# A Superlative Closed-Loop Controlled High-Voltage Gain DC-DC Converter for EV-BESS Charger Fed Induction Motor Drive

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## ABSTRACT

*Efficient, cost-effective, and simple structure of battery charging for EV system by utilizing suitable power conditioning stages with assisted knowledge of control scheme. Based on the summarized merits & demerits of conventional boost DC-DC converters, a single-switch high voltage gain converter is greatly suitable for EV-charging system due to high voltage gain, low switch stress, low current ripples, low EMI issues, and low complex design. The voltage 22V coming from the solar-PV system is converted into 51V by using proposed modified boost converter with a moderate duty cycle of 48% which reduces the switching losses and maximizing the efficiency. The main objective of this work is proposing a novel single switch high step-up DC-DC converter for EV charging system powered by solar-PV system. The DC-link voltage at load terminals is affected due to sudden switching of other loads which impacts the entire stability of the system. To overcome these issues, a closed-loop controlling of modified boost converter has been proposed for enhancing system performance under sudden load variations. The well-recognition of proposed scheme is validated under constant and variable DC-link voltage conditions by using closed-loop PI controller which is demonstrated through Matlab/Simulink tool and results are conferred with proper comparisons.*

**Keyword:** - *Battery Energy Storage System, Closed-Loop PI Controller, DC-DC Converter, Electric-Vehicle Charging System, High Voltage Gain, Power Conversion*.

## 1. INTRODUCTION

The automotive industry growing and the proliferation of automobiles in use around the world are engendering grave environment problems in terms of pollution and hydrocarbon resources. This has led to an increased interest in vehicle electrification, foremost hybrid electric vehicles (HEVs) which can reduce fuel consumption compared to conventional vehicles, but also battery electric vehicles (BEVs)[1]-[3]. BEVs offer high powertrain efficiency and no tailpipe emissions, which is why they are so far considered CO2 neutral in the regulations. If charged with electricity that is produced by fossil free and renewable sources, BEVs have the potential to offer an emission free. Today a large part of the major automotive manufacturers in the world have developed their own BEV model, and BEV sales have seen increased annual growth rates, as high as 54%-87% during 2025-2030.

Still, the battery related drawbacks of relatively short driving range (mainly due to prize constraints) combined with long charging time, prohibit BEVs from taking up the commercial competition with fuel energized cars on a large scale. In this light, it becomes important to investigate the effect on energy efficiency as well as performance that different design choices have, both when it comes to design of the different components in the powertrain, but also regarding the design of the drive system as a whole. Another interesting research aspect is to investigate the possibility to design the drive system according to a specific type of usage, and then to assess the consequence on energy efficiency and performance [4]. Moreover, due to the often limited space for drive system components in vehicles, the choice of peak torque versus thermal capability for a certain electric machine size also becomes highly important [5]-[9].

In general, effective charging infrastructure is required to promote the growth of EV's in the country. Range anxiety, higher initial cost and lack of adequate infrastructure support for charging of vehicles are the issues affecting the adoption of EV's. The already overburdened transmission network will not be able to cater to this huge demand hence alternate sources need to be explored. PV based systems can offer a viable alternative solution. The photovoltaic (PV) system as a source is intermittent. Though the sun shines for more than 300 days in many parts of the country, the irradiance and temperature vary with time of the day and seasons [10]-[13].

Battery as a load has a variable profile. The Battery can be modeled as an electrochemical model, Thevenin based electrical model and impedance based model. The power converter should be capable of meeting the wide variations caused due to varying irradiance and providing dependable power. Buck, boost, buck-boost and fly back are the DC-DC converter topologies widely reported for extraction of maximum power. Conventional buck based topologies have inductor performing the dual function of energy storage and filtering. The conventional boost converter has inductor on the source side and hence requires filters on the load side. It offers a maximum gain of twice the input for higher efficiency with a limitation of 50% duty cycle.

Efficient, cost-effective, and simple structure of battery charging for EV system by utilizing suitable power conditioning stages with assisted knowledge of control scheme. Based on the summarized merits & demerits of conventional boost DC-DC converters, a single-switch high voltage gain converter is greatly suitable for EV-charging system due to high voltage gain, low switch stress, low current ripples, low EMI issues, and low complex design. The voltage 22V coming from the solar-PV system is converted into 51V by using proposed modified boost converter with a moderate duty cycle of 48% which reduces the switching losses and maximizing the efficiency. The main objective of this work is proposing a novel single switch high step-up DC-DC converter for EV charging system powered by solar-PV system [14]-[16].

The DC-link voltage at load terminals is affected due to sudden switching of other loads which impacts the entire stability of the system. To overcome these issues, a closed-loop controlling of modified boost converter has been proposed for enhancing system performance under sudden load variations [17]-[19]. The well-recognition of proposed scheme is validated under single and multiple battery connected conditions by using proposed closed-loop PI controller. Finally, the performance of proposed converter is verified in induction motor drive system to develop complete EV system powered by solar-PV system is verified through Matlab/Simulink tool and results are conferred with proper comparisons.

## 2. ESTIMATION AND CHARACTERIZATION OF LOAD AND SOURCE

### 2.1 Characterization of lithium battery load

Lead Acid, Nickel-Cadmium, and Lithium-Ion are the conventional battery types used for rechargeable batteries in the industry. Lithium-ion based batteries have superior performance in terms of highest energy density (90 Wh / Kg), higher charge-discharge cycles (3000) and lowest self-discharge (2%) and facilitate fast charging and preferred in EV applications. Disadvantages of these batteries are higher cost and intolerance of higher temperatures. Conventional two-wheeler EV's use 48 V Lithium-ion battery. 48V, 24 AH battery of Amptek as in Fig.1 was used for the present study. Charging characteristics from the vendor's battery charger (Conventional 230 Vac/ 48 Vdc) is studied to understand the safe charging profile. The charging characteristics from the observations are plotted in Fig.1 – 3. The study indicates a CC charging for 6 hrs with 3 A and 2 hrs with CV. when the terminal voltage reaches 54.5 V, the battery was cut off. The power requirement increases from 120 W initially to 145 W and then linearly falls to 20 W before the battery is cut-off.

