Laboratory for Electromagnetic and Electronic Systems

General Description

The mission of the Laboratory for Electromagnetic and Electronic Systems (LEES) is to conduct research and teaching in efficient electric energy production, distribution, utilization, and storage, and in electromechanics from the macroscopic through the nanoscopic levels. Electric energy and electromechanics are defined broadly to include power systems design, monitoring, and operation; electrical energy storage; automatic control; power electronics; high-voltage engineering; and conventional, continuum, and biological electromechanics. In recent years, the laboratory has extended its expertise in control and monitoring of complex electrical distribution networks to the area of control and monitoring of complex patient monitoring systems such as in a hospital intensive care unit, a new area of research that offers considerable promise.

Much of the work of the laboratory is experimental, and industrial sponsorship represents a large part of its support. The laboratory's professional staff consists of eight faculty members from the Department of Electrical Engineering and Computer Science (EECS), one principal research engineer, one principal research scientist, three postdoctoral associates, and approximately 50 graduate students. The laboratory faculty and most of the staff are heavily involved in teaching and course development, including outreach through freshman seminars and women's and minority programs; two of the faculty are involved in managing the EECS 6-A Internship Program. Faculty from the Departments of Mechanical Engineering, Chemical Engineering, and Materials Science and Engineering collaborate in many of the laboratory's programs, and there are extensive joint activities with the Microsystems Technology Laboratories, the Gas Turbine Laboratory, the Materials Processing Center, the Laboratory for Information and Decision Systems, and the Harvard–MIT Division of Health Sciences and Technology. A substantial number of Undergraduate Research Opportunities Program and senior projects are being carried out by undergraduate students in LEES every term.

Research Emphasis

The LEES research emphasis has broadened from traditional applications of electrical power and energy and now includes several exciting nontraditional and cross-disciplinary areas that show great promise. In particular, many of the projects described here relate to the pressing topic of increased efficiency in generating and storing electrical power.

Automotive Consortium

The MIT/Industry Consortium on Advanced Automotive Electrical/Electronic Components and Systems, managed within LEES by director Thomas Keim and business manager Gary DesGroseilliers, continues to provide a venue for interested parties from around the world to come together and discuss innovations in the use of electric power in automobiles. Despite the difficult financial state of many companies, membership has remained above 20 companies.

The name of the consortium suggests an emphasis on hybrid electric automobiles, or, possibly, to invoke the latest hot topic, plug-in hybrid electric automobiles. While both of these subjects are of ongoing interest to the Consortium, a more important ongoing emphasis has been on improving the overall efficiency of more conventional autos by more effective generation and use of electric power. Instead of concentrating on making one percent of the fleet 20 percent more efficient, we emphasize methods that can make 100 percent of the fleet one percent or maybe even two percent better.

One of the more gratifying aspects of this work is that concepts discussed in the earlier days of the Consortium are now being announced in present-day and in planned high-volume models. At our most recent meeting in April, BMW described the electric energy management system being introduced across their model line, and several suppliers described their hardware and control system contributions.

Representative LEES energy-related projects

1. Nanotube-enhanced ultracapacitor (synthetic battery) for portable electrical energy storage
2. High-efficiency thermophotovoltaic energy conversion using photonics (heat to electricity)
3. Miniature gas turbine generators (in conjunction with digital avionics systems)
4. Scavenging (reclaiming) vibrational energy
5. High-frequency (lightweight) DC-DC conversion
6. High-efficiency windmill generator
7. Electromagnetically actuated valves for internal combustion engines
8. High-efficiency automobile alternator
9. Design and monitoring of high-efficiency buildings (in conjunction with Architecture)
10. Nanofluids for efficient cooling and improved electrical breakdown characteristics in high-voltage electrical transformers
11. Research on breakdown mechanisms in high-voltage electrical insulators
12. Leadership of international automobile consortium on improved automobile performance through electronics.

