

PERFORMANCE EVALUATION OF AC-DC ACTIVE-PFC BASED CHARGING DEVICE FOR TWO-WHEELER EV APPLICATION

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Abstract

Fossil fuels emit greenhouse gases during their usage process. The emission of greenhouse gases leads to global warming. Alternative energy resources with zero pollution are a viable option in these modern days to protect the environment. Vehicular pollution contributes more to global warming and Electric vehicles (EVs) driven from a battery source can control this condition. Due to limitations in the storage system, electric vehicles are not much popular but to reduce the pollution from vehicles, EVs are a must and is recommended for (public/personal) transportation. EV (battery) is charged through a DC source (converting the available AC supply to DC). The conversion process diminishes the input source power factor and is a worrying factor. This paper addresses the power factor issue while charging the battery of EVs. The paper focuses on maintaining the unity power factor on the source side while charging the battery of the EV from AC-DC conversion. The model is developed and the results are discussed (for three different battery levels) using MATLAB/SIMULINK software.

Keywords: AC-DC Conversion, Battery Units, Charging, Electric Vehicle, Unity Power Factor

Introduction

Pollution is a major constraint these days and certain measures have to be taken to control global pollution. Vehicular pollution contributes to global warming (Yong *et al.*, 2015) and measures to limit the emissions from IC engine vehicles should be considered. Electric Vehicles (EVs) (Yilmaz and Krein, 2013; Williamson and Rathore, 2015; Praneeth and Williamson, 2018) driven by non-conventional or battery sources show promissory results in reducing global pollution. The running cost of EVs is less compared to conventional

sources-driven vehicles. The range of operation of EVs is a major constraint in using them but the major advantage is they save environmental energy. Advanced battery technology and research can increase the range of EVs and thus their usage increases. Electric Vehicles are driven by an electric source and the EV wheels are coupled to an electric motor through a gear system. On-board charging is an important feature in EVs that is trending nowadays. Advanced power electronic technology made onboard charging (Geng *et al.*, 2018; Zhang,

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2018; Zhang *et al.*, 2018) possible for EVs and adds ease of charging in EV technology. The on-board charging system taps AC source directly from the point and internally converts tapped AC to DC to charge battery of EV (Nussbaumer *et al.*, 2009).

The AC-DC conversion for EV application can be done by using a simple diode bridge rectifier as a front-end converter. To obtain refined DC output from the diode bridge rectifier, the capacitor is connected to the output terminals of the diode bridge rectifier (Pahlevaninezhad *et al.*, 2012). The use of an output capacitor causes power factor concerns creating the phase angle difference between the input source voltage and current. The conversion process diminishes the input source power factor which is a worrying factor and insists on a power factor correction converter (Anwar *et al.*, 2010; Musavi *et al.*, 2013; Lopatkin and Zinoviev, 2021). Poor power factor at the input of the charging system leads to over-sizing of electrical equipment, increase in conductor size and cost, poor voltage regulation, and poor efficiency. This paper addresses the power factor issue while charging the battery of EVs. The paper focuses on maintaining the unity power factor on the source side while charging the battery of the EV from AC-DC conversion. The model is developed and the results are discussed (for three different battery levels) using MATLAB/SIMULINK software.

Electrical Vehicle Charging System

Finite supply, cost, and pollution of conventional sources are the major constraint that makes us to think while employing a source of energy. Vehicular transportation using conventional sources like coal, gas, or petroleum products emits a lot of pollution and increases global warming. This opened a way to search for alternative sources of energy to drive vehicles. Electric vehicles run by battery sources emit no pollution and help in protecting the environment. The model of the EV charging station is shown in Figure 1. Onboard charging system taps the AC source directly from

the point and internally converts tapped AC to DC to charge the battery of EV. The tapped AC is converted to DC type of power using a diode bridge rectifier with a conventional PWM rectifier or any DC-DC converter and the refinement of DC output is done by placing a capacitor at the output. The capacitor output is fed to a DC-DC converter to regulate the voltage as required by the battery to drive an electric vehicle.

The general available source of electrical power is AC type and is the main source for EV as well. The available AC type of power supply is converted to DC type to charge a battery of EV. The onboard socket is provided for charging purposes. The AC type is tapped through an onboard socket to a diode bridge rectifier (DBR). DBR converts AC to DC type and to obtain refined DC output, a capacitor is connected at the output terminals of DBR. The capacitor output is fed to a DC-DC converter to regulate the voltage according to the requirement of the EV system. The output of the DC-DC converter charges the battery of the EV.

