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A University-Industry Partnership for Developing a Learning Environment for Advanced Energy Storage*

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The escalating demand for energy and the increasing concerns over the environment have called for clean and sustainable energy development. Generating electricity from renewable and clean energy sources such as solar and wind power as well as driving highly efficient vehicles are promising solutions to the energy development strategies. There is a great need for electrical energy storage for the effective commercialization of renewable energy resources, load-leveling, and maintaining a constant supply of electrical energy. Another important factor related to the need of electric energy storage is transportation electrification. The electric energy storage, such as battery and ultracapacitor, is a major electric drivetrain component for vehicle electrification. This paper describes a university-industry partnership in the establishment of a learning environment for advanced energy storage that responds to critical need through the creation of laboratory-based undergraduate courses in advanced energy storage systems, tailored with an emphasis on the vehicular and stationary sectors.

Keywords: electric energy storage; energy storage; renewable energy; vehicle electrification

1. Introduction

The growing demand for energy and the increasing concerns about man-made climate changes have called for clean and sustainable energy development. Generating electricity from renewable and clean energy sources such as wind and solar as well as driving highly efficient vehicles are promising solutions to the energy development strategies. A central feature here is maintaining a secure and constant supply of electrical energy, derived from a widely distributed supply infrastructure. These variable output energy sources require energy storage facilities to maintain customer requested output. Another important factor related to the need of electric energy storage is the transportation electrification. The on-board electric energy storage, such as battery and ultracapacitor, is a key component for electrifying vehicles. Energy storage technologies are a strategic and necessary factor for the efficient utilization of renewable energy sources, energy conservation, and vehicle electrification. The United States is competing with companies around the world to create less expensive and more efficient ways to develop and deploy new forms of advanced energy storage systems.

The purpose of energy storage is to accumulate the energy for use at a different time than when it was generated. Renewable energy is often intermittent (like wind and sun) while the energy storage allows use at a convenient time. The process of converting the energy to storable form means that some energy is lost due to inefficiency and heat. Additional energy is lost when the energy is released or recovered due to a second inefficiency. Ideally, energy storage is avoided to have a more efficient process. Shifting the energy from usage peaks to low-use times helps the utility, and customers would be rewarded by lower charges. Additional application of the energy storage is vehicle electrification that is occurred in Electric Vehicles (EV), Hybrid Electric Vehicles (HEV), and Plug-in Hybrid Electric Vehicle (PHEV). The on-board, high-power energy storage of these electric-drive vehicles serves primarily to support the mobile provision of electric energy.

The steadily increasing capacity of generating power from renewable energy and production of electric-drive vehicles by the industry coupled with the specialized set of skills required to accommodate the energy storage systems in both the stationary and transportation sectors, have created an urgent and continuous demand for more knowledgeable energy storage engineers and technicians. The required education includes safety, regulations, maintenance, system integration and control for energy storage devices. Recently, several universities and colleges have offered courses and certificate

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programs for training students and returning engineers in advanced energy storage technology [1–5]. Few integrated advanced energy storage laboratories have also been established for educational purposes [6–9]. However, neither systematic courses nor laboratory have been developed to train engineer and technicians in the emerging technology of advanced energy storages in both the vehicular and stationary applications. To date, neither an undergraduate engineering curriculum nor service technician program in energy storage technology has been developed.

It is not necessary to establish a new degree program in the advanced energy storage systems; however it is essential to integrate the energy storage courses and laboratory experiments into the existing engineering curricula. An integrated or progressive learning system is proved to be the most effective approach for professional development. This paper describes a university-industry partnership in the establishment of a learning environment for advanced energy storage that addresses the critical need for energy storage trained engineers and technicians that currently exists and will continue to grow. The energy storage learning environment that tailored with an emphasis on the vehicular and stationary sectors of the advanced energy storage includes undergraduate courses, professional development short courses, and a learning-by-doing laboratory. We particularly look into four types of electric energy storages: electro-chemical battery, ultracapacitor (also called supercapacitor), electro-mechanical flywheel (or flywheel battery), and pumped hydroelectric unit. The developed curricula targets engineering/engineering technology students in four-year universities, engineers and technicians in industries.

2. Learning environment establishment

An energy storage learning environment development team has been formed by the faculty at Wayne State University (WSU), local community colleges, and industrial partners from major battery manufacturers, automobile manufacturers, solar energy developer, and suppliers. The main activities include:

- Create an advisory committee to oversee the program.
- Integrate advanced energy storage curriculum with existing programs in WSU.
- Develop advanced energy storage specific courses, and deliver these courses.
- Create an advanced energy storage specialized laboratory.
- Develop and delivered a two-day short course.
- Create internship and co-op opportunities, plant visits, and an expert lecturer series.

2.1 Advisory committee

Initiating the development and implementation of all activities requires a system of coordination for exchange of information and resources and effective utilization of institutional strengths. Collaboration among faculty, administrators from all institutions, and industry partners was formalized through the creation of an advisory committee, which met regularly to develop and implement the planned activities and monitor progress.

2.2 Curriculum integration

The primary objective of curricula development is to prepare students and working engineers and technicians to be skilled advanced energy storage professionals. To achieve this objective, WSU, local community colleges in collaboration with their industry partners integrate energy storage education courses into their programs. WSU integrates two energy storage courses into the Bachelor of Science curriculum in Engineering Technology.

The energy storage curriculum at WSU is shown in Table 1. The structured curriculum is divided into two sequential sections: Energy Fundamentals and Advanced Energy Storage Technology. Section I, Energy Fundamentals, consists of four basic

Table 1. Curriculum for advanced energy storage in WSU

Section I: Energy Fundamentals—Current Courses		
Course No.	**Course Title**	**Credit Hours**
ETT 4150	Fundamental of Hybrid and Electric Vehicle Technology	3
ETT 4310	Energy Storage Systems for Hybrid and Electric Vehicles	3
MCT 4150	Applied Thermodynamics	3
MCT 5210	Energy Sources and Conversion	3
Section II: Advanced Energy Storage Technology (new courses)		
Course No.	**Course Title**	**Credit Hours**
ETT 4410	Introduction to Advanced Energy Storages	3
ETT 4510	Power Management and Applications of Energy Storages	3

courses of critical importance to energy systems. A student completes this section by completing at least three courses for nine credit hours. All courses are offered by WSU and are currently enrolling students. Section II, Advanced Energy Storage Technology, requires two new courses that were developed. Together they are total six credit hours, covering advanced knowledge in energy storage technology. Students must take both Section I and II (for a total of 15 credit hours) to complete the advanced energy storage training program and obtain an undergraduate certificate in advanced energy storage technology.

