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An Integrated Power Flow Controlled Charging Station for Various Categories of Electric Vehicles

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ABSTRACT— Electric Vehicles (EVs) are a clean energy alternative to gas and energy powered vehicles, which appear to be the efficient replacement to IC engines. Due to large number of EVs in the road, charging of the vehicles with conventional based grid is not economical and efficient. Thus, a renewable energy based charging station finds great potential and control for electric vehicle charging. An electric vehicle charging station integrating solar power and a Battery Storage System (BES) for three categories of plug-in electric vehicle with batteries of vastly different voltage and power ratings is designed for the current scenario. For uninterrupted power supply in the charging station an additional grid support is also considered. An efficient design of charging station with MPPT, current control strategy is developed for the optimal power management between solar, BSS, grid with the EVs in the charging station. The design of charging station is formulated and simulated in MATLAB/Simulink.

Keywords: Charging Stations, Electric Vehicles, Solar, State of Charge, Battery Energy Storage System

I. INTRODUCTION

The advancement in battery technology and increased demand to reduce greenhouse gas emission has led to plug in electric vehicles gaining widespread popularity as a means to replace internal combustion engines . But with the deployment of more electric vehicles on the road, charging of the vehicle will be strenuous if electric grid power is used. The most simple method to charge a PEV battery is to utilize its on-board charger, that can be connected to residential single phase ac supply. When more number of EVs are connected to the grid, it will bring a huge impact to its function and control. Charging the EVs using the electric grid powered by conventional energy sources gives no benefits. So, there need for an efficient charging system for EVs utilizing the renewable energy sources. Solar energy is green and renewable, but the undependable gathered energy from the Photo-voltaic (PV) system and dynamic charging needs of individual EVs bring new issues to the efficient charging of vehicles from these sources. An important aspect in designing these charging stations is the capacity of each PEV battery and the number of PEVs to be charged simultaneously. Most of the literature till now has investigated battery charging from the perspective of electric car. Thus, the battery capacity is anywhere between 25 and 75 kWh and battery voltage between 350 to 400 V. However, for heavy PEVs like trucks and buses, battery capacity is higher than 150 kWh and it is beneficial to use batteries with voltage around 800 V . Further, in case of two and three wheeler PEV, the battery capacity is less than 20 kWh and battery voltage is 48 V. So, the future PEVs can be divided into three categories depending on their specifications of battery. Similar to the conventional refueling station, a charging station must be able to charge all the three classes of PEVs simultaneously. Different charging strategy and power management for EV charging station are reviewed in the literature depending on the various energy sources and EV demand.

Solar powered charging station with battery storage system with approach introduces forecasted PV system and projection of EV pattern according to collected data is explained in paper [2]. In paper [3], charging scheduling for EVs by PV and Grid is given by reducing the total cost of the parking lot. With the real- time information about EVs, Model Predictive Control is applied for present time slot and projected information in the coming time slots. Prioritizing the EVs charging from the limited available solar energy is given in [4]. Feasibility of different types of PV and BESS charging for commercial, home and business has been explained in [5]. In paper [6] shows the solar powered e-bike charging station that provides AC, DC and contactless charging of e-bikes. The charging station has an integrated battery storage that gives both grid-connected and off-grid function. In paper [7], it shows the model of a grid connected rapid electric vehicle charging station ensuring power quality with reduced harmonics. The control of each vehicle charging is centralized and individual control is given to transfer energy from AC grid to the DC bus.So, for a well grounded charging station for EVs, the concept of utilising both the renewable energy and an energy storage system with additional grid support becomes very prominent in current scenario.

In this proposed work, an optimal approach for design and power management of Electric Vehicle charging station for various categories of electric vehicles powered by solar PV and a Battery Energy Storage System (BES) with AC grid is explained. There are three charging ports that cater to the voltage and power requirement of each category of PEV. The unreliability of solar and dynamic charging requirements of EVs are considered for the power flow strategy. Solar PV acts as the primary source for charge all connected EVs in the charging place. Since the power from solar PV at night is not there, a battery as an energy storage device is provided to charge the EVs connected in the charging station. Whenever there is a deficiency in the power output of solar or Battery Energy Storage System to charge the EVs, required amount of power will be taken from the AC grid ensure continuous operation of charging station throughout the day. The proposed system is formulated, and simulated using MATLAB/Simulink.

This paper is organized as follows: Section I presents the overall structure and case study II discusses the design specification of the proposed system and architecture of the system. Section III operation and control of the proposed system and simulation results.

II. DESIGN SPECIFICATION OF THE PROPOSED CHARGING STATION

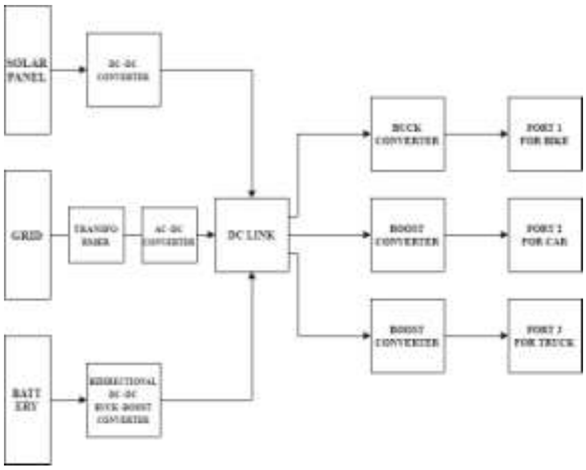

Fig. 1. Block Diagram of Proposed Charging Station

Fig. 1 gives the block diagram of the proposed EV charging station. A 110 V DC link bus with various rated power outlet for bike, car and truck respectively is considered for the charging station. Various voltage level created by using suitable converters and transferred power required for each port. Here buck converter used in the bike charging port and boost converter is used in car or truck port.

A buck- boost converter used in BES system.

A. Electric Vehicle as load

A load of three electric vehicles of 48V ,30Ah , 400V,100 Ah and 800V ,150 Ah with maximum 0f 1 hour as charging time is studied for the charging station. Charging requirements of incoming EVs changing time to time. The user can specify the State of Charge (SOC) limit, SOC_{lt} and the required time h hours for charging the EVs. The requirement of power ,for charging all the EVs are calculated in terms of its SOC.The remaining SOC, SOC_r required to charge the vehicle is calculated from time to time with the difference between SOC_{lt} and current SOC, SOC_c.

$$SOC_r = SOC_{lt} - SOC_c \qquad (1)$$

If EV battery voltage V_{EV} and its Ampere-hour rating is known as Ah_{rating} required energy E_{EV} for each electric vehicle to be charged is given as

$$E_{EV} = \frac{SOC_r V_{EV} Ah_{rating}}{100} \qquad (2)$$

The power required by the individual vehicle for charging in h hours is

$$P_{EV} = \frac{E_{EV}}{h-t} \qquad (3)$$

where t is the time already covered time by the EV for charging. Thus, the total power required for charging all the EVs can be obtained by summation of equation (3)

$$P_{tot} = \sum PEV \quad (4)$$

B. Solar PV with Boost Converter

PV array of 20 KW at 35 V as open circuit voltage is considered for the charging station design in MATLAB/Simulink. To step-up the PV array voltage, a boost converter is used to get the required DC bus voltage as 110 V. With boost converter efficiency as 90%, the solar PV is designed for a load of 3 EVs to charge from 20% to 100% SOC for 1 hours.

C. BES with Bidirectional DC-DC Converter

A battery energy storage system is employed to store the excess power from the solar for charging the EVs at night. A bi- directional DC-DC converter controls the charging and discharging operation of the BESS. Considering charge-discharge efficiency and bi-directional converter efficiency as 90%, for supplying maximum energy to the connected EVs for 1 hours, a 60V 110Ah BES is used for the charging station. It is assumed that BESS maintains/ discharges to a minimum of 20% SOC and charges to a maximum of 95% SOC

D . Grid with Rectifier

For uninterrupted power supply in the charging station an additional 230V AC grid support is also considered for the charging station. In MATLAB/Simulink, a 230V AC source with a transformer is considered as grid to step down the voltage to 110V AC. A controlled rectifier is provided to convert the AC voltage to constant 110V DC bus voltage.

III. OPERATION AND CONTROL OF CHARGING STATION

A. Modes of Operation

Mode 1: $P_{PV} > P_{tot}$ and $SOC_{BES} < maxSOC_{BES}$
If the delivered power from the solar PV is more than the required power of all the connected EVs, then the EVs will be charged to its SOC_{lt} using solar power only. If the current SOC of BESS is lower than its maximum SOC, then surplus power from solar is used to charge the BESS by connecting it to bus.

Mode 2: $P_{PV} > P_{tot}$ and $SOC_{BES} \geq maxSOC_{BES}$ With the power from the solar, EVs are charged but if the SOC of BESS reaches its maximum, then it is disconnected from the grid .

Mode 3: $P_{PV} < P_{tot}$
Due to rain or cloudy condition, Power harvested from the solar PV is lower than the power required by the EVs for charging, then deficient power will be taken from the AC grid by connecting it to the DC bus

Mode 4: $P_{PV} = 0$ and $SOC_{BESS} > minSOC_{BES}$
At night conditions, when there is no solar output, BES provides energy for charging the EVS in the station by maintaining the minimum SOC in the battery.

