

Design and Control of Electric Power Train by Using Advanced Power Electronics Interface

B Gururaj¹, K Rajeshgoud² and A Mallikarjuna Prasad³

¹Assist. Prof. EEE Dept., at SJ CET, Yemmiganur, Kurnool (dist), Andhra Pradesh.

²PG Student at SJ CET, Yerrakota, Yemmiganur, Kurnool (dist), Andhra Pradesh.

³Assoc. Prof. EEE Dept., at SJ CET, Yemmiganur, Kurnool (dist), Andhra Pradesh.

Abstract: A new integrated power electronics interface (IPEI) for battery electric vehicles (BEVs) in order to optimize the performance of the power train is proposed in this paper. As Power electronics interfaces plays important role in the automotive vehicle technologies the proposed IPEI is responsible for the power-flow management for each operating mode. The operating modes will explain how IPEI works during different modes like charging/discharging and traction/breaking modes. In this concept, an IPEI is proposed and designed to realize the integration of the dc/dc converter, on-board battery charger, and dc/ac inverter together in the BEV power train with high performance. The proposed concept improves the system efficiency and reliability, and reduces the current, voltage ripples, and also reduces the size of the passive and active components in the BEV drive trains compared to other topologies. And control strategy for IPEI is designed and analyzed by using MATLAB/Simulink. The simulation results related to the output waveforms are obtained and validated.

Index Terms: Battery electric vehicles (BEVs), interleaved dc/dc converter, on-board battery charger, power-train control strategies, power-train modeling, small-signal model.

I. Introduction

A critical factor propelling the shift from conventional gasoline/diesel engine vehicles to electric, hybrid and fuel cell vehicles is the revolutionary improvement in performance, size, and cost of power semiconductor switches over the past decade, with parallel improvements in sensors and microprocessors. The issues to be addressed in the design of HEV power electronics circuits include [1], [2], [3]. Electrical Design: including main switching circuit design; controller circuitry design; switching frequency optimization; and loss calculations.

Mechanical and Thermal Design: including modeling of the loss of power devices and magnetic components; cooling system, heat sink, and enclosure design; and integration of the power electronics unit. Control algorithm design: including developing the control algorithm to achieve the desired voltage, current and frequency at the output, and to realize bidirectional power flow as needed.

Magnetic Design: including the design of inductors, transformers, and other components, such as capacitors, needed for filtering, switching, and Gate driver units. The on-board voltage levels of vehicular power system have been raised to 42 V, to 300 V, or higher, as the case may be [1], [7], [5] assuming that there is almost 4% increase in automotive load per year.

Owing to the high voltage levels being produced in HEVs, it becomes essential to have DC/AC converters to supply all the auxiliary loads on board the vehicle. Although the DC/DC converter technology is well developed for low-power applications at lower cost, much work needs to be done for high-power applications. In addition, power electronic converters also dictate how and when fuel/electricity is used in HEVs.

A suitable inverter draws dc power from the batteries to drive the electric traction motor, which in turn provides power to the wheels. The inverter also performs the function of recharging the batteries during regenerative braking in HEVs.

