The HEP/DG PRECISION POWER PLATFORM ™

(Hybrid Electric Power/Distributed Generation System, an Advanced Version of the DERP TECH Power Control Unit)

Resilient Power Works (DBA for DERP TECH) and the National Energy Technology Lab (NETL) are working together under a US. Department of Energy CRADA (Collaborative Research and Development Agreement): included in this CRADA is the AMES Lab. They are specifically working to design and develop advanced power controls to be commercialized that will enable wide-spread Distributed Generation in several configurations to be integrated into the utility infrastructure, or bulk power system, to vastly enhance the grid's resilience to and to expedite recovery from extreme weather events, and to provide a more stable and clean operation during normal operating conditions, by providing peak power shaving and highly efficient ancillary local power generation.

DERP TECH (now a.k.a "Resilient Power Works") was one of the first eight microgrid FEED (Front End Engineering and Design) companies whose design for a "Safe Haven Microgrid™" was chosen in Connecticut under their 2012 Microgrid law to improve public safety, reduce recovery times, and include clean renewable energy in the local generation mix after destructive storm events. Our project was deemed a Safe Haven Microgrid because it was the only site of the first eight awardees that is a designated Red Cross Shelter – intended to take in 3,000+ evacuees from the New London area in the event of a plume event at the Millstone Nuclear Power Plant or severe storm events.

The Safe Haven Microgrid's original design was a hybrid model, incorporating rooftop Solar Photovoltaics, Natural Gas Turbines (Yankee Gas) and Storage. The Microgrid is commissioned and working at a two-school site in Willimantic, CT, which is 50 miles north of Millstone/New London. (Contact person is Jean deSmet, former Chair of the Town of Windham Energy Commission.)

NETL's Hybrid Performance ("HyPer") Lab is located in Morgantown WV and its focus is on Hybrid Power configurations, which are based on Natural Gas turbine technologies and thermal storage, provided by Solid Oxide Fuel Cells (SOFC). To this base power combination, additions of renewable sources of generation (including solar PV, wind and hydro) are intended to be modeled.

One of the many significant outcomes that the HyPer Lab's research has demonstrated in recent years is that, with well-designed supervisory and dynamic controls, the hybrid generation configuration is capable of extending a SOFC's life by seven times , from about 2 years to about 14 years. This outcome alone may be capable of changing the commercial and utility acceptance of SOFCs.

Another outcome of the NETL HyPer Lab research has resulted in dramatically improving the turn-down ratio and rapid start-up of the natural gas turbine, making the hybrid model a potential champion for providing low-cost spinning reserves for the utility industry.

Furthermore, to advance the cyber-security elements of our HEP/DG Precision Power Control Platform, one of our academic research partners is investigating the utilization of "block-chain" algorithms and processes to make the sensors associated with the advanced power control systems less likely to be hacked and corrupt operations, reducing risk to the utility organization and its associated generation and distribution assets.

The HEP/DG Precision Power Platform suite of controls under development are to be principally installed at the secondary mid-voltage bus of a distribution substation – with the Point of Common Coupling (PCC) being at the feeder level, although other configurations may be possible. Therefore the "sandbox" that Iberdrola offers – "miles of transmission lines, transformers, distribution substations and customers is well-suited to expedite the proof of concept and commercialization phases for our HEP/DG Precision Power Platform and derivations of the work presently underway.

