Abstract

The depletion of fossil fuel resources, the adverse environmental impact of greenhouse gases, and the advent of power electronics have increased the interest in Electric vehicles (EVs). The culminated effect of the price hikes in fuel and easy availability of cheap electric power has motivated the public acceptance of this emerging era of EVs. In EVs, the internal combustion engine is replaced by an electric motor. Switched reluctance motor, induction motor, and Permanent magnet brushless DC (PMBLDC) motor are the most popular drivers in the powertrain of EVs. Among these, PMBLDC motors are being used extensively due to their high starting torque, less maintenance, high torque density, and high efficiency. PMBLDC motors have added advantages of easy control and regenerative braking capability.

The EVs have a low battery voltage of 24-48 Volts. Thus, operating motors at these low voltage levels increase the operating current leading to increased heating and losses in the system. A DC-DC converter can be employed to boost the battery voltage in order to get a high voltage DC link to drive the PMBLDC motor. To perform regenerative braking on the motor a bi-directional buck-boost converter is required to fulfill the demand of bidirectional power flow.

Conventional buck-boost converter can not provide high voltage gain at a low duty cycle, which leads to

- an increased conduction loss and
- reverse recovery problem in the diode.

Thus, quadratic gain bidirectional buck-boost converters can be used to alleviate the above-mentioned problems. A vast literature survey on recently proposed topologies of bidirectional buck-boost converters is included in the thesis. Finally, three novel quadratic bidirectional buck-boost converter topologies are presented for electric vehicle application.

A Quadratic gain bidirectional converter (QGBC) of 1 kW is designed and developed for motoring and Regenerative braking (RB) of a 1.1 hp PMBLDC motor through a conventional Voltage source inverter (VSI) for EVs application. The design parameters of the converter are selected as dictated by the battery voltage (V_i = 48 V), the output voltage (V_o = 98 V), and switching frequency (f_s = 15 kHz). EV's drive cycle is emulated using a highly inertial load driven by a PMBLDC motor during the converter's boost mode operation. RB is a crucial process in extending the driving range of EVs by utilizing battery power prudently. During RB, the converter operates in buck mode. Simultaneously, the back Electromotive force (EMF) of the PMBLDC machine is boosted using the self-inductance of the PMBLDC motor and the VSI. The braking technique used in this work eliminates the traditional drawback of RB in buck mode, as the power is extracted even when the motor's back EMF is lower than the battery's voltage. The three-switch strategy to control the VSI for RB of PMBLDC motor boosts the back-EMF. In the three-switch strategy, all three switches on the lower side of VSI are controlled. The three-switch control strategy does not require rotor position information. Thus, this control strategy for RB is simple and more reliable.

A modified QGBC is proposed to operate in two different stages step-up (motoring) and step-down (regenerative braking) which is suitable for EV applications. In the presented work, a QGBC of 1 kW is designed to drive a 1.1 hp PMBLDC motor through a VSI. The converter is designed to operate in continuous inductor current mode (CICM). For RB of PMBLDC motor, the self-inductance of the motor is exploited to boost the back EMF of the motor to extract the energy even at low rotor speeds. The design parameters of the converter are selected as battery voltage (V_s) of 48 V, the output voltage (V_o) at 200 V, and switching frequency (f_s) of 20 kHz. The design system is simulated using MATLAB/Simulink and a laboratory prototype of 1 kW is developed for validation and performance analysis of the converter. The converter operates at maximum efficiency of 96 % during step-up operation of the converter.

A coupled inductor-based QGBC is presented to lower the input and output current ripples in step-up and step-down operation respectively. The coupled inductor-based QGBC is also designed and developed for motoring and RB of PMBLDC motor. In the presented work, a coupled inductor-based QGBC of 1 kW is designed to drive a 1.1 hp PMBLDC motor through a VSI. During the converter's step-up operation, EV's drive cycle is emulated using a pulley belt setup being driven through a PMBLDC motor. The design parameters of the converter are selected as battery voltage (V_s) of 48 V, the output voltage (V_o) at 200 V, and switching frequency (f_s) of 40 kHz. The converter is operating in step-down mode during RB of the PMBLDC motor. During RB, the kinetic energy is stored in the inertial load connected through a belt-pulley system to the PMBLDC motor is converted to electric energy and fed back to the battery through VSI and the QGBC. A single-switch strategy to control the VSI for RB of PMBLDC motor to boost the back-EMF is reported in this thesis. In this RB strategy, only one switch on the lower side of VSI is controlled according to the rotor position derived from the hall sensors of the driven motor. The single-switch control strategy has been observed to produce a smoother armature current from the PMBLDC motor. The converter operates at maximum efficiency of 95 % in step-up operation.

The inertial load (J) of 0.1 kg-m^2 has been used throughout the work. The control strategies have been implemented using the TMS320F28335 DSP controller for the developed converter prototypes and driving the PMBLDC motor.

This thesis focuses on the study of different converter topologies of bidirectional power converters for regenerative braking of PMBLDC motor-based EV power drive.