AC 2012-3266: DEVELOPMENT AND IMPLEMENTATION OF DEGREE PROGRAMS IN ELECTRIC DRIVE VEHICLE TECHNOLOGY

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Development and Implementation of Degree Programs in Electric Drive Vehicle Technology

Abstract

In 2009, the US Department of Energy awarded $39.1 million to nine universities and colleges and a professional association, through the American Recovery and Reinvestment Act (ARRA), for development and implementation of Advanced Electric Drive Vehicle education programs. Wayne State University in Detroit, Michigan, in partner with Macomb Community College and NextEnergy, a State of Michigan organization to facilitate alternative energy technology development, was funded a $5 million grant to develop a comprehensive set of advanced educational programs, including a Master's Degree in Electric Drive Vehicle Engineering (EVE), a Bachelor's Degree in Electrical Transportation Technology (ETT), Associate's Degrees in Automotive Technology and Electronic Engineering Technology, with emphasis on Electric Drive Vehicles. The programs also include certificates with Electric Vehicle Technology courses, an undergraduate concentration and a graduate certificate program in EVE, and to simultaneously provide for general public and consumer education. This paper presents the design of the program curriculum, development of undergraduate and graduate courses and the laboratories, implementation of the degree programs, and the outreach activities, including the Summer Academy on HEV for community college students, professional development short courses in Advanced Energy Storage for community college automotive instructors and K-12 science and technology teachers, and a national workshops to engage electric vehicle manufacturers, battery, electric components, fuel cell developers, and electric infrastructure companies.

1. Introduction

The automotive industry has been one of the largest and most important industries in the United States, employing more than 3.3 million Americans[1], accounting for 4% of total gross domestic product, and representing the single largest U.S. export (nearly $121 billion) in 2008[2]. The world economy, however, has shifted over the past year. Today the automotive industry is engaged in a transformational change that incorporates a technological shift from the petroleum-powered engine that drove the transportation economy of the 20th Century to the renewable resource-based electric powered motor that will sustain the dynamic global economy and environmental assets of the 21st Century. In response to the change in consumer demand towards increasingly fuel efficient vehicles and compliance with the new Corporate Average Fuel Economy (CAFE) standards passed by the U.S. Congress in 2009 to decrease our dependence on fossil fuels by increasing a standard on new vehicles to 35 miles per gallon by model year 2020[3], the U.S. auto industry is developing vehicle propulsion systems that will reduce emissions today and provide a platform for further technological advances into the future. The primary developments are Hybrid Electric Vehicles (HEV), Plug-in Hybrid Electric Vehicles (PHEV), Electric Vehicles (EV), Alternative Fuel Vehicles (AFV) including common rail diesels, and Fuel Cell Vehicles (FCV). The impact today and in the long run is an increasing need for trained automotive

engineers, engineering technologists, and technicians prepared to support every stage of the product life cycle of these new automotive technologies, which requires the acquisition of an expanded skill set for each sector of the industry.

On the other hand, the installation of renewable and clean alternative energy generation sources has been growing rapidly recently. In his 2011 address of the State of Union, President Obama mentioned an ambitious goal of achieving 80% of electricity from clean energy sources by 2035[4]. Together with the need from the auto industry, the development of educational programs of training qualified and skillful workforce in renewable energy and advanced vehicle technology sectors becomes more urgent than ever. In the U.S.A, there are a few educational programs on renewable/alternative energy systems that have been developed in the universities such as University of Minnesota, Montana State University and North Carolina State University, etc[5,6]. Among these universities, Wayne State University (WSU) has created the nation's first comprehensive Master of Science Degree program in Alternative Energy Technology (AET) in 2006[7], sponsored by the Michigan's 21st Century Job funds. The program provides broad training in various alternative energies: hydrogen, solar, wind, and biofuels; fuel cell technology, hydrogen infrastructure, hydrogen safety, and process and systems design. The program is well-received and has graduated a number of students readily employed by the alternative energy industry. At the associate degree level, Macomb Community College (MCC) offers six certificate programs for AET technicians.