II. Circuit Topologies

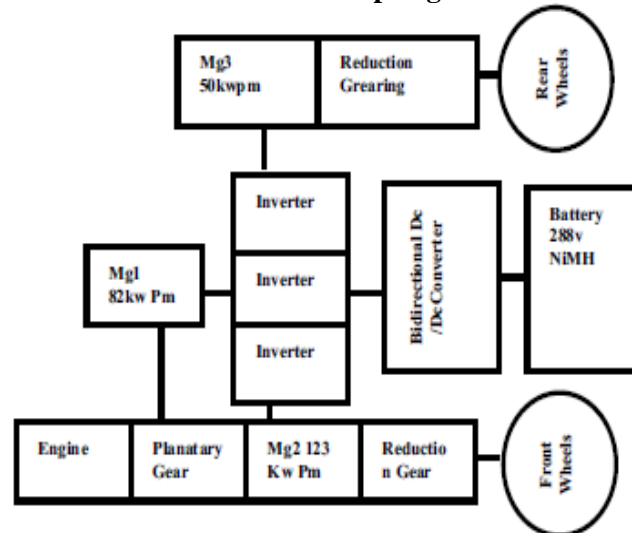


Fig. 1. Typical layout of HEV

Fig. 1 shows the general power train layout of hybrid electric vehicle [1], [5]. The power electronics unit consists of a bidirectional DC/DC converter that links the lower voltage hybrid battery and the higher voltage DC bus, and three motor drive circuits that control the front and rear motor/generators. Fig. 1 shows that other than propelling the vehicle, power electronics converters are used for activation and control of all other loads such as air conditioning, power steering, fans, pumps, video, and many other hotel and ancillary loads in sports utility vehicles.

While the detailed circuit of the proposed APEI (Advance power electronics interface) is shown in Fig. 2. In this power train, the battery pack is connected to the dc-link through the BMDIC. The BMDIC comprises two inductors, eight switches (IGBTs), and eight anti parallel diodes for boost and buck operating modes. The BMDIC has the ability to reduce the size of the passive components (such as inductors and capacitor), and to reduce input/ output EMI filters by means of increasing the frequency of inductor current ripple and the output voltage ripple without increasing the switching frequency.

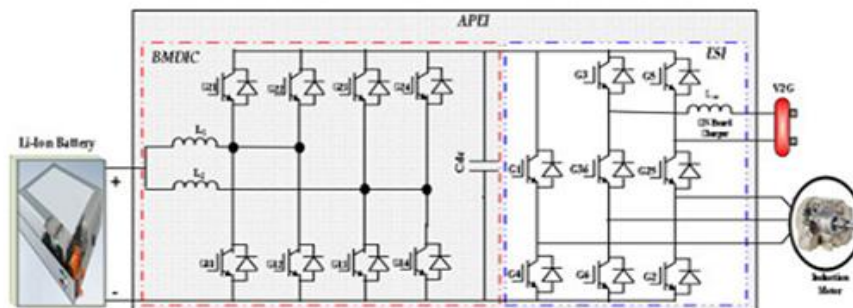


Fig.2 Detailed circuit diagram of the proposed APEI.

To achieve the control strategy of the BMDIC, a phase-shift interleaved control between phases and parallel devices is used to generate the switching patterns. These switching patterns are shifted by $360^\circ/(n \times m)$ (or $T_s/(2 \times 2)$) as shown in Fig. 3, where n is the number of phases or channels per port, while m is the number of the switches per phase. As can be seen from Fig. 3, the sequence of the driving signals is very crucial to achieve a doubled ripple frequency in inductor current at the same switching frequency, and to provide the interleaved control between inductors as well as power switching devices. This sequence can contribute to a higher system bandwidth compared to bidirectional-interleaved converter (BIC) with four switches (IGBTs) and four diodes. Furthermore, this control strategy can achieve a fast dynamic response for the proposed converter.

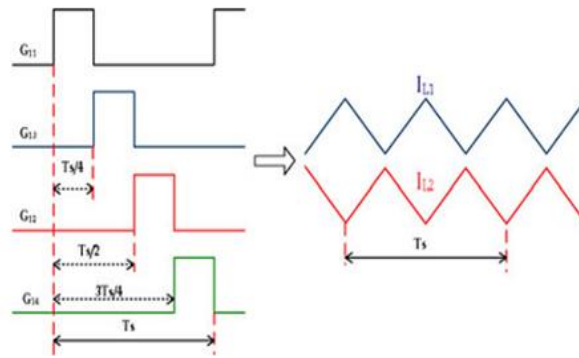


Fig. 3. Switching pattern of the BMDIC in boost mode.

In the proposed power train, the ESI is the only means to transfer the energy from/to the traction motor during traction and braking modes or to transfer the energy from/to the ac grid during charging and discharging modes. Thereby, the proposed APEI combines the merits of the BMDIC and ESI, which can improve the power train efficiency and reliability as well as minimizing the size of the passive components (such as inductors, capacitors, and filters).