Research Projects

Micro Gas Turbine Project

The MIT micro gas turbine engine project seeks to advance the state of the art of small portable electric power supplies. As part of this project, Professor Jeffrey H. Lang and graduate student Bernard Yen, in collaboration with Professor Zoltan Spakovszky of the Department of Aeronautics and Astronautics and colleagues at the Georgia Institute of Technology, have finished redesigning the microelectromechanical system (MEMS) generator and have begun fabricating it. The goal of their effort is to produce the first fully integrated and fully packaged magnetic generator driven by an air turbine and use it to produce approximately 10 W of electrical output power from a volume of approximately 0.5 cm^3.

Micro Electrical Relay Development

Professor Lang and graduate student Alexis Weber, in collaboration with Professor Alexander Slocum of the Department of Mechanical Engineering, have fabricated and demonstrated MEMS relays that are capable of hot-switching electric power at voltages up to several hundred volts. During the next year, their goal is to improve the current handling capability of these relays so that electric power can be hot-switched simultaneously at currents in the 1- to 10-A range. Such relays could find use in residential and light industrial applications.

Micro Energy Harvesters

Professor Lang, and postdoctoral researchers Alejandro Domínguez-García and Francis O'Sullivan have recently begun a study of vibration energy harvesters for use in powering autonomous sensors and communication systems. The goal of these harvesters is to generate between 0.1 and 1 W of electrical power from low-frequency vibrations.

MEMS Pressure Sensor Arrays

Professor Lang and graduate students Stephen Hou and Vicente Fernandez, in collaboration with Professors Michael Triantafyllou and Franz Hover of the Mechanical Engineering Department, have begun developing MEMS pressure sensor arrays, and the corresponding signal processing, for use in underwater obstacle avoidance and navigation. The passive sensor arrays are biologically inspired since they mimic the lateral-line organ of fish and consume very little power, making them ideal for underwater autonomous vehicles.

Data Multiplexing Over Power Cables

Dr. Chathan Cooke working with industry and visiting graduate student Frank Schubert (now graduated) has continued studies on the use of electric power cables such as those used by motors for carrying control and position data. The "data-over-power" approach reduces costs and enhances flexibility. The specific example studied and evaluated analytically was the transfer of feedback data for pulse with modulator (PWM) motors on the existing motor power cables. Optimization of the data transfer process was explored by consideration of encoding and frequencies. Because the data transfer is a dual-use technology, the power cables are not the best design for data. Nevertheless, it was found that an optimum frequency could be identified as a trade-off between cable attenuation and the PWM interference spectral content. The optimum is cable dependent. Frequency shift keying was shown to be an effective encoding in this environment. The modeling techniques used were general and developed to enable evaluations for a range of existing cables. The next step is to send encoded data over a cable with and without PWM noise to determine actual performance and compare it with theory.

Stress-Induced Conduction in Insulators

Dr. Cooke, working with industry for electric power apparatus, has applied ultrasonic diagnostics to quantify space charges and internal stresses in high-voltage epoxy dielectrics. This work has included simultaneous thermal and electrical gradients. These multistress test results have shown they induce conduction-driven space charges and enhanced internal fields. Measurement values are being compared with theoretical values and suggest that the spatial variation of conduction induces substantial space-charge accumulations. The purpose of this effort is to improve the long-term reliability of materials used in electric power systems and other high-voltage applications. Ongoing work has been directed at determining the influence of material and processing on the resultant conduction characteristics. Changes of epoxy can shift the amounts of conduction and temperature dependence, but similar basic charge responses are observed. In some cases, trapped charge persistence can last many months. Further work is to be directed at electrode effects and material changes.

High-Voltage Electron Beam Facility

Dr. Cooke and Kenneth Wright have been improving the instrumentation and performance of the electron beam facility at LEES. Beam position and control of energy and intensity are each being improved. Additionally, an energy increase to 3.5 MeV is being sought. The facility has been used for a variety of measurements, including the processing of silicon wafers for improved radiofrequency windows, the production of gamma rays for the stimulation of nuclear fluorescence radiation for cargo inspection, charge implantation studies, and polymer processing for biocompatible materials, especially joint replacement studies with Massachusetts General Hospital in Boston.

