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# Electric Vehicle Battery Charging System with Solar PV system and PID Controller

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**Abstract- As infrastructure advances rapidly across the globe, the need for electricity has grown significantly. Among the potential renewable energy resources available, photovoltaics (PV) is a particularly alluring choice. By expanding the use of PV systems, it is possible to fulfil the required energy demands. To extract the maximum power from PV modules, the maximum power point tracking (MPPT) technique is implemented. The Perturb and Observe MPPT algorithm is employed to track the peak power point of the photovoltaic panel, even under fluctuating solar irradiance conditions. A battery charge controller is also utilized to monitor the battery's state of charge (SOC) and voltage levels. Additionally, a DC-DC boost converter has been designed and integrated with the PV model to validate the PV module's performance as a power source. The simulation results with the DC-DC boost converter, both with and without the PID controller model, show its effectiveness in increasing the input voltage to the necessary level for charging electric vehicle (EV) batteries.**

**Keywords- DC-DC converter, MPPT, Solar PV, Battery charging.**

## I. INTRODUCTION

The worldwide concern for environmental issues continues to persist and intensify, leading numerous countries to implement strict regulations on carbon emissions. Electric vehicles (EVs), which primarily run on electricity, offer a promising solution for replacing conventional gasoline and diesel vehicles [1]. The adoption of EVs can result in enhanced energy efficiency and cost savings, especially when the electricity originates from sustainable sources like solar and wind power. Furthermore, integrating EVs into intelligent grids can not only serve as an electrical load but also as a power asset.

A technique for portraying EVs as an additional load on the distribution network has also been studied. Several research efforts have focused on photovoltaic systems connected to the grid for EV charging. The configurations of these grid-connected systems eliminate the need for backup batteries [2]. However, the growing demand for EVs necessitates the expansion of charging infrastructure. The proliferation of EVs requires a substantial increase in the number of charging stations, which could potentially strain the distribution network in the coming years.

The term "off-grid PV system" or "standalone PV system" refers to a system that lacks connection to the primary grid. Such systems are well-suited for providing electricity to small communities and are particularly viable in remote regions. Off-grid setups are deemed appropriate for powering EV charging stations located in distant locations. To mitigate the impact of fluctuations in renewable energy generation, research has identified various methods for controlling the charging process of electric vehicles[3].

A discussion on EV fast-charging technologies is presented in. Backup battery banks play a vital role in energy storage for off-grid systems. A comparative analysis of Lead-Acid and Lithium-Ion Batteries for energy storage in off-grid systems is detailed. The charging control techniques for backup batteries in PV systems, aiming to enhance efficiency and overcome limitations of conventional controllers.

Notably, Lithium-ion batteries are highlighted for their superior energy storage capabilities, making them a preferred choice for solar charging stations that operate on renewable energy sources. The effective regulation of battery charge and discharge processes is essential for PV-Battery Energy Storage application to function optimally.

This paper concentrates on the design and managing of an independent photovoltaic (PV) system coupled with a battery bank intended for the purpose of charging electric vehicle (EV) batteries[4]. The essential criteria and power electronic converters essential for the EV charging facility are also delineated.

A design featuring a bidirectional converter is introduced to facilitate bidirectional power flow regulation, which in turn controls the charging and discharging processes of the battery bank. The incorporation of the PV system with the battery bank system is aimed to boost the power obtained from renewable energy sources, ensuring efficient regulation of electrical power for battery charging, optimizing solar panel power generation, and supplying a high-caliber DC output for electric vehicle charging. The PV module is positioned as the primary power supplier, whereas the battery bank operates as an auxiliary storage system[5].

An evaluation comparing the efficacy of lithium-ion batteries against lead-acid batteries as an emergency storage solution for the off-grid PV system is delineated. The proposed system has been developed and simulated within the MATLAB-Simulink environment, with the simulation outcomes showcasing the operational efficiency of the proposed module EV battery charging facility is good.

## II. DETAILS OF BOOST CONVERTER, SOLAR PV AND MPPT ALGORITHM

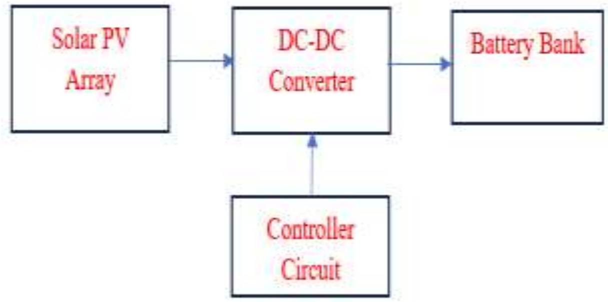


Fig. 1: Block Diagram of Battery with Boost converter

### 1. Photovoltaic Array

A photovoltaic cell is essentially a p-n junction formed on a small semiconductor wafer, showcasing nonlinear properties in current-voltage (I-V) and power-voltage (P-V) relationships. The PV cell's structure is comparable to that of a diode, as it features a P-N junction, which facilitates the transformation of photons into electrical energy by harnessing photons and converting them into electrons. This process occurs by absorbing solar radiation until a specific point is reached. When a load is connected, direct current flows through a PV cell until the irradiance ceases, requiring cells to be connected in parallel or series to obtain the appropriate voltage and current. Connecting cells in series results in high output voltage, while connecting them in parallel to increase high output current.

The model of a PV cell consists of a diode, resistances, and a current source (Ipv), representing the cell's I-V and P-V properties under standard test conditions (STC). The illustration demonstrates how the I-V and P-V properties of a PV cell change during charging at a constant temperature and irradiation levels[6]. Conversely, variations in the I-V and P-V properties occur when constant irradiance is combined with fluctuating temperature, as depicted in the image. The DC-DC converter is responsible for transferring the terminal voltage (V) generated by the PV cell to the load, the maximum power point tracking (MPPT) is crucial for enhancing system performance by tracking the

MPP and regulating the duty ratio of the converter. This adjustment to change operating point position and increased power generation from the PV array, as indicated by the characteristics of I Vs. V and P Vs V at specific irradiances shown in Fig.2.

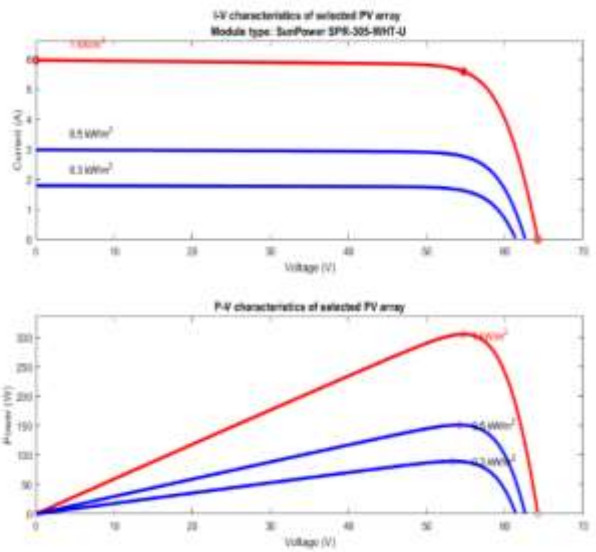


Fig.2. I-V and P-V characteristics of Solar PV array at various irradiance level and Specified temperature

**2. Details of DC-DC Boost Converter**

The DC-DC Boost converters operate as step-up converters, where the load voltage required exceeds that of the supply voltage. Boost converters are commonly utilized in both standalone and grid-connected solar power systems. The DC-DC boost, also referred to as the step-up converter, represents a modified version of the traditional boost converter, incorporating the interconnected inductor or switched capacitor with the integration of newly added switched capacitor inductors to achieve enhanced gain and efficiency[7].

Situated between the solar module and the batteries, converter employs a PWM control strategy to elevate the solar panel's voltage, even in instances where it falls below the necessary level for battery charging. The incorporation of a boost converter addresses this concern due to the high cost associated with solar cells. Among the four fundamental topologies for switched-mode DC-DC converters, the boost converter stands out[8]. The diverse topologies yield varied outputs. The fundamental DC-DC boost converter circuit is simulated with various load resistor values to facilitate the analysis of the impacts of load fluctuations on the output, particularly in terms of overshoot, rise time, and settling time.

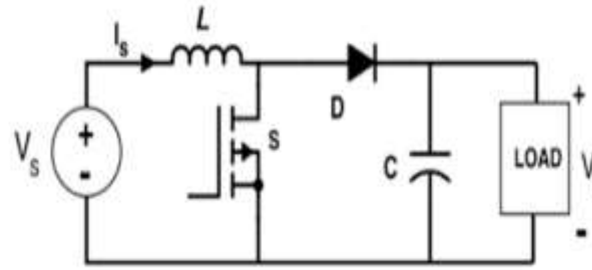


Fig.3. Boost converter with Load

**Calculation of Duty Cycle (D).**

The first step to calculate the switch current is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used because to increase the maximum switch current.

$$D = 1 - \frac{(Vin\ (\mathrm{Min})\mathrm{X\ Efficiency\ }(\eta))}{Vout}$$

Where,
Vin(min) = Minimum input voltage
Vout = Required output voltage
η = efficiency of the DC-DC Converter
The efficiency is also taken for the duty cycle calculation, because the converter has to deliver also the energy dissipated.
The output voltage and input voltage of the converter is expressed

$$\frac{\mathrm{Vo}}{\mathrm{Vin}} = \frac{1}{1 - \mathrm{D}}$$

Where,
Vin – Input or supply voltage
Vo – Output voltage
D - Duty Cycle

**Calculation of Inductor Current ($\Delta IL$).**

The change of Inductor current ($\Delta IL$) calculated by

$$\Delta IL = \frac{Vin(Min)\ X\ D}{Fs\ X\ L}$$

Where,
Vin (min) = Minimum input voltage

D = Duty cycle
Fs = Minimum switching frequency of the converter
L = selected inductor value

**Calculation of Inductance ($L$).**

The circuit inductance (L) is calculated by given formula

$$L = \frac{VsD}{\Delta IL\ F}$$

Where,
F- Operating frequency
$\Delta IL$- Change in inductor current

**Calculation of Capacitance ($C$).**

The value of capacitor can be selected from this equation $C = \frac{D}{\left(\frac{\Delta Vc}{Io}\right)F}$

Where, ΔVc is the change in capacitor voltage.
Fs = Switching frequency of the converter
D = Duty cycle
Io = Output current

**Maximum Power Point Tracking (MPPT) algorithm**

The performance of PV modules is influenced by varying solar irradiance levels and temperature conditions, leading to non-linearities in the current-voltage characteristics curve [9]. Consequently, the delivery of power to a load exhibit non-linear characteristic. As a result, operational efficiency is closely linked to the extent to which the actual operating point approaches the maximum power point. Moreover, the cost of installing a PV system is directly proportional to its operational efficiency.

Various methods available for Maximum Power Point Tracking (MPPT) can be categorized into two main groups: Mechanical and Electrical methods. In mechanical approaches, the orientation of PV panels is adjusted either manually or automatically based on predetermined angles aligned with the sun's trajectory throughout the day[10]. On the other method is, electrical techniques involve tracking the Maximum Power Point (MPP) using the PV-curve of the system, typically employing DC-DC converters with one or two conversion stages to achieve the MPP of the PV array. Various MPPT methods are currently available, including Fractional Open Circuit Voltage methods (FOCV), Fractional Short Circuit Current (FSCC), Perturb and Observe (P&O), Ripple Correlation Control (RCC), System oscillation, Temperature method, Current sweep, Curve fitting method, Incremental conductance, and Look-up table method.

From the above methods, FOCV and FSCC methods has serious drawbacks as they require either disconnecting the PV from the load or short-circuiting the PV terminals for a fraction of seconds, during this process significant energy losses occurs. Next method is P& O this method most widely used maximum power point algorithm and Perturb and Observe algorithm works by disturbing the solar PV array voltage and observing consequent PV power. The P&O is widely installed in commercial inverters and charge controller modules. This algorithm is greatly challenged because the problem of the trade-off between oscillations at steady-state and dynamic response condition[11].

