. The battery energy storage system work like an intermediate block between input DC grid and output DC bus. BES has been extensively used in applications like Uninterruptible Power Supplies (UPS) is such another application[3].

The DC-DC converter with battery energy storage (BES) can be used along with renewable energy systems also[4,5]. The power generated with renewable energy systems is variable, due to variation in weather conditions. Therefore, to store the energy a battery bank may be used[6,7]. The Voltage Regulator – Battery Energy Storage System (VR-BESS)[8] is developed by combination of Buck converter and Boost converter operated in a single structure. In normal mode, the load gets fed from a DC grid or DC source by Boost converter operation and battery gets charged in buck converter operation. When load power is more than DC grid power capability, then battery feeds the load for extra power that can't be supplied by DC grid, through Boost converter operation. When the DC grid voltage falls below the rated level, then duty cycles of power switches are adjusted such that load feeding and battery charging can reestablish. All modes of operation are simulated and results are presented.

The arrangement of the paper is as follows: section II describes various modes of operation of operation of VR –BESS, section III presents design aspects present in VR-BESS like voltage and power levels considered, design of values of inductors and capacitors, duty cycles of switches and representation of battery in simulation and experiment and results and analysis is presented in section V.

2. VOLTAGE REGULATOR-BATTERY ENERGY STORAGE SYSTEM (VR-BESS)

A block diagram of a VR-BESS is shown in fig 1.It has two power stages: battery energy storage and DC-DC voltage regulator

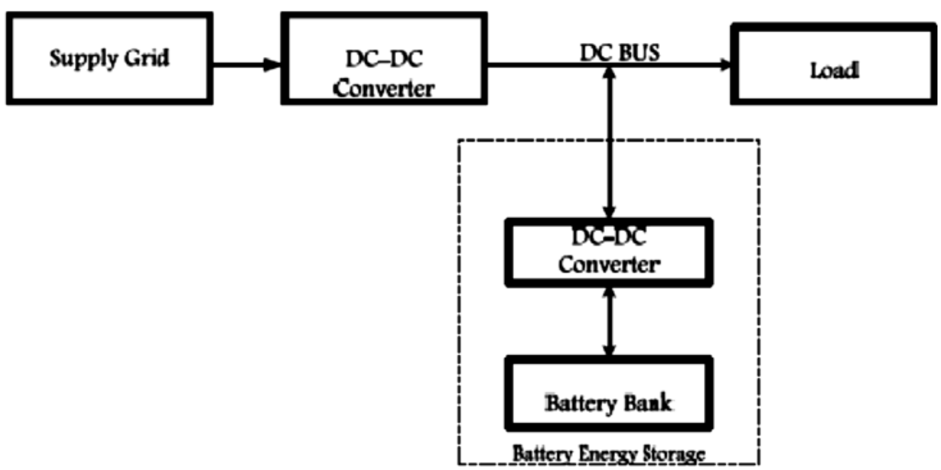

Figure 1: Block diagram of a VR-BESS

The DC- DC converter provides voltage regulation, by increasing the supply voltage to a regulated output DC voltage[9]. Battery/ultra capacitor hybrid energy storage system (HESS) plans for electric vehicles[10,11]. It uses the DC link to maintain the peak voltage value. With the help of BES, it stores the energy from the supply grid in the battery bank and injects the energy from the battery bank to the output bus. Thus, peak power leveling and power variation problems are addressed using this. The circuit of the VR-BESS is depicted in Fig. 2.

The system is connected to an unregulated DC grid (V_s). S_1 and S_2 operate simultaneously, the voltage regulator is formed by DC grid voltage V_s, inductor L_s, diode D_3, capacitor C_0 and the load. Buck converter operation is performed by V_s,L_s,L_{bat},S_1,D_2,C_{bat} and the battery bank, which is used for battery charging. The battery bank, C_{bat},C_0,L_{bat},S_2,D_1 and load forms the boost converter which steps up battery voltage to output DC bus.

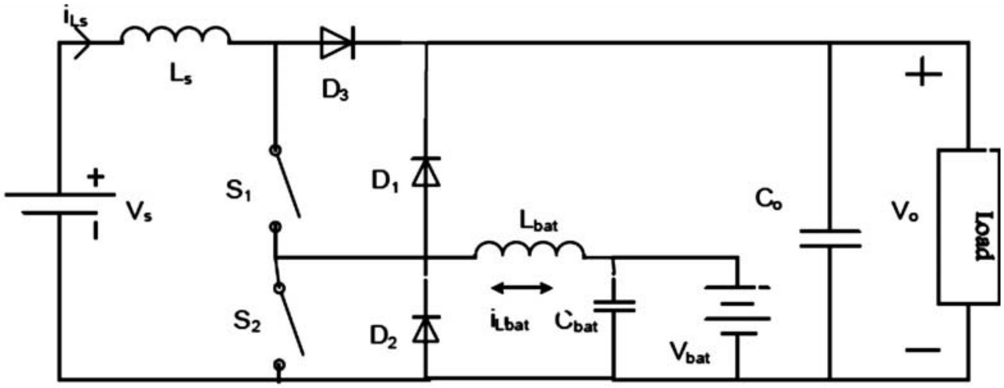

Figure 2: Circuit of VR-BESS

In this system, energy flow is differentiated into three modes : Mode 1: DC grid supplies power to load as well as the battery charges. Mode 2: This mode involves peak power leveling and compensation for variations in power. If the energy supplied by DC grid doesn't meet the demand, then battery supplies the energy. Mode 3: If the condition of power outage or voltage sag is observed, then battery bank supplies full load current[3]. Design considerations are presented in the next section as per the specifications mentioned in the table 1.