Magnetic and Dielectric Fluid Research

Professor Markus Zahn and his students have been studying and developing modern applications of magnetic nanoparticle suspensions, or ferrofluids, which are synthesized, superparamagnetic, colloidal mixtures of nonmagnetic carrier liquid, typically water or oil, containing single-domain permanently magnetized particles, typically magnetite, with diameters of 5–15 nm and volume concentration up to 10 percent. Brownian motion keeps the nanoparticles from settling under gravity and a surfactant surrounds each particle to prevent agglomeration, which can also be carefully chosen to be selectively adsorbing to specific materials such as tumors for biomedical applications. Applications of the magnetic and dielectric fluid research directed by Professor Zahn include more accurate detectability in vivo of disease and interaction with hyperthermia and other therapeutic treatments as possible cancer therapies.

Industrial applications of ferrofluids in loudspeakers and rotating seals are extensive. However, with modern advances in fabrication and biotechnology, ferrofluids are being studied by Professor Zahn, PhD student Padraig Cantillon Murphy, and research collaborator Professor Elfar Adalsteinsson as a means of controlling and improving magnetic resonance imaging (MRI) signal intensity through the use of rotating magnetic fields or fluid vorticity to induce nanoparticle spin. This work seeks to use the ferrofluid's complex magnetic susceptibility to affect the signal intensity in MRI.

Recently graduated master's degree student Clinton Lawler has worked with Professor Zahn to develop a new two-sphere "fluxball" design to create a highly uniform rotating magnetic field to be used with MRI research and microfluidic research of ferrofluid flows. This project is being continued by PhD student Shahriar Khushrushahi with possible applications to MRI combined with hyperthermia, directed drug delivery, and other therapeutic applications.

PhD student Hsin-Fu Huang and Professor Zahn are researching electrorotation of suspended insulating dielectric particles in a more conducting fluid known as the Quincke effect. This work is the dielectric analog to related magnetic fluid research and has significant applications to improved microfluidic devices.

Nanoparticle Suspensions and Electrical Breakdown

In ABB-sponsored research for improved performance of power transformers, Professor Zahn and recently graduated PhD student Frank O'Sullivan have developed a comprehensive multiphysics electrodynamic and thermal model of streamer initiation and transport that leads to electrical breakdown in pure transformer oil and in transformer oil nanoparticle suspensions, called nanofluids. Modeling has shown that molecular ionization is the most important mechanism for streamer development by forming fast electrons and slow positive ions, where the electrons are quickly swept away from the ionization zone, toward a positive needle electrode or away from a negative needle electrode. This explains why positive streamers are filamentary and slow while negative streamers are bushy and fast. Space charge modifies the electric field distribution in the oil and results in the propagation of an electric field wave that causes electrical dissipation in the oil that increases temperature to boiling and results in development of the low-density streamer channel.

ABB experiments have shown that transformer oil-based nanofluids with conductive nanoparticles have substantially higher positive voltage breakdown levels with slower positive streamer velocities than that of pure oil. Analysis has shown that conductive nanoparticles act as electron scavengers in electrically stressed transformer oil-based nanofluids and that the trapping of fast electrons onto slow nanoparticles is the cause of the decrease in positive streamer velocity. This explains the paradoxical fact that the positive electrical breakdown performance of nanofluids manufactured from conductive nanoparticles is superior to that of pure oil. Nanofluids manufactured from insulating nanoparticles offer no insulation advantage over pure oil.

Dielectrometry of Moisture Diffusion and Temperature Dynamics in Oil-Impregnated Paper-Insulated Electric Power Cables

Professor Zahn and recently graduated PhD student Zachary Thomas worked on this Electric Power Research Institute project to understand moisture- and temperature-induced failures in oil-impregnated paper-insulated power cables. They used newly designed and built cylindrical geometry interdigital dielectrometry sensors to monitor three-dimensional transient moisture diffusion as a function of temperature in oil/paper-insulated power cables together with improved modeling and analysis to characterize and understand moisture-induced failures in these cables.

Electromagnetic Engine Valves

Electromagnetic engine valves offer a substantial increase in fuel economy by allowing easy and flexible implementation of the ability to vary valve lift height, lift duration, and lift timing in response to changes in the engine operating condition. LEES principal contribution to development of electromagnetic engine valves has been the invention of a system that provides inherent soft landing of the valve on the seat and also at its rest position at the open end of the stroke. Further demonstration of the feasibility of this approach has required the development of a custom-designed electromagnetic actuator, with features providing an especially high torque-to-inertia ratio and also low electrical loss. This year, the staff includes Professor David Perreault, Dr. Thomas Keim, and graduate student Yihui Qiu.

During the reporting period, LEES received a contract from the Industrial Technology Research Institute, a government agency in Taiwan, to support this work.

High-Efficiency Automotive Alternators

In previous years, Professor Perreault has proposed the combination of an automotive alternator with a boost-mode rectifier in place of the standard diode rectifier. Several important advantages result, including both a large increase in the output capability of the alternator, when averaged over a drive cycle, and a substantial increase in efficiency. The increase in output makes it possible to make the overall vehicle more efficient, by reducing the empty vehicle mass-to-payload ratio. The increase in alternator efficiency reduces fuel consumption directly.

Also in past years, these benefits have been demonstrated in benchtop prototypes. This year, principal research engineer David Otten finished a program to demonstrate an alternator with the boost rectifier built into the machine, as is the practice with diode rectifiers. Again, the projected benefits were achieved.

The system demonstrated by Mr. Otten was built by modifying a production alternator. It required that the case of the alternator be lengthened (at no increase in diameter) to accommodate the modification. During the present year, Professor Perreault, along with Dr. Keim and graduate student Armando Mesa, designed a boost rectifier system that can be installed in the space currently occupied by the diode rectifier.

Very High Frequency Electronic Power Conversion

A principal means for improving performance and reducing the size of power electronics is through increases in switching frequency. However, conventional power converter designs are subject to a number of constraints that greatly limit their practical switching frequency. Professor David Perreault; postdoctoral fellow Juan Rivas; and graduate students Yehui Han, Anthony Sagneri, Robert Pilawa, Olivia Leitermann, and Jackie Hu have continued the development of power conversion circuits that operate at very high frequencies (30–300 MHz), two orders of magnitude higher than conventional designs. Advances this year include validation and design optimization of new power-converter topologies suited for very high frequency operation. This work has demonstrated the ability to achieve and maintain high efficiency (85–90+ percent) at very high frequencies across wide operating conditions (>2:1 voltage, >20:1 power) and to achieve an extremely fast transient response. This work has resulted in three journal publications, two conference publications, and a patent filing in the past year. Continued development of this technology for a variety of applications is being pursued in collaboration with National Semiconductor and Draper Laboratory among others. Moreover, application of this technology to achieve extremely high efficiencies (>95 percent) at contemporary switching frequencies is now being pursued.

Model-Based Patient Monitoring

Clinical staff in modern intensive care units receive an overwhelming amount of monitoring data, to the point that critical and potentially life-threatening indications can easily be missed. The premise of work being done in the LEES group of Professor George Verghese and his postdoctoral associate, Thomas Heldt—in collaboration with Professors Roger Mark, Health Science Technologies, EECS, and Peter Szolovits, Computer Science and Artificial Intelligence Laboratory, EECS, and with funding from the National Institutes of Health, NASA and Philips—is that medical care can be significantly enhanced by using computational tools incorporating well-established static and dynamic models from physiology. The resulting advanced patient monitoring system would integrate, analyze, and interpret clinical data in real time, relating measured variables to each other, extracting underlying parameters, generating more sophisticated alarms and alerts, and presenting distilled information in useful forms to the clinical staff.

The focus of the group so far has been on cardiovascular monitoring. With Tushar Parlikar, who recently completed his PhD in the group, they have established model-based algorithms to accurately monitor—noninvasively and continuously—four important hemodynamic variables—namely, cardiac output, total peripheral resistance, left-ventricular ejection fraction, and left-ventricular end-diastolic volume (part of this being in collaboration also with Professor Ramakrishna Mukkamala at Michigan State University, an EECS alumnus). These variables are particularly important for diagnosing and tracking conditions such as heart failure and different kinds of shock. The methods have been validated on data from earlier experiments on pigs and dogs, as well as from patients in the intensive care unit. Two associated provisional patents have been filed, and a related publication has been accepted for oral presentation at the Computers in Cardiology conference. Additional papers are in preparation. Supporting work has also been done in the recent master's theses of Said Francis and Shirley Li, in Professor Verghese's group.

