(23) Energy Conservation Sciences for operation and Security of Large-Scale Systems
The objectives of the proposed effort are to expand and/or supplement the research presently underway as past of the Center on Security of Large Scale Systems. In particular, the project will seek to (1) expand solid-state research in the area of Silicon Carbide (SiC) for the purpose of reducing size, weight, and cost of power converters for motor drives and distributed generation, (2) to investigate methods of motor control including the advantages of SiC devices to increase the efficiency and reduce the cost of electric drives, and (3) to incorporate the results of the Center's research in fuel cell testing and modeling to suggest design and operation of these devices in distributed generation during islanding of an Electric power Grid.

Total project cost: $322,834
Funding request: $249,999
Project Lead: Purdue University
Project Participants: Wright State University

Start Date: May 23, 2005
End Date: May 23, 2007

Task 1 Silicon Carbide Devices for Advanced, High-Efficiency Power Conversion
Michael Capano, Purdue University

Objectives:

The objectives of the SiC component of this research are to (1) develop criteria for the selection of SiC SBDs or PiN diodes and, (2) examine power dissipation and cooling requirements needed for SiC electronics.

Background:

To accomplish these objectives, simulation of SiC diodes are being performed using *Medici*, with the purpose of designing PiN and SBD diodes with nominally equivalent voltage ratings. Selection of PiN and SBDs are based on simulations using total power dissipation as the criterion for selection. Also, these simulations serve the purpose of defining device structures to be examined experimentally. Two voltage regimes are investigated: 1000 V and 5000 V. PiN diodes and Schottky diodes nominally in the 1000 V range are finished or nearly fabricated and there electrical and thermal characteristics are being evaluated. All activities performed under this project fall into one of the four categories below:

1. Design system requirements for SiC diodes, including selection of adequate coolant. SiC PiN and Schottky diodes with similar voltage ratings (1500 V and 5000 V).
2. Build SiC PiN and Schottky diodes. Measure diode characteristics under forward (on-state) and reverse (off-state) bias conditions.
3. Develop selection criteria for choosing PiN or SBDs based on current rating, switching frequency and power density limitations.
4. Investigate cooling requirements for SiC devices.

Research Progress:

A no-cost extension was requested due to a physical move of processing tools from the old Electrical Engineering building to the new Birck nanotechnology Center. This move is complete and work has resumed.

Research within the last quarter has focused on testing of SiC pin diodes with voltage ratings of 1000 V. Diodes have been tested in forward bias conditions and show little Vf (forward voltage drop) drift over several hours of testing. The lack of significant Vf drift is attributed to the thin epilayer required for this voltage rating. Higher voltage devices require thicker epilayers. The stacking fault defects which are known to be responsible for Vf drift can expand as far in thin layers as in thicker layers.

Plans for Next Quarter:

No additional technical work is planned. Activities will primarily include preparation of the final report. This will be completed by October 23, 2007.

Task 2. Optimal Efficiency Motor Control Strategies

Marian Kazimierczuk, Wright State University

Objectives:

1.

The objective of this part of the project was to design a dc/ac variable- frequency three-phase power inverter, using Si and SiC power devices, estimate the inverter power losses and efficiency, and compare the losses and efficiency with Si and SiC devices.

Background:

The benefits of silicon carbide devices include high-breakdown voltage, high-temperature, high-frequency, high-reliability, and nearly zero reverse recovery. In previous quarters, electrical and thermal characteristics of SiC power devices were studied and areas of applications were identified [1]. High-voltage SiC Schottky diodes appear to be the most promising SiC power devices for high-voltage, high-frequency applications, such rectifiers and clamp circuits in dc/dc power converters and power-factor correctors [2]. The use of theses diodes allows the designers to avoid snubber circuits and increase the switching frequencies. Also, parallel combinations of power Si MOSTETs and SiC diodes are very promising arrangements in many applications. A topology of the dc/dc inverter was selected and designed. A Class D half-bridge dc/ac power inverter was selected for further investigations and the circuit was designed.

Research Progress:

During the past quarter, the final report for this task was prepared. During the next quarter, this report will be integrated with the overall final report of the project.

Task 3 Islanding and Distributed Generation for Enhanced Electric Power Grid Security

Academic Faculty:

Shripad Revankar, Associate Professor, Department of Nuclear Engineering, PU
Mitch Wolff, Professor, Department of Mechanical Engineering, WSU

Graduate Students:

Brian Wolf M.S. Candidate Nuclear Engineering, PU

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[1] N. Das and M. K. Kazimierczuk, ``Applications of Silicon Carbide Power Devices in Power Electronics," Electrical Manufacturing and Coil Winding Association, Indianapolis, IN, September 18-20, 2006.

