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Analysis and Implementation of a Switching Bi-Directional BUCK-BOOST Conerter for the HEV Applications by using FLC

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Abstract: A switching bi-directional buck-boost converter (SBBBC) has been proposed for integration into a vehicle-to-grid (V2G) system. This topology facilitates bi-directional energy flow between the hybrid energy storage system (HESS), comprising a Li-battery and a supercapacitor (SC), and the grid. The SBBBC offers both buck-boost capability and energy management functionality. Stability analysis of the topology in both boost and buck modes has been conducted using the state-space averaging method. Additionally, a control strategy has been devised based on the state of charge (SOC) of the energy storage system to ensure stable output voltage and current In terms of charging the Li battery, a constant current (CC) and constant voltage (CV) mode are employed. Furthermore, voltage and current controllers have been designed in the frequency domain utilizing bode plots. The overall feasibility of the topology, as well as the adequacy of the designed controller and control strategy, have been assessed to ensure effective operation within the V2G system.
Keywords: Buck Boost converter, FUZZY LOGIC Controller ,MATLAB, Li-Battery , HESS.

1. Introduction

Electric vehicles are extensively used for their environmental benefits, particularly their reduced emissions and lower impact on the environment. A critical component in these vehicles is the lithium-ion (Li-ion) battery, which serves as a key element in their energy storage systems. While Li-ion batteries boast high energy densities, enabling them to supply sufficient energy during steady-state operations, their power densities are inadequate to meet peak power demands. This issue can be addressed by combining Li-ion batteries with supercapacitors (SC) to create a hybrid energy storage system (HESS).

Supercapacitors, known for their higher power densities, can supply the transient power needed by the load. In a HESS, a supercapacitor is directly connected to the inverter, enhancing the dynamic response during periods of transient peak power demand. Conversely, the Li-ion battery is connected to the DC-link via a bi-directional DC-DC converter. The role of this converter is crucial: it manages energy transfer and stabilizes the DC bus voltage. Additionally, the bi-directional power flow capability of the converter is essential to facilitate energy exchange between the energy storage system and the grid.

1.1. Literature Survey

The energy storage system and the grid necessitate the implementation of an Advanced Hybrid Energy Storage System (AHESS) topology. In this topology, the Li-battery can either connect to the supercapacitor (SC) through a bi-directional DC-DC half-bridge converter or directly to the DC bus via a diode. This two-stage converter setup maximizes the power capacity of the SC, although it has a relatively low boost ratio. The lack of bidirectional energy flow between the grid and the energy storage device, the proposed buck-boost converter design should be reevaluated. The existing design, as described in the paper, is characterized by numerous switching devices, substantial losses, and complex control mechanisms. Therefore, a revised approach is needed to enhance efficiency, reduce complexity, and enable bidirectional energy transfer. By optimizing the converter topology, minimizing switching losses, and simplifying control algorithms, a more efficient and versatile solution can be achieved for plug-in hybrid electric vehicles.

1.2. Problem Formulation

A Hybrid Energy Storage System (HESS) topology incorporates a Li-battery connected to a Supercapacitor (SC) either through a bidirectional DC-DC half-bridge or directly to the DC bus via a diode. While

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this configuration effectively utilizes the SC's power capacity, it suffers from a low boost ratio. The current buck-boost converter proposed for plug-in hybrid electric vehicles faces limitations in achieving bidirectional energy flow, along with issues such as numerous switching devices, significant losses, and complex control mechanisms. To address these shortcomings, a high voltage gain bidirectional DC-DC converter is recommended. This converter operates under zero voltage switching conditions, thereby reducing switching and conduction losses. However, it involves many switching states and complex operation.

In the context of hybrid energy storage systems for electric vehicles, Z-source inverters (ZSI) and quasi-Z-source inverters (qZSI) have been proposed. These topologies offer boost capability and facilitate bidirectional energy flow, enhancing system reliability through shoot-through characteristics. Additionally, they can increase power density. However, their control strategies are intricate, and the presence of multiple passive components between the SC and the DC bus can significantly enlarge the device size.

1.3. Top of Form Objective of Thesis

This project introduces a novel switching bi-directional buck-boost converter (SBBBC) and its corresponding control strategy tailored for use in a Hybrid Energy Storage System (HESS) within a Vehicle-to-Grid (V2G) framework. The converter design permits the simultaneous shoot-through of two switches in any phase while maintaining anti-electromagnetic interference capability. Moreover, by incorporating three switches on the DC side, the system enables bi-directional power flow between the Supercapacitor (SC) and the Li-battery.

Additionally, the project establishes a small-signal model of the topology using the state space averaging method and conducts stability analysis of the system. The control strategy is formulated based on the State of Charge (SOC) of the energy storage system and the operational state of the circuit, ensuring efficient management of energy transfer.

2. DC-DC Converters

DC-DC converters, essential in efficiently changing DC electrical power between different voltage levels, supersede linear regulators due to their superior performance, as discussed earlier. Switching Mode Power Supplies (SMPS) represent a broad category encompassing converters utilizing switches for power conversion. Moving forward, DC-DC converters will be referred to as SMPS for consistency. Various applications underscore the significance of SMPS. For instance, in personal computer motherboards, where stepping down 5V DC to 3V, 2V, or even lower voltages is essential for powering the latest CPU chips. Similarly, situations arise where elevating 1.5V from a single cell to 5V or beyond is necessary for operating electronic circuitry. Across these scenarios, the primary goal is to efficiently alter DC energy from one voltage level to another while minimizing energy loss—a pursuit synonymous with achieving maximum conversion efficiency.

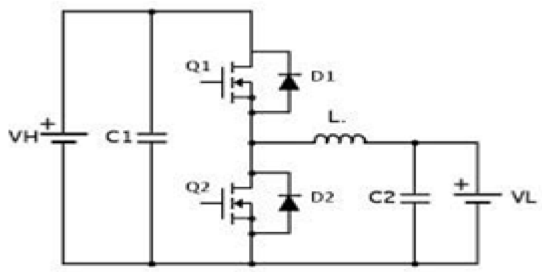

Figure. 1 Bidirectional DC-DC Converter

2.1. Types of Bi – Directional Converters

There are two distinct types of Bidirectional DC/DC converters classified based on the presence or absence of galvanic isolation between the input and output sections:
Non-Isolated Bidirectional DC/DC Converter (NIBDC): NIBDC operates without employing a high-frequency transformer to provide electrical isolation between the source and load.

Consequently, these converters are not suitable for high-power applications due to safety concerns. However, in low-power applications, NIBDCs exhibit higher efficiency, ease of control, and lighter weight owing to the absence of a transformer.

Isolated Bidirectional DC/DC Converter (IBDC): Safety standards necessitate the presence of isolation between an electronic system's AC input and DC output. Isolation is crucial for systems operating from the AC power line.

Typically, an isolated "brick" DC/DC converter is followed by a non-isolated point-of-load converter to meet these requirements. Isolated DC/DC converters utilize a switching transformer to provide DC isolation between the input and output voltages, eliminating the direct current path between them.

These converters utilize a switching transformer, with its secondary side equipped with diodes or synchronous rectifiers to generate a DC output voltage. This setup allows for multiple output voltages by incorporating additional secondary transformer windings. Moreover, transformer-isolated converters are more versatile for higher input voltages.

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2.2. Applications

Buck-boost converters find widespread applications across various fields, particularly in scenarios where input voltages exhibit significant fluctuations, such as in battery-powered systems experiencing varying charge levels over time. Some key applications include:

- Self-regulating power supplies leverage buck-boost converters to maintain stable output voltages despite fluctuations in input power.
- Consumer electronics benefit from the compact size and efficient voltage regulation provided by buck-boost converters.
- Battery power systems utilize buck-boost converters to efficiently manage varying input voltages as batteries discharge.
- Adaptive control applications utilize buck-boost converters to adjust output voltages dynamically based on changing input conditions.
- Power amplifier applications employ buck-boost converters to ensure consistent power delivery to amplifiers, enhancing overall system performance..

