Volume 9, Issue 3
June 2020

ITEE Journal
Information Technology & Electrical Engineering

ISSN: - 2306-708X

EV Battery Charger Using Bridgeless Landsman Converter and Isolated Converter

[1]Athira Krishnan, [2] Vipin V A

[1]Department of Electrical Engineering, GECI

[2]Department of Electrical Engineering, GECI

E-mail: [1]athirakrishna070@gmail.com, [2]vipinva1990@gmail.com

ABSTRACT

Implementing of a battery charger for EV with power factor improvement is presented. Instead of conventional diode rectifier a modified landsman Power Factor Correction (PFC) converter is used at the source end of the existing EV charger. PFC converter is cascaded with forward converter. Battery charger fed by Bridgeless (BL) converter consists of two stages, a front end bridgeless landsman converter used to revamp the shaping of the input wave and a forward converter is used to charge the EV battery. In BL converter fed charger the losses are reduced compared to conventional charger consisting of bridge diode rectifier. Here improvement in power quality is ensured. Input and output ripple currents are reduced also harmonics are eliminated. The converter topology is designed and simulation was done in MATLAB/Simulink.

Keywords: *Bridgeless Landsman converter, EV battery charger, Forward converter, Power factor correction.*

1. INTRODUCTION

Over the years, headway in the field of electric vehicle is happening and it is an emerging technology. It provides an efficient need of transportation, as saving of fuel has been a major concern due to the global warming issues and availability of energy resources since its availability is meagre. Battery chargers can be classified as off-board chargers where the battery is charged at high power and on-board chargers where the battery is charged at lower power [1]. The consumption of longer charging times by on-board charger make it suitable for charging the vehicle. On-board battery chargers with high efficiency can be considered to be the key component for an electric vehicle [2]. Researchers have analyzed of the various topologies and methods to improve the efficiency of EV chargers. The basic desideratum for on-board chargers includes the parameters such as high efficiency, high power density, high reliability, small size and low cost [3]. Battery charger on board consists of an AC-DC converter with Power Factor Correction (PFC) and a DC-DC converter [4]. PFC eliminates lower order harmonics and improves power factor. Bridgeless (BL) design [5] is usually preferred for PFC converters as it reduces the excessive conduction loss due to the forward voltage drop of each diodes forming bridge in circuit. Bridgeless power factor correction boost converter with soft switching is proposed for power supply and battery charging application [6]. Though this topology reduces total number of semiconductor switches, switching losses are increased in AC-DC converter and it ultimately reduces converter efficiency. BL boost suffers from high Electro-Magnetic Interference and has a complex control which is the major limitation. Battery chargers are required to dispense DC voltage in order to charge high-energy battery packs used in EVs. On board arrangement allow battery charging at any time given the obtainability of the supply grid [7], the duty cycle is adjusted in full bridge converter by pulse width modulation mode but there are harmonics and in this case efficiency is lower. The current status and requirements of primary electrical propulsion components are carefully reviewed and the future trends in electrical propulsion system battery charging are also discussed here [8]. Electrical motor converts the energy supplied by the battery into mechanical energy to provide wheel traction. A battery equalization circuit and its control strategy are discussed [9].In this case equalization speed is too low for practical application. Usually multiphase interleaved converters are used for battery equalization but for this structure two more switches are required and high current stress in switches are perceived. The single phase AC-DC PFC bridgeless rectifier is analyzed with multiple stages to improve efficiency and reduce the stress of the switch voltage [10]. The major drawback includes input output isolation which cannot be easily implemented. The occurrence of high startup inrush current and lack of current limiting during overload conditions are also the cause of the limitations. The bridgeless landsman PFC Converter is used to feed a DC-DC flyback converter [11], which ends power to the forced LED cooling unit and the galvanic-insulated LED lighting module. Here conduction loss is reduced. The cognizance about bridgeless Landsman Converter is done through this paper. Here proposed system is a bridgeless (BL) landsman converter followed by a forward converter. This riddance the need of front end diode bridge rectifier. The elimination of full bridge converter reduces the current drawn during battery charging and it eliminates harmonic distortion. Also the current conduction loss is less as current conduction is present in the current conduction path of each switching cycle through less number of semiconductor components which is only a single semiconductor switch. The proposed system consists of a bridgeless landsman converter for shaping the input wave and a forward converter for charging the EV battery under regulated voltage and current conditions. The current topology offers improved power quality, low ripple current input and output, low stress on the device and improved overall efficiency. The paper is organized in the following manner. Section 2 comprises of Block Diagram, Section 3 describes the Circuit Topology; Section 4 depicts

Simulation Results followed by Design considerations in section 5 and Conclusion and Future work in Section 6 and 7 respectively.