Buck DC-DC Converter for Battery Charging

A Buck converter is a simple DC-DC converter that gives out the reduced output voltage compared to the input voltage. Figure 2. shows the Buck converter which consists of a switch, diode inductor, and a capacitor. Switching (Buck) converter gives more efficiency than linear regulators. During the switch ON time of the buck converter, as shown in Figure 3(a), the switch is ON and the diode becomes reverse biased. The inductor is charged up to the input source level and the voltage across the inductor is given by Equation (1). The current circulates from the input source to load through an inductor.

$$V_L = V_{out} - V_{in} \quad (1)$$

During the switch OFF time of the buck converter, as shown in Figure 3(b), the switch is OFF and the diode becomes forward biased. The

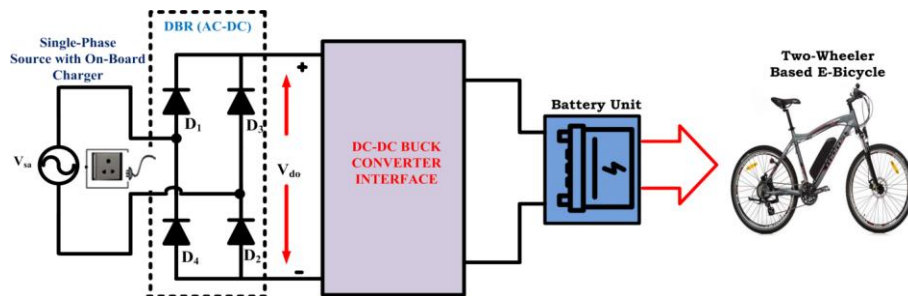


Figure 1. Electric Vehicle Charging System

loop circuit of the buck converter for the generation of control gate pulses for the power transistor is shown in Figure 4. The output actual voltage is compared to the reference voltage level and the error is fed to the PI controller to obtain the reference voltage signal which is then operated along with carrier signal through a comparator to obtain controlled gate pulses to the power transistor in buck converter.

AC-DC Unity Power Factor Charging For Ev

The general available source of electrical power is AC type and is the main source for EV as well. The available AC type of power supply is converted to a DC type to charge a battery of EV. The onboard socket is provided for charging purposes. The AC type is tapped through an onboard socket to a diode bridge rectifier (DBR). DBR converts AC to DC type and to obtain refined DC output, a capacitor is connected at the output terminals of DBR. As the presence of DBR deteriorates the source side power factor the control methodology to correct the source side power factor is shown in Figure 5. Battery actual voltage is compared with the reference value and the error signal is fed to the PI controller which gives out the current magnitude (input source side) signal. AC input source shape is sensed and is multiplied with the current magnitude signal to obtain the current reference signal.

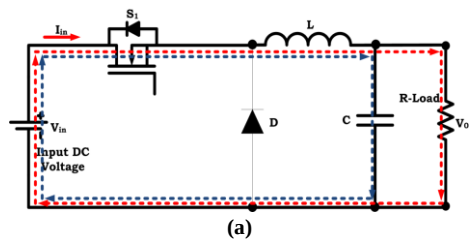
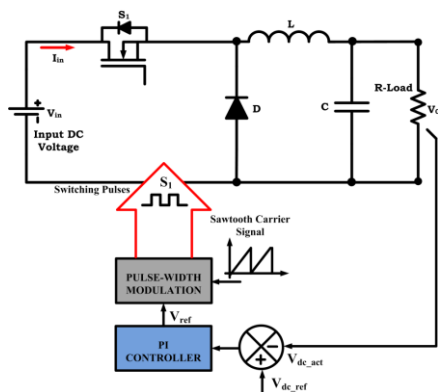


Figure 3. Operating Modes of Buck Converter
 (a) Buck converter Switch ON condition,
 (a) Buck converter Switch OFF condition



From Single-Phase Source

V_{sa}

V_{max}

I_{ref}

I_{mag}

I_{shape}

PROPORTIONAL-INTEGRAL (PI) CONTROLLER

V_{dc_ref}

V_{dc_actual}

HYSTERESIS CURRENT CONTROLLER

SWITCHING PULSES TO S_1

The current reference signal is compared with the actual current (from Buck output) and the net signal is fed to Hysteresis current controller to generate the gate pulses to the power transistor in the buck converter. This process corrects the input current shape and hence maintains the input source side power factor unity. The overall EV battery charging system with unity power factor correction is shown in Figure 6. The output of the DC-DC converter charges the battery of the EV. Closed-loop Buck converter while regulating the voltage, also regulates the current signal, and accordingly gate pulses are generated. Hence input (on the AC side) source power factor is corrected yielding a unity power factor.