With further validation, and expansion to other organ systems, these model-based algorithms have the potential to improve the efficiency, timeliness, and accuracy of clinical decision making and thereby improve patient outcome in intensive care.

The group continued its work to elucidate the mechanisms of spaceflight-induced changes in cardiovascular performance. With colleagues from the Man Vehicle Laboratory in the Department of Aeronautics and Astronautics, Dr. Verghese's group has investigated the cardiovascular effects of short-radius centrifugation (SRC) using a combined modeling and experimentation approach. SRC is a candidate multiorgan countermeasure in which astronauts on long missions would be exposed intermittently to centrifugal forces that mimic earth's gravitational acceleration. This line of work has led to the master's thesis by Ahmad Zamanian and will be presented at an invited session at this year's annual conference of the Biomedical Engineering Society.

Thermophotovoltaic (TPV) Project

Our work under this research topic encompasses theoretical and experimental exploration of controlling thermal radiation by means of photonic crystal design and the design and development of a low-temperature high-efficiency palm-sized TPV power generator.

TPV power generation is a static power-conversion system that generates electricity from radiant heat. The advantages of this type of static power generation, to mention a few, are no moving parts, multifuel operation, low-noise operation, and scalability.

Professor John Kassakian, principal research engineer Dr. Thomas Keim, postdoctoral research associate Dr. Ivan Celanovic, and doctoral student Natalija Jovanovic have continued the experimental and theoretical investigation of advanced spectral control components—based on photonic crystal devices. Major advances this year include the new nanofabrication process for fabricating two-dimensional tungsten photonic crystal (PhC) selective emitter and extensive optical characterization of fabricated structures. The newly developed process enables the fabrication of two-dimensional PhC structures in tungsten with unprecedented dimensional control, using inexpensive and scalable microfabrication techniques. Fabrication and characterization of fabricated samples demonstrated spectral efficiencies of more than 90 percent. This development is the critical experimental verification step toward the record TPV efficiency of more than 25 percent. We have successfully concluded our research collaboration with the Toyota Motor Company.

In addition, we have continued our collaborative effort with Professor John Joannopoulos and Professor Marin Soljacic on theoretical and experimental exploration of resonant thermal-emission phenomena in two-dimensional silicon photonic crystal slabs. Resonant thermal emission, which was first conceived and proposed by our group in 2005, enables the design and practical implementation of narrow-band highly directional thermal radiation sources that exhibit increased temporal and spatial coherence compared with other thermal radiation sources.

The work done under this research topic has resulted in one conference publication, one journal publication, and one patent filing.

Nanotube-Enhanced Ultracapacitors for Improved Electrical Energy Storage

The ultimate goal of this project, conducted by Professors Joel Schindall and John Kassakian and graduate student Riccardo Signorelli, is to develop a practical electrical energy storage device that combines the long life and rapid charge-discharge capability of a capacitor with the much higher energy storage capacity of a rechargeable battery. We believe this can be achieved by increasing the energy storage capacity of a commercial electrical energy storage device, called a double-layer capacitor or ultracapacitor, by replacing the activated carbon electrode coating with an array of vertically aligned nanotubes.

The predicted performance of the nanotube-enhanced ultracapacitor using the vertically aligned nanotube array is significantly higher (30 to 60 Watt hours/kilogram) because of its improved electrical characteristics and because the diameter and spacing of the nanotubes are matched to the dimensions of the electrolyte ions, in contrast to the irregular pores exhibited by activated carbon. Calculations indicated that this structure could achieve an energy storage density approaching that of a lithium battery, while providing significantly higher power, faster recharge, and an almost unlimited lifetime.

We have successfully fabricated electrode material using a reactor designed and assembled in our laboratory, and we are now assembling test cells using this electrode material to experimentally validate the predicted storage density. Ongoing funding for this activity is being provided by the Ford–MIT Alliance.

