Simulation Design and Analysis of Power Converters for Hybrid Electric Vehicle Applications

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Abstract — *HEVs (Hybrid-Electric Vehicles) are a new technology in the automobile industry. It is vital to employ contemporary principles of electronic power conversion to create optimal converters in order to develop efficient yet powerful HEVs that can be charged quickly. The current project details the design and development of a suggested converter, as well as a comparison of its performance to that of other existing HEV battery charging converters. The suggested converter's simulation results and analysis reveal that it has a high output voltage and current, resulting in a high output power. The suggested device can deliver up to double the output power of a standard fly-back converter, according to simulations.*

Keywords — *Energy management strategy, hybrid electric vehicle (HEV), hybrid energy storage source, power converters.*

I. Introduction

A hybrid-electric vehicle (HEV) is a vehicle that has both an internal combustion engine (ICE) and an electric propulsion system [1]. The fuel efficiency of a HEV is better than that of a normal car due to the inclusion of an electric powertrain. In today's market, there are a variety of electric cars to choose from. A automobile is the most frequent example of a HEV, however other vehicles such as trucks, carts, buses, and tractors can also be HEVs. The primary types of HEVs are classed based on the systems' drivetrains. More highly efficient HEVs have been created and made as a result of the advancement of current technologies and engineering. Power electronics have played a critical part in creating the optimal amount of power converters for HEV systems, according to I. Hussain in his book Electric and Hybrid Vehicles Design Fundamentals [2]. Convertors come in a variety of shapes and sizes and are used in the production of HEVs.

The two systems that are commonly transferred from one form to another or kept in the same form with their values modified are Alternating Current (AC) and Direct Current (DC). In HEVs, there are four different types of converters. I AC to DC, (ii) DC to DC, (iii) DC to AC, and (iv) AC to AC are among them.

II. Environmental Effects and Advantages

According to I. Hussain, current environmental challenges provide a compelling incentive for the development of clean and sustainable urban transportation vehicles [2]. Low pollutant emission rates are the primary benefit of HEV automobiles. When compared to a traditional car, these vehicles use electric engines that create little to no emissions. HEVs' high-frequency electric equipment must be safeguarded against Electromagnetic Interference to guarantee proper operation (EMI).

III. Different Types of Configurations for HEV

C. Mi et al. point out that a Hybrid-Electric Vehicle's traction system consists of two types of transmission systems: an Internal Combustion Engine (ICE) and an Electric Vehicle (EV) [1]. A conventional car fueled by gasoline as a fuel is an example of a classic ICE. Vehicles powered by electrical engines, such as electric motors, electric converters, and other sorts of light and heavy electrical machinery, are known as electric vehicles. There are several ways to combine ICE and EV technologies and components, each with its own topologies and architecture. Electric engines, gearboxes, clutches, and other mechanical and electrical components are all considered in these designs. Series and parallel connections are the two most common forms of connections. Hybrid and sophisticated topologies can be created by combining these two kinds.

A. Series Configuration

The ICE is the primary energy converter in this design. The ICE's mechanical output will power a generator, which will subsequently power a motor. The generator output can be utilised to partially charge the battery storage unit and to power other minor vehicle components. This is the simplest configuration. The engine is disconnected from the wheels in this design. A vehicle may attain optimum speed and excellent fuel efficiency since the engine is disconnected. In addition, the engine may be put in any location within the vehicle. According to C. Mi et al. [1,] an all-wheel drive (AWD) capability may be provided in this setup.

Controlling the electric motor in this sort of setup, however, can be difficult. This is due to the unique modules and instruments that must be incorporated in the system to handle the electric motor's speed control and operation, resulting in a larger and more complex system. Electric motors are not as efficient as traditional ICEs at high speeds or on motorways. Figure 1 depicts a series combination's architecture design and component layout for a HEV.

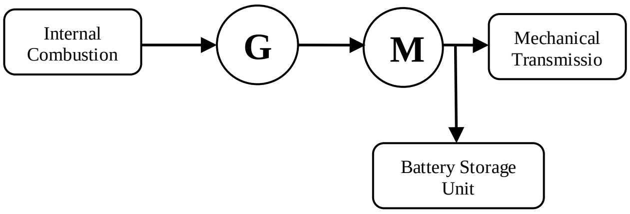

Fig. 1 The construction of a series HEV.