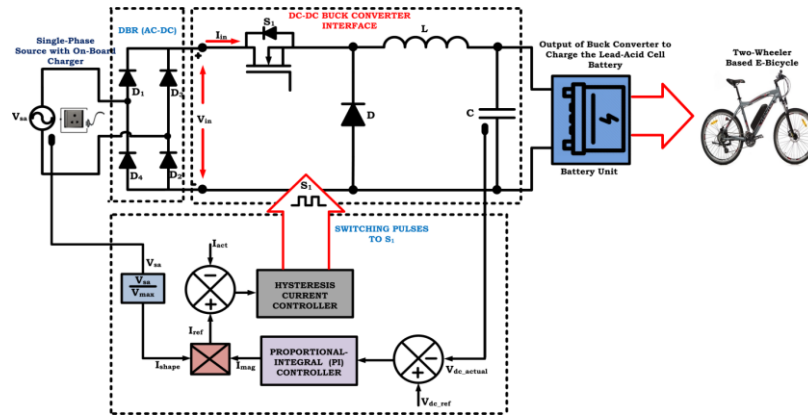


Figure 6. Overall EV Battery Charging System with Power Factor Correction

Table 1. System Parameters

S. No	Parameter	Value
1	Single-Phase AC Source	1-Ø, 230Vrms, 50Hz
2	Buck Inductor	1mH
3	Buck Capacitor	4500µF
4	Battery Type	Lead-acid type
5	Battery Rating	Nominal Voltage (64V, 120V, 200V), 200Ah
6	Battery nominal discharge current	40 A
7	Battery SoC (%)	80 %
8	Battery response time	30 Sec

Matlab/simulink result & analysis

The different parametric values of the circuit used in the simulation of the AC-DC UPF Charging Circuit for Two-Wheeler Electric Vehicle Application are illustrated in Table 1. The lead-acid type battery is used in the analysis for electric vehicle applications. The analysis is carried out for three different charging conditions of Lead-acid battery for EV application.

Conversion of AC-DC using diode-bridge rectifier without load filter

The Simulation Results of AC-DC Conversion using Diode-Bridge Rectifier without Load Filter are depicted in Figure 7. The single-phase AC source is used with a value of 230Vrms and the source current is measured as 3A as shown in Figure 7(a), (b). The diode-bridge rectifier converts the AC to pulsating DC, but a constant DC voltage is required for charging the battery. In this case, the load side filter is not connected that's why the source current is maintained as sinusoidal and in-phase with the source voltage which represents the unity power factor as shown in Figure 7(c), (d). The pulsated DC output voltage is measured at load

terminals of 320V as shown in Figure 7(e). The FFT window of AC input source current is measured with a value of 0.38% which is complying with IEEE-519 standards as shown in Figure 7(f).

The Simulation Results of AC-DC Conversion using Diode-Bridge Rectifier with Load Filter are depicted in Figure 8. The single-phase AC source is used with a value of 230Vrms and the source current is measured as non-sinusoidal and consists of some harmonic components with a value of 110A as shown in Figure 8(a), (b). The diode-bridge rectifier converts the AC to pulsating DC, but a constant DC voltage is attained by using a load-side capacitor filter for charging the battery. In this case, the load side filter is connected at the load side that's why the source current is maintained as non-sinusoidal and out-phase with the source voltage which represents the non-unity power factor as shown in Figure 8(c), (d). The constant DC output voltage is measured at load terminals of 320V as shown in Figure 8(e). The FFT window of AC input source current is measured with a value of 85.78% which is non-complying with IEEE-519 standards as shown in Figure 8(f).