2.3 Courses development

To integrate the energy storage curriculum into the Engineering Technology Program, two new courses in advanced energy storage technology are developed. The two new courses that form the requirements for Section II of the curriculum are *ETT4410 Introduction to Advanced Energy Storages* and *ETT4510 Power Management and Applications of Energy Storages.* These two courses target current students as well as returning or lifelong students already working in the alternative energy and advanced automotive propulsion fields.

The first new course, *Introduction to Advanced Energy Storages*, covers the fundamentals of advanced energy storage technologies including electrochemistry, electro-chemical batteries, ultracapacitors, electro-mechanical flywheels, pumped hydroelectric, and fuel cell. The introduction of alternative energy systems and electric propulsion systems for transportation are also given. The second new course, *Power Management and Applications of Energy Storages*, covers the design, control and power management of different energy storage systems as well as hybrid energy storage systems. The energy storage systems for applications in stationary alternative energy systems and alternative vehicle propulsion systems are covered. The fundamentals of power electronics and system modeling and simulation are introduced as well. Table 2 lists the contents of two new courses in

Table 2. Course contents of the two energy storage courses

ETT4410 Introduction to Advanced Energy Storages	**ETT4510 Power Management and Applications of Energy Storages**
Introduction • Sustainable energy development • The need for energy storage	Introduction • Energy storage systems and sustainable energy development
Fundamentals of electro-chemical batteries	Review of different types of energy storage systems: batteries, ultracapacitors, flywheel, fuel cells, electrolyzers, and hydrogen storage
Types of electro-chemical batteries • Lead-acid • Nickel-cadmium • Nickel-metal hydride • Lithium ion and Lithium polymer • Other (Sodium-Ni, Zinc-air, etc)	Power management of batteries and ultracapacitors • Fundamentals of power electronics • Energy characteristics of batteries and ultracapacitors • Charge and discharge management
Lab 1: Measurement of internal voltage and resistance of a battery	Lab 1: Battery test
Ultracapacitors • Fundamentals • Applications	Thermal management of batteries • Thermal modeling of batteries • Thermal management for durable and reliable operation of batteries • Thermal management of battery pack
Lab 2: Charging and discharging ultracapacitors Electro-mechanical flywheels • Physics and features • Operation of flywheel • Advantages and disadvantages	Lab 2: Thermal management studies of a battery pack Control of flywheels
Fuel Cells • Fundamentals • PEMFC and SOFC	Control of fuel cells • Stand-alone systems • Grid-connected systems
Electrolyzers and hydrogen storage	Control of electrolyzes with hydrogen storage
Regenreative fuel cells Lab 3: Simulation of hydrogen storage system	Energy management of hybrid vehicles: case study Lab 3: Hybrid vehicle lab
Introduction to alternative energy systems: wind, solar, and fuel cells.	Design and power management of an alternative energy system with multiple sources: a case study
Introduction to electric propulsion systems for transportation	Lab 4: Simulation of a hybrid wind/PV/energy storage system

Table 3. Course contents of the two-day professional development short course

Modules	Contents	Lecture Hours
Alternative Energy and Energy Storage	• Introduction to alternative energy storage systems including wind, solar and fuel cells • Fundamentals of batteries, ultracapacitors and flywheel • Power electronics and system integration • System safety, design, control and power management	4
Electric Machines and Power Systems	• Operation principles of different electric machines including DC machines, AC synchronous and asynchronous (induction) machines • Introduction to power generation, transmission and distribution • Power system operation and control • Energy storages in power systems	4
Modeling and Analysis of Energy Storage Systems	• Fundamentals of different energy storage systems including batteries, ultracapacitors, flywheels, and fuel cells • Modeling energy storage systems: case study on modeling battery and fuel cell • Modeling alternative energy systems with energy storage devices • Modeling electric propulsion systems in vehicles	6

WSU. The development of these courses is based on input from industrial partners, textbooks, manuals and training materials provided by the energy storage manufacturers. The course development activities include the initial development of the course materials, delivery of the course, and modification of the course contents and materials based on student feedback.

2.4 Two-day short course development

In addition to the two new courses, a two-day short course is developed for engineers, technologists, technicians, and community college instructors working in the alternative energy and alternative automotive propulsion fields who wish to gain an in-depth understanding of advanced energy storage and their energy management schemes. This professional development short course consists of three modules as listed in Table 3. A set of computer-based courseware is developed as a teaching and learning tool. MATLAB/Simulink is used for simulations of energy system control and integration.

3. Laboratory establishment

There are several types of methods to store energy, including chemical, mechanical, thermal, electrical, electrochemical, etc. The developed laboratory focuses on four types of electric energy storage devices: electro-chemical batteries, electro-mechanical flywheel (or flywheel battery) [9, 10], supercapacitors (or ultracapacitors), and pumped hydroelectric system. The laboratory is divided into two units: (1) the electric energy storage unit consists of the batteries, electro-mechanical flywheel, and supercapacitors; and (2) pumped hydroelectric unit. The developed laboratory is capable of demonstrating and displaying the principles, performance characteristics, and applications of advanced electric energy storages. The developed laboratory experiments serves as hands-on experience workstations for students with multidisciplinary backgrounds that are enrolled in the advanced energy storage courses. The students are also encouraged to design their own experimental tests using the current setup as a baseline.

3.1 Electric energy storage unit

The developed electric energy storage unit is shown in Fig. 1. The entire system is installed on an aluminum flat stabilizer base that is portable to the classroom or demonstration event. A transparent box covers the flywheel because the high rotational speed might be dangerous in case of the failure on the flywheel mounting device. The components and their connections for the developed energy storage system are shown in Fig. 2. The main components include flywheel, DC electric machine, supercapacitor, electrolytic capacitor, batteries, data collector, tachometer, relay output module, switch panel, RS232/RS485 converter, etc. A DC power supply is used to supply the 10V and 12V DC power to the components. The tachometer is used to measure and display the rotating speed of the flywheel. A battery analyzer is used to measure and analyze different types of batteries. This battery analyzer also functions as data collector to measure the voltages of the components and provide communication with the computer. The main components, such as the flywheel unit, capacitors, resistor, lamp, power supply, and data collector, are all placed or connected to a circuit board which is then connected to the switch panel. The students can use the switches to control the circuit and make it operate in variant functions. Furthermore, the computerized experiments are implemented by replacing the manual-controlled switch panel with one relay output module.

The specifications of the major components in the system are listed in Table 4.

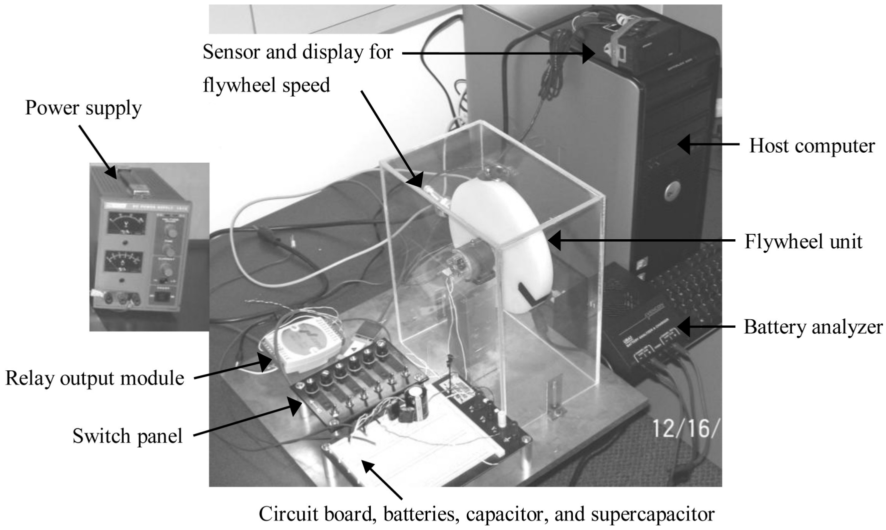


Fig. 1. The developed electric energy storage system.

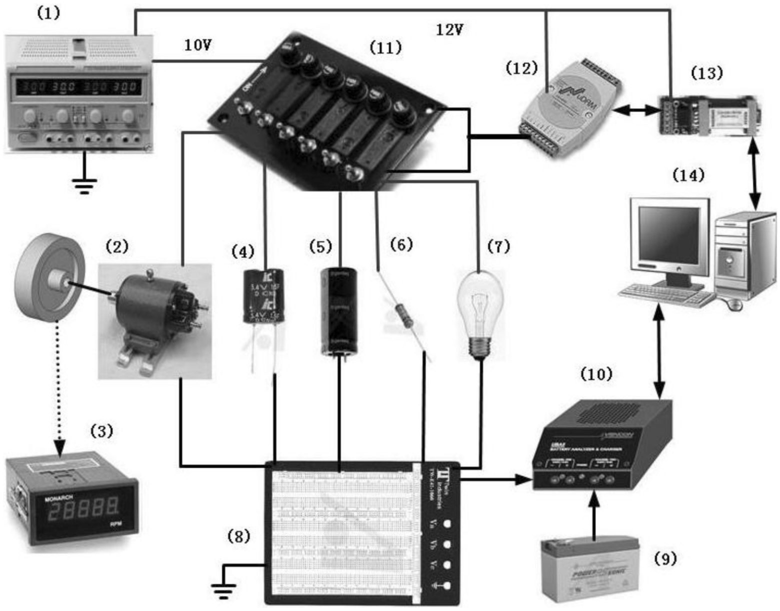


Fig. 2. Hardware and connections of the laboratory devices.

Table 4. Major components of the developed laboratory

DC power supply	Mastech variable DC power supply (HY3003F-3) 0-30V/0-3A
DC electric machine	Dynamo/Generator—Fully machined kit, 10W, 10V
Tachometer	Monarch Instrument ACT-1B Series Panel Tachometer
Flywheel	In-house fabrication
Data collector	Vencon UBA5 battery analyzer
Batteries	Lead-acid, sealed lead avid, 12 V, 7 rechargeable, F1 termination, 5.95 lbs NiMH AA 3100 mAh NiCd, 1.2 V, 700 Ah, AA-700, pressure Li-ion, 2200 mAh, 3.7 V
Supercapacitor	Super Cap; 2.5F 5.4 V—10+30%
Capacitor	CAP 27000UF; VOL-RTG 16V; snap-in; 105C
Switch panel	6 GANG 12 V fused boat switch panel 10060
Relay output module	Adlink NuDam ND6063 8-channel relay output module
RS485/232 converter	Serial adapter RS232 to RS422 and RS485 data converter
Lamp	L010 10pcs model trains layout lamp post lamp HO TT 65mm 3*6V

(1) DC power supply: DC power supply provides the 10V DC power to most of the components and 12V DC power to the relay output module and RS232/485 converter.
(2) Flywheels and DC electric machine: Three types of flywheel materials (steel, aluminum, and plastic) with two dimensional sizes are fabricated. The DC electric machine acts as a motor when it is supplied with DC power and accelerates the flywheel to a high speed (5000 rpm). When the electric power supply is disconnected, the electric machine then acts as a generator.
(3) Tachometer: The tachometer is used to measure the flywheel angular velocity in RPM. A digital tachometer, ACT-1B [11], displays the rotational speed in RPM or RPS using a speed sensor providing a single (or multiple) pulse(s) per revolution.
(4) Supercapacitor: The rate voltage of the selected supercapacitor is 5.4V. Two supercapacitors are connected in series in order to suit for the 10V power supply.
(5) Electrolytic capacitor: The electrolytic capacitor is used to make characteristics comparison with the supercapacitor. It is easy to recognize that the conventional capacitor is larger than the supercapacitor in size but its capacitance is much smaller than the supercapacitor.
(6) Resistor: One resistor is connected to the motor/flywheel unit when the motor acts as a generator. By measuring the voltage in the time domain, the electric energy generated by the generator can be calculated.
(7) Lamp: Lamp is used as a load for the capacitors, flywheel unit, battery, and power supply.
(8) Bread board: The components and electric circuits are placed on the bread board that allows the flexibility to redesign or modify the circuits.
(9) Rechargeable batteries: Rechargeable batteries include lead acid, Li-ion, NiCd, and NiMH.
(10) Battery analyzer: An Ultimate Battery Analyzer (UBA5) is used for measurement and data acquisition [12]. The UBA5 is connected to a serial port (or USB with adapter) of the computer to analyze, charge, cycle, and recondition the batteries. The testing capacity is from a single cell to 20 V and from 10 mAh to over 120 Ah. The UBA5 has two channels and each one has its own programmable discharging and charging capability. These two channels can be operated independently or in unison for higher current.
(11) Switch panel: The main electric components are connected to the switch panel. The users can control the switches to select which components are active in the circuit loop to perform different functions.
(12) Relay output module: ND6063 provides eight channels and a relay output module that can control high power devices without external circuits [13]. The module is controlled by a computer through the serial port connection. Therefore, the computer-controlled relay module can replace the manual-controlled switch panel.
(13) RS232/485 converter: A RS232/485 converter is utilized for the communication between host computer and ND6063 because the ND6063 module supports RS485 interface for communication and the host computer supports RS232 interface.
(14) Host computer: The host computer operates the battery analyzer software and the developed LabView-based software for testing and measurement. The computer needs two RS232 serial ports for the UBA5 and ND6063.

