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Plug-in Electric Drive Vehicles: Experiences in Research and Education

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***Abstract*—This paper briefly describes the research and educational activities related to a current NSF CAREER grant titled "Vehicle Fleet as a Distributed Energy Storage System for the Power Grid". The PI, Dr. Ferdowsi, is an assistant professor at the Electrical and Computer Engineering Department of the Missouri University of Science and Technology (MST).**

***Index Terms*—NSF CAREER grant, Plug-in hybrid electric vehicles**

I. INTRODUCTION

Transportation and electric power generation are major consumers of fossil fuels. The constantly increasing price of fuel and global warming are the two major motives to improve the efficiency and fuel economy of the vehicle fleet as well as electric power generation [1]. Furthermore, with heavier power transfers, power systems are increasingly vulnerable to cascading failure. The power grid of the future needs to be more reliable and secure. Plug-in hybrids and the vehicle to grid concepts [2] have been independently introduced; however, minimal effort has been directed at systematically combining these two concepts.

An electric drive vehicle (EDV) is a vehicle in which partial or entire propulsion power is electrically provided. Each EDV has an energy storage unit (ESU) included in its powertrain. The ESU may consist of batteries, ultracapacitors, flywheels, or a combination of them. Interaction of the ESU with the powertrain improves the overall efficiency of the system. For instance, in the charge sustaining mode of a hybrid electric vehicle, efficiency improvement is attained by running the main source of power, internal combustion engine (ICE), at a constant operating point or at least with minimal operating point variations. In order to generate enough power, the operating point of the ICE has to be set equal to the average road load demand. The control concept is to run the ICE at a relatively constant power rate; if more power is required the ESU is discharged and if less power is required then ESU is charged.

The demand for electricity in the power grid is not constant over a 24-hour cycle. By using an ESU, the exact same concept of powertrain hybridization of vehicles is applicable. Excess generating capacity available during periods of low demand can be used to store energy in the ESU. The stored energy can then be used to provide electricity during periods of high demand, helping to reduce power system loads during these times. Furthermore, many renewable resources, wind and solar power for example, are intermittent. Hence, storing energy from the renewable source allows the supply to more closely match the demand. Energy storage can improve the quality, efficiency, reliability, cost-effectiveness, and flexibility of the electric utility system by reducing the requirements for spinning reserves to meet peak power demands, making better use of efficient base-load generation, and allowing greater use of renewable energy sources [3]. In addition, they also reduce the environmental impact of electricity generation, transmission, and distribution. Conventionally, ESUs connected to the power grid have been implemented in small and medium scales including batteries, compressed air energy storages, flywheels, pumped hydro, ultracapacitors, and superconducting magnetic energy storages.

II. INTEGRATION OF THE VEHICLE FLEET WITH THE POWER GRID

In the last section, it was discussed how the application of an ESU benefits the performance, efficiency, cost, and reliability of both vehicles and power systems. Utilization of ESUs in vehicles is already available on the market in hybrid vehicles. ESUs with higher capacity will soon be available on the plug-in hybrid models. On the other hand, ESUs in different capacities and with various mechanisms are already connected to the grid. One may devise using the same ESU for both purposes [4]. It is obvious that the capacity of the ESU of a single vehicle is not comparable to the required ESU for the power grid; however, considering the more than 150 million vehicles in the U.S., the idea of integration may not be too unrealistic. Considering the projected data, by the year 2020, at least ten percent (10%) of the vehicle fleet will be in some form of EDVs with a storage capacity of at least 30 kWh. The storage capacity of the whole EDV fleet will be 450 GWh; whereas the power capacity of the total installed generation capacity of U.S. electric utilities is almost 750 GW. In the future, one can envision power systems utilizing millions of EDVs plugged in to the power grid. Most vehicles are in use an average of 1 hour per day and they idle for 23 hours a day. This indicates that having EDVs plugged into the grid does not impose any restrictions on the driving schedule of the drivers.