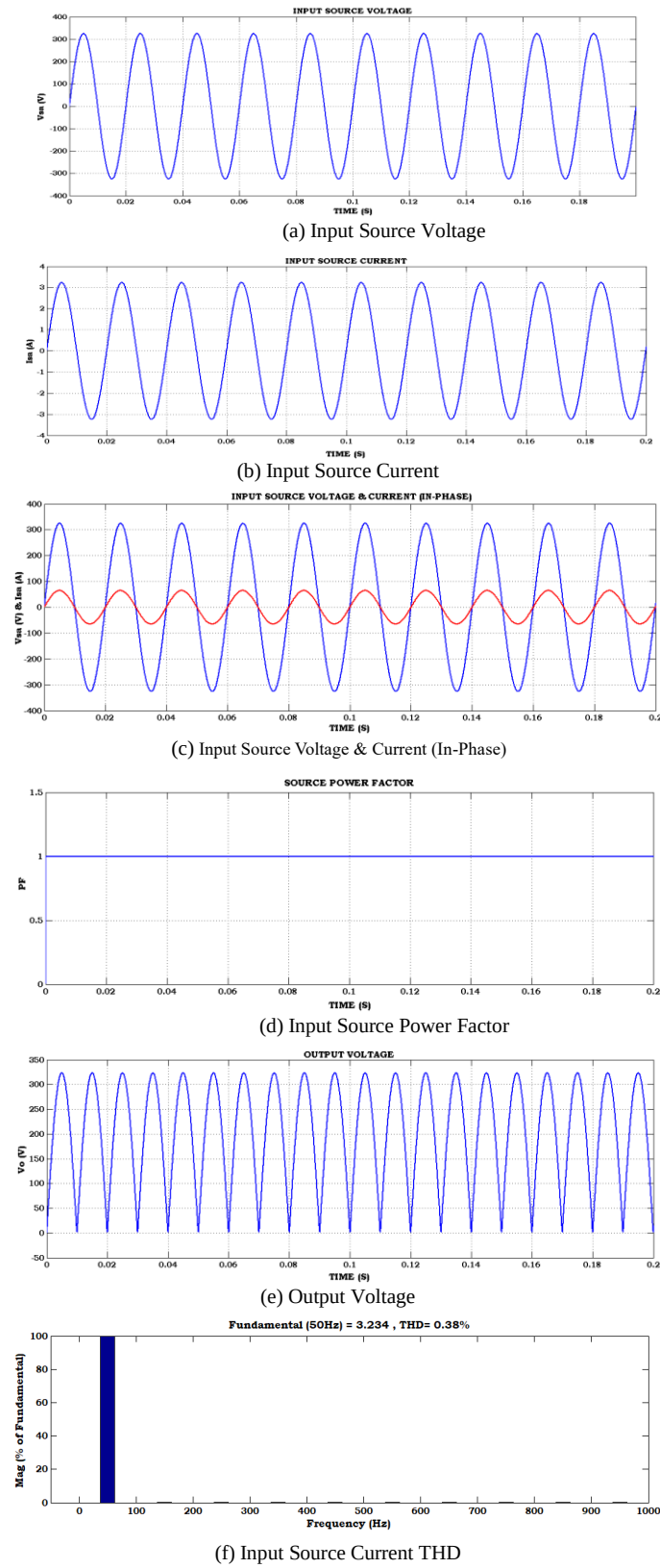


Figure 7. Simulation Results of AC-DC Conversion using Diode-Bridge Rectifier with Load Filter

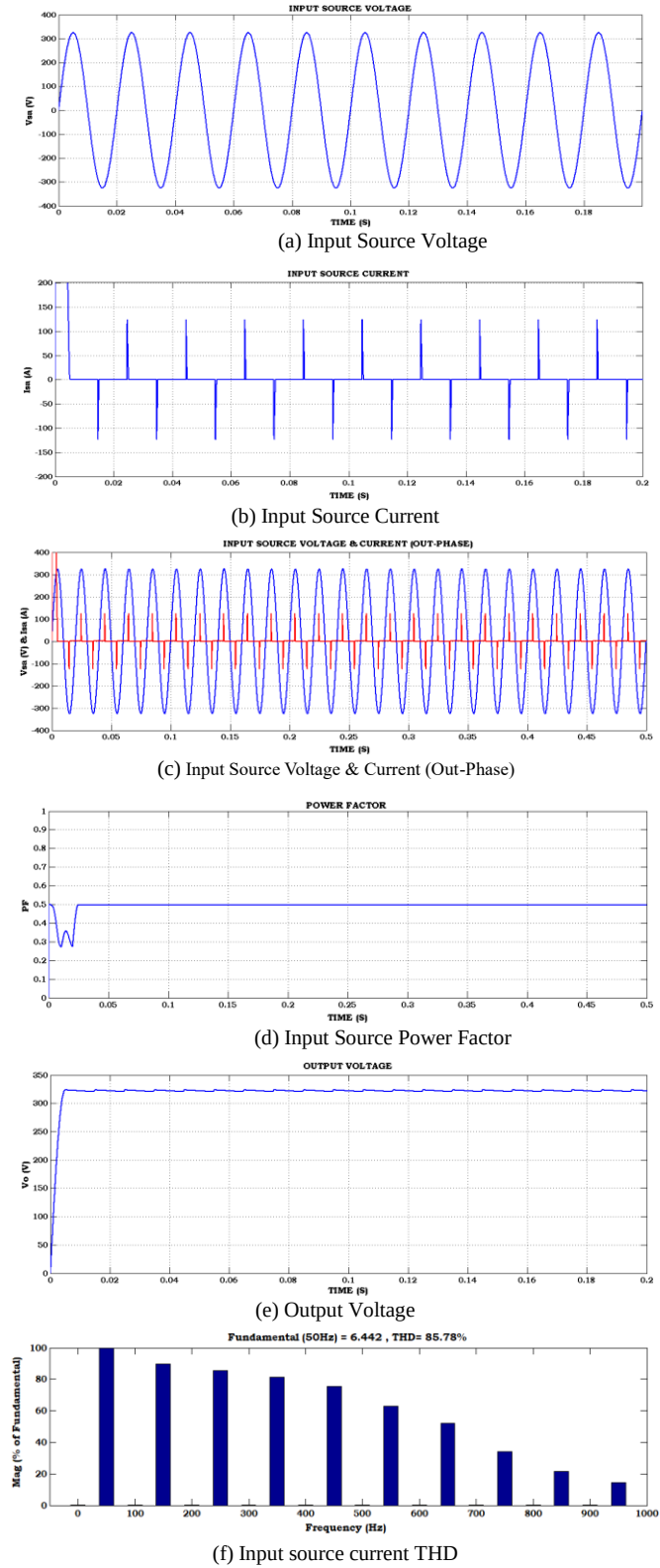


Figure 8. Simulation Results of AC-DC Conversion using Diode-Bridge Rectifier with Load Filter

