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OPTIMIZED POWER MANAGEMENT FOR ELECTRIC VEHICLES THROUGH SINGLE-INDUCTOR MULTI-PORT CONVERTER DESIGN

[1]Y Yeswanth Kumar Reddy, [2]Dr V Maheswari
[1]P.G Student, [2]Professor
[1] Dept.of EEE, Sreenivasa Institute of Technology and Management Studies, Chittoor, India
[2] Dept.of EEE, Sreenivasa Institute of Technology and Management Studies, Chittoor, India

Abstract: This study describes a non-isolated multi-port power converter that combines energy sources such as solar Photo Voltaic and batteries in electric vehicles. The converter optimizes power distribution and enables for more flexible charging and discharging by taking from different sources. It enhances voltage levels using dual inputs and delivers two distinct output voltages to power a variety of Electric Vehicle loads, including motor drives and auxiliary systems. The converter's output may also be connected to the multilayer inverters, which reduces motor drive distortion and torque ripple. The converter design is simple and cost-effective. It operates in two different modes for efficient charging and discharging.

Index terms: Multi-port DC-DC converters, hybrid energy storage system, state-space modeling, electric vehicles.

I. INTRODUCTION

As electric vehicles become popular, there is a great demand for efficient power management systems that can combine several energy sources. Many Electric Vehicles combine battery storage with renewable energy, such as solar Photo Voltaic, to increase range and minimize dependency on the battery. However, controlling power flow of these sources and properly distributing to various vehicle components. Such as the motor drive and auxiliary systems, can be difficult. Traditional converters frequently have complex designs, limited control flexibility, and challenges like as source interference, which is known as cross-regulation.

To meet these difficulties, this research develops a novel multi-port DC-DC converter. The architecture combines solar PV and battery systems to give dual outputs that can provide both high-demand and low-power loads in the Electric Vehicles. The converter's streamlined form, which has some components, makes it more cost-effective and simpler to put into a tight location. It also connects to multilayer inverters, minimizing the noise and torque ripple in Electric Vehicle motors. This presentation develops how the proposed converter works and the possible benefits for Electric Vehicle applications.

II. LITERATURE SURVEY

Electric vehicle power electronics have advanced dramatically in recent years, with an emphasis on boosting efficiency and reducing system complexity. Multi-input converters have been identified as an efficient approach for increasing system efficiency while decreasing design complexity [1]. Dual-current pump modules have been shown to improved transient response in DC-DC converters [2]. Furthermore, multipurpose non-isolated dual input-output converters have been designed particularly for EV applications to improve performance (Author [7]). Multi-output DC-DC converters are required to manage many power sources, such as batteries and super capacitors, resulting in effective power distribution [4]. Non-isolated multi-input converters have shown useful in properly integrating renewable energy sources [10].

Inverter technology has also advanced tremendously, particularly in the form of multilevel inverters. Asymmetrical multilevel inverters are known to reduce component stress and improve efficiency [8]. Furthermore, many inverters have shown the capacity to increase power quality while lowering costs in Electric Vehicle applications [12]. In terms of energy management, effective energy management methods have been developed to balance energy sources and increase Electric Vehicle range [5]. Hybrid power systems which contains fuel cells, batteries, and super capacitors provide superior energy management capabilities [6]. High step-up converters with linked inductors have proven useful for renewable energy integration, meeting the demand for higher voltage levels in a different application [9]. Finally, bidirectional converters have received attention for their capacity to properly balance battery charge and discharge, particularly in Vehicle-to-Grid applications [13].

III. PROBLEM IDENTIFICATION

Existing converters confront major challenges due to their complexity, size, and high cost. Interference between power source is a common cause of system instability. Furthermore, these converters lack flexible control systems that allow effective charging and discharging, which is crucial for advanced applications. The large number of components not only increase total costs, but also takes up a lot of room, making the system less compact. Connecting such converters with multilayer inverters is difficult, reducing motor performance. In addition, they have limited efficiency due to energy loss and interference. Furthermore, harmonics produce higher noise and torque ripple in motors, which reduces performance and reliability. These challenges underscore the need for novel methods to overcome the limits of present converters.

IV. MODELLING OF PV ARRAY

To combine a Photo Voltaic array with a multi-port DC-DC converter and a battery, the Photo Voltaic array will supply DC power to the system, while a Maximum Power Point Tracking controller will guarantee that it gives the most energy possible. The multi-port converter will give two inputs: one from the PV array and another from the battery. It will minimize electricity from both sources and distribute it to several outputs according on the requirements of the electric vehicle loads. PWM signals will control the switching of the converter to change the voltage levels of the PV array and battery, guaranteeing smooth charging and discharging. When the PV array generates more power, the battery charges; when the PV array cannot provide enough power, the battery discharges to satisfy the load needs. The coordination between the PV array and the battery, which is regulated by PWM control and the converter, ensures that the Electric Vehicles receives efficient power flow.

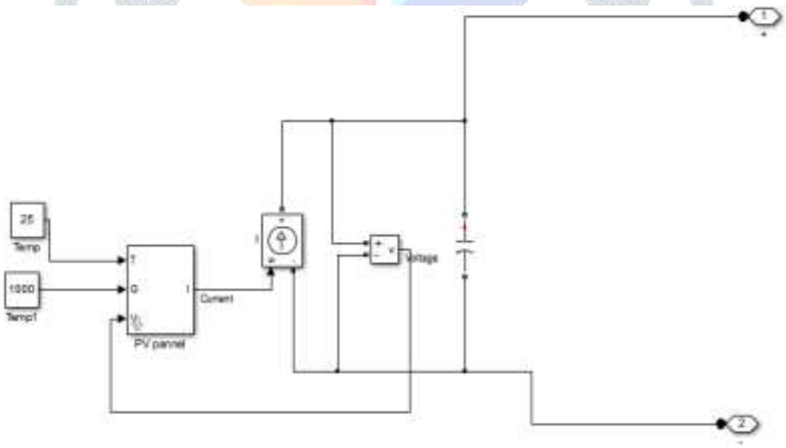


FIGURE 1. PV ARRAY

a. Equivalent Circuit of a PV Cell

A single PV cell may be described as an equivalent circuit, which comprises:

- A current source (Iph) represents the photocurrent.
- The diode (D) represents the p-n junction.
- The series resistance (Rs) accounts for internal resistances.
- The parallel resistance (Rp) represents leakage currents.

b. Output Current of a PV Cell

The output current (IPV) is given by:

$$I_{\mathrm{PV}} = I_{\mathrm{ph}} - I_0 \left[\exp\left(\frac{q(V_{\mathrm{PV}} + I_{\mathrm{PV}}R_s)}{nN_skT}\right)\right.$$

Where:

- Iph: Photocurrent (depends on irradiance and temperature).
- I0: Diode saturation current.
- q: Electron charge (1.6×10^{-19} C).
- VPV: Output voltage of the PV cell.
- n: Ideality factor of the diode.
- Ns: Number of series-connected cells.
- k: Boltzmann constant (1.38×10^{-23} J/K).
- T: Temperature in Kelvin (K=°C+273.15).
- Rs: Series resistance.
- Rp: Parallel resistance.

c. Photocurrent (Iph**)**

The photocurrent depends on irradiance and temperature:

$$I_{\mathrm{ph}} = [I_{\mathrm{SC,STC}} + K_i(T - T_{\mathrm{STC}})]\,\frac{G}{G_{\mathrm{STC}}}$$

Where:

- $I_{SC,STC}$: Short-circuit current at standard test conditions (STC).
- Ki: Temperature coefficient of short-circuit current.
- T_{STC}_: Reference temperature (25°C).
- G: Solar irradiance (W/m^2).
- G_{STC}: Reference irradiance (1000 W/m^2).

d. Diode Saturation Current (I_0**)**

The saturation current of the diode is:

$$I_0 = I_{\mathrm{SC,STC}} \exp\left(-\frac{qV_{\mathrm{OC,STC}}}{nN_skT_{\mathrm{STC}}}\right)$$

e. Power Output

The power output (PPV) of the PV array is:

PPV=VPV*IPV

V. PROPOSED MULTIPORT CONVERTER

The proposed multi-port converter employs a non-isolated architecture to connect two energy sources—a solar photovoltaic (PV) array and a battery—with dual-output loads. This converter uses a single inductor, which dramatically reduces component count, simplifies the circuit, and increases cost-effectiveness. The solar PV array is the major renewable energy source, with the battery serving as an energy storage device for load balancing and backup power supply.