Buying energy at night and selling it back during the peak load demand will potentially be lucrative. In addition, drivers

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will be relying on the electric energy purchased off the grid as the major source of traction in their vehicles (the concept of plug-in hybrids). This in turn improves the market penetration of EDVs. Also, the equivalent gas mileage of these vehicles will drastically increase. Furthermore, EDVs connected to the grid can provide a range of services to the power network including backup power for homes and businesses, peak shaving, regulation, reactive power, and transmission stabilization [5]. Another major advantage is that unlike the utility-owned energy storages, EDVs are geographically distributed and sit closer to loads. This leads to less stress on the power transmission lines. ESUs in the future vehicles also offer advantages in modularity, speed of response, and efficiency. The idea of plug-in EDVs increases the penetration of more green vehicles to the market and also improves the efficiency of the electricity generation. As a result of that, both transportation and electric power generation sectors will be more environmentally friendly. In addition, transportation and electricity generation are the two major consumers of fuel. By integrating these two sectors with a distributed ESU, strategic planning for the energy market will be easier and more fruitful.

III. EDUCATIONAL ACTIVITIES

Missouri University of Science and Technology (MST) offers a broad range of courses in electric power engineering. However, the PI has been creating new courses in power electronics in order to expand and deepen the electric power curriculum in the ECE Department. Since power electronics is increasingly used in power systems and, on the other hand, the quality of the electric power has great impacts on converters connected to the utility grids, the new courses follow an integrated approach in the study of power electronics and power systems. The PI is integrating his teaching and research activities into the department's Power Engineering Group at different levels (undergraduate and graduate students and public) and in various forms (degree and non-degree programs, on-campus and online programs, workshops, and conferences).

Current courses offered in power electronics and electric machines at MST are depicted in Fig. 1. The electric and hybrid vehicles course has already been developed by the PI. There are two Power Elective courses in the curriculum Electromechanics (EE 205) and Power System Design and Analysis. Taking one Power Elective course is mandatory for all undergraduate students. EE 205 along with five other courses is also listed as upper-level electives. Taking three upper-level electives is mandatory for all undergraduate students. All the 300-level courses including EE 305 and EE 353 are Senior Electives. Taking four Senior Electives is mandatory for all undergraduate students. EE 354, Power Electronics Laboratory, is listed as a co-requisite to EE 353 in the catalog; however, this laboratory has not been offered for the past three years due to the lack of the required lab equipment.

The major shortfall of the current curriculum at MST is the lack of a junior-level (200-level) power electronics course and laboratory. Power electronics is only taught as a senior/graduate level course. Power electronics is a unique incorporation of concepts from a diverse set of fields including: analog circuits, electronics, magnetics, controls, electronic devices, electric machines, and motor drives. Due to the interdisciplinary nature of power electronics and variety of topics, it is not possible to cover the useful materials in only one three-credit-hour senior-level (300-level) course. As a result, the PI intends to offer power electronics in three levels of <u>I)</u> a junior/senior 200-level introductory course associated with a one-credit our laboratory. This course will be added to the two existing Power Electives in the curriculum, <u>II)</u> a senior/graduate level course, and <u>III)</u> an advanced graduate-level course. The latter has already been created and offered by the PI once. Fig. 2 depicts the proposed restructuring in the curriculum.

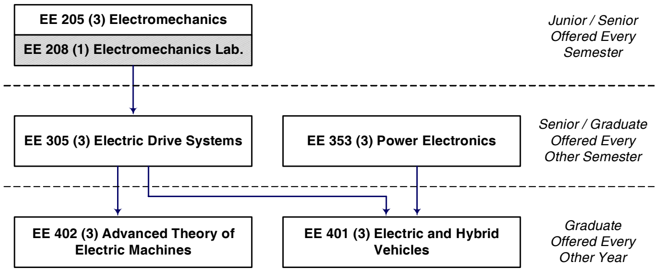

Fig. 1. Current related courses offered at MST

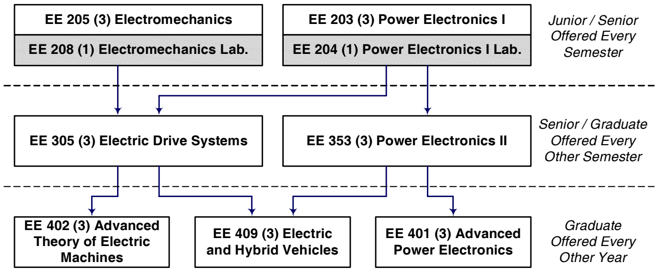

Fig. 2. Proposed curriculum restructuring

There are several advantages to the proposed curriculum restructuring. Almost half of the students in the current power electronics classes are undergraduates and half are at the graduate level. It is hard to make the class interesting and challenging to both groups at the same time. By adding a third power elective, undergraduate students will have more options in choosing their power elective course. Power electronics is more diverse than Electromechanics and the alternate Power System Design. The introductory Power Electronics course will be accompanied with a laboratory course; therefore, the students with have hands-on experience in the related field. Research of several faculty members at MST is directly or indirectly related to power electronics. However, the curriculum lacks an advanced course in this field.

