Solar Powered EV Charging Station with an Energy Storage System

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Abstract— The effects of global warming and pollution are leading the entire world to focus on the adoption of electric vehicles (EVs) in the upcoming years. The use of EVs will also focus on the development of EV charging stations with several new technologies based on renewable energy resources (RERs). Among all the different types of RERs, solar energy is one of the most prominent and popular sources of energy for long-term use. Thus, the renewable energy-based EV charging station provides immense potential for EV charging and control. In the past, several innovative, advanced technologies have been developed. Grid-tied solar PV must be combined with an energy storage system to provide continuous power as an efficient source for electric vehicle charging stations. The proposed scheme was developed using MATLAB Simulink and tested with different case studies of an EV charging station.

Key words: PV based CS, EV CS Power Management, Controlling of EV CS

I. INTRODUCTION

Due to the ever-growing demand for energy, conventional energy sources like oil and fossil fuels are depleting at a very fast rate. With the increase in the depletion rate of these sources, not only the cost of electricity generation has increased, but also aggravating issues like pollution, greenhouse gas emissions, global warming etc. In this context, power generation through renewable energy sources is gaining more attention compared to power generation from conventional fossil fuels. The prospective shortage of fossil fuels and the current environmental challenges of reducing greenhouse gases motivate the extensive research on EV systems. However, the research on EVs is highly impacted by the consumer's willingness to switch from using conventional internal combustion engine vehicles to EVs as an alternate means of transport. This willingness is the main factor in predicting the future demand for EVs.

A. Recent Scenario of EV Charging station

Recently, three different levels of EV charging station research have been conducted in the United States [1] as shown in fig 1.In these three categories, charging stations are classified according to their power charging rates. These three are classified as given below:

1) First EV Charging, which takes place overnight with slow charging rate of 1.5-2.5 kW with convenient output voltage level of 120 V.
2) Second level charging technology is which requires 240V outlet with power charging rate of 4-6.5 kW very fast. These level-2 charging can fully charge the batteries of EV within 3-6 hours.
3) Third technology of charging level are undergoing of research is requires very high power rating of 50-75 kW. For this level-3 charging system three phase power systems are used with off board chargers. This level-3 charging system is also known as DC Fast charger.

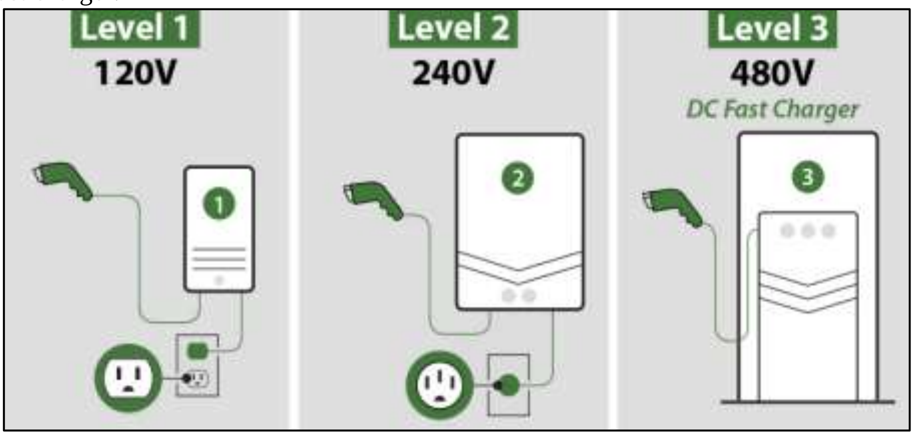

Fig. 1: Three levels of chargers for EV charging stations

In this paper, different charging topologies and their energy management systems are reviewed in the literature papers. Different researchers have represented various kinds of control strategies for solar powered EV charging stations. Solar powered charging station operation and the role of BESS is discussed in [2] with Buck-Boost converter topology. For constant power management grid integrated charging station concept is explained in [3] for number of EVs charging with solar PV source. The grid integrated solar powered charging station provides multiple benefits for charging a number of EVs at the same time with different operating modes. Prioritizing the EVs charging from the limited available solar energy is given in [4]. The viability of various types of PV and BESS charging for commercial, residential and business has been explained. In [5] the electrical vehicle charging station has an integrated with battery storage that represents both grid-connected and standalone function. In paper [6], it shows the model of a grid connected to a rapid electric vehicle charging station ensuring power quality with reduced harmonics.