The detail circuit connection of the unit is illustrated in Fig. 3. The DC electric machine, DC power supply (10V DC), resistor, capacitors, lamp, and data collector (UBA5 battery analyzer) are all installed or connected on the bread board. The negative terminals of these components are connected together. The positive terminal of each component is connected to its corresponding switch on the switch panel and also connected to a relay output port of the ND6063 module. The ND6063 is powered by 12V DC supply. The Data+ and Data- port on the ND6063 is connected to its corresponding port on the RS485/232 converter. The RS485/232 converter is connected to a serial port of the host computer. The UBA5 battery analyzer is also connected to a serial port of the host computer.

3.2 Software development for the laboratory

The LabView-based computer-controlled automatic scheme is developed to facilitate the students doing laboratory experiments. The developed software is capable of measuring, computing, and displaying (on the digital screens) the characteristics of several types of electric energy storage devices. Figure 4 shows an interface screen of the developed LabView-based software after executing the software and selecting the calibration file for the UBA5. In the interface screen (as shown in Fig. 4), the left panel has a brief description of how to use the software to do the experiments. On the middle panel, the Start Test button is for starting the experiment and the Power button is used to stop

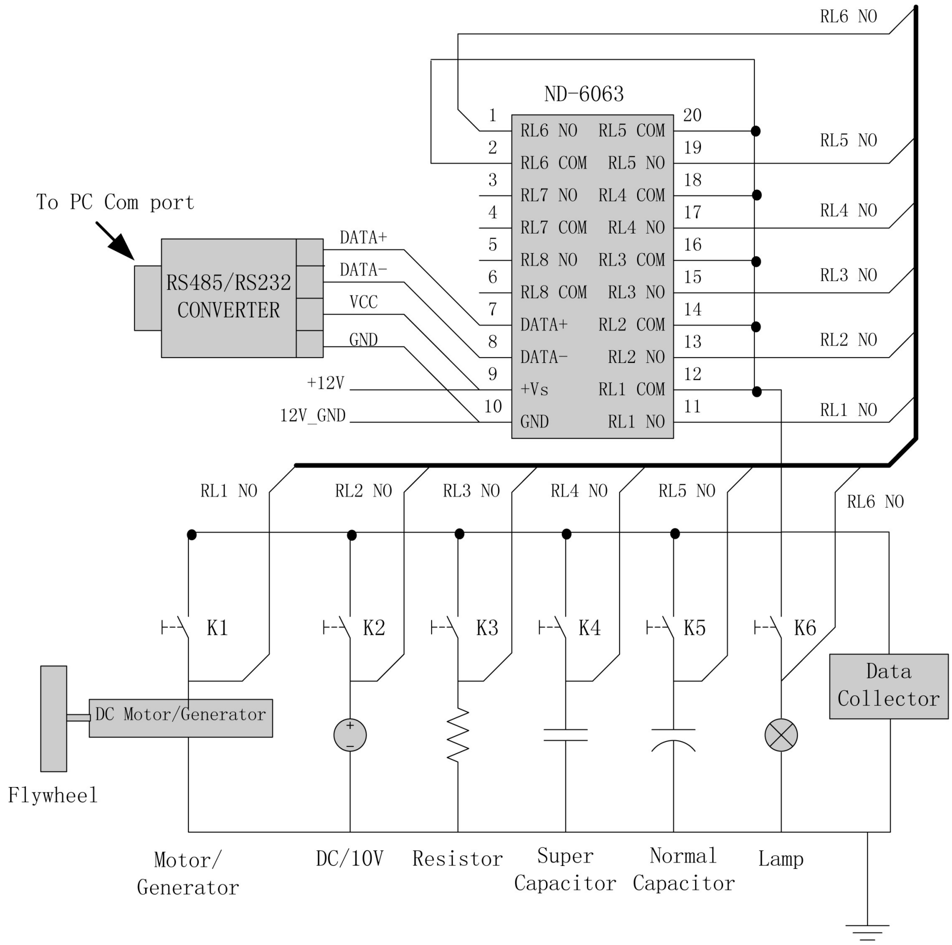


Fig. 3. Schematic diagram of the laboratory.