3. Proposed System Topology

Figure3.1 illustrate a hybrid energy storage system and Supercapacitors (SCs), offering advantages such as prolonged lifecycle, rapid response, and reduced stress on batteries. However, this enhanced functionality comes at an increased overall cost for the storage system. In this setup, the SC is directly linked to the inverter, enhancing the HESS's dynamic response during transient peak power demands. Conversely, the Li-battery connects to the DC-link via a bidirectional DC/DC converter.

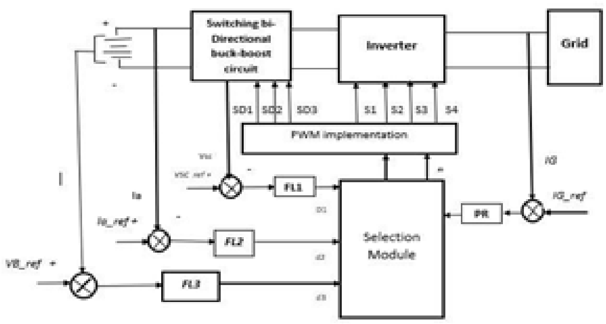

Figure. 2 Proposed Topology

The bidirectional DC/DC converter plays a crucial role in the HESS by facilitating energy transfer while ensuring stability of the DC bus voltage. Since the ESS requires energy exchange, it is essential for the converter to support bi-directional power flow. This can be achieved using either a bi-directional DC/DC half-bridge or a diode in the topology, enabling the battery.

3.1. PI Controller

The Proportional Integral (PI) controller is a widely utilized variant of the Proportional Integral Derivative (PID) control scheme. More prevalent than full PID controllers, the PI controller combines proportional and integral terms to determine the output. Specifically, the output is the sum of the proportional and integral values.

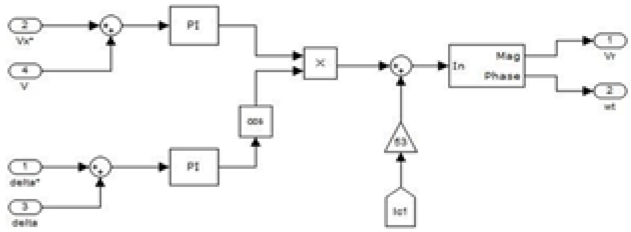

Figure. 3 PI Strategy

In PI control, the proportionality value inversely affects the output power at similar control errors, with higher percentage values resulting in lower output power. Conversely, the integration value increases with slower cumulative integration, leading to higher integration values. One notable advantage of PI control is its ability to eliminate control errors and remain unaffected by setpointchanges.

However, a drawback of PI control is its sluggish response to disturbances. To fine-tune a PI controller, it's recommended to initially set the addition time and maximum percentage time to zero. Subsequently, reducing the proportionality value may introduce periodic oscillations into the system.

3.2. Structure of FLC

Fuzzy logic, a computer-based technique, utilizes degrees of truth to process information. In a fuzzy logic system, these degrees of truth, along with linguistic elements, determine the system's output. The input conditions dictate the type of output produced. Fuzzy logic serves as a tool for defining and implementing solutions, bridging expert inputs with desired outcomes. Key components of fuzzy logic include fuzzy sets, fuzzy rules , Linguistic variable and membership function.

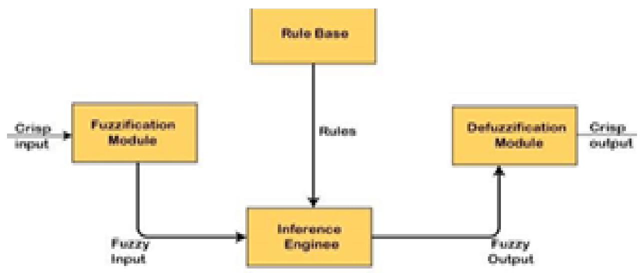

Figure. 3 Structure FLC

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3.3. Converter Topology

To enhance performance and resilience, the converter is equipped with multiple controllers and modulation techniques. Effective coordination and management of Energy Storage Systems (ESS), swift tracking of system parameters, uniform power distribution, and reduced steady-state error necessitate the implementation of efficient controllers. Additionally, modulation plays a crucial role in achieving controllable output voltage/current, minimizing harmonic distortions, and reducing switching losses. Optimization methods can be applied to enhance the operational efficiency of the converter's control system, ensuring optimal performance under various operating conditions.

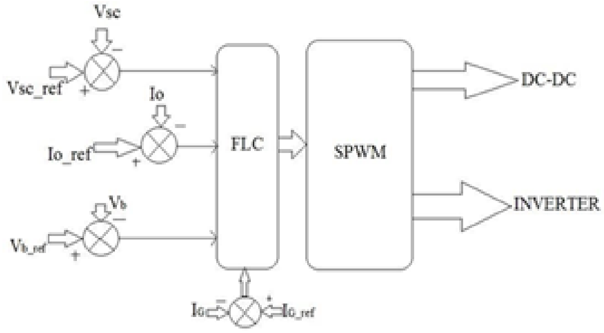

Figure. 4 Proposed Controller

The controlled proposed utilizes the following formula to compute the dtuty cycle:

"Here 'm' is inverter's modulation index, θ is output voltage's vector angle, and d, ds, and d0 are the Duty cycle of the Active, conduction, and zero voltage states", respectively.

$$d = m\sin(\theta)$$
$$\{d_s = \mathrm{const}(d_s \le 1 - d)$$
$$= 1 - d - d_s$$

$$\begin{cases} L\frac{di_L}{dt} = -(R_L + R_C)i_L - V_{SC} + V_B \\ C\frac{dV_{SC}}{dt} = i_L \end{cases}$$

$$\begin{cases} L\frac{di_L}{dt} = -(R_L + R_C)i_L - V_{SC} + V_B + R_C i_O \\ C\frac{dV_{SC}}{dt} = i_L - i_O \end{cases}$$

The duty cycle calculation incorporates various parameters:

- VBVB: Lithium-ion battery voltage
- VSCVSC: Supercapacitor voltage
- ILIL: Current flowing through inductor LL
- RLRL and RCRC: Parasitic resistances of inductor LL and the supercapacitor,
- Respectively
- IoIo: Output current

These variables are essential for determining the duty cycle in the proposed controller.