The focus of this research is on the best design and power management of an electric vehicle charging station that is powered by solar PV and a Battery Energy Storage System (BESS) and is connected to the AC grid. The power flow operation takes into account solar deceptions as well as EV dynamic charging requirements. Solar PV is used to charge all of the EVs in the charging station. Since PV power is not available at night, a battery is used to charge the EVs plugged into the charging station. When solar or BESS power is insufficient to charge the EVs, the required amount of power is drawn from the AC grid, ensuring the charging station's continuous operation during the day. MATLAB/Simulink is used to create, design, and validate the proposed framework.

II. Architecture of Solar Powered EV Charging Station

The proposed energy management system developed for fast DC charging stations located on highways is defined as an EV public charging station. The system is designed for 50 EVs charge per day or 5 EVs/2hr. For the calculation of EV power demand, five Indian companies' EV battery parameters are considered. Such as Mahindra e2O has 16 KWh, TATA Tigor EV has 21.5 KWh, Mahindra e-Verito has 21.2 KWh, KIA Soul EV has 27 KWh and Hyundai Kona has 39.2 KWh.

The sun's energy in the form of radiation falls on the solar modules, To create a high-voltage system, modules are connected in series, which is known as a string, and to obtain a high current, all strings are connected in parallel, which produces DC electricity. A unidirectional dc-dc converter is connected between the PV array and the dc link. The P & O Algorithm is considered for extracting maximum power from the PV.

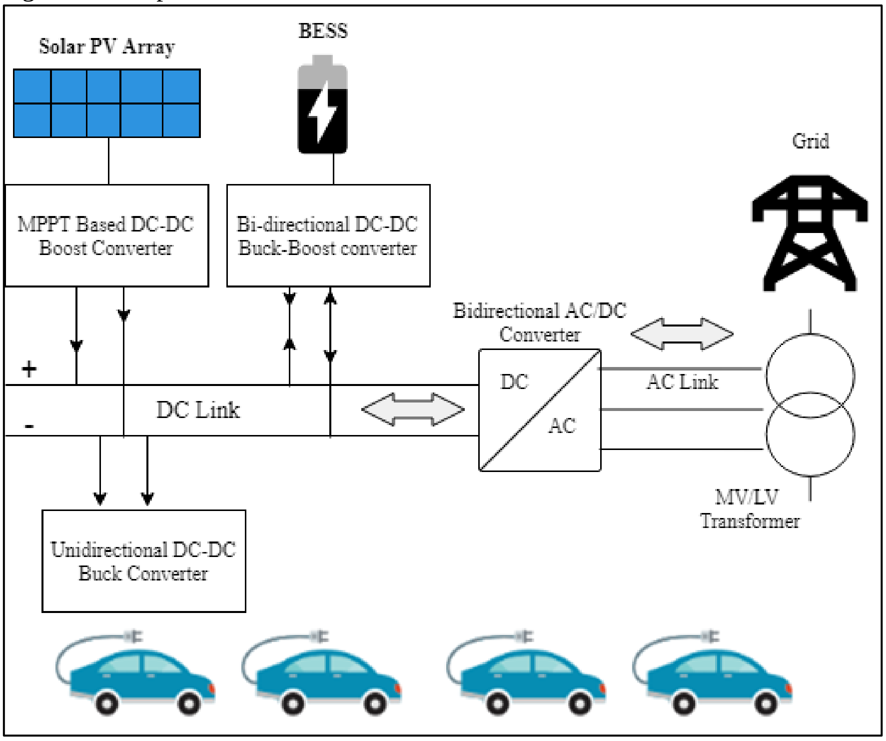

Fig. 2: Structure of PV, BESS and Grid powered EV charging station

The ESU requires a bidirectional flow of energy for charging it and discharging when it delivers energy to the load. It is charged by a buck converter and discharged by a boost converter. On the grid side, the bidirectional converter converts dc to ac when surplus PV power and it converts ac to dc when the deficit in power to fulfill the EV load.

A. Design of solar PV system for EV Charging station

Total connected load on PV panel system: 300 KWh/day
Total KWh rating of the system = Total connected load (KW) × Operating hours
= 156 × 6 = 1800 KWh
The actual power output of a PV panel = Selected module Wp × operating factor
= 305 × 0.75 = 228.75 watt
The operating factor" is used to estimate the actual output from a PV module.
[*The operating factor between 0.60 and 0.90 (implying the output power is 60 to 80% lower than rated output power) in normal operating conditions, depending on temperature, dust on module, etc.]*
The power used at the end use is less due to lower efficiency of the system.