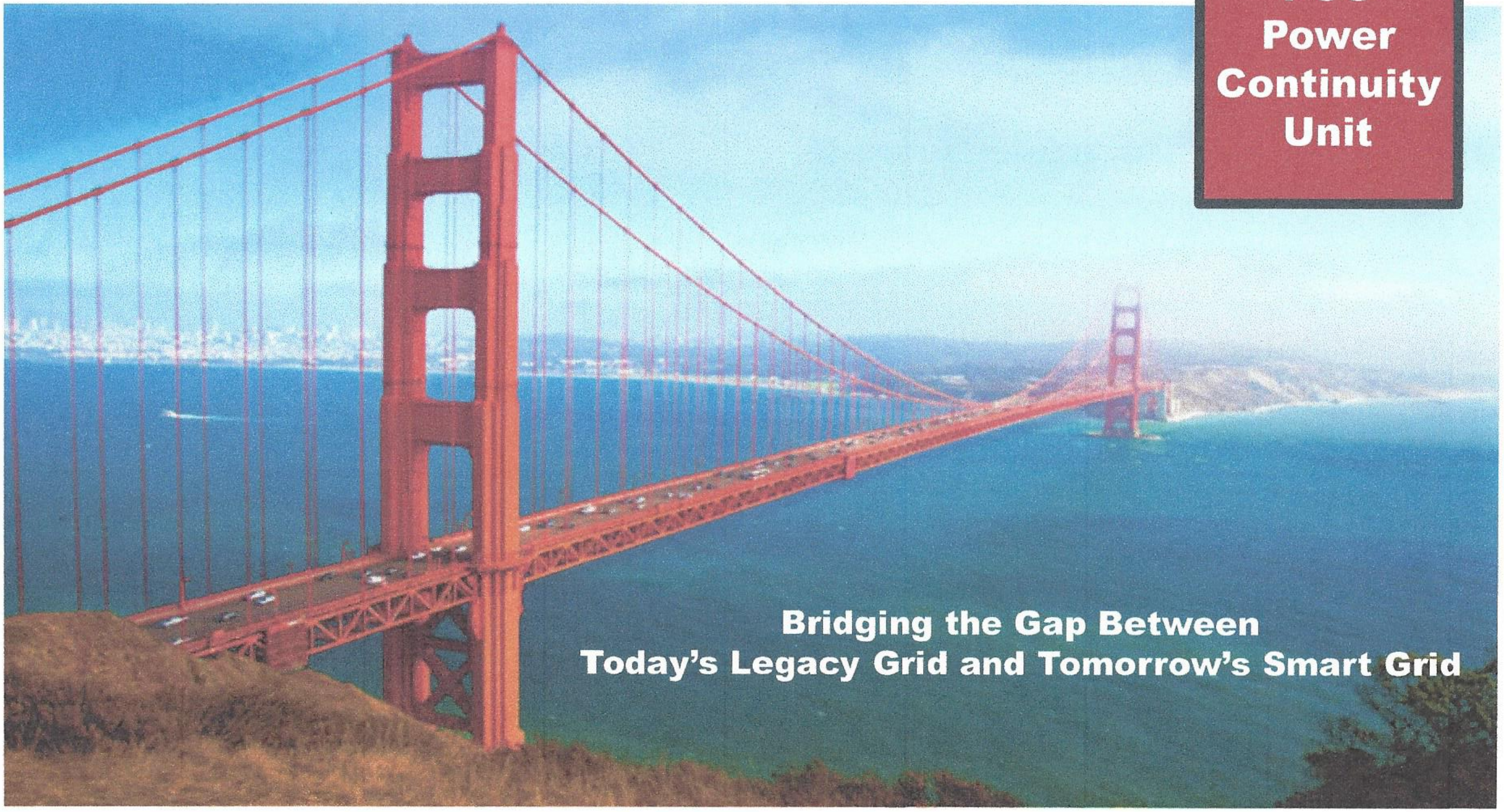
It is against this background, Resilient Power Works/DERP TECH is pleased to submit our application for the opportunity to collaborate with Iberdrola. It is essential to have a progressive, experienced utility partner, with environmental sensitivity, vision and corporate capabilities necessary to commercialize and to install the types of hybrid-power controls we are proposing to Iberdrola here.

We have included in our attachments:

1. Three White Papers that discuss some of the research conducted under the CRADA with the US. Department of Energy, National Energy Technology Laboratory.
2. A presentation (power point) prepared by the National Energy Technology Laboratory for their presentation at the US Department of Energy National Headquarters in Washington D.C.
3. A video clip of the NETL HyPer Lab capacity in Morgantown, WV.

DERP TECH **D**istributed **E**lectric **R**enewable **P**ower

PCU
Power Continuity Unit



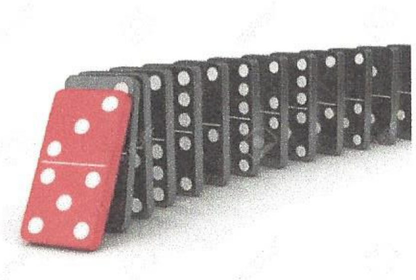
Bridging the Gap Between Today's Legacy Grid and Tomorrow's Smart Grid

Photo: Fodors

Problems with Today's Legacy Grid:

U.S. Electricity System is backbone of business productivity, critical infrastructure operations and public safety. However:

- U.S. Electric grid is old and is becoming less reliable
- Blackout/brownout risk here higher than other developed countries
- Utilities and substation owners seeking more reliability:
    - * Outdated energy - technologies not "smart"
    - * Outdated power controls do not accommodate local distributed generation
- Centralized power production models take decades to permit/construct new sources
- Standby power (diesel generators) are an inadequate solution.



NATIONAL ENERGY TECHNOLOGY LABORATORY (NETL)

"The HyPer Lab" – Hybrid Power Generation

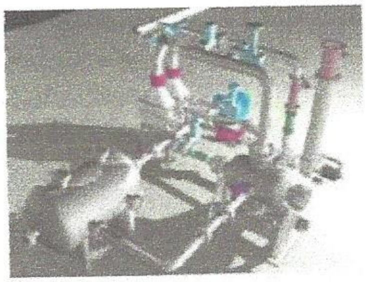
CRADA Partner (Collaborative Research and Development Agreement) – Advanced Power Controls

Energy System Dynamics Division - *The Hybrid Performance Facility*

The Hybrid Performance Facility: Called the Hyper facility, which is now fully operational at the Department of Energy's National Energy Technology Laboratory (NETL). This one-of-a-kind facility, developed by NETL's Office of Science and Technology, will be used to develop control strategies for the reliable operation of fuel cell/turbine hybrids.

Combined systems of turbines and fuel cells are expected to meet power efficiency targets that will help eliminate, at competitive costs, environmental concerns associated with the use of fossil fuels for producing electricity and transportation fuels.

A fuel cell is an electrochemical device that produces electricity from hydrocarbon fuels without combustion, while a turbine produces electricity when steam or hot gases expand, spinning the turbine blade. When the two devices are combined into an integrated power-producing system, the combined system achieves fuel efficiency and emissions performance that are beyond the reach of any single standalone system.


