Advanced Power Conditioning System Technologies for High-Megawatt Fuel Cell Power Plants

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***Abstract*-- High-megawatt Power Conditioning Systems (PCSs) are required to convert the low-voltage produced by fuel cell modules in central station scale plants to the very much higher voltage levels required for delivery to the grid. As part of a NIST/DOE Interagency Agreement, advanced PCS architectures, circuit topologies, and component technologies are being evaluated to identify technologies requiring development to meet the fuel cell power plant PCS cost goals of $40-$100/kW. In addition, several industry, government, and university programs are being initiated to, in part, support these fuel cell power plant PCS goals.**

***Index Terms*—SECA, Fuel Cell, Power Conditioning System**

I. Introduction

High-megawatt Power Conditioning Systems (PCSs) are required to convert the low-voltage power produced by fuel cell modules in central station scale plants to the very much higher voltage levels required for delivery to the grid [1,2]. The DOE Solid State Energy Conversion Alliance (SECA) power plant PCS cost goal of $40-$100/kW is generally recognized as a difficult stretch goal that cannot be met with today's technology. To address this challenge, DOE and NIST have entered into an interagency agreement to have NIST lead an effort to evaluate various advanced technology options for high-megawatt PCSs and to identify technologies requiring development to meet the cost and efficiency goals of the SECA central station fuel cell power plant.

Various PCS approaches that focus on the use of advanced technologies for low-, medium-, and high-voltage architectures are being considered. The advanced component technologies being considered include advanced power semiconductor devices made with the SiC material, advanced nano-crystalline magnetic materials for filter inductors and transformers, advanced capacitor technologies, advanced power electronic component cooling systems, and modular power electronic package and interconnect approaches. Each PCS approach is being evaluated for its ability to meet the performance requirements of the fuel cell power plant, including requirements for interfacing to fuel cell modules and for power grid connectivity, as well as the cost of constructing and maintaining the PCS.

II. High-Megawatt PCS Program Coordination

The identification and development of advanced technologies for high-megawatt PCSs requires input from, and coordination with, the broad power electronics community. To initiate this interaction and to review the approach being used for the advanced technology impact evaluation, a "High Megawatt Converter Workshop" [3] was held at NIST in Gaithersburg, MD on January 24, 2007. The objectives of the workshop were to exchange information focused on state-of-the-art technologies for high-megawatt PCSs, discuss the merits of proposed approaches for achieving significant cost reduction and improved electrical conversion efficiency, discuss how federal resources could potentially be utilized in a coordinated effort to address these issues, and to discuss the merits of establishing an industry-led roadmap committee to offer guidance that could facilitate the achievement of the desired goals.

The High Megawatt Converter Workshop included 42 invited participants and 21 invited presenters. Ten of the presentations described specific technologies deemed to have the potential to reduce PCS cost and seven presentations discussed the common needs for high-megawatt PCSs across industry and federal government agencies. During the workshop, a consensus was reached on the parameters of the Technology Impact Analysis being led by NIST. The Workshop participants also agreed that a federal interagency task group for high-megawatt power converter technologies could play an important role in this area and that a roadmap process should be initiated to offer guidance for further development of PCSs that could meet the requirements for more cost-effective and more efficient power conversion.

In response to the consensus reached at the High Megawatt Converter Workshop, an interagency working group was established to address the high-megawatt PCS and other federal government PCS needs. The group was established under the umbrella of the Interagency Advanced Power Group (IAPG) as the reinitiated Electrical Systems Working Group (ESWG). The first meeting of the ESWG was organized and held on September 13, 2007. Progress has also been made in initiating a process to establish an industry-led high-megawatt PCS technology roadmap committee and a number of individuals have expressed a willingness to serve on such a committee.

