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CHARGING STATION FOR ELECTRIC VEHICLE USING HYBRID SOURCES

B. MOHAN[1], M.V.RAMESH[2], P.MUTHU KUMAR[3], RAJAN. VR[4]

[1]Assistant Professor, [2,3]Associate Professors, EEE Department, PVP Siddhartha Institute of Technology, Vijayawada, Andhra Pradesh, India
[4]Professor, EEE Department, Siddharth Institute of Engineering & Technology, Puttur, Andhra Pradesh, India

E-mail: [1]mohan.victory1@gmail.com, [2]vrmaddukuri@gmail.com, [3]muthukumarvlsi@gmail.com, [4]rajan.vrrp@gmail.com

ABSTRACT

In future transportation depends on Electric Vehicles (EVs). EVs are run by rechargeable batteries which consume more amount of time to get recharged. Based on voltage level and current rating, EVs have 3 levels of DC fast charging. Each level of charging system has various limitations and takes more time. EVs are not preferred by the consumers as their charging time lasts longer and range anxiety. So, to overcome the issues a combination of the solar and grid supply is used to get fast charging to batteries. The charger uses a DC to DC converter which enhances the current and voltage ratings, so the charging time of the battery will decrease. The interconnected solar powered and grid connected hybrid source charging system was developed for EVs charging. The characteristics of Lead-acid and Lithium-ion batteries were studied. Obtained results shows that Lithium-ion battery have better performance. The results are verified by using MATLAB/Simulink Software.

Keywords: *Solar Energy, EV Charging station (EVCS), Maximum Power Point Tracking (MPPT), DC-DC Converters, Permanent Magnet Brushless DC (PM BLDC) motor*

1. INTRODUCTION

As seen by the ongoing need for petroleum, cars are now seen as essential components of daily life for both personal mobility and the transportation of commodities. Along with such a demand, rising fuel prices and growing environmental anxiety due to air pollution and climate change have sparked concerns [1]. As a result, several governments have pushed automakers to provide low-emission, ecologically friendly transportation options. EVs have been created and used in this environment to reduce reliance on fossil fuels, which has decreased emissions of greenhouse gases and other pollutants [2].

The owner of the EV can conveniently charge the vehicle while engaging in other activities. We have outlined the Photovoltaic (PV)-powered charging station's several advantages in here. The savings are significant because charging takes place throughout the day, when load demand and electricity prices are highest. Additionally, it has very low CO2 emissions and little fuel costs. The roofed parking facilities are advantageous structurally because they offer free protection from the sun and rain, which is important in countries with hot climates.

There have been numerous PV-EV charging systems proposed. However, only two strategies seem to be workable: (1) the PV-Grid, which combines solar energy with the grid [17–21], (2) the PV standalone which relies solely on solar energy, (3) grid standalone i.e., using grid energy as energy source. Due to the worries about climate change and the continued expansion of EVs, the integration of solar PVs into the electric vehicle charging station (EVCS) is becoming widely employed and highly advocated by environmental experts. Now a day's the use of solar PV-grid charging systems is growing [5–10]. When solar energy is available, it uses it; otherwise, it switches to the utility grid. For PV standalone systems, charging is done independently of the utility grid [3–4]. However, due to the small surface area, its utilization is restricted to the auxiliary parts rather

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than the actual EV propulsion. Numerous elements of EV charging with utility power (grid-only) have been thoroughly reported in the literature for many years. In addition, a number of review papers in this field have been published.

To charge the EVs there are two types of charging based on nature of supply (AC & DC) and again it consists of different levels of charging depends on power rating and current as follows.

General AC charging for EVs

• Level 1: 120 V AC supply (Charging from the ordinary household outlet may take around 20-22 hours.)

• Level 2: 240 V AC supply (Fast charging in a few to several hours is guaranteed with 20 kW chargers. This is a typical method used in public charging stations. The advantage of this charging method is that it would not require significant adjustments to the electricity infrastructure in the majority of business and metropolitan locations) [11–12].

DC charging in general for EVs

The SAE combo (The Society for Automotive Engineers) and CHAdeMO chargers are two different types of DC fast-charging stations that can charge a car to 80% in 30 minutes. Based on voltage and current ratings, DC charging can also be divided into the following categories [13–14].

• Level 1: up to 36 kW at 200/450 V (80A).

• Level 2: up to 90 kW at 200/450 V (200A).

• Level 3: up to 240 kW at 200/450 V. (400A).

Assumptions made in the proposed system are as listed below:

For the solar array output power to be constant, temperature, irradiation are taken as 25˚C and 1000 W/m^2 respectively. As solar irradiation and temperature changes time to time in nature. Monocrystalline solar cells are taken with a efficiency of 18%.

Weight of the car is taken as 1500 kg to select the motor rating.

Efficiency of the motor, boost converter and buck converter is considered as 95% to calculate the required parameters of the load and select the battery rating.

Battery calculations are done based on DC level 1 charging.

The main aim of the study is

1. It is possible to lessen the issues caused by the greenhouse gases produced by internal combustion engines and conventional power generation by utilizing the EV and PV.
2. The integrated (PV-grid) EV charging station offers economic and technological advantages, lessens the load on the current grid, and prevents the need for overproduction of power from conventional plants to satisfy EV charging requirements.
3. The designed system provides fast charging to EV.
4. The proposed system will give detailed calculations to the EV users.
5. The proposed system have been developed for three cases. Case1: EVs charging takes alone from the PV system, if excess power available sends to grid. Case2: EVs charging takes place by using grid only. Case3: EVs charging takes from both the grid and PV system. In this case if the power is not available to charge EVs, then total power will be drawn from grid.
6. In previous studies the systems are designed with lead-acid battery and DC motors, but in this designed system fast charging Lithium-ion battery and PM BLDC Motor were used to enhance range anxiety.

2. CHARGING STATIONS DESIGN

This section describes the different types of charging stations designed in this work and MPPT control used.

2.1 Solar powered Charging Station:

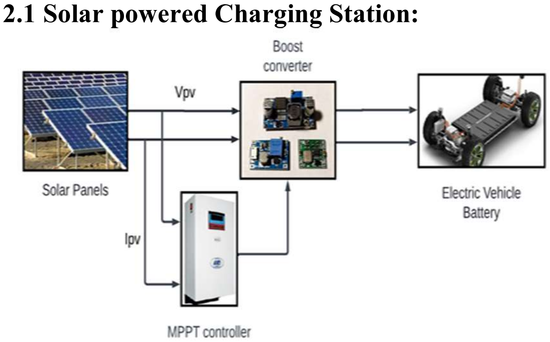

Figure 1: Solar powered charging station.

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Figure 1 is the proposed block diagram of solar powered charging station and it consists of solar PV array to supply required power to the EVCS, MPPT controller used to control the power of solar PV array, boost converter to step up the voltage and maintain constant voltage, battery to store the energy which drives the motor used.

2.2 AC Grid-Connected Charging Station:

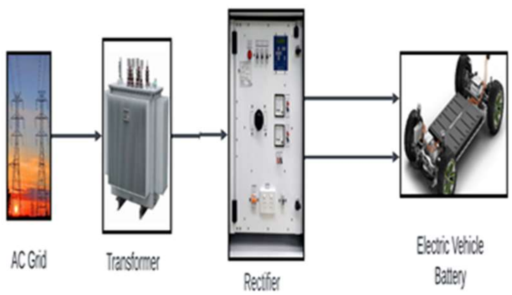

Figure 2: AC grid connected charging station.

Figure 2 have AC grid which supplies the power to EVCS, transformer used to step down the voltage, rectifier is utilized to convert AC to DC voltage which intern used to charge battery that is used to drive the motor.

2.3 Solar Powered and Grid Interconnected Block Diagram:

Figure 3 represents the combination of solar power and AC grid power. One source may be used at a time by using switch or two sources at a time as for requirement.

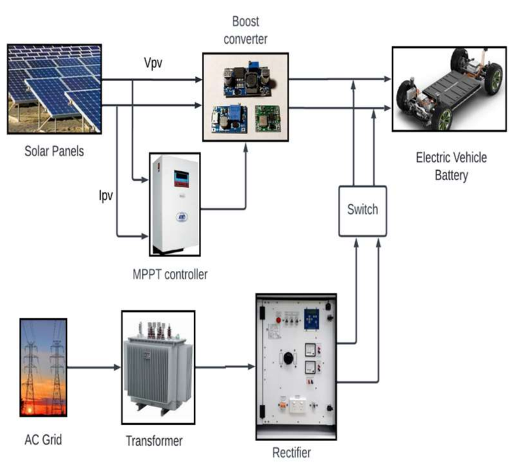

Figure 3: Solar powered and grid interconnected system.

2.4 MPPT Control Technique:

MPPT is an algorithm used for extracting the maximum available power from PV arrays under certain conditions. The voltage at which maximum power occurs is called maximum power point voltage. Maximum power point changes with solar irradiation, temperature, etc. In this developed system Perturb and Observe (P & O) method is used for MPPT control [15]. This method takes the PV array output voltage and current as input. It compares the difference between present power and old power, present voltage or current, and old voltage or current. Power formula can be written as given in expression (1)

$$\text{Power } (P_{PV}) = \text{Voltage*Current} = V_{PV}*I_{PV} \quad (1)$$

Where, P_{PV} is PV array output power, V_{PV} is the PV array output voltage and I_{PV} is the PV array output current.

MPPT algorithm steps followed and flow chart are given in figure 4.

Let the difference between present power and old power = ΔP.
Difference between present voltage and old voltage = ΔV.
If $\Delta P > 0$, it checks whether ΔV is greater than zero or less than zero.

1. If $\Delta V > 0$ then Dref is decreased by ΔD.
2. If $\Delta V < 0$ then Dref is increased by ΔD.

If $\Delta P < 0$, it again checks for ΔV whether it is greater than zero or less than zero.

1. If $\Delta V > 0$ then Dref is increased by ΔD.
2. If $\Delta V < 0$ then Dref is decreased by ΔD.

3. CALCULATIONS OF THE PROPOSED SYSTEM

This section describes the how to calculate the rating of the motor, the power required from the solar plant, battery rating, boost converter, buck converter and power requirement from the AC grid. The general weight of the car lies in the range of 1200 kg to 2900 kg. In this paper assumed weight of the car is 1500 kg. To run the 1500 kg weight of car, the rating of the motor is calculated as follows [16].

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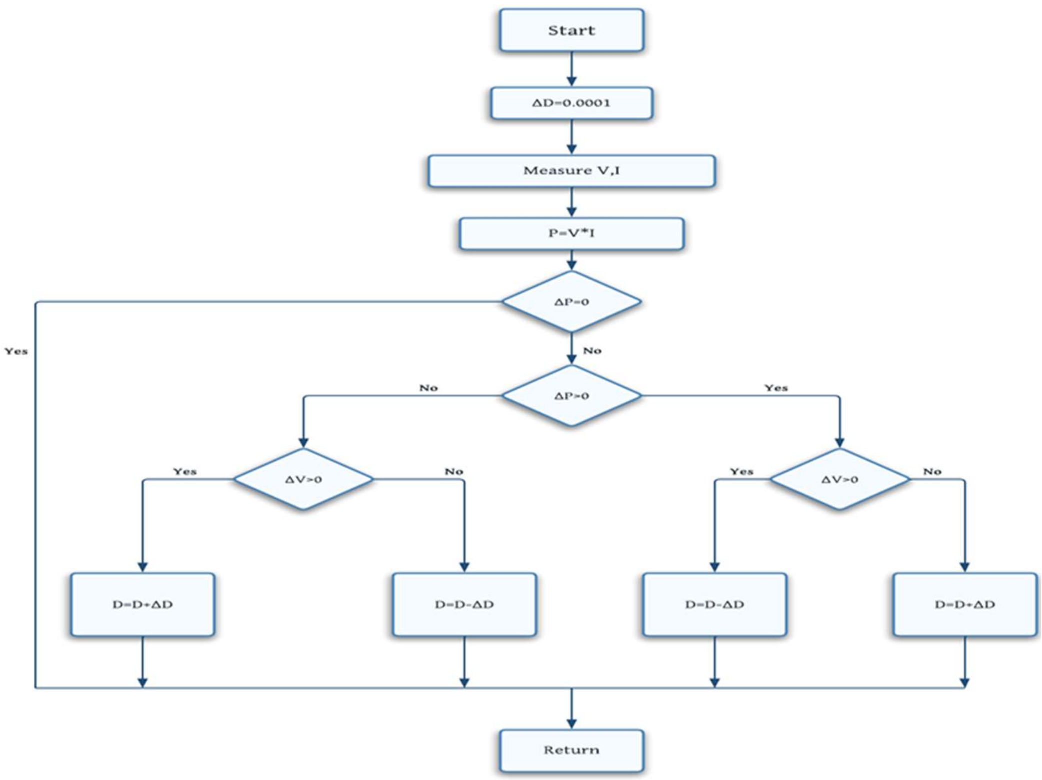

Figure 4: MPPT control flow chart.

3.1 Selection of the Motor Rating:

$$F_{total} = F_{rolling} + F_{gradient} + F_{aerodynamic\ drag} \quad (2)$$

Where, $F_{rolling}$ is force due to rolling resistance.
$F_{gradient}$ resistance of force due to gradient resistance
$F_{aerodynamic\ drag}$ is force due to aerodynamic drag
F_{total} is the total tractive force that the output of motor must overcome, in order to move the vehicle.

Rolling Resistance further can be expressed as shown in equation (3)

$$F_{rolling} = C_{rr} * M * g \quad (3)$$

Where, C_{rr} is coefficient of rolling resistance = 0.01
M is mass in kg = 1500 kg
g is acceleration due to gravity (9.81 m/s ^{2})
Force of rolling resistance and power rating can be calculated as shown in below in expression (4).

