AC 2009-649: AN ENERGY-HARVESTING CURRICULUM DEVELOPED AND OFFERED AT THE ILLINOIS INSTITUTE OF TECHNOLOGY

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Energy Harvesting Curriculum Developed and Offered at the Illinois Institute of Technology (IIT)

Abstract

This paper presents the curriculum development to satisfy the needs in teaching energy harvesting and renewable energy systems. In order to restructure the energy industry through energy harvesting from renewable sources instead of fossil fuels, energy industry will require young and talented minds in very close future. The offered course in the Electrical and Computer Engineering Department at the Illinois Institute of Technology (IIT) allows the students not only apply their previous knowledge of power electronics, control systems, system analysis, and system design to this new field, but also provides them with experience of new methods and trends in various scales of energy harvesting applications. Many harvesting techniques such as solar, ocean wave-tide-thermal, vibration, linear motion, passive and active human power generation methods are taught in the class. Their operational principles are addressed. Research, simulation, or experiment based projects with emphasis on power electronic interfaces for energy harvesting applications are assigned to student groups. Descriptions of course topics and interesting concepts are given in details with the provided results from the students projects.

Introduction - The Need for an Energy Harvesting Course

Energy harvesting also called energy scavenging is a concept by which energy is captured, stored, and utilized. Unlike the conventional electric power generation systems, in energy harvesting concept, fossil fuels are not used and the generation units might be decentralized. There are many sources for harvesting energy. Solar, wind, ocean, hydro, electromagnetic, electrostatic, thermal, vibration, and human body motion are renewable sources of energy. Even the energy of radio frequency waves, propagated due to television and radio broadcasting in the environment, can be harvested. Economic, environmental, and geopolitical constraints on global conventional energy resources started forcing the nation to accelerate energy harvesting from renewable energy sources. Thus, advanced technical methods should be developed to increase the efficiency of devices in harvesting energy from various environmentally friendly resources and converting them into electrical energy. These developments have sparked interest in engineering community as well as the engineering education community to develop more energy harvesting applications and new curriculums for renewable energy and energy harvesting topics.

Table I summarizes the contents of the offered Energy Harvesting course at IIT.

Table I. Syllabus of the course.

Week	Topic
#1	Introduction to Energy Harvesting
#2	**Solar Energy Harvesting:** Characteristics of Photovoltaic (PV) Systems, PV Models and Equivalent Circuits, Sun Tracking Systems, Maximum Power Point Tracking (MPPT) Techniques, Power Electronic Interfaces for PV Systems, Sizing the PV Panel and Battery Pack in a Stand-alone PV Applications
#3	Modern Solar Energy Applications (Residential Applications, Electric Vehicle

	Applications, Naval Applications, and Space Applications)
#4	**Wind Energy Harvesting:** Fundamentals of Wind Energy**,** Wind Turbines and Different Electrical Machines in Wind Turbines, Power Electronic Interfaces, and Grid Interconnection Topologies
#5	Midterm Exam
#6	**Ocean Energy Harvesting:** Physical Principles of Tidal Energy, Tidal Turbines (Horizontal axis turbines and Vertical Axis Turbines) and grid connected systems
#7	Principles of Energy available from Ocean Waves, Off-shore and Near-shore Wave Energy Harvesting, Wave Power Absorbers, Wave power turbines, and grid connection topologies
#8	Ocean Thermal Energy, Thermodynamic energy conversion principles, Closed-cycle and open-cycle OTEC Systems, Components of OTEC Systems,
#9	Control of OTEC Power Plants, and Multipurpose Utilization of OTEC Systems
#10	**Piezoelectric Energy Harvesting:** Physics and Characteristics of Piezoelectric Effects, Materials, and Mathematical Description of Piezoelectricity Effect
#11	Piezoelectric Parameters, and Modeling Piezoelectric Generators, Power Electronic Interfaces for Piezoelectric Energy Harvesting, Piezoelectric Energy Harvesting Applications
#12	**Electromagnetic Energy Harvesting:** Linear Generators, Physics, Mathematical Models, and Structures, Recent Applications and Projects on Electromagnetic Energy Harvesting, Hybrid Piezoelectric-Electromagnetic Energy Harvesting
#13	Presentations of term projects
#14	Summary and conclusion, presentations of term projects
#15	Final Exam

Since the world has been experiencing a great shortage of energy nowadays, the energy which is everywhere and surrounding the environment should be considered to be captured, stored, conditioned, and utilized by alternative techniques. Therefore, modern electric power energy systems education should include a significant impact on energy harvesting and renewable energies.