III. Advanced PCS Technology Impact Analysis

During the High Megawatt Converter Workshop, various aspects of the NIST/DOE Advanced High-megawatt PCS Technology Impact Analysis effort were reviewed including: the overall approach of the study, the current and voltage boundary conditions, the grid-connectivity requirements, fuel cell current regulation and ripple requirements, as well as, the topology and component technologies being considered by the

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study. Various conversion approaches that focus on the use of advanced technologies for low-, medium-, and high-voltage architectures were outlined.

The initial baseline for the study is a center-tapped fuel cell (approximately 700 V DC, 0.6 MW) with a DC-DC converter for fuel cell current regulation, a 480 V AC inverter, and a 60 Hz transformer to raise the output voltage to 18 kV AC for plant distribution. This option was chosen as the baseline because it includes the individual functions necessary to expand to architectures having a DC common bus, and/or a medium-voltage or high-voltage inverter. The "present lowest-cost" option combines the DC-DC regulator and 480 V AC inverter functions into a single converter stage that uses the "present lowest-cost" switching power device, a 1200 V insulated gate bipolar transistor (IGBT) module.

On the other extreme, high-voltage inverter options are being considered that use DC-DC voltage step-up converters to feed high-voltage inverters connected to the 18 kV AC power plant distribution bus. In this case, voltage step-up and galvanic isolation is provided by the high-frequency transformer within the DC-DC converters as opposed to the 60 Hz transformers of the baseline low-voltage inverter options. The high-frequency transformer requires orders of magnitude less magnetic material and copper than the expensive conventional 60 Hz copper-iron transformer. The high-frequency transformers are enabled by advanced high-frequency magnetic materials. The cost of these advanced magnetic materials can be reduced in the near future whereas the cost of the copper required by the 60 Hz transformers is expected to increase. The high-voltage inverter for this PCS architecture would be enabled by the rapidly advancing High-Voltage, High-Frequency (HV-HF) semiconductor devices made with the SiC material [4].

IV. Modeling Advanced PCS Technologies

Simulation models for advanced PCS architectures, circuit topologies, and component technologies are required to verify the interactions between components for the technology impact evaluation. One of the most potentially revolutionary technologies for high-megawatt PCSs is SiC power semiconductor devices. NIST is developing models and parameter sets for 1200 V and 10 kV SiC MOSFETs and junction barrier Schottky diodes to be used in this work. The NIST developed SiC power semiconductor models, in addition to the well known NIST Silicon IGBT model, will be used as part of the effort to evaluate the cost and performance advantages of the various DC-DC and DC-AC converter options.

V. Conclusions and Future Directions

It is generally recognized that the SECA cost goal of $40-$100/kW for the power plant PCS cannot be met with today's technology. To address this challenge, DOE and NIST have entered into an interagency agreement to have NIST lead an effort to evaluate various advanced technology options for high-megawatt PCSs. The High Megawatt Converter Workshop held at NIST on January 24, 2007 resulted in a consensus on the process and parameters for the NIST/DOE study and the formation of an interagency task group and a roadmapping committee for high-megawatt PCSs.

Various PCS architectures and advanced technologies have been identified that may lead to the cost reductions required for central station fuel cell power plants. Component technologies such as SiC power semiconductor devices and advanced high-frequency magnetic materials may hold the key for future high-megawatt PCS cost reduction. Simulation models for such advanced component technologies and simulation schematics for alternative DC-DC and DC-AC converter topologies are now under development. Predictive simulations including advanced technologies will aid in validating the interaction between components and demonstrating the overall system benefits of new high-megawatt PCS technologies.

VI. References

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VII. Biography

Dr. Allen R. Hefner received a PhD in Electrical Engineering from the University of Maryland in 1987. He joined the NIST Semiconductor Electronics Division in 1983 where he leads the NIST Power Semiconductor Devices project and is very active in several other government agency programs to develop and utilize advanced power electronics technologies. He was the recipient of the 1996 NIST Applied Research Award and a U.S. Department of Commerce Silver Medal Award in 1993, and was elected to IEEE Fellow in 2001.