The Hyper facility allows assessment of dynamic control and performance issues in fuel cell/turbine hybrid systems.

The Hyper facility provides a unique opportunity for researchers to explore issues related to the coupling of fuel cell and gas turbine technologies. While the efficiency benefits of hybrid plants are well recognized, controlling the flow of power from both the fuel cell and turbine during load changes is expected to be more complicated than in conventional power systems.

In addition to planned NETL studies, the Hyper facility and modeling efforts are available for public research collaboration. Collaboration with academic, non-profit, or commercial research groups can be arranged under a variety of cooperative programs, such as a Cooperative Research and Development Agreement, and student or visiting scholar programs. Several industry and academic partnerships are now in place, including support from Woodward Governor Company, West Virginia University, Georgia Tech, and others.

HEP-DG POWER CONTROLS – POWER CONTINUITY UNIT #2111

Solid Oxide Fuel Cells, Advanced Hybrid Power System Controls and their Role in Transfiguring the Grid

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ABSTRACT:

Distribution generation (DG) and microgrids integrated into the nation's distribution grid are the future of the nation's power supply; at the heart of any distributed generation model is reliable and resilient locally produced electricity. Developing the optimum platform for DG power generation - a platform that is acceptable to the utilities and to regulators - is of paramount importance for commercialization and marketplace acceptance. To that end, DERP TECH and the HyPer Lab at NETL in Morgantown WV have entered into a CRADA relationship (which is a Collaborative Research and Development Agreement) in order to design and optimize Advanced Hybrid Power Control Systems.

This work is being done to advance distributed generation and microgrid controls for hybrid power that are for the utility industry; they will enable locally produced power generating stations to incorporate both fossil fuels (natural gas turbines) and non-fossil fuel sources (including PV solar), as well as integrating the most advanced fuel cell technologies for resilience and super-efficiencies.

The CRADA will enable DERP Technologies to pursue its goal of designing an interconnection and power management device that enables the local distribution utility to readily integrate locally produced hybrid electricity into the feeder system and to create one or more microgrids per installation in its service territory.

Keywords: Advanced Power Controls, Hybrid Power Generation, Microgrids, Smart Grid, Distributed Generation (DG)

Generation and Distribution Management at the Local Distribution Level with HYBRID POWER Sources

The advanced power controls are central to the successful scalability of such a generating system – they involve both dynamic and supervisory controls for the generation side of the DG equation. The HEP/DG PCU merges other functions that involve designing interfaces with the utility's local distribution grid, including smart substation two-way communications and networking between DG sources located at critical nodes.

Reliability **and** ***flexibility*** are two major goals of distribution utilities in the wake of SuperStorm Sandy and the retirement of older centralized power plants; it is the intent of the DERP TECH and NETL design team to enable the utilities to add DG and microgrids with the most efficient and reliable scalable power source possible.

Why the Hybrid Power Generation System is Well-Suited to Tomorrow's Increasingly Decentralized Smart Grid

Ever since Hurricanes Sandy and Katrina, utility companies have been changing their business model to accept and incorporate more clean energy into their energy portfolios while, at the same time, hardening the vast local grid to withstand heavy weather and adapt to disruptive events. Many States from the mid-Atlantic to New England have allocated significant funds and offered other incentives to build innovative microgrid demonstration sites and are now adding clean energy while retiring old fossil-fuel and nuclear plants. Regulatory bodies in those States are struggling to catch up with these changes, but there are technological challenges for all stakeholders (political bodies, utilities, consumers, innovators) as we "bridge the gap" between Yesterday's Legacy Grid and Tomorrow's Smart Grid.

Exacerbating the problem of adapting a new "smart grid"/microgrid business model to the utility industry is the lack of a national standard. (NIST is working on interoperability standards, and has been for years, but microgrids to date have been "one offs," largely behind-the-meter.) So we are – as a nation – in the same dilemma as when there was no standard gauge for the railroads or no "National Banking Act" before the Civil War. Railroads couldn't readily interconnect; once, there was no nationally accepted currency and commerce was more difficult to transact. Same principles apply to electricity.

Adding microgrid and local power generation (DG) capacity to the local grid in a regionally coordinated and strategic fashion hasn't happened yet – and so the local utilities have to accommodate more and more "DER" being added to their distribution lines with every passing day, pushing the limits of the "legacy" grid.

The HEP/DG PCU advanced power controls are being designed with several goals in mind, one of which is seeking a universal "plug-and-play" design that would enable utilities and private substation owners to adapt to a more strategic distributed power business model.

Here are a few of our Long-Range Objectives with NETL

1. Extending the Useful Life of Fuel Cells

And central to their work is examining the gamechanging role that solid oxide fuel cells can play in the mix, in terms of a cleaner footprint and creating a far more responsive and reflexive local power supply, one that can react quickly to shifting loads and providing reliable power nearly instantaneously when there is a black-out or sustained grid power failure. Most significantly, research in the HyPer Lab at NETL has recently demonstrated that is a realistic objective to dramatically extend the useful life of utility-scale fuel cells -- from the current life expectancy of 2 years to perhaps 10 or even up to 14 years IF and ONLY IF the fuel cell is used in the Hybrid Power Generation Configuration being worked on at the NETL Lab AND if the correct Advanced Power Controls are developed to balance and optimize the power capabilities of all of the Hybrid Power Generation components.