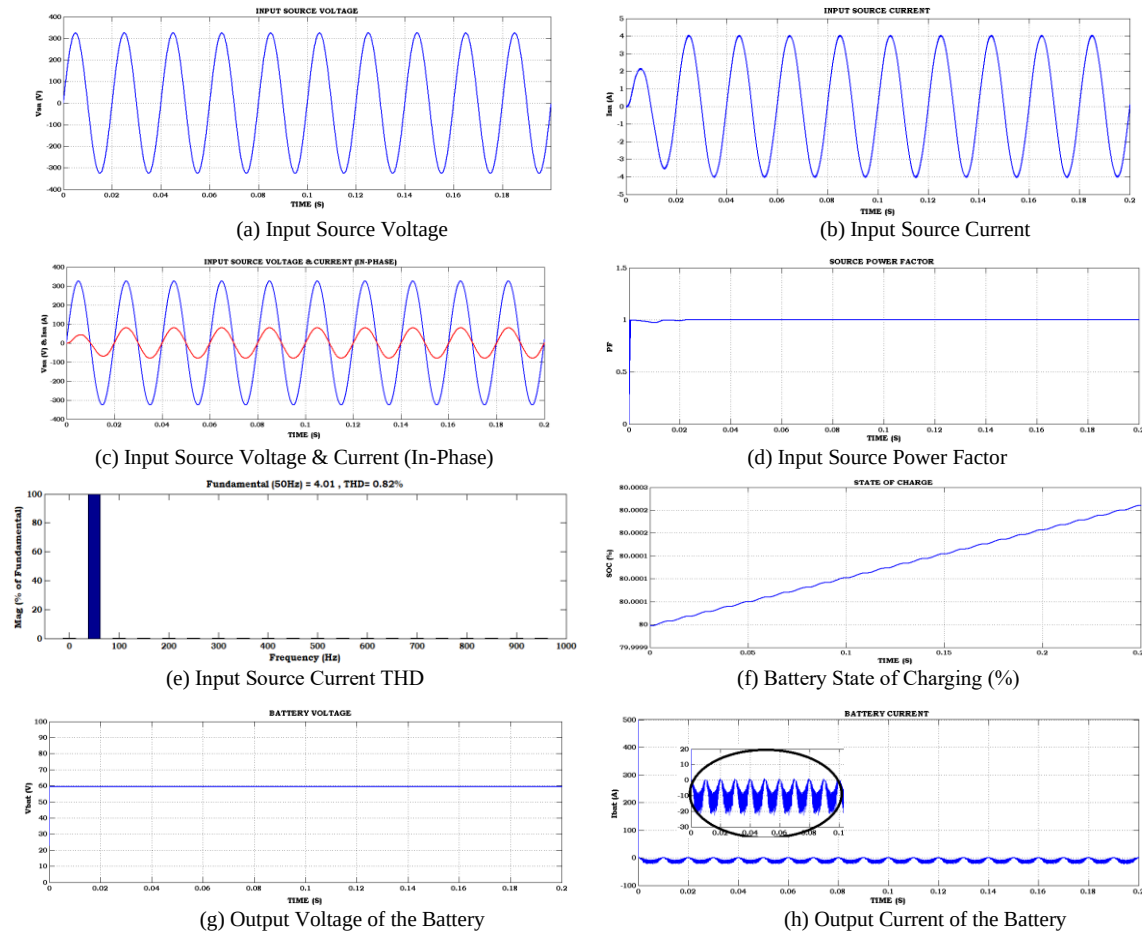


Figure 9. Simulation Results of AC-DC Conversion with Unity-Power Factor using DC-DC Buck Converter for Battery Charging under $V_{ref}=61V$

AC-DC unity power factor charging for 61v battery

The Simulation Results of AC-DC Conversion with Unity-Power Factor using DC-DC Buck Converter for Battery Charging under $V_{ref}=61V$ is depicted in Figure 9. The single-phase AC source is used with a value of 230Vrms and the source current is measured as 4A as shown in Figure 9(a), (b). The diode-bridge rectifier with a DC-DC buck converter converts the AC to constant for charging the battery. In this case, a DC-DC buck converter is connected at intermediate to load, hence the source current is maintained as sinusoidal and in-phase with the source voltage which represents the unity power factor as shown in Figure 9(c), (d). The FFT window of AC input source current is measured with a value of 0.82% which is complying with IEEE-519 standards as shown in Figure 9(e). The state of battery charging (%) (Charging under $V_{ref}=61V$) is close to 80% over the period as shown in Figure 9(f). The battery output voltage is measured

with a value of 61V (full charge condition) and the current is negative -20.1A in magnitude illustrating the battery is in charging mode as shown in Figure 9(g) and (h).