The Course

The course addressing the needs discussed above has been developed at Illinois Institute of Technology. This is the three-credit ECE 548 - Energy Harvesting course that lasts 15 weeks in length and typically meets twice per week for one hour and fifteen minutes class sessions. The class is offered for graduate students. However, undergraduate students with good academic stand can register for the class with the instructor and advisor permit. The class has been offered for the second time in spring 2009 semester. The enrollment of the class was 33 in spring 2008; however, it is increased to 66 students in spring 2009. The class is held in a technological classroom that includes a complete projection system connected to a networked computer in order to present the concepts, digital illustrations, modeling and simulations, and animations. Moreover, classes are recorded for online students and all registered students have access to the recorded classes online. Internet students can ask their questions through e-mail or in person during the office hours of the instructors. During the course period, the concepts and theoretical background is built for energy harvesting applications. Furthermore, various applications of utilization and grid connection methodologies for energy harvesting are addressed with particular emphasize on power electronics interfaces.

The Course Assessment

In the Energy Harvesting class, multiple perspectives and multiple occasions are used for the assessment of the students' learning. These assessments ensure that the instruction fosters high-quality learning and developing application skills during the class. The assessment aspects for the class include but not limited to:

- Encouraging the students' preparation for the course. Students are given the course syllabus on the first day of the class. As the course goes on, students are asked to effectively share their knowledge and information they obtain from the external resources before coming to the class. This increases the familiarity of students to the topics that are going to be taught and creates a better platform for students' contribution.
- For on-going instructional adjustment, students provide feedback about their learning. These feedbacks are evaluated for class betterment and improvement to increase the students learning expectations.
- Instructor also provides feedbacks to the students by the in-class quizzes and by informal meetings and discussions. Furthermore, during their projects, instructor provides feedback in order to improve their work, increase the originality, and creating projects that are publishable and citable in the literature.
- Students' perceptions on learning processes and instructional effectiveness are elicited.
- Finally, students' abilities and knowledge are summarized upon the course completion.

Traditional class evaluations are mainly based on paper assignments, quizzes, and exams since many electrical engineering courses are theoretical[1] with almost no simulation or experimental work. However, in the Energy Harvesting class offered at IIT, the dominant evaluation criterion is the individual or group projects that are performed experimentally or in simulation platforms. Students are expected to be capable of transforming their class room knowledge into the practical applications. This transformation requires creativity, critical thinking, design abilities, design optimization, management skills, and team-work. Students need visual concepts, illustrations, and simulations in order to better understand the topics of the class[2]. Such visualized concepts are very attractive to the students and provide active learning to them. By this method, not only students are a part of a course topic, but also they are attracted to learn the real world applications of the classroom material. This simplifies understanding the energy harvesting concepts.

Example Topics from the Course Content

In the introduction, the importance of energy harvesting is emphasized. Around 37% of the world's total energy is consumed by industrial sectors such as manufacturing, mining, construction, agriculture, and so on. 20% of total consumption is by the personal and commercial transportation. Residential consumption such as residential lighting, heating, and household appliances corresponds the 11% of the total. Consequently; commercial lighting, heating, cooling as well as the water provision and sewing services consume 5% of the total[3]. The other 27% of world's energy is lost in the energy generation and transmission stages. The overall energy consumption percentages by sector are shown in Fig. 1.

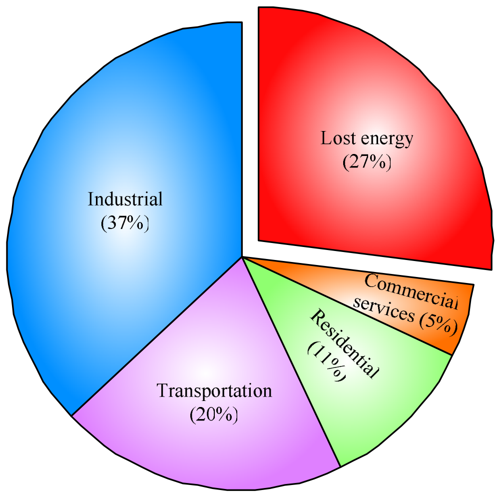

Fig. 1. Percentage share of sectors on energy consumption.

According to Fig. 1, the generation and transmission losses are considerably high. Fig. 1 imposes that more than a quarter of the produced energy is lost in low efficient conventional energy conversion systems and in transmission lines. This issue encourages the increased focus on high efficient energy harvesting systems, which may also reduce or eliminate the transmission losses if they are built as distributed energy generation units.

Similarly, a comparison based on the environmental effects of traditional energy generation technologies and the energy harvesting applications can be used to emphasize the need for energy harvesting.

In addition; the operating principles, efficient utilization, and grid connection issues as well as power electronic interfaces for the energy harvesting applications are demonstrated throughout the class in a visualized manner. For instance, a fixed stator and direct-drive permanent magnet linear generator based buoy concept for "ocean wave energy harvesting applications" is explained using the illustration shown in Fig. 2. The fixed stator windings can be mounted on a yoke that is fixed to the ocean bottom through a support unit. In this method, the permanent magnet is connected through a rope to a buoy, which is on the ocean level and moves up and down and can be dragged towards different directions. Once a wave results in the motion of the buoy, the buoy pulls the permanent magnet piston. The permanent magnet moves up and down within the fixed stator windings. This also generates an electromagnetic field generating the electricity.

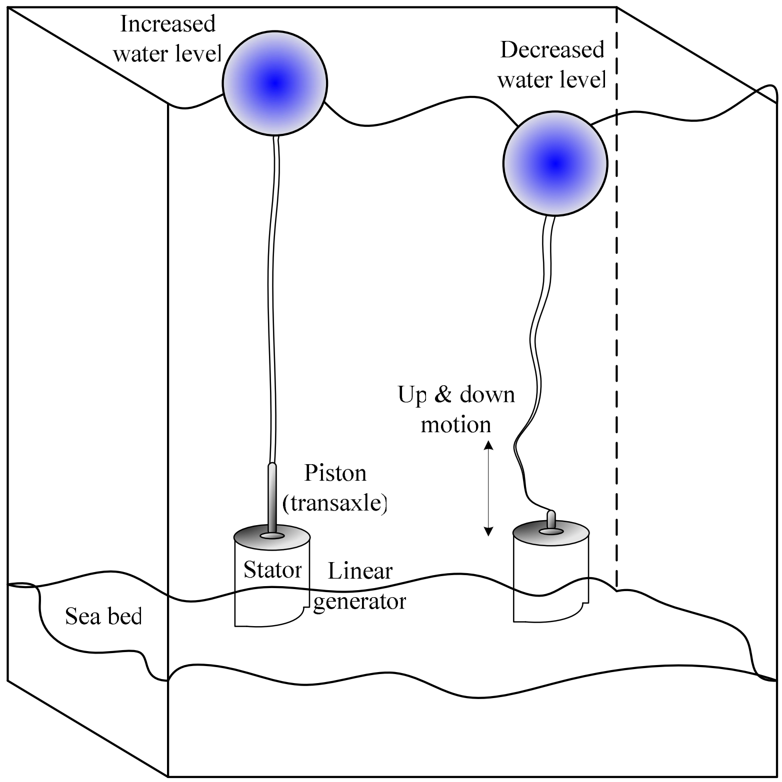

Fig. 2. Linear generator based buoy type wave energy harvesting method.

Another method of using linear, synchronous, longitudinal-flux permanent magnet (LFM) generators is shown in Fig. 3[4].

