IEEE Canada Electrical Power and Energy Conference, Halifax, NS

Tutorial Proposal

Design Issues and Practical Solutions for Electric and Hybrid Electric Vehicle Propulsion Systems

Tanvir Rahman[1], *Member, IEEE*, and Sheldon S. Williamson[2], *Member, IEEE*

[1]Infolytica Corp.
300 Leo Pariseau, Suite 2222
Montreal, Quebec H2X 4B3
Phone: +1/514-849-8752, ext. 308
Fax: +1/514-849-4239
EML: tanvir@infolytica.com
URL: http://www.infolytica.com/

[2]Power Electronics and Energy Research (PEER) Group
P. D. Ziogas Power Electronics Laboratory
Department of Electrical and Computer Engineering
Concordia University
1455 de Maisonneuve Blvd. W.
Montreal, Quebec H3G 1M8, Canada
Phone: +1/(514) 848-2424, ext. 8741
Fax: +1/(514) 848-2802
EML: sheldon@ece.concordia.ca
URL: http://www.ece.concordia.ca/~peer/

Plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs) are generally regarded as the future for a sustainable automobile industry. Encompassing sufficient energy storage on-board is one of the major hurdles, delaying the proliferation of EVs in the commercial market. Hence, there is a need to build more efficient, light weight, and compact electric propulsion systems, so as to maximize driving range per charge. Primarily, there exist two methods to achieve high power density as well as high efficiency drives. One method includes employing high-speed motors, so that the motor volume and weight are greatly reduced at the same rated output power. However, mechanical losses are incurred by the clutch, reduction gear, and differential gear, during power transmission from the motor to the wheels. An alternate method involves using high-torque low-speed motors, which can be directly mounted inside the wheel, known as “wheel motor” or “hub motor.

In order to exclusively understand EV/HEV propulsion system requirements and design issues, this tutorial will initially introduce various vehicle power system architectures. Thereafter, an overview of applications of permanent magnet synchronous machines (PMSM) and switched reluctance machines (SRM) will be addressed. Advanced motor drive solutions for both PMSM and SRM will be presented, for in-wheel direct drive applications as well as integrated starter-alternator applications, respectively. In addition, power electronic converter topologies for drive purposes as well as control algorithms for efficient performance will be discussed in detail for both propulsion applications. Digital control techniques for SRMs will be introduced, with usage of advanced field programmable gate array (FPGA) based control techniques.

Another goal of this tutorial is to address practical electric machine design issues for EVs/HEVs. Design alternatives based on performance requirements, electrical as well as geometrical constraints, and other criteria, such as cost and efficiency, will be discussed in detail. The design aspects of popular types of electric motors being currently used in the auto industry will be addressed in detail. Interior Permanent Magnet (IPM) motor and Induction Motor (IM) design will be introduced. Furthermore, design issues related to SRM based propulsion systems will also be covered. Finally, a practical HEV propulsion system design case study will be presented, whereby the advantages and disadvantages of various machine options will be illustrated.

This tutorial will be useful for engineers with entry-level knowledge of EV/HEV motor drives and machine topologies.

Major Topics and Tentative Schedule

The proposed tutorial will be split up into 3 major topics of discussion, each spanning a period of **60 minutes (including Q&A), with breaks of 10 minutes between each session**. The topics include:

- Introduction to Electric and Hybrid Electric Vehicle Propulsion Systems;
- Modeling, Design, and Control of Advanced EV/HEV Motor Drives;
- EV/HEV Machine Design Issues and Solutions.

I. Introduction to Electric and Hybrid Electric Vehicle Propulsion Systems

This topic will introduce the operational characteristics and power system architectures of various hybrid electric (HEV) and electric vehicle (EV) propulsion systems. The basic performance requirements for a typical EV/HEV electric drive system will be addressed. The function of electric machines for electric traction will be addressed, considering practical efficiency issues. The efficiency analysis of the inverter/motor is of prime importance for the calculation of the overall efficiency of an EV/HEV drive train. In order to utilize the full value of the high energy storage system cost, it is imperative that the overall HEV electric drive efficiency be maintained at an elevated level. In this regard, one of the main issues to be addressed in this topic would be accurate modeling of the DC/AC traction inverter and motor losses (efficiencies) over typical city and highway driving schedules.

Efficiency maps are a convenient way to represent motor drive systems of large and complex systems, like that of an HEV. This topic will introduce the efficiency map based modeling technique for various traction motor/inverter options, such as induction motors, advanced permanent magnet motors, as well as switched reluctance motors. A number of case studies will be presented, wherein the drive train efficiency evaluation of diverse HEV arrangements will be summarized, based on the efficiency mapping method.

II. Modeling, Design, and Control of Advanced EV/HEV Motor Drives

This section will introduce basic as well as advanced power electronic motor drive topologies for EV/HEV propulsion systems. Various control systems issues and solutions will be highlighted in the presentation. In addition, the first half of this presentation will consider a case study, specific to an in-wheel direct drive propulsion system. Such an arrangement is unlike typical EV applications, wherein a central high speed electric motor is mechanically coupled to the wheels by a single speed reduction gearbox and a mechanical differential. The modeling, design, and control of a practical PMSM based in-wheel direct-drive system will be presented. In addition, the developed in-wheel PMSM drive will be analyzed in terms of converter efficiency, torque ripple, converter rating, vehicle performance, and cost.

In addition to PMSMs, tremendous attention has been drawn towards the SRM, as a suitable machine for EV propulsion. This is mainly due to the high starting torque, excellent wide speed range, as well as its low-cost rugged structure of the SRM. However, a well-known drawback of the SRM is significant output torque ripple. As opposed to conventional current control, this presentation will introduce an innovative methodology, wherein the problem of minimizing output torque ripple is tackled by continuously monitoring the motor phase voltages. A novel FPGA based control strategy will be demonstrated, which proves to be highly effective over the entire speed range. Experimental test results of the developed controller and motor drive will be presented, emulating city stop-and-go type driving conditions for an EV drive train. Overall drive system performance of the developed control system as well as the motor/controller operating efficiency for acceleration and regenerative braking capabilities will be presented.

III. EV/HEV Machine Design Issues and Solutions

This section will address electric machine design alternatives based on performance requirements, electrical as well as geometrical constraints, and other criteria, such as cost and efficiency. The design aspects of popular types of electric motors being currently used in the auto industry will be addressed in detail, including IPM, SRM, and IM. Finally, a practical HEV propulsion system design case study will be presented, whereby the advantages and disadvantages of various machine options will be illustrated. The case study will include the following sub-topics:

- Review of performance based sizing algorithms for electric motors (IPMs, Induction machines, and SRMs);
- Design of electric machine components; selection of motor type, drive, winding, and lamination modeling;
- Analysis and design iteration: calculation of back-emf (if applicable), torque-speed characteristics, K_T, K_e calculations, magnetic field analysis, hysteresis, eddy current and ohmic loss, and efficiency calculations;
- Thermal and acoustics calculations of electric machine design. Design validation methods; FEA based calculations and experimental validation.

The case study will include quantitative comparisons on each of these aspects for the three types of electric machines mentioned above for the same design task.

Biographies

Tanvir Rahman

Tanvir Rahman obtained his Ph.D. in Computational Physics from McGill University, Canada, in 2005, in the area of Astrophysical Fluid Dynamics. Dr. Rahman is currently an Application Engineer at Infolytica Corporation, where his primary responsibility is computer aided design and applications of electromagnetic solvers to electric machines. More recently, Dr. Rahman has been involved with applying the latest CAD tools for the design and simulation of Brushless DC motors and induction motors. Dr. Rahman has been professionally involved with the simulation and modeling of electric machines since 2006. His current research interests include multi-physics simulations of electric machines, new design algorithms of switched reluctance machines, among many others. Dr. Rahman is a member of the IEEE.

Sheldon S. Williamson

Sheldon S. Williamson (S'01–M'06) received his Bachelor of Engineering (B.E.) degree in Electrical Engineering with high distinction from University of Mumbai, Mumbai, India, in 1999. He received the Master of Science (M.S.) degree in 2002, and the Doctor of Philosophy (Ph.D.) degree (with Honors) in 2006, both in Electrical Engineering, from the Illinois Institute of Technology, Chicago, IL, specializing in automotive power electronics and motor drives, at the Grainger Power Electronics and Motor Drives Laboratory. Since June 2006, Dr. Williamson has been working as an Assistant Professor within the Department of Electrical and Computer Engineering, at Concordia University, Montreal, Canada. His main research interests include the study and analysis of electric drive trains for electric, hybrid electric, plug-in hybrid electric, and fuel cell vehicles. His research interests also include modeling, analysis, design, and control of power electronic converters and motor drives for land, sea, air, and space vehicles, as well as the power electronic interface and control of renewable energy systems.

Dr. Williamson has offered numerous conference tutorials, lectures, and short courses in the areas of Automotive Power Electronics and Motor Drives. He is the principal author/co-author of over 60 journal and conference papers. He is also the author of 4 chapters in the book entitled, Vehicular Electric Power Systems (Marcel Dekker, 2003). He is also the author of 2 chapters in the book entitled, Energy Efficient Electric Motors (CRC Press, 2004). In addition, Dr. Williamson has been selected as the General Chair for the IEEE Vehicle Power and Propulsion Conference, to be held in Montreal, in Sept. 2013. He was the Conference Secretary for the 2005 IEEE Vehicle Power and Propulsion Conference, Chicago, Illinois.

Dr. Williamson is also the beneficiary of numerous awards and recognitions. He has the honor of being included in the prestigious International Who's Who of Professionals and the International Who's Who in Engineering Higher Education. He was also the recipient of the prestigious "Paper of the Year" award, for the year 2006, in the field of Automotive Power Electronics, from the IEEE Vehicular Technology Society (IEEE VTS). In addition, he also received the overall "Best Paper" award at the IEEE PELS and VTS Co-sponsored Vehicle Power and Propulsion Conference, in Sept. 2007. He was awarded the prestigious Sigma Xi/IIT Award for Excellence in University Research, for the academic year 2005-2006. In 2006, he also received the "Best Research Student" award, Ph.D. category, within the ECE Department, at the Illinois Institute of Technology, Chicago.

Dr. Williamson is a member of the IEEE and currently serves as Associate Editor for the IEEE Transactions on Power Electronics and the IEEE Transactions on Industrial Electronics. He also serves as the IEEE Industry Applications Society (IAS) chapter chair as well as the IEEE Power Engineering Society (PES) chapter chair for the IEEE Montreal section.