The Hybrid Power Generation methodology (natural gas turbine plus SOFC) at the NETL HyPer Lab makes dynamic use of the coupling of an electrochemical device with a heat engine, or more specifically, a virtual Solid Oxide Fuel Cell (SOFC) and a physical natural gas (NG) turbine. According to NETL findings, the synergies associated with coupling these systems in a hybrid configuration provide the potential "for reaching the highest possible electrical conversion efficiency ever realized." (source: U.S. Department of Energy or DoE) This capability could be "transformative" and meet the broadest goals set by the DoE for reliable and abundant electricity. Furthermore, DERP TECH and NETL have agreed that the Hybrid Power Generation configuration can be the optimum foundation for utility-scale DG power production, both for civilian and for military use because it also holds much promise for wide-spread microgrid power generation - to provide base-load power when the main power grid fails, to add spinning reserves and contribute to "black start" capabilities.

The advanced power controls for smart substation conversions (to enhance adaptive islanding capability) that can integrate hybrid generation (multiple-sources) of locally produced power at critical nodes can be possible with the device we call the **HEP/DG Power Continuity Unit (PCU).** (The HEP/DG is DERP TECH's brand and it stands for "Hybrid Electric Power/Distributed Generation.") The HEP/DG family of power controls, including the PCU and the "Power Protector," are designed with the intent of optimizing hybrid power generation for utility-scale distributed generation and creating microgrids during power failures.

2. Achieving Higher Efficiencies in Clean Energy Production for Wide-spread Distributed Generation embedded in the Local Distribution Network

The most apparent synergy of integrating a fuel cell and a gas turbine is the gain of total system efficiency. Using a turbine to recover electricity from the waste heat of the fuel cell system allows for such an increase through a combination of topping and bottoming cycle efficiencies; for hybrid systems, the fuel cell is generally used as the topping cycle with the turbine in a bottoming configuration. However, a hybrid system generally has efficiencies that are greater than the simple sum of its parts (up to 60% Higher Heating Value or HHV of coal).

The incorporation of exhaust gas recuperators can provide pre-heat for the fuel cell and still further improve the efficiency of the turbine cycle. In a similar fashion, the turbine cycle allows the fuel cell to be operated under pressure, improving fuel cell performance without a parasitic cost.

3. System Flexibility and Energy Security – Prerequisites for Resilient Microgrids and Protecting Critical Loads

There are specific design optimization strategies for hybrid power generation systems ("Hybrids") that enable the Hybrids to serve the microgrid and distributed generation markets exceptionally well. For example, there is the need to pre-heat the fuel cell cathode and the cooling flow can be facilitated by the integration of a recuperated turbine cycle which operates at low pressure ratios. Such "lenient" requirements eliminate the need for complex turbine technologies associated with high temperature operation and inter-stage compressor cooling.

A solid oxide fuel cell (SOFC) is capable of achieving excellent performance using Hydrogen (H2) and Carbon Monoxide (CO) as a fuel source, eliminating the requirement for complicated gasification technology and opening the possibility of fuel flexible systems capable of operating at very high efficiency.

4. Achieving Low-Cost Spinning Reserves

In Germany, where they have achieved a high level of renewable energy generation in the national grid, there have been notable problems with the imbalance of power generation as such a large percentage of electricity is produce by so-called "intermittent" sources, which in turn require more and more spinning reserves that – ironically – are typically fossil-fuel burning sources. The Hybrid Power DG model with the HEP/DG Advanced Power Controls can offset that "dirty fuel" spinning reserve requirement while reducing parasitic fuel consumption.

Since high system efficiency can be achieved even if the NG Turbine in the cycle does not produce electricity, there is the capability of maintaining a ***low-cost spinning power reserve*** and peaking demand. A spinning power reserve could also be maintained without parasitic drain on finite fuel supplies. That is one of the main objectives of the work on designing the HEP/DG Advanced Power Controls.

5. Recovery from a Full Load Reject – Meeting the Needs of a Utility-Scale Microgrid

Another major objective is to enable exceptionally low turn-down on the NG Turbine – with a demonstrated 69% turn-down having already be achieved in the lab. The hybrid generation system can recover in minutes – a great feat for a NG Turbine, and it can be on-line after a grid black-out has occurred in a very acceptable time parameter.

6. Adding Renewables to the Turbine/Fuel Cell Hybrid Generation Model

The optimum power generation mix for utility-scale DG power sources (from 500 KW to 500 megawatts) would be a "trifecta" comprised of turbine (natural gas, concentrated solar, CHP, etc.), a fuel cell and one or more sources of renewable power – any of which will have intermittency issues and challenges.

DERP TECH recognizes that many microgrid models in the New England states have had stringent requirements for long duration, due to Hurricane Sandy's experience, where power was lost to millions for weeks on end. A combination of reliable sources – both fossil and non-fossil – provides the longevity of reliable service that has been mandated in many states.