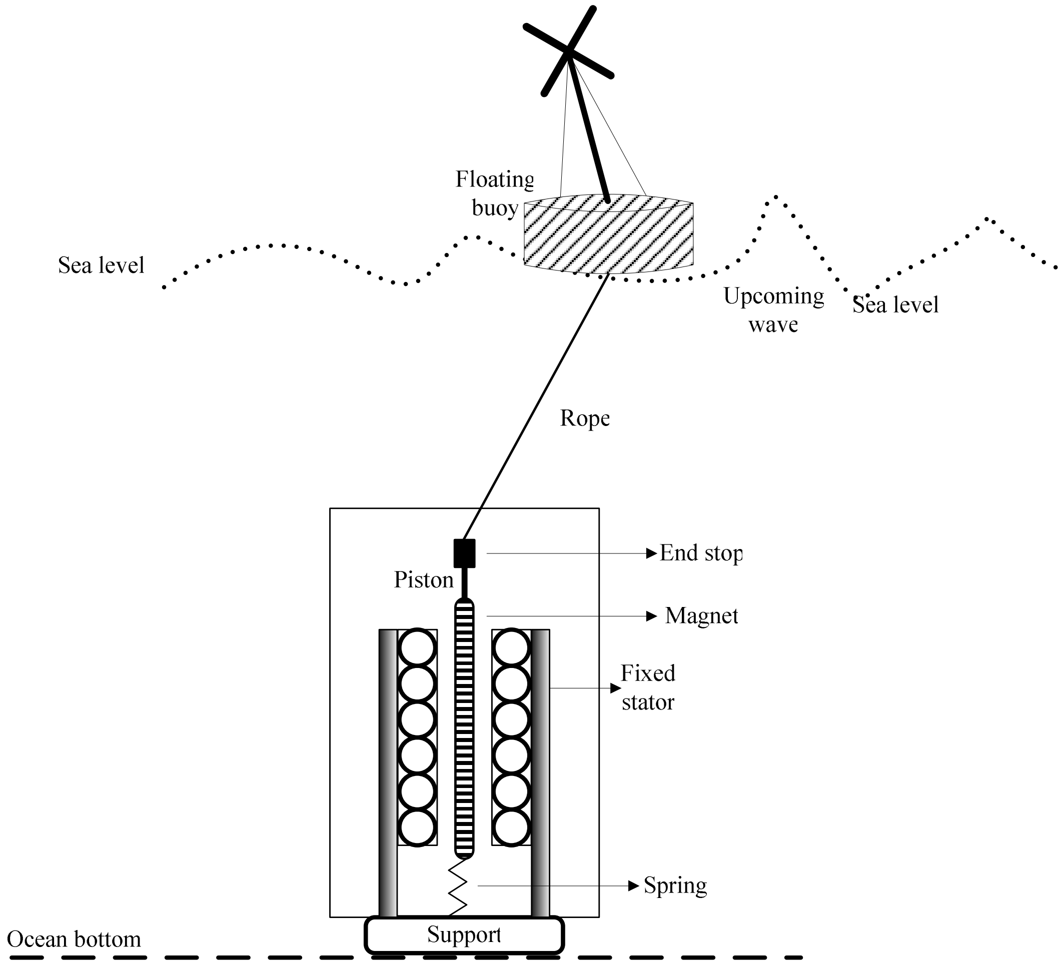

Fig. 3. Another method of using LFMs for wave energy conversion.

Not only concepts of various energy harvesting applications are presented, but also their mathematical background and the modeling issues are taught. The force equations along with the required parameter definitions are also given for the concept of Fig. 3. For a given set of parameters, the force equations are analytically or numerically solved in a simulation environment which is generally MATLAB/Simulink. Once the system is modeled and solved, power electronic interfaces, such as Fig. 4, can be implemented for further utilization and realization of the described system.

The system in Fig. 4 is modeled by a student as a course project. The modeling, design, and control of the wave activated linear generator are performed in MATLAB/Simulink. The effect of the load resistance on the generator performance, i.e., the generator output power and the generator efficiency are analyzed through the developed model. The resistance-average power and resistance-efficiency curves are shown in Fig. 5 in the same x-axis.

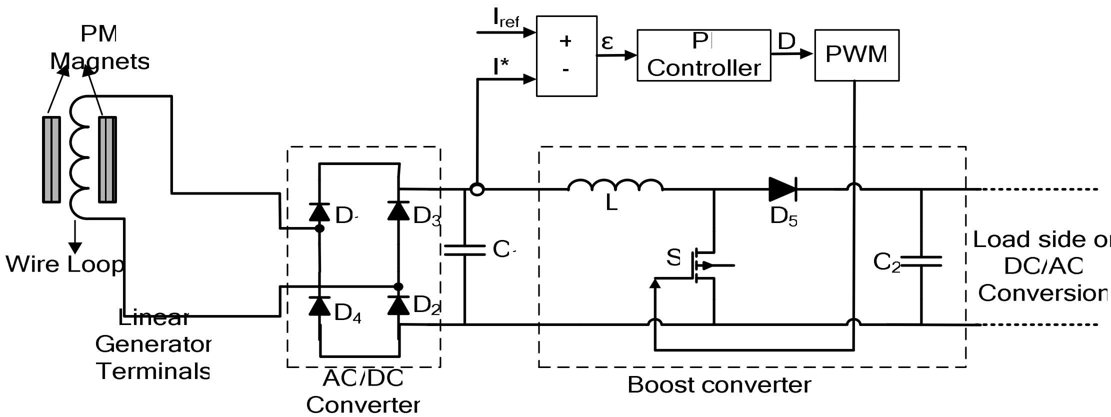

Fig. 4. System level configuration of the linear generator and power converters.

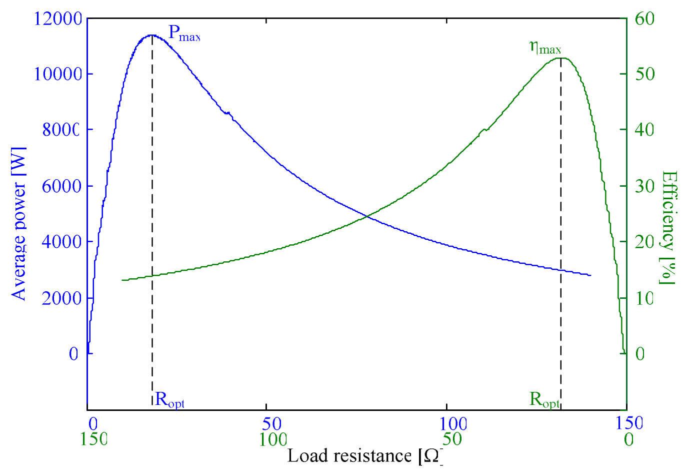

Fig. 5. Average power and efficiency variation versus load resistance.

Propose of this project was to control the generator's loading scheme in order to operate at the most optimal point. Using the current control mode shown in Fig. 4, the optimal load control of the wave activated linear generator is achieved as shown in Fig. 6.

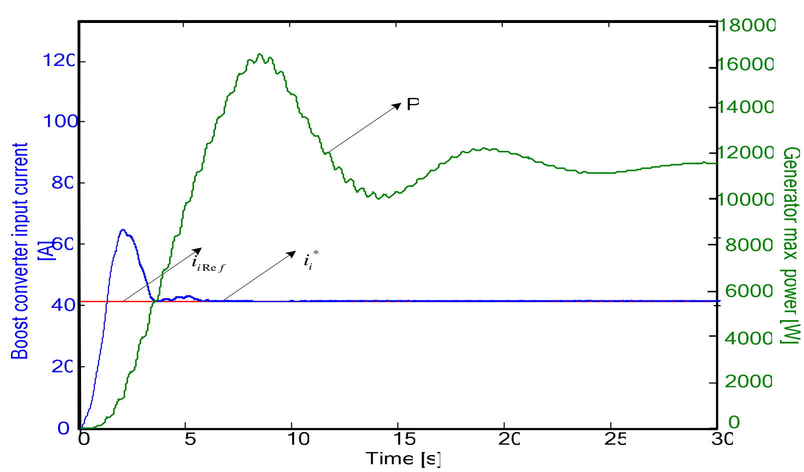

Fig.6. Reference current tracking and power output for the linear PM generator.

This project yielded to an article, which was published in proc. IEEE 34th Applied Power Electronics Conference and Exposition which is one of the most world wide prestigious conferences on power electronics that was held in February 2009, Washington, DC[5].

As another example, one of the students proposed the “Control and Power Management of a Grid Connected Residential Photovoltaic System with Plug-in Hybrid Electric Vehicle (PHEV) Load” which was also published at the APEC conference[6]. The topology proposed by the student is represented in Fig. 7.

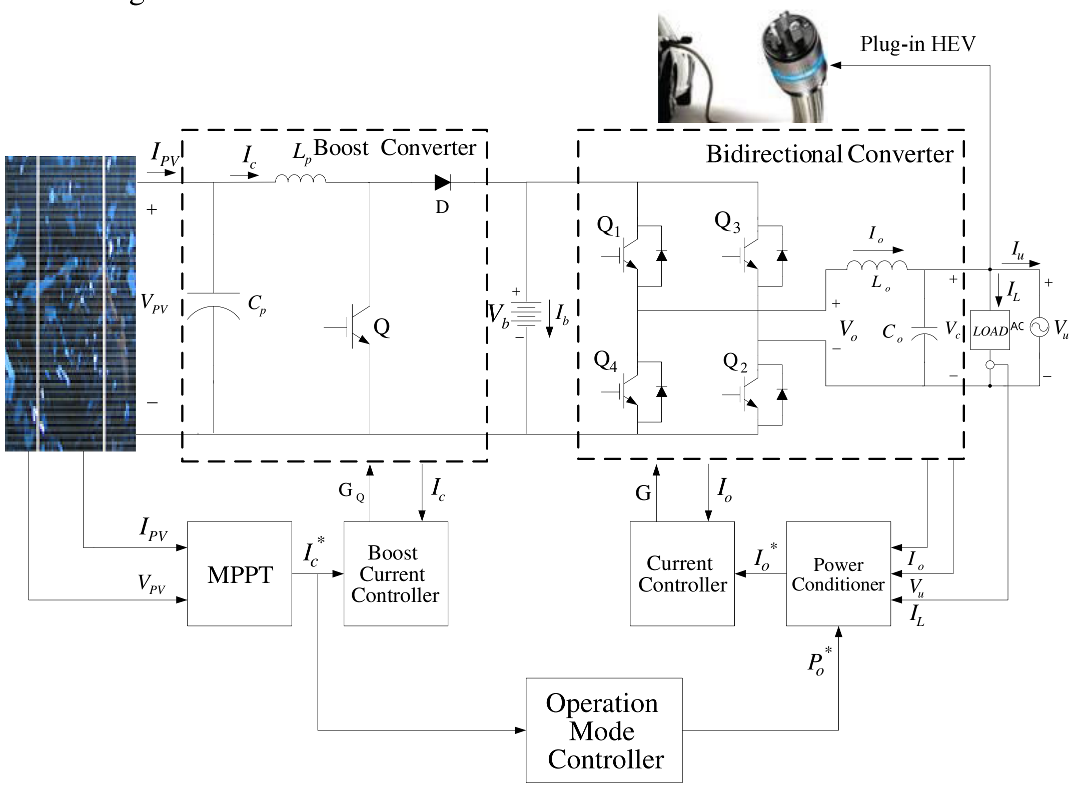

Fig.7. Residential photovoltaic approach with plug-in hybrid electric vehicle load.

The results of this project, the operation mode controller and some of the simulation results expressing the dynamic behavior of the proposed system are given in Figs. 8 and 9.

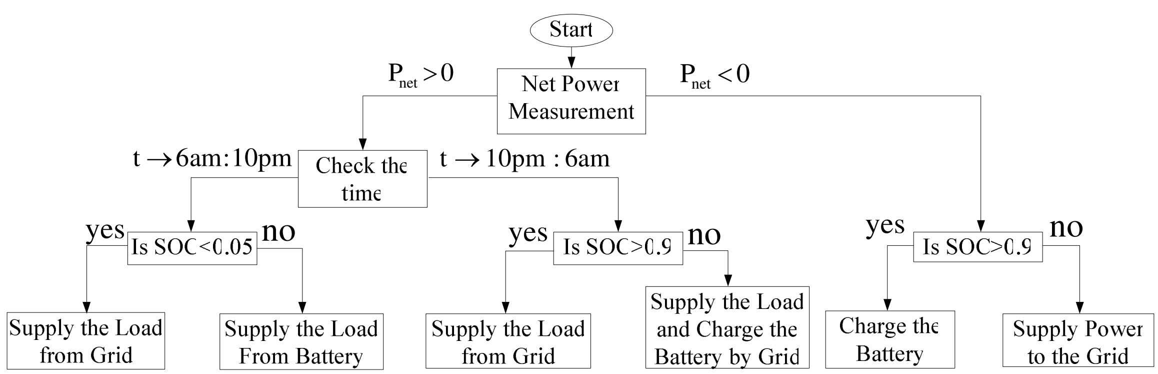

Fig.8. Operation mode controller for the proposed system.

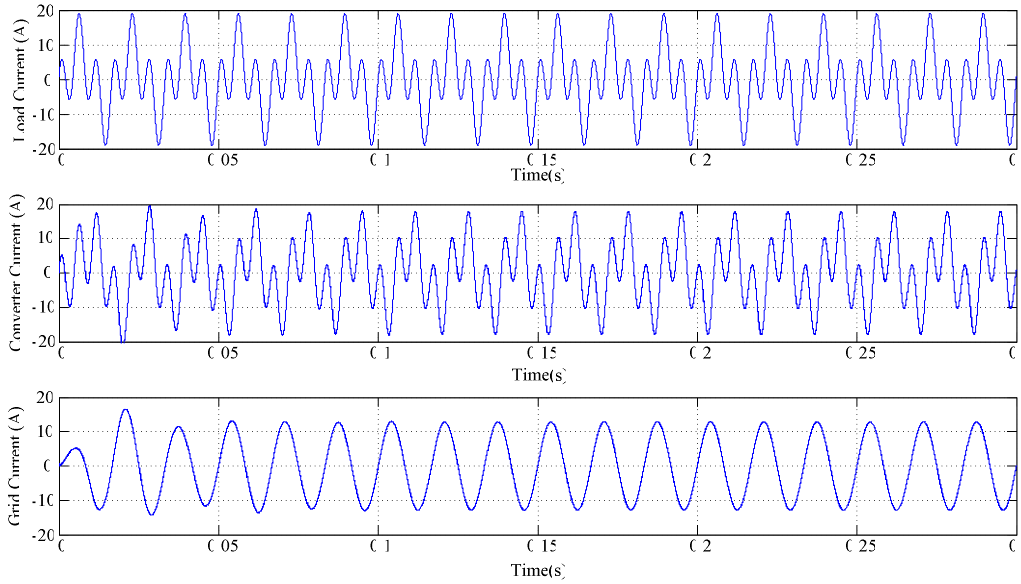

Fig.9. Simulation results showing load, converter, and grid current of the residential photovoltaic system.

The course covers many real world examples. The other fields include power electronic interfaces and utilization topologies for the solar, wind, ocean tidal, ocean thermal, piezoelectric and electromagnetic energy harvesting. Furthermore, the course focuses on modeling and simulation of many topologies and power electronic interfaces for energy harvesting applications.

Conclusions

Energy harvesting curriculum developed and offered at the Illinois Institute of Technology has been described. The main themes covered in the course are the needs, concepts, operation principles, modeling issues, and simulations of solar, wind, ocean wave, ocean tidal, ocean thermal, piezoelectric, and electromagnetic energy harvesting techniques. This course is aimed at providing the student with the concepts and theoretical background as well as the various applications of utilization and grid connection methodologies for energy harvesting. These topics are addressed by the course with particular emphasize on modeling and simulation of the various topologies for energy harvesting applications.

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