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Electric Utility Sponsored Energy Related Student Projects

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ABSTRACT

The industrial world is driven by an uncountable series of energy conversion processes. Engineering curriculums have been developed to provide students with the fundamentals to analyze these processes in various courses such as physics, chemistry, thermodynamics, transfer, heating ventilation and air conditioning, electric machinery, combustion and thermal energy conversion, but it is also important that the students have the opportunity to apply these principles to relevant industrial and social problems. Over the last ten years the Niagara Mohawk Power Corporation has provided funding for students, equipment and faculty to perform energy related projects during the summer and then to present and discuss their results to the utility research and development engineers and managers. Many of these projects have also provided material for papers that have been co-authored by students and faculty for the Intersociety Energy Conversion Engineering Conference. This paper will describe projects that were performed during the last summer. These projects were chemical kinetics modeling, ice storage, landfill gas powered generation, performance evaluation power conditioner for an induction motor and harmonic analysis of a DC to AC inverter. These projects are also representative of about fifty projects that have been performed over the decade. The paper will also discuss the relationship between the energy conversion related courses and the ability of the students to perform these projects.

1. Introduction

The electric utility system is a vital and massive industry that is based on a myriad of energy conversion and transfer processes starting with the combustion of fuels and leading to the delivery of electricity to the customer. Appliances represent other energy conversion processes, where energy is converted to end uses such as light, heat, refrigeration, television and computer based services. Utility research and development departments are charged with improving existing processes and developing new technologies and potential efficiency improvements. This requires engineers who have a knowledge of electric utility related issues.

Accordingly, the Niagara Mohawk Power Corporation has funded energy related student research at Union College for several years. The combined objective is expanding the technical knowledge base and introducing engineering students to energy conversion and conservation related fundamentals and practices. The authors are engineering professors who serve as Principal Investigators for the research and mentors for the students.

This paper will describe five projects that have been performed during the last summer and are representative of the types of projects that have been performed in the past and proposed projects for the future. The described projects are 1) using computer based models for evaluating chemical reaction kinetics related to processes such as combustion and fuel cells, 2) development and demonstration of a methodology to evaluate ice storage versus non-storage for chillers, 3) evaluation technologies and issues for power generation from landfill gas, 4) test and evaluation of the electricity saving potential for a commercially available power conditioner for induction motors and 5) test for efficiency and harmonic characteristics of a MOSFET DC to AC inverter.

2. Projects

This section will describe these five projects in terms of the research that was performed.

2.1 **Chemical Reaction Kinetics** (Student Peter Zannitto)

It is important to understand the oxidation and combustion of practical fuels such as natural gas, biomass and biomass derived fuels for electric power generation. These fuels are most commonly used as a thermal energy source for heat engines that produce mechanical power that is then converted to electricity by interacting rotating magnet fields inside of a generator or the fuels can be reformed for direct chemical to electric energy conversion in fuel cells.

Consequently, the understanding of the chemical kinetics of oxidation and combustion processes of these fuels is very important in determining the efficiency of the conversion processes and also the formation of undesirable products such as NOX and CO.

During the last ten years a combustion laboratory has been developed along with the procurement of chemical kinetics data bases and programs from national laboratories. Work performed during the summer of 1998 used these programs as a basis to develop models for these fuels that can be used to predict combustion processes and characteristics.

The technique is in keeping with the philosophy of the building block approach to the development of the reaction mechanism in which the reaction mechanism of a given compound can be constructed by combining the mechanisms of smaller and simpler compounds inherent in the reaction process of the larger one. For example the fundamental building blocks of the reaction mechanisms of methane and all other hydrocarbon fuels are the reaction mechanisms of hydrogen, CO and formaldehyde.

Efforts were concentrated on developing the most fundamental building block for these reactions which is hydrogen. Along with being the most fundamental building block for combustion, hydrogen and oxygen are the input elements for fuels cells. Thus the fuel cell requires a front end chemical conversion process that is called reforming that extracts hydrogen from the raw fuel such as methane. Hydrogen is also used as the coolant in generators and as a reactant in numerous other chemical processes.

Accordingly, a working model was developed for hydrogen reactions and results were validated against available experimental data. To run the model we obtained the newest version of CHEMKIN, which is a software package that numerically integrates the chemical reaction rate equations and solves the energy equation for various types of systems. An important feature of the new CHEMKIN package is that it allows the inclusion of heterogeneous surface reactions. This enables the modeling of catalytic systems. The previous work on hydrogen oxidation had been limited to homogeneous assumptions.