$F_{rolling}$ = 0.01*1500*9.81=147.15 N

$$P_{rolling} = (F_{rolling} * V) / 3600 \quad (4)$$

= 147.15 * 100 / 3600 = 4.0875 kW.
Where V is velocity of the vehicle in kmph.
Gradient Resistance is expressed as in equation (5)

$$F_{gradient\ resistance} = +M * g * \sin \alpha \quad (5)$$

$F_{gradient\ resistance}$ = 1500 * 9.81 * sin 0º = 0 N.
Aerodynamic Drag force can be expressed in (5)

$$F_{aerodynamic\ drag} = 0.5 * C_A * A_f * \rho * (V + V_o)^2 \quad (6)$$

Force due to aerodynamic drag is 4.2 N

$$P_{total} = P_{rolling} + P_{aerodynamic\ drag} \quad (7)$$

$P_{total} =$ 4.0875 kW + 4.2 kW = 8.2875 kW
Finally the rating of the motor assuming the efficiency (η=95%) is calculated considering all the forces and various factors acting on the vehicle as.

$$M_{tractive} = P_{total} / \eta \quad (8)$$

= 8.2875 / 0.95 = 8.72 = 10 kW.
Load current of Permanent Magnet BLDC Motor is obtained as follows.
Resistive Load (Motor) Power (P) = 10 kW, Voltage (V) = 72 V.

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$I_{load} = P / V = 10 * 10^3 / 72 = 139A$.

3.2 Solar PV Array:

As per the load 10kW, 20 kW solar power plant is designed P = 20 kW, Vpv = 260 V, Ipv = 77 A and for 315 Watts panel.

$I_{pv} = 20 * 10^3 / 260 = 77$ A
Series connected panels for voltage = V_{pv} / V_{mpp}
= 260 / 37.5 = 7 Panels
Parallel connected panels for current = I_{pv}/I_{mpp}
=77 / 8.4 = 9 Panels.

Table 1. Solar array module data.

Parameter	Value
Voltage at maximum power point (V_{mpp})	37.5 V
Current at maximum power point (I_{mpp})	8.4 A
Open circuit voltage (Voc)	45.8 V
Short circuit current (Isc)	8.92 A

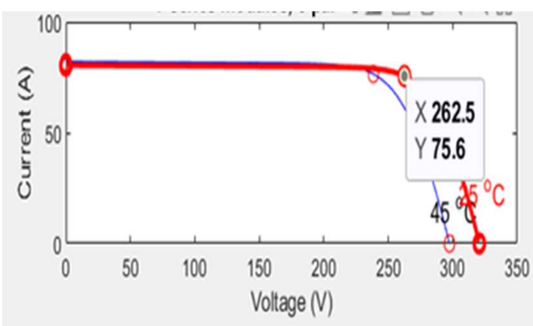

Figure 5: Solar PV array voltage and current values.

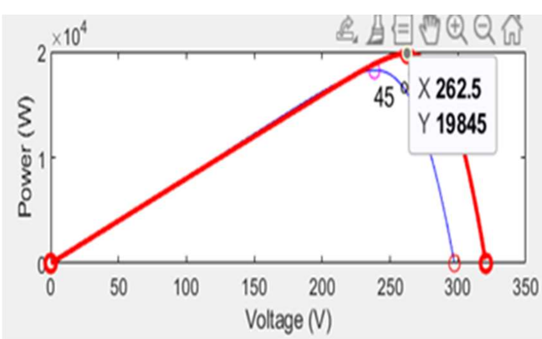

Figure 6: solar PV array power and voltage.

Table 1 represents the solar array module data used while simulation done.

Figure 5 and Figure 6 shows the solar PV array simulated values of voltage, current and power.

3.3 Boost Converter:

Assume the efficiency (η) of boost converter as 95% and calculated the input power to the boost converter and parameters as shown below.

$$P_{in}=P_{out}/\eta \quad (9)$$

$P_{in} = (260 * 72.4) / 0.95 = 19.814 = 20$ kW
For the boost converter the input voltage is 260 V and output voltage is 290 V.
Inductor and Capacitor values of Boost Converter taken as
L= 3.4966e-04 H and C= 4.9203e-04 F.

3.4 Buck Converter:

Let's assume η = 95%
$P_{in} = P_{out} / \eta = 10 * 10^3 / 0.95 = 10.5263$ kW
$I = 10.5 * 10^3 / 290 = 36.2069A = 36.2$ A

3.5 Battery:

Battery Voltage (V_b) = 290 V
Ampere hour of the battery = 150 Ah
If the battery needs to be charge in 2 hours
So, current = 144.80 / 2 = 72.4 Ampere-hour (Ah)
For 4 hours withstand motor (load) = 36.2 * 4 = 144.80 Ah = 150 Ampere-hour.

$$\text{kWh of Battery} = V_b * Ah \quad (10)$$
$$= 290 * 150 = 43.5 \text{ kWh.}$$

3.6 AC Grid:

For 11 kV/ 415 V AC grid voltage
To convert AC grid voltage to DC voltage the formula used is given in (11).

$$V_{DC} = \frac{3\sqrt{3}}{2\pi} V_P = 0.827 * V_{PEAK} \quad (11)$$

DC voltage (V_{DC}) = 0.827 * Peak Voltage (V_{PEAK})

$V_{RMS} = V_P / 1.414$
V_{DC}= 290 V
$290 = 0.827 * V_p$
Voltage at Peak (V_{PEAK}) = 290 / 0.827 = 350.66 V
$V_{RMS} = V_{PEAK} / 1.414 = 248$ V.

4. SIMULATION RESULTS

This section describes the results obtained using solar, grid and interconnected EVCS and analyzed the waveforms by using two batteries lead acid and lithium-ion and also observed the performance of the three cases considered as follows.

4.1 Solar Powered Charging Station:

Figure 1 is a simulated diagram of a solar powered charging station. The main components are PV array, boost converter, MPPT control technique, battery, buck converter and resistive load. A resistive load is assumed as a motor (PMBLDC) load of 10 kW. In this paper temperature 25°C and irradiation is assumed as 1000 W/m^2. The output power of the PV array 20 kW, voltage 260 V and current is 77A as shown in figure 7, is given to the boost converter and MPPT controller. MPPT controller controls the boost converter. The output of the boost converter (290 V) is given to the battery. Buck converter is connected between the battery and resistive load. Buck converter step-downs 290 V to 72 V.

Battery performance characteristics:
The figure 8 represents Lithium-ion battery characteristics. The first one is Battery State of Charge (SOC) which is increased from 50 % to 50.04 % in 5 seconds. After 2.5 sec load is connected to the battery. The second one is battery current and the last one is battery voltage. Figure 9 represents Lead acid battery characteristics Percentage State of Charge (SOC), current and voltage of a battery. Initial SOC is 50%. While charging SOC increases from 50% so that battery is charging. After 2 seconds load is connected to battery and solar source is disconnected from battery so that battery supplies power to the load. It is less efficient than the Lithium-Ion Battery. The below Figure 10 shows the load voltage and current drawn by the system given load. Load voltage is around 70-80 V and Current drawn 150A.

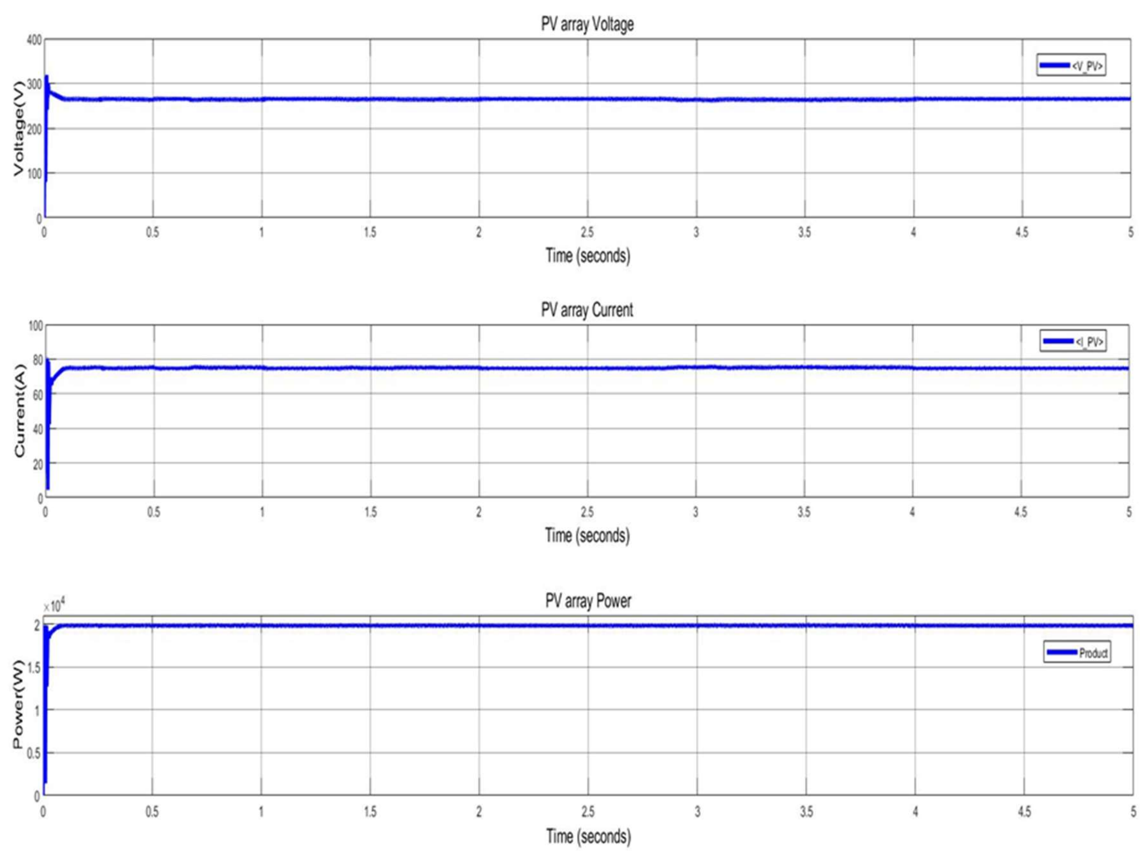

Figure 7: PV Array output.

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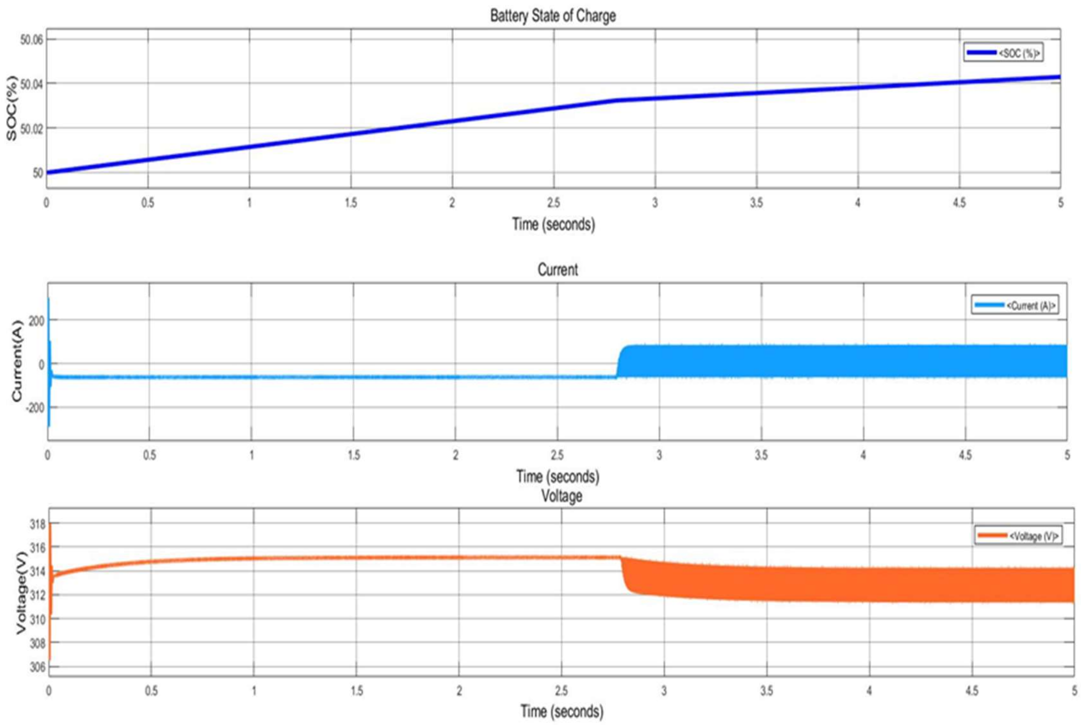

Figure 8: Lithium-ion battery charging from PV Array.

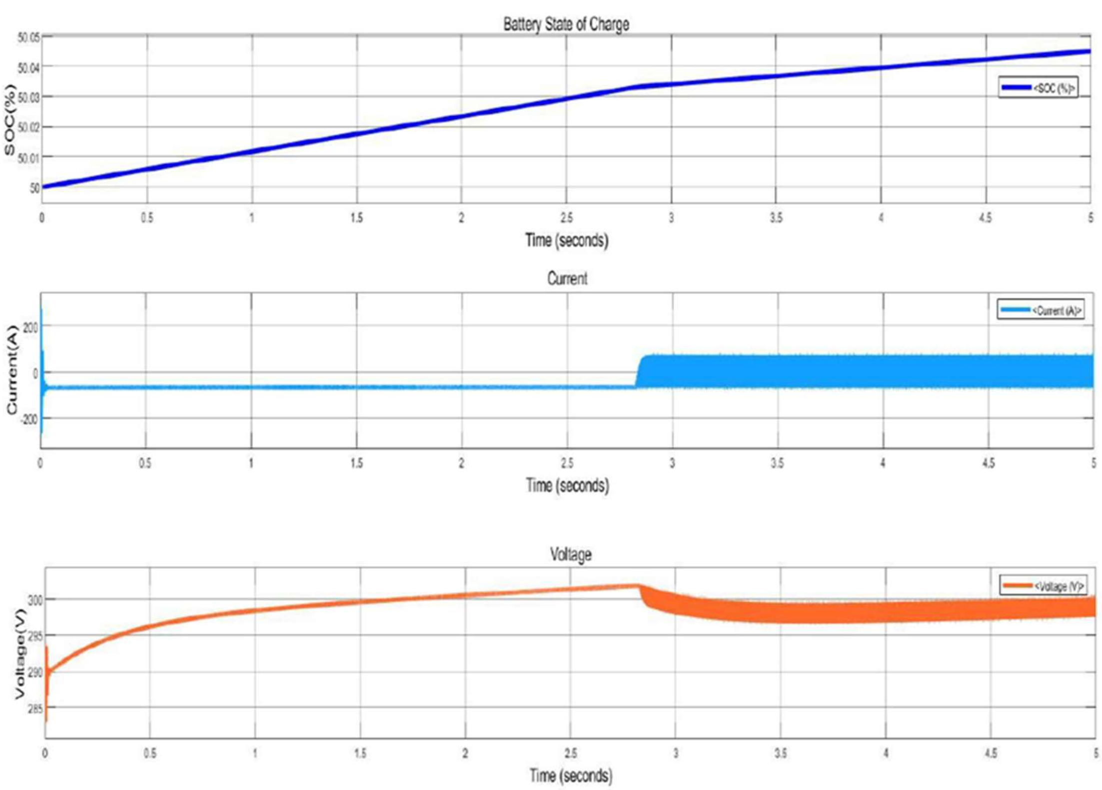

Figure 9: Battery Charging Behavior (Lead-acid battery).

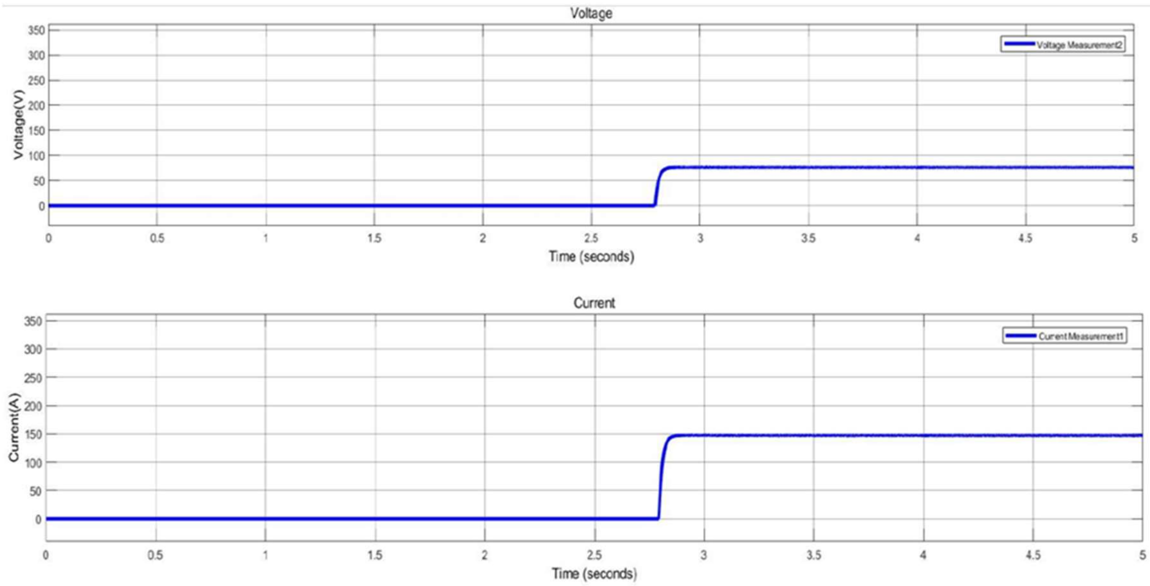

Figure 10: Load waveforms.

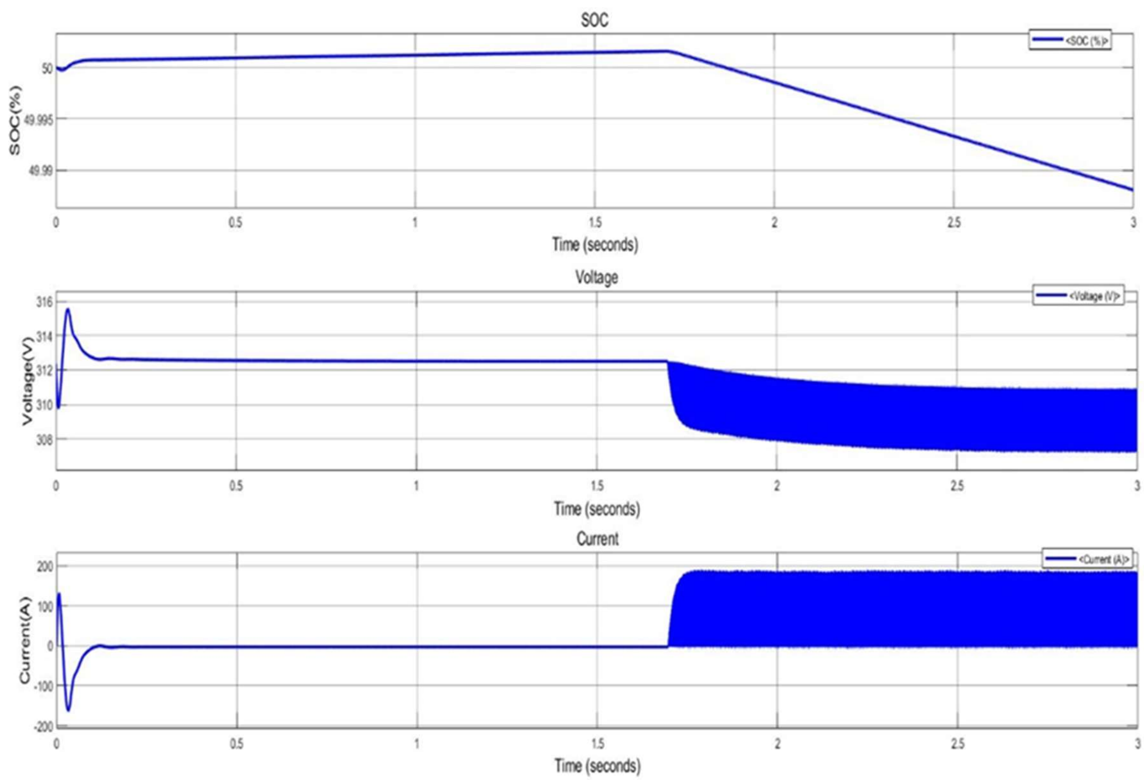

Figure 11: Lithium-ion battery charging from AC Grid.

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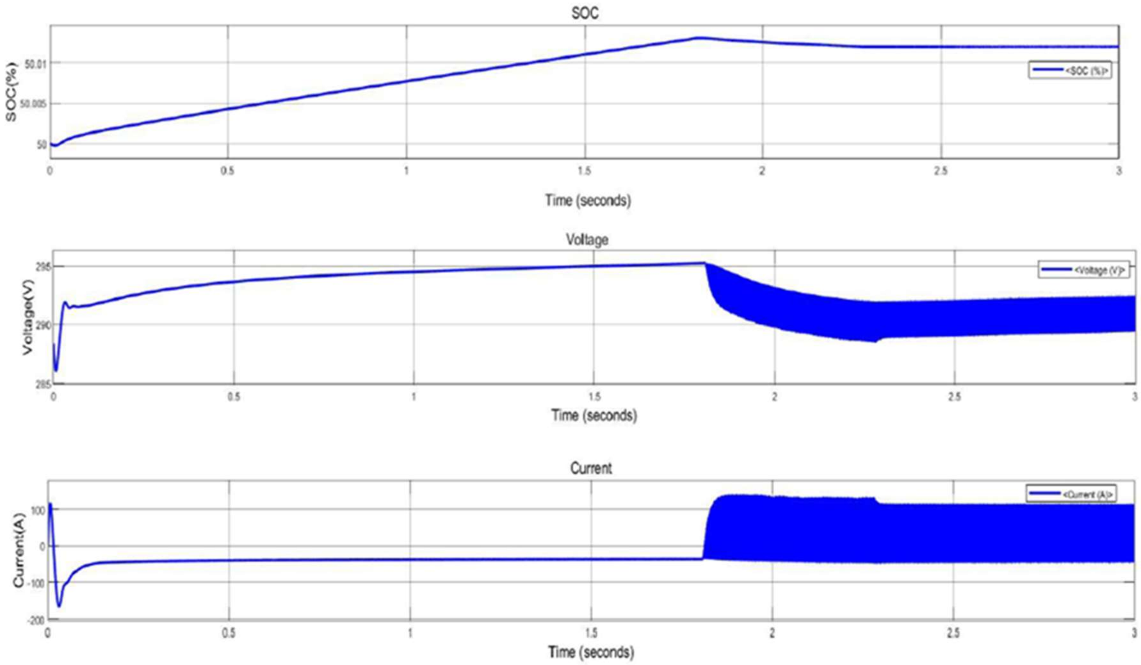

Figure 12: Battery Charged by Grid Charging System (Lead acid battery).

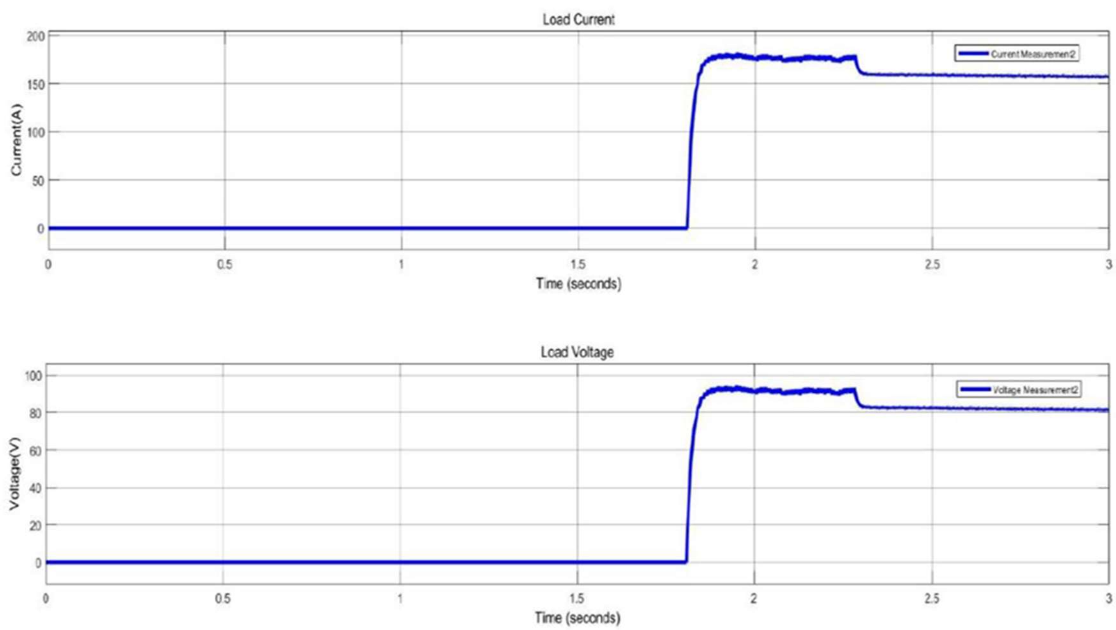

Figure 13: Load side in Grid Charging System.

4.2 AC Grid- Connected Charging Station:

Figure 2 is a simulated block diagram of an AC Grid-connected charging station. The main components are a three-phase source, transformer, rectifier, battery, and resistive load. The voltage of the three-phase source is 11 kV. By using a transformer 11 kV is reduced to 248 V. Secondary winding of a transformer is connected to a rectifier or AC to DC converter. The output of the rectifier is 290 V. Capacitor and inductor are used to reduce ripples in the output. The figure 11, represents battery characteristics. It consists of 3 graphs.1.

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Battery State of Charge: Initial SOC is 50% it increases up to 1.7 seconds. After 1.7 seconds load is connected to a battery and the battery is Above figure 12 represents State of Charge (SOC), current, voltage of a battery. Initial SOC is 50%. While charging SOC increases from 50% so that battery is charging. No load is connected in this case. The above figure 13, shows the Load voltage and current drawn by the system when load was connected. Load voltage is around 160-190 V and Current drawn 90A.

4.3 Solar Powered and Grid Interconnected Charging Station:

Figure 3 is a simulated diagram of the solar and AC grid interconnected. As solar is intermittent in nature and the AC grid charges high cost during peak hours to avoid these issues interconnection is the best choice such that when solar is off or in maintenance AC grid charges the battery. So the burden on the grid reduces. We assumed solar irradiation as zero for 2 to 3 seconds and 4 to 5 seconds. In those cases, the battery gets supply from the gird. A circuit breaker is used to on the grid at that particular time. The remaining time circuit breaker is in off condition. Two switches are placed before and after the battery. When the load is connected to the battery, source is disconnected such that the battery discharges because the load draws power from the battery. Below figure 14 represents State of Charge (SOC), current, voltage disconnected from the source. The battery supplies power to the load so SOC is decreasing. 2. Battery current and 3. Battery Voltage. of a battery. Initial SOC is 50%. While charging SOC increases from 50% so that battery is charging. No load is connected in this case. The figure 14, represents PV array output i.e. PV array voltage = 260 V, PV array current = 77A, PV array power= 20 kW. The figure 15 represents the output of the AC grid. For 0 to 2 sec and 3 to 4 sec AC grid is off. For 2 to 3 sec and 4 to 5-sec Grid is on such that the battery charges from the grid. The first graph represents the current supplied to the battery for charging. The second graph represents voltage supplies to the battery. The figure 16, represents battery characteristics. The first one is Battery State of Charge (SOC) which is increased from 50% to 50.04 % in 5 seconds. Solar PV array operating times are 0 to 2 seconds and 3 to 4 seconds, AC grid operating times are 2 to 3 seconds and 4 to 5 seconds. The figure 17, represents Percentage State of Charge (SOC), current and voltage of a battery. Initial SOC is 50%. While charging SOC increases from 50% so that battery is charging. After 2 seconds load is connected to battery and solar source is disconnected from battery so that battery supplies power to the load. It is less efficient than the Lithium-Ion Battery.

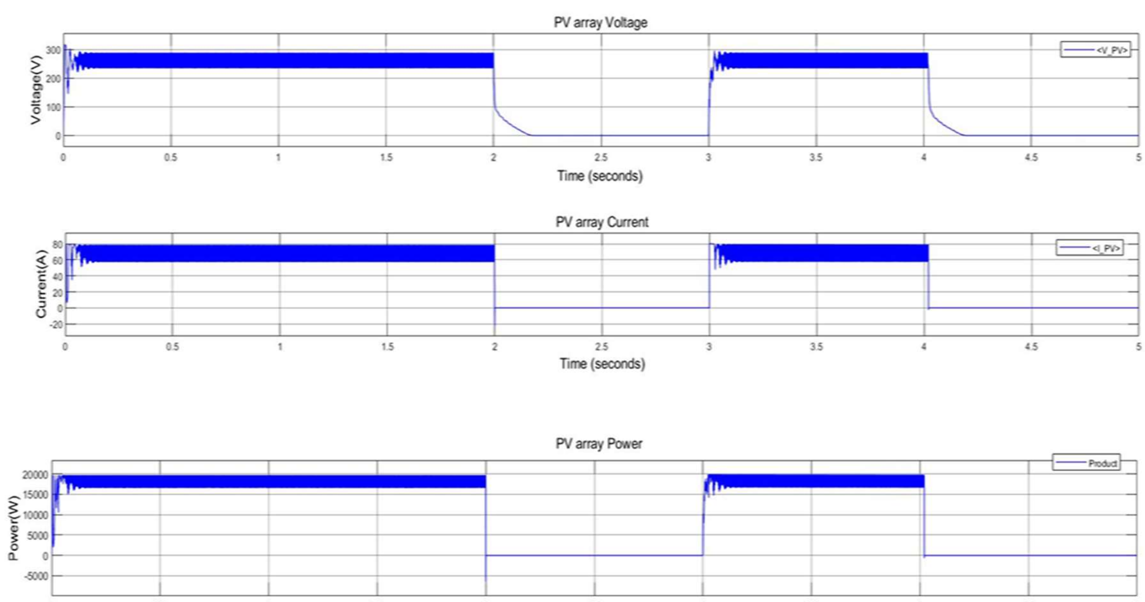

Figure 14: PV array output.

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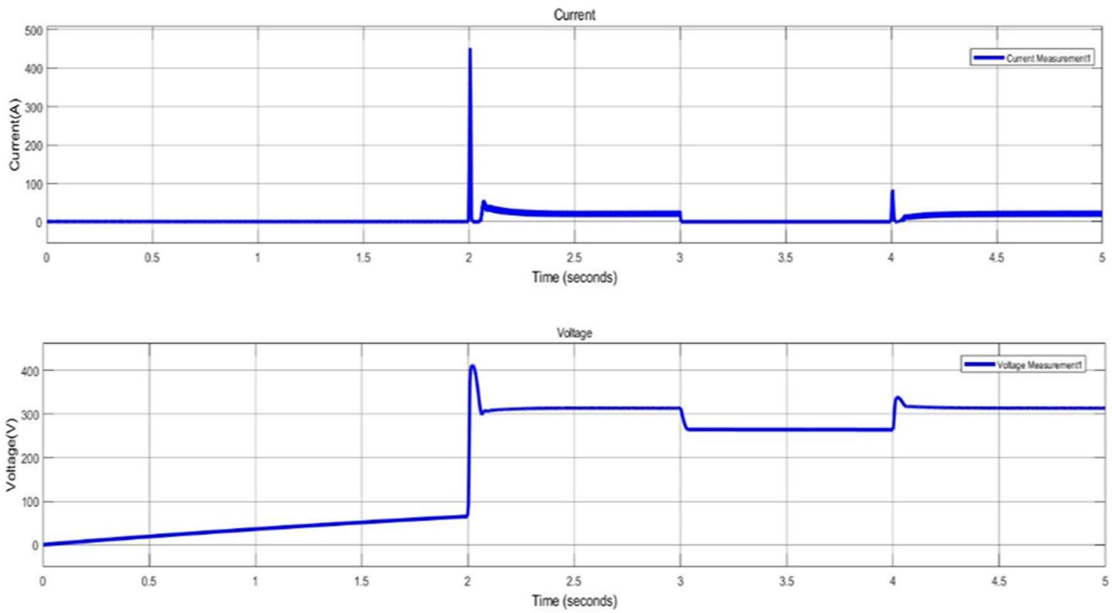

Figure 15: Input from AC grid.