[2] D. Murthy and M. K. Kazimierczuk, ``Active Clamp Circuits for Flyback PWM DC-DC Converter," Electrical Manufacturing and Coil Winding Association, Indianapolis, IN, September 18-20, 2006.

Karleine Justice M.S. Candidate Mechanical Engineering, WSU
Carlos Gutierrez M.S. Candidate Mechanical Engineering, WSU

Objective:

Investigate the control and performance of distributed generation during islanding of an electric power grid. High temperature fuel cell hybrid systems will be used for power generation.

Background:

Advancement in research of distributed generation of electrical power is a result of energy security issues and changing markets and technologies. Fuel cell hybrid technologies which integrate high temperature fuel cells with another power generation technology have promising abilities which make them an important research topic for development and commercialization. They meet many demands of U.S. energy goals of the future including independence from foreign sources, greater security, and pollution free emissions.

Previous work accomplished includes a thorough literature survey on hybrid fuel cell distributed generation systems. Steady state models for both Molten Carbonate Fuel Cells (MCFC) and Turbines of different capacities have been created. Other component models such as oxidizer, and heat exchangers have also been developed for steady state conditions. Certain controls were then implemented to begin the transition to dynamic modeling. Dynamic modeling of the fuel cell was successful and benchmarked with model results in literature. Multiple visits between Wright State and Purdue have proven to be very productive. Coupling of the MCFC fuel cell model and the turbine model has been a success. Fuel pre-conditioner models for the hybrid system are complete along with controls. Controls for the entire fuel cell hybrid system have been incorporated with control objectives met.

Research Progress:

From studying the dynamic response of the fuel cell / turbine system, it was concluded that some optimization should be established. The first parameter being studied is the fuel cell/ turbine power ratio. For each data point all the shell-and-tube heat exchangers must be designed to meet the steady state flow rates the fuel cell requires. This process has been started and a greater overall efficiency should result.

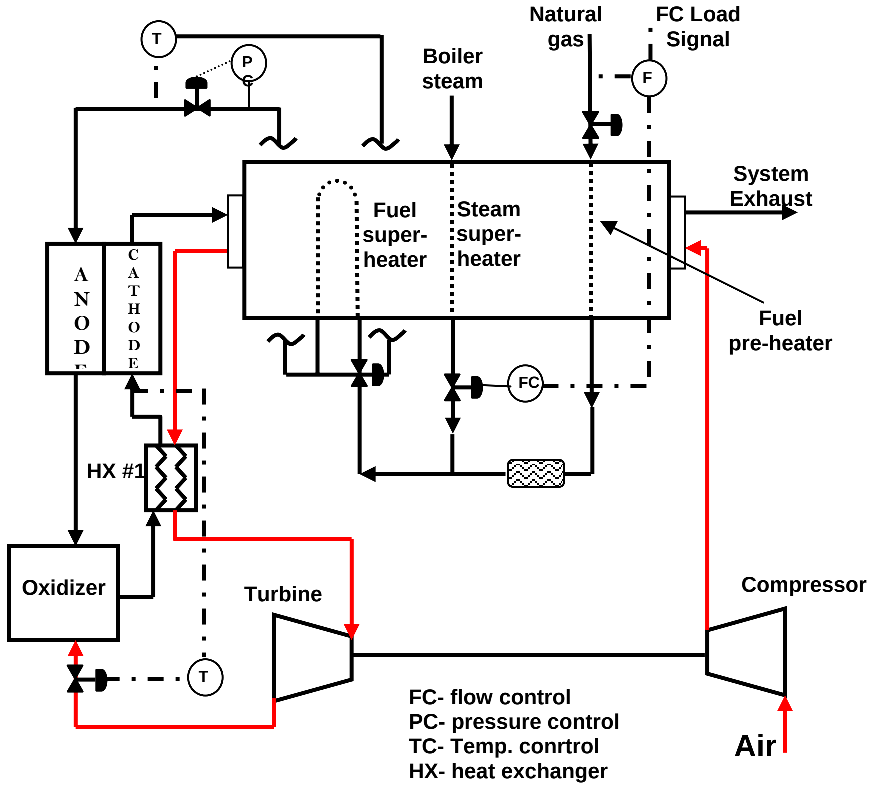

Fig. 1 Hybrid Cycle Configuration

Table 1 Steady State Results of Hybrid System with constant current load density, fuel utilization and steam to carbon ratio.