7. Observations concerning the Supervisory Controls under Review and Development

Hybrid power systems combine multiple power sources, as discussed, to serve a community and critical circuits. Typically, each of the sources is controlled by a local controller which responds to commands from a centralized supervisory controller. The Supervisory Controller must determine when to start and stop individual components, as well as how to operate those components once they have been turned on. The goal of the algorithms is to minimize fossil fuel consumption (in the mix) while ensuring that the load requirements are always met. Furthermore, the control software must not only operate the generation and storage components in a steady-state, but also know how to operate each component when the generation system is transitioning from one System Operating Mode to another.

8. Preventing Compressor Stall and Surge

Further research is being conducted into methodologies for protecting generation equipment from stalls and surges under a very dynamic range of operating parameters. This work has been the "mother of invention" for a companion technology – the HEP/DG Power Protector with "Blue Button" valve control. A separate product, there is a separate white paper covering this innovation.

Distribution Management paired with Generation Management – The HEP/DG PCU fuses the Two Critical Functions at the Point of Common Coupling (PCC)

The HEP/DG PCU enables the owner/operator of any distribution substation to infuse locally produced power with the capability of creating one or more microgrids within a community or installation (commercial, educational or municipal). The PCU controller is both an interconnection and power management system that is installed at or near to a Distribution Substation to merge the bulk grid with the local distribution network; the PCU interfaces with and provides interconnection with the local distribution grid.

A typical installation would be at the secondary bus of a distribution substation and would be at mid-voltage ranges; the PCU itself is voltage agnostic. Each feeder can become the Point of Common Coupling (PCC), where the local DG is infused into the bulk grid source. Each feeder, thereby, can either be shed or can be powered when there is a prolonged grid failure. A myriad of sensors provide the PCU with data required to optimize both the generation and the distribution of electricity.

The impact on the Grid is multi-faceted and far-reaching: adding to grid security, promoting more clean and efficient power production locally (while not disrupting the integrity of the centralized "legacy" grid) and enabling the utility industry more options to meet the future demands for electricity in the future. The business model combines and integrates the advanced power controls and the local source(s) of power generation. Further design provisions for the PCU are adding the capabilities for networking the sources of local hybrid power generation, enabling more benefits to the distribution utility, including bolstering Black Start capabilities.

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4. **"Energy Storage will Replace Many Peaker Spinning Reserve Plants"** Roy L. Hales, Clean Technica, November 6, 2014

5. **"Consolidated Utility Base Energy (CUBE) Model Report,"** NREL/TP 5B00-62768 December 2014

6. **Provisional Patent** #US 62/495,268 Filing date September 8, 2016 – Foreign Filing License Granted

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Selected for Showcase
May 2017
TechConnect
World Conference
National Harbor, MD
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TOPIC: SOLID OXIDE FUEL CELL & NATURAL GAS TURBINE HYBRID SYSTEMS: LOAD FOLLOWING CAPABILITY FOR MICROGRID APPLICATIONS

DESIGNING THE OPTIMUM HYBRID POWER SUPPLY MODEL FOR DISTRIBUTED GENERATION & THE FUTURE OF THE GRID

Released August 2017

Released under the Collaborative Research and Development Agreement (CRADA) between DERP Technologies and the National Energy Technology Lab (NETL) (the HyPer Lab facility in Morgantown, WV)

Background and Overview

DERP Technologies (DERP TECH) and NETL (a Laboratory operated by the U.S. Department of Energy) formally entered into a Collaborative Research and Development Agreement (CRADA) in January of 2017. The purpose of the CRADA is to develop and ultimately commercialize *advanced power controls (specifically the HEP/DG Power Continuity Unit™)* for utility-scale applications; the HEP/DG PCU will harness the power and responsiveness of the Hybrid Power Generation Systems (involving natural gas turbines, energy storage and renewable sources of power production).

The HEP/DG PCU power management system, coupled with the Hybrid Power Generation station, will enable both the wide-spread adoption of distributed generation (DG) in the local distribution network (mid-level voltages at the feeder level), while adding resilience and reliability for power-users through providing microgrid capacity for critical circuits/loads when there is a general grid failure (extended black-out).

This is the SECOND White Paper in a series of white papers/updates that pertain to the HEP/DG Power Continuity Unit (PCU) designed for the utility market.

A previous white paper – released in the late Spring of 2017 – gave an overview of the PCU's capabilities and applications; it focused on the "beneficial outcomes" of the Hybrid Power Generation configuration and the collaborative work being undertaken at the HyPer Lab in Morgantown, West Virginia on the advanced power controls. That initial white paper is available upon request.