An Incremental Conductance (INC) method is an alternative method of P&O. This method is contingent upon the fact that the derivative of the P-V curve is equal to zero at the point of maximum power production (MPP) This method suffers similar challenges of P&O: oscillations and tracking inefficiency. However, under certain frequencies, the power extracted by INC is higher than its P&O counterpart. The Ripple Correlation method (RCC) makes use of the power oscillations induced by the inverter to follow the MPP. It uses a high-pass filter to detect and pass power ripples. Although the RCC methods converges maximum power point faster in tracking the MPP, the initialization time is very low compared to the INC and P&O. The drawback of this method is its mathematical complexity[12]. An additional drawback to this method is its mathematical complexity. The temperature-based method is among the numerous MPPTs available methods. works based on the mathematical relationship exiting between the Solar PV module maximum power point voltage and temperature. Due to this it is very inefficient.

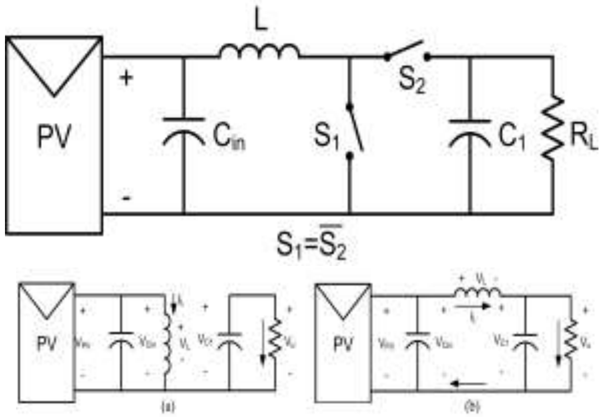


Fig.4. Modes of the DC-DC Boost converter (a) On-mode (b) Off-mode

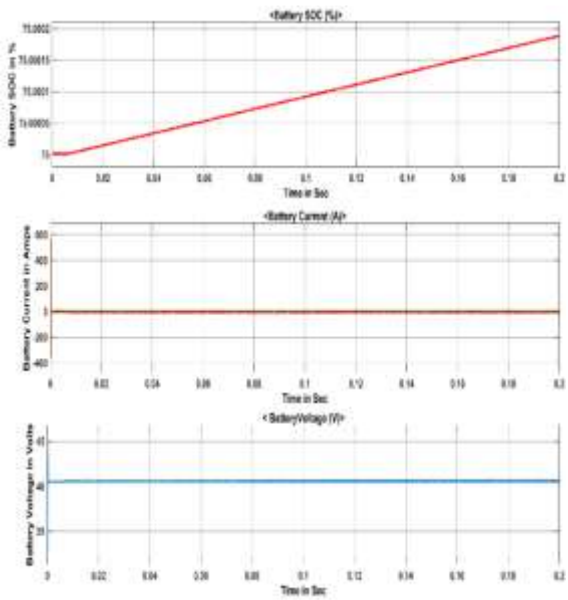


Fig.5. Battery Output Waveforms

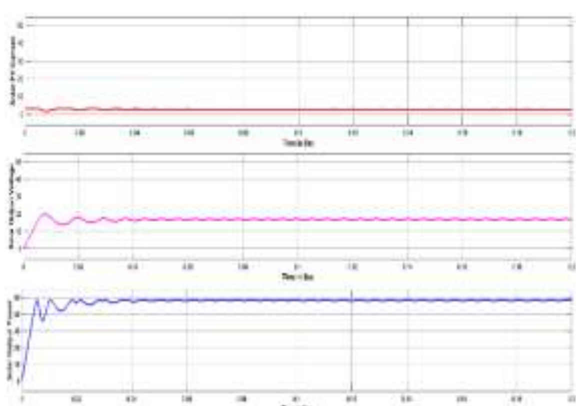

Fig.6. Solar PV Output Waveforms With PID Controller

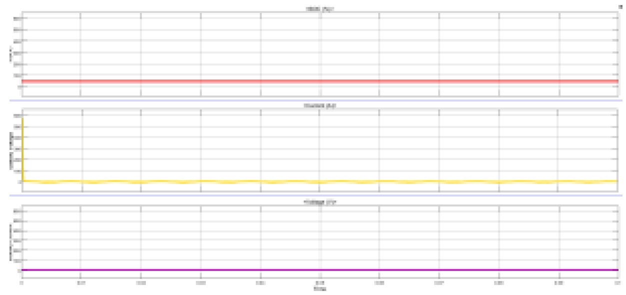

Fig.7. Solar PV Output Waveforms without PID Controller

## III. SIMULATION RESULTS AND DISCUSSION

**Table.1. Solar PV Model Specifications**

| Characteristics | Values |
|---|---|
| Array data | Parallel strings- 1 Series connected cells- 1 |
| Open circuit voltage ($Voc$) | 21.8 V |
| Voltage at maximum power point ($Vmpp$) | 17 V |
| Current at maximum power point ($Impp$) | 2.88 A |
| Short circuit current ($Isc$) | 3.11 A |
| Current at maximum power point | 8.13 A |
| Maximum power ($Pm$) | 49 W |
| EV battery | Lithium-ion 20V, 14 Ah |

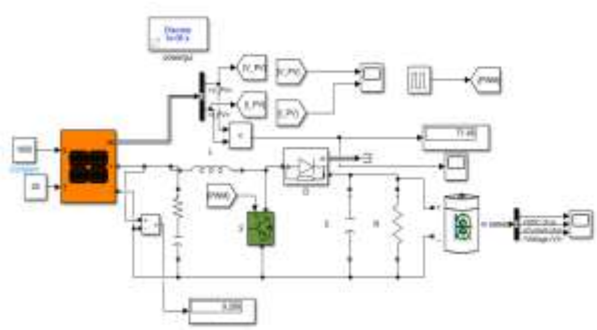

Fig.8. Simulation model of Withouts PID Controller

To confirm the effectiveness of the PV model, a dc-dc boost converter has been incorporated into the Electric vehicle battery system. Input source to the dc-dc boost converter given from Solar PV module. Initially, a dc voltage source is boosted using DC-