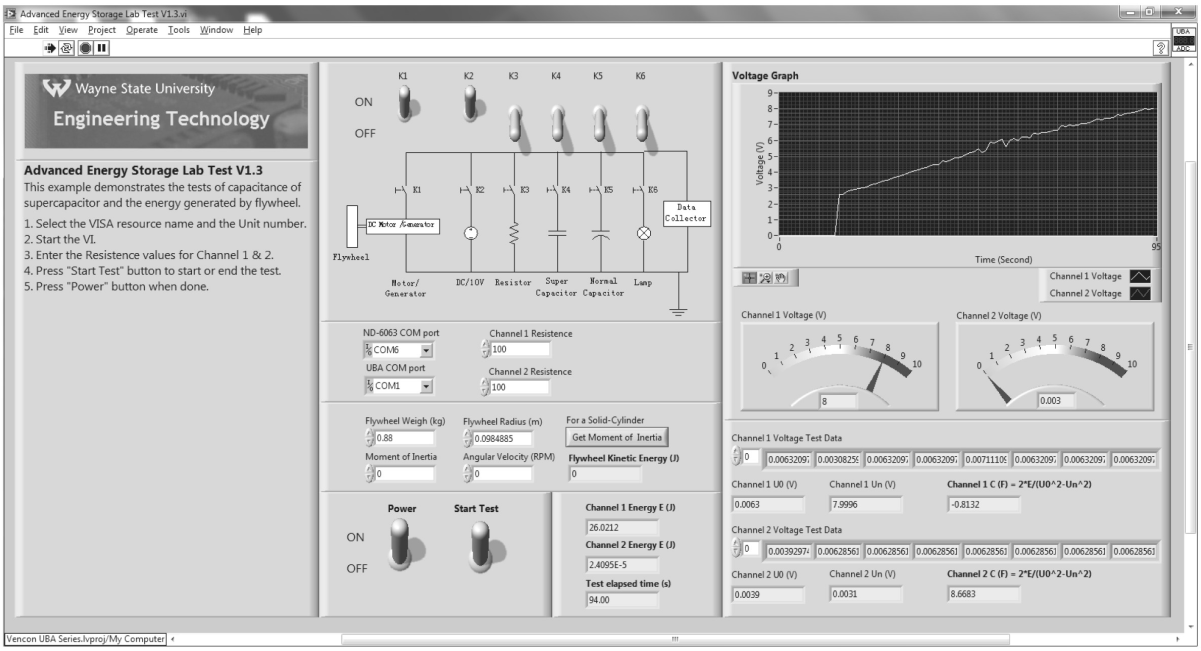


Fig. 4. Interface screen of the developed LabView-based software for laboratory.

the software execution. Before doing the experiments, the student needs to configure the correct COM port numbers of the UBA5 and ND6063. A resistance value of the resistor is also required. There are six switch buttons (K1 to K6) to control the circuit. The switches on or off statuses are controlled by the developed software. During the experiments, the software measures the voltages and electric energy of the active components, therefore the efficiency of the flywheel unit is automatically computed. The capacitance values of the capacitors are also calculated in the software. The voltage, capacitance, and voltage curve graph are then displayed on the right panel of the interface screen.

3.3 Small-scale pumped hydroelectric unit

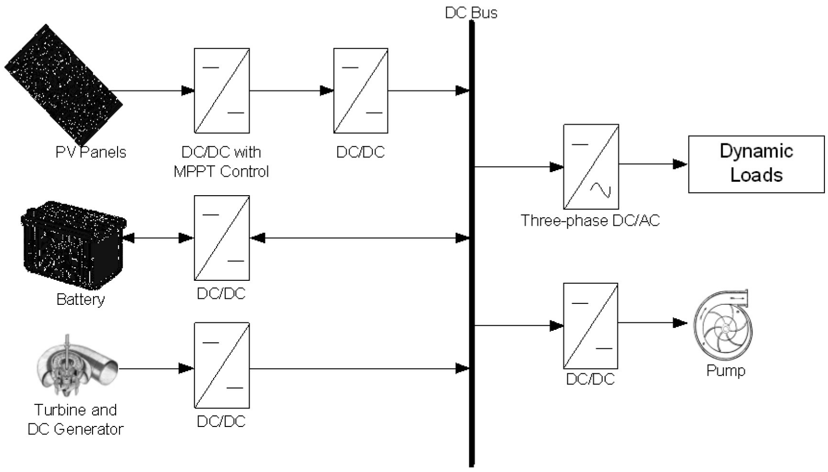
Pumped hydroelectric energy storage is a process that converts electrical energy to potential energy by pumping water to a higher elevation, where it can be stored indefinitely and then released to pass through hydraulic turbines and generate electrical energy. A typical pumped-storage development is composed of two reservoirs of equal volume situated to maximize the difference in their levels. The major equipment of the station is the pumping-generating unit, which is a special turbine either to spin an alternator or act as a pump. Electric energy is stored by pumping water from a lower elevation reservoir to a higher elevation during low-cost off-peak time and the water is released through turbine generators during times of high electricity demand. This generating and pumping cycle typically happens only a few times a day, and the overall efficiency is typically 70% to 85% [14].

A small-scale, laboratory setting pumped hydroelectric energy storage is established for teaching and demonstration purposes. This hydroelectric is a separate unit from the other three energy storages. The system utilizes a photovoltaic (PV) panel as the external energy source, which is controlled by a maximum power point tracking technique. A battery pack is used as the main energy storage device to smooth the fluctuation of solar power and to mitigate load transients and variations. In addition, a pumped hydroelectric energy storage system is used for supplying extra electric power via a hydro-turbine DC generator. The system diagram and hardware implementation is shown in Fig. 5(a) and (b) respectively. The DC coupling configuration is used for the system, and different power sources and loads are connected to the DC bus through the appropriate power electronic converters. This kind of system has a simple wired connection structure and control strategy. The PV panel, as the external energy source, is controlled by a DC/DC converter and then connected to the DC bus via a voltage controlled boost controller. The battery is connected to the DC bus via a bi-directional DC/DC converter. When the load changes and/or the PV generation varies suddenly, the battery is utilized to compensate the DC voltage and smooth the variations in power flow. The hydro generator used in this study is a DC generator for the easy control and high efficiency. On the load side, a three-phase DC/AC inverter is used to convert the DC energy into 60 Hz AC.