Email DERP TECH at pcu@derptech.net

TOPIC: SOLID OXIDE FUEL CELL & NATURAL GAS TURBINE HYBRID SYSTEMS: LOAD FOLLOWING CAPABILITY FOR MICROGRID APPLICATIONS –

DESIGNING THE OPTIMUM HYBRID POWER SUPPLY MODEL FOR DISTRIBUTED GENERATION & THE FUTURE OF THE GRID

Situational Analysis:

Distribution generation (DG) and microgrids integrated into the nation's distribution grid are the future of the nation's power supply; at the heart of any distributed generation model is reliable and resilient locally produced electricity. Developing the optimum platform for DG power generation - a platform that is acceptable to the utilities and to regulators - is of paramount importance for commercialization and marketplace acceptance. To that end, DERP TECH and the HyPer Lab at NETL in Morgantown WV (through a CRADA relationship) are designing and testing models for Advanced Hybrid Power Systems that incorporate both fossil fuels (natural gas turbines) and non-fossil fuel sources (including PV solar). And central to their work is examining the gamechanging role that solid oxide fuel cells can play in the mix, in terms of a cleaner footprint and creating a far more responsive and reflexive local power supply, one that can react quickly to shifting loads and provide reliable power nearly instantaneously when there is a black-out or sustained grid power failure.

This analysis of load following capabilities was primarily prepared by

Marlene Llaugel, Rochester Institute of Technology,

under the mentorship and guidance of Dr. David Tucker, Principal Investigator

in the DERP TECH/NETL CRADA and manager of the HyPer Lab

at the National Energy Technology Lab (NETL)

Introduction

The utility industry is facing new operational challenges due to the rapid penetration of variable resources on the grid. To address these challenges, flexible energy systems with the capability to withstand net load ramping will need to be developed. The U.S. Department of Energy's National Energy Technology Laboratory (NETL) is currently exploring the load following capability of solid oxide fuel cell/gas turbine (SOFC/GT) hybrid systems to assess the technical feasibility of implementing the hybrid technology in distributed generation environments.

The purpose of this work is to characterize the load following capability of the SOFC/GT hybrid system during load transients through numerical analysis. To study the load transient responses of SOFC/GT hybrid systems, experimental tests were performed at NETL's Hybrid Performance Facility (HyPer) which has been described in a previous paper [1].

I. Background and Motivation

Hybrid power generation systems integrate several technologies to supply load demands. The SOFC/GT hybrid systems studied in this work consists mainly of a gas turbine hardware component and a cyber physical solid oxide fuel cell. While the gas turbine component is physically connected to the system, the cyber physical solid oxide fuel cell is driven by computational models and real input data from the hardware components. An air plenum and combustor emulate the dynamic responses of a real solid oxide fuel cell and feeds these inputs to a real gas turbine.

Previous research performed at the Hyper Performance Facility (HyPer) characterized the load following capabilities of SOFC/GT hybrid systems by feeding different fuel compositions to the SOFC [2]. However, load following of this hybrid system has not been characterized using variations in load on the different components. The fuel composition utilized in this work was a steam reformed methane composition consisting of 6 mol%CH_4, 5.40 mol%CO_2, 10.3 mol% CO, 52.7 mol%H_2, 25.6 mol%H_2O, 0 mol%N_2, and 0 mol%O_2. Ultimately, this study intends to broaden the understanding of the dynamic interdependencies of these two generation technologies and to describe the operational characteristics of SOFG/GT hybrid systems resulting from load fluctuations.

II. Technical approach

A flexibility analysis of the SOFC/GT hybrid system is conducted based on NETL's daily power load demand profile over a week period, shown in **Fig. 1**. The minimum and peak loads over the week period were 1,277 kW (June 1, 2017 at 4:45 a.m.) and 3,044 kW (June 14, 2017 at 1:30 p.m.), respectively.

