Grid Connected Electric Vehicle Charging Station Using PV Source

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***Abstract*—This paper provides an insight of electric vehicle charging station which is supplied by three sources grid, photovoltaic system (PVS) and battery energy system (BES), and this system works in both conditions like shore and off-shore. Power grid, equipped with an AC/DC converter supplies a continuous and constant power to EV charging station through a DC/DC converters. BES used as a buffer by storing excessive energy at light load conditions and supplying it when needed. Control unit enables the bi-directional DC/DC converter for charging and discharging. MPPT (maximum power point tracking) technique is used to get the appropriate pulses for DC/DC converter to extract the maximum output power from PVS at different conditions. The proposed system is simulated in MATLAB/SIMULINK environment and results are discussed to validate the system.**

Keywords—Electric vehicle charging station, Grid and PV source, BES, Bi-directional DC/DC converter, DC/DC converters, MPPT.

I. INTRODUCTION

Carbon emission by vehicles using internal combustion engine (ICE) is one of the major factors in polluting the environment. ICE vehicles can be replaced by electric vehicles, as they have several advantages like energy efficiency, economy, and the most important advantage of EVs is that they are environmental friendly, there is no harmful gas emission like greenhouse gases and particulate matter polluting the environment, hence EVs help to improve the air quality [1].

EVs are adopted by many countries on a large scale in place of ICE vehicles and adoption of EVs as transportation means is following on upward trend [2]. Indian government announced several schemes and set targets in order to emphasis use of EVs, schemes like National Electric Mobility Mission in 2012 (target of deploying 5 to 7 million vehicles in the country by 2020), FAME (Faster Adoption and Manufacturing of Electric Vehicle) scheme in 2015 (target of reducing price of EV's), charging infrastructure project, and also announced in 2017 that ban of fossil fuel vehicles from 2030 [3].

EVs use electricity as their main source of power for driving operations, this electric power is provided by a battery which is placed in EVs. So, EVs need to charge at certain points when their battery discharges. Hence there is a need for an EV charging station to charge up its battery. EV charging station needs a constant supply for round the clock operation. Electric grid can be used, but it is difficult to control and function if the load at the charging station increased, and also there is no benefit if the grid is supplied by conventional energy sources [4]. So there is a need for renewable energy, solar energy can be used in this scenario because it is renewable and green. The integration of an electric vehicle charging station and renewable energy source should be widely employed as suggested by environmental experts [5]. Energy harnessed from solar photovoltaic (SPV) is not reliable as it can't work through the day and its utilization is subjected to climate condition. A battery energy system (BES) can be connected to make EV charging station more stable and dependable. In paper [6], a model has been proposed in which EV charging station is powered by solar PV and a battery storage system and when these sources are unavailable, the grid and diesel generator fulfil the requirement. In paper [7], a grid-connected EV charging station has been proposed in which with the help of control scheme load demand and load fluctuations on the grid have been reduced.

In this paper, the EV charging station is supplied by PVS and BES, and additional support is provided by grid supply for continuous operation. BES is charged up through PVS and grid supply, and discharged through load modeled as an EV charging station. The main objective is to attain the best method among PVS, Grid, and BES to provide continuous supply to the EV charging station, and prevent the potential stress on the grid and improve the stability and quality of delivering power. BES is equipped with a bi-direction DC/DC converter that responds at high power demand by supplying power to the charging station and absorbs extra power by charging the BES [8], [9]. The converters help to maintain constant output voltage and control the fluctuations by charging or discharging the BES, it is also used for energy time-shifting and load leveling. Time-shifting means it stores energy in off-peak time and gives supply to load during peak time. Load leveling means battery supports grid input power by providing some amount of power when the load demand is high. The controller provides the appropriate pulses to the battery side and grid side converters which helps in maintaining output voltage constant and to get the desired power demand to the charging station. Fig. 1 shows the block diagram of the proposed system. This proposed system is designed in MATLAB.

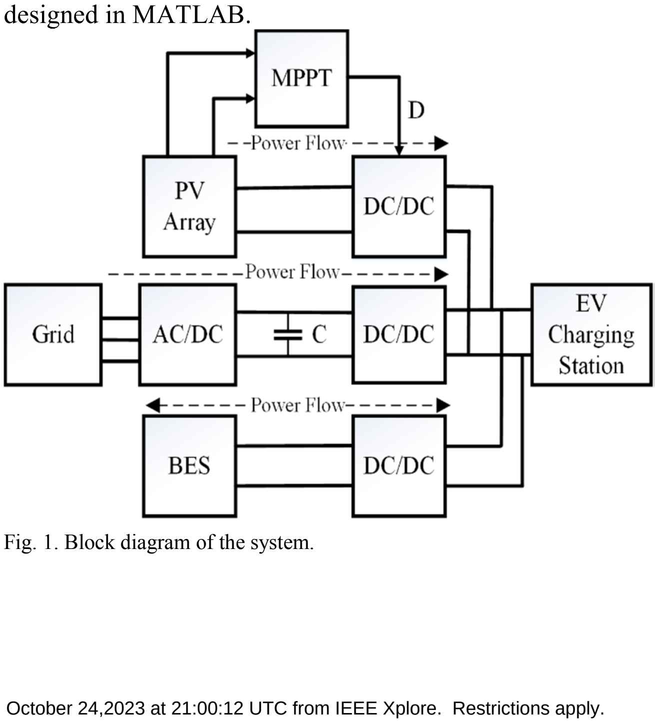

Fig. 1. Block diagram of the system.

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II. MODEL DESCRIPTION

A. PV Array

PV array is made of using several solar cells that work on the principle of photovoltaic effect. This PV array is modeled as a single diode model. A MATLAB function is formed as an ideal PV array that acts as a controlled current source, with output current. To make this system practical resistance is connected in series to the output of the controlled current source. There is an assumption that the PV array has negligible parallel resistance. The value of PV array open-circuit voltage, short circuit current, number of the solar cell, temperature and ideality factor is to be defined to a desired value to get the controlled current output. Under the short circuit current and open-circuit voltage condition [4], it can be concluded that

$$I_d = I_{SC}\left[1 - e^{\frac{(V_d - V_{OC})q}{N_S nkT}}\right] \tag{1}$$

Where I_d is output current of PV array, I_{sc} is the short circuit current, V_d is the diode voltage, V_{OC} is the open-circuit voltage, Ns is the number of solar cell in series, T is the temperature of solar cell in kelvin, n is represented by ideality factor of solar cell, k is the Boltzmann constant and the value of k is 1.3806488*10^-23 joule per kelvin, q is the electron charge and the value of q is 1.602176565*10^-19 coulomb.

B. MPPT with DC/DC converter

The power draws out from the PV array should be maximum under all operating conditions. MPPT (maximum power point tracking) techniques are used to extract the maximum power from the PV array by changing the duty ratio of the DC/DC converter. In this paper, the perturbation and observation (P&O) method is implemented for MPPT and buck type DC/DC converter is used to get the desired output voltage. In the P&O method, the maximum power point occurs when the derivative of power to voltage is zero, this derivative is negative at the right and positive at the left side of the MPP [7], [8]. In power-voltage characteristics, at MPP

$$\frac{\delta P}{\delta V} = o \tag{2}$$

P&O MPPT method with DC/DC buck converter is equipped to get a constant output voltage where DC/DC buck converter works in continuous conduction mode. An embedded MATLAB function is used for the P&O MPPT method and also for DC/DC buck converter.

$$V_{pv} = \frac{V_o}{D} \tag{3}$$

Where V_o, V_{pv}, and D are the output voltage, input voltage and duty ratio of the DC/DC buck converter. The perturbation step of P&O and output voltage of the DC/DC buck converter is set to the desired value. Different levels of short circuit current applied at a different time to get the appropriate value of current and voltage of PV array and also duty ratio of DC/DC converter, by doing this we get the maximum power point of the PV source.