Hence, actual power output of a PV panel = 228.75 × 0.81 = 184.68 ≈ 185 W
Energy produced by one 305 Wp panel in a day = Actual power output × 8 hours/day
= 185×8 = 1480 = 1.48 KWh/module
The number of solar modules required to satisfy given estimated daily load:
(Total KWh rating (daily load)/ (Daily energy produced by a panel)
1800/1.48 = 1216.21 ≈ 1217

B. Design Calculation of BESS for Charging Station

The SOC Estimation of energy storage unit is adopted from [7,8]

$$SOC(t) = SOC(t-1).(1-\delta_{bat}(t)) + \left(\frac{p_B(t)}{V_{bus}}\right)\eta_{bat}.\Delta t \quad (1)$$

Where :

$\delta_{bat}(t)$ = Hourly self discharge rate (Practically it considered 0)

$p_B(t)$ = Charging or discharging power

V_{bus} = Common DC bus voltage

η_{bat} = Charging and discharging efficiency

Δt = Hourly time step

The required BESS power is the minimum amount of power in KW that increases the SOC from initial. On the other side, the available BESS power is the maximum amount of power in KW, which BESS can supply in time step Δt before its SOC reaches the minimum limit. It is referred as;

$$\text{Req\_P}_{\text{ESU}}(\text{t}) = \frac{SOC_{\max} - SOC(t)\times C_b.N_b}{\Delta t} \quad (2)$$

$$\text{Avl\_P}_{\text{ESU}}(\text{t}) = \frac{(\text{SOC(t)-SOC}_{\min})\times \text{C}_b.\text{N}_b}{\Delta \text{t}} \quad (3)$$

Where :

C_b = rated capacity of single battery

N_b = Total no. of batteries in ESU

SOC set minimum 10% and 90% maximum.

The battery model contains a nonlinear voltage source and it models open circuit voltage, series resistance. Hence, the output voltage is dependent on both current and the SOC, where SOC is a function of time as a nonlinear. Battery voltage and SOC can be described as follows;

$$\text{V}_b = \text{V}_0 - R_b I_b - K\frac{Q}{Q - \int I_b dt} + A.\exp(-B\int i_b dt \quad (4)$$

The internal resistance of the battery is Rb, open circuit voltage potential (v) is Vo, charging and discharging current of the battery is ib and K is the polarization voltage, A is the exponential voltage and B is the exponential capacity.

$$SOC(\%) = SOC_0(\%) - 100\left[\frac{\int I_{bat}.dt}{Q}\right] \quad (5)$$

State of charge (SOC) of a battery can be calculated from equation (5), where Q and I are extreme battery capacity and is battery current. [9].

C. Calculation of EV Load Demand for Charging Station

For the modeling of EV power demand, mainly three parameters are considered;

1) Rated battery capacity (KWh)
2) Plug in time (Hrs)
3) Initial SOC (%) and Final SOC (%)

In this proposed EV charging model, it is assumed that at departure time, the SOC of the EV batteries should be 80% of its full load capacity and to avoid over- discharging EV charging should be stopped at 10% of rated capacity. Therefore, maximum demand of an individual EV is the 70% of its rated battery capacity. Calculation of the power demand of single EV at a time (t) is referred based on work in [10, 11].

$$P_{EV.t} = P_{EVreq.} \times S_t \times w_t \times C_t$$

Where:

$P_{EV.t}$ = Power demand by EV in time slot t (KW)

$P_{EVreq.}$ = Maximum required power by EV battery at the time of plug in.

S_t = EV Connectivity status (o if EV not connected, 1 if EV connected)

w_t = EV Charging status in time slot t.

Which depends on battery SOC as per equation.

$$w_t = \begin{cases} 0, \ SOC_0 \geq SOC_{\max}, \\ 1, \ SOC_0 \leq SOC_{\max} \end{cases}$$

C_t = Control signal for EV in time slot t. which is 1 for working hrs. (9:00 to 22:00) and 0 otherwise.

The required EV Power can be found as;

$$P_{EV.req.} = (SOC_{max} - SOC_{min}) \times C_{bat}$$

For multi connected Evs, the total EV power demand can be expressed as

$$EV_S\_demand_{total} = \left\{ \sum_{n=1}^{N} p^{n}_{ev.t,(t=9,10,...22)} \right.$$

Since proposed EMS is designed for day hours 9:00 am to 10:00 pm.

III. SIMULATION RESULTS & DISCUSSION

In this simulation, the MATLAB modeling of EV is done in the Simulink tool, and it is connected to the proposed system.

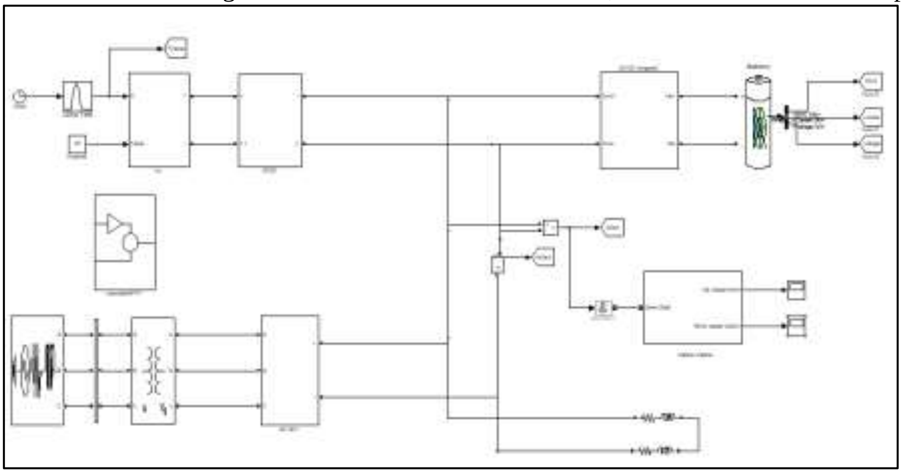

Fig. 3: MATLAB Simulation model of Grid tied PV and BESS

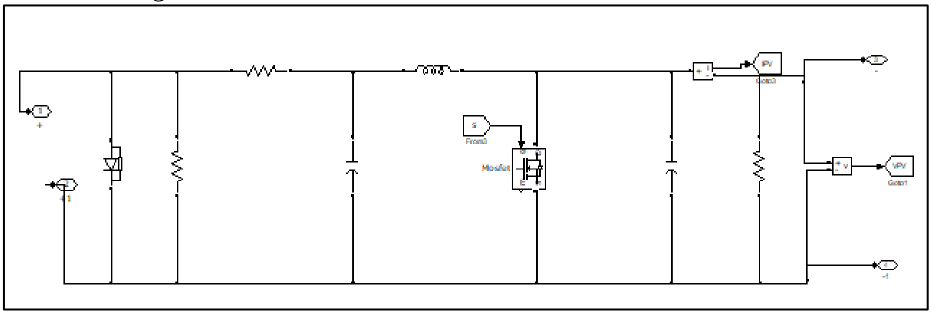

Fig. 4: MATLAB Simulation model of DC-DC Boost Converter

The Solar PV is developed by mathematical modeling with maximum output power tracking ability through a modified P & O MPPT algorithm. The duty cycle set by the MPPT algorithm is given to the Boost converter for output DC voltage regulation in the Solar PV system.

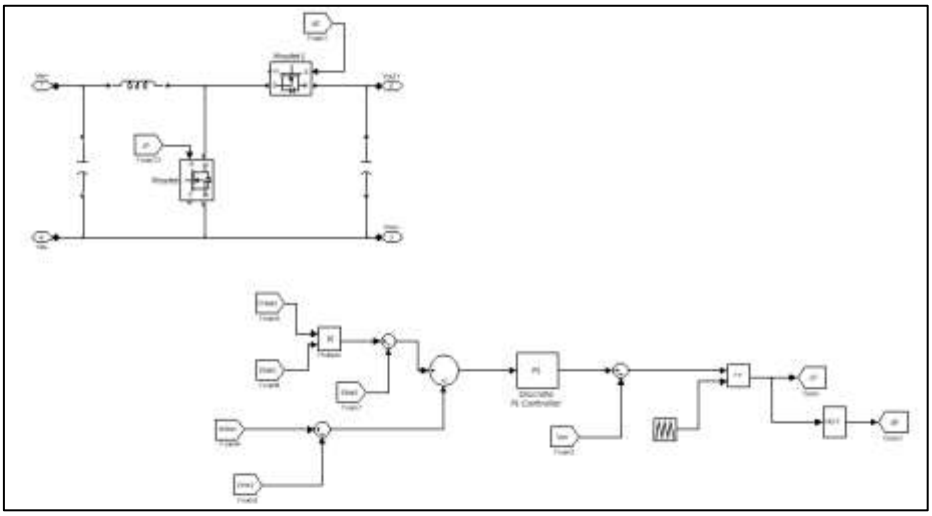

Fig. 5: MATLAB Simulation of DC-DC bidirectional Converter with PI Controller

There is a buck-boo boost dual converter topology also developed by PI controlling for Charging and Discharging control for a battery storage unit.