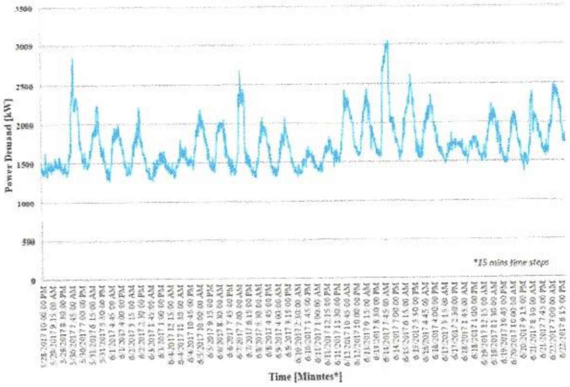

Fig. 1. *NETL load demand profile*

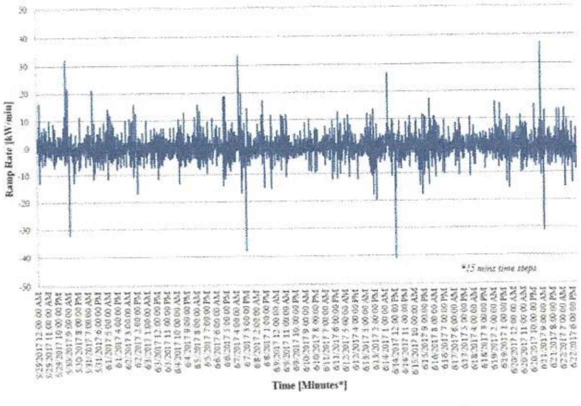

Fig.2. *NETL power demand ramp rate*

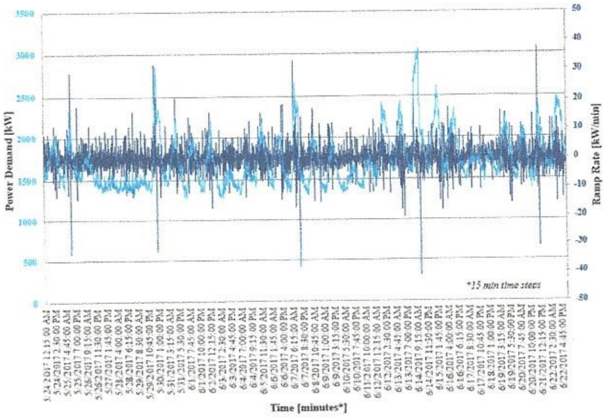

Fig.3. *NETL power demand and ramp rate curves*

The derivative of the power load demand curve represents the amount of power load change over a minute, also known as ramp rate. **Fig. 2** shows the ramp rate in kW/min for the NETL power demand curve. The highest ramp up and ramp down were 37.3 kW/min and 41.2 kW/min, respectively. **Fig. 3** shows both power load demand and ramp rate curves.

In this work, a SOFC/GT hybrid system is considered for a microgrid also consisted of a photovoltaics system and a battery. For this study, the microgrid is operated in island-mode. Because the microgrid would operate with both dispatchable and non-dispatchable generating sources, the effect of the non-dispatchable source (photovoltaics system), must be considered with respect to load fluctuations. The National Renewable Energy Laboratory's PVWatts data was used to determine the hourly solar energy profile at the selected location for the corresponding week. The net load fluctuations, originated by incorporating a photovoltaics system to the proposed microgrid is shown **in Fig. 4**. The minimum and peak net loads over the same week are 721.5 kW (May 29, 2017 at 12:15 p.m.) and 2,580.3 kW (June 14, 2017 at 7:00 a.m.), respectively.

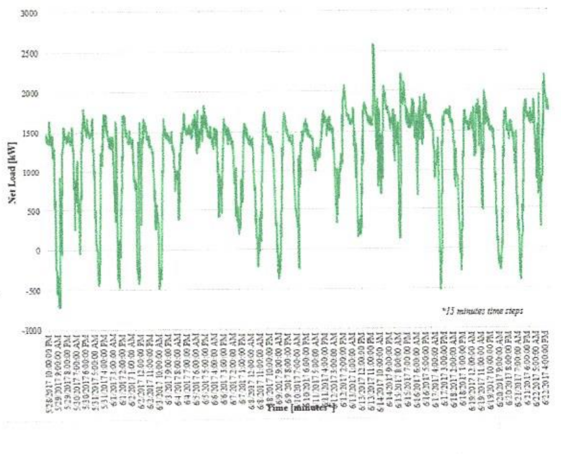

Fig. 4. *NETL net load profile*

The net load ramping for the proposed microgrid is presented in **Fig. 5**. The maximum ramp up and ramp down were 105.4 kW/min and 128 kW/min. The amount of ramping that would be required for the SOFC/GT hybrid system is significantly higher with the incorporation of the variable resource component. Thus, the net load ramping of the microgrid will be assumed in this work, as it represents a worst-case scenario that ensures the hybrid system can provide the amount of ramping associated with variable resources.

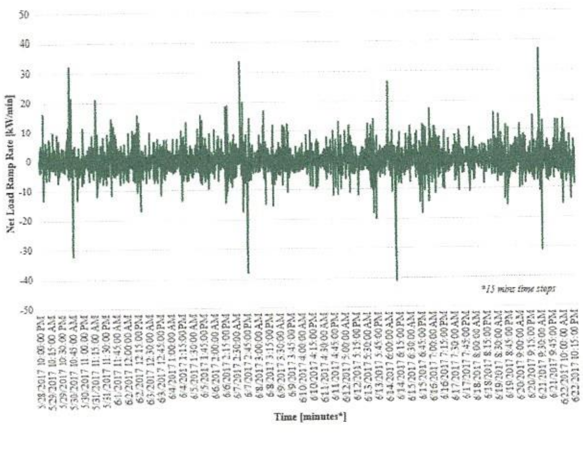

Fig. 5. *NETL net load ramping*

III. Methodology

To understand how each system component behaves under load stresses and the overall impact of load fluctuations in the individual components, two different tests were performed. In the first test, step changes in the SOFC load were performed. In this test, the gas turbine power load was held constant at 40 kW to determine the dynamic impacts of load changes in the SOFC. The SOFC load was varied from 200 Amps to 190 Amps and from 200 Amps to 210 Amps.

In a second test, the fuel cell load was held constant at 200 Amps and power load changes were executed in the gas turbine. Similarly, two step changes in the gas turbine load were completed. The gas turbine power load varied from 40 kW to 36 kW and from 40 kW to 44 kW. In these preliminary studies, the load step changes performed in the system components are for testing the dynamic response of the hybrid system, and do not necessarily represent the profile in NETL load fluctuations.

IV. Results

Fuel Cell Load Step Changes

The results for the fuel cell current load step changes in the SOFC/GT system are shown in **Fig. 6** and **Fig. 7**. At nominal conditions, the overall power generated by the system is around 368 kW. However, a 5% decrease in fuel cell load resulted in approximately 3.5% decrease in the overall hybrid system power. Similarly, the overall system power increased 3.5% with a 5% increase in the fuel cell load. As expected, the power of the fuel cell component, also known as stack power, changed by 5% with the changes in fuel cell current load.