The Simulation Results of AC-DC Conversion with Unity-Power Factor using DC-DC Buck Converter for Battery Charging under $V_{ref}=120V$ are depicted in Figure 10. The single-phase AC source is used with a value of 230Vrms and the source current is measured as 1.4A as shown in Figure 10(a), (b). The diode-bridge rectifier with a DC-DC buck converter converts the AC to constant for charging the battery. In this case, a DC-DC buck converter is connected at intermediate to load, as a result the source current is maintained as sinusoidal and in-phase with the source voltage which represents the unity power factor as shown in Figure 10(c), (d). The FFT window of AC input source current is measured with a value of 0.85% which is complying with IEEE-519 standards as shown in Figure 10(e). The state of battery charging

(%) (Charging under V_{ref} -120V) is close to 80% over the period as shown in Figure 10(f). The battery output voltage is measured with a value of 120V (full charge condition) and the current is negative -2.5A in magnitude illustrating the battery is in charging mode as shown in Figure 10(g) and (h).

The Simulation Results of AC-DC Conversion with Unity-Power Factor using DC-DC Buck Converter for Battery Charging under V_{ref} -200V are depicted in Figure 11. The single-phase AC source is used with a value of 230Vrms and the source current is measured as 5.8A as shown in Figure 11(a), (b). The diode-bridge rectifier with a DC-DC buck converter converts the AC to constant for charging the battery. In this case, a DC-

DC buck converter is connected at intermediate to load that's why the source current is maintained as sinusoidal and in-phase with the source voltage which represents the unity power factor as shown in Figure 11(c), (d). The FFT window of AC input source current is measured with a value of 0.59% which is complying with IEEE-519 standards as shown in Figure 11(e). The state of battery charging (%) (Charging under V_{ref} -200V) is close to 80% over the period as shown in Figure 11(f). The battery output voltage is measured with a value of 200V (full charge condition) and the current is negative -18.5A in magnitude illustrating the battery is in charging mode as shown in Figure 11(g) and (h).