B. Parallel Configuration

The ICE and the electric motor can both give power to the wheels in a parallel arrangement. Mechanisms such as a clutch, belts, and pulleys connect the ICE with the electric motors. In a single vehicle, both the ICE and the electric motor may be used at the same time. If one of the traction systems fails, the vehicle's whole weight can be transferred to the other system. When the electric motor is braking, kinetic energy is saved and used to charge the battery, allowing the electric motor to function as a generator. Depending on the demands and speed of the vehicle, this arrangement allows the vehicle to run in ICE mode, electric motor mode, or a combination of both. According to C. Mi et al., the key benefit of this vehicle is the regenerative braking capability [1]. A short build of the parallel combination for a HEV is shown in Figure 2. Mechanical connection connects the ICE and the electric motor. The traction power is subsequently sent to the engine's final transmission via this mechanical link.

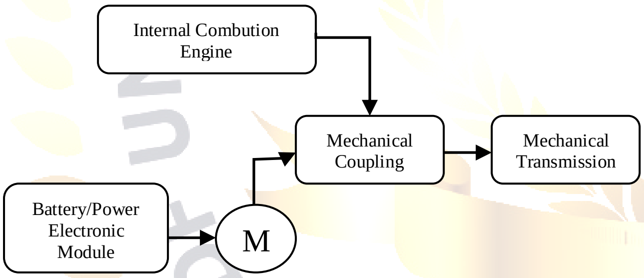

Fig. 2 The construction of a parallel HEV.

C. Series-Parallel Configuration

Both the series and parallel HEV architectures are used in the series-parallel arrangement. As a result, this design may be used as a series or parallel HEV. A mechanical link between the engine and the final drive is added to a series parallel setup. The engine may directly drive the wheels thanks to this mechanical coupling. This setup, as opposed to a parallel layout, features a second electric motor that may be utilised as a generator. Fuel efficiency and drivability may be optimised in this mode dependent on the vehicle's operating state. This is a popular arrangement among manufacturers. However, I. Hussain claims that this arrangement is more costly than other topologies due to its complexity [2]. Figure 3 depicts the assembly of a series-parallel HEV and the positioning of its components in the vehicle.

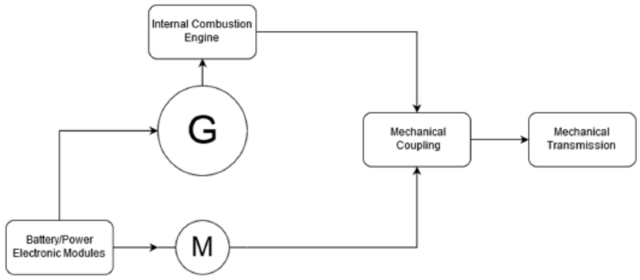

Fig. 3 The construction of a series-parallel HEV.

IV. PSIM ANALYSIS TOOL FOR POWER CONVERTERS

PSIM is a power electronics, motor drive, and power conversion system that is particularly intended [3]. Even when modelling complicated designed circuits, it offers a user-friendly interface and is quick and powerful. PSIM has various pre-built and add-on options, such as the Motor Drive Module and the Digital Control Module [3]. PSIM was chosen because it has the characteristics and components needed for a straightforward design and comprehension of the HEV issue. In PSIM, there is also a Hybrid Vehicle Design module . The component's values may simply be changed depending on how it's used in the circuit. As shown in Figure 4, the selection of circuit components such as capacitors and resistors is available at the bottom of the schematic window. Transformers and motors, among other complex components, are also available. These transformers and motors' attributes and values may be readily adjusted by simply clicking on them. A window showing the parameters of these components will show up when clicked on, which can be used to modify their internal properties. At last, a salient feature of PSIM is the Sim-Coupler module that links a PSIM module to the MATLAB software. By using the Sim-Coupler, a user can directly access a PSIM control module in MATLAB and can vary any parameters easily.