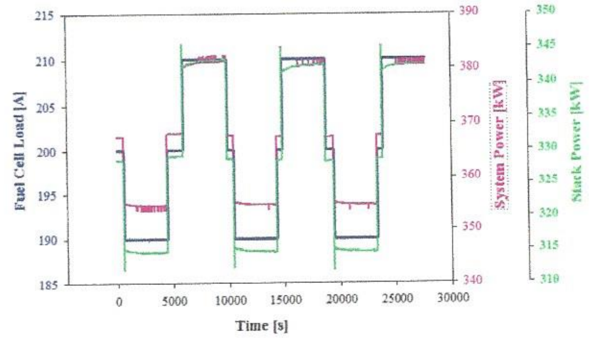

Fig. 6. *Step changes in fuel cell load vs. stack and system power*

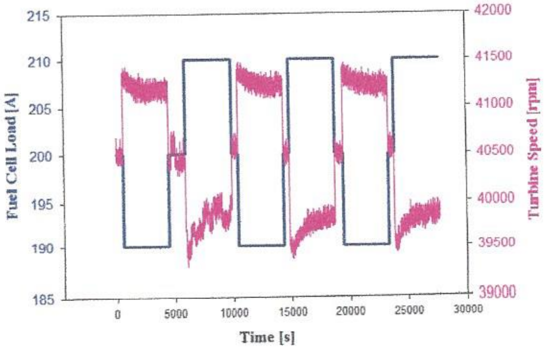

Fig. 7. *Step changes in fuel cell load vs. turbine speed*

On the other hand, the gas turbine speed showed an opposite response to the changes in the fuel cell load. A 5% increment in the fuel cell current load induced a 2% decrease on turbine speed. This is due to the increase in the SOFC fuel utilization that results in less unutilized fuel entering the post-combustor and thus less overall thermal effluent. The thermal effluent directly affects the position of the fuel valve which regulates the amount of thermal energy going into the turbine. As a result, a decrease in thermal effluent causes a decrease in the fuel valve opening and consequently, the turbine speed is reduced.

Gas Turbine Load Step Changes

The change on the overall system power, stack power and turbine speed during the turbine load step changes are illustrated in **Fig. 8** and **Fig. 9**.

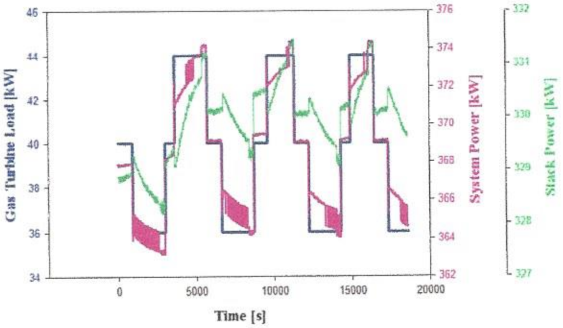

Fig. 8. *Step changes in turbine load vs. stack and system power*

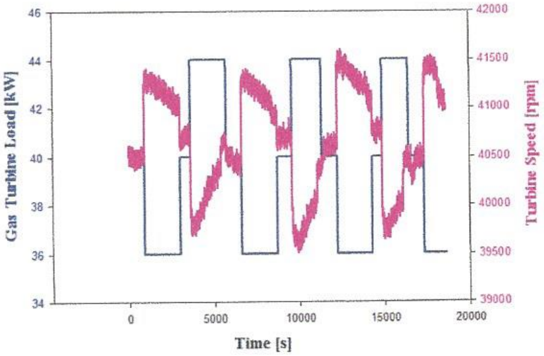

Fig. 9. *Step changes in turbine load vs. turbine speed*

A 10% change in turbine power load produced a 1% change on the opposite direction in the final overall system power output. The stack power profile exhibits a similar response as the overall system power. As seen in **Fig. 9**, the immediate response on turbine speed after the steps is a 2.7% change in the opposite direction. However, as time elapses after the step change, the thermal equilibrium is re-established and the turbine speed is recovered by 1%.

V. Conclusions

A preliminary study was performed on a SOFC/GT hybrid system to investigate the dynamic response characteristics of the system under load changes in the different components. In the current configuration, the HyPer facility demonstrated the capacity to handle 5% load changes in the fuel cell component and 10% changes in the gas turbine component. This study suggests that the hybrid system can increase and decrease the output power up to 15 kW. However, future work is needed to determine the impact of the load changes in fuel cell degradation, fuel utilization rate, fuel flow, and other parameters. Furthermore, research is needed to evaluate the system's capacity to generate higher or lower power output, similar to the ramp rates of typical load profiles.

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7450

Optimizing Microgrid Design and Performance through Cyber-Physical Design and Prototyping

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ABSTRACT

As the nation's electrical grid continues to age and external events (climate change, regulatory shifts, changing fuel and energy sources) make new and unprecedented demands on the infrastructure, resilience has become a key goal for the nation's utilities to achieve. This is becoming a national security issue. Distributed generation (DG) has become both an increasing problem and opportunity to utilities – the current "legacy" grid was built around centralized power plants and immense transmission capabