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Solar PV Charging Station for Electric Vehicles

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***Abstract*—Of late, electric vehicles (EVs) have attracted much attention owing to their use of clean energy. Large progress in lithium-ion battery has propelled the development of EVs.However, the challenge is that growing number of EVs leads to huge demand in electric power, which will aggravate the power grid load. This leads to an exploration for alternative and clean sources of energy to charge EVs. This project implements solar energy system to erect a charging station for EV application. The charging station employs multi-port charging by providing a constant voltage DC bus. The charging controllers are operated based on the concept of power balance, and constant current/constant voltage charging. Performance of the charging system is validated with simulation and experimental results.**

Keywords— Electric Vehicles, Solar Power, Charging station, DC-DC converters, MPPT, CCCV battery Charging

I. INTRODUCTION

It is estimated that by 2022, EVs will be over 35 million in the World. The Indian government has set ambitious targets to accelerate the adoption of electric vehicles (EVs) due to potential of Electric Vehicles to reduce pollution along with many other advantages like high torque, easy speed control, and higher efficiency compared to the conventional ICEs. However, if all IC engines were to be replaced by EVs at large, then their high penetration causes heavy electricity demand to the power grid and the electric grid will collapse not being able to withstand the load demand[12, 13].

In case of India-like countries, the main sources of electricity are fossil fuels. Currently (as of March 2020), 62.8 % of total electricity of the country is being powered fossil fuel-based (coal, lignite, gas diesel) plants. Adding to this, the transmission and distribution losses in the country on an average is around 22%, and in states such as Assam is as high as 38.2%[20, 21].However, with Demand increasing exponentially and the availability of fossil fuels decreasing at two-fold rate, the gap between the resource and the demand is widening at an alarming rate.One efficient approach to relieve the effect is to integrate local power generation such as RESs[18] into the EV charging infrastructure[16, 17]. Renewable energy installations such as solar energy panels generate zero emissions in their generation of electricity. If taken advantage of it to its maximum extent, sunlight focused on the earth for 1 hour could meet energy demands of the whole earth for an entire year [22].

The system implemented in this paper incorporates a PV panel fed through boost converter and MPPT algorithm, bi-directional converter, buck converters and a BESS. While the energy generated by solar PV panel, during low solar irradiance conditions, is insufficient to meet the power demanded by the Electric Vehicle battery. Then BESS meets the required power demand. On the other hand, while the solar power generation is greater than the demand, the BESS stores the excess solar energy. Later, the system has been implemented in MATLAB/ Simulink to verify the system performance. The design, and performance analysis of the proposed system using experimental studies are discussed in further sections of the paper**.**

II. SOLAR PV CHARGING STATION

The main objective of this paper is to design and model a solar charging station for Electric vehicles. The paper also aims to develop a suitable switching strategy for the control of solar charging station and to test the effectiveness of the system under different operating conditions usingMATLAB / Simulink tool. The charging station will implement MPPT algorithm[8,9]to trap maximum solar power at any instant and executes fast charging control methods to charge EV batteries.

The proposed system includes PV array with boost converter, station back-up battery with a bidirectionalconverter and buck converters at the charging ports for EV battery charging. The bidirectional converter has been used for charging/discharging of the BESS.

Figure 1 shows the block diagram of the proposed system. The boost converter uses MPPT algorithm and extract maximum solar power at all instants. The bidirectional converter helps in charging and discharging of the station battery depending on source - load power balance in addition to maintaining a constant 48 V bus at its higher voltage terminals. The buck converters step down the 48V to 36 V and charge at most 3 EV batteries. The fast charging method used here implements CCCV charging based on the SoC of the EV battery.

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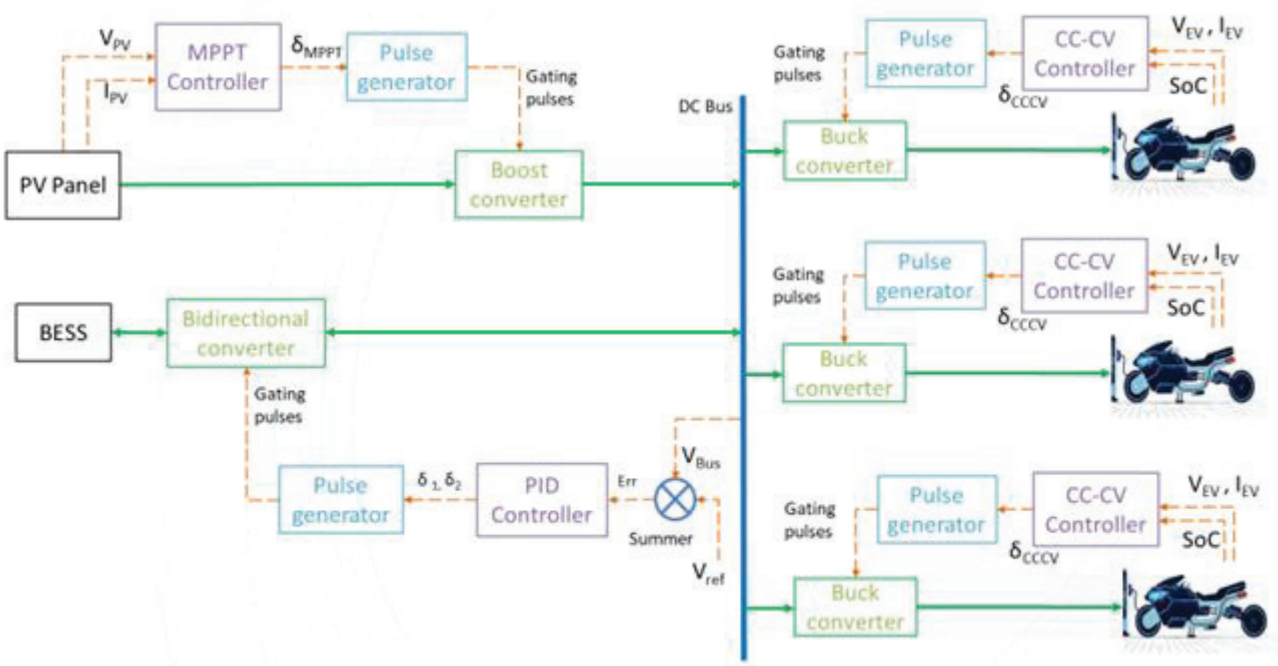

Fig. 1. Overall Block Diagram of the EV charging station system

III. Design of Solar Ev Charging Station

The charging station is to be installed in a workplace and the charging duration is assumed to be 8 hours. Of these 8 hours, the PV panel is assumed to supply power for 6 hours and the station battery for 2 hours. The following designs are done based on the above-mentioned assumptions.

A. *Selection of Station Battery and Solar Panel*

Assume PV panel charges the EV battery for 6 hours and station battery charges it for maximum of 2 hours in the absence of Solar Energy.

Energy required by the EV battery,

$$E_{EV} = 36 \text{ x } 12 \text{ x } 3 = 1296 \text{ Wh} \tag{1}$$

Considering parking for 8 hours, the power required by the battery

$$P_{EV} = \frac{1296}{8} = 162 \text{ W} \tag{2}$$

For battery selection,

- Assuming DoD of battery to be 50%, and battery efficiency as 80%, and
- Considering converter efficiency to be 90%,

Energy supplied by the battery

$$E_{bat} = \frac{(162 \text{ x } 2)}{(0.9 \text{ x } 0.9 \text{ x } 0.8)} = 500 \text{ Wh} \tag{3}$$

Considering a 36 V battery,

$$\text{The Ah rating of battery} = \frac{500}{36 \text{ x } DoD} = 27.77 \text{ Ah} \tag{4}$$

So, a 36 V, 28 Ah, lead-acid battery is chosen as station battery.

Energy to be supplied by the panel

$$E_{PV} = 500 + \frac{162 \text{ x } 6}{0.9} = 1580 \text{ Wh} \tag{5}$$

Average global horizontal irradiance is 5.52 kWh/m^2/day

Power supplied from the solar panel

$$P_{PV} = \frac{1580}{5.52} = 286.23 \text{ W}_p \tag{6}$$

So, two 180 W solar panels are connected in parallel

B. *Boost Converter Design].(All citations are not superscripts.*

Switching frequency f = 20 kHz.[19]

Maximum operating power of converter = 360 W

MPP operating voltages = 16 – 24 V[15]

$$D_{min} = 0.5,\ D_{max} = 0.667 \tag{7}$$

Considering current ripple $\Delta i_L = 0.1$A, [19]

$$L^{[19]} = \frac{DVo}{f\Delta iL} = 12 \text{ mH} - 16 \text{ mH} \tag{8}$$

$$I_{out} = \frac{(0.9 \text{ x } 360)}{48} = 6.75 \text{ A} \tag{9}$$

Considering voltage ripple $\Delta V_o = 0.5$ V [19]

$$C^{[19]} = \frac{D\,I\,out}{f\,\Delta Vo} = 450.2\ \mu\text{F}. \tag{10}$$

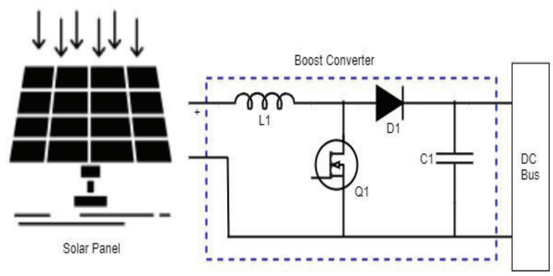

Fig. 2. Boost converter between the PV panel and the DC bus

C. *Bidirectional Converter Design*

Buck Side Design:

Switching frequency f= 20 kHz.[19]

$I_{pv,\,max} = 8.07$ A, $V_{pv,\,max} = 41.5$ V [15]

V_o =36 V

Duty ratio (D) $=\frac{36}{48} = 0.75$ (11)

Considering voltage ripple $\frac{\Delta Vo}{Vo}$= 0.05 (5%), and current ripple Δi_L =0.1A [19]

$$L^{[19]} = \frac{Vo(1-D)}{f\Delta iL} = 6\text{mH} \quad (12)$$

$$C^{[19]} = \frac{1-D}{8L\left(\frac{\Delta Vo}{Vo}\right)f^2} = 0.26\ \mu\text{F} \quad (13)$$

Boost Side Design:

Switching freq f= 20 kHz

Voltage ripple =0.1V, current ripple =0.1A [19]

$I_{pv,\,max}$ = 8.07 A, $V_{pv,\,max}$ = 41.5 V [15]

V_o= 48 V

Duty ratio (D) $= 1 - \frac{36}{48} = 0.25$ (14)

Considering voltage ripple $\frac{\Delta Vo}{Vo}$= 0.05 (5%), and current ripple ΔiL =0.1A [19]

$$L\,[19] = \frac{D\ Vbus}{f\ \Delta iL} = 6\text{ mH} \quad (15)$$

$$C\,[19] = \frac{Io\ D}{f\ \Delta Vo} = 0.26\mu\text{F} \quad (16)$$

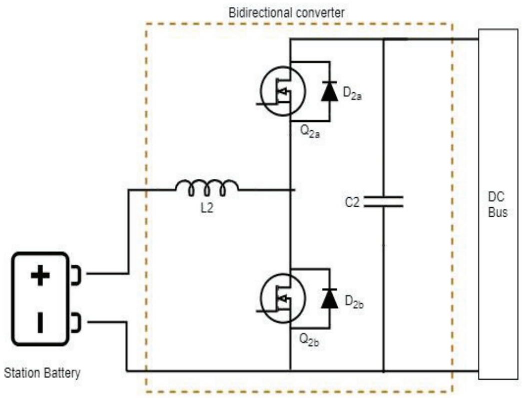

Fig. 3. Bidirectional converter for charging

D. *Buck Converter Design*

Switching freq f= 20 kHz.[20]

$I_{pv,\,max}$ = 8.07 A, $V_{pv,\,max}$ = 41.5 V [15]

$V_o = V_{EV}$ = 36 V

Duty ratio (D) $= \frac{36}{48} = 0.75$ (17)

Considering voltage ripple $\frac{\Delta Vo}{Vo}$= 0.05 (5%) [19], and current ripple Δi_L =0.1A[19]

$$L^{[19]} = \frac{Vo(1-D)}{f\Delta iL} = 4.5\text{mH} \quad (18)$$

$$C^{[19]} = \frac{1-D}{8L\left(\frac{\Delta Vo}{Vo}\right)f^2} = 0.363\mu\text{F} \quad (19)$$

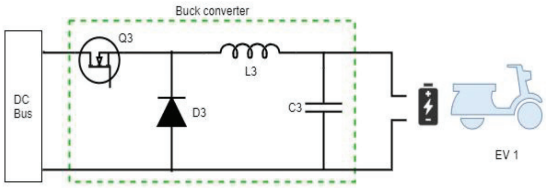

Fig. 4. Buck converter for charging EVs from the DC bus

Figure 2,3 and 4 represents Boost converter, Bidirectional converter and Buck converter respectively.

IV. Control Algorithms

A. *MPPT Algorithm*

MPPT is an algorithm that forces the point of operation of the panel to be at the MPP. Perturb &Observe algorithm, which is the most-commonly used MPPT algorithm, uses a simple feedback arrangement and a few measured parameters (specifically V and I of PV panel).

B. *CCCV control algorithm*

Constant current / constant voltage (CCCV) is a combination of CC (constant current) charging and CV (constant Voltage) charging. The charger limits the amount of current to a reference level until the battery reaches a value of SoC. The charging current then decreases as the battery becomes fully charged. This system allows fast charging without the risk of over-charging and is widely used in EV charging.

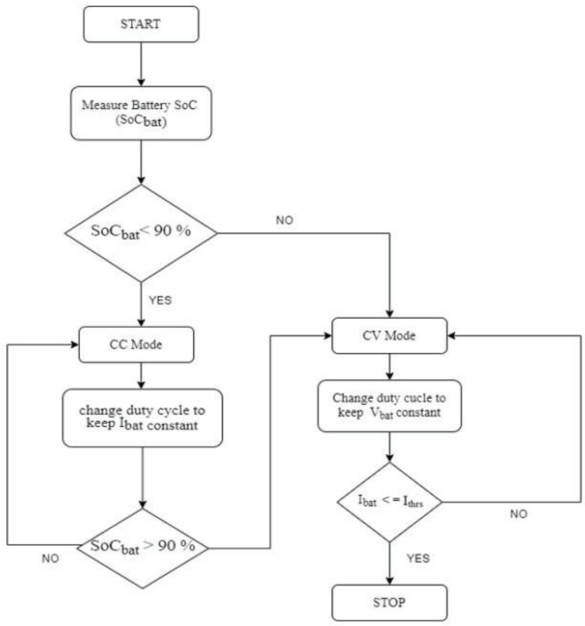

Fig. 5. CCCV charging control – Flowchart

The battery normally charges with a constant current which is approximately 20 % of the battery capacity. If the battery reaches a SoC greater than 90% then it goes to CV mode of charging and in this mode, the change in duty maintains the battery voltage constant. The methodology is as depicted in Figure 5.

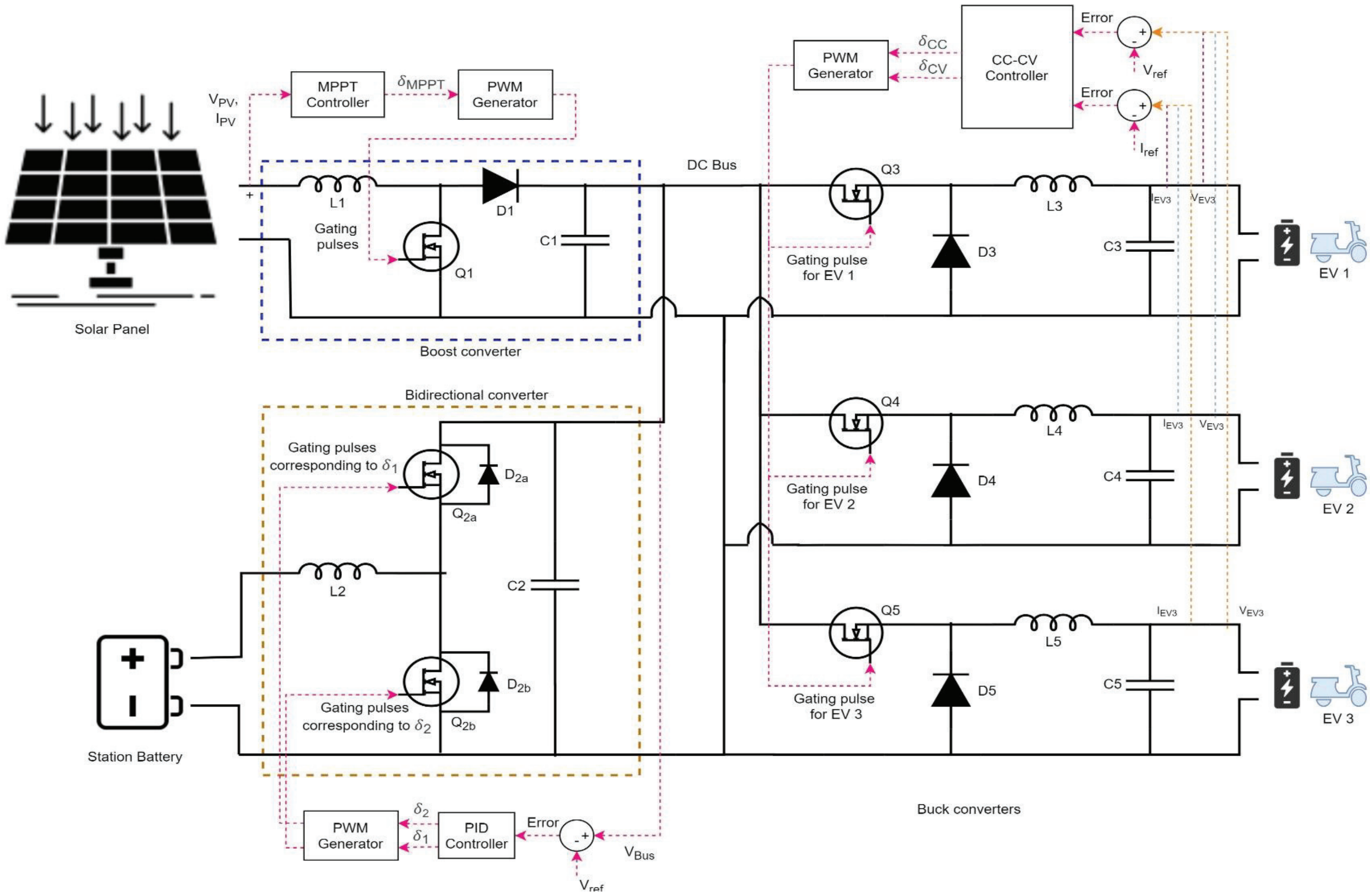

Fig. 6. Overall Schematic diagram with all component specifications and control mechanisms

V. Simulation Results

The proposed Solar Charging Staion can charge upto three E-Bikes of capacity 36V, 12Ah. A constant DC Bus is maintained with a voltage of 48V. Station Battery is connected through a Bidirectional converter, which decides mode of operaion of Station Battery i.e either charging or discharging based on solar power supplied at that instant.

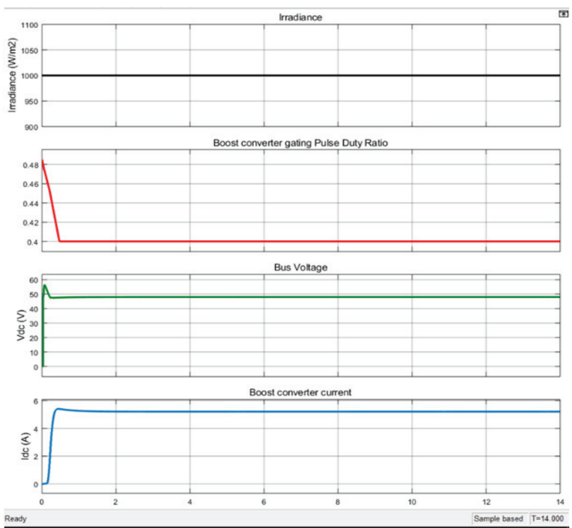

Fig. 7. Boost converter Outputs for constant irradiance of 1000 W/m^2 on the solar panel

Figure 7 shows output parameters of the boost converter fed from the PV panel at 1000 W/m^2 irradiance. The bus voltage is maintained constant by the PID controller of the bidirectional converter.

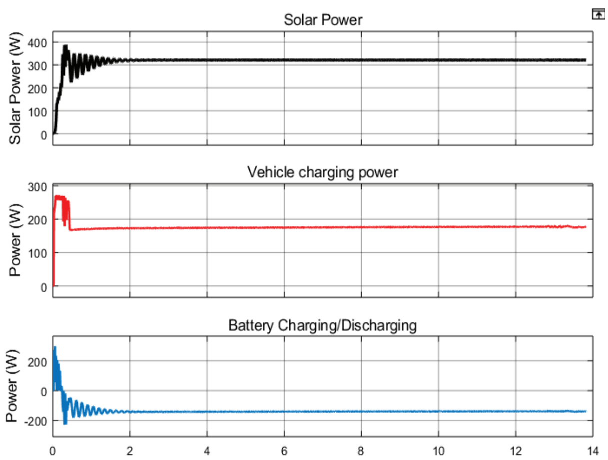

Fig. 8. Station battery behaviour at higher irradiance (1000 W/m^2)

Figure 8 shows the power balance in the system. When three vehicles were charging from the station, the station battery was discharging power. When one of the batteries entered CV mode, the power consumed by that battery became minimum and hence a drop in total Vehicle power is observed. It is then that the station battery begins charging, as seen in Figure 8.

Figure 9 shows the charging of station battery due to excess power available from solar panel. The SoC of the battery is seen to rise gradually when it charges.

Hence, it can be concluded that the station battery

1. Discharges when the PV power is lower than that required by the vehicles charging
2. Charges when the Solar power exceeds that required by the vehicles
3. Maintains a constant DC bus across the ends of the boost converter.

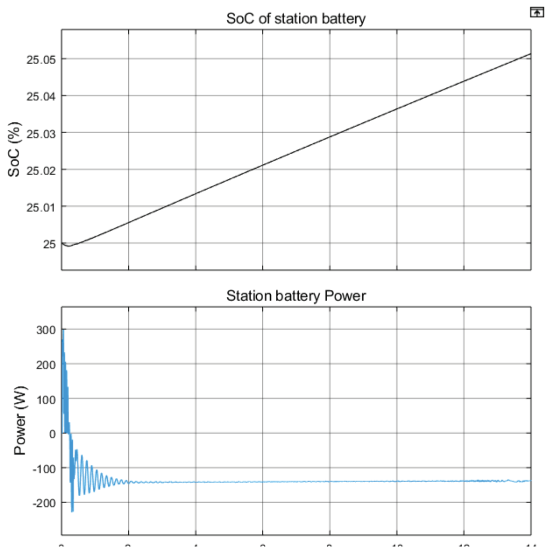

Fig. 9. Station battery charging/ discharging

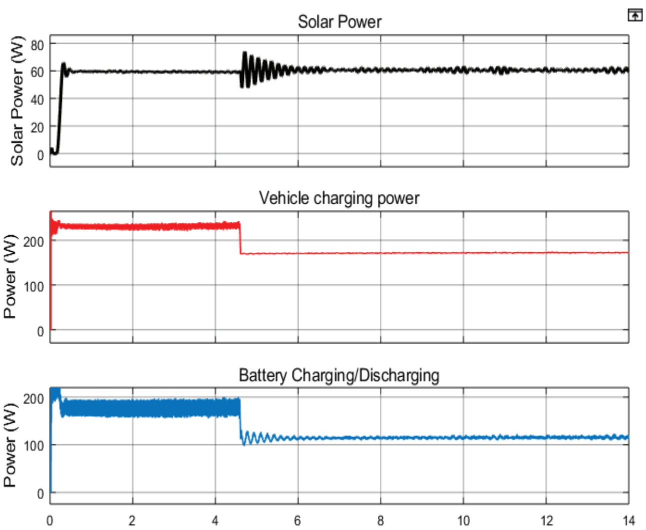

Fig. 10. Station battery behavior under low irradiance(200 W/m^2)

Figure 10 shows the behaviour of station battery under lower value of solar irradiance (around 200 W/m^2).When the solar irradiance is less, the EV batteries are charged up by the station battery.These backup batteries discharge power to EV batteries. The SoC of three EV batteries EV-1, EV-2, EV-3 are set to 90%, 50% and 20% respectively.

As EV-1 has a higher SoC, it changes to CV mode of charging in some amount of time nearly 4 seconds, the current drawn is very less and hence the vehicle charging power reduces to 2/3 times of the initial power.

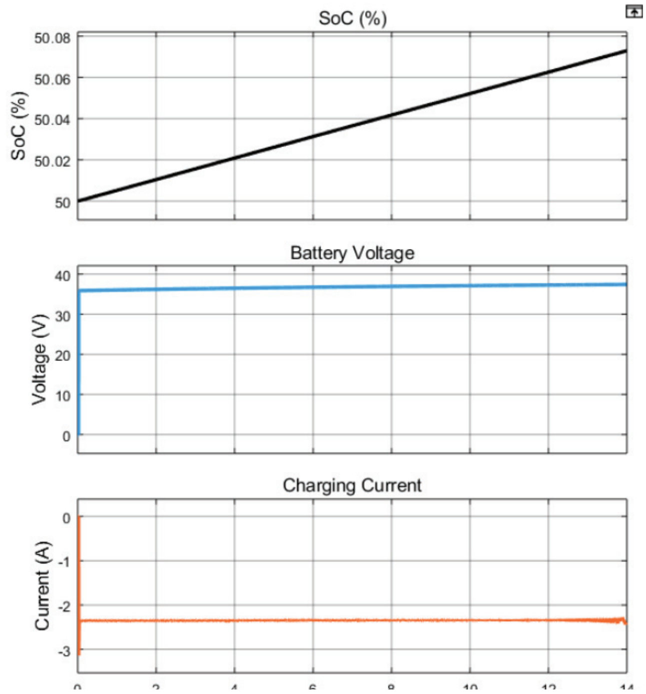

Fig. 11. Battery Characteristics @ SoC=50%

Batteries are connected to the DC Bus (48 V) through Buck converters. CCCV mode of charging is implemented in buck converters through PI Controller based on SoC of Vehicle battery. The capacity of the vehicle battery is 36V, 12Ah.

Figure 11 shows CC charging as observed in EV2 with battery SoC of 50 % initially. Gradual rise in SoC is seen.

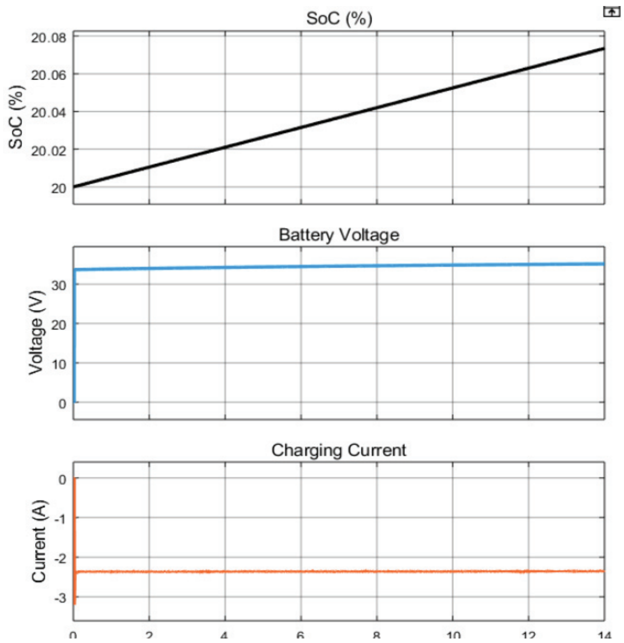

Fig. 12. Battery Characteristics @ SoC=20%

From Figures 11 and 12, it can be observed that charging current is constant, at 2.5 A. The voltages however increase with time and so do the SoCs of the batteries.

It is to be noted that the rate of increase in SoCs and the Voltages is the same for both batteries since the same magnitude of current charges both the batteries.

Figure 13 shows a battery with a 90 % SoC connected to the station. Initially the battery had an SoC of 89.998 %. As CC charging took place, and the SoC quickly crossed 90 %, the transition from CC to CV mode occurs at SoC = 90 %. Since the SoC > 90 % afterwards, CV charging takes place. It is seen that a very low current flows through the battery while it charges at a constant voltage of 39.2 V. The rate of change of SoC is much lesser than that observed with CC charging. CV charging when the battery is almost full ensures the safety of the battery i.e., prevents high currents from flowing through the battery when battery is nearing full charge, which may damage the battery.

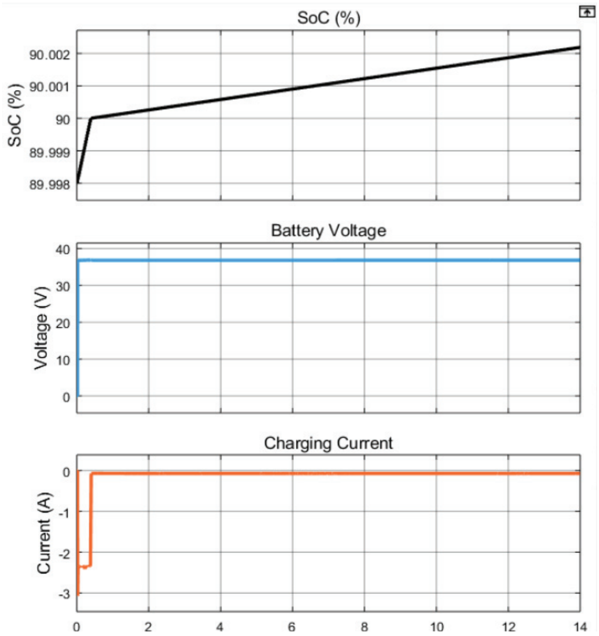

Fig. 13. Battery Characteristics @ SoC= 90 %

VI. Laboratory Implementation

A portion of the analyses conducted in simulationis implemented in hardware which shows a buck converter charging a battery from solar panel using CCCV charging.

Block diagram of the experimental system is shown in Figure 14.

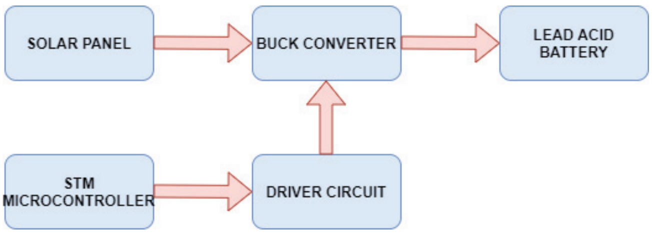

Fig. 14. Block Diagram of the Experimental system

The solar panel is connected through buck converter to lead acid battery. The buck Converter consists of a MOSFET (IRFP460), inductor and the MOSFET (IRFP460) used as a diode by shorting the source and drain. The buck converter is operated based on Constant Current Constant Voltage Charging. The CCCV Charging controller is implemented with the help of STM Controller. Initially when the SoC of battery is less than 90%, the system uses CC method. This is a fast charging mode and majority of the capacity of the battery is charged using CC mode. Here, the current is maintained constant at 1.4 A, rated by the manufacturer.A gating pulse of 5kHz, is given by the STM324F407 Board forthe operation of buck converter. The driver circuit boosts pulsemagnitude from the STM board and is given to the base of the MOSFET (IRFP460). Experimental setup is shown in Fig 15.

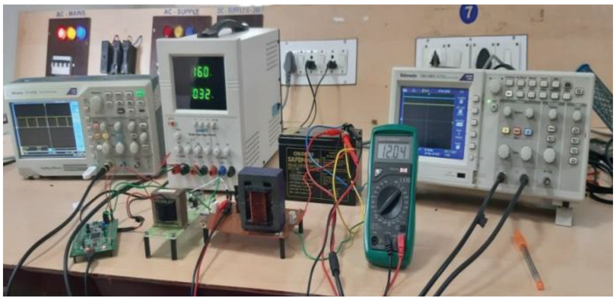
Fig. 15. Experimental Setup

During the initial stages of charging, while SOC <90%, Battery Voltage increases with increase in the state of Charge. Once the SoC reaches the 90%, the battery is charged using Constant Voltage mode. A constant voltage of 12V is maintained the battery terminals and the charging current keeps decreasing till the battery is fully charged. The modes of charging are controlled by the STM microcontroller which calculates SoC depending on the current and voltage of the Lead acid battery.

Initial studies were carried out in the system with charging controlled by an STM Microcontroller.The gating pulse given by the STM microcontroller during CV mode of charging is at5kHz. Switching Pulses with duty ratio keeping constant at 0.75 are shown Fig 16(a). Fig 16(b) Shows the DC input and output voltage of the Buck Converter to charge the lead acid battery.

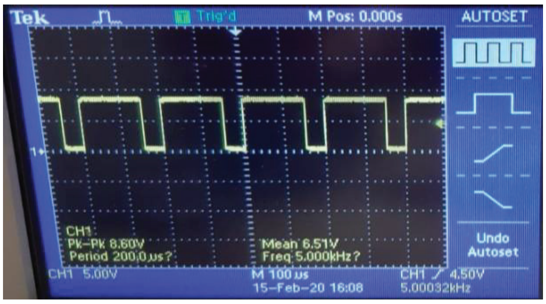

Fig. 16. (a) Switching Pulses Generated from STM

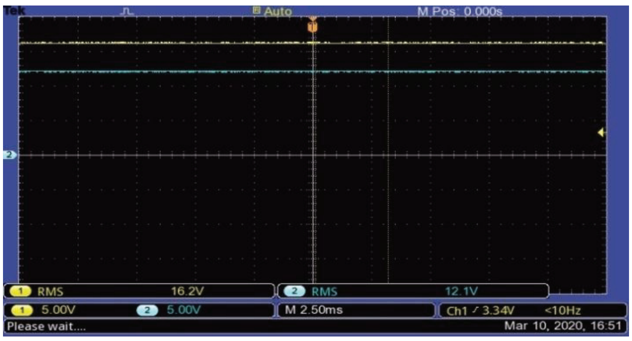

Fig. 16 (b) Input and output voltage of Buck Converter

VII. Conclusion

Electric vehicles (EVs) will replace internal combustion engine vehicles (ICEVs) in near future. It utilizes the power electronic devices, motor drives, energy storage systems, and renewable energy-based power sources. It helps a lot to reduce GHG gases and global warming. But these vehicles will add additional burden to the power system network and their demand also varies throughout the day. In addition, in rural areas, the accessibility to electricity is very less, so it is preferred to utilize renewable sources in an effective manner.

A solar EV charging station with station battery and a parking area, which can accommodate three Electric Vehicles is designed. Later, suitable controllers were selected and implemented in the system. Whenever solar power is excess compared to EV charging demand, available power balance is used to charge the battery. Similarly, during times of solar power shortage, station battery discharges to meet the EV demand.

The effectiveness of this EV charging station is analyzed by means of simulation model studies and experimental testing under various scenarios like changing solar irradiance and change in the initial SOC. System performance is found to be satisfactory.

VIII. FUTURE SCOPE

Utilization of Optimization techniques in the use of renewable resources like Solar, wind, biofuel will enhance the opportunities of Electric Vehicles. Extension of the system with fast response storage scheme can be implemented for Fast charging stations. Intelligent Controllers or Machine Learning Techniques can be implemented to avoid excess loading of EV Charging stations on the grid. Hybrid charging stations incorporating more than one renewable source or a backup diesel generator will certainly increase the stability and reliability of the system.

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