The converter may have two output voltage levels, accommodating both high-power loads like motor drives and low-power auxiliary loads like lighting systems. It has two modes of operation: charging mode, in which the solar Photo Voltaic powers the loads while also charging the battery, and discharging mode, in which both the solar PV and the battery deliver electricity to the loads. This flexible and adaptable design is also compatible with multilayer inverters, resulting in which reduced harmonic distortion and torque ripples in electric vehicle applications. Overall, the suggested converter provides efficient power conversion, easy energy management, and dependable operation for hybrid energy systems.

a. PWM SIGNALS

PWM signals ensures the switching of the multi-port DC-DC converter's components, such as MOSFETs or IGBTs, regulating the flow of power from the Photo Voltaic array and batteries to the EV's systems. The PWM signal is a periodic square wave that turns on and off the converter's components at more frequency. The duty cycle, of the signal is "on" during each cycle, is the most important aspect of Pulse Width Modulation.

- maximizing the duty cycle allows more power to flow through the converter, which can adjust the voltage from the PV array to the desired level.
- minimizing the duty cycle decrease the power flow and adjusts the voltage correspondingly.
- The PWM control stabilizes the voltage from the PV array and battery, which allows the electric vehicle's motor, lights, and other components to work properly. By modulating the PWM signals, the converter may also regulate the charging and discharging of the battery, ensuring that the system runs easy and avoids overcharging. PWM signals plays an important role in optimizing power distribution and maintaining efficient operation in the system.

b. BATTERY

When the Photo Voltaic array produces high electricity, such as during the day, the battery can stores it. When the Photo Voltaic array cannot produce enough electricity, such as at night or on cloudy days, the battery gives energy to the electric vehicles. The multi-port converter controls the charging and discharging of the battery, ensuring that it is charged when there is high energy and supplies power when needed. This way, the battery ensures that the vehicle has a constant power source even when there is insufficient solar energy.

The proposed multi-port converter is intended to allow multiple output loads, making it ideal for a wide range of applications in electric vehicles. The initial load output is designed for high-power applications such motor drives, which are used for vehicle propulsion. The second load output supports low-power auxiliary device such as lights and other onboard electronics. This dual-load capacity generates optimal energy consumption from both the solar PV array and the battery, allowing the system to effectively control power distribution based on the needs of the associated loads. The converter's ability to produce several voltage levels at its outputs allows it to be compatible with a wide range of load needs, boosting the overall flexibility and performance of the electric vehicle powertrain.

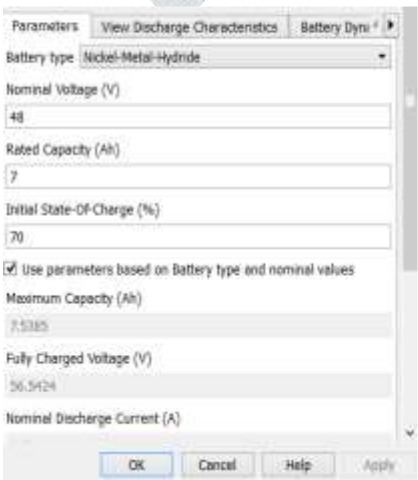


FIGURE 2. BATTERY PARAMETERS

VI. SIMULATIONS RESULTS

The simulation results show how the multi-port DC-DC converter interacts with the solar PV array, batteries, and loads in an electric vehicle. Key elements such as Photo Voltaic voltage, Photo Voltaic current, battery voltage, battery State of Charge, and output voltages are investigated to better understanding how the power is controlled in the system. The data aid in determining how the converter adjusts the power from the solar array and batteries to serve the motor drive and auxiliary loads. These findings are crucial for determining how effectively the system performs in different conditions and ensuring efficient power distribution.

