A SINGLE INDUCTOR MULTI-PORT POWER CONVERTER FOR ELECTRICAL VEHICLE APPLICATIONS.

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Abstract - Electric Vehicles (EVs) are emerging as a sustainable alternative for eco-friendly transportation, significantly reducing harmful emissions and dependence on fossil fuels. However, a major challenge in EV technology lies in the efficient utilization and management of multiple energy sources, such as batteries and renewable sources like solar power. This paper proposes a novel Single Inductor Multi-Port (SIMP) DC-DC converter specifically designed for EV applications to address these challenges.

The proposed converter enables efficient integration of multiple DC power sources while utilizing a single inductor, thereby reducing the overall size, weight, and cost of the power conversion system. The system is designed as a dual-input SIMP converter connected to both a solar panel and a battery, supplying energy to the main traction system through an inverter and electric motor, as well as to auxiliary loads. The converter operates in multiple modes, including solar-to-load, battery-to-load, and solar-to-battery charging, ensuring optimal power distribution with minimal energy loss.

A key feature of the design is the time-multiplexing of a common inductor, which facilitates energy transfer between different ports. This allows dynamic source switching and efficient energy sharing without the need for multiple bulky inductors or transformers. Simulation results obtained using MATLAB/Simulink validate the proposed design, demonstrating stable operation, effective voltage regulation, and high conversion efficiency under varying load and input conditions.

The converter performs efficiently under both light and heavy load scenarios, making it suitable for real-time EV applications with fluctuating power demands. Additionally, the reduced component count leads to lower electromagnetic interference (EMI), improved power density, and enhanced thermal performance. Overall, the proposed SIMP converter represents a significant advancement in compact and intelligent power management systems for electric vehicles.

Keywords—Single Inductor Multi-Port Converter (SIMP), Dual-Input DC-DC Converter, Solar PV Integration, Battery Management.

1. INTRODUCTION

EVs (Electric Vehicles) are gaining to be a primary Eco-friendly option to the traditional vehicles powered by internal combustion engines because of environmental concerns and the gradual extinction of fossil fuel reserves. The effective power management system design, which should be efficient, small, and inexpensive, that can control the multiple energy sources, is one of the key areas of the development in the field of EV technology. Usually, in the present-day EVs energy comes primarily from a battery pack, but the application of solar photovoltaic (PV) panels as a renewable source can additionally increase energy efficiency and decrease the dependence of the grid. In order to achieve such a multi-source integration, this project has a plan for a Single Inductor Multi-Port (SIMP) DC-DC power converter that connects together many energy sources, chiefly a battery and a solar PV panel, through a single inductor. The power converter will be operationally feeding the traction motor through an inverter and will also be supporting auxiliary loads. The application of the single inductor in the converter helps to reduce hardware complexity, and weight, and volume compared to traditional multiple-converter systems which results in a reduction of the overall cost of the EV powertrain. The proposed converter offers the opportunity of bi-directional energy flow which means that the battery can either provide or consume energy depending on the power availability. stochastic and deterministic models to determine driving conditions and solar availability.

Below are the advantages

1. The overall architecture is compact and. It is also lightweight: Perhaps multiple converters are being used, but the single magnetic component reduces both the size and weight of the system permanently.
2. Cheap and cheerful: The fewer the components, the less the cost of manufacturing and maintenance.
3. Efficient: The Optimized Power Sharing and the fewer conversion stages improve the energy efficiency of the entire system thereby a very high efficiency is achieved.
4. Power flow in both directions: The battery charging and discharging occurs which in turn enhances the regenerative braking and energy recovery.
5. Integration of solar energy: The entire process now has a great deal of flexibility—solar PV is now not just an auxiliary source but has been fully integrated thus reducing the inverter dependency.
6. The Architecture is Scalable: It can easily be modified for different EVs including two-wheelers, cars and even electric buses.
7. Improved Reliability: Components are fewer and thus the possibility of failure is lesser while the control strategy becomes easier.