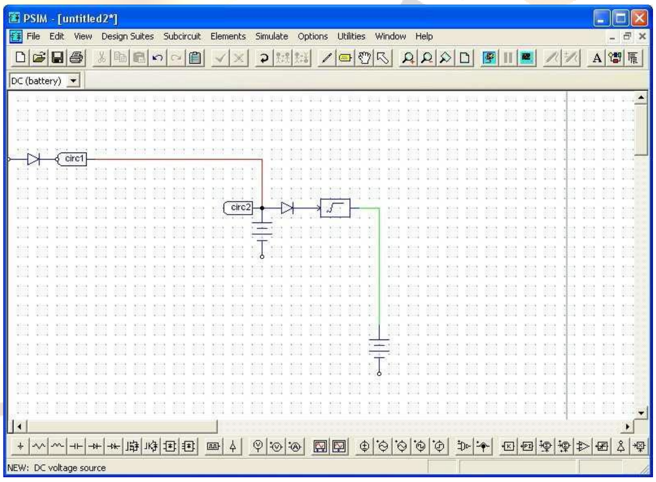

Fig. 4 PSIM window for the circuit schematic

V. Simulation Of A Proposed Dc-Dc Converter

DC to DC converter as an electrical circuit, or a device that converts a source of Direct Current (DC) from one voltage level to another [4]. It is a type of a power electronic converter.

Similar to a transformer, it can either be a step-up or step-down. With the development of power semiconductor technologies, it is possible to convert a high voltage level DC to a low power application and vice-versa.

A. Different Types of Converters and Construction

DC-DC converters can be grouped into many groups, according to M. H. Rashid, depending on the type of application. Convertors are divided into two categories: buck and boost [4]. When converting a high voltage level to a low voltage level, buck is employed. When a low voltage level is turned to a high voltage level, boost is employed [7]. These converters can also be separated into two types: non-isolated and isolated converters. A buck or boost converter may be created by adding a transformer to the circuit and adjusting the turn ratio. A basic buck, boost, and Single Ended Primary Inductor Converter are examples of non-isolated converters (SEPIC). Push-pull, flyback, half, and full bridge converters are examples of isolated converters. Both a buck and a boost converter may be effectively built in one circuit if the internal components are suitably arranged [8].

B. A High Voltage DC-DC Converter for Battery Charging in a HEV

The phrase "battery charging" refers to the process of charging a battery from any voltage level to its rated voltage level for HEVs. A high current, high voltage DC-DC converter is presented for the purposes of this article. PSIM software was used to model the converter. Figure 8 depicts the suggested model.

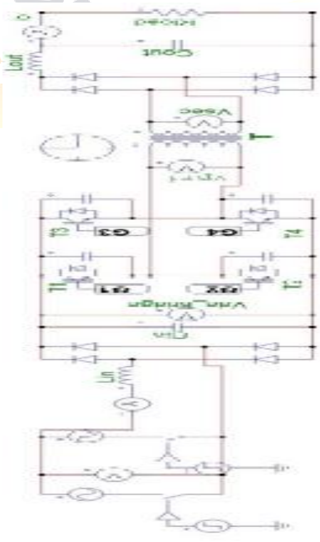

Fig. 5 Proposed circuit for the converter. This includes a high frequency transformer

The suggested converter in the diagram is a DC-DC converter that is isolated and may be used as a buck, boost, or a combination of the two. Because of the existence of a High Frequency Transformer in the arrangement depicted in Figure 5, this design is unique (HFT). In the suggested model, the IGBTs have a switching frequency of kHz. A basic AC source is used as the converter's input, which is converted to a high pulsing DC using a simple rectifier circuit. This pulsing DC is then sent through four switching devices (IGBT or MOSFET) before being fed into the HFT.

The suggested system's distinguishing characteristic is this HFT. The size and substance of the transformer are inversely related to the switching frequency of the circuit: the bigger the frequency magnitude, the smaller the transformer size. A rectifier receives the transformer's output (secondary side). A high frequency diode is used in this rectifier circuit. These sorts of diodes are required for the high pulsing DC voltage at kHz. Finally, an RLC load is applied to the final output curve to smooth it out. The feedback loop will be created in order to receive a constant voltage and current for the suggested system, which will enhance the overall characteristics and output. In HEVs, the use of this converter is critical for battery charging.

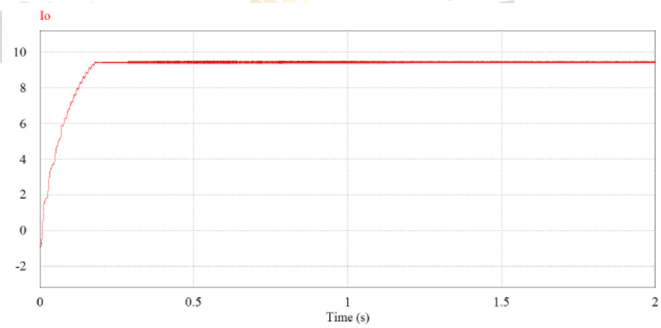

Fig. 6 Output current waveform for the proposed converter

Figure 7 depicts an appropriate feedback loop for the proposed converter. Even if there is a disturbance in the input, a highly precise output can be generated by employing a feedback loop [9]. In HEV systems, this is the most sought characteristic. The gating signals of the IGBT are modified by this system in order to maintain a very precise voltage and current measurement during the charging of the battery [10].

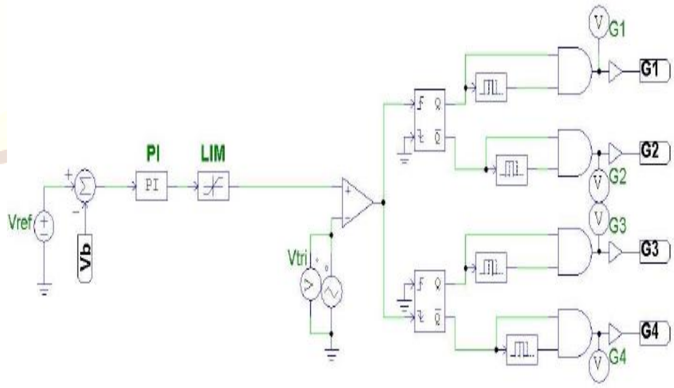

Fig. 7 Feedback loop for the proposed converter

VI. TABLE I
PARAMETER VALUES FOR THE COMPONENTS OF THE PROPOSED CONVERTER

Parameter	Value (Unit)
Input Inductor (L_{in})	0.1 H
Input Capacitor (C_{in})	4700 µF
Capacitor across IGBTs	0.01 µF
Transformer Turn Ratio (N)	17/7
Output Inductor (L_{out})	20 µF
Output Capacitor (C_{out})	4700 µF
Resistive Load (R_{load})	50 Ω
Switching Frequency (f_s)	5 kHz

VII. PROPOSED MODULATION TECHNIqUE AND CIRCUIT DESIGN FOR THE THREE PHASE INVERTER

A three-phase voltage source inverter using the SPWM approach is shown in the proposed project. The suggested inverter's fundamental block diagram is shown in Figure 8. The PSIM programme is used to model the inverter, and its functioning and benefits are explored. The creation of PWM waves, as well as its circuit, is also discussed and demonstrated. B. Majhi discusses the key components of the inverter in the figure in a paper report titled "Analysis of Single-Phase SPWM Inverter."

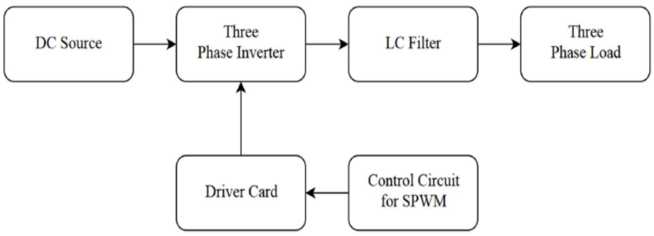

Fig. 8 Block diagram for the proposed three phase inverter

There are three branches in the three-phase inverter, therefore a total of six IGBTs are needed. The inverter's control circuit incorporates circuits for generating various waveforms, including a triangle waveform generator and a sinusoidal waveform generator. The sine wave will be compared to the triangle waveform, which is a high frequency carrier wave. Three separate waveforms are necessary since the sinusoidal waveform is employed for all three phases. Three separate waveforms that are phase-shifted by 120° are created from a single sine wave source [11].

VIII. TABLE III
SPECIFICATION OF THE INVERTER

Description	Rating
Input Voltage	450 V DC
Maximum Input Current	10 A DC
Output Voltage (Phase-to-Phase)	300 V AC
Output Current	7.5 A AC
Inverter Power Rating	2.2 KVA
Maximum Power Rating	3.4 KVA

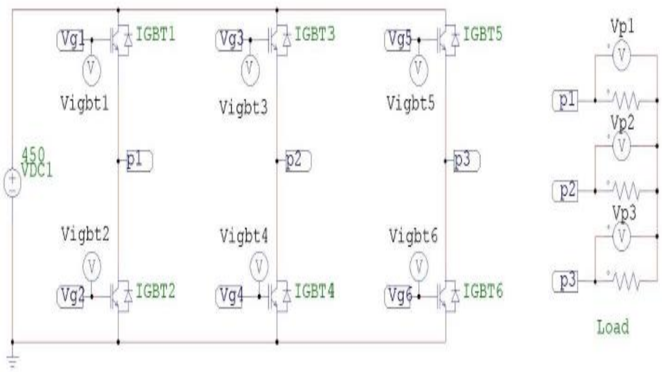

Fig. 9 Schematic diagram of the proposed inverter

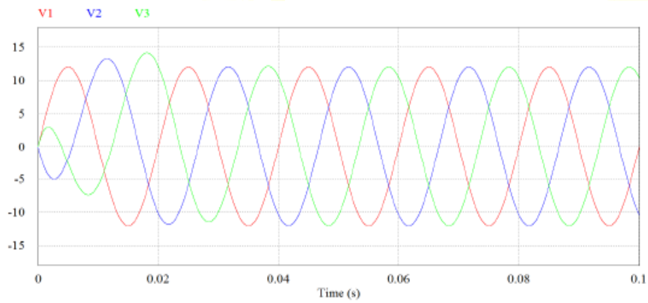

Fig. 10 Output waveforms of the circuit used for phase shifting for sinusoidal waveforms

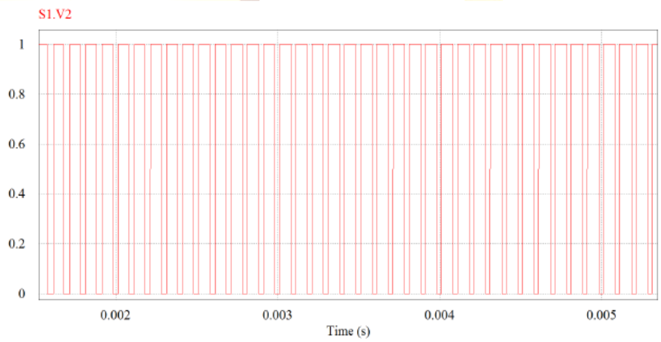

Fig. 11 Pulses generated at the comparator output. There will be six different pulses. Pulse 1 and 2 will be complementary to each other similarly for every other consecutive pulse for any IGBTs

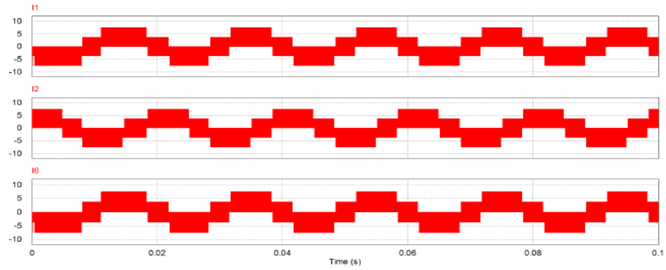

Fig. 12 Output current of the inverter. The phase current and line current are equal

IX. Conclusion

Since the high frequency transformer (HFT) has a turn ratio greater than 1, the suggested DC-DC converter is a step-down or buck converter. This converter's main function is to convert a DC voltage to a different level of DC voltage, which may then be separated into four stages. The AC to DC conversion is the first stage, which is necessary due to the low current provided by the DC source. The converter may create a high output current by giving a high input current. There is an inductor at the output of the first stage that stores the energy and makes it available for the following step. The high frequency inverter is the second step. Pulses are sent from the control circuit to the IGBTs at this point. Furthermore, the DC voltage is transformed to a high-frequency AC voltage. The HFT, which is the third stage of the system and the most crucial portion of the proposed converter, has access to this high frequency AC power. It's one-of-a-kind, and it's composed of unusual materials for a transformer. The AC voltage is stepped down by the HFT. The high frequency diode functions as a rectifier in the final step, converting a high frequency AC to DC voltage. The final voltage and current outputs are provided at this point. The battery is modelled as a single 2 V cell, with these single cells linked in series to form a 12 V battery. Depending on how the converter is utilised, it can also be used to control the speed of a DC motor that can be used for traction.

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