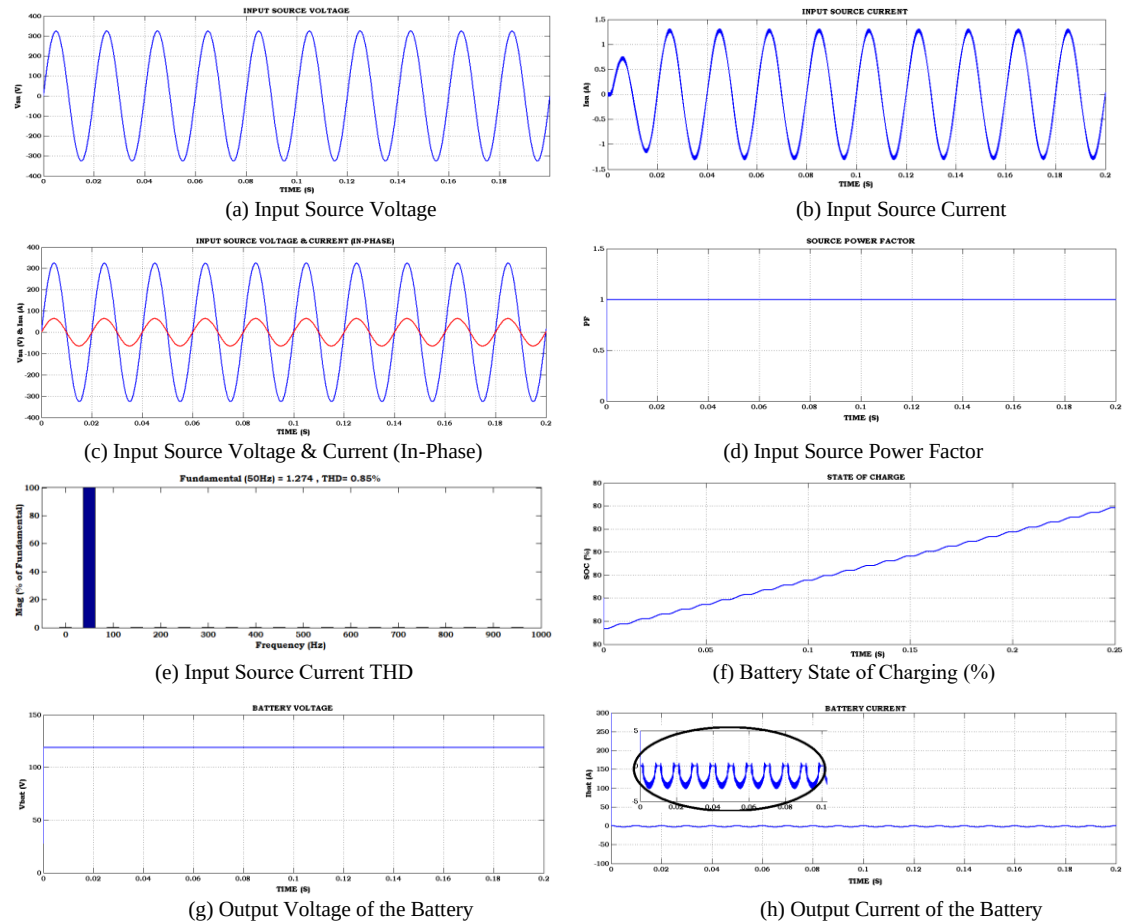


Figure 10. Simulation Results of AC-DC Conversion with Unity-Power Factor using DC-DC Buck Converter for Battery Charging under V_{ref} -120V

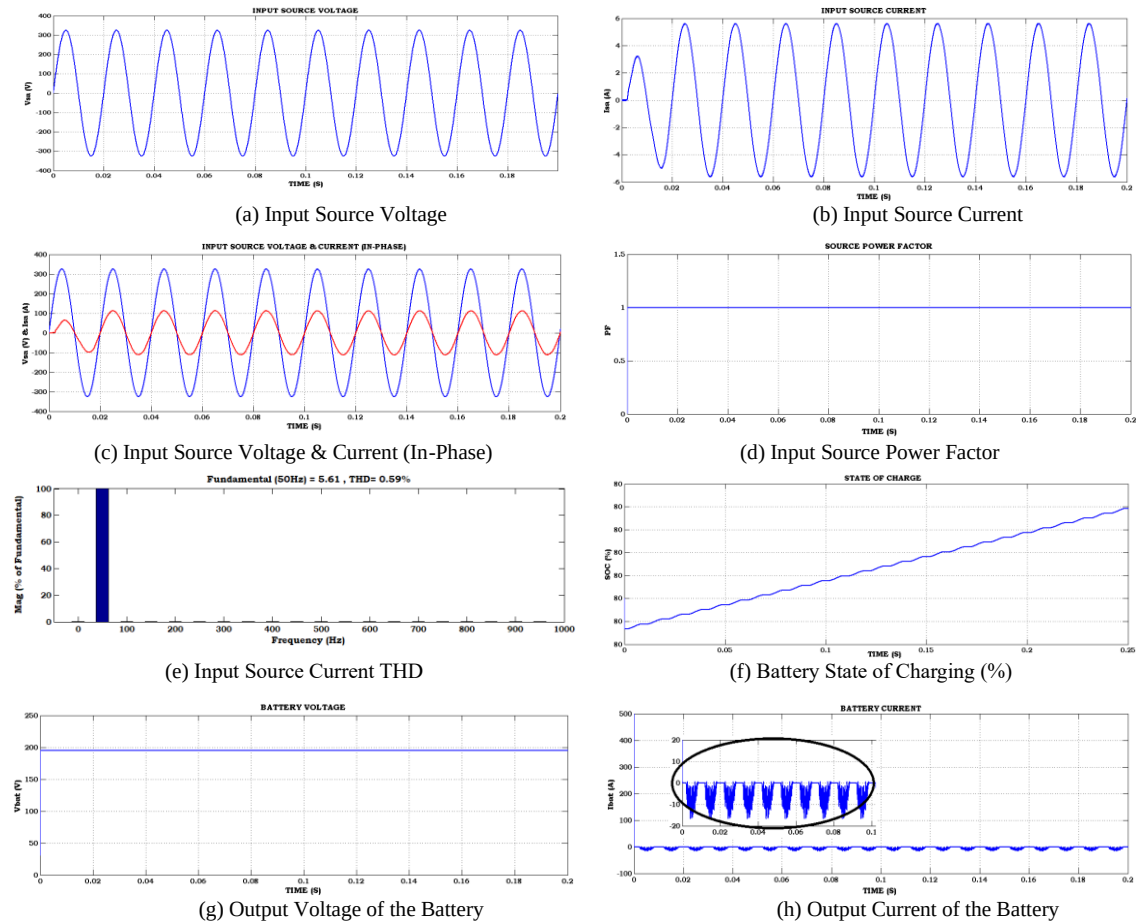


Figure 11. Simulation Results of AC-DC Conversion with Unity-Power Factor using DC-DC Buck Converter for Battery Charging under $V_{ref}=200V$