Table 1

Design Specifications

DC grid voltage, V_d	30V
Battery Bank Voltage, V_b	16V
Output DC Bus Voltage, V_o	40V
DC grid power (Ps)	50W
Load power, Po	40-60 W
Switching frequency (Fs)	50KHz

3. DESIGN CONSIDERATIONS

In general the design of the topology is very simple because only passive component sizes, *i.e.*, L_S $L_{Bat,}$ $C_{S,}$ C_0 are to be determined. The source side inductor, Ls value is designed in the way of designing inductor value for Boost converter. Here in mode1, DC source has to feed load with 40W power and charge battery drawing 10 Watts power. In total a boost converter supplying 50W power. D is duty cycle, Δi_L is source side inductor ripple current, f_S is switching frequency and V_S is input Voltage.

$$L_S = \frac{V_S D}{\Delta i_L f_S} \tag{1}$$

The inductor value L_{bat} is designed, as inductor value for boost converter when battery is feeding the load in mode2. V_{bat} is Battery voltage, Δi_L is battery side inductor ripple current, f_S is switching frequency.

$$L_{bat} = \frac{V_{bat} D}{\Delta i_L f_S} \tag{2}$$

In mode 2 load draws a power of 60W which is greater than the DC source power (50W) Here 50W power is supplied by DC source and remaining 10W by battery. As load feeds from a DC source in boost converter operation, the capacitor across load can be determined in the following way. Ripple in output voltage of boost converter is given by the following expression

$$\frac{\Delta V_o}{V_o} = \frac{D_1 T_S}{R_1 C_o} \tag{3}$$

From the equation (3), we can get

$$Co = \frac{D_1 T_S}{R_1 \left(\frac{\Delta V_o}{V_o} \right)} \tag{4}$$

R_L is load resistance and Maximum value of Co needs a minimum value of R_L. ΔV_0 is ripple in output voltage, T_S switching time period. As the battery charges from source in mode 1 through buck converter operation, the capacitor across battery can be designed as a capacitor across the load in buck converter. Ripple in voltage across the load terminals of Buck converter is

$$\frac{\Delta V_o}{V_o} = \frac{\Pi^2}{2}(1 - \Delta D)\left(\frac{f_c}{f_s} \right)^2 \tag{5}$$

ΔV_0 is ripple in output voltage; ΔD is difference in duty ratios D_1 and D_2. f_s is switching frequency. From this f_c is obtained as

$$f_c = \frac{1}{2\Pi\sqrt{L_b C_b}} \tag{6}$$

using f_c and L_b, C_b is obtained using above formula.

4. SIMULATION RESULTS

VR-BESS has been simulated and analyzed. Mode 1 simulation diagram is shown in the fig.3.

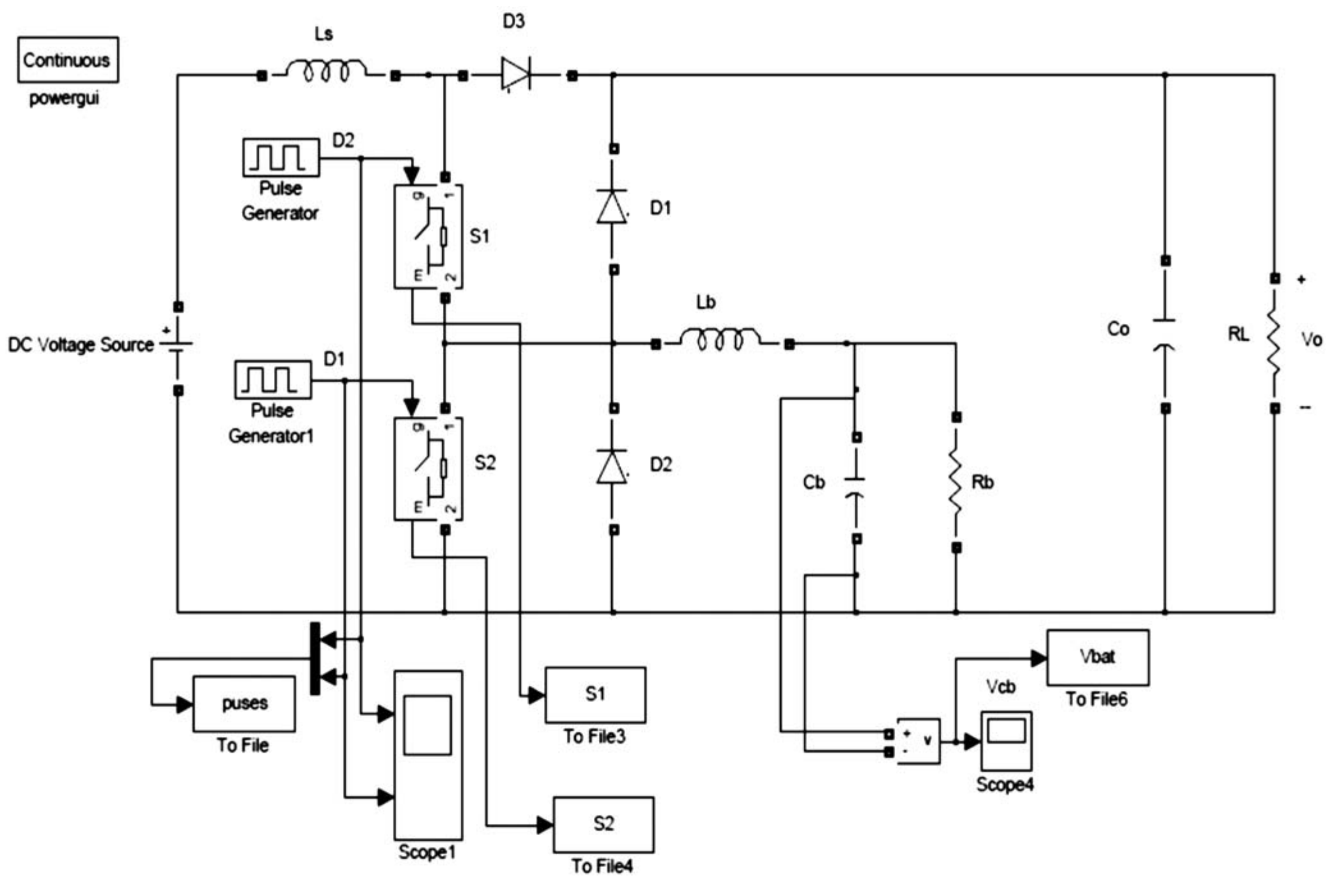

Figure 3: Simulation diagram of the converter in Mode 1

The figure 4 shows voltages across load, battery and inductor currents and corresponding ripples in load, voltage and battery voltage are shown in figure 5

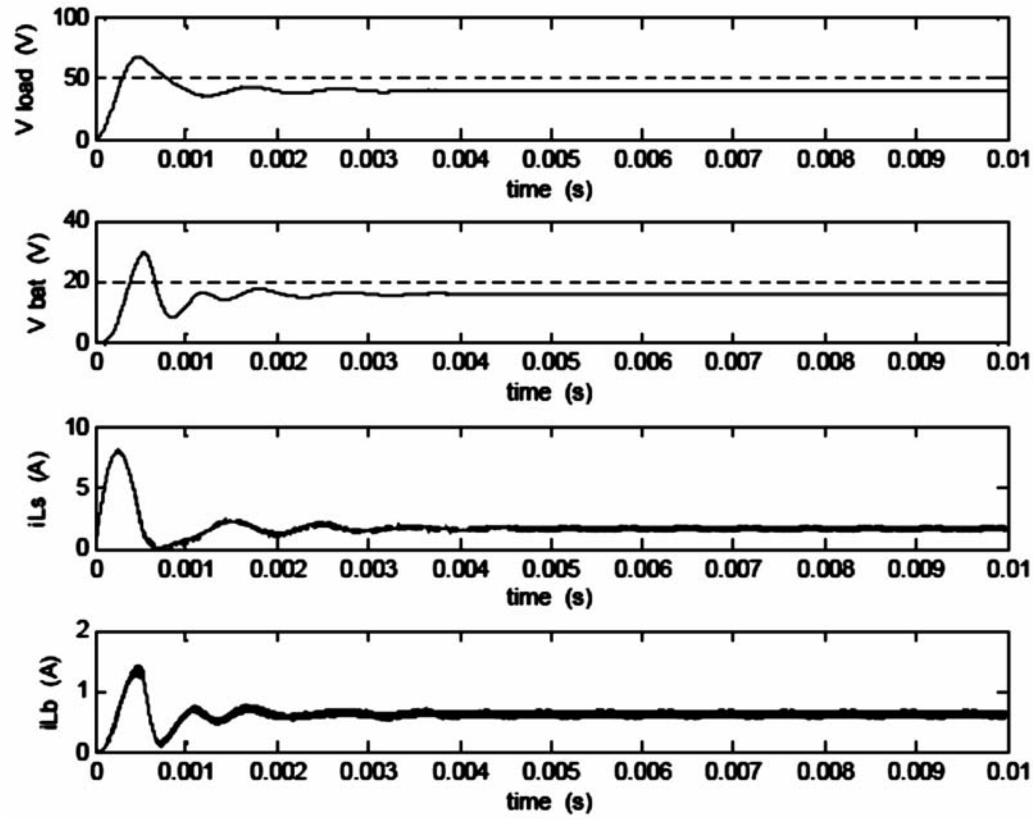

Figure 4: Voltages across load, battery and inductor currents

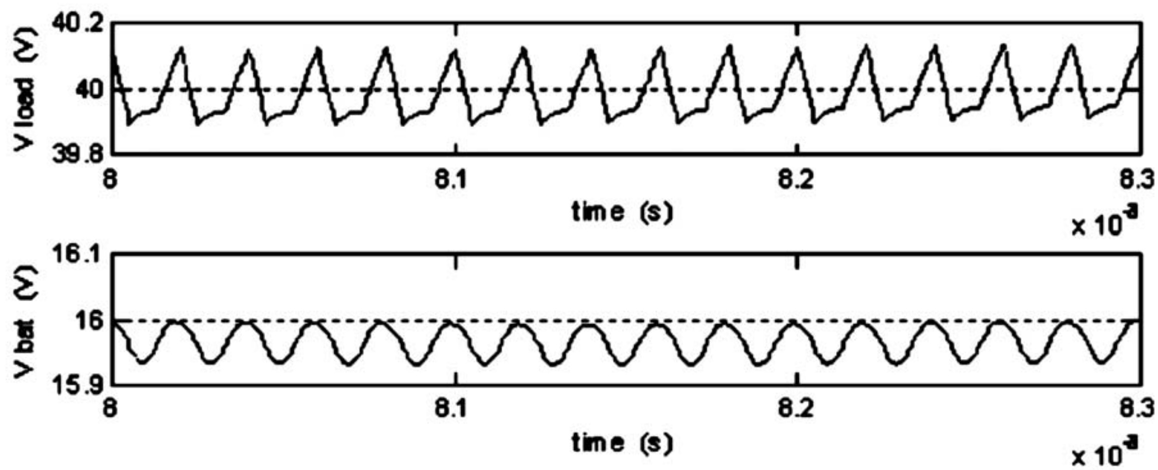

Figure 5: Ripples in V_{load}, V_{bat}.

From the figure 4, it is observed that battery is charged to 15Vand the output voltage is boosted to 40V.

In mode 2, load power becomes greater than maximum power available from DC grid. The excess power will be supplied by battery. As battery is not available in simulation software, the battery discharging current is represented by a voltage source equivalent to battery bank open circuit voltage, in series with a resistance representing the internal resistance of battery, is used in simulation as shown in fig.6

In Mode 2 compensation for power fluctuations occurs. Figure 7 shows the battery voltage and output voltage in mode 2. From the figure it is observed that even with output power drawn is increased, the output voltage is maintained at 40 V and corresponding ripples in load voltage and battery voltage are shown in figure 8.

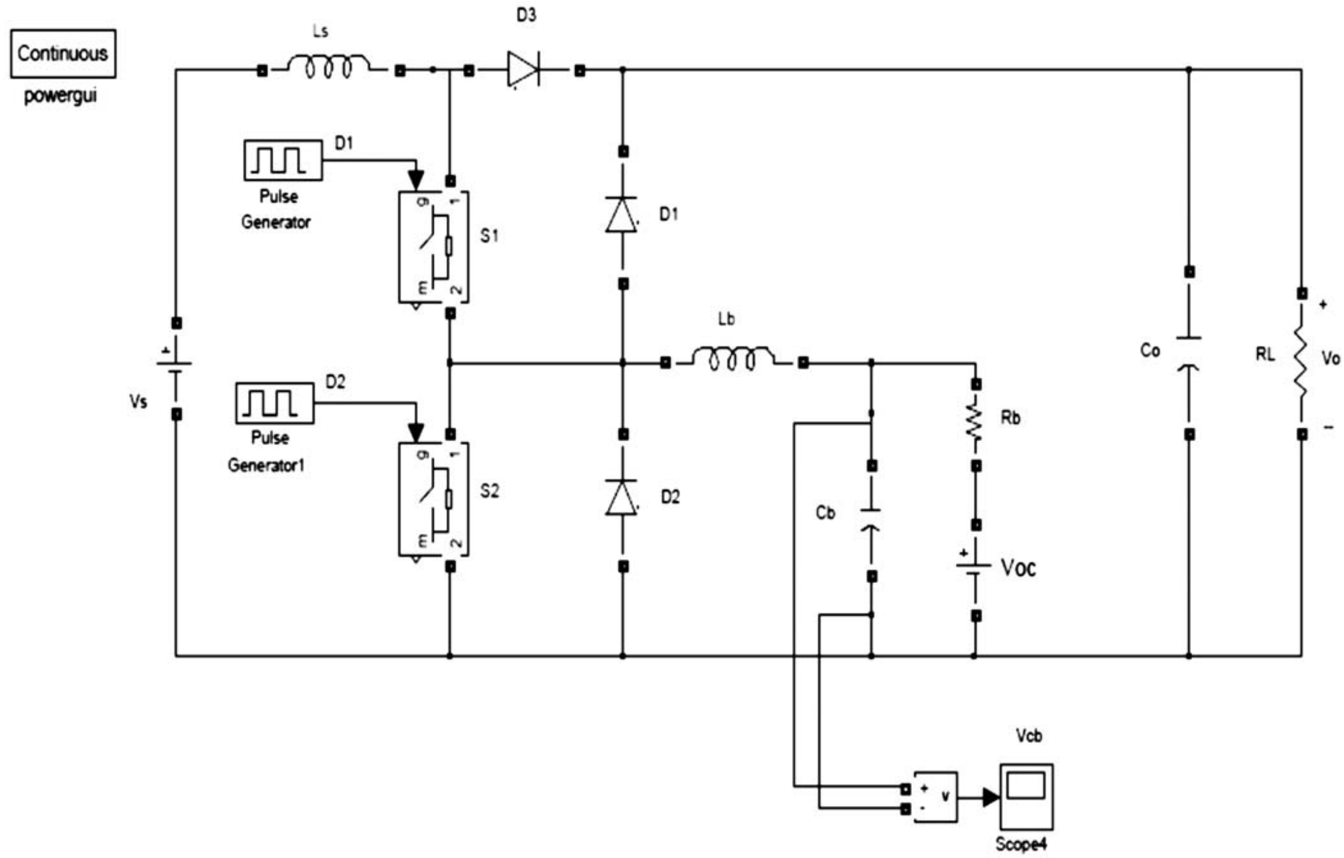

Figure 6: Simulation diagram of the converter in Mode 2

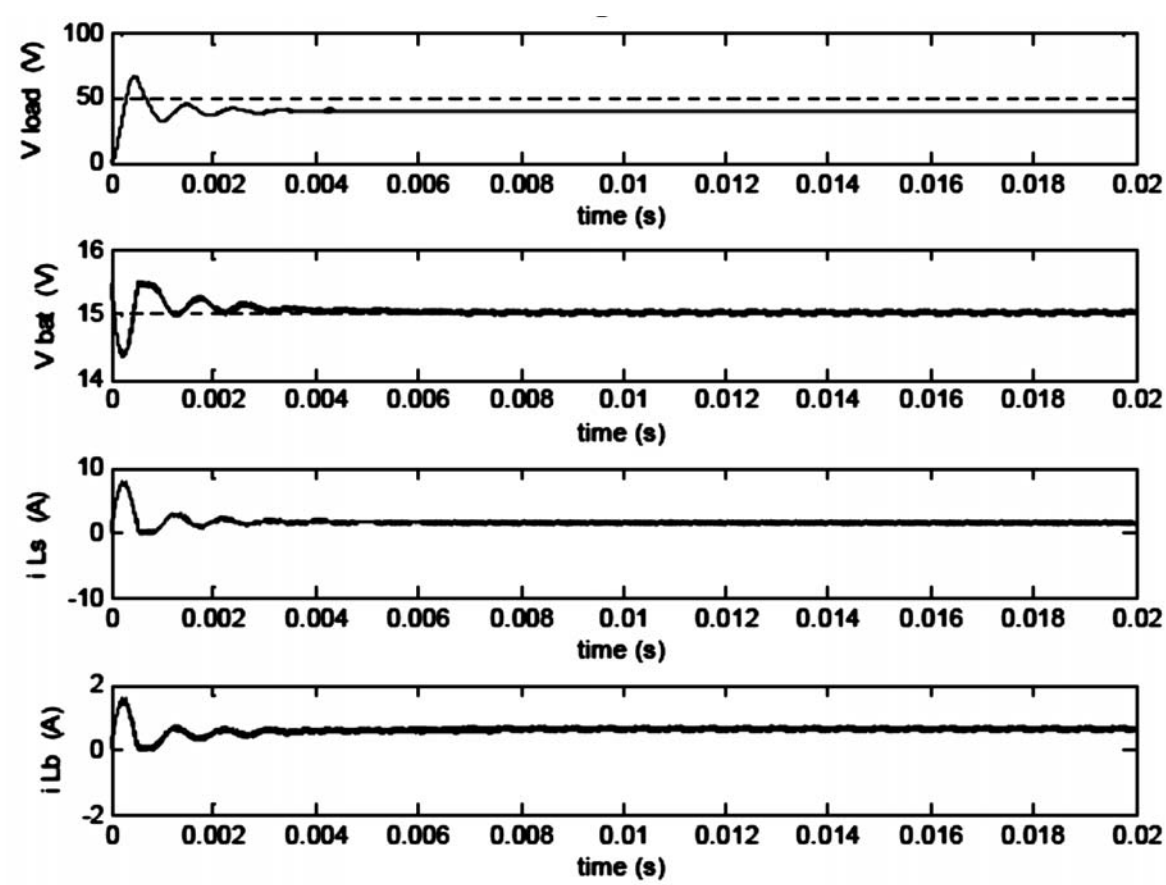

Figure 7: Voltages across load, battery and inductor currents.

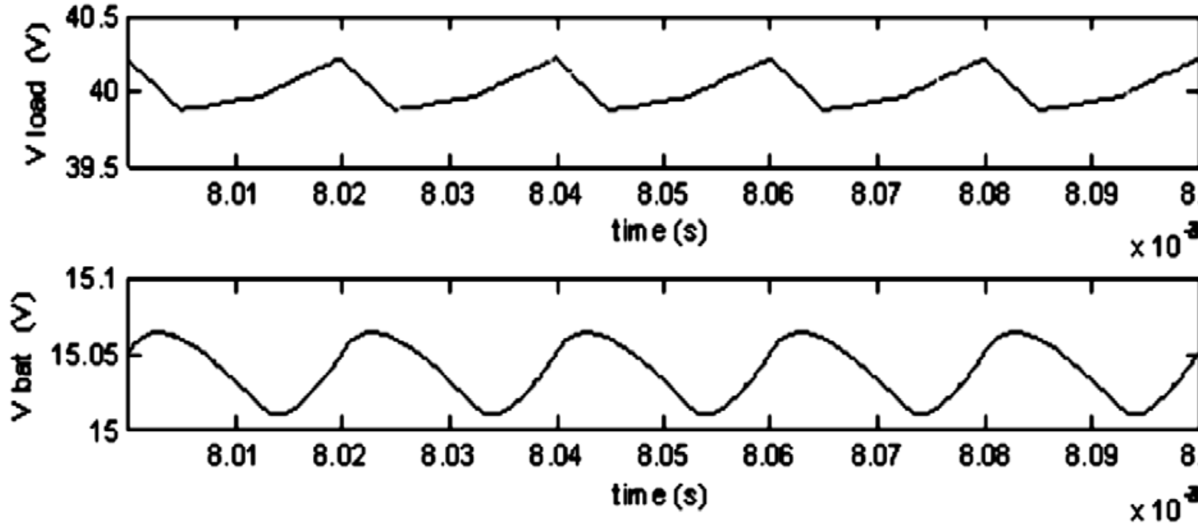

Figure 8: Ripples in V_{load}, V_{bat}

The simulation diagram for mode 3 operation is shown in figure 9.

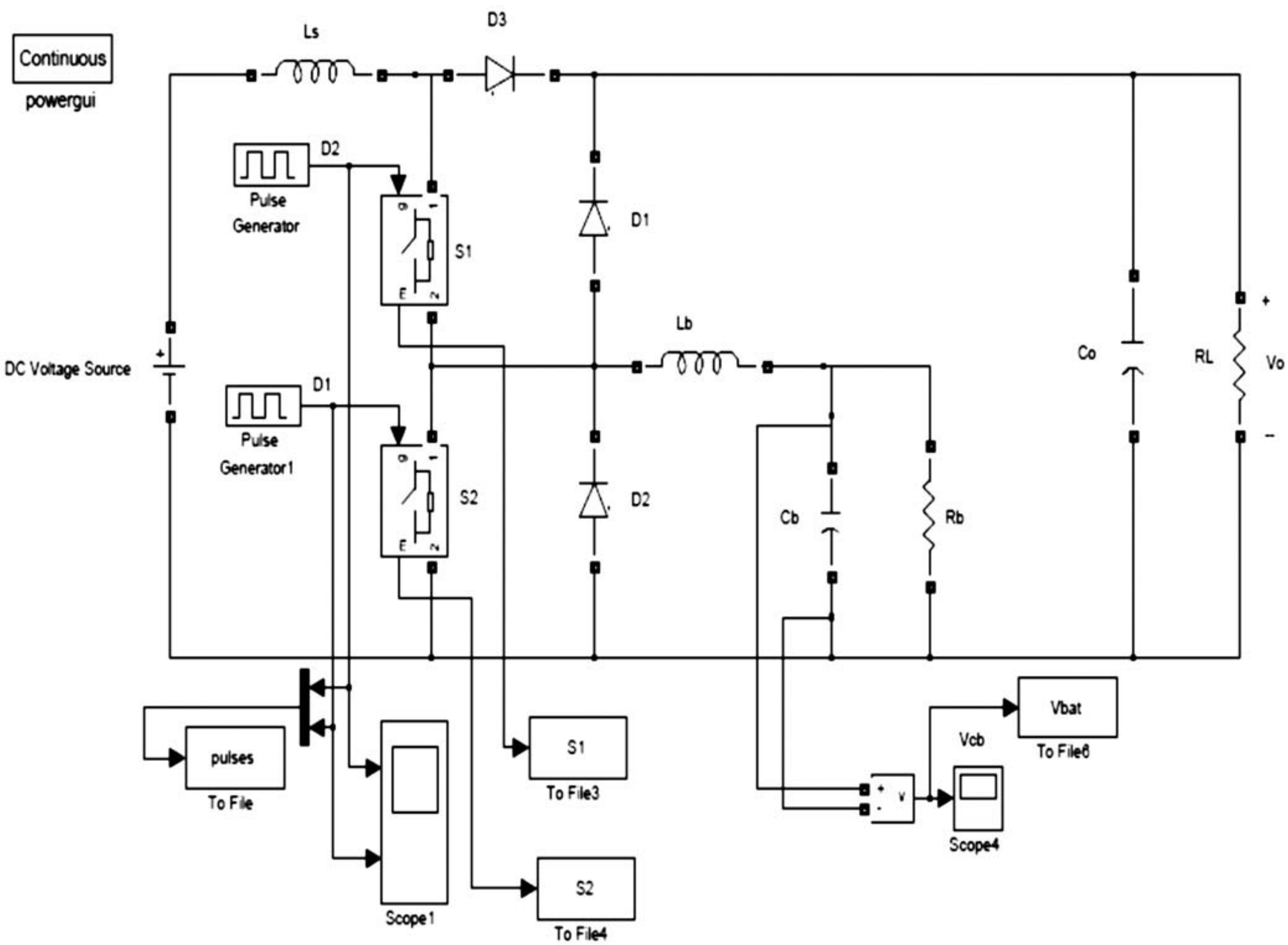

Figure 9: Simulation diagram of the converter in Mode 3

The figure 10 shows voltages across load, battery and inductor currents and corresponding ripples in load, voltage and battery voltage are shown in figure 11 for mode 3 operation.

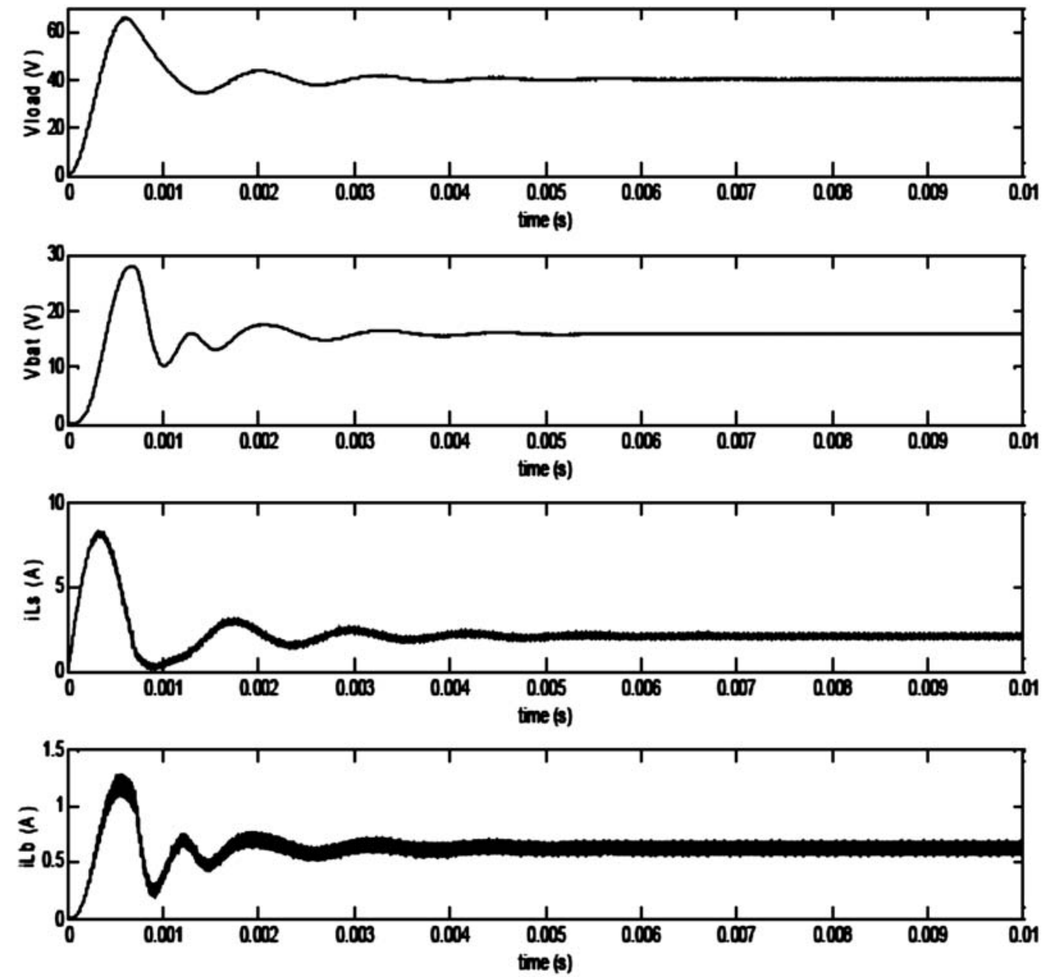

Figure 10: Voltages across load, battery and inductor currents

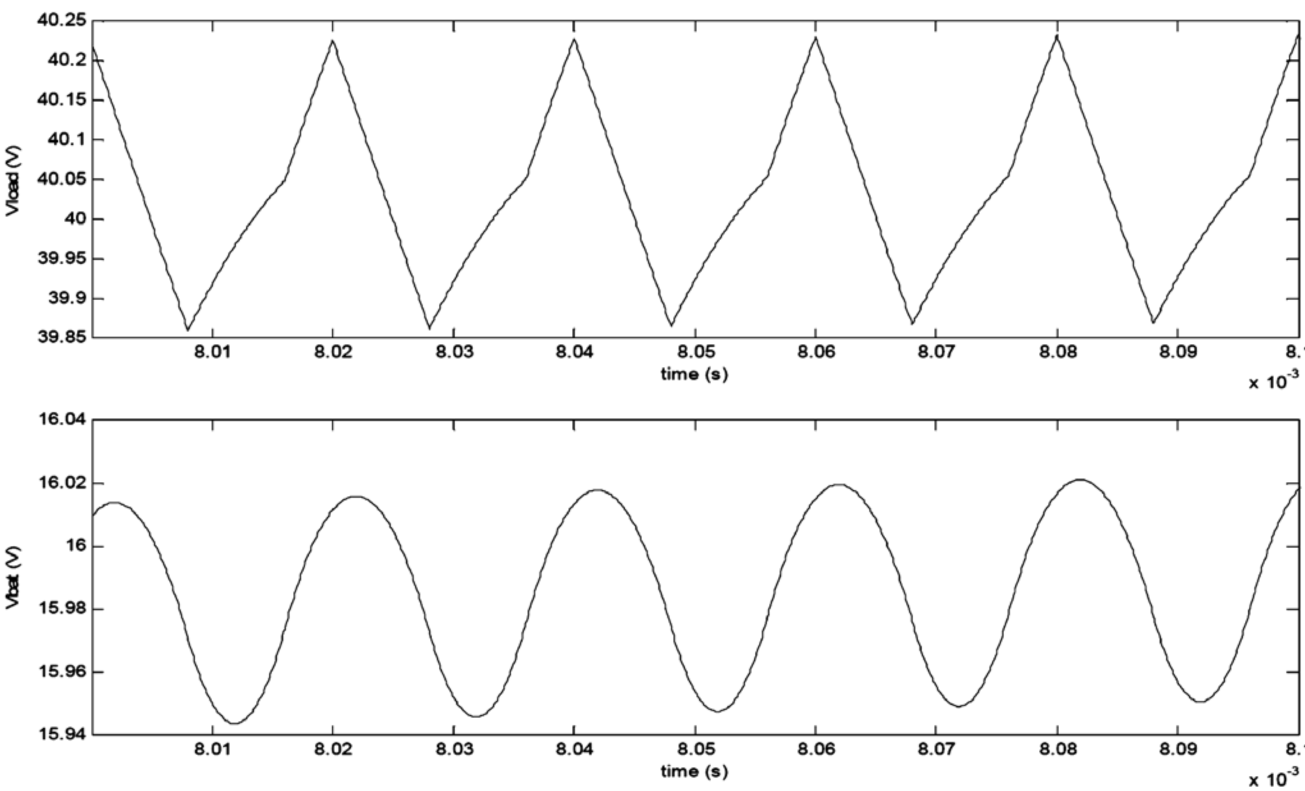

Figure 11: Ripples in V_{load}, V_{bat}

It is found from the results that, Ripple in load voltage is, $\Delta V_0 = 0.4V$ and ripple in voltage across the battery terminals, $\Delta V_{cb} = 0.08V$.

5. CONCLUSIONS

A converter with voltage regulator and battery energy storage system is presented in this paper. It is capable of providing voltage regulation, peak power leveling, compensate for power variations and is adequate for applications in Electrical Vehicles. Functionally, VR-BESS operates like a conventional boost converter and as well as buck converter. Mathematical expressions, simulation results for various modes of operation are presented to describe the operation of the VR-BESS.

6. REFERENCES

1. Chuyue Chen and Guowei Hua. A New Model for Optimal Deployment of Electric Vehicle Charging and Battery Swapping Stations. International Journal of Control and Automation.2014; 7(5), 247-258.
2. N. Jabbour , C. Mademlis , I. Kioskeridis .Improved performance in a super capacitor-based energy storage control system with bidirectional DC-DC converter for elevator motor drives. *Proceedings of 7th IET International Conference on Power Electronics, Machines and Drives, Bristol, 2014,1-6.*
3. V. M. Pacheco, L. C. Freitas , J.B. Vieira Jr. E. A. A. Coelho and V.J. Farias. A DC-DC converter adequate for alternative supply system applications. *Proceedings of APEC Seventeenth Annual IEEE Applied Power Electronics Conference and Exposition, USA, 2002, 1074 – 1080.*
4. V. A. Pacheco , L. C. Freitas, J. B. Vieira, E. A. A. Coelho.Stand-alone photovoltaic energy storage system with maximum power point tracking. *Proceedings of Eighteenth Annual IEEE Applied Power Electronics Conference and Exposition, USA, 2003, 97 – 102.*
5. Samikannu Sarojini Mary, Subramaniam Senthil Kumar, Syam Prasad Poluru, and Maddikara Jaya Bharata Reddy. A Dual DC Output Power Supply for a Stand-alone Photovoltaic System. *Electric Power Components and Systems*.2015; 43(8), 939–950.
6. M. P. Pálsson, K.Uhlen,T. Toftevaag. Modeling and Simulation of an Autonomous Wind/Diesel System Equipped with Forced Commutated Converter. *Proceedings of 7th European Power Electronics Conference, Norway, 1997, 2646-2651.*
7. H.-S. Kim, N. Okada, K. Takigawa. A Study on Utility Interactive PV System in Harmony with Utility. *Proceedings of IEEE 31st Annual Power Electronics Specialist Conference, Galway,2000, 1179-1184.*
8. V. M. Pacheco, L. C. de Freitas, J. B. Vieira, A. A. Pereira. An online no-break with power factor correction and output voltage stabilization. IEEE Transactions on Power Electronics. 2005; 20(5),1109 – 1117.
9. M. H. Rashid. Power Electronics: Circuits, Devices and Applications. 6th edn. Englewood Cliffs, Prentice Hall, 1993.
10. *M.* Gopikrishnan. Battery/ultra Capacitor Hybrid Energy Storage System for Electric, Hybrid and Plug-in Hybrid Electric Vehicles. Middle-East Journal of Scientific Research.2014;20 (9),1122-1126.
11. Geetha A,Subramani C,Krithika V.Development and Analysis of Switched Capacitor Four Quadrant DC-DC Converter for Hybrid Electric Vehicle, Indian Journal Of Science and Technology,2016,9(22),pp.1-10.