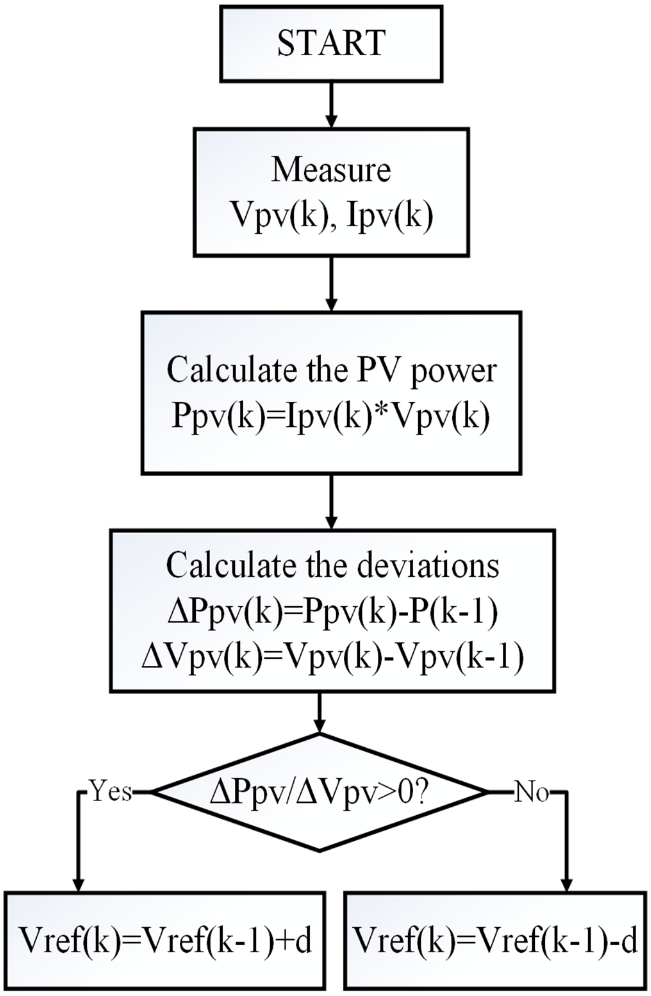

Fig. 2. Flowchart of P&O MPPT algorithm.

C. Battery energy system with bi-directional DC/DC converter

BES is used to store the electrical energy from grid and PV, and give supply to the load when load demand increases. A lithium-ion battery is used in BES because of its high power density, good energy density, long life cycle, low self-discharge, safety purposes, economically good and also there is a low risk of explosion if overloaded and short-circuited unintentionally [12].

A bi-directional DC/DC converter is used in BES. Bi-directional DC/DC converter acts in buck or boost mode, it works in buck mode when the battery charged through the grid and PV and in boost mode when the battery discharges through the charging station.

As shown in Fig. 3, a simple structure is used in the bi-directional DC/DC converter which has two ideal switch and the advantages of low cost, simple structure, high reliability and high efficiency [8], [9]. V_b is the battery voltage and V_{dc} is the output dc voltage. Switch S2 works in boosting mode and switch S1 works in buck mode.

Switch S_1 and switch S_2 are compliment to each other which means when switch S_1 is on switch, S_2 is off. When switch S_2 is on, switch S_1 is off.

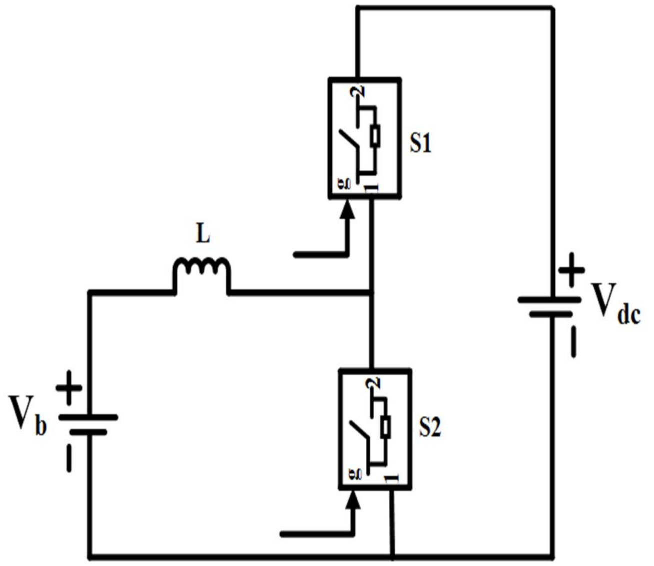

Fig. 3. Bi-directional DC/DC converter.

D. Control Unit

Two independent control schemes are used in the control unit to generate the pulses for the grid-side DC/DC converter and BES side bi-directional DC/DC converter. In the first control scheme, there are two reference battery current inputs, one for charging mode and second-one for discharging mode of battery, controlled by a switch. The value of BES current is subtracted from reference value and this result is closely tracked by a PI controller. The result of the PI controller is compared by a triangular signal from repeating sequence through a relational operator which is true for greater input. When the input of the relational operator from PI controller is less than input from repeating sequence block then converter works in buck mode and when the input PI controller greater, the converter works in boost mode.