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2. Assessment of Need and Technical Approach

The first HEV came to the market in 1999 and it has caught increasing attention since then. Current projections show that 44 models of hybrid vehicles will be available by 2012, and that sales will exceed 870,000 units[8]. Nearly 20% of U.S. cars will be HEVs by 2020[9]. The automobile manufacturers, and the Department of Energy (DOE), as well as a number of vehicle conversion companies are actively involved in electric vehicle development through the Partnership for a New Generation of Vehicles (PNGV)[10]. Electric conversions of gasoline powered vehicles, as well as electric vehicles designed from the ground up, are now available to reach super highway speeds with ranges of 50 to 200 miles between recharging[11]. A PHEV is a HEV with batteries that can be recharged by connecting a plug to an electrical power source. The PHEVs have characteristics of both conventional hybrid electric vehicles and of battery electric

vehicles[12]. CEO's of the Detroit three automakers committed that by 2012, half of all vehicles produced will be compatible with ethanol (E85) fuel[13]. The new diesel engine technologies have made diesel vehicles cleaner, quieter and more powerful than past vehicles. J.D. Power & Associates survey shows nearly one-third of consumers would consider a clean diesel engine[14-16]. The longer term trend of automobiles includes fuel cell vehicles. Fuel cell vehicles represent a future of the development of the automobile. A fuel-cell vehicle will produce zero emissions, while being very fuel efficient, noiseless, vibration free and have a long service life. Advanced automotive technologies will have significant growth in the near future and will have implications for industries beyond auto manufacturing. The industry demands highly trained technical workers, of which there is currently a shortage. More than 80% of employers indicate an added need for highly trained technicians and 13% report a severe shortage[17, 18]. It was stated in the 2009 Michigan Green Job Report that more than 84,000 positions requiring postsecondary training remain to be filled with the majority in technical fields including the auto industry[19, 20].

As continuously emphasized by the US auto-makers, to enhance quality and improve global competitiveness, the American automotive industry needs a pipeline of innovative and knowledgeable engineers, as well as highly trained automotive technicians and technologists for the design, development, testing, service, and R&D sectors of the industry. To meet industry needs in an era of new technology, these engineers, automotive technicians and technologists must have education and experience in advanced automotive technologies and possess certain industry-identified and desired skills.
As a part of a National Science Foundation (NSF) project, WSU and MCC conducted a survey in 2008 to study the needs of workforce in the hybrid electric sector of the industry. The survey showed that 87% of the employers provide post-hire training to engineers and 93% of the employers provide post-hire training to technicians[21-22]. This shows that automobile manufacturers are training their EDV engineers and technicians mainly "in-house," which raises the cost for automotive manufacturers, delays product development and launching, and ultimately limits the numbers of engineers and technicians available for the growing EDV market. The survey also showed that engineers, technicians or technologists in advanced powertrain technology will be highly demanded over the next 5 years. More than 35% of the manufacturers and suppliers considered bachelor degree as the minimum educational level of their desired EV/*HEV technicians*[21-22]. There is a clear need for a systematic and comprehensive education and training program on EVE and ETT, which will contribute to job creation and retention, particularly in our southeastern Michigan region, where automotive manufacturers and their suppliers are highly concentrated.

The Department of Energy has established Graduate Automotive Technology Education (GATE) Centers of Excellence to provide a new generation of engineers and scientists with knowledge and skills in advanced automotive technologies. The programs described in this paper adopt the concept of GATE to provide the 21st Century automotive engineers, technicians, and technologists with knowledge and skills to meet the industrial needs for vehicle electrification. Specifically, the courses and curricula focus on EDV and infrastructure for a Master's Degree in Electric-drive Vehicle Engineering (MS-EVE), a Bachelor's Degree in Electrical Transportation Technology (BS-ETT), Associate of Applied Science Degrees in Automotive Technology and Electronic Engineering Technology, with emphasis on Electric Drive Vehicles, that include certificates with Electric Vehicle Technology courses, and a graduate certificate program in

Electric-drive Vehicle Engineering (GC-EVE). In addition, WSU and MCC also deliver a set of workshops, seminars, and short courses for emergency first responders, high school and middle school teachers, and corporate partners, among others.