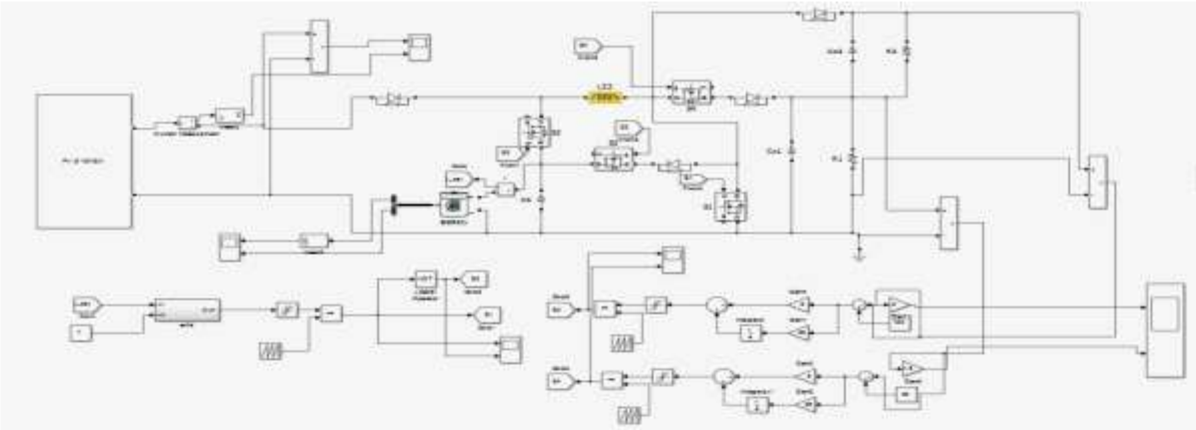
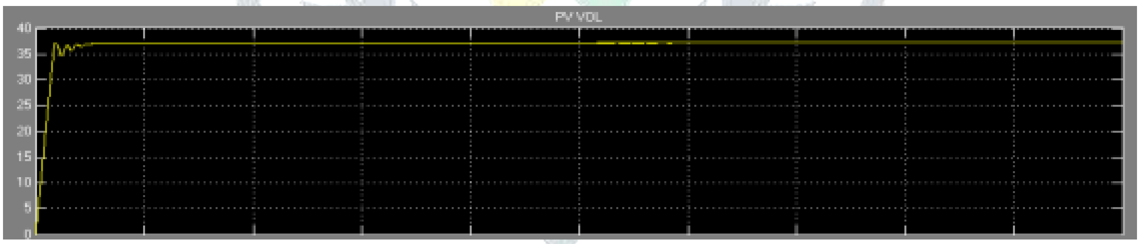


FIGURE 3: SIMULINK

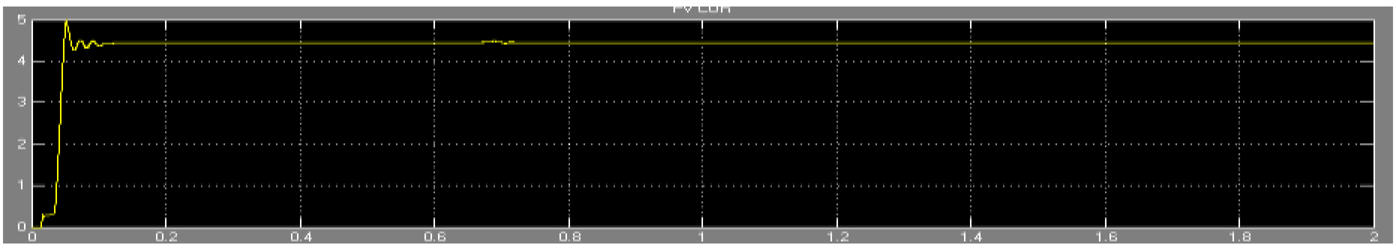
a. PV VOLTAGE

PV voltage is the voltage generated by a solar panel, which converts sunlight into electrical energy. The PV voltage varies with the intensity of sunlight hitting the solar panels. During peak sunlight hours, the PV array produces more voltage, whereas on overcast days or in low-light situations, the voltage is lower. The PV voltage is crucial because it determines how much energy can be collected from the solar array. This voltage is then used to either directly power the vehicle's systems or to charge the battery, depending on the vehicle's energy requirements at the moment. The multi-port DC-DC converter often modulates the PV voltage to match the voltage requirements of the battery or the load.