2.2 **Ice Storage for Air Conditioning** (Students James Bailey and Pasquale Pilato)

The capability of using of ice storage for air conditioning has been installed at several locations around the country. In 1998 it was proposed for the expansion of chiller capacity at Union College that was required to meet the demand of two new large buildings.

The purpose of this project was to research techniques available and operating options for ice storage and then to develop a methodology for evaluation. Since any air conditioner performance is a function of load and the evaporator and condenser temperatures which are functions of cooling tower and space air temperatures, a mathematical model of chiller performance was developed as a function of these variable operating conditions.

The potential benefit of storage is site specific and can be expected to be a function of the daily and weekly variations of demand, temperature and electric power rates. For the hypothetical case of all of these things being constant, storage would be of no value. Thus, hourly data of temperatures and loads were obtained for summer week from the central computer that monitors and controls the heating, ventilation and temperature conditions throughout the campus.

The resulting model and data was used to evaluate the hourly electric power requirements and cost for three modes of operation and two electric rate schedules. The modes of operation were a) no storage, b) ice storage with chiller operating at constant demand corresponding to weekly average demand and ice produced or melted at required rate and c) ice storage with chiller operating six hours per day from midnight to 6 AM at a rate of four times the average demand. The electric cost assumptions were either a) constant rate at all times or b) lower rates during the midnight to 6 AM hours.

Along with the cost for each case, the rate of ice forming or melting and the resulting mass of the ice was calculated for each case. The operating cost results were graphed and tabulated, and then compared with capital cost differences for the three modes of operation. The Coefficient of Performance (COP) while making ice is lower than for normal cooling because the evaporator has to operate substantially below 32 F. This contrasts with normal operation that produces chilled water at about 45 F for the buildings.

Continuous operation with storage would result in a somewhat smaller chiller than the no storage case, whereas operating only six hours at night would require a substantially larger chiller capacity. Comparing the two storage cases shows that four times more chiller capacity is required for the six hour per day during off peak hours operation relative to continuous operation. Thus, evaluation of ice storage involves many considerations and much site specific information.

Our evaluation showed ice storage is not now justified for Union College, but this conclusion could change with changes in electric rates or demand patterns. Despite the negative recommendation for Union College, the methodology and program that was developed represents a valuable tool for such evaluations.

2.3 **Landfill Gas Generation Technologies** (Students Pasquale Pilato and James Baily)

There have been estimates that the solid waste stream of municipal garbage could be burned and converted into 5% of total electric power requirements. This led to the installation of many high capital cost and often controversial incinerators around the country over the last two decades. Success has been marginal and several, such as the mass burn facility in Rutland, Vermont, and the facility with front end separation in Albany, New York have been shut down. The Vermont plant was shut down because the ash was defined as toxic and the inability to procure the required lined landfill for the ash. The Albany plant shut down in response to air quality complaints. An alternative to incineration is to continue to use solid waste landfills, but to capture the methane that is produced by the decay of organic matter for the production of power and electricity.

The purpose of this project was to research the techniques and technologies available for power generation from landfill gas, along with the related considerations of state and federal regulations and public health concerns that result from exposing the public to unburned and potentially toxic landfill gas. Four landfills were visited and additional information was obtained from equipment manufacturers and regulating agencies.

The first visit was to a capped landfill in Utica/Frankfort that has been producing electric power for the last five years from two 800 kW spark ignition engines. This has been successful, but the gas flow has decayed from 1600 kW to 1000 kW capacity. This visit also provided our first opportunity to examine the landfill from the top and see the grid of wells, water pumps, pipes, condensate separation and collection equipment, compressors, and monitoring instrumentation, including an online chemical analyzer that continuously measures the percentage of methane contained in the gas from the landfill.

The second visit was to a double capped landfill in Saratoga that is also operating grid connected, but is nominally producing the power for two adjacent municipal skating rinks. One landfill was capped municipal waste which was yielding only about 50% methane. The other landfill is manure from the race track that yields a higher methane level of about 65%. This contrasts with pipeline natural gas with methane levels above 90%.

The third landfill visit was to a newly installed system in Albany where there is both an active and a capped dump. This best represents the newest technology. Some novel techniques have drawn visitors from various sections of the country along with substantial numbers of international visitors. A unique feature is that it is mining landfill gas from an active landfill. This is performed with horizontal rather than vertical pipes. Mining the active portion has resulted in improved air quality in the surrounding neighborhood that includes a residential trailer park.