3. Curriculum Programs in EDV

Master of Science in Electric Drive Vehicle Engineering

The MS-EVE program is designed to admit students with Bachelor's degrees in engineering or engineering technology, and with mathematics-based science degrees in exceptional cases or equivalent. Students will receive the master's degree after completing 32 credits of formal courses, directed studies, research, or thesis. The program offers a thesis (8 credits) and a non-thesis option, both of which have a group of required core courses, supplemented by elective courses.

With an emphasis in integrated learning by reinforcing theoretical comprehension with computer simulations, hands-on learning in the laboratory, and capstone design projects, the MS-EVE curriculum covers fundamentals, physical laboratories, computer simulations, technical areas, and capstone design. In terms of technical areas, this covers advanced energy storage, EV/HEV modeling and simulation, thermal management, power electronics and electric machines, control and optimization, onboard communication, and product development and infrastructure. Most courses involve multiple Departments and instructors to maximize the multi-disciplinary nature of the proposed program. Laboratories, computer simulations, and/or design and case study projects all have both stand-alone courses as well as being an integrated part of all lecture-dominant courses. The MS-EVE program currently offers the following courses:

- EVE 5110 Fundamentals of Electric-drive Vehicle Engineering
- EVE 5120 Fundamentals of Battery Systems for Electric and Hybrid Vehicles
- EVE 5130 Fundamentals of Fuel-cell Powered Systems for Transportation
- EVE 5150 Advanced Energy Storage
- EVE 5310 Electric-drive Vehicle Modeling and Simulation
- EVE 5410 Power Electronics and Control
- EVE 5430 Modeling and Control of Electric-drive Powertrains
- EVE 5450 Control and Optimization for Integrated Electric-drive Vehicle Systems
- EVE 5600 Electric-drive Vehicle Product and Infrastructure Development
- EVE 5620 Energy Economics and Policy
- EVE 5640 Energy and the Environment
- EVE 5700 Electric-drive Vehicle Capstone Design
- EVE 5810 Power Management for Advanced Energy Storage Systems and its Applications
- EVE 7110 Materials Science Aspects of Lithium Ion Batteries
- EVE 7320 Electric-drive Vehicle Thermal Management
- EVE 7410 Hydrogen Production and Storage for Vehicles
- EVE 7450 Embedded Systems for Vehicles
- EVE 7990 Directed Study
- EVE 7995 Special Topics in Electric-drive Vehicle Engineering

- EVE 7996 Directed Research
- EVE 8999 Master's Thesis Research and Direction

Bachelor of Science in Electric Transportation

The BS-ETT program is offered as an upper division program offered in the Division of Engineering Technology (DET) at WSU. The degree requires a total of 128 semester credit hours, including 29 credits in Math and Science, 9 credits in Written and Oral Communication, 18 credits in Humanity and Social Science, and 72 credits for technical courses, of which 30 credits are lower division technical courses transferred from community college. The program is offered in a 2+2 format with the expectation that students enter with an associate degree from community colleges or equivalent education. To further encourage community college transfer, Wayne State University and Macomb Community College has signed the articulation agreement that allows Macomb graduates with an Associate of Applied Science (AAS) in Electrical Engineering Technology degree or AAS in Automated Systems Technology - Mechatronics degrees to applied up to 80 transfer credits toward the BS-ETT degree.

The upper division technical core courses required in the BS-ETT curriculum include 18 credits for Electrical/Electronic fundamental courses, 16 credits for Electric Transportation required courses, and 6 credits for Electric Transportation elective courses. Students are also required to take an Engineering Project Management course (3 credits) and complete a Senior Project (3 credits) to earn the BS-ETT degree.