The SIMP converter parts list consists of just one single component Inductor which allows for cheaper and more compact electric vehicle system designs with fewer components. There are solar panels and batteries available as different energy resources and power is managed in a flexible and efficient way through this. It also controls the power flow in both directions which simplifies the regenerative braking and energy recovery process. Its architecture is such that conversion losses are limited thus resulting in a high overall efficiency. Solar PV integration not only reduces grid dependence but also makes the use of renewable energy more eco-friendly.

2. SYSTEM ARCHITECTURE AND DESIGN

2.1 Overall System Design

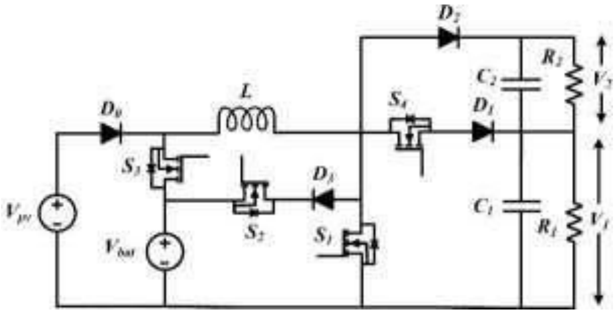

Fig1: Proposed multi-port converter with two inputs and two outputs

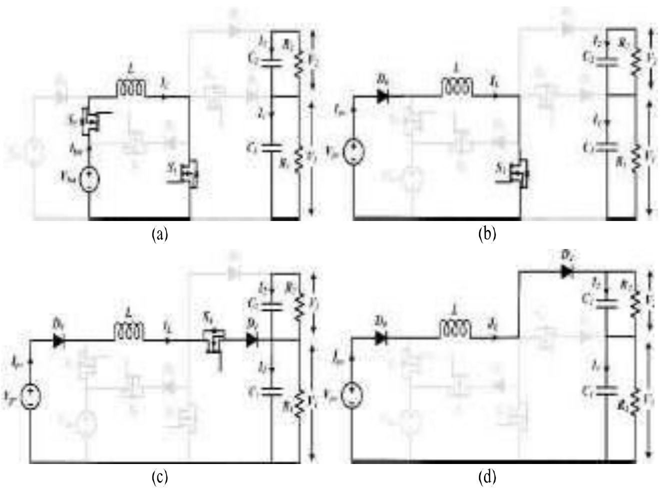

Fig2: Battery discharging modes: (a) Mode-1 (b) Mode-2 (c)Mode-3 (d) Mode-4.

The illustration provided displays the four operational modes of the Single Inductor Multi-Port (SIMP) DC-DC Converter, which is a device that allows to control the power flow between different energy sources (such as a solar panel and a battery) and the load in an electric car. During the first mode (top left corner), the solar panel and the battery together supply electricity to the load. Here, S_1 and S_2 switches are activated, and the current from both sources flows through the single inductor, thus meeting the energy demand at high times. In the second operating mode (top right), the battery is the only source to power the load while the solar input is turned off or is too low to be used; this is done by keeping S_1 ON and S_2 OFF. The current goes from the battery through the inductor to the load through diode D_1. The next mode (bottom left) allows the solar panel to power the load only, with S_2 ON and S_1 OFF, using the same inductor path to transfer energy. This step lengthens battery life when solar energy is available. Ultimately, the fourth mode (bottom right) presents the situation where the solar panel is directly charging the battery as the load is not drawing power. In this case, the current flows from the source of solar energy through the inductor to the battery, and the battery is charged via switch S_3 and a diode. All these working modes signify the converter's adaptability in power sharing, proficiency in using renewable energy, and cutting of components by using only one inductor in all power paths.

This converter topology allows independent regulation of two output voltages using one inductor shared among several power sources. In the first mode (top-left), the solar PV source feeds the power into both outputs V1V_1V1 and V2V_2V2. The current IpvI_{pv}Ipv coming from the PV will flow through diode D_0 and the inductor L, and it stores energy. Switch S_1 is turned ON to transfer this energy to capacitor C1C_1C1 (output V1V_1V1). Concurrently, it provides current to C2C_2C2, output V2V_2V2, through resistor R2R_2R2, and hence, active delivery of power to both outputs is possible. In the second mode (top-right), the battery source Vb at V_{bat}Vb at becomes active when the solar input sleeps. Here, switch S_2 turns ON, and energy is transferred from the battery through L and diode D_3, charging the first output capacitor C1C_1C1 and powering V1V_1V1. Hence, this mode is used for battery-powered operation of output In the third mode (bottom-left), the PV source continues charging the second output V2V_2V2 alone. Switch S_4 connects the inductor with the output capacitor C2C_2C2, and through diode D_1, the current is guided correctly. Therefore, power can be routed to the second output alone if needed. Finally, the fourth mode of operation, bottom-right, reflects the case where the battery feeds both the outputs through the inductor.