Fault-Tolerant Systems

Professors Kassakian and Schindall and recent MIT graduate Dr. Alejandro Domínguez-García continue to work on advances in the design of ultrareliable embedded electronic systems and controls for safety-critical/fault-tolerant applications used in aircraft, aerospace, tactical, automotive, and power systems.

Advanced Reliability Modeling Techniques

Dr. Dominguez-Garcia finished his PhD in June 2007 under the supervision of Professors Kassakian and Schindall. A principal focus of Domínguez-García's thesis is to overcome the aforementioned pitfall of current reliability evaluation techniques by using a behavioral model of the system dynamics, similar to those used by control engineers when designing the control system, but with additional features to model the failure behavior of each component. The group is now working on developing a unified optimization framework for fault-tolerant systems design based on the unified model they developed for evaluating system reliability. This framework aims to guide the system design toward optimal system dynamic performance, robustness, and reliability with respect to redundancy allocation, cost, weight, and other metrics, depending on the system under consideration.

Development of Analysis and Design Computer Tools

The group is working on the development of a Matlab/Simulink evaluation tool to support the design evaluation and optimization of fault-tolerant systems—InPRESTo, an acronym for integrated performance and reliability evaluation Simulink toolbox. This toolbox is being used by the Systems Engineering and Evaluation Division of the Charles Stark Draper Laboratory for the evaluation of space and tactical systems. The group has used the tool to evaluate several case studies.

Critical Infrastructures

The group is starting to explore the application of their expertise in fault-tolerant/safety-critical system design to a much broader set of problems. Critical infrastructures such as power systems and gas and oil systems are examples of these applications.

Commonality Analysis of Guidance Navigation and Control (GN&C) Architecture for Space Systems

Dr. Domínguez-García is also working with Professors Edward Crawley and Steven Hall from the Department of Aeronautics and Astronautics and NASA Engineering and Safety Center to study the potential for developing common architectures for GN&C systems of different space applications, both human-rated and robotic.

Dissimilar backup mechanisms for safety-critical automotive applications

The group has also worked on the development of dissimilar backup mechanisms based ultimately on differentiated orthogonal systems to overcome uncovered and common mode failures of the main system. In this regard, Professor Schindall and Dr. Domínguez-García worked with undergraduate student Stephan Green to assemble a small-scale car prototype to demonstrate the feasibility of implementing an independent backup steering system, brake-actuated steering, for automobiles. Such an independent backup is vital to achieve the near-perfect reliability that will be required before steer-by-wire can be deployed in automotive applications.

Electrostatic proximity detection and scanning

During the reporting period, Professor Steven Leeb and his team have further developed capacitance sensing circuitry to enable a fluorescent lamp fixture to serve "dual use" as a proximity detector for occupants below the lamp. The lamp sensor measures changes in the electric fields produced by and surrounding the lamp, with two electrodes on the luminaire cover. The sensor has been refined this year to detect changes on the order of femtofarads. The lamp sensor has been demonstrated as a presence and motion detector in publications this year. With funding from the US Department of Justice, the National Science Foundation, and a local startup, NEMOmetrics, the lamp sensor has also been demonstrated in a proof of concept for metal detection and vertical scanning. Current work is directed toward applying the lamp sensor as an occupancy sensor in any place illuminated by discharge lighting. Because the sensor detects changes in dielectric configuration around the lamp, it does not require motion or a thermal signature to detect a person. MIT's Technology Licensing Office filed a provisional patent on this technology this year.

Shipboard Power System Monitoring and Condition-Based Maintenance

Professor Leeb and his group continued their monitoring activities on the United States Coastguard Charter (USCGC) Escanaba and the USCGC Seneca. They had major success in detecting a vacuum cycling system failure onboard one of the cutters before getting under way for an extended cruise. This success is documented in a letter of appreciation from the engineering officer onboard the USCGC Seneca. They have developed new models for the shipboard reverse osmosis water purification system that appear to have a remarkable ability to predict the need for maintenance, including filter changes and other pathologies in the system. This preliminary work will be under scrutiny for the next several quarters. They continue to collaborate with Professor Robert Cox at the University of North Carolina, Charlotte. Graduate work by Navy and Coast Guard officers Patrick Bennett, Greg Mitchell, and Mark Piber continues at MIT, under the cosupervision of Professors Leeb and Cox. They have identified a new team of four United States Navy officers and an EECS PhD student who will begin work on the electric ship team in June.

