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Ultra-Capacitor Based Energy Storage System Design for Diesel Locomotive in Regenerative Braking

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Abstract

The aim of this project is to build an energy storage system for regenerative braking, with use of dc to dc converter, and testing rig to perform testing for dc drive with dc motor with the super capacitor bank against diesel locomotive (WDM2) regenerative braking profiles. A bank was constructed along with a bidirectional DC to DC converter allowing practical testing of two of the four possible bank configurations. An average of 55% and 63% end to end efficiency was found for the two configurations respectively when tested fewer than two modes of regenerative braking profiles. It was found that capacitor banks with a higher maximum voltage i.e. more cells in series were more efficient as there were lower input and output currents and most of losses were restricted to the converter.

Keywords: Energy, WDM2, Braking

Introduction

Energy is prime issue of mankind. The requirement for energyis for heating, electricity, manufacturing, construction andtransportation. Sustainable growth of the organization is in alldepending on energy planning for the future. Similarly, energyconsumption has become increasingly important, as concernabout the effects of economic growth [1]. The increase of the specific power demand by present day railway traction vehicles implies to find reliable technical solution in order to reduce the energy consumption. The typical journey i.e. of subway trains, light rail vehicles (tram) is made of accelerations, coasting and braking periods. In particular, the largest part of the energy drawn by the train is ascribed to the acceleration and braking because of the reduced distance between two subsequent stations. Modern electrical drives for traction motors benefit from the possibility of regenerative braking and the advantages related to the saving of energy attempting to inject the energy into the supplying line [2].

As the future of electric and hybrid electric vehicles is evidently becoming promising, significant research efforts worldwide have been directed towards improving propulsion systems and energy storage units. In the course of vehicles becoming "More electric" with increasing number of onboard electrically powered subsystems for both commercial and military applications, the need to manage the vehicular power system is imperative. Electrical loads for both traction and ancillary loads are expected to increase as the automotive power system architecture shifts towards a more silicon rich environment. The complex demand profiles anticipated by these dynamic loads require accurate and optimized control of power flow and energy storage subsystems within the vehicle, thus presents a technical challenge and opportunity for vehicular power and energy management research [3].

Research Rationale

Research efforts of this project is in line with specifications of the EU Joule III program, which stipulates the need of technical contributions in the area of vehicular energy storage technology, electrical management systems and energy management in electric vehicle drivelines. The vehicular technology industry is currently going through a transition period with the introduction of multiple voltage systems to meet future electrical load requirements. As such, research contributions towards this field are timely. Efficiency of electric vehicle energy storage systems is a system-level issue. Every aspect of the system has an impact on the energy efficiency, and the impact of a given subsystem is usually dependent on its interactions with other subsystems. The objective of a strategic power and energy management system for a charge depleting energy source(battery/ultra-capacitor) powered electric vehicle is to meet the performance expectations of the vehicle operator and to maximize the overall system efficiency while the charge levels of the energy sources are depleting. This energy source integration has to be done with an objective of minimizing the total mass and cost of the vehicle.

Literature Survey

This paper [4] given energy[4](and hence range) and performance limitations of electro-chemical batteries, hybrid systems combining energy and power dense storage technologies have been proposed for electric vehicle propulsion. The paper will discuss the application of electro-chemical batteries, supercapacitors and fuel cells in single and hybrid source configurations for electric vehicle drive-train applications. Simulation models of energy sources are presented and used to investigate the design optimization of electric vehicle on-board energy source in terms of energy efficiency and storage mass/volume. Results from a case study considering a typical small urban electric vehicle are presented, illustrating the benefits of hybrid energy sources in terms of system mass and vehicle range. The models and approach can be applied to other vehicles and driving regimes.

This paper [5] regardless of the topology of the hybrid electric vehicle, the essence of the HEV control problem is the instantaneous management of the power flows from the various energy storage devices to achieve the overall control objectives. In this paper we consider the case of energy management for a series hybrid powertrain configuration with two energy storage systems, i.e. batteries and ultracapacitors. The proposed power split algorithm is based on a modified instantaneous equivalent consumption minimization strategy (ECMS). The methodology could easily be applied to any kind of powertrain subject to the charge-sustaining constraint, and can readily be adapted to the specific characteristics of the components used in the powertrain.

This paper [6] focuses on the electrical modeling techniques of renewable energy sources and storage devices such as batteries, fuel cells (FCs), photovoltaic (PVs) arrays, ultra-capacitors (UCs), and flywheel energy storage systems (FESS). All of these devices are being investigated recently for their typical storage and supply capabilities for various industrial applications. Hence, these devices must be modeled precisely taking into account the concerned practical issues. An obvious advantage of electrically modeling these renewable energy sources and storage devices is the fact that they can easily be simulated in real-time in any CAD simulation program. This paper reviews several types of suitable models for each of the above-mentioned devices and the most appropriate model amongst them is presented. Furthermore, a few important applications of these devices shall also be highlighted.

Design

The regenerative braking system consists of six fundamental components listed below[7]. These components are arranged.

1. **Electric Motor** – Provides the negative torque necessary to reduce vehicle speed as well as the voltage potential needed to transfer charge into the bank of ultracapacitors.
2. **Control Circuit** – Provides an interface between the user input (ie the brake lever on the bicycle) and the power transfer circuit.
3. **Power Transfer Circuit** – Provides a controllable path for the energy to flow from the motor into the bank of ultracapacitors.
4. **Ultracapacitor Bank** – Provides temporary storage for the energy collected during braking.
5. **Energy Transfer Circuit** – Allows for the energy contained within the ultracapacitor bank after braking to be transferred to the battery bank, allowing for its use in acceleration later.
6. **Battery Bank** – Primary energy storage used for acceleration and auxiliary loads.

Simulink Experiment Model

Matlab/Simulink version 7 R2007b is being used as a tool for simulation. For simulation purposes in place of OHP cable a 25KV power supply is used. Popular two quadrant chopper model DC6 is used to study normal and braking modes. The battery bank is considered as 72V 100Ah. To change over between battery bank and main power supply current direction is taken as feedback. At the reverse direction ofcurrent a contractor is operated automatically that redirects the braking generated EMF to the battery bank. Further a charging control system can be used to regulate the current being supplied to the battery bank. And that will also take care of overcharging and deep discharge. On normal run i.e. on first quadrant operation system operates normally in motoring mode. Speed and torque values are taken as variables that represent engine speed and torque. Depending on these values choppers switching pulses are generated [8].

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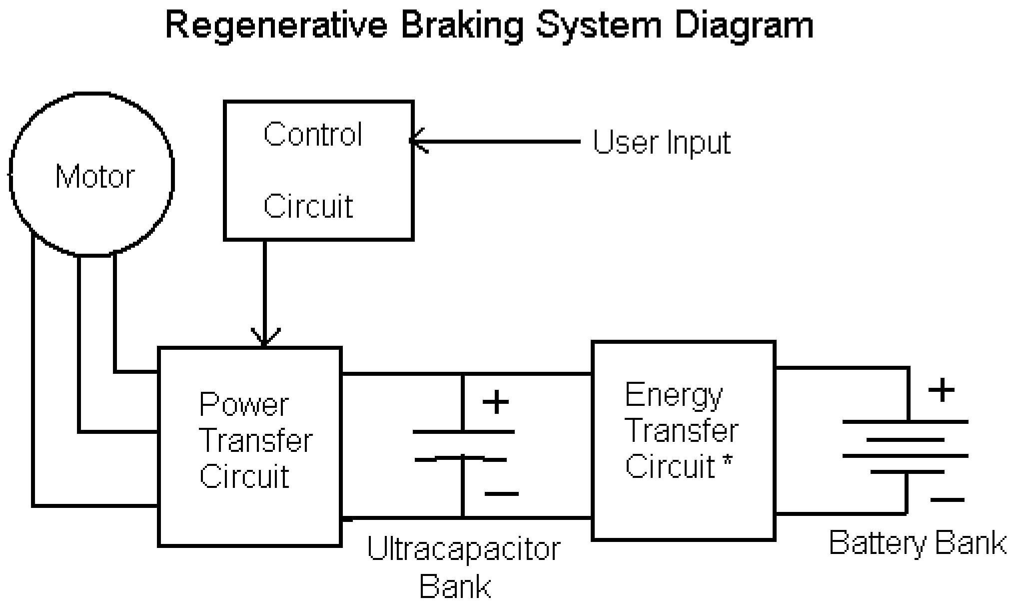

Figure1: Block diagram of simulation model

SYSTEM ARCHITECTURE

The basic principle of solar and wind hybrid train is to use sunand wind energy & store this energy in storage system. Thissystem will store energy during sunshine and running condition [8].

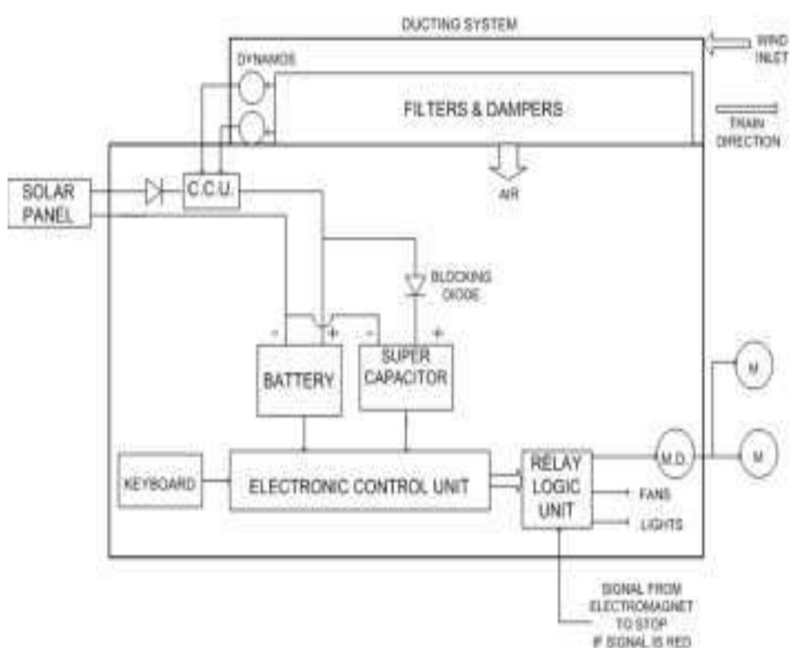

Figure 2: System Architecture

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Modelling Of Ultracapacitor

There are several propositions of ultra-capacitor model representation. The easiest of all the classicalequivalent circuit with the lump capacitance, equivalent parallel resistance(EPR) and equivalent seriesresistance(ESR). Figure 2 shows the classical equivalent circuit with the three parameters, Determination ofthese parameters provides a first approximation of an ultra-capacitor cell. The equivalent parallelresistance(EPR) represents the current leakage and influences the long-term energy storage. Through experimental measurements of voltage decays of several ultra-capacitors having various capacitancevalues, these shown that the equivalent parallel resistance effects could be neglected for transient dischargecalculations. However, the equivalent parallel resistance(EPR) value is important when cell balancing ofseries connected super-capacitors is considered. This parameter is not significantly dependent on the terminalvoltage nor the charge rates. Hence the equivalent series resistance (ESR) can be considered as a non-time dependent parameter. A three resistors and capacitor (RC) branch network with one branch having a voltage
dependent capacitance [9].

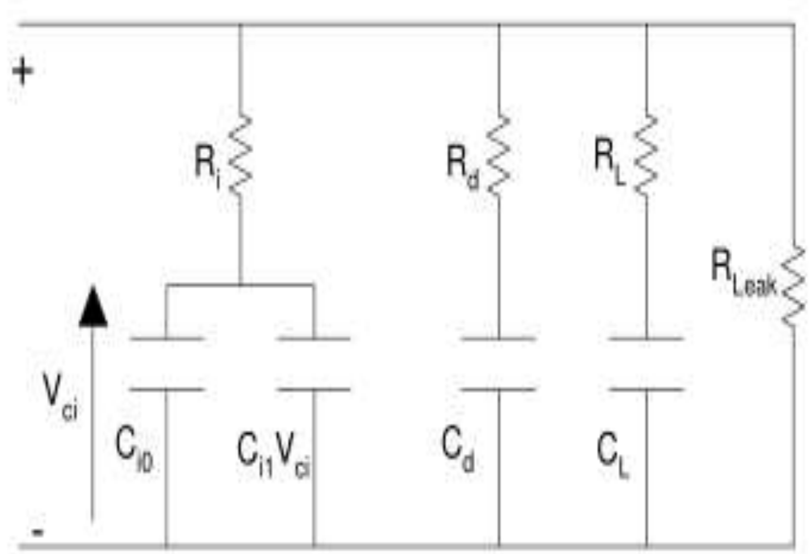

Figure 3: Brach representation ultra-capacitor model

Regenerative Braking

Forward and Reverse braking in DC6 chopper for Operation in quadrants II and IV, respectively. For the DCmodels of the Electric Drives library, this type of braking is regenerative, that means the kinetic energy of themotor-load system is converted to electric energy and returned to the energy or power source. Thisbidirectional power flow isobtaining by inverting the motor's connections when the current becomes null (DC1and DC3) or by the use of a second converter (DC2 and DC4). (DC1 and DC3) and (DC2 and DC4) methodsallow inverting the motor current in order to create an electric torque opposite to the direction of motion. Thechopper-fed DC drive models (DC5, DC6, and DC7) produce regenerative braking in similar fashions [10].

Conclusion

By the use of these techniques we save a large amount of energy which is wasted on the time of regenerative braking. Same study with some specification changes can be used for hybrid electric vehicle and other locomotives as well. In place of battery bank, ultra-capacitor can be used. This chapter concludes the dissertation. The chapter summaries the main contributions of this work and present a forward path to extend the research. In this research, an attempt has been made to provide a new perspective to the problem description of electric vehicle power and energy management. This dissertation has described a comprehensive and systematic frame work to address and implement such a power and energy management system. To demonstrate this, the frame work was implemented in the development of a test vehicle.

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