III. TEACHING STYLE AND ASSESSMENT

The PI's educational goal is to provide an effective learning environment in which best teaching practices are incorporated.

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This can be achieved by 1) observing seven principles for good practice in undergraduate education [6], 2) applying new teaching/learning models and methods such as active student learning and student collaboration, 3) enhancing communication, teamwork, and critical thinking skills among the students, and 4) involving the students in research projects.

Teaching is best assessed and evaluated using multiple techniques and broadly-based criteria. Assessment benefits the instructor to stimulate growth, change, and improvement in teaching through reflective practice. There are several strategies to assess and evaluate the quality of teaching and its impact on student learning [7] including: 1) teaching dossiers, 2) student ratings, 3) peer observations, 4) letters and individual interviews, 5) course portfolios, and 6) classroom assessment.

IV. PUBLIC OUTREACH

The PI plans on hosting one-day workshops and training sessions to introduce the alternative forms of energy and hybrid vehicles. The targeted audiences of these workshops include fire marshals, paramedics, FIRE (financial, insurance, and real estate companies), code officials, maintenance repair technicians, and the general public. These activities are designed to improve professionals and public awareness, understanding, and confidence in hybrid vehicles, fuel cell vehicles, plug-in hybrids, and hydrogen infrastructure.

V. SHORT COURSE

The PI is developing a new short course titled "Applications of Power Electronics," which will be offered annually mainly for part-time students at the main campus of MST for four days in the summer. This short course provides new opportunities to attract more students to pursue careers in the field of power engineering. In addition, the course will be useful for engineers and managers from different disciplines. This short course will serve to attract more engineers to the power industry, which is in dire need of recruiting new engineers. This, in turn, sustains and strengthens the nation's energy and power engineering capabilities. These capabilities are used in service to society by ensuring a reliable supply of electricity. The PI also intends to develop a series of short courses, seminars, and semester long courses which can be held on an in-house basis at companies' locations.

VI. INTEGRATION OF EDUCATION AND RESEARCH

Discovery is common to both research and educational missions [8]. Numerous permutations of research and education are currently under exploration to establish a strong power electronics and motor drives program at MST. 1) Research in education: Students at all levels are exposed to discovery-based exercises in the classroom, laboratory, and field. 2) Research on education: The PI is actively working on providing creative educational tools and demonstrations for K-12, undergraduate, and graduate students as well as the general public. Visualization tools will be used to represent the general concepts of power conversion, renewable energy resources, and hybrid vehicles. 3) Research and education: The PI is also attempting on the delivery of the cutting edge research and scientific advances to the students. Effective translation between funded research and educational materials is a key issue. 4) Education in research: What is learned about student learning, will ultimately impact how future research is done. The PI seeks the ways in which learning strategies are developed and employed by students to set the stage for their participation in future research contributions.

VII. CONCLUSION

Research and educational activities related to an NSF-sponsored project have briefly been described. Integration of research and education has also been presented.

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IX. BIOGRAPHY

Mehdi Ferdowsi received his B.S. degree in electronics from the University of Tehran in 1996, his M.S. degree in electronics from Sharif University of Technology, Tehran, Iran in 1999, and his Ph.D. degree in electrical engineering from the Illinois Institute of Technology (IIT), Chicago, USA in 2004. He joined the Electrical and Computer Engineering Department of the Missouri University of Science and Technology (MST), as an assistant professor in August 2004. He has more than 35 publications in the areas of multi-input converters, multi-level converters, battery charge equalization techniques, hybrid vehicles, and digital control. His current research is focused on the integration of plug-in hybrid electric vehicles with electric power grid under a current NSF CAREER grant titled "Vehicle Fleet as a Distributed Energy Storage System for the Power Grid". Dr. Ferdowsi received the Joseph J. Suozzi INTELEC 2003 Fellowship Award from the IEEE Power Electronics Society. He has received MST's Outstanding Teaching Award in the 2005-2006 academic year. Dr. Ferdowsi is a member of IEEE and an Associate Editor of IEEE Transactions on Power Electronics.

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