DC Boost converter. Subsequently, the PV model takes over as the power supplier to the load through the boost converter. The DC-DC Boost Converter consist of an inductor (L), a diode (D), a capacitor (C), a load resistor (R) and a (MOSFET) serving as the switching device. The MOSFET's switching signals are generated by a pulse generator, which adjusts the converter's dc output voltage. The Switching Frequency is 25Khz. The input voltage (Vi) is set to 17V, and the desired output voltage (V0) is 49 V. The simulation was conducted using the MATLAB/Simulink software environment to acquire the input and output characteristics. Using the given input and output voltage and power requirements of 49W, the value of the resistor, R is determined to be 32Ω. Additionally, the values of the inductor and capacitor are calculated to be 0.0136 H and 0.0000704 F, respectively.

## IV. CONCLUSION

The developed mathematical modelling of the PV panel is integration with dc-dc boost converter, MPPT algorithm and battery were presented in this paper. This Integration model was simulated in the MATLAB/Simulink Professional software environment. The EV charging station using the stand-alone PV system with an energy storage system to charge an EV battery has been successfully designed and simulated in this paper. The MPPT controller with P and O algorithm has been applied. The PV model given power source to the dc-dc boost converter. In this study DC-DC boost converter is to increase voltage level from solar panel to required charging voltage. The proposed scheme is similar way as MPPT charging technique where the maximum possible output is obtained by various MPPT algorithm. In this design the charging voltage of the battery is to be controlled using the voltage mode control principle so boost converter to achieve charging of battery when SOC is greater than 80% and this PV charging system is standalone system. The performance of the Simulink model also validated with a real commercial solar PV MPPT charge controller experimental setup. This validated model contributes to a better sizing of PV panel and battery energy storage for small and medium standalone PV systems.

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