In the second control scheme, two PI controller is used one for load voltage V_{dc} and the second one for grid current. Load voltage V_{dc} is subtracted from the reference value of output voltage and a reference value is generated for grid current using a PI controller. Then, the reference value of the grid current is subtracted from the grid current and given to the PI controller. The output of this controller and a triangular wave are compared through a relational operator which is true for greater value. In this way, pulses are given to the grid side DC/DC converter.

III. RESULT AND DISCUSSION

Grid-connected EV charging station using a PV source is modeled and simulated in MATLAB SIMULATION. 230V, 50Hz grid supply is used which is converted into DC with the help of an AC/DC converter and a constant power is delivered to the charging station through a DC/DC boost converter. In the starting, the PVS and grid give supply to the BES (battery charging) for 1 sec as well as give supply to the EV charging station. At 1 sec, the load at EV charging station increases and the increased load supplied by BES (battery discharging). The short-circuited current of PV array is stepped at 0, 0.75s and 1.25s and with help of P&O MPPT technique, the value of PV array current, voltage, power and duty ratio of DC/DC buck converter converse in such a way that PVS works at the maximum power point. The waveforms of PVS output voltage, current and power are shown in Fig. 4 (a), Fig. 4 (b) and Fig. 4 (c).

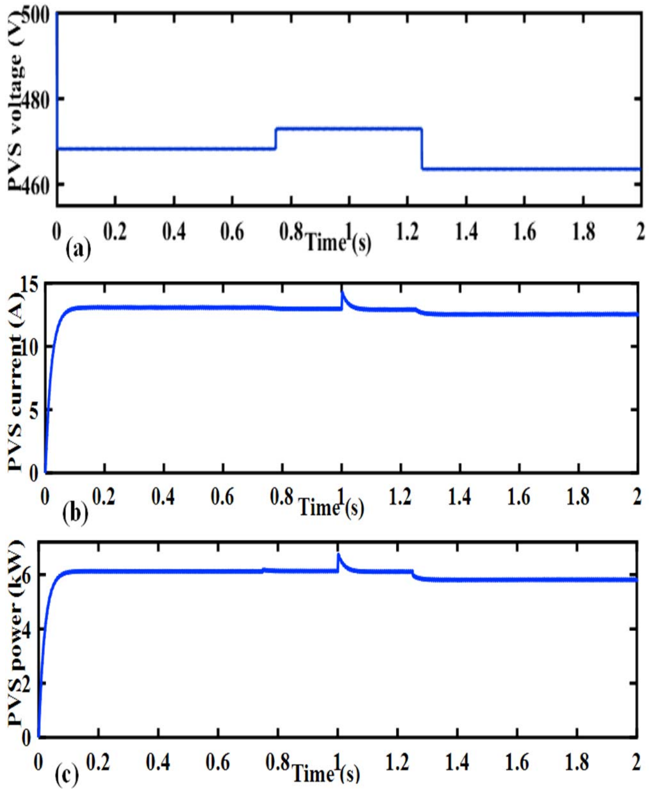

Fig. 4. PVS output waveforms of (a) voltage (b) current and (c) power.

As shown in Fig. 5, grid gives the continuous and constant supply so that EV charging station can work when the power from PVS is not available.

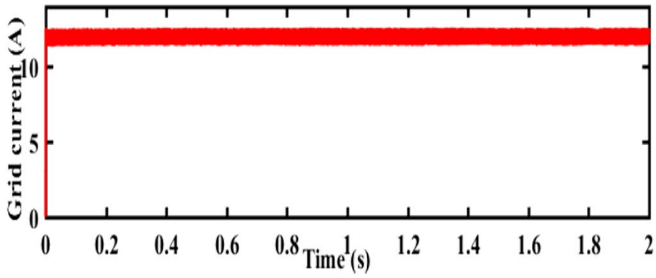

Fig. 5. Grid current.

In Fig. 6, charging and discharging current of BES is shown. The BES is charged up to 1 second, the charging station load is increased after one sec, and this extra power is provided by BES (when the load demand at the charging station increased it starts to discharge). This phenomena is done with the help of PI controller used in control scheme by generating appropriate pulses for the bi-directional DC/DC converter. So in this way, BES helps to reduce the electric burden on grid by providing the demand-supply.

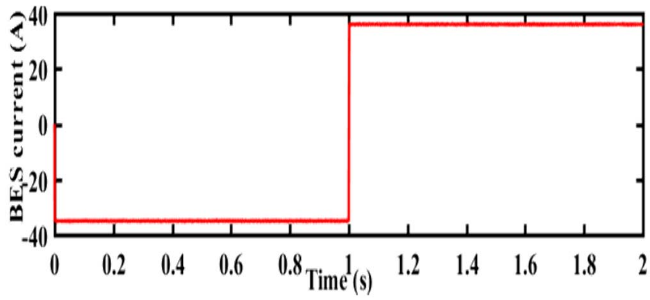

Fig. 6. BES current.

The EV charging station voltage is shown in Fig. 7 which changes when short circuited current of PV array is changed.

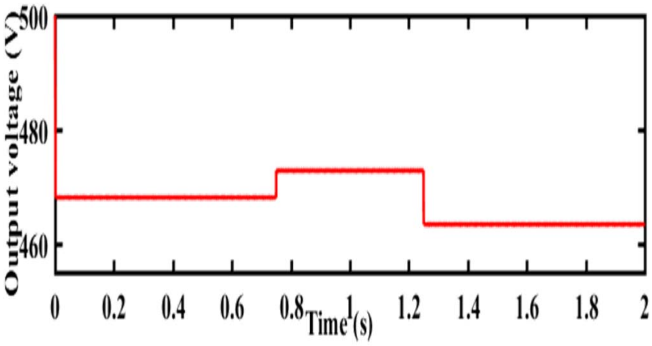

Fig. 7. Output voltage at EV charging station.

Fig. 8 shows a constant waveform of EV charging station current that changes at 1 second when the load demand is increased.

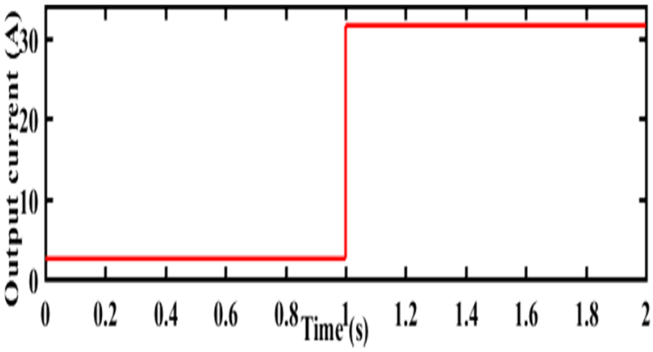

Fig. 8. Output current at EV charging station.

The EV charging station supplied through PV and grid sources till 1 second and the supplied power is 1.2 kW after 1 second EV charging station demand increases to 15 kW and the BES provides this increased power demand. In the Fig. 9, the waveform of EV charging station power is shown.

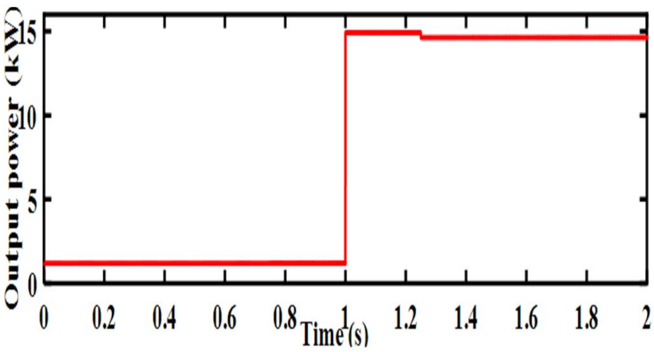

Fig. 9. Output power at EV charging station.

IV. CONCLUSION

In this paper, a grid connected PV based electric vehicle charging station with the use of BES is proposed. It is concluded that PV source along with BES reduces the burden on the grid and a stable and better quality power is delivered to the EV charging station. With the help of control scheme EV charging station receives nearly uninterrupted power which is used for electrical vehicle charging throughout the day. The simulation results have been shown to verify the power scenario from different sources to the charging station.

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