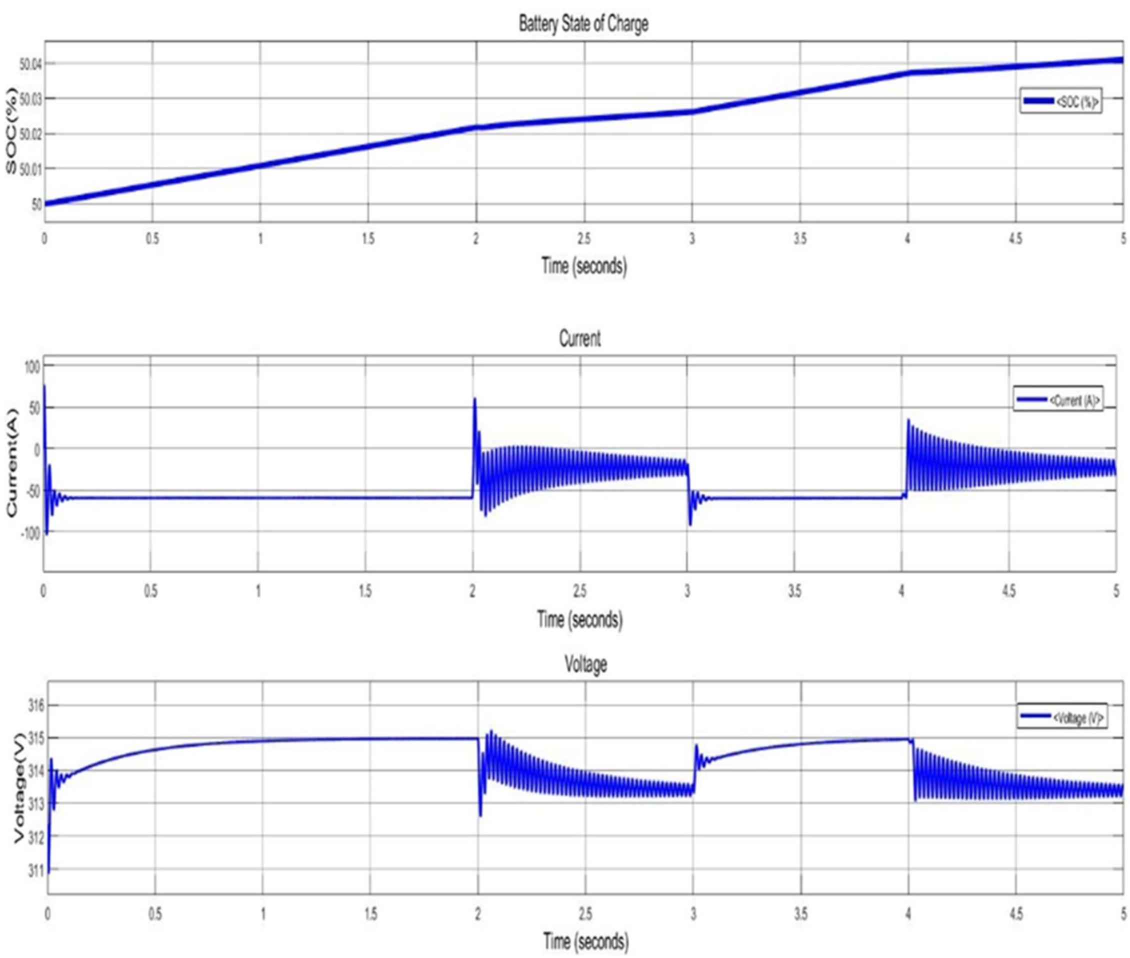

Figure 16: Lithium-ion battery behavior.

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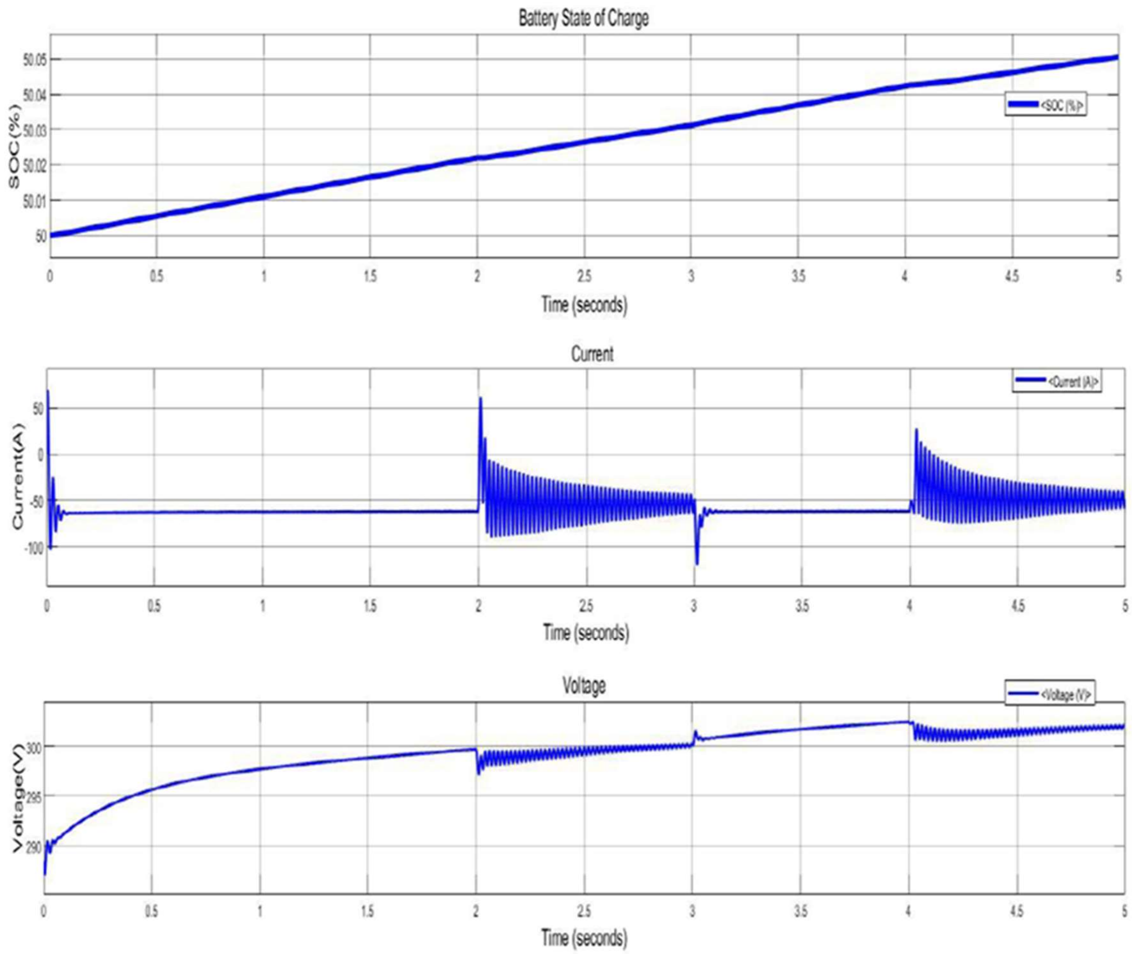

Figure 17: Battery Charging Behavior (Lead-acid battery).

Table 2: Comparison of existing systems.

Parameters	Existing system1,Ref.[22]	Existing system2 Ref.[23]	Existing system3 Ref.[24]	Proposed system
Motor	DC Motor 36V/42A, 2HP/1.5kW	48V,28Ah(dummy loads)	3kW, 48V, 3000rpm	PM BLDC Motor 72V/139A, 13.41HP/10kW
Battery	Sealed Lead acid 12V, 100Ah, 3.6kWh	24V,350Ah	Lead acid, 48V, 100AH, deep cycle rechargeable battery	Lithium Ion Battery bank 290V(24*12V), 150Ah, 43.5kWh
PV solar array	350W,38.7V,9.04A	250W,37.3V	1.26kW, 36.92V 8.55A	20kW,37.5V,8.4A
Grid Connection	-------	230V/48V	------	11kV/415V/248V
DC/DC converter(Buck-Boost)	36V/30A	48V	48V, 20A	290V/72V,36.2A
EV weight	360kg	------	1500kg	1500kg

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5. CONCLUSION

This paper presents EVCS using hybrid sources developed with AC grid, solar and integration of solar-grid system. In AC grid, solar and in integrated systems Lithium-ion and Lead Acid batteries were tested to check the battery performance, in which the characteristics of Lithium-ion battery shown the best performance. The proposed system will reduce carbon emissions and minimizes the fuel cost. The designed system charges the battery very fast. In addition, peak hour cost also saved. So, the developed charging stations are working efficiently but the integrated solar-grid charging system shown less charging time, saves economy and enhances range anxiety of EVs.

Renewable energy sources like wind energy can be included in the system to enhance the energy saving and reduces the burden on the grid during the night time. Further energy storage device super capacitor can also be used.

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