Design and Development of Charging Station for Swappable Batteries of Electric Vehicle

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Abstract.

Petroleum and oil resources across the globe are deteriorating at a high rate due to a significant reliance on it, being a primary source of fuel for automobiles. Electric Vehicles (EVs) are one of the immediate alternatives that have been implemented. Development of EVs is heavily reliant on Battery design, its charging infrastructure, Motor drives and Power Electronics. One of the most important aspects is the charging station infrastructure and its design that should accommodate the changing scenario, and the same is discussed in this paper. The designed charging system is an AC charging system consisting of a two-stage converter which provides a regulated DC Voltage supply to the swappable EV Battery. The designed system consists of a single-phase diode bridge rectifier, a boost converter and a buck converter. The boost converter is mainly used to incorporate Active power factor correction in the circuit. The proposed work involves a current controller for Power factor correction.

Keywords. Electric vehicle, Charging stations, swappable battery, active power factor correction, uncontrolled rectifier.

1. INTRODUCTION

Electric cars are growing more appealing every year in comparison to automobiles with Internal Combustion Engines (ICE) due to a number of advantages namely less pollution, lower transportation costs and less petroleum consumption.[1] Manufacturers and researchers have paid close attention to the development of electric vehicles (EV), which relies on the development of charging stations with higher efficiency and improved power factor [1].

In many applications, fast-charging stations have two conversion stages: an input AC to DC rectifier and an output DC to DC converter. The DC-to-DC converter regulates the Charging Station's (CS) output voltage and current [1]. The battery receives this regulated output voltage via a relay, which disconnects the battery from the main supply when it is fully charged.

A swappable battery charging station was proposed to solve the problem of charging time and the urgent need to charge a vehicle. A vehicle's discharged battery or battery pack can be immediately swapped for a fully charged one, eliminating the time spent in waiting for the vehicle's battery to charge. [2]

When it comes to establishing a swappable battery charging station, there are a number of obstacles to overcome. One of the primary challenges that may be overcome is the design of a battery pack in such a way that it can be simply and quickly detached from cars and reattached in a short amount of time. Another issue is the battery packs' brand compatibility. [2]

Electric vehicle batteries can be charged using either a single phase or three phase power supply. EV chargers are linked to this system due to the widespread availability of single-phase supply outlets.

These EV chargers behave like non-linear loads due to the presence of power electronic converters. An EV charger's nonlinear feature might cause harmonics in the current and influence the system's voltage profile. Non-linear voltage loss can be caused by high non-linear loads, resulting in distorted voltage waveforms.[3]

In this paper, the EV battery charging station with power factor correction was designed, simulated, and described. Plecs, a software tool for system-level simulations of electrical circuits developed by Plexim, was used to simulate the EV charger. It is specifically built for modeling of Power electronic circuits but can be employed for any other electrical circuit applications.

2. CHARGING STATION DESIGN DETAILS

The block diagram of the proposed EV Battery charging station is shown in Fig 1.1

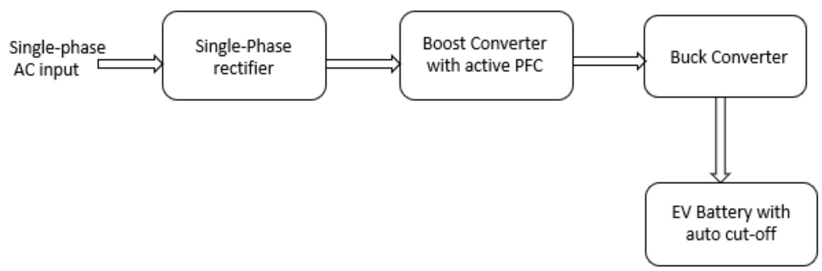

Fig.1.1 Block diagram of the charging system

The requirements for the proposed charging station design are shown in Table 1.

TABLE 1 - Requirements

Sl.No	Parameters	Values
1.	Input Voltage	220V AC
2.	Output Voltage	54.6V DC
3.	Output Current	6A
4.	Battery specifications	48V, 24Ah Li-ion Battery suitable for an e-bike
5.	Other requirements	Battery Protection circuit, heat sinks

The proposed EV Battery Charging Station consists of four stages as shown in Fig. 1 namely
1. Rectification
2. Power factor Correction using Boost Converter

3. Higher to lower voltage conversion using DC-DC Buck Converter
4. Auto cutoff using a Relay

The Rectification is accomplished by a single phase uncontrolled full wave rectifier which produces a pulsating output waveform having an average value given by the equation (2.1) below.[8]

$$Vavg = 2*Vmax/\pi = 0.637*Vmax \qquad (2.1)$$

where,

Vavg= Output Voltage of rectifier

Vmax= Peak of input AC Voltage

In this work, a single-phase supply of 220V having an amplitude of 311.12V is connected in series with an inductor of 100 uH. It is meant for current smoothing and the output has been fed to the uncontrolled full wave rectifier for conversion of AC to DC Voltage.

The relative phase difference between the voltage and current signals fed to a load is known as Power factor. The phase difference should be kept to a minimum so that the maximum amount of power delivered to the load is usable power which is nothing but real power. The block diagram showing the Power Factor Correction mechanism is shown in Fig 2.1 The Boost converter Inductor Current and rectifier output voltage is sensed using a sense resistor. The voltage is given a gain and the output of it is multiplied with reference Inductor current. The current controller compares this with the actual inductor current, and the controller output is fed to the boost converter switch, which switches such that the current drawn by the inductor and the rectified DC voltage are in phase with each other.

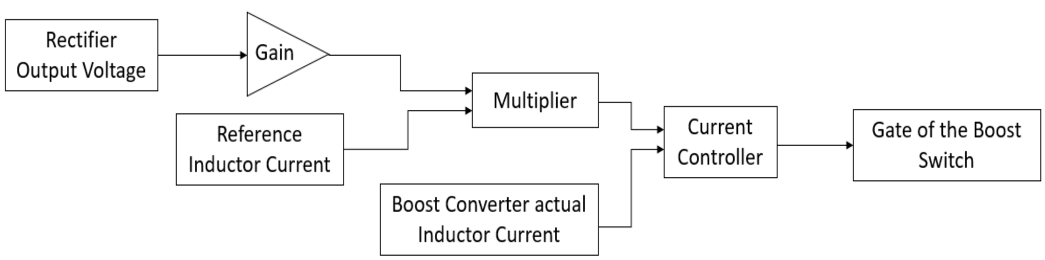

Fig. 2.1 Block diagram of Power Factor Correction mechanism

The output of the Power factor correction boost Converter is connected through a filter capacitor to a buck converter which is used to step down the voltage to 54.6V required for the Battery. The switching frequency of the buck MOSFET Switch is set as 500 kHz. The load is a resistor across which the output voltage and current has been measured. All the semiconductor switches used in the circuit have been provided with heat sinks to make sure the switches operate at optimal temperature conditions.

The design equations for the proposed buck converter are as follows: [9]

$$\text{Duty cycle } D = Vout/Vin \qquad (2.2)$$

Where, Vout = Output Voltage

Vin = Input Voltage

$\Delta IL = 5\%$ of Iout (2.3)

Where, Iout = Output Current

ΔIL = Inductor current ripple

$L = (Vout*(1-D))/(Fsw*\Delta IL)$ (2.4)

Where, L = Inductance

Vout = Output Voltage

D = Duty Cycle

Fsw = Switching Frequency

TABLE 2 - Specifications of Buck Converter

Sl No.	Parameter	Value
1	Input Voltage (Vin)	690V
2	Output Voltage (Vout)	54.6V
3	Output Current (Iout)	6A
4	Switching Frequency (Fsw)	500 kHz
5	Inductor Current Ripple (ΔIL)	5% of Iout=0.3A
6	Duty Cycle (D)	0.08
7	Inductor(L)	334μH

To limit the input voltage to the load, the relay is used for auto cut-off of the battery. The relay will be in on state if the input signal surpasses the upper threshold and if the input falls below the lower threshold, it will be in off-state. Input levels between the thresholds have no effect on the relay.

3. SIMULATION MODEL

The simulation model of the charging station developed using Plecs Software is shown in Fig 3.1

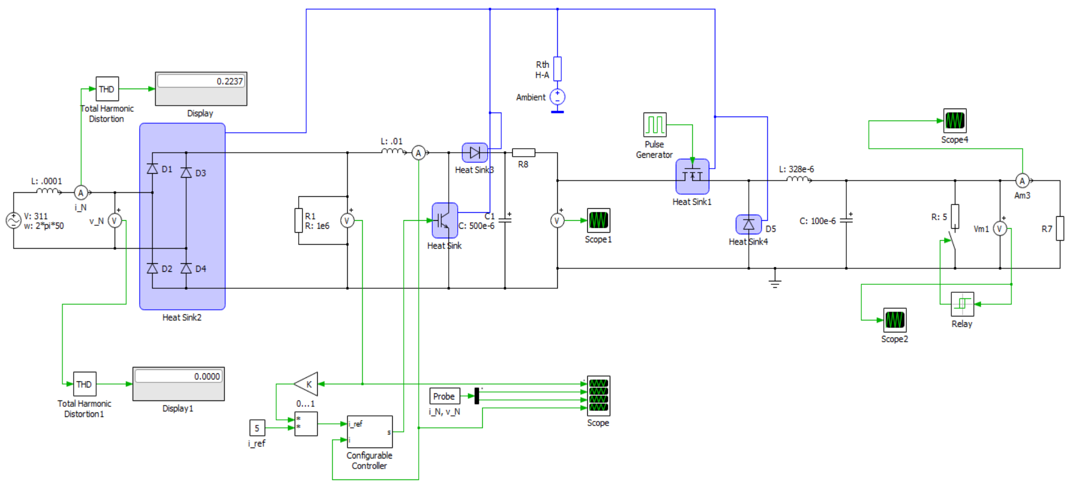

Fig 3.1 Simulation Model of the proposed charging station in Plecs

In the simulation model, the single phase 220V RMS AC Supply is given as input to the single-phase diode rectifier. The output of the rectifier is connected to a Power factor correction boost converter whose IGBT switch is controlled by a Configurable Controller. The output of PFC Boost Converter is connected to a buck converter which steps down the voltage as per the battery voltage and current requirement. The output of the boost converter is connected to the relay which cuts off the battery from the supply when the battery is fully charged. In the simulation, a load resistance is connected instead of a battery to validate the designed system and the working of the current controller.

The Simulation model of the current controller is shown in Fig 3.2

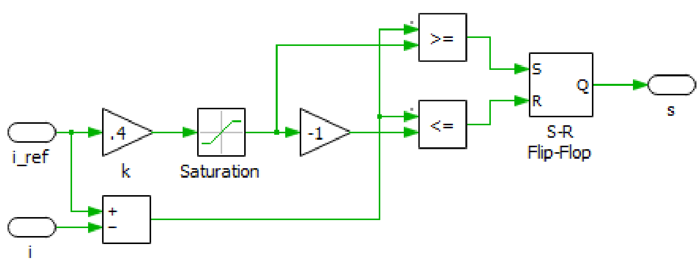

Fig 3.2 Configurable controller scheme

The output of the configurable controller is used to drive the IGBT of the Boost Converter for achieving power factor correction. The inductor current in the boost converter is compared with a reference current and given to the SR Flip Flop. The state of the SR Flip Flop is decided by the error in the inductor current compared to reference current. The output of the SR Flip Flop is given to the IGBT switch of the PFC Boost Converter of the proposed charging station.

4. RESULTS

The input and output waveforms of the single-phase diode bridge rectifier without power factor correction is shown in Fig.5.1 The mains current and voltage refer to input AC supply which are not in phase with each other which leads to non-unity power factor. Also, it can be observed that the mains current waveform is peaky in nature and not sinusoidal.

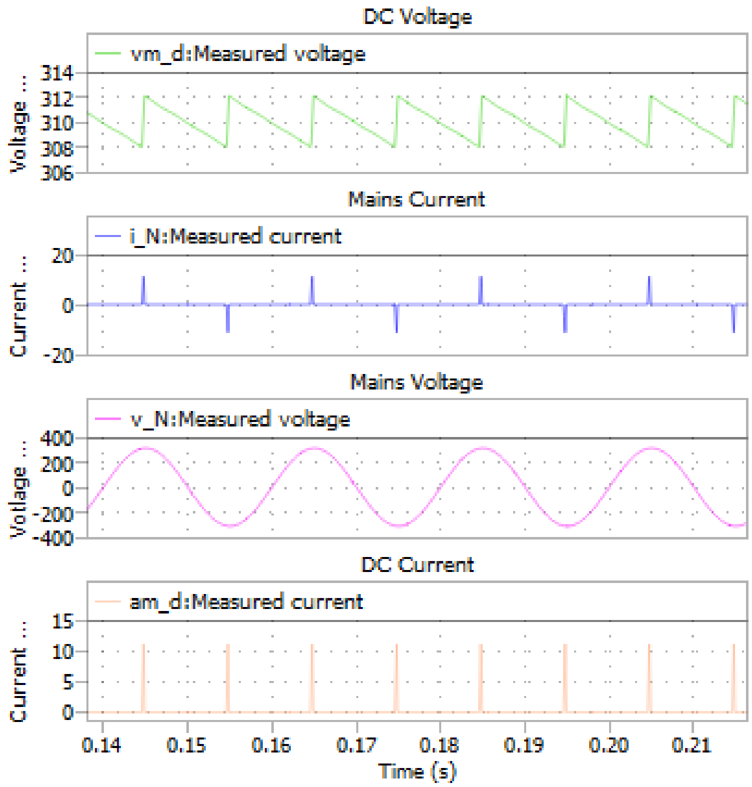

Fig.5.1 Measured voltages and currents without PFC

The input and output waveforms of the single-phase diode bridge rectifier with power factor correction as explained in the previous sections is shown in Fig.5.2 It can be observed that the mains voltage and current are in phase with each other and the mains current waveform is sinusoidal.

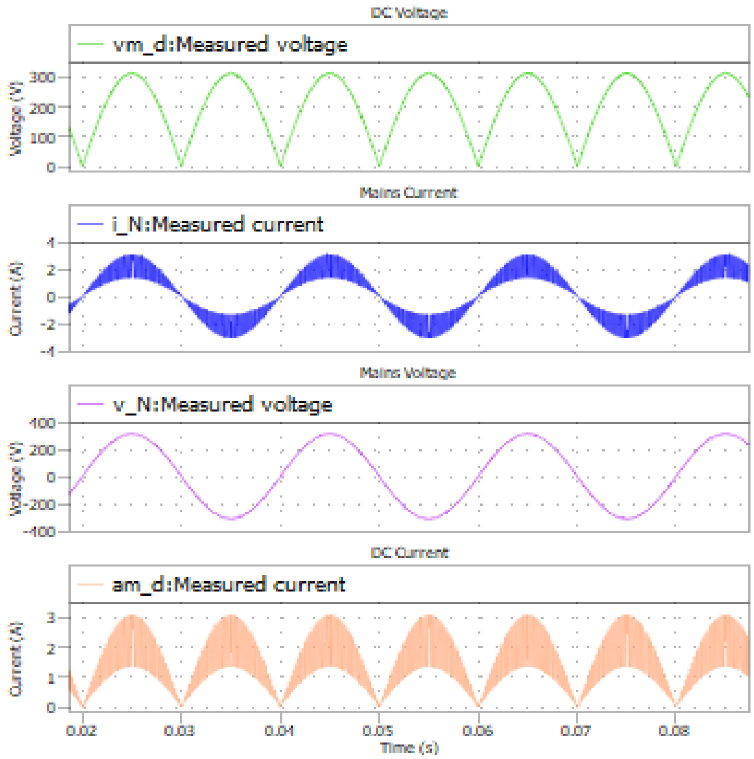

Fig.5.2 Measured voltages and currents with Active PFC

The output voltage waveform of the PFC Boost Converter is shown in Fig.5.3 It can be observed that the voltage has been rectified and has been boosted depending on the gate pulses given by the current controller to the IGBT Switch of the Boost Converter.

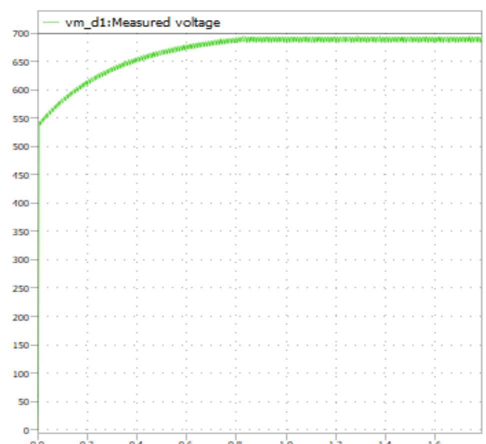

Fig.5.3 Measured voltage after boost converter and PFC

The output voltage and current waveforms of the buck converter is shown in Fig.5.4 and Fig.5.5 This steady DC voltage is fed as input to the EV Battery through a relay which is meant for auto cut-off. The duty ratio of the Buck converter switch was fixed based on the output voltage requirement and input voltage fed.

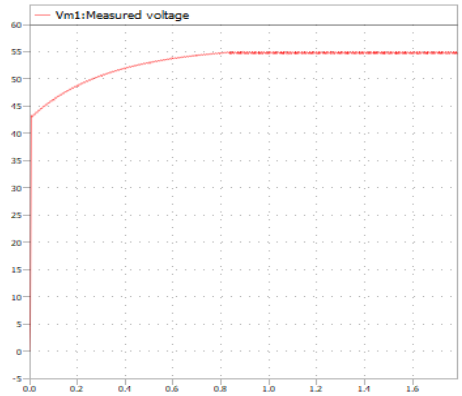

Fig.5.4 Measured voltage across the load

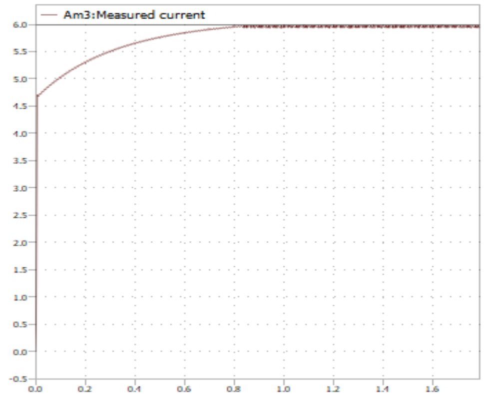

Fig.5.5 Measured current through the load

5. CONCLUSION

In this paper, the design of a charging station for EV swappable batteries is described. It was designed considering the requirements of the swappable Li ion battery for an e-bike. The proposed circuit design is simulated and verified using an open-source software called Plecs. The working of the current controller for Power Factor Correction and the designed system was validated by connecting a resistive load in the simulation. The results obtained from the simulation clearly shows that the incorporation of the Power factor Correction circuit reduces the amount of Reactive Power drawn from the AC Supply thereby reducing the Power losses and increasing the Power factor of the system. Hence the Power Factor Correction plays an important role in increasing the overall efficiency of the EV Charging Station.

6. ACKNOWLEDGMENT

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7. REFERENCES

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Biographies

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