The EV charging rate is controlled through a proposed bi-directional DC-to-DC converter. The regulating supply is helpful for EV charging stations. With the help of the proposed system, EVs can be charged through a charging station and the energy cost is also very optimal due to the use of RES.

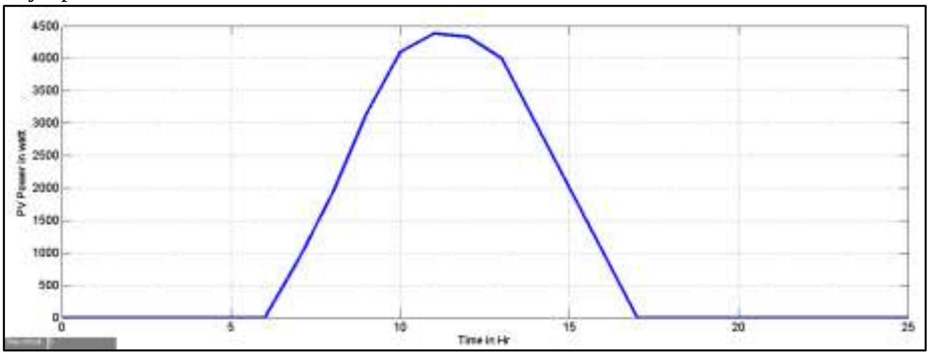

Fig. 6: Maximum power extracted from the PV array.

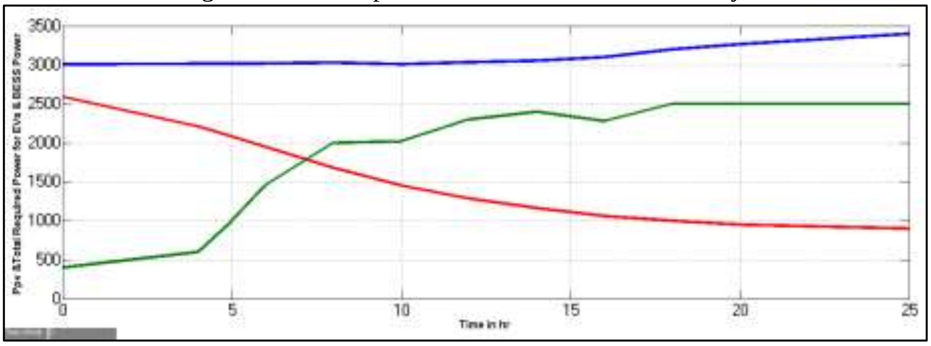

Fig. 7: Solar PV power and total power required for EVs and BESS power

The simulation results of Solar PV output power, BESS Power taken for 24 hours, in relation to the required power for EVs. In fig. 7, solar PV power increases from 3000 W to 3350 W. The total power needed for charging all the five EVs, which is taken here in case study at a time is obtained as 2688W to 980W. The BESS delivers power from 450 W to 2500 W. The results indicate that the power generated from solar and BESS is sufficient to charge the number of EVs as per the load requirements. In the low energy generation conditions from Solar PV, the Grid supply is available for EV charging.