4. Results

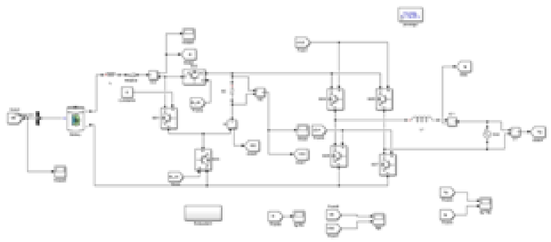

Figure. 5 Simulation Circuit

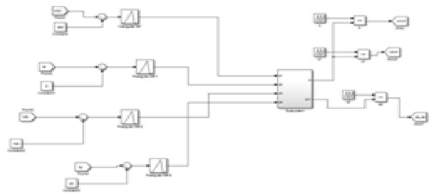

Figure. 6 **Sub-system with triangular membership**

4.1. Simulation waveform of PI Technic by using MATLAB

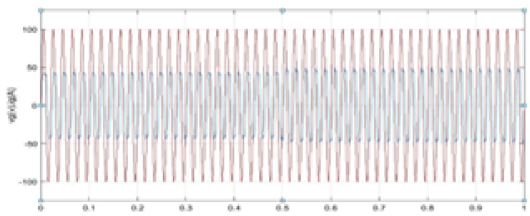

Figure. 7 Grid Voltage and Current

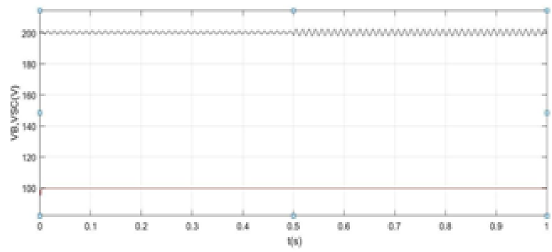

Figure. 8 Battery & SC voltage

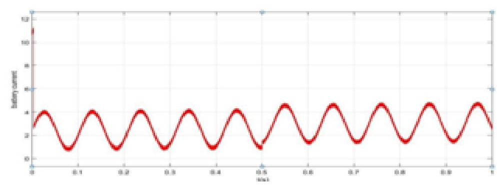

Figure. 9 Battery current Waveform

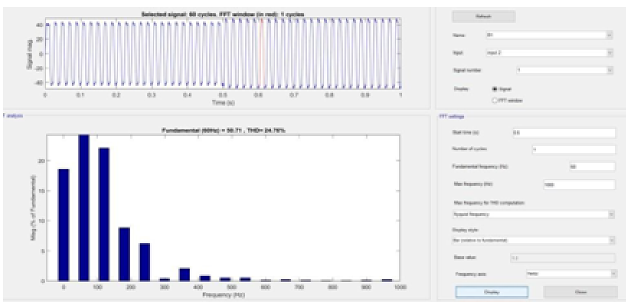

Figure. 10 T.H.D Waveforms (Grid current(A))

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4.2. Simulation waveform of FUZZY Technic by using MATLAB

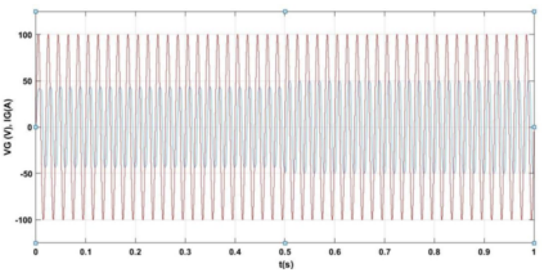

Figure. 11 Grid Voltage and Current

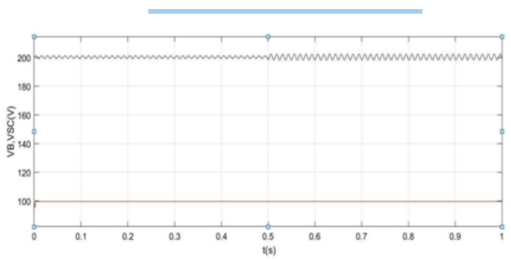

Figure. 12 Battery & SC voltage

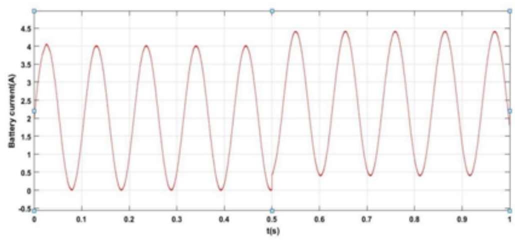

Figure. 13 Battery Current

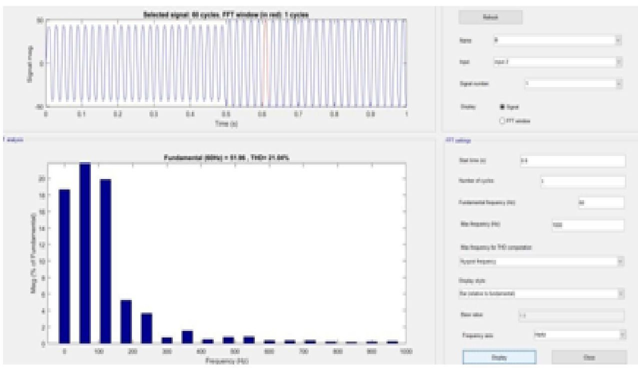

Figure. 14 T.H.D Waveforms (Grid current)

5. Conclusion and Future Scope

In all working modes, the proposed converter is modelled in MATLAB/SIMULINK software. In order to confirm its perfect capacity to track references (voltage and current) in terms of dynamic response and steady state ripple, current and voltage waveforms with their transient and steady state in all working circumstances are presented. THD(Total harmonic distortion) is also assessed using a comparison of the conventional and proposed methods in the operating modes when the grid serves as a power source. The converter is simulated in various scenarios to demonstrate its behaviour during mode switching and voltage changes.

The future scope of this project is implemented with the advanced controllers like PID , NN , PSO etc. By using these controllers, the system performance and efficiency may be increased compared to our proposed fuzzy method.

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