Mode 5: $P_{PV} = 0$ and $SOC_{BES} < minSOC_{BES}$
When the current SOC of BES is less than its minimum SOC, then the required power for charging the vehicles will be taken from AC grid by connecting it to DC bus.

B. Control Strategy

- **MPPT and PID Control for Boost Converter**

For obtaining the maximum power from solar, Maximum Power Point Tracking (MPPT) using Perturb and Observe (P&O) method is adopted in this system. Using P&O method, if power is more, voltage is adjusted in that direction until power no longer increases. The duty ratio for the converter obtained by P&O method is noted as D_1. Here a PID controller is used for making the DC bus voltage constant at 110 V . DC bus voltage V_{bus}, is measured and considered with the desired voltage and error obtained is given to the PID controller. D_2 gives the desired duty ratio from the PID controller. The average of the 2 duty ratios, D_1 and D_2, is fed to the boost converter for getting the required power from the solar by keeping the DC bus voltage constant.

- **Current Control for Bi-directional Converter**

Whenever there is excess power in solar, the battery storage system is to be charged and at night this is to be discharged to supply power for EVs. Here, current control strategy is adapted for the charging/discharging of the BES. When battery is charging, the duty ratio of the the converter in Buck mode is given in (7)

$$I_b = \frac{P_{pv} - P_{tot}}{V_{bat}} \quad (5)$$

$$I_{charging} = \frac{P_{pv} - P_{tot}}{V_{bus}} \quad (6)$$

$$D_{buck} = \frac{I_{charging}}{I_b} \quad (7)$$

in boost mode, BES discharges to supply power for charging for all EVs in charging station. For boost mode of operation in bidirectional converter D_{boost} is given as the duty ratio.

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$$I_b = \frac{P_{pv} - P_{tot}}{V_{bat}} \quad (8)$$

$$I_{discharging} = \frac{P_{pv} - P_{tot}}{V_{bus}} \quad (9)$$

$$D_{boost} = 1 - \frac{I_{discharging}}{I_b} \quad (10)$$

- **Voltage Control for Rectifier**

Using a PWM rectifier, voltage at DC bus is made constant at 110V by comparing it with V_{bus} and reference voltage 110 V

- **Boost Converter**

The boost DC-DC converter is a power converter that steps- up the input voltage while stepping down the input current. In the proposed system 110 V voltage from dc link step up into 500v & 900v for the charging ports of car and truck respectively.

- **Buck Converter**

The buck DC-DC converter is a power converter that steps- down the input voltage. In the proposed system 110 V voltage from dc link step down into 50v for the charging ports of bike.

IV. SIMULATION RESULTS AND DISCUSSION

For simulation study, three electric vehicles of 48V ,30Ah , 400V,100 Ah and 800V ,150 Ah with maximum 0f 1 hour with various rated power outlet for bike, car and truck respectively are connected to charge from 0% to 95% SOC . Based on the design and simulation in MATLAB some of the results are discussed below:

Figure 2 shows. Power from solar and total power required for EVs and BES power. In the figure 3 shows the solar production.In figure 3 will explain DC link voltage .These figure 4,5 and 6 shows the total voltage, current drawn and SOC of various categories of vehicle . In figure 7 and 8 shows output of buck and boost converter. Nominal discharge characteristics of various vehicle battery shows in the figure 9 ,10 and 11 .

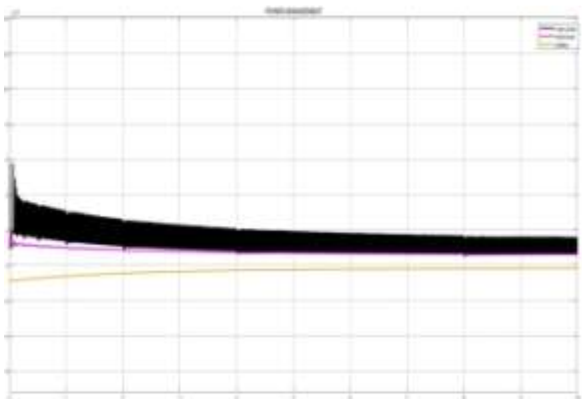

Fig.2. Power from solar and total power required for EVs and BES power.