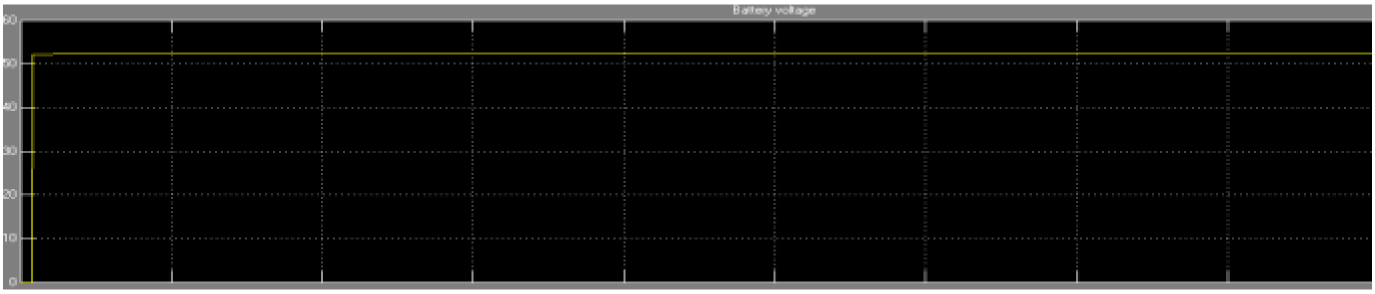
b. PV CURRENT

PV current is the electrical current produced by solar panels when they convert sunlight into electricity. It varies depending on how much sunlight the panels get, with more current produced on light days and less on gloomy days. This current is used to charge the battery or power the vehicle's systems, and the converter modulates it to provide the appropriate amount of power as needed.



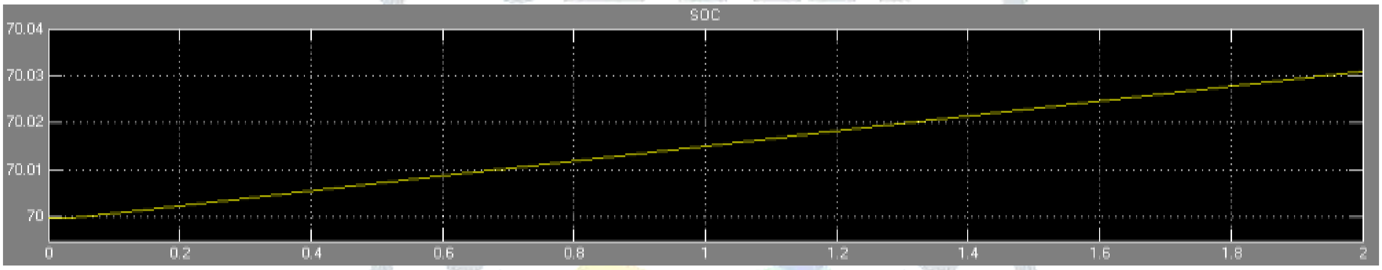
c. BATTERY VOLTAGE

Battery voltage refers to the battery's voltage level, which changes depending on whether it is charged or discharged. When the battery is charged by the solar Photo Voltaic array, the voltage increases. When it discharges, provides electricity to the electric vehicle's loads, the voltage drops. The battery voltage is a vital indicator of the battery's charge state and helps to govern that the battery does not overcharge excessively, which might cause harm. The multi-port DC-DC converter modulates the battery voltage, ensuring optimal charging and discharging cycles.



