Extended summary

Energy Storage System Control, Management and Optimization in the Hybrids and Electrics Road Vehicles

Curriculum: Ingegneria Informatica, Gestionale e dell' Automazione

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Abstract. This PhD thesis wants to investigate different approaches to design, control and optimize the Hybrid Electric Vehicle (HEV) power-train with particular in-depth examination of the Energy Storage System (ESS) management, and the aim to increase the Battery Management System (BMS) efficiency and efficacy. This document therefore includes an introduction of the scenario in which this work fits, the research activity and the main results of this works.

Keywords. Hybrid and Electric Vehicle, Battery Management System, Energy Storage System, Lithium Battery, Fuel Cell Electrics Vehicle

1 Scenario Introduction

The fossil fuel depletion and the air pollution limit are the main drive of the restrictions on fuel consumption and emissions increasing. An possible solution to meet these requirements, is to make smaller, lighter and more aerodynamics vehicles, in this way the power necessary to propel the vehicle can be reduced, and thereby also the fuel consumption. Fuel reduction can also be obtained by improving the power-train components (especially the engine), by introducing new high efficiency components (like: electrics machines, lithium battery system, fuel cells module, etc.) and, by reviewing the conventional power-train architecture. These are the more radical ways to lower fuel consumption and emissions, and open up several alternative drive train configurations. This technological challange motivate the scientific community to look for new solutions to minimize fuel consumption and the production of polluting gases. In this scenario, Hybrid and Electric Vehicle can combine the high efficiently of the electric traction with the new energy storage system technologies, and the low pollution production of the last engine generations, up to reach the pollution production absence with a Fuel Cell Electric Vehicles[1]. In this contest the most critical component is the energy storage system. The energy storage technologies offers today several opportunity: the lithium – ion cell, with very interesting performance, high compactness and lightness, or as an alternative, the energy conversion from the hydrogen with fuel cell module.

The full electric and hybrid electric mobility has strongly increased worldwide in the recent years and first vehicles are available to customers, unconventional propulsion has found its way to the automotive mass market yet. Besides technical and economical obstacles caused by the car onboard technology, like battery safety, reliability, and cost, the integration of HEV or BEV into mobility and logistics concepts requires the parallel development of a sufficient charging infrastructure, information and communication technology (ICT) to connect user, car, and charging points, technical support and maintenance, etc. From technical side these changes open very interest challenges [2].

2 Research planning and activities

The research activity investigate the use of advance modeling and control techniques to design a Hybrids and Electrics Road Vehicles, with a specially attention on the Lithium Energy Storage System and its management . The activity can be spitted in two main objective. The first objective is to develop an completely simulation tool for to support the model based design in the HEV power-train, the second goal is to develop an Battery Management System efficacy.

The HEV have their own intrinsic management complexity, and to have an tool capable of choices conveying and control strategies test from the earliest design stages is fundamental. The rest part of the work are focused on the Battery System and Battery Management System. The Battery System as touched because an intelligent cells grouping and battery pack creation allow to increase the overall efficiency of the pack, with relevant economic benefit on the battery use. An Self Organization Maps clustering are used for cells grouping. An Battery Management System AUTOSAR compliant are developed. In this thesis

are presented the key device aspect with particular emphasis to the devices basic software architecture, the control algorithm implemented and the develop process used.

3 Analysis and discussion of main results

The main result in order to support and optimize the HEV power-train design, and the control system strategy development, it is presented and validated a Simulink toolbox created ad hoc. This toolbox permit to optimize the power-train right from the early stages of design. The models are developed to be fully parameterized and scalable, and adaptable to the different component size and power-train technologies available today. The simulation tool in addition to providing results that are very close to those actually achieved in real situations, it can perform the first analysis and testing of control algorithms developed. In this way the development of algorithms and control strategies takes place in parallel to the design of other vehicle components allowing a considerable time reduction in overall development process. The complete modeling toolbox it is presented that can be used for a model based design and sizing of the HEV. In addition, the modeling toolbox can be used for reduce the vehicle control and optimization strategy. An real case use are presented. In this case a Fuel Cell Vehicle is designed starting from an Electric Vehicle called Smile and produced by FAAM S.p.A.. This vehicle is classed as a heavy quadricycle commercial vehicle [3].

Particular attention is given to the storage systems modeling and characterization. Several models and approve has been propose to simulate the dynamic behavior and battery degradation in real operative conditions. The lithium battery models are used also to affront the problem of non-homogeneity in battery pack that has an impact in the reliability and performances and lowering costs of Electric Vehicles. In order to minimize the intense balancing activity impact in the Battery Management System, has been developed a cells grouping technique. All the cells that exhibit similar behavior in the operational field are aggregated. The optimization of the battery pack overall efficiency is based on neural networks SOM (Self Organization Map), in order to minimize the energy lose during the cells balance with a precise characterization, modeling and aggregation of the same. In this way, it is possible to maximize the useful energy in the battery pack at each vehicle cycle.

A challenging problem in energy storage systems for electric vehicles is the efficiency use of lithium multicell batteries. Because of production tolerances, unbalanced cells can be overstressed during usage leading to the reduction of the available capacity and premature failure of the battery pack. In order to reduce this problem a method was developed for the selection and classification of homogeneous cells to form uniform battery pack using Self Organizing Maps (SOM) neural networks. Experimental data are collected from a set of LiFePO cells tested in laboratories. The selection considers both experimental data and identified characteristics: Discharge Voltage, Open Circuit Voltage, Total Capacity and identified parameters from Randle's equivalent circuit modeling. The State of Charge variability within each selected group of cells has been chosen as the clustering criterion to find the method which gives the best results in terms of homogeneity of the battery.

The results consider an experimental EV load profile and show a great reduction of the SOC variability and, consequently, in the balance of the battery pack for all the methods

presented compared to random selection. Capacity and discharge voltage based methods give the best results over all with an valuable energy lose reductions.

The whole procedure that starts with the single cell testing and comes to the cells grouping has been patented.

The final aim of this works is the Battery Management System development with specially attention at the battery control strategies and their implementation. The Battery Management System (BMS) is an essential component within a multiple cell battery pack. It monitors the state of a battery, measuring and controlling key operational parameters, and thus ensuring safety. Lithium ion cells have high energy density so abuse of the cell can cause a thermal runaway leading to a cell fire and explosion. The single cells have safety devices and the battery has a safety circuit that monitors each cell and prevents over-charging and over-discharging. For this reason a AUTOSAR compliant BMS are developed. The AUTOSAR aims to establish a standard that will serve as a platform upon which future vehicle applications will be implemented and will also serve to minimize the current barriers between functional domains (vehicle centric versus passenger centric). In the BMS application software is present several software components, model based, with control strategies able to ensures the best lithium cells performance in completely safety. In details has been developed: a charge and discharge control for to maximize the battery life cycle, a cells balancing with a minimization of energy lose, an accurate cell impedance tracking, an State Of Charge (SOC) and State Of Health (SOH) estimator.

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