The fourth visit was to a capped facility in Schenectady County that is capped with a system of wells and flares, but is not now producing power. Because of wind and unsteady flow, the flares occasionally burn out. Thus, solar powered electric igniters are installed on each well that are timed to periodically operate and thus re-ignite the flares.

Solid waste disposal and abandoned landfill maintenance is a growing environmental and land use problem and this project provided students and faculty an opportunity to better understand the problems, options and opportunities.

2.4 **Evaluation of a Microprocessor Based Power Conditioner for Induction Motors** (Laboratory Assistant Stanley Gorski and Student Philip Haynes)

The hardware and electrical department of some stores have marketed plug-in type devices for reducing electric bills for refrigerators or other motor driven appliances. The newer devices have an increased sophistication as indicated by a RISC-based microprocessor that first evaluates the voltage and current signal to the motor and possibly uses neural network or fuzzy-logic based algorithms to calculate switching times and then performs solid state switching so as to condition the power supply so that less electric energy is consumed.

The algorithm for the power conditioner was not available and may be proprietary. Thus, the objective of this project was to experimentally evaluate one of these devices over a range of operating loads on an induction motor in terms of electric power consumption and to also observe the voltage and current waveforms.

An engine driven dynamometer that employed a DC generator that allows continuously variable speed and torque operation was modified so that the induction motor replaced the engine. The output load could be controlled by the field current to the DC generator and the corresponding motor output torque, speed and mechanical power could be measured. The electric power to the motor was measured by both a conventional kWhr meter that is used by the utilities to bill customers and also by means of rapid sampling of current and voltage, multiplying and then averaging the product.

The voltage and current wave forms were displayed on an oscilloscope and harmonics were measured and calculated with Fast Fourier Analysis Software. The voltage had higher harmonic levels than the current which could be expected because of the high frequency filtering effect of the inductance.

The results of this test showed a decrease in electric power consumption at low loads, but a somewhat higher rate of electric power consumption and at rated motor load. Thus, the device would be beneficial for motor application that usually spins without load but would result in higher electric consumption for a refrigerator where the motor is either Off or On and operating at nominally the full power condition.

2.5 Efficiency and Harmonic Measurements of a MOSFET DC to AC Inverter
(Students Fariad Anwari and David VanBuren)

The existing electric power system is an AC transformer based multiple voltage system. This system is based upon the principle that high voltage should be used for efficient transmission and low voltage should be used for safe use. However, AC is incompatible with distributed generation such as photovoltaics or fuels cells which generate DC power which is then typically inverted to AC for connection to the electric power system.

An alternative technique that would result in a decreased conversion requirement and a corresponding lower loss and lower cost would be to convert the end use service from AC to DC by rectifiers that are simple solid state passive devices. Thus, the distributed DC generation would interface directly with the DC distribution system, but some remaining devices such as refrigerators would require DC to AC inverters of about 300 watt ratings.

A specific purpose of this project was to evaluate the possibility of a more efficient refrigerator by replacing the ON/OFF control with continuous operation at varying electric power supply frequency. The fundamental benefit is to reduce the temperature differences across the evaporator and condensing heat exchangers. Thus, along with evaluating the energy conversion performance of a MOSFET based variable output frequency inverter, this project performed a 2^{nd} Law analysis of the refrigeration cycle to evaluate the reduction of extra power for continuous rather than ON/OFF operation.

3. Student Presentations, Papers and Future Projects

At the end of the summer the students and faculty met with management and engineers from the sponsoring Niagara Mohawk Power Corporation to present and discuss the projects that have been performed and to propose projects that should be continued and new projects for the next year.

Papers based on results of four of the five 1998 projects are being prepared for the 1999 Intersociety Energy Conversion Engineering Conference along with this paper for the 1999 ASEE conference. Projects that have been proposed and for the summer of 1999 are a) further test and analysis of power electronic devices, b) biomass gasification and combustion, c) chemical reaction kinetics and CHEMKIN based analysis, and d) landfill gas and engine technology.

This new proposal has been approved which results in a total funding of over $500,000 that has been awarded to Union College by Niagara Mohawk Power Corporation over the last 10 years. Thus, students and faculty will continue to have the opportunity to perform research on the type of energy related projects that are vital for the present and future.

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