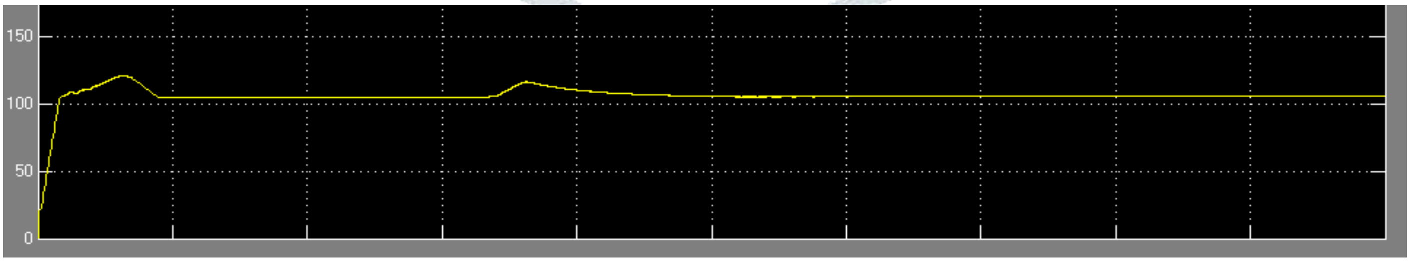
d. BATTERY SOC

Battery SOC (State of Charge) is the proportion of the battery's capacity that is currently charged, with a range of 0% to 100%. It indicates how much energy the battery has stored at any particular time. The State of Charge improves as the battery charges from the solar PV array or other devices, while reducing when the battery distributes power to the loads. Monitoring the SOC is crucial for maintaining the battery's health and preventing overcharging or excessive discharge. The multi-port DC-DC converter uses SOC data to determine when to charge or discharge the battery for increasing performance and longevity.

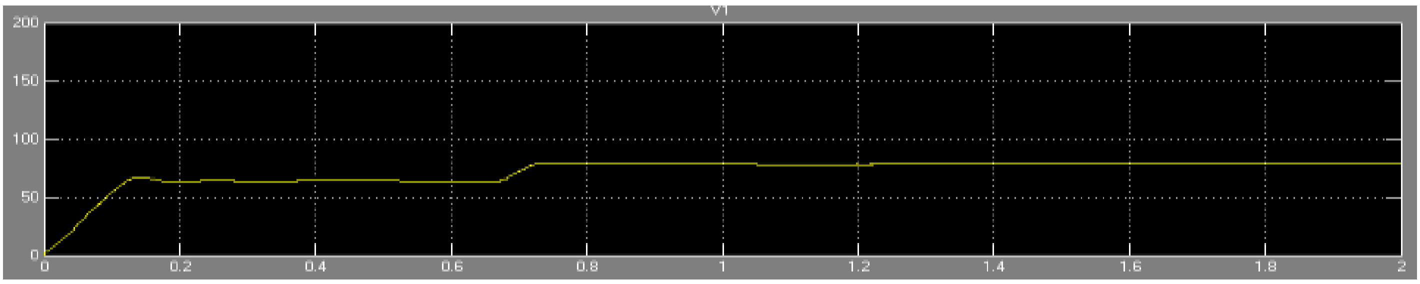


e. OUTPUT VOLTAGES 1&2

The voltage delivered by the multi-port DC-DC converter to power a high-power load, usually the motor drive in an electric car. The motor drive requires a specific voltage, which is typically more, to function effectively and propel the vehicle. The converter adjusts the output voltage to meet the motor's power requirements, resulting in smooth operation. This voltage is often modified to preserve the motor's efficiency and performance, with adjustments made based on load requirements. The output voltage is crucial for allow that the vehicle's propulsion system operates efficiently, without overloading.



The voltage delivered by the multi-port DC-DC converter to low-power loads in the electric vehicle, such as lights, auxiliary systems, or control circuits. These components are demand lower voltage than the motor drive. The converter changes the output voltage to give the required power to many systems, ensuring that they run effectively and without wasting of energy. Output Voltage 2 allows that vital but low-power equipment, such as lights and sensors, receive the necessary voltage for smooth operation.



VII. CONCLUSION

Finally, the multi-port DC-DC converter, when combined with the solar PV array and battery, provides an effective power management solution for electric vehicles. It provides renewable energy from solar panels and stores it in the battery, ensuring that the vehicle's motor and other components receive an adequate supplyappropriate electricity. This method minimize dependency on external power devices, improves energy efficiency, and boosts the overall performance of electric vehicles while remaining cost-effective.

VIII. FUTURE SCOPE

In the future, this project may be extended to accommodate more energy sources such as wind or grid electricity. The system may also be made more efficiency, allowing for quicker charging and improved performance under many situations. Additional advancements can help make electric vehicles more sustainable and energy-efficient, as well as better integrated into a different vehicle types.

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