Advanced Building Energy Monitoring

Air conditioning alone accounts for a substantial portion of the total energy an average building consumes in the United States. One estimate of the cost required to bring building air within an acceptable temperature range is 30 to 60 percent of the total yearly energy cost for a building. As of 2000, package air conditioning equipment (so-called because all the components are manufactured and sold as a package) has been installed in 45 percent of US commercial and industrial buildings and consumes a total of 76 billion kilowatt-hours annually at a cost of $5.6 billion. These statistics suggest two general observations: air conditioning is important, and air conditioning processes use a great deal of energy. During the performance period, Professor Leeb's group received an award from the National Science Foundation and NEMOmetrics. They are developing the capabilities of their nonintrusive load monitoring technology to monitor the operation of air conditioning units, keep them running at peak efficiency, and flag problems so they may be addressed with preventive maintenance before expensive repairs are needed.

Wind Turbine Generator

Professor James Kirtley and Bin Lu have built an experimental generator intended as a prototype for wind energy. This is a variable shaft speed, constant electrical frequency machine that operates in a fashion similar to doubly fed (slip ring) machines. However, it uses a second rotor that contains permanent magnets and is freely spinning. This permits the use of an air-gap armature winding and should be more efficient and more compact than ordinary doubly fed machines in this application. The initial effort at an experimental machine encountered mechanical difficulties associated with the stability of the two rotors. This has been fixed with a new, stiffer case, and now we have a machine that actually operates and has yielded some interesting experimental data.

We have examined the use of the same machine geometry to large adjustable speed motors, particularly for ship propulsion. In this application, the low mutual coupling does not appear to be a problem, and, because of the polynomial nature of required power, it appears that a small power electronics package will be required. We are pursuing this with support from the Office of Naval Research.

Induction Motor Research

Induction machines have been around for a long time and are widely used in many applications. It has been our contention for some time that replacing cast aluminum with cast copper in integral horsepower induction motors could save a lot of energy by improving the efficiency of those motors. The electrical conductivity advantage of copper over aluminum could mean between one and three percentage points difference in such motors. This may seem small, but multiplied by the enormous number of electric motors in operation, the energy savings could be enormous. However, the substitution is not a simple matter because the different properties of copper affect the performance of the motor. Designing induction motors to take advantage of the higher efficiency of copper is an interesting and challenging problem. MIT has been collaborating with the Advanced Technology Institute and other institutions, including the Copper Development Association, to better understand how to design and build induction motors with cast copper rotors. Steven Englebretson, a PhD student in LEES is working with Professor Kirtley to investigate the effect of high conductor to lamination contact on stray load and no-load losses, with the objective of being able to predict such losses, which in turn affect motor efficiency.

Professor Kirtley is starting to work on the MIT/Portugal program, where we will be considering how to make microgrids work. We are considering the possibility of real-time pricing of electric power and load responsive control of power systems (that is, use some types of loads to help stabilize the power system, shave peak load, and fill in times of low load).

New Appointments and Promotions

David Perreault was promoted from associate professor without tenure to associate professor with tenure.

Ivan Celanovic (last year), Juan Rivas, Alejandro Domínguez-García, Frank O'Sullivan, and Tushar Parlikar all received postdoctoral appointments upon completion of their PhD studies in the laboratory.

Honors and Awards

Professor Steven B. Leeb received a joint appointment in the Department of Mechanical Engineering. Professor Leeb also became an IEEE Fellow this year.

Professor James L. Kirtley Jr. was elected to the National Academy of Engineering.

Joel Schindall
Associate and Acting Director
Bernard M. Gordon Professor of Electrical Engineering and Computer Science

More information about the Laboratory for Electromagnetic and Electronic Systems can be found at http://lees.mit.edu/lees/.