FC Current Density (mA/cm2)	**160**
Fuel Utilization	**0.75**
Natural Gas Flow rate (mol/s)	**30.43**
Steam to Carbon Ratio	**2**
Oxidizer Air Flow (mol/s)	**319.5**
Number of Stacks	**64**
Cathode Inlet Temperature (K)	**825.3**
Anode Inlet Temperature (K)	**861**
Stack Temperature (K)	**949**
Cell Voltage (Volts)	**0.67**
Fuel Cell DC Power (MW)	**8.47**
Turbine Output Power (MW)	**3.836**
Total Plant Output (MW)	**11.1**
Overall LHV efficiency	**59.70%**

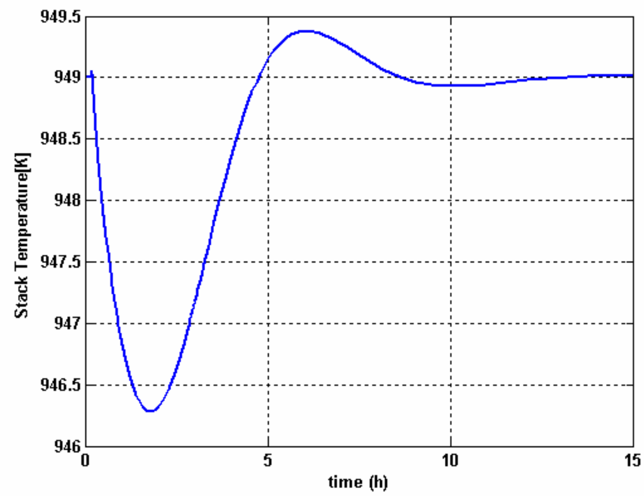

Fig. 2 Dynamic Response of FC Stack Temperature for hybrid system to 25% load reduction on fuel cell with a stack temperature control objective set point of 949 K.

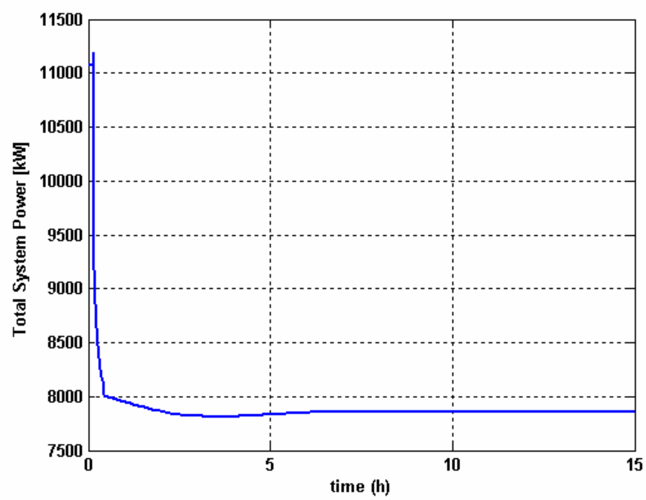

Fig. 3 Dynamic response of Total System Power for hybrid system with 25 %load reduction on fuel cell.

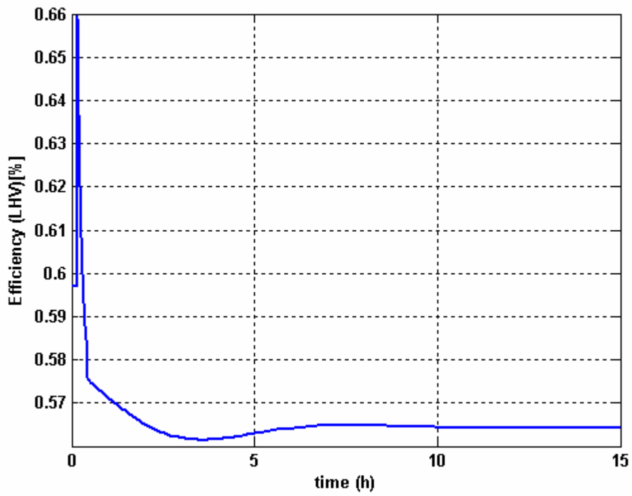

Fig. 4 Dynamic response of Hybrid system LHV efficiency for a 25 % load reduction on fuel cell.

Plans for Next Quarter:

No additional technical work is planned. Activities will primarily include preparation of the final report. This will be completed by October 23, 2007.