WSU-DET currently offers the following Electric Transportation technical courses:

- ETT 3190 Automotive Electric and Electronic Systems (Required)
- ETT 3510 Electric Machine Design and Application for Automotive (Required)
- ETT 4150 Fundamentals of Hybrid and Electric Vehicles (Required)
- ETT 4210 Control Systems for Hybrid & Electric Vehicles
- ETT 4310 Energy Storage Systems for Hybrid & Electric Vehicles (Required)
- ETT 4650 Power Electronics and Charging Infrastructure for EV/HEV (Required)
- ETT 4410 Introduction to Advanced Energy Storage (AES)
- ETT 4510 Power Management and Applications for AES
- ETT 4740 In-Vehicle Networking and Embedded Systems
- ETT 5000 Mechatronics in Vehicle Control Systems

Students are required to take basic Control Systems (EET4200) as prerequisite for Control Systems for Hybrid & Electric Vehicles (ETT4210). ETT4650 and ETT4740 are a substantial expansion and revision from existing EET courses, Power Electronics (EET4600) and Embedded Systems Networking (EET4730), with more advanced materials for electric drivetrain and electric propulsion systems. Other technical courses were developed based on inputs from industrial partners, manuals and training materials provided by EV/HEV manufacturers, and student feedback.

Associate of Applied Science and Certificate Programs

Macomb Community College has a Hybrid Electric Vehicle curriculum, an Alternative Fuels Certificate for the Automotive AAS degree, and a Renewable Energy Certificate for AAS degrees in Electronic Engineering Technology and Automated Systems to complement the Automotive Technology program. MCC offers five EV/HEV/PHEV exclusive courses: Hybrid Electrical Vehicle Fundamentals, Hybrid Electric Vehicle Powertrain and Controls, Electric Vehicle/ Plug-In Hybrid Electric Vehicle Technology, Electric Vehicle/ Plug-In Hybrid Electric Vehicle Machines, and Electric Vehicle Infrastructure Development and Operation. These courses are designed to be transferable to the WSU BS-ETT degree described above.

MCC is also working with the National Automotive Technician Education Foundation (NATEF) to initiate a pilot program for Automotive Service Excellence (ASE) certification in hybrid electric vehicles. Currently MCC's Automotive Technician program is ASE certified in all eight areas ASE offers certification. The potential of MCC's program to become the pilot program for Automotive Service Excellence (ASE) certification in hybrid electric vehicles extends the program's impact on the auto industry nationally.

4. Laboratory Development

It is critical for curricula of electric drive vehicle to provide ample hands-on laboratory experiences to practice classroom learning to gain in-depth understanding about the operation of electric drive components and systems. More than two thousand square feet of laboratory space has been set aside in WSU's Engineering Technology Building and the newly constructed Danto Engineering Development Center connected to the Engineering Building. The laboratories will consist of two focus areas: energy storage and electric propulsion integration.

Energy Storage Laboratory

The energy storage area provide for the testing of energy storage devices and systems with a focus on batteries and fuel cells at the cell, module, and pack system level. Electrical testing of these devices and systems will be performed to characterize and understand full size systems utilizing high power ABC150 test equipment, following USABC and DOE test procedures for batteries and fuel cells under standard and real world simulated driving profiles. Cycle life testing procedures will also be demonstrated with appropriate care for instrumentation and thermal management issues. Abuse tolerance and safeness testing will be demonstrated.

Battery pack testing will be performed on packs instrumented with voltage sensor, temperature probe and infrared imaging camera to understand variations in module and cell voltage and temperature within the pack during operation. Battery management system algorithms and techniques will be adopted at the battery pack level. Battery thermal management issues will be examined.

An automotive scale 10-kW test stand with automated humidity and flow control of reactant gases is proposed for basic operational performance features of fuel cell stacks including polarization and response time measurements and the effect of temperature on power performance.

Electric Propulsion and Integration Laboratory

The Electric Propulsion and Integration Laboratory provides for the testing of different types of power electronic converters and electric machines and machine drives/controllers for electric drive applications. Automotive scale motor controllers will be developed based on well instrumented bench dynamometer systems. A four quadrant dynamometer with capability for motor-controller systems powered by 50 kW at 500 V will provide for operation and demonstration of a wide variety of motor-controller technologies and designs. Instrumentation for 3-phase power analysis and high frequency data analysis will provide for detailed demonstration of power electronic circuits and electric machines aimed at hybrid and electric vehicles. A universal electric drive test bench will be developed with the flexibility to demonstrate different electric drive systems including plug-in hybrid and electric vehicles. The time dependent power input from the vehicle can be simulated by an ABC150 battery test unit which can provide DC power modulated with a driving profile waveform. This is a convenient way to test the dynamic response of electric machines for electric and hybrid vehicle applications. In addition to power, torque, and efficiency studies, we will have the opportunity to study thermal management issues.

5. Outreach Programs

To promote green transportation and alternative energy technologies, and the increase the awareness of the technologies by the general public, WSU and MCC jointly offer a variety of workshops and seminars to various groups with a stake in learning more about HEV technology:

Summer Academy for EV/HEV Technology

To encourage transferring from community colleges to four year universities, the program recruits 30 community college students each year to participate in the WSU Summer Academy for EV/HEV Technology. The program provides room and board for community college students to receive a "university experience" by spending four days at the WSU main campus. WSU engineering and engineering technology faculty are served as mentors to introduce the technology and the programs to the participants.

Faculty Development Program

WSU offers a two-day short course each summer for high school science and technology teachers, community college instructors, and automotive related professionals. The course consists of four modules:

- Electric Drive Vehicle Fundamentals
- Power Electronics and Charging Systems
- Advanced Energy Storage
- In-Vehicle CAN Embedded Systems

The short course also included lab sessions in each day to provide hands-on experiences:

- Demonstration of GM and Ford Hybrid Vehicles on On-Board Diagnosis Systems
- Demonstration of Traction Motor and Battery Testing Systems

Professional Development Short Courses

In responding to industry request, WSU has also developed four professional development short courses for incumbent automotive engineers:

- Fundamentals of Electric Drive Vehicles
- Battery Systems for Electric Drive Vehicles
- Motor Drives and Power Electronics for EV/HEV/PHEV
- Automotive Direct Injection Engines

Each course includes 14 hours for lectures and 4 hours for laboratory experiences. All of the four courses are endorsed by the state initiated Michigan Academy for Green Mobility Alliance. The program was first offered in August 2011 for 62 engineers and professionals sent by automotive manufacturers and suppliers.

Workshops for K-12 Automotive Teachers

MCC is a founding member of the Southeast Michigan Automotive Teacher Association (SEMATA), which represents 40 secondary schools and approximately 120 teachers and provides a forum for this project to educate teachers.

Informational seminar for automotive repair facilities and other corporate partners

There are approximately 4,845 repair facilities in Southeast Michigan. This seminar will introduce the technology and safety of Electric Vehicles and the supporting infrastructure.

Summer Academies for K-12 Students

These academies will be offered to encourage the learning of the EV technology and the advantages of these vehicles to the future of young people in terms of costs, environmental advantages, and future national and personal prosperity.

Excel Institute Training Program

This program will provide the latest technology training to a Macomb partner servicing a disadvantaged population in the District of Columbia. The Macomb developed curriculum will be share in a train the trainer session with Excel faculty.

6. Summary

This paper reviews the educational program development of alternative energy at Wayne State University and specifically discusses the development and implementation of a set of 2+2+2 programs in electric drive vehicle engineering and technology, including a Master's Degree in Electric-drive Vehicle Engineering (EVE), a Bachelor's Degree in Electrical Transportation Technology (ETT), and Associate's Degrees in Automotive Technology and Electronic Engineering Technology with emphasis on electric-drive vehicles. The 2+2+2 degree programs, with strategic alliance of engineering, engineering technology, and community college automotive programs, and industrial partners, is the first of its kind in its focus on EDV training for automotive engineers, technologists, and technicians.

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