The Comparison of THD & PF in AC-DC Conversion Using Diode-Bridge Rectifier without and with Load Filter and Proposed DC-DC Buck Converter PFC Topology is illustrated in Table 2. In that, the THD of the source current is 0.38% and the source power factor is measured as 0.998 which is near to the unity power factor in AC-DC conversion without a load filter. But the DC output voltage is attained as pulsated because of uncontrolled switches. The THD of source current is 85.78% and source power-factor is measured as 0.51 which is distorted to unity power-factor in AC-DC conversion with load filter because load filter is connected which injects the harmonics and distorts the source current. The DC output voltage is attained as constant DC voltage because of capacitor filter is connected to the load side of the AC-DC rectifier. The THD of the source current is 0.59% and the source power factor is measured as 0.999 which is near to the unity power factor in AC-DC conversion with the proposed DC-DC buck PFC topology. The DC output voltage is attained as constant DC

voltage because of DC-DC buck converter is connected between the rectifier and the R-load. It converts the pulsating DC to constant DC and also step-down the input voltage to the required load voltage. Compared to classical AC-DC conversion with load filter, the proposed DC-DC buck PFC topology has a low THD value and improved power factor which is near to the unity power factor.

Table 2. Comparison of THD & PF in AC-DC Conversion Using Diode-Bridge Rectifier without and with Load Filter and Proposed DC-DC Buck Converter PFC Topology

Condition	Parameter		
	THD%	PF	DC Output Voltage
AC-DC Conversion without Load Filter	0.38%	0.998	Pulsated
AC-DC Conversion with Load Filter	85.78 %	0.51	Constant
Proposed DC-DC Buck Converter PFC Topology	0.59 %	0.999	Constant

The Comparison of THD & PF in Conventional PWM Rectifier Condition and Proposed DC-DC Buck Converter PFC Topology is illustrated in Table 3. In conventional PWM rectifier circuit is employed for power-factor correction, the THD of the source current is 1.80% and the source power factor is measured as 0.9982 which is near to unity power factor during the selected battery voltage is 61V. The THD of the source current is 1.28% and the source power factor is measured as 0.9985 which is near to the unity power factor during the selected battery voltage is 120V. The THD of the source current is 1.73% and the source power factor is measured as 0.9989 which is near to the unity power factor during the selected battery voltage is 200V. Coming to the proposed DC-DC Buck Converter PFC Topology, the THD of the source current is 0.83% and the source power factor is measured as 0.9991 which is very close to the unity power factor during the selected battery voltage is 61V. The THD of the source current is 0.85% and the source power factor is measured as 0.9994 which is very close to the unity power factor during the selected battery voltage is 120V. The THD of the source current is 0.59% and the source power factor is measured as 0.9999 which is very near to the unity power factor during the selected battery voltage is 200V. The proposed DC-DC buck converter topology has enhanced THD% which is complying with IEEE-519-1992 standards (less than 5%) and power factor compared to conventional PWM rectifier circuitry.

Table 3. Comparison of THD & PF in Conventional PWM Rectifier Condition and Proposed DC-DC Buck Converter PFC Topology

Battery Condition	AC-DC Conversion Techniques			
	PWM Rectifier Lopatkin and Zinoviev, 2021		Proposed Buck PFC	
	THD	PF	THD	PF
61V	1.80 %	0.9982	0.83 %	0.9991
120V	1.28 %	0.9985	0.85 %	0.9994
200V	1.73 %	0.9989	0.59 %	0.9999

Conclusion

Electric vehicles are trending these days replacing conventional gasoline engine vehicles. Gasoline engine vehicles emit green house gases which deteriorate the environmental conditions and leads to global warming which is dangerous for living species. Charging technology and range of performance are the key factors in EV technology. Battery driven EVs takes AC supply and convert them to DC for charging the battery of EV. During this process of conversion for battery charging,

input source current is distorted and goes out of phase with respect to input source voltage diminishing the power factor.

Vehicles using conventional fuels emit a lot of pollution and increases global warming. Electric Vehicles with battery sources run emitting zero pollution. Charging technology and range of performance are the key factors in EV technology. Battery-driven EVs take AC supply and convert them to DC for charging the battery of the EV. Input source current is distorted and goes out of phase with respect to input source voltage diminishing the power factor. This paper addresses the battery charging system of EVs with a unity source power factor. THD in input source current is tabulated and the power factor for three different battery charging conditions is shown which illustrates that the power factor is almost unity on the source side. The AC power after converting to DC is fed to the battery for charging through the Buck converter. The controlled Buck converter improves the input source power factor and charges the battery for the EV.

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