2. BLOCK DIAGRAM

The block diagram of the EV battery charger is shown in figure 1.1. A battery charger generally consists of an AC-DC converter and a DC-DC converter, separated by a DC-link condenser. Here the AC-DC converter is a bridgeless landsman converter and DC-DC converter is an isolated forward converter. A bridgeless converter is selected as it eliminate the need of front end diode bridge rectifier and it also reduces the input current drawn hence results in lower harmonic distortion. Also here due to absence of diode bridge the current conduction is through less number of semiconductor devices which ultimately reduces conduction loss. The bridgeless converter helps in providing the power factor near to unity and also improves efficiency.

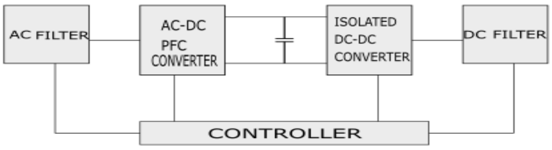

Fig.1. Block diagram representation of EV battery charger

A single phase AC source feeds the input side of the charger. The output of the bridgeless landsman converter is fed as an input to the forward converter. The output of forward converter can be supplied to battery. Forward converter uses a transformer to control the output voltage. It provides electrical isolation between input side and output side and can be used to produce isolated and controlled DC output voltage.

3. CIRCUIT TOPOLOGY

EV battery charger consists of a BL landsman converter and an isolated converter. Here the input diode bridge rectifier is eliminated. The existence of two parallel working landsman converters during the positive half line and negative half line removes the diode at the front end. A voltage mode PI controller at the charger's output terminal controls the intermediate DC voltage over a wide range of inputs. Regulated DC voltage from stage BL PFC is given at isolated converter input.

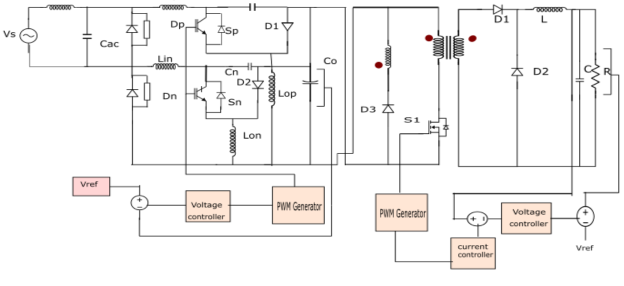

Fig.2. Circuit diagram of EV battery charger

For a bridgeless landsman converter operations can be divided into positive and negative half cycle. During positive half cycle, the switchS_p, attached to the upper line, is in ON condition and the L_{op} inductor starts charging and the intermediate DC contact capacitor, C_o discharges via the isolated converter connected to the load side. Due to the load stored in the inductor, the diode, D 1 has no conducting path during this period, and thus contains a reverse bias voltage through it. The diode D_1 operates, when the gate pulse to the switch is averted. The forward converter at the output is supplied for each half cycle as the inductor, L_{op} discharges and the DC link capacitor, C_o starts charging.The operation is similar in the negative half cycle.

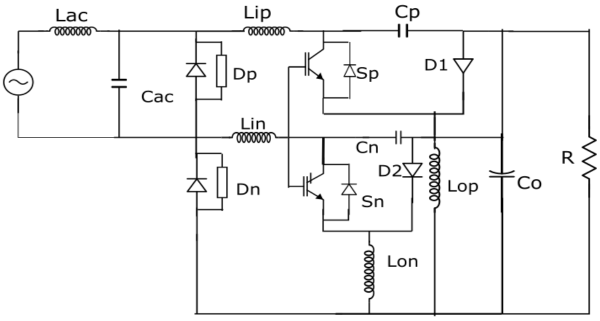

Fig.3. Circuit diagram of Bridgeless Landsman converter

In case of Forward converter when switch S_1 is on, energy transfer occurs to battery side and vice versa. The transformer's primary winding is attached to the input supply in series with switch S_1 which is the output of the BL landsman converter and the secondary winding is connected by a rectification and filtering circuit at the rear end. The primary winding of transformer is connected in series with switch to the input supply which is the output of BL landsman converter and the secondary winding is connected through a rectification and filtering circuit at the back end. The load is connected across the rectified output of the transformer secondary. When the switch S_1 is ON, energy transfer occurs. The primary voltage is transferred to the secondary winding, and is rectified by the forward diode. The voltage rectified is then filtered and is stored in the output LC section of the circuit. Generally there can be 3 modes of operation and are accounted below:

- When the switch S_1 is ON diode D_1 is forward biased and other diodes are reverse biased. The voltage across capacitor is the input voltage multiplied by transformation ratio. The magnetizing current of transformer increase with a slope.
- When switch S_1 is OFF, D_2 conducts as output inductor current freewheels through $D_2$and the transformer magnetizing current continue to flow and are positive at this time. The diode D_3 conduct and energy which is stored in magnetizing inductance is fed back to source.
- The magnetizing current reaches zero in the third mode. Operation is similar to mode 2 and when Im reaches zero the diode D_3 become reverse biased.

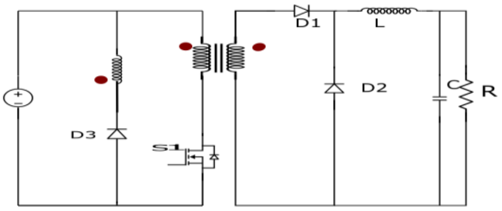

Fig.4. Circuit diagram of Forward converter

Figure 2 shows the circuit diagram of an EV battery charger along with the control circuit. Figures 3 and 4 show the circuit diagram of one battery charger's individual units. The AC-DC converter unit is a bridgeless landsman converter and the DC-DC converter unit is represented by the forward converter. Li-ion batteries can be used as the energy storage system. Nowadays lead acid batteries are replaced by Li-ion batteries as they have higher efficiency and better temperature characteristics.

4. DESIGN CONSIDERATIONS

The main objective is to design a bridgeless converter and a forward converter for an EV battery charger. For a 20KHz, 1000 W bridgeless landsman converter the major design equations are given below. L_{ip} and L_{in} represent input inductance of the converter, L_{op} and L_{on} represent the output inductance of converter whereas C_p and C_n are the transfer energy capacitances and ϒ indicate the dc link voltage ripple and ω indicates the line frequency in radian/second. C_o is the dc link capacitor.

$$L_{ip} = L_{in} = \frac{DVsmin^2}{P0.2f} \quad (1)$$

$$C_n = C_p = \frac{P}{\square\sqrt{2}\,Vs_{max}f(\sqrt{2}\,Vs_{max}+V_o)} \quad (2)$$

$$L_{op} = L_{on} = \frac{DVsmin^2}{2fP} \quad (3)$$

$$C_o = \frac{P}{2\omega\Delta Vo^2} \quad (4)$$

$$D = \frac{V_o}{V_{in}+V_o} \quad (5)$$

$$A_p = \frac{\sqrt{D_{max}}P_{out}*1+\frac{1}{n}}{K_wJ*10^{-6}fB_m} \quad (6)$$

$$N_p = \frac{Vin_{min}D_{max}}{A_ef\Delta B} \quad (7)$$

$$N_s = N_p\frac{V_o+V_F+D_{max}}{Vin_{max}D_{max}} \quad (8)$$

$$V_o = \frac{V_{in}}{m}D \quad (9)$$

$$L = \frac{R(1-D)}{2f} \quad (10)$$

$$C = \frac{V_o(1-D)}{8Lf^2\Delta V_o} \quad (11)$$

$$R = \frac{Vo^2}{P} \quad (12)$$

Equations (6)-(12) represents the equations to find the parameters of a forward converter operating at 20KHz.Here number of primary turns is considered to be equal to number of secondary turns as maximum duty cycle is considered to be 50 percentage, so $N_p = N_t$. Also m represents the turns ratio and $m = \frac{N_p}{N_s}$. Diode drop is given by V_F and is assumed to be 0.8V. The efficiency of the converter n is assumed to be around 95 percentages for the calculation and also ΔV_o is considered to be 10 percent of voltage V_o across the resistance R, while L and C are the circuit inductance and capacitance respectively.

5. SIMULATION RESULTS

Closed loop simulation of a battery charger is done with respect to the design parameters in table I and table II along with the control circuit. The landsman converter input is a single source of AC in phase. Output of the intermediate DC link capacitor is fed to a forward converter. For an input of 230 V_{rms} in the ac side, an output of 400 V is obtained across DC link capacitor.

PARAMETERS	VALUE
Input inductors L_{in},L_{ip}	2.89mH
Transfer energy capacitances C_p , C_n	2μH
Output inductor L_{op} ,L_{ip}	289μH
Intermediate DC link Capacitor	995μH
Line filters L_{ac} ,C_{ac}	506μH , 2μF

Table I: Design parameters of BL landsman converter

A voltage follower based proportional and integral (PI) controller used effectively regulate the intermediate DC link voltage of the charger. A dual loop PI controller is used to control the forward converter at the second stage. Here the simulation of an EV battery charger fed by a bridgeless landsman converter along with a regulated DC link voltage at an intermediate stage is done. DC voltage obtained from the Bridgeless PFC stage is given at the input of an isolated converter.

PARAMETERS	VALUE
Input Voltage	400V
Inductance L	46.8μH
DC bus capacitance	34.7μF
Output voltage	60V
Resistance	3.6Ω

Table II: Design parameters of Forward converter

A single phase AC source maintains the input side tension of the proposed charger. For improved performance based switching; two converters are switched at 20KHz. The figures show the simulink model and output waveform result of a battery charger using BL landsman converter and forward converter.

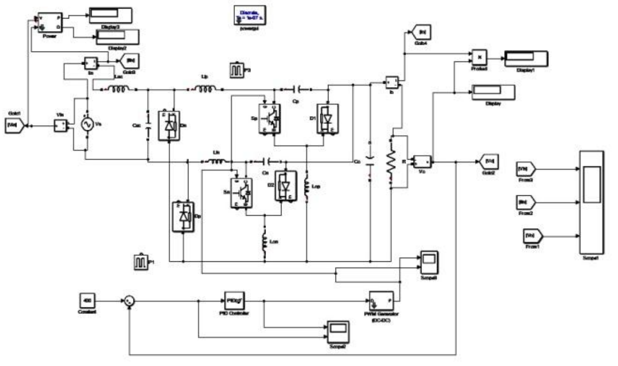

Fig.5. Simulink model of Bridgeless Landsman converter

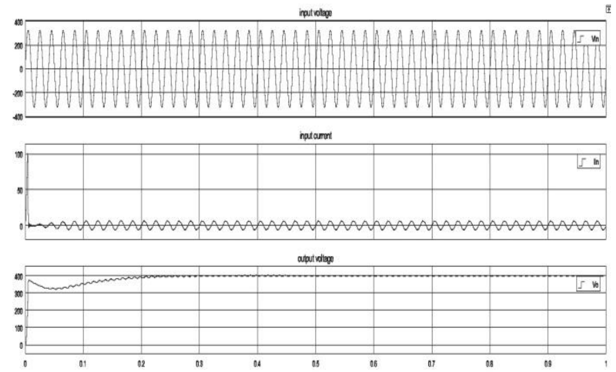

Fig.6. Waveform result of Bridgeless Landsman converter

Figures 5 and 6 show the simulink model of individual units for a battery charger. Figure 5 shows the simulink model of BL landsman converter and figure 6 shows the waveform result of BL landsman converter. For an input value of $230V_{rms}$ an output voltage of around 400V is obtained.

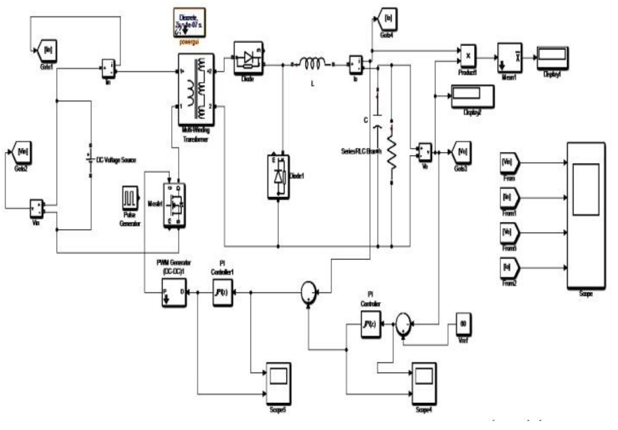

Fig.7. Simulink model of Forward converter

Figure 7 is the simulink model of forward converter and 8 show the waveform result obtained. Here for an input of 400V an output of 60V is attained across the DC bus capacitor. The simulation of each converter is done one by one and then is coupled to form the desired units of battery charger. Individual closed loop circuit simulations are done and output of around 400V is obtained across the DC link capacitor and output of 60 V.

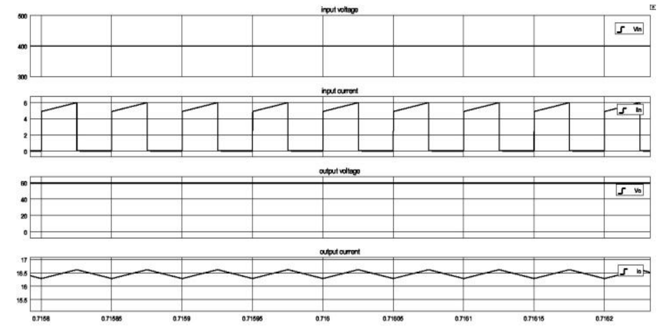

Fig.8. Waveform result of Forward converter

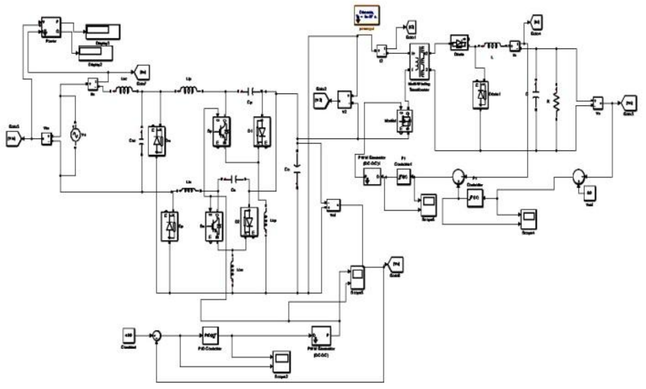

Fig.9. Simulink model of EV battery charger

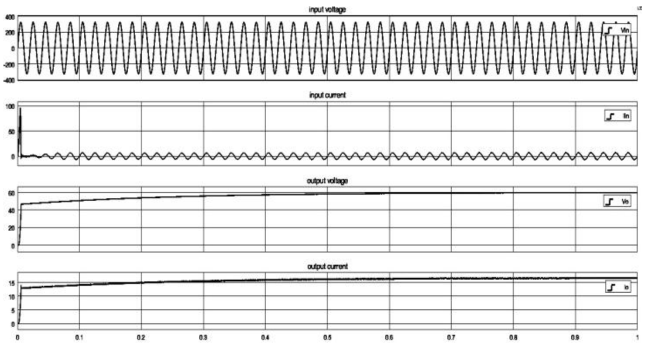

Fig.10. Waveform result of EV battery charger

The figures 9 and 10 respectively shows the simulink model and waveform result of EV battery charger using BL landsman converter at front end and forward converter at the back end. Here the simulation is done with respect to the design parameters listed in table I and II. Here for an input of $230V_{rms}$at the front end gives a voltage around 60 V at the output providing a power factor around 0.99 and at a maintained power of 1KW.

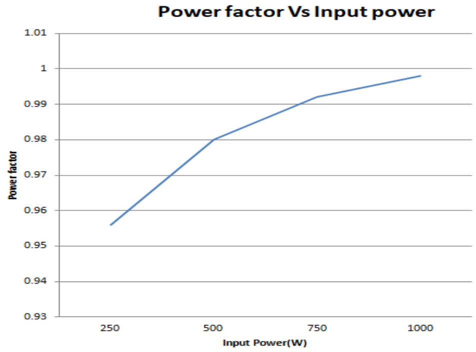

Fig.11. Power factor Vs Input power

Figure 11 shows the graphical representation of power factor Vs input power and from this graph we can speculate that the power factor is improved and is nearing to unity having a value of 0.99 with the above design parameter values.

6. CONCLUSION

The closed loop simulation of an enhanced EV charger with BL Landsman converter was carried out followed by a forward converter. BL converter reduced input and output current ripples due to inductors in both the converter's input and output. Also the harmonic distortion is reduced due to the elimination of diode bridge rectifier at front end. The design calculations are done with respect to parameters and efficiency is attained to be 85 percentages. The power factor is obtained as 0.999 which is near to unity as observed from the simulation findings.

