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A Dual Control Regenerative Braking Strategy for Two-Wheeler Application

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Abstract

To reduce the harmful emissions from automobiles and massive surges in fuel prices, automotive electric vehicles are an effective alternate solution. In this paper, a cascaded bi-directional DC/DC buck-boost converter with dual control strategy during regenerative braking is used for a two-wheeler application. The dual control strategy with the cascaded converter is used to increase the average power stored during the braking period and to reduce the vehicle's stopping time. The converter with the proposed control strategy used in this work has made it possible to charge the battery even when the back emf of the machine is less than the battery voltage. A fuzzy logic control strategy is used to consider the non-linear factors like SOC, speed of the vehicle and the required brake force. This is done in order to make the system more reliable and realistic. The complete model is simulated in MATLAB/Simulink. By implementing the dual control strategy, the average power stored by the battery is increased by 2.5 times and the vehicle comes to halt faster in comparison with the existing control strategy. The versatility of the strategy is shown by examining three different scenarios during the regenerative braking process. To support the above claims, simulation results are presented to show the effectiveness of the proposed method

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Keywords: regenerative braking; electric vehicle; fuzzy logic; dual control; bi-directional converters; battery charging

1. Introduction

In today's world of dwindling resources and ever increasing prices, spending a lot on fuel has become a major part of the economic budget. Reducing fuel consumption can have a major impact on decreasing the capital spent on fuel. To achieve this, hybrid electric vehicles (HEV) [1]- [3] and plug in – hybrid electric vehicles (PHEV) [4]-[6] are an alternate solution. Installation of high energy battery packs and regenerative braking play an important role in improving the drive range [7] of the electric vehicles as well as improving the battery life.

In order to extract the maximum electrical energy from the rotational mechanical energy, DC/DC converters with appropriate charging and discharging profile are required. Various topologies of DC/DC converters have been discussed in [8]-[10]. However, regenerative braking [11, 12] has to be carried out with the conventional frictional braking. In the braking process, there are two

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issues that are to be addressed. First is accurately applying the brakes which restrains the vehicle speed and maintains the vehicle's travelling course. And the second issue is to recover the braking energy to increase the energy efficiency of the battery[13,14]. In practical scenario, factors like state of charge (SOC) of batteries, speed of the vehicle and driver's brake force requirements limit the effectiveness of electric braking. Thereby mechanical braking has to be incorporated along with regenerative braking. In literature, many works on regenerative braking and various algorithms for the control during the regenerative braking are proposed. The work in [15] proposed a method wherein vehicle's speed is taken into account and not the SOC. Authors in [16] have taken the SOC into account and computed the regenerative force. However, the above works have not stated any methods to utilize the regenerative power to charge the battery. Works carried out in [17] and [18] have used different topologies of bi-directional DC/DC converters to charge the battery. However, the converters used in the works do not address the issue that arises if the terminal voltage of the machine falls below the battery voltage [19] during low speed of the vehicle. In [20] the back emf is neglected when the battery voltage is greater than the terminal voltage of the machine.

In this paper, the focus is on the dual (voltage and current) control strategy which is used to extract the maximum possible energy during the regenerative braking and to ensure that the vehicle stops in an optimum time frame. In addition, fuzzy logic control is used to determine the battery charging current as its determining factors (SOC, vehicle speed and brake force requirement) have an uncertain relation with it. In addition, a cascaded bi-directional DC/DC buck-boost converter with a PMDC machine has been used. This is done to charge the battery even when the back emf of the PMDC machine is less than the battery voltage and at the same time have an effective braking while taking the safety issues and battery conditions into consideration.

2. System Description

The overall configuration of the electric vehicle with the proposed control strategy is shown in Fig. 1. The system consists of a lithium ion battery, permanent magnet DC (PMDC) machine, bidirectional DC/DC buck-boost converter, fuzzy logic reference current generator and control logic block. The bi-directional DC/DC converter can operate in both buck and boost mode. The converter operates in boost mode during motoring operation. During regenerative braking mode, the converter can operate in boost or buck mode and the power flow is from the machine to the battery. The mode of operation during the regenerative braking [21]-[23] depends upon the generated voltage at the terminals of the PMDC machine. If the generated voltage is less the than battery voltage, the DC/DC converter operates in the boost mode and if the generated voltage is greater than the battery voltage the converter works in the buck mode. The control logic block functions during the regenerative braking mode and is responsible for shifting of control strategy from current control (CC) to voltage control (VC) mode during the braking process.

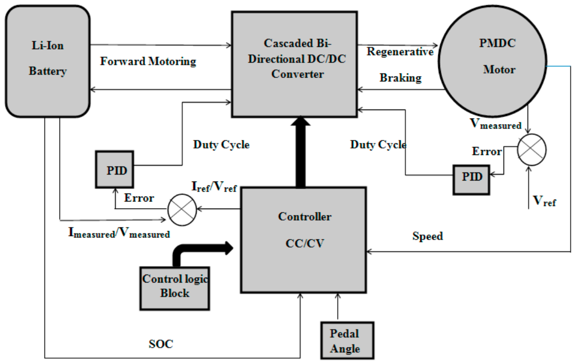

Fig.1. Block diagram of the system

3. Cascaded Bi-directional Converter

The cascaded bi-directional buck-boost DC-DC converter [8] used in this work is shown in Fig. 2. The advantage of this converter is that it can extract the energy when the generated voltage is less than the battery voltage. This is possible because it can operate in both buck and boost modes in both directions whereas a conventional bidirectional converter [17] can operate only in one mode and in one direction. Totally there are four operational modes. However, only three operational modes are used in this work. During the motoring mode, the voltage of the battery is stepped up to the appropriate level as required by the motor. And during the braking mode, regenerative power extraction is achieved by either stepping up or stepping down the voltage generated by the PMDC machine, which in this case is acting like a generator. The switching sequence of the switches for different modes of operation is illustrated in Table 1.

Table 1. Switching sequence for various operating modes

MODE	S1	S2	S3	S4
1	ON	SW	OFF	OFF
2	ON	OFF	SW	OFF
3	OFF	OFF	ON	SW

3.1 Operation Modes of the Converter

3.1.1 Mode 1: Boost Operation – Battery to DC Bus during motoring operation (Primary Boost Mode)