Fig.3 110v DC link voltage

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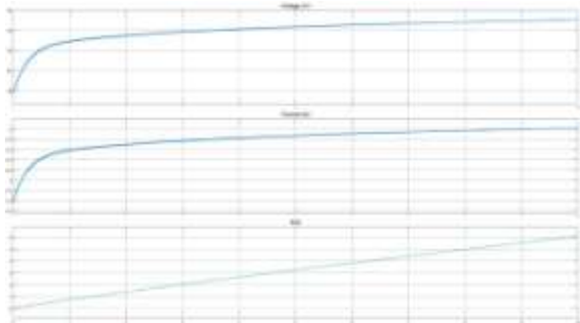

Fig.4 Total voltage , current drawn and soc of bike battery which is connected in port 1

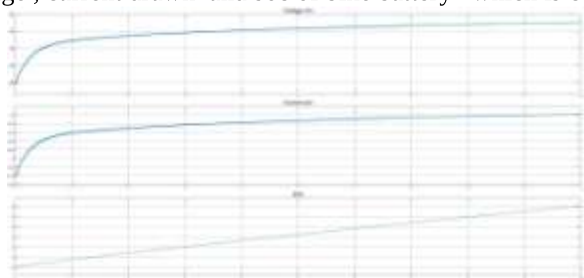

Fig.5 Total voltage , current drawn and soc of car battery which is connected in port 2

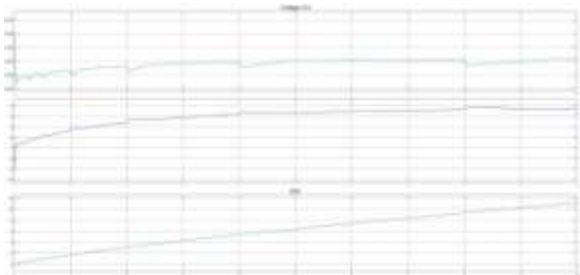

Fig.6 Total voltage , current drawn and soc of truck battery which is connected in port 3

Fig.7 Output of buck converter

Fig.8 Output of boost converter

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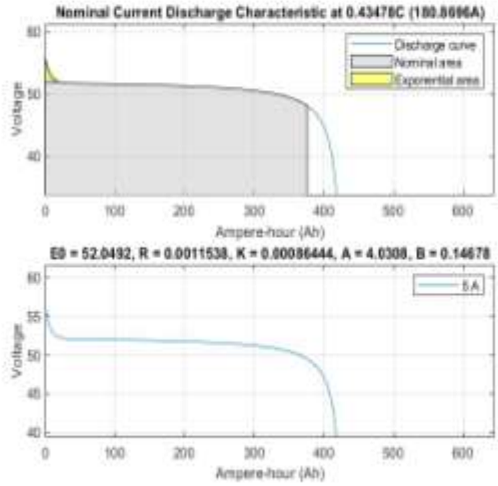

Fig.9 Nominal discharge characteristics of bike battery

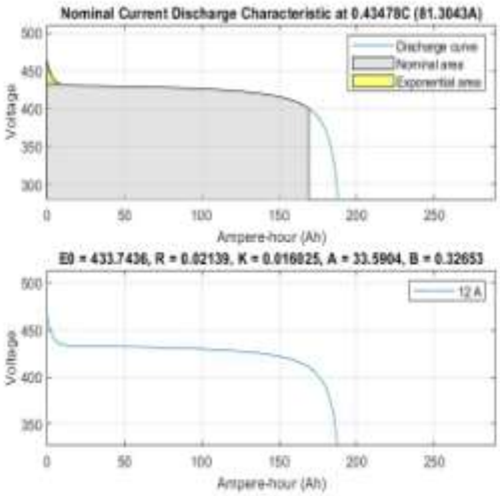

Fig.10 Nominal discharge characteristics of car battery

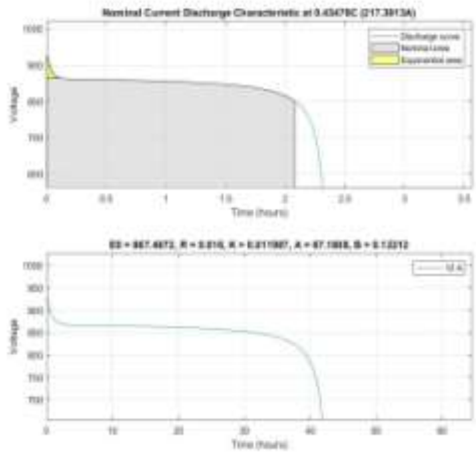

Fig.11 Nominal discharge characteristics of truck battery

V. CONCLUSION

In this paper introduces a charging station with solar, battery storage system with additional grid support for various rated power outlet for bike, car and truck gives a promising solution for satisfying charging requirements of all EVs connected throughout the day. Using PID, current control and voltage control desired power is obtained by maintaining the DC bus voltage constant for the station. The design and its power management of proposed station is explained and simulated in MATLAB/ Simulink considering 5 different modes of operation and studying about EV requirement thus making design and algorithm robust. The proposed will improve the over all efficiency of charging station also it will reduce power quality issues in the power system due to the charging of electrical vehicles.

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