7. FUTURE WORK

Hardware implementation of the EV battery charger is planned to be done in the future. The requirements and selection of components are to be studied and further efficiency can be increased by using soft switching circuits as they reduces current and voltage stress in switches.

REFERENCES

[1] Pui Yee Kong, Aziz, J. A, M. R Sahid, “A Bridgeless PFC Converter for On-Board Battery Charger”, IEEE conference on energy conversion, 2014.

[2] Woo-Young Choi, Min Kwon Yang, Hyoung-Sup Cho, “High frequency link soft switching PWM DC-DC converter for EV on-board battery chargers”, IEEE Transactions Power Electronics, vol. 29, no. 8, Oct. 2014.

[3] J. Deng and S. Li and S. Hu and C. C.Miand R.Ma, “Design Methodology of LLC Resonant Converters for Electric Vehicle Battery Chargers”,IEEE Transactions on Vehicular Technology, vol. 63, no. 4, pp. 1581-1592,2014.

[4] P. He and A. Khaligh, “Comprehensive Analyses and Comparison of 1 kW Isolated DC-DC Converters for Bidirectional EV Charging Systems”,IEEE Transactions on industrial application,vol.52, no.1, 2016.

[5] Peiwen He, Alireza Khaligh, “Comprehensive Analyses and Comparison of Isolated DC-DC Converters for Bidirectional EV Charging Systems”,IEEE Transactions on Transportation Electrification,vol. 3, no.1,pp. 147-156,2017.

[6] M. Alam and W. Eberle and D. S. Gautam and C. Botting, “A Soft-Switching Bridgeless ACDC Power Factor Correction Converter”,IEEE Transactions on Power Electronics Vol. 32,2017.

[7] Luca Solero, “Non conventional on-board charger for electric vehiclepropulsion batteries”,IEEE Transactions Vehicular Technology, vol. 50,no. 1, pp. 144-149, Jan 2001.

[8] K. Rajashekara, “Present Status and Future Trends in Electric Vehicle Propulsion Technologies”, IEEE Journal of Emerging and Selected Topics in Power Electronics IEEE, vol. 1, no. 1, pp. 310, Mar. 2013.

[9] X. Zheng and X. Liu and Y. He and G. Zeng, “Active Vehicle Battery Equalization Scheme in the Condition of Constant-Voltage/Current Charging and Discharging”, IEEE Transactions Vehicular Technology,vol. 66,no. 5, pp. 3714-3723, 2017.

[10] Ahmed M. Al-Gabri, Abbas A. Fardoun, and Esam H. Ismail, “Bridgeless PFC modified SEPIC rectifier with extended gain for universal input voltage applications” IEEE Transactions Power Electronics, vol. 30, no. 8, pp. 4272 4282, Aug.,2015.

[11] A. Jha and B. Singh,“ Power quality improvement using bridgeless- Landsman converter for LED driver” IET Power Electronics,vol. 9, no.13, pp. 2591-2601, 2016.

[12] Radha Kushwaha,Bhim Singh, “A Power Quality Improved EV Charger with Bridgeless Cuk Converter” 2019 IEEE Transportation Electrification Conference and Expo (ITEC),pp. 1-6, 2019.

[13] Daniel W Hart, “Power Electronics” Tata McGraw Hill,2011.

[14] Robert W Erickson, Dragan Maksimovie, “ Fundamentals of Power Electronics” .

[15] L Umanand, “Power Electronics Essentials and Applications” Wiley publications, 2013 .

[16] V Ramanarayanan, “ Course material on Switch Mode Power Conversion”2016.

AUTHOR PROFILES

Athira Krishnan received B.Tech degree in Electrical and Electronics Engineering from Kannur University, Kerala in 2018 and is currently pursuing M.Tech degree in the stream of Power Electronics and Control from APJ Abdul Kalam Technological University.

Vipin V A received B.Tech degree in Electrical and Electronics Engineering and M.Tech degree in Power Systems from University of Kerala. He has more than two years of work experience in field of Electrical System Design and Electrical Safety Inspections. His area of interest includes Power System and Power Electronic Converters. He is currently working as an Assistant Professor in Government Engineering College Idukki, Kerala, India.