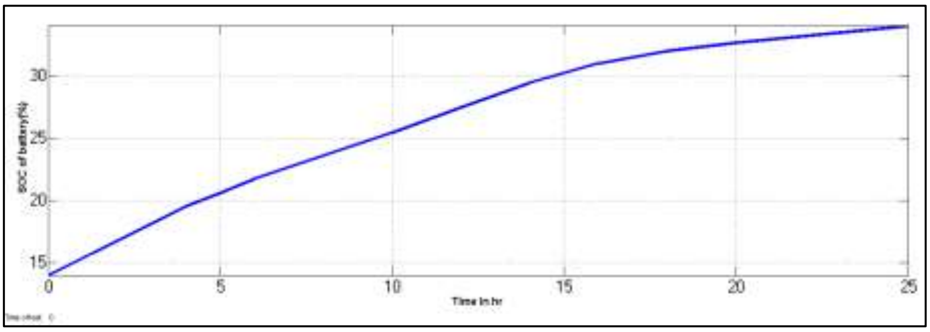

Fig. 8: SOC of EV battery charging

The power management system is designed in such a way that if solar power exceeds the power required for EVs, the surplus power is used to charge the BESS until it reaches the maximum SOC.In Fig. 7, with excess power. (3000-2688=312, 3350-980=2370. Hence, excess power 312W to 2370W, the BESS charges from 20 % to 34 % SOC.

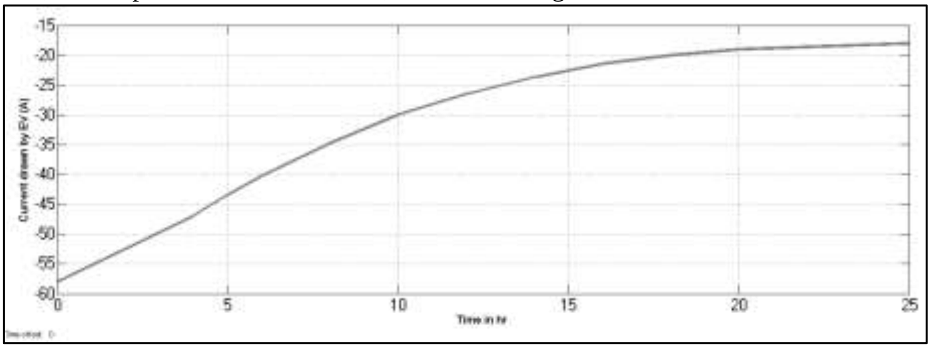

Fig. 9: Total Current Drawn by EV charging

The total current drawn by EV from the bus, for the charging is given in Fig. 9. It is denoted negative because the EV battery is charging.

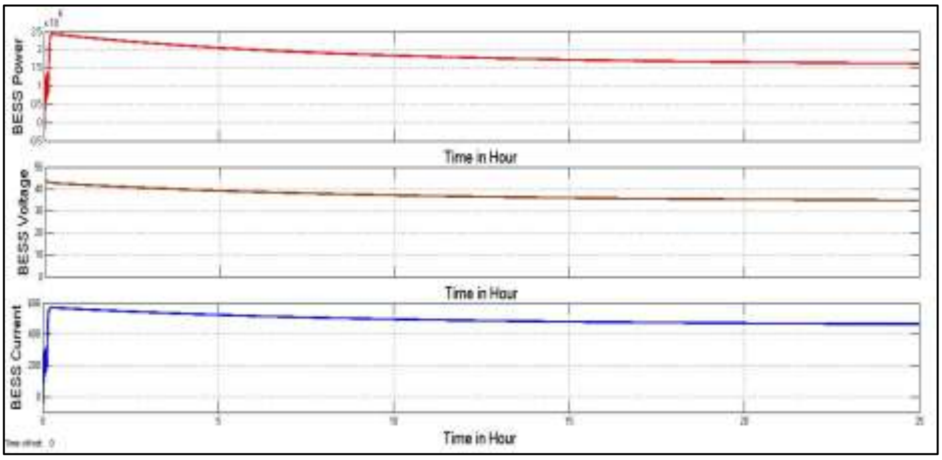

Fig. 10: BESS simulation parameters results

Fig. 10 shows the power, voltage and current waveform of BESS. In this simulation study, the battery's nominal voltage is 48, its rated maximum capacity is 416 Ah, its fully charged voltage is 52.26, and its nominal discharge current is 80A. result, it can be seen that BESS performs nearer to its defined value.

IV. CONCLUSION

This paper discusses EV charging stations powered by solar PV and grid supply; as backup energy storage, BESS is also developed in MATLAB Simulink. A different design calculation is presented for the development of an EV charging station based on RERs. The calculation suggests that the PV plant installation requirement is greater than the required capacity for energy storage. The implementation of grid-tied solar PV and energy storage batteries as the base charging station has been realized for electric vehicles. The main issue is to avoid grid interruptions when several EVs are simultaneously plugged into the system during a very short period of time. At the same time, optimization of the availability of PV power, real-time electricity demand, and tariff structure are important aspects.

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