2.2 Hardware Architecture Design

The Single Inductor Multi-Port Converter Applications (SIMPC) hardware architecture proposed for electric vehicles comes with a power-processing stage that connects the driving and auxiliary systems of the vehicle to several energy sources. Three main hardware units are presented in the architecture, which are: the solar PV panel, the battery pack, and the single-inductor multi-port DC-DC converter. The solar PV panel acts as an additional renewable energy input whereas the battery is the primary storage device. The converter is the common point for all sources and it carries out power conditioning, regulation, and bidirectional energy transfer using a single inductor that is shared across all ports. The multi-port converter then directs its output to two major subsystems. The first output goes to the inverter whose job it is to change the regulated DC into AC for the electric motor to run. The motor output is passed through the transmission assembly where it is mechanically transferred to the wheels. This hardware structure allows the PV panel, battery, and load ports to act with power flow control coordinated within a single integrated converter platform. The outcome of this system is an efficient energy distribution and stable EV operation even when there are fluctuations in load and source conditions.

Primary Hardware Components:

- Dual Power MOSFET Drive
- Rshunt
- MOSFET
- Current Sensor

3. IMPLEMENTATION METHODOLOGY

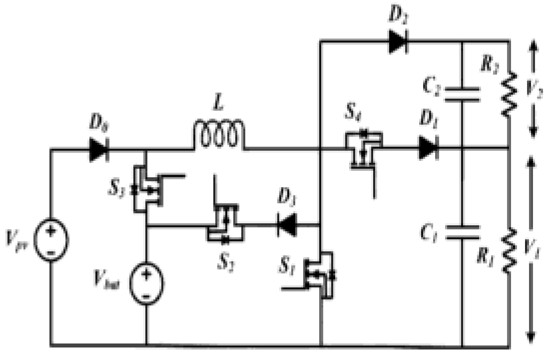

FIG 3: Connection Diagram of a Single Inductor Multi-Port Power Converter for Electric Vehicle Applications

The Single Inductor Multi-Port Power Converter development went hand in hand with a reliable performance-oriented methodology that was strictly applied for electric vehicle applications. Analyzing the power to be shared between the different ports was the initial step, and thus the range of operating conditions of the converter was established. For example, the different scenarios that were conceived included charging the battery with solar energy, directly powering the load, or supporting the system during changes in the driving conditions. The topology that was selected was an appropriate one in which a solitary inductor is conventionally shared among several ports to minimize the size, cost, and component count. Every single switch and diode in the circuit was the subject of detailed analysis in order to identify the modes of power flow and thus ensure that the converter could handle both the unidirectional and bidirectional energy transfer. Mathematical modeling was performed to understand the dynamic behavior of the converter after the topology was fixed. The modeling included the establishment of averaged state-space equations and small-signal models to characterize the voltage and current response to the duty cycle change. The models were very crucial in the developing of the control strategy which was necessary to output voltage regulation, safe battery interface management, and incorporation of maximum power point tracking for the solar source.

3.1 Experimental Setup and Validation

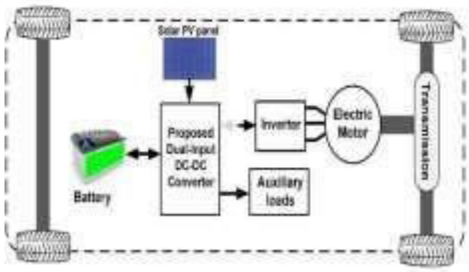

FIG 4: Block Diagram of a Single Inductor Multi-Port Power Converter for Electric Vehicle Applications