A. Modes of Operation for the Proposed APEI

Table I: Summary of the Operating Modes of the Proposed APEI

Operating Modes	APEI		
	ESI		BMDIC
Mode1	Three-Phase Inverter	dc/ac	Boost Mode
Mode2	Three-Phase PWM rectifier	ac/dc	Buck Mode
Mode3	Single-Phase rectifier	ac/dc	Buck Mode
Mode4	Single-Phase Inverter	dc/ac	Boost Mode

As can be seen from Fig. 2, in the structure of the BMDIC, the power switching devices are operated by using an interleaved technique, which leads to share the current between these power-switching devices. As a result, the current ratings of these switches can be reduced. It means that the proposed topology can decrease the current stress on the switches and EMI especially at transients. In addition, this structure can also provide a high reliability compared to other topologies, thanks to multichannel and multi device topology. The BMDIC can reduce the size of the passive components and the input/output ripples in operating conditions (such as output power, switching frequency, and temperature). The proposed APEI can be mainly operated in four operating modes. These operating are given as follows:

- 1) In the Mode 1, the ESI will operate as a dc/ac inverter to transfer the power from dc-link to the IM, while the BMDIC operates in boost mode to set-up the LV battery to the high-voltage dc-Link.
- 2) In the Mode 2, the ESI operates as a three-phase PWM ac/dc rectifier to transfer the power from motor to dc-link, whereas the BMDIC works in buck mode to transfer the energy from the high-voltage dc-Link to the battery pack.
- 3) In the Mode 3, the ESI works as a single-phase PWM ac/dc converter to charge the battery from the ac grid, while the BMDIC operates in buck mode to transfer energy from the DC link to the battery pack.
- 4) In Mode 4, the ESI can operates as a single-phase dc to ac inverter to deliver the power from the dc-link to the ac grid during peak load, whereas the BMDIC works in boost mode.

These operating modes are summarized in Table I. In order to investigate the proposed BEV power train, the dynamic modeling of the power train (such as battery and EM), small-signal model of the BMDIC, and the power train control strategies are explained.

III. Dynamic Modeling Of Power Train

A. Dynamic Modeling of the Battery System

The battery stores energy in the electrochemical form and is the most widely used device for energy storage system in the variety of applications such as EVs, HEVs, and PHEVs. Lithium-Ion batteries are increasingly accepted to be an optimal choice for energy storage in automotive applications.

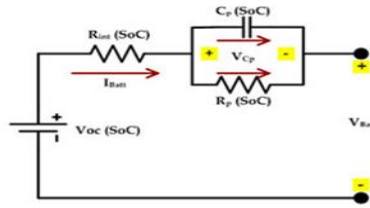


Fig.4. Thevenin battery model.

The mathematical modeling of the Li-Ion battery package used in the simulation program is defined as a thevenin battery model. The Thevenin battery model, the most commonly used battery model, consists of an internal resistance R_{int} , polarization capacitance C_p , and over voltage resistance (R_p , polarization resistance), and open circuit voltage V_{oc} . All elements that are used in this model are functions of the battery state of charge (SoC). Fig.4 illustrates the thevenin battery model. The battery system comprises a package with N batts cells that are connected in series and N batt p that are connected in parallel. The terminal voltage of the battery pack, V_{Batt} , can be denoted as follows:

$$V_{batt} = N_{batt} S [V_{oc} - I_{batt} R_{int} - V_{cp}] \quad (3.1)$$

$$SoC = SoC + \frac{1}{3600} \frac{I_{Batt}}{C_b} dt \quad (3.2)$$

Where

$$I_{Batt} = \frac{I_{Load}}{N_{BattP}} \quad (3.3)$$

$$\frac{dV_{cp}}{dt} = \frac{V_{cp}}{C_p R_p} + \frac{I_{Batt}}{C_b} \quad (3.4)$$

The MATLAB/Simulink-based battery system is designed and modeled in this paper by using the aforementioned equations.

B. Bidirectional DC-DC Converter

The bidirectional DC-DC converter [12],[13] allows for a bidirectional flow of power to utilize grid power when necessary and to supply power to the grid when excess power is generated, the bidirectional DC-DC converter shown in Fig 5. Applications of bidirectional DC-DC converters include battery energy storage systems, next generation motor drives, interconnecting load centers that possess on site generation. The bidirectional DC-DC converter used in this concept based off of the one designed.

In this the bidirectional DC-DC converters operation within the context of the EVCS (Electrical vehicle charge station), will be considered as Buck/Boost mode. In buck mode, the bidirectional DC-DC converter utilizes constant voltage control to operate as a voltage regulator for the LVDC bus.

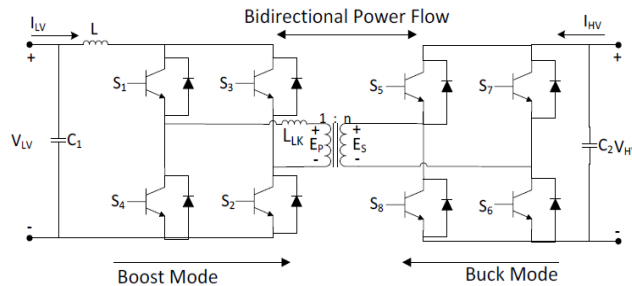


Fig.5. Bi direction dc to dc converter

The gating signals and key operating waveforms as well as the converter current paths for the boost and buck modes of operation for the bidirectional DC-DC converter are presented in above Fig.5 The currents I_{HV} and I_{LV} are measured using the reference of ‘going into the converter’ as the positive direction, which is why I_L is negative in buck mode and positive in boost mode. In boost mode only one current wave form is displayed. Bidirectional DC-DC Converter Buck/Boost Mode Operating Waveforms are shown in Fig 6 and Fig 7.

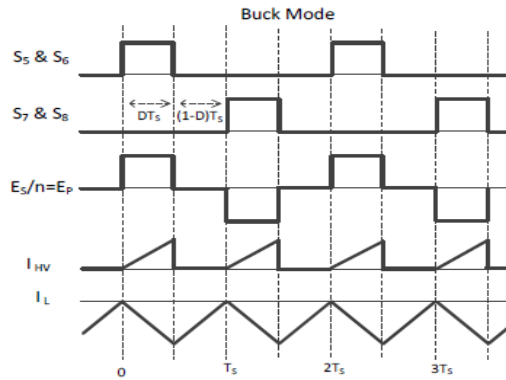


Fig.6. Bidirectional DC-DC Converter Buck Mode Operating Waveforms

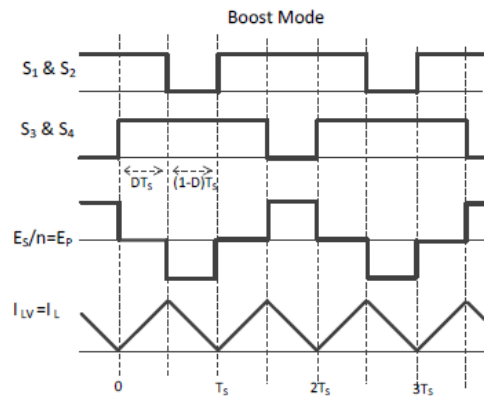


Fig.7. Bidirectional DC-DC Converter Boost Mode Operating Waveforms

IV. Simulation Results

The proposed APEI which is show in below Fig 8, which takes responsibility of power flow management in drive train. The circuit works under the different modes of operation like charging/discharging, and traction/breaking modes. APEI has different control strategies that are design by using MatLab/Simulink.

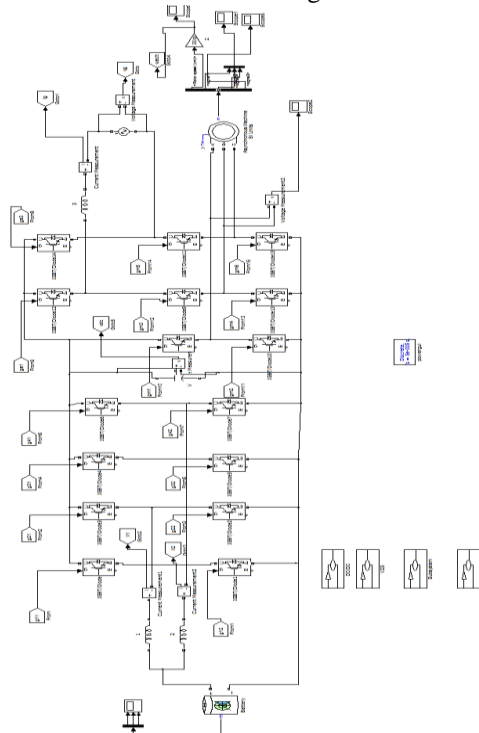


Fig.8. MatLab Models for BEV with APEI

The fundamental output wave form of the voltage(V_g) and current(I_g) is shown which is shown in the subsystem of the below Fig 9(a)

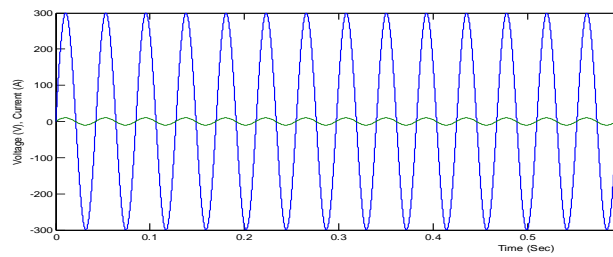


Fig 9(a) Fundamental voltage and current waveforms

The speed (rpm) with respect to the time(sec) curve which is shown in Fig 9(b) this is dynamic response of the power train during traction and braking modes.

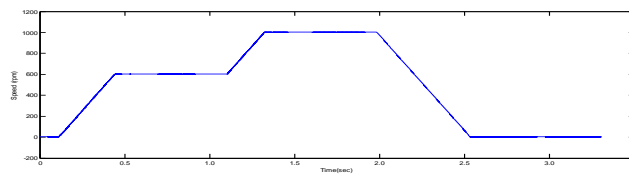


Fig 9(b) speed curve

The Torque (N-m) with respect to the time(sec) which is shown in Fig 9(c) this is dynamic response of the power train during traction and braking modes.

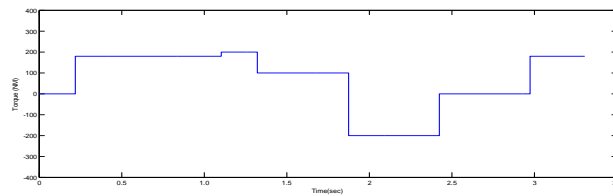


Fig 9(c) Torque curve

The Line Voltage with respect to the time(sec) which is shown in Fig. 9(d)

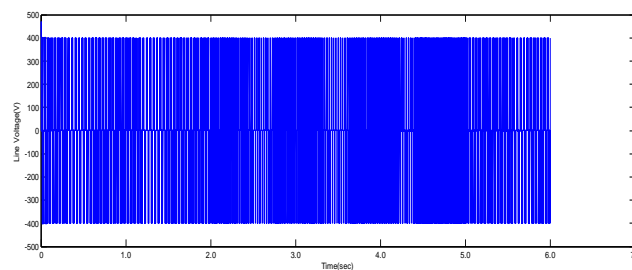


Fig. 9(d)Line voltage

The Stator Current with respect to the time(sec) which is shown in Fig 9(e)

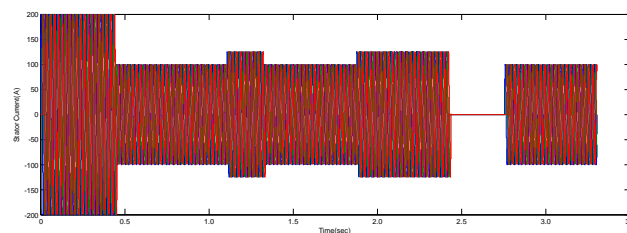


Fig 9(e)Stator Current

Output wave forms V_{batt} , I_{batt} and State of charge of the battery with respect to the time which is show in Fig 9(f)

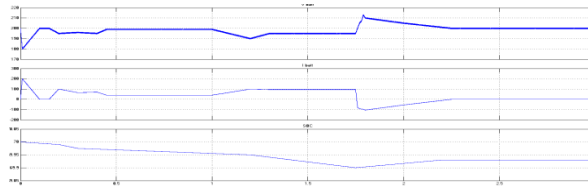


Fig 9(f) Line voltage

In the conventional simulation results the vehicle to grid control strategy has the THD output is shown in Fig 9(g) For PI controller THD is 6.94% shows in V2G control strategy.

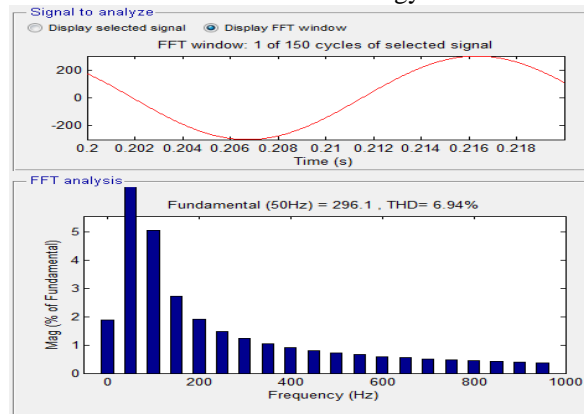


Fig 9(g) THD for a PI controller

The extension of proposed concept for given power train by using Fuzzy controller the output of THD is reduced 3.10% which is show in Fig. 9(f).

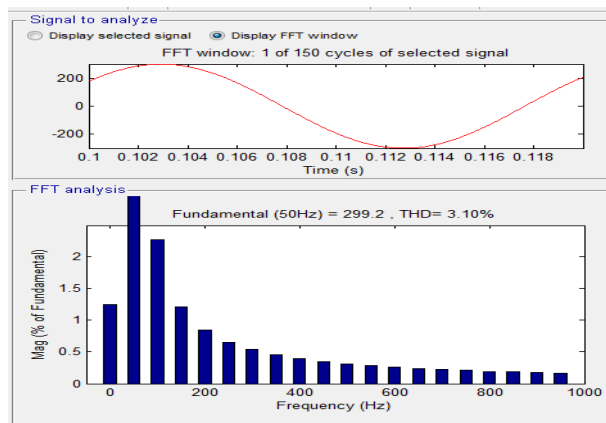


Fig. 9(f) THD for a Fuzzy controller

V. Conclusions

A novel integrated power electronic interface for BEV (Battery Electric Vehicle) which optimizes the performance of the power train is proposed. The proposed concept of APEI (Advanced Power Electronics Interface) combines the features of the BMDIC (Bi-directional Multi Device interleaved DC-DC converter) and the ESI (Eight Switch Inverter). The proposed APEI and its performance characteristics had been analyzed and presented. Different control strategies are designed to verify the performance of the proposed APEI during different operating modes. It should be pointed out that the IFOC based on PWM voltage is more efficient which is used to drive the EM (Electric Machine) during traction and braking modes. Moreover, the proposed APEI can achieve a high power factor correction, and can achieve a low THD for the input current during charging mode from the ac grid. As is clear from the simulation results, the proposed APEI can reduce the current and voltage ripples, can improve the efficiency and reliability, and can provide a compact size for the BEV power train. Furthermore, the battery lifespan can be increased due to the ripple reduction. Finally, the results of simulation are demonstrated for the proposed APEI has been successfully realized and it promises significant savings in component count with high performance for BEVs compared to other topologies. Therefore, it can be expected that these topologies can be utilized for development of high efficiency BEV power trains.

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