Chapter 6

Conclusions and Future Scope

6.1 Conclusions

The chief contribution of this research is the realization of three quadratic gain bidirectional DC-DC converters of different topologies with improved performance and significant versatility. The utilization of the designed and fabricated converters and their usefulness in EV application has been demonstrated and is summarised below.

- The first Quadratic gain bidirectional converter (QGBC) is designed, developed, and tested for motoring and Regenerative braking (RB) of PMBLDC motor in EV application. The power flow direction is controlled by changing the working mode of the Voltage source inverter (VSI) and the QGBC. A physical changeover switch is used to alter the modes of the operation. The motor is loaded with the help of a belt and drum during motoring operation. For RB operation, the PMBLDC motor is coupled with an inertial load through another belt and pulley arrangement. The inertial load's mechanical energy is converted to electrical energy in the regenerative braking mode and fed back to the battery, as demonstrated in the work with results. A three-switch commutation control strategy is applied on the VSI for RB of PMBLDC motor when the vehicle's speed is to be reduced. This boosts the back-EMF of the PMBLDC motor by controlling the VSI and using the self-inductance of the motor without any requirement of rotor position information. The QGBC operates at maximum efficiency of 95.4 % at output voltage of 98 V during boost mode (motoring) operation. The implemented strategy and the system configuration proposed in this work demonstrate an economical and practical approach to eliminate the drawbacks of regenerative braking in buck mode of a bidirectional DC-DC converter.

- A second modified Quadratic gain bidirectional converter (QGBC) is designed, fabricated, and tested on PMBLDC for motoring and RB in EV application by reconfiguration of the converter circuit and doing away with the two power diodes. Thus, the converter cost gets reduced with enhanced efficiency, while the voltage gain of the converter remains unaffected. The power flow direction control from motoring to RB mode works well with the same fashion and principles involved in this case also with good results. The only difference is that here the motor runs at a higher speed due to higher terminal voltage making the inertial load acquire greater kinetic energy, thereby energizing the battery more in the RB mode. This modified QGBC converter operates at maximum efficiency of 96 % at output voltage of 200 V and switching frequency of 20 kHz during the converter's step-up operation. The modified QGBC converter also operated at output voltage 98 V and switching frequency 15 kHz and it operates at maximum efficiency of 96.5 % in step-up operation of the converter. This adopted strategy along with system configuration removes the pitfalls of regenerative braking in the buck mode of the bidirectional DC-DC converter in a frugal and pragmatic manner.

- The third QGBC comprising a coupled inductor is also designed, fabricated, and tested on PMBLDC motor for motoring and RB in EV application by replacing the two inductors. Thus, the converter size and weight gets reduced. The converter operation for step-up and step-down modes in Continuous conduction mode (CCM) and Discontinuous conduction mode (DCM) has been discussed. The voltage gain is found to be similar to that of a cascaded boost converter in step-up mode, whereas it is comparable to that of a cascaded buck converter in step-down mode. However, the presence of coupled inductor having an appropriate number of turns exhibits a lower current ripple in the modified converter. The working of the converter and energy flow direction control in both the step-up and step-down modes by using a mode transition switch have been satisfactorily verified. This converter is found to achieve significant voltage gain with a low current ripple at all operating points. A single-switch commutation control strategy of VSI for RB of PMBLDC motor is implemented. This RB control strategy of VSI gives smooth armature current profile as evident from results. The VSI control approach is used to raise back-Electromotive force (EMF) of the PMBLDC motor by leveraging the motor's self-inductance. The coupled-inductor based QGBC operates at maximum efficiency of 95 % at the output voltage of 200 V and switching frequency of 40 kHz during step-up operation. The coupled-inductor based QGBC is also operated at output voltage 98 V and switching frequency 15 kHz and its maximum efficiency is 96 % in step-up operation of the converter. For EV applications, the adopted control technique and system design are cost-effective and very efficient.

6.2 Future Scope

Many limitations can be identified in the presented works, which lays the foundation for future scopes of improvement. Following are the future scopes of the presented work.

- Soft-switching can be used to minimize the switching losses, thus increasing the efficiency of the system.
- A control technique can be developed to control the phase currents of the PMBLDC motor during regenerative braking mode.
- A multi-level inverter can be used for current shaping and torque ripple elimination of the PMBLDC motor.
- To accurately emulate the vehicular load for every driving scenario, a controlled motor can be used in place of inertial load.
- The developed regenerative technique can be employed in an EV with urban drive cycle to analyze the practical implementation of the proposed system.