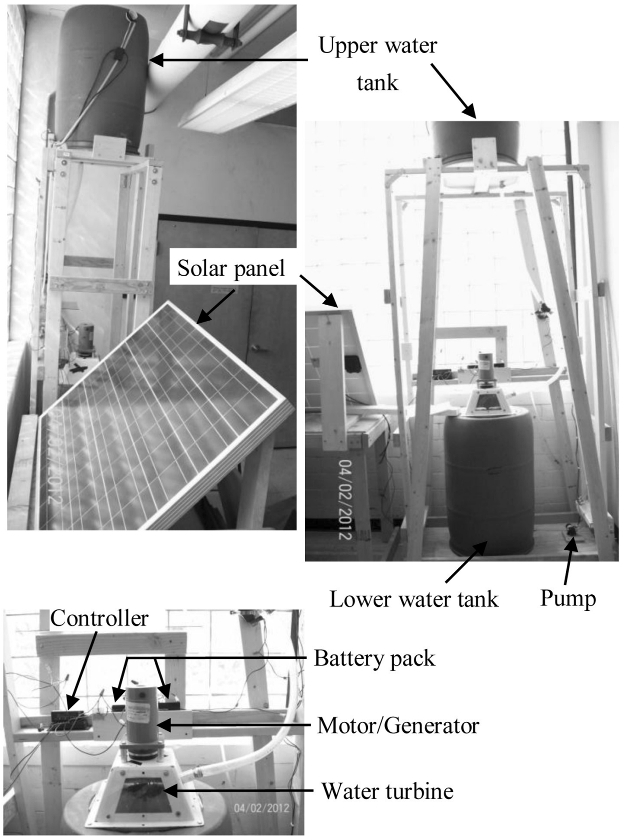
In the current setup, only the stand-alone operation is studied. The battery pack is the primary energy storage and the pumped hydroelectric is the secondary storage if the battery State of Charge (SOC) is full or too low. The system uses the battery pack as the main energy storage because the solar energy might be intermitted due to uncontrollable sunlight. Once the battery is nearly fully charged, the extra energy (from PV) will be used to pump the water from the lower tank to the upper one in order to form the hydroelectric energy storage. When the solar power is weak or unavailable, the battery will be discharged to supply electric power. As the battery SOC reaches a certain low-threshold value, the valve will be open to allow water stored in the upper tank run through the hydro-turbine generator such that extra electricity is generated from hydroelectric system. The selected DC pump needs two hours to pump enough water under the nominal power supply.

4. Education activity and student learning outcomes

The implementation of the electric energy storage learning environment was a resounding success. WSU has completed the development of two new courses of advanced energy storage systems in Fall term 2010. These two new courses are ETT4410 (Introduction to Advanced Energy Storages) and ETT4510 (Power Management and Applications of Energy Storages). The developed courses were delivered in 2011 Winter and Fall terms, and 2012 Winter term. The chief scientist of the Ovonic Battery at BASF and his team of scientists along with WSU faculty members collaboratively developed and taught the courses. Samples of student home work (disassembly and investigation of more than 10 types of battery cells) in Winter term 2012 ETT 4410 course is shown in Fig. 6. The industry partners also provide WSU with internship opportunities, plant tours, and the usages of their testing equipment for variant energy storages. Fig. 7 shows students were working on the charging and discharging testing of the NiMH battery pack which was used in a 2011 Toyota Prius HEV. The students have worked in the Ovonic Battery/BASF facility and



(a) System diagram of the small-scale pumped hydroelectric energy storage.



(b) Hardware of the small-scale pumped hydroelectric energy storage.

Fig. 5. The developed pumped hydroelectric energy storage.

utilized the company's charging/discharging chamber, instrumentation, data acquisition system, and testing peripherals (wirings, thermal couples, etc). WSU has offered summer professional development two-day short course for community college instructors and high school science teachers. The learning environment has been able to provide instruction on energy storage technology short courses and regular semester courses to 218 participants (115 in the first year and 103 in the second year) over the last two years (8/2010 to 7/2012).

4.1 Education activity

The WSU Board of Governors approved the certificate programs of advanced energy storage on January 26, 2011. WSU becomes the first in the

Fig. 6. Samples of student home work in Winter term 2012 ETT 4410 course.

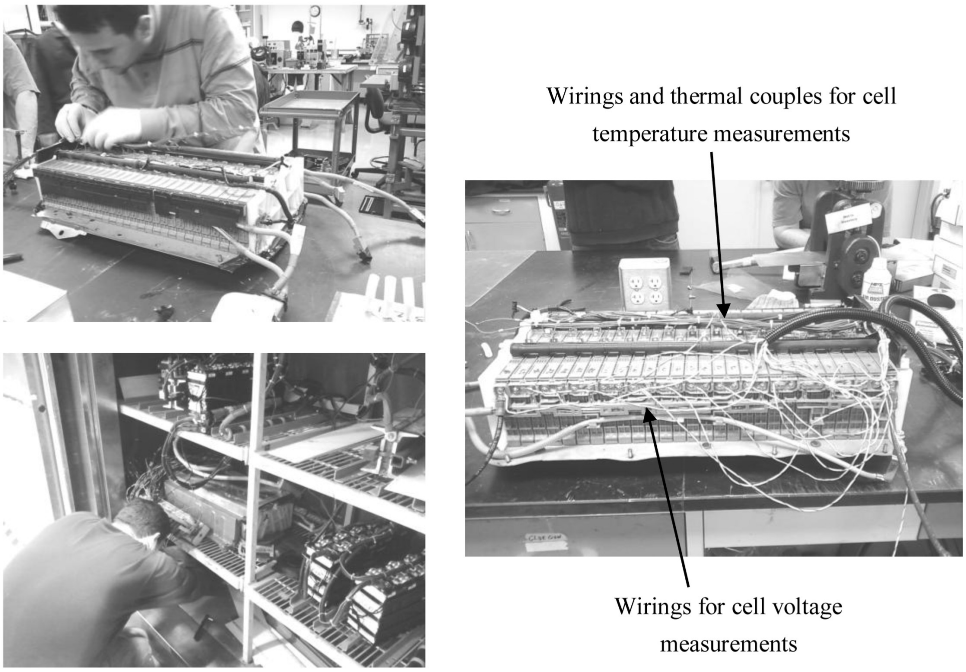


Fig. 7. Students working in the industry partner facility for NiMH battery pack testing.

country to offer undergraduate certificate programs in advanced energy storage systems as the state of Michigan's automotive industry transitions into producing more electric-drive vehicles. The new certificate programs draw from Wayne State's curriculum and research in electric-drive vehicle and alternative energy technologies, making the university a key education provider for the new engineering workforce critical to the transition and the state's economic growth. It had received much nice coverage in the local media:

- CBS Detroit "Wayne State offers nation's first certificates in advance energy storage," 2/17/2011 [15].
- CRAIN'S Detroit Business "Wayne State to offer program in energy storage systems," 2/17/2011 [16].

- MITECHNEWS-Green Tech "Wayne State offers certificate program in advanced energy storage systems," 2/17/2011 [17].
- Autotech Daily "Wayne State adds advanced energy engineering programs," 3/15/2011 [18].

In 2010 the WSU and its local community colleges partnership was invited by the State of Michigan Workforce Development Agencies (WDA) to serve as education providers in a proposal to the U.S. Department of Labor (DOL) for green job training. The proposal was awarded a $6 million State Energy Sector Partnership (SESP) grant for providing training in four green job areas [19]. WSU and its community college partners are responsible for providing advanced energy storages training programs for engineers and technicians, respectively. This grant provides tuition for 60 undergraduate and 50 graduate candidates to attend WSU courses and obtain undergraduate and graduate certificates in Advanced Energy Storage Systems. The candidates are recommended by the Michigan Works Association.

In 2011 the partnership was invited by Macomb/St. Clair Workforce Development Board to serve as education providers in a DOL project for the New Obama Administration Initiative to Spur Job Creation and Accelerate Economic Growth. The proposed "Southeast Michigan-Advanced Energy Storage Systems Initiative (AESSI)" was one of the 20 funded projects nationwide [20]. This grant is continues providing tuition for selected students who are enrolled in the advanced energy storage courses in Fall term 2011 and Winter term 2012. The students who received the tuition aid are displacement workers. Recently, Michigan Academy for Green Mobility Alliance (MAGMA) [21] also endorsed the professional development short-course on advanced battery systems developed by WSU. The MAGMA was established in 2008, in conjunction with Michigan's Green Jobs Initiative, to ensure the automotive industry has the trained workers necessary to grow and prosper in the emerging green economy. Its members are from industry, educational institutions, government agencies, workforce development, professional societies and non-profit organizations. Through election by members, MAGMA has established a Governance Board consisting of six employer representatives, four education/training providers, and three members from government agencies, workforce development and professional societies.

4.2 Student learning outcomes

The impact of the project on students was assessed through evaluation of Student Outcomes at WSU as part of the normal Accreditation Board for Engineering and Technology (ABET) assessment process. The standard evaluation was carried out in the form of end-of-semester student surveys in which students were asked to rate if they agreed that they had mastered the learning outcomes specified in the advanced energy storage systems. The results of the surveys are shown in Table 5. Students indicated their response by selecting from five options: Strongly Agree, Agree, No Opinion, Disagree, or Strongly Disagree. Internally, the department has set a target of 75% of students being in the 'Agree' or 'Strongly Agree' categories as an indicator of success on achieving any given outcome. As can be seen in Table 5, the evaluations show that students met the desired level of performance in all the competency outcomes assessed.

In a supplemental mode of evaluation not nor-

Table 5. Advanced energy storage course outcomes assessment

Course	Strongly Agree	Agree	No Opinion	Disagree	Strongly Disagree
ETT 4410 Introduction to Advanced Energy Storages	84%	16%			
E1 Understand the fundamentals of energy and the latest development of sustainable energy					
E2 Explain the energy conversion and the need for energy storage systems	80%	20%			
E3 Understand the fundamentals of electrochemistry	47%	43%		10%	
E4 Analyze pros and cons of various types of energy storage systems and their applications	77%	23%			
E5 Analyze pros and cons of various types of electro-chemical energy storage and their applications	52%	36%		7%	5%
ETT 4510 Power Management and Applications of Energy Storages	72%	28%			
P1 Describe the fundamental principles of various energy storage techniques					
P2 Understand the fundamentals of power electronic circuits, electric machines, and control systems	19%	58%		17%	6%
P3 Determine the characteristics and the technological needs for power management of different energy storage systems	32%	55%		8%	5%
P4 Able to design a simple power management of energy storage for different applications	22%	56%	3%	11%	8%
P5 Identify design issues of implementing energy storage systems	47%	35%		18%	

mally undertaken for ABET purposes, an external evaluator was engaged to conduct face-to-face focus group interviews with the students. Interviews provide a mechanism for capturing information that may be difficult to observe or that may not be captured in traditional surveys. Focus groups are a special type of interview that takes place within a group context rather than one person at a time. Interpersonal interactions within a focus group often lead to more detailed responses than would be possible otherwise. The interviews were conducted close to the end of the semester after students had ample opportunity to complete significant portions of the hands-on laboratory activities and thus could comment on whether project intent was being met. Using an external evaluator ensured anonymity for the participants. The interviewer met with the students without any members of the project team being present and assured the students of the confidentiality of all their responses. During the interviews, students were asked to respond to the following set of questions and to indicate whether there was consensus on the response or if there was a split, to provide an indication of the range of responses:

Question 1: To what degree has this course led you to a better understanding of what it means to store energy? Do you feel that there was enough time allowed in the lab and industry facility and that the experiments were effective?

Question 2: To what degree has this course helped you to understand what happens at the energy conversion, both as regards processes and efficiency?

Question 3: To what degree has this class helped you to better understand the terminology that is used on the energy storage domain, particularly in the electric energy storage systems? Do you feel better prepared, as a result of this class, to interact with others involved in the technical processes covered here?

Question 4: How helpful has the lab manual been in your learning and in your ability to follow lab practices?

Question 5: Please evaluate the pace followed in this course: has this lab course moved too quickly, too slowly, or has it been just right?

Question 6: Have the assignments and activities in this class facilitated your learning and understanding?

Question 7: If you could change this course, what are the top 3 things that you would change to increase your learning? If this course were to be changed, what would you say should not be changed at all because to change it would be to weaken your learning?

Responses to the first three questions, (Q1, Q2, Q3), showed strong agreement among the students that they learned how the electric energy is stored and released in four types of electric energy storage devices, learned the different forms of energy and its conversion, and learned the terminology used on the energy storage industry. All these strongly suggest that the goals of the student learning outcomes were met by this approach. This conclusion is supported by the results of the end-of-semester surveys, which showed that all course outcomes were being met at the 75% level or higher. The results of the focus group interviews together with those from the surveys are very strong evidence for the effectiveness of this approach in giving students hands-on experience. One of the strongest themes identified in the focus group interviews was a desire by the students to have more time allowed for the projects (Q1, Q5, and Q7). We remain convinced however that while challenging, the work involved in the projects is not excessive. This is buttressed by the fact that while the students did complain, they were all able to complete the lab experiments. Interestingly, the students also expressed a desire to experience other types of energy storage systems (Q1), or other types of energy conversions (Q2) which would require additional effort. Whereas the results of the student surveys and the focus group interviews showed encouraging results of student accomplishment of the goals of the project, we recognize that these are only indirect measures. The direct measures will be conducted in the form of employer surveys. The companies employ WSU graduates, who had completed courses or obtained the certificate in energy storage, will be asked to evaluate their new employees in terms of his/her knowledge and skill in advanced energy storage technology. We plan to carry out this employer surveys after several WSU graduates have completed their first year of employment.