The block diagram illustrates the power distribution in an electric vehicle with the proposed Single Inductor Multi-Port Power Converter at the center. There are two main sources of energy for the system: one is the battery and the other is the solar panel. Both sources connect to the new converter that processes multi-port power using controlled bidirectional and unidirectional pathways. The converter takes in dirty power from the battery, the PV panel, and the vehicle subsystems and then conditions and regulates it. The regulated DC output from the converter goes to the inverter, which turns the DC into AC for the electric motor. The output of the motor is connected to the transmission system, which moves the car's wheels. The second regulated DC output channel covers the needs for auxiliary electrical loads like control electronics, lighting, and low-power subsystems. The block diagram shows the converter as a power processing unit that not only centralizes the power flow from multiple sources but also distributes it to both propulsion and auxiliary loads maintaining stable operation during fluctuating energy and load conditions.

The battery and the solar PV panel provide the converter with two independent DC inputs, which are then processed according to control algorithms that manage the voltage, current, and power flow. Depending on the needs, the converter will merge or separate the inputs for the operating states of the vehicle such as solar-assisted propulsion, battery-only propulsion, PV-based charging, or auxiliary load supply. The output from the converter is further divided into two regulated channels: one channel is provided to the inverter-motor drive system to power the propulsion while the other is for the auxiliary loads for non-propulsion electrical functions.

4. Results and Discussion

The hardware implementation described in the block diagram consists of a centralized Single Inductor Multi-Port Power Converter interconnecting various energy sources and loads. The system includes a battery module, sensor interface units, a control platform based on a microcontroller, driver circuits, and load components like a DC motor. The battery acts as the main DC input which gets routed via the converter where switching devices and a common inductor are balancing power allocation. The microcontroller being the control center issues switching pulses depending on real-time data from voltage and current sensors linked with the input and output terminals. The driving circuit boosts the control signals and triggers the switches to perform the desired power-processing functions. The regulated power is provided to the DC motor and extra loads while an LCD panel displays system state and measurement parameters. The interconnection of these parts illustrates the capacity of the converter to handle energy flow, keep regulated output levels, and perform multi-port operation also in a scenario of an electric vehicle power support.

5. CONCLUSION

The advent of the Single Inductor Multi-Port Power Converter is an efficacious and unified methodology for the multiple energy inputs management in the electric vehicle power architectures. The configuration of the converter leads to power from the battery and solar photovoltaic sources being processed together via a single magnetic element; thus, it reduces the size of the system and the number of components. Theoretical modeling and computer simulations come to the conclusion that the converter is able to keep stable voltage regulation, it is capable of allowing bidirectional energy flow for battery management, and it can take on different input conditions without degrading operational integrity. The control methods that are used for the converter successfully perform the required variations in duty-cycle, guarantee continuous conduction in the required areas, and allocate appropriate amount of power to the propulsion and auxiliary loads.

Based on the tests, the topology that is proposed is seen to be capable of delivering very high conversion efficiency along with reliable operation during the transition between different modes, e.g. PV-to-load, PV-to-battery, and battery-to-load. The converter has been very reliable in providing continuously regulated outputs that can be used for both the inverter–motor drive system and secondary vehicle subsystems, thereby it is confirmed to have compatibility with the basic requirements of electric vehicle power. To sum up, the findings are a testament to the fact that the single-inductor multi-port configuration is the best choice for the integrated energy management in electric vehicles, that it is a small and effective solution for multi-source DC power conversion.

6. Future Scope

The future research can be, likewise, concerned with improving thermal management and electromagnetic compatibility so that the long-term reliability of electric vehicles is increased. The possibilities of wide bandgap components, like GaN and SiC switches, will be considered in the quest for higher frequency of operation and lower losses which, in turn, will allow smaller size for passive devices. Real-time validation with testing of the converter's design refinement under commercial electric vehicle platforms is going to be the main aspect in the adaptation of the converter design to the latter. The vehicle energy management system (EMS) integration shall also be investigated in order to establish the coordinated operation of the converter, battery management system, and propulsion system that would further enhance system performance.The converter can be stretched to have more input ports for the purpose of combining more renewable sources or high-power charging interfaces, which wouldn't involve any major changes to the basic structural design.

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