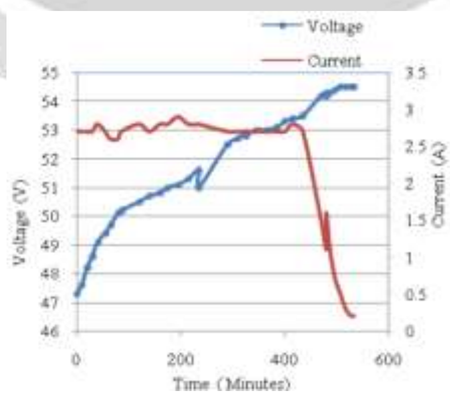



**Fig.1** VI Characteristics of Lithium -Ion Battery

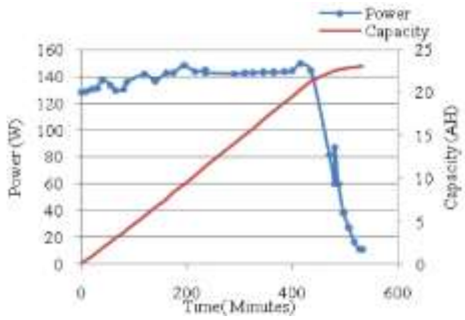



**Fig.2** Power and Capacity Vs. Time characteristics

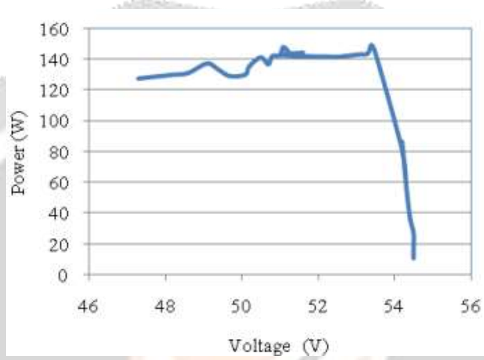



**Fig.3** Voltage vs. Power Characteristics

### 2.2 PV Panel Selection

The study of the nature of the load, indicated the source required could be over 150 W. The National Renewable Energy Laboratory (NREL) has made a detailed repository of temperature, irradiance, pressure, etc. data which can be used for the designing of the PV systems. From the NREL data, the normal room temperature in the city of Mangalore is found to be around 33 oC and PV panel temperature is considered to have 10 oC higher temperature than the room. For lower irradiance, the VMPP further reduces. Thus the voltage at MPP point could be variable from around 21V at 400 W/ m2 irradiance to 27.7 V for 1000 W/ m2. Observations made from the studies conducted on the PV panel indicate the requirement of a converter that can have a higher gain and charge a battery of 54 V with 21 V PV source. Conventional boost converter as in Fig. 8 might be required to be operated over 62 % duty cycle considering ideal conditions. Practically considering diode, inductor and switch drops and drop across ESR of the capacitor will require the system to operate at still higher duty cycle where efficiency reduces and the size of the components will increase.

## 3. PROPOSED MODIFIED BOOST CONVERTER

A number of unidirectional and bidirectional high gain topologies are available in the literature. Most of the topologies are applied for a gain of over five and above which is required to step up low PV voltage to high dc link voltage through MPP extraction and processed further for inversion. The proposed topology in Fig.4 has additional two diodes, extra capacitor and an inductor as a gain cell for the realization of higher voltage gain. The proposed topology is represented in the figure below

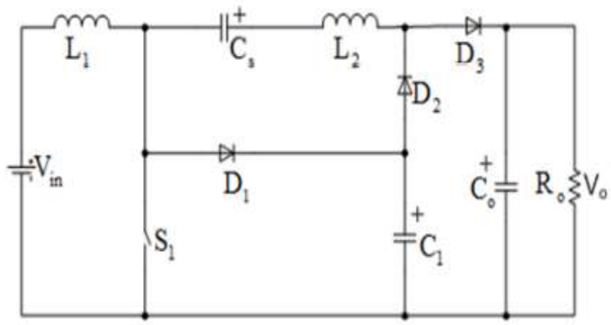



**Fig.4** Modified Boost Converter

The operation of the converter can be described as follows.

**Mode 1:** When the switch S1 is closed, the inductor L1 charges through the switch and the current through the L1 increases. C0 supplies the power to the load and get discharged. In addition, through the path D2, L2, the series capacitor gets charged through the switch S1 connected to the ground. D1 does not conduct as its anode gets reverse biased. The diode D1 blocks the voltage of C1 and needs to be rated at the load voltage.

**Mode2:** The switch S1 is turned off. The current through the inductor now flows through D1 and C1 gets charged as the conventional boost converter with a gain 1/1 −d. The load voltage becomes the summation of Vin and VCs. The Conventional gain of the cell is 2/1 −d, But the loss due to the capacitor reverse biasing the diodes leads to a lower gain. The series capacitor and the inductor L2 with diode block /switch is one of the types of gain cells as found in the literature which aids in achieving higher voltage gain.

**3.1 Closed-Loop Controlling of Proposed Modified Boost Converter Using Voltage Follower Control Technique**

The simplified voltage follower control strategy proposed in this work for regulating the output voltage under sudden battery switching by sensing the actual measured voltage at load terminals. The reference voltage signal is compared with actual measured voltage output obtained from modified boost DC-DC converter. The error signal is passed through PI controller and the PI controller reduces the error and yields a reference signal for pulse generation. This reference signal is related with carrier signal (saw-tooth shape) with the help of a relational operator to produce pulses to switch in proposed modified boost DC-DC converter. The DC-DC converter with high voltage gain switches according to triggering pulses and operates to give out required voltage level that will be sufficient to charge the main battery at required voltage and state of charge. The reference speed signal is varied accordingly and the whole process continues to yield sufficient output voltage to charge the battery at defined voltage and state of charge. The complete schematic arrangement of solar photovoltaic fed closed-loop controlling of modified boost DC-DC converter with simplified voltage follower control scheme is depicted in Fig.5.

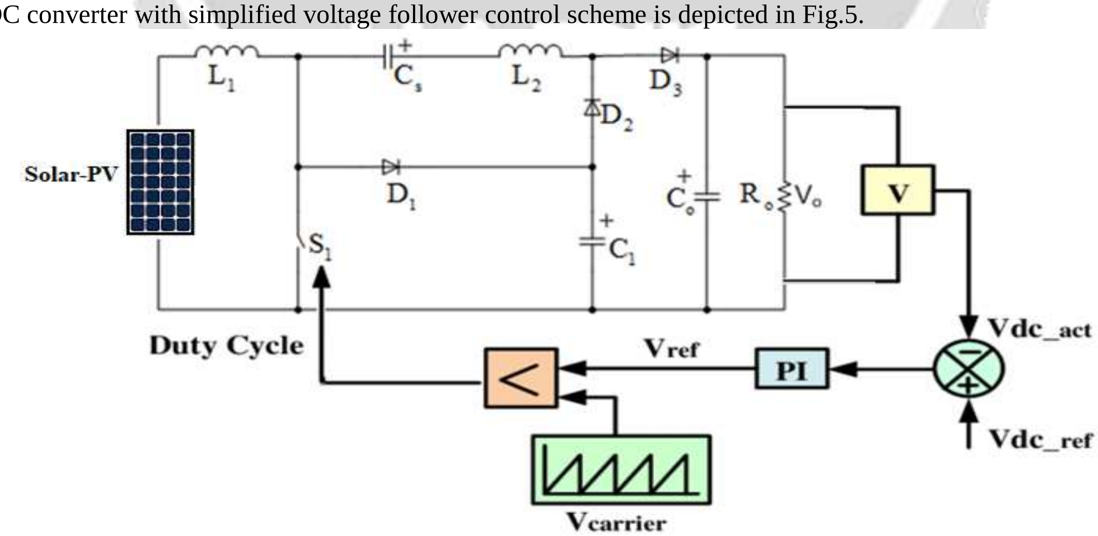



**Fig.5** The schematic arrangement of solar photovoltaic fed closed-loop controlling of modified boost DC-DC converter with simplified voltage follower control scheme

### 3.2 Closed-Loop Controlling of Proposed Modified Boost Converter Using Voltage Follower Control Technique Fed Induction Motor Drive

The simplified voltage follower control strategy proposed in this work for regulating the output voltage under sudden battery switching by sensing the actual measured voltage at load terminals. The reference voltage signal is compared with actual measured voltage output obtained from modified boost DC-DC converter to drive the induction motor using voltage source inverter. The error signal is passed through PI controller and the PI controller reduces the error and yields a reference signal for pulse generation. This reference signal is related with carrier signal (saw-tooth shape) with the help of a relational operator to produce pulses to switch in proposed modified boost DC-DC converter. The DC-DC converter with high voltage gain switches according to triggering pulses and operates to give out required voltage level that will be sufficient to charge the main battery at required voltage and state of charge. The reference speed signal is varied accordingly and the whole process continues to yield sufficient output voltage to charge the battery at defined voltage and state of charge.

The low voltage from photovoltaic (PV) system is stepped-up to desired value using a proposed closed-loop modified boost DC-DC converter is fed to induction motor through a inverter for on-board charging system. The simplified control strategy explained in the previous section produces gate pulses to modified boost DC-DC converter to yield required voltage level that will be sufficient to drive induction motor at required speeds. The complete schematic arrangement of solar photovoltaic fed closed-loop controlling of modified boost DC-DC converter with simplified voltage follower control scheme fed induction motor drive is depicted in Fig.6.

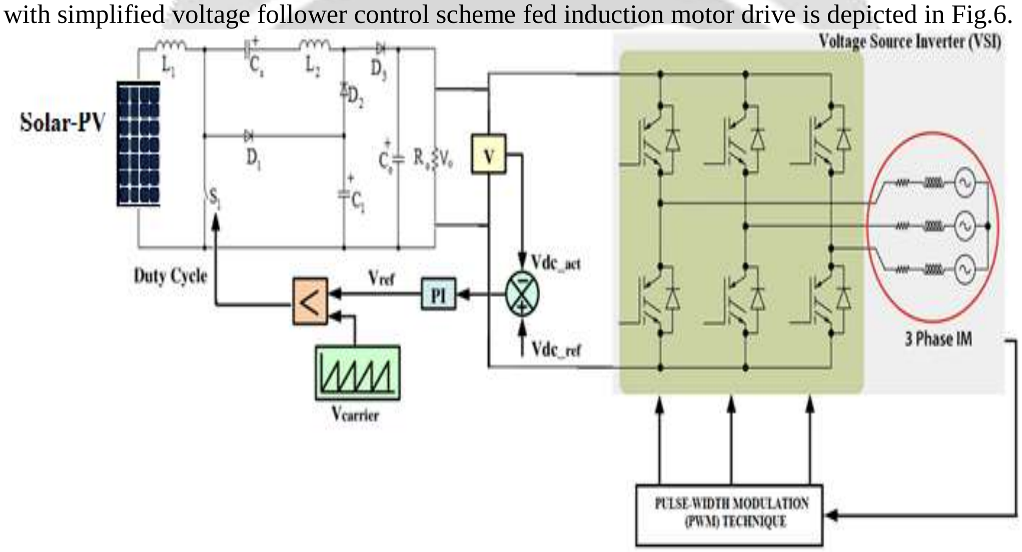



**Fig.6** The schematic arrangement of solar photovoltaic fed closed-loop controlling of modified boost DC-DC converter with simplified voltage follower control scheme fed induction motor drive for on-board charging system

## 4. MATLAB/SIMULINK RESULTS & ANALYSIS

The Matlab/Simulink modelling is carried based on various cases and the proposed models are developed by using described system specifications illustrated in Table.1.

**Table.1** System Specifications

| S. No | Specifications | Values |
|---|---|---|
| 1 | Input DC Voltage | Vdc-21V to 27V |
| 2 | Traditional DC-DC Converter | Vin-21V, L-1mH, C-1000µF |
| 3 | Proposed Modified Boost DC-DC Converter | Vin-21V, L1-570µH, L2-270µH, Cs-0.47µF, Co-220µF, C1-1000 µF |
| 4 | Solar-PV System | Vpv-27V, Ipv-10A, Ppv-270W |
| 5 | Battery Energy Source | Nominal Voltage-40V-50V, Rated Capacity-0.1Ah |
| 6 | Closed-Loop PI Controller | Kp-1, Ki-0.5 |
| 7 | Induction Motor | P-1KW, 300V, Rs-2.9Ω, Ls-0.5mH |

### 4.1 Design of Conventional DC-DC Converter

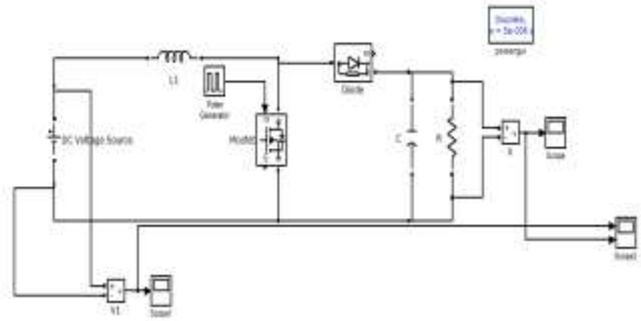
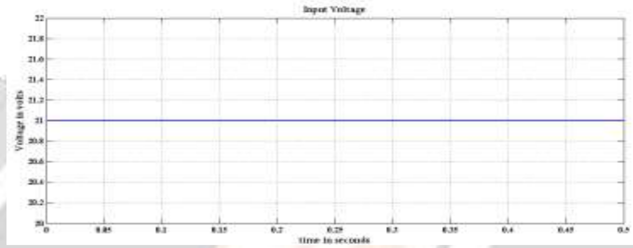
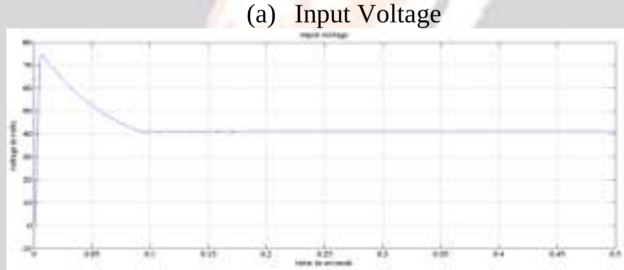


**Fig.7** Matlab/Simulink model of Conventional DC-DC Converter



(a) Input Voltage



(b) Output Voltage

**Fig.8** Simulation Results of Conventional DC-DC Converter for EV Charging Station

The Matlab/Simulink model of conventional DC-DC converter is illustrated in Fig.7. The simulation results of conventional DC-DC converter for EV charging station is depicted in Fig.8 and it includes, (a) Input Voltage, (b) Output Voltage, respectively. The input voltage of conventional DC-DC converter is given as 21V and it converts high voltage output at load terminals of 42V with a gain of 2 times. But for higher voltage it is not suitable due to low voltage gain, high dv/dt switch stress, high switching loss and low efficiency, etc.

### 4.2 Performance of Proposed Modified Boost Converter Fed R-Load

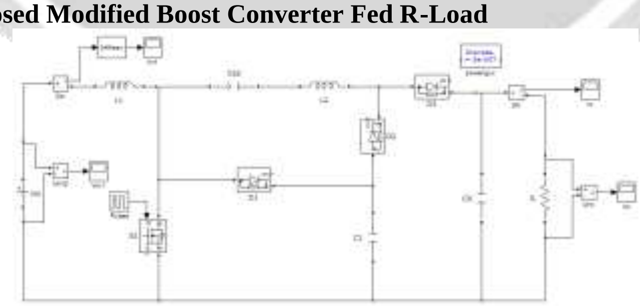
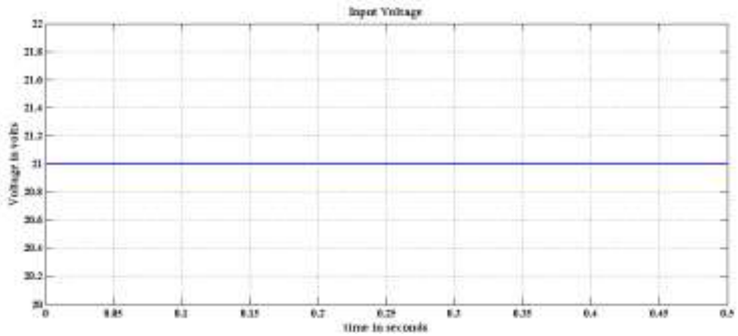
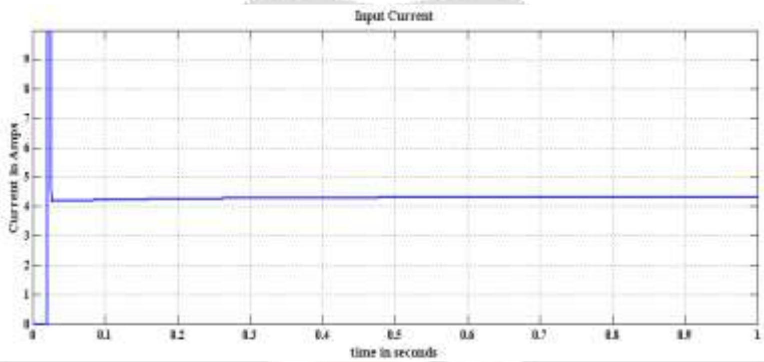


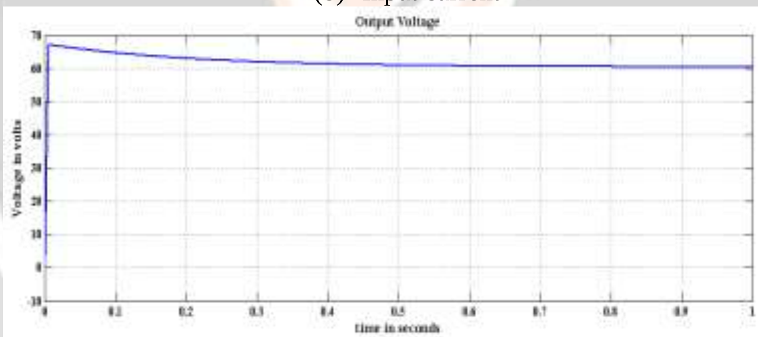
**Fig.9** Matlab/Simulink model of Proposed Modified Boost DC-DC Converter



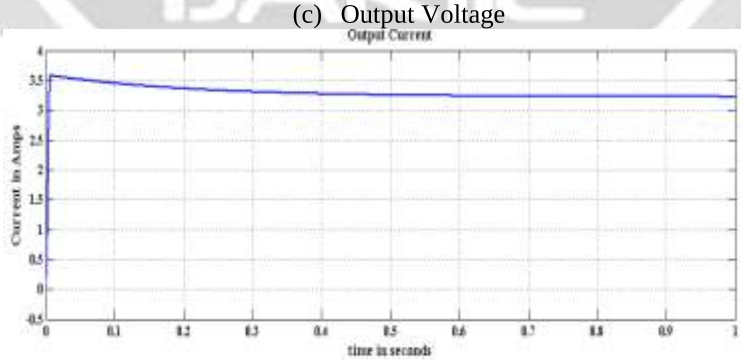

(a) Input Voltage




(b) Input current




(c) Output Voltage




(d) Output Current

**Fig.10** Simulation Results of Proposed Modified Boost DC-DC Converter for EV Charging Station

The Matlab/Simulink model of proposed modified boost DC-DC converter is illustrated in Fig.9. The simulation results of proposed modified boost DC-DC converter for EV charging station is depicted in Fig.10 and it includes, (a) Input Voltage, (b) Input Current (c) Output Voltage, (d) Output Current, respectively. The input voltage of proposed modified boost DC-DC converter is given as 21V with a input current of 4.2A and it converts high voltage output at load terminals of 61V with a output current of 3.5A as a gain of 3 times to drive the R-load.

### 4.3 Performance of Solar-PV Powered Proposed Modified Boost Converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System

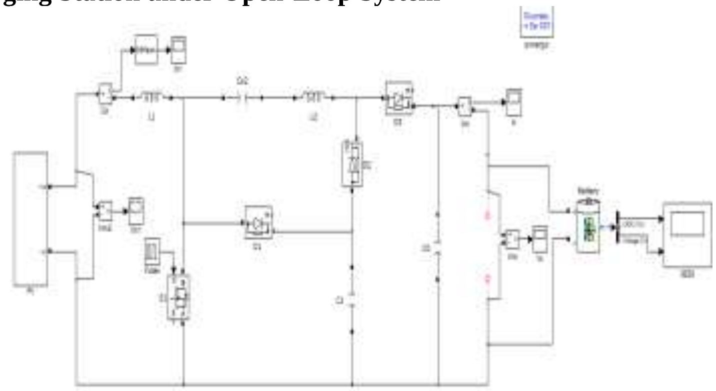
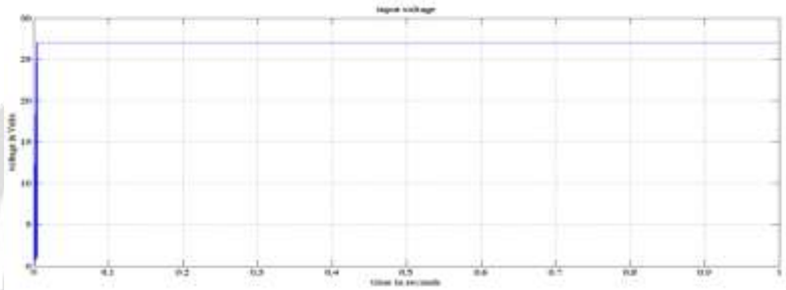
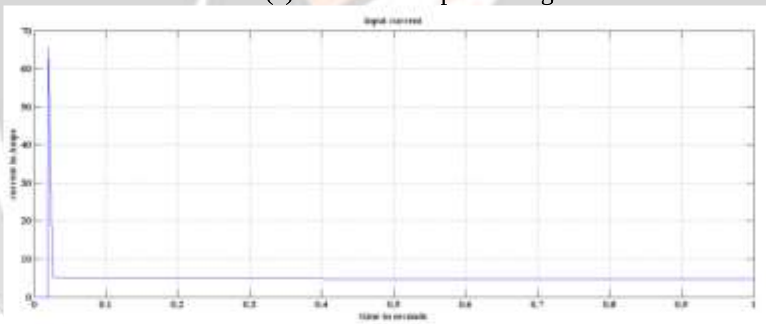


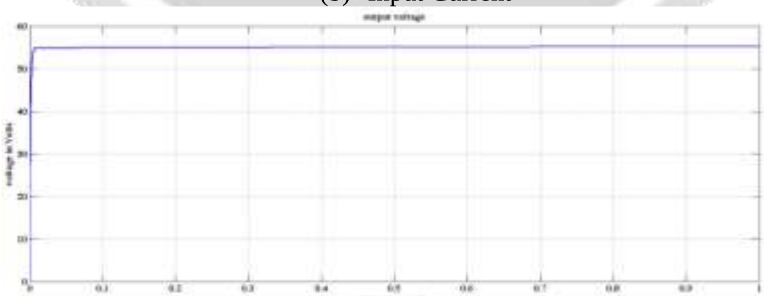
**Fig.11** Matlab/Simulink model of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System



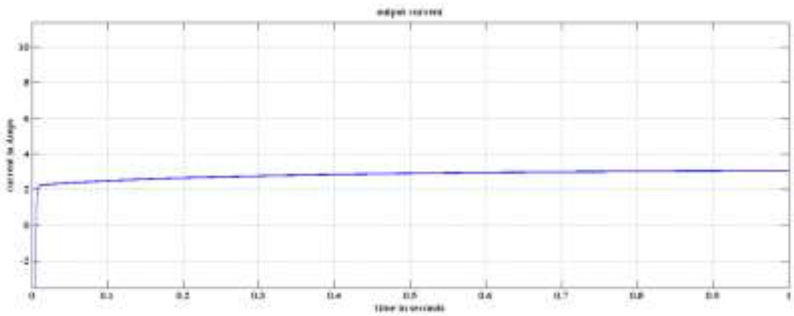
(a) Solar-PV Input Voltage



(b) Input Current



(c) Output Battery Voltage



(d) Output Battery Current

**Fig.12** Simulation Results of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System

The Matlab/Simulink model of proposed modified boost DC-DC converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System is illustrated in Fig.11. The simulation results of proposed modified boost DC-DC converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System is depicted in Fig.12 and it includes, (a) Solar-PV Input Voltage, (b) Input Current (c) Output Battery Voltage, (d) Output Battery Current, respectively. The solar-PV input voltage of proposed modified boost DC-DC converter is given as 27V with a input current of 4.8A and it converts high voltage output at load terminals of 54V with a output current of 3.2 A as a gain of 3 times to drive the battery of EV charging station.

### 4.4 Performance of Solar-PV Powered Proposed Modified Boost Converter for Charging the Battery Energy Source in EV Charging Station under Sudden-Battery Integration

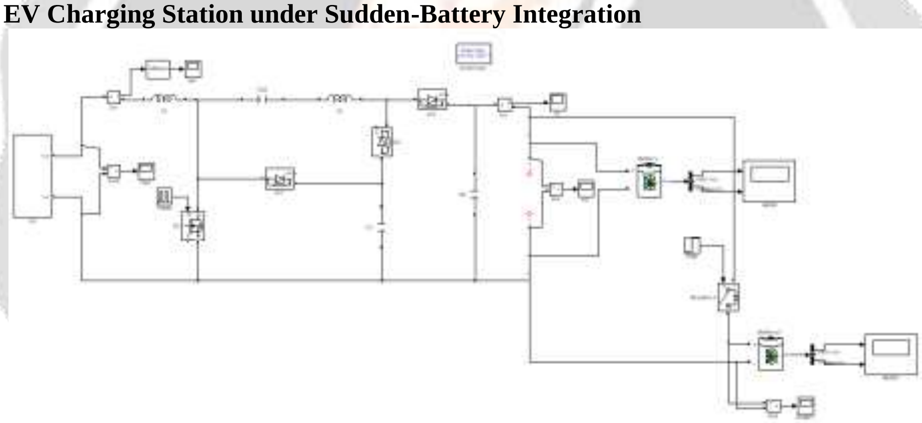
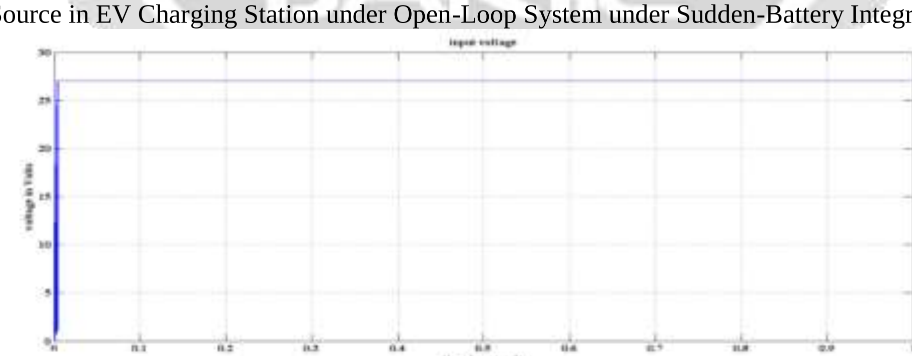
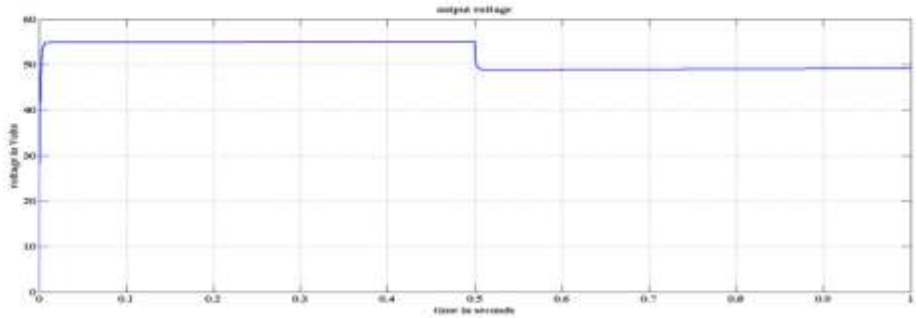


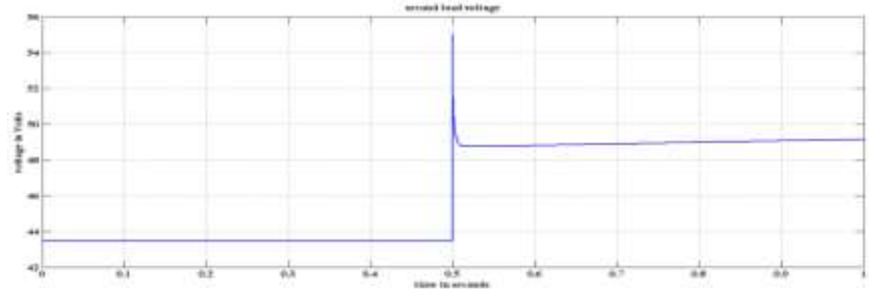
**Fig.13** Matlab/Simulink model of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System under Sudden-Battery Integration



(a) Solar-PV Input Voltage



(b) Output Battery Voltage



(c) Output Voltage of Second Battery

**Fig.14** Simulation Results of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System under Sudden-Battery Integration

The Matlab/Simulink model of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System under Sudden-Battery Integration is illustrated in Fig.13. The simulation results of proposed modified boost DC-DC converter for Charging the Battery Energy Source in EV Charging Station under Open-Loop System is depicted in Fig.14 and it includes, (a) Solar-PV Input Voltage, (b) Output Battery Voltage, (c) Output Voltage of Second Battery, respectively. The solar-PV input voltage of proposed modified boost DC-DC converter is given as 27V and it converts high voltage output at load terminals of 54V to drive the battery of EV charging station. But suddenly, at time t-0.5 sec, the additional second battery is conducted to charge the battery-2 and affecting the main battery voltage because of open-loop system. To overcome this issues and maintain main battery voltage as constant by using closed-loop control scheme.

**4.5 Performance of Solar-PV Powered Proposed Modified Boost Converter for Charging the Battery Energy Source in EV Charging Station under Sudden-Battery Integration with Closed-Loop Voltage-Follower Control Technique**

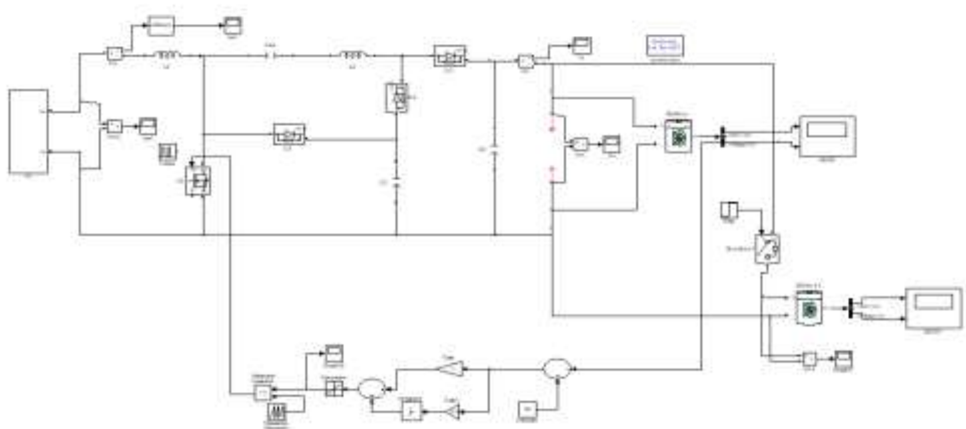
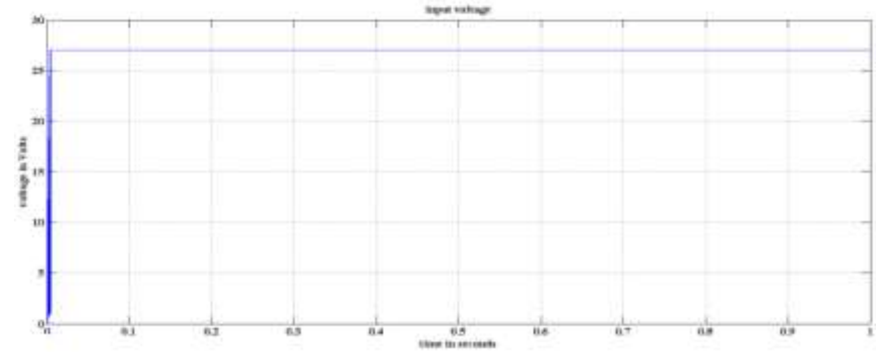
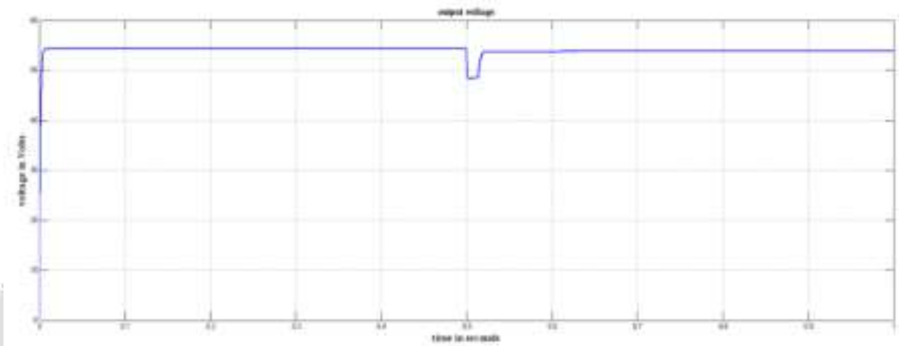


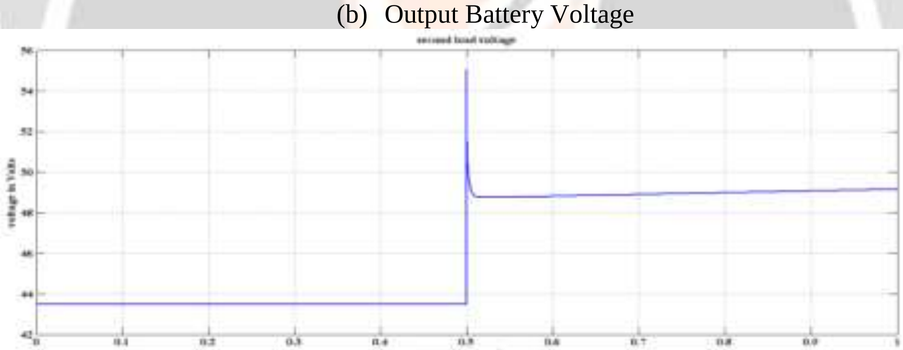
**Fig.15** Matlab/Simulink model of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Sudden-Battery Integration with Closed-Loop Voltage-Follower Control Technique



(a) Solar-PV Input Voltage



(b) Output Battery Voltage



(c) Output Voltage of Second Battery

**Fig.16** Simulation Results of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Sudden-Battery Integration with Closed-Loop Voltage-Follower Control Technique

The Matlab/Simulink model of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Sudden-Battery Integration with Closed-Loop Voltage-Follower Control Technique is illustrated in Fig.15. The simulation results of Proposed Modified Boost DC-DC Converter for Charging the Battery Energy Source in EV Charging Station under Sudden-Battery Integration with Closed-Loop Voltage-Follower Control Technique is depicted in Fig.16 and it includes, (a) Solar-PV Input Voltage, (b) Output Battery Voltage, (c) Output Voltage of Second Battery, respectively. The solar-PV input voltage of proposed modified boost DC-DC converter is given as 27V and it converts high voltage output at load terminals of 54V to drive the battery of EV charging station. But suddenly, at time t-0.5 sec, the additional second battery is conducted to charge the battery-2 and affecting the main battery voltage because of open-loop system. To overcome this issues and maintain main battery voltage as constant by using closed-loop control scheme. By using the closed-loop voltage follower technique is used for regulating the main battery voltage under sudden switching of second battery. It regulates the sudden fluctuations coming from the load and maintains battery voltage as constant and makes as charge state.

**4.6 Performance of Solar-PV Powered Proposed Modified Boost Converter for Charging the Battery Energy Source Fed Induction Motor Drive System**

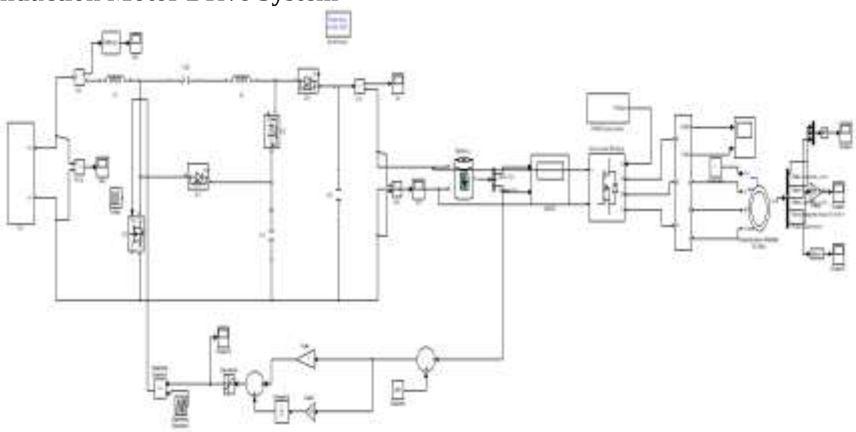
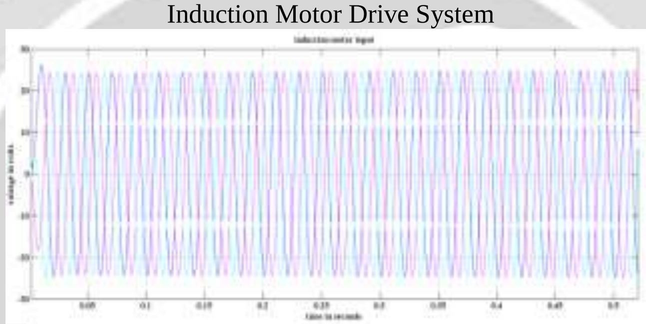
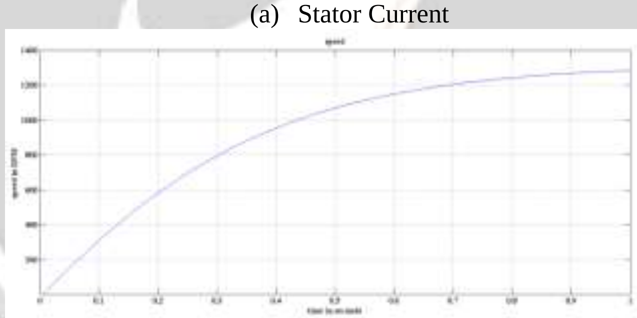


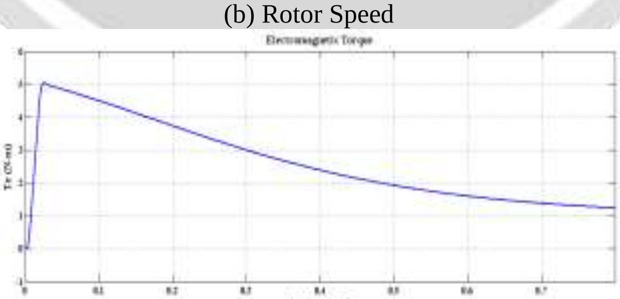
**Fig.17** Matlab/Simulink model of Proposed Modified Boost Converter for Charging the Battery Energy Source Fed Induction Motor Drive System



(a) Stator Current



(b) Rotor Speed



(c) Electromagnetic Torque

**Fig.18** Simulation Results of Proposed Modified Boost Converter for Charging the Battery Energy Source Fed Induction Motor Drive System

The Matlab/Simulink model of Proposed Modified Boost Converter for Charging the Battery Energy Source Fed Induction Motor Drive System is depicted in Fig.17. Simulation Results of Proposed Modified Boost Converter for Charging the Battery Energy Source Fed Induction Motor Drive System is depicted in Fig.18; it includes (a) Stator Current, (b) Rotor Speed, (c) Electromagnetic Torque, respectively. The stator current of induction motor drive is measured as 25A, runs with a rotor speed of 1320 rpm and the electromagnetic torque of drive is measured as 1 N-m to achieve the required load torque to define the complete EV system.

## 5. CONCLUSION

In this work, a unidirectional modified boost converter is proposed. Simulations results using MATLAB / Simulink are presented. The simulation studies of the open-loop and closed-loop operation of the proposed modified boost converter with solar-PV source and induction motor drive load are carried and were discussed. The simulation studies indicated a higher gain over a conventional boost converter. The studies on the variation of sudden load with open-loop system have been studied and evaluate some issues which are eliminated by proposed closed-loop controller used in EV charging stations. The results indicate a higher voltage gain is achieved by the reconfigured modified boost topology and in agreement with simulation results. Based on superlative performance of proposed modified boost converter is verified in induction motor drive system as EV system.

## 6. REFERENCES

[1] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho," Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays", IEEE Transactions on Power Electronics, Vol. 24, No. 5, May 2009

[2] Geoff Walker," Evaluating MPPT Converter Topologies Using A Matlab PV Model", Journal of Electrical and Electronics Engineering, Australia · January 2001.

[3] N. Femia, G. Petrone, G. Spagnuolo and M. Vitelli, "Optimization of perturb and observe maximum power point tracking method," IEEE Transactions on Power Electronics, vol. 20, no. 4, pp. 963-973, July 2005.

[4] T. Esram and P. L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Transactions on Energy Conversions, vol. 22, no. 2, pp. 439–449, Jun. 2007.

[5] A. Safari and S. Mekhilef, “Simulation and hardware implementation of incremental conductance MPPT with direct control method using Cuk converter,” IEEE Transactions on Industrial Electronics., vol. 58, no. 4, pp. 1154–1161, Apr. 2011

[6] I. H. Alta and A. M. Sharaf, “A novel maximum power fuzzy logic controller for photovoltaic solar energy systems,” Renewable Energy, vol. 33, no. 3, pp. 388–399, Mar. 2008.

[7] M. Killi and S. Samanta, "Modified Perturb and Observe MPPT Algorithm for Drift Avoidance in Photovoltaic Systems", IEEE Transactions on Industrial Electronics, vol. 62, no. 9, pp. 5549-
5559, Sept. 2015

[8] Srdjan M. Lukic and Ali Emadi," The Development of Adequate Energy Storage Systems in Electric, Hybrid Electric and Plug-In Hybrid Vehicles", IEEE Industrial Electronics Magazine, December 2008.

[9] Ching-Ming Lai,Yuan-Chih Lin,Dasheng Lee ," Study and Implementation of a Two-Phase Interleaved Bidirectional DC/DC Converter for Vehicle and DC-Microgrid Systems", Energies,2015.

[10] H. Wu, T. Mu, H. Ge and Y. Xing, "Full-Range Soft-SwitchingIsolated Buck-Boost Converters With Integrated Interleaved Boost Converter and Phase-Shifted Control," in IEEE Transactions on Power Electronics, vol. 31, no. 2, pp. 987-999, Feb. 2016.

[11] Jong-Jae Lee, Jung-Min Kwon, Eung-Ho Kim, Woo-Young Choi, Bong-Hwan Kwon, " Single-Stage Single-Switch PFC Flyback Converter Using a Synchronous Rectifier", IEEE Transactions on Industrial Electronics, Vol. 55, No. 3, March 2008

[12] R. J. Wai, R. Y. Duan and K. H. Jheng, "High-efficiency bidirectional dc-dc converter with high-voltage gain," IET Power Electronics, vol. 5, no. 2, pp. 173-184, Feb. 2012

[13] M. P. Shreelakshmi, M. Das and V. Agarwal, "High gain, high efficiency bi-directional DC-DC converter for battery charging applications in stand-alone Photo-Voltaic systems," 2013 IEEE 39th Photovoltaic Specialists Conference (PVSC), Tampa, FL, 2013, pp. 2857-2861.

[14] S. M P, M. Das and V. Agarwal, "Design and Development of a Novel High Voltage Gain, High-Efficiency Bidirectional DC–DC Converter for Storage Interface," in IEEE Transactions on Industrial Electronics, vol. 66, no. 6, pp. 4490-4501, June 2019.

[15] H. Kang and H. Cha, "A New Nonisolated High-Voltage-Gain Boost Converter With Inherent Output Voltage Balancing," in IEEE Transactions on Industrial Electronics, vol. 65, no. 3, pp.
2189-2198, March 2018.

[16] M. Nguyen, T. Duong and Y. Lim, "Switched-Capacitor-Based Dual-Switch High-Boost DC–DC Converter," in IEEE Transactions on Power Electronics, vol. 33, no. 5, pp. 4181-4189, May 2018.

[17] https://maps.nrel.gov/nsrdb-viewer

[18] L. Darbha and P. Parthiban, "High gain bidirectional DC-DC converter with reduced component count," 2017 National Power Electronics Conference (NPEC), Pune, 2017, pp. 314-318

[19] G. Satyanarayana, K. Lakshmi Ganesh "Incorporate of FB-MMCs Converter Topologies for Hybrid PV/FC Based EV Applications" is Published in International Journal of Procedia Technology (ELSEVIER), Vol-21, ISSN-2212-0173, pp.271-278, November 2015.