5. Conclusions

There is a great need of electrical energy storage for the effective commercialization of renewable energy resources and transportation electrification. To date, neither an undergraduate engineering curriculum nor service technician program in energy storage technology has been developed. It is essential to integrate the energy storage courses and laboratory practices into the existing engineering curricula. A university-industry partnership in the establishment of a learning environment for advanced energy storage is presented. The energy storage learning environment that tailored with an emphasis on the vehicular and stationary sectors of the advanced energy storage includes undergraduate courses, undergraduate certificate, professional development short courses, and laboratory.

In order to establish energy storage learning environment, a partnership was formed among faculty at WSU and local community colleges as well as industrial partners from major battery manufacturers, solar energy developer, automobile manufacturers and suppliers. Two new courses of advanced energy storage systems and professional development short courses have been developed and delivered for several times. A reconfigurable, interactive, and computer controllable laboratory is developed for four types of electric energy storage devices: electro-chemical batteries, electro-mechanical flywheel, supercapacitor, and pumped hydroelectric. The developed laboratory experiments not only enhance the advanced energy storage training and education, but also inspire students' interest in the green movement of renewable energy and vehicle electrification.

It is our intent to develop collective effort, among educators, industry, and government agency, to make positive, continual, and lasting contribution for engineering education on the emerging technology for advanced energy storage systems in both the stationary and transportation sectors. The implementation of the energy storage learning environment is a resounding success. The work is still ongoing and initial student reaction has been quite enthusiastic.

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References

1. D. Tallon, R. Streit, C. Wang, C. Bakis, C. Randall, M. Lanagan, J. Anstrom, D. Jonassen, R. Marra and J. Wakhungu, Graduate Automotive Technology Education in energy storage systems—GATE Penn State, International Journal of Continuing Engineering Education and Lifelong Learning, **11**(4/5/6), 2001, pp. 534–541.
2. J. Keith, M. Miller, K. Opella, J. King, J. Meldrum, C. Green, G. Gwaltney and S. Bradley, Engineering education in alternative energy, *Proceedings 2006 ASEE Annual Conference*, Chicago, Illinois, 18–21 June 2006, AC2006-191.
3. D. Rouch and A. Stienecker, A Delphi study to project the future of alternative energy and its implication to engineering technology, *Proceedings 2007 ASEE Annual Conference*, Honolulu, Hawaii, 24–27 June 2007, AC2007-1614.
4. J. Gillespie, K. Bhatia, P. Jansson and W. Riddell, Rowan university's clean energy program, *Proceedings 2008 ASEE Annual Conference*, Pittsburgh, Pennsylvania, 22–25 June 2008, AC2008-1329.
5. F. Yildiz and K. Coogler, Development of a renewable energy course for a technology program, *Proceedings 2010 ASEE Annual Conference*, Louisville, Kentucky, 20–23 June 2010, AC2010-1232.
6. F. Falcone, T. Davidovits, E. Schacht and M. Wahlstrom, Integration of modern energy storage design practices into university automotive engineering programs, *Proceedings 2010 ASEE Annual Conference*, Louisville, Kentucky, 20-23 June 2010, AC2010-1388.
7. R. Chen, D. Goodman, A. Izadian and E. Cooney, Teaching renewable energy through hands-on project-based learning for engineering technology students, *Proceedings 2010 ASEE Annual Conference*, Louisville, Kentucky, 20-23 June 2010, AC2010-229.
8. B. Bosma and G. Kallio, Renewable-energy labs for an undergraduate energy-systems course, *Proceedings 2009 ASEE Annual Conference*, Austin, Texas, 14–17 June 2009, AC2009-1621.
9. T. Rutar and G. Mason, Three freshman team design projects, *Proceedings 2005 ASEE Annual Conference*, Portland, Oregon, 12–15 June 2005.
10. U.S. Department of Energy, *Flywheel energy storage—an alternative to batteries for uninterruptible power supply systems*, Federal Technology Alert, DOE/EE-0286, Federal Energy Management Program (FEMP), http://www1.eere.energy.gov/femp, Accessed 15 August 2012.
11. Monarch Instrument, *ACT-1B series panel tachometer instruction manual*, http://www.monarchinstrument.com, Accessed 12 May 2012.
12. Vencon, *UBA5 battery analyzer manual*, http://www.vencon.com/ubasw/UBAManualFull2010May.pdf, Accessed 12 May 2012.
13. ADLINK Technology, Inc., *ND-6063 manual*, http://www.adlinktech.com, Accessed 12 May 2012.
14. *Hydroelectric pumped storage technology: international experience*, Task Committee on Pumped Storage, Committee on Hydropower of the Energy, American Society of Civil Engineers, New York, 1995, ISBN-13: 978-0784401446.
15. CBS Detroit, *Wayne State offers nation's first certificates in advance energy storage*, 2/17/2011, http://detroit.cbslocal.com/2011/02/17/wayne-state-offers-nations-first-certificates-in-advanced-energy-storage/, Accessed 17 June 2012.
16. CRAIN'S Detroit Business, *Wayne State to offer program in energy storage systems*, 2/17/2011, http://www.crainsdetroit.com/article/20110217/FREE/110219895/wayeChromeHTML/Shell/Open/Command#, Accessed 15 August 2012.
17. MITECHNEWS-Green Tech, *Wayne State offers certificate program in advanced energy storage systems*, 2/17/2011, http://www.mitechnews.com/printer.asp?Id=12773&sec=104&layout=1, Accessed 8 August 2012.
18. Autotech Daily, *Wayne State adds advanced energy engineering programs*, 3/15/2011, http://autobeatgroup.com/?s=wayne+state&cat=4, Accessed 8 August 2012.
19. State Energy Sector Partnership (SESP) and Training Grant Summary, http://www.michigan.gov/documents/mdcd/SESP_Summary_01-28-2010_313382_7.pdf, Accessed 15 August 2012.
20. Southeast Michigan-Advanced Energy Storage Systems Initiative (AESSI), http://www.michiganadvantage.org/Advanced-Energy-Storage, Accessed 8 August 2012.
21. Michigan Academy for Green Mobility Alliance (MAGMA), http://www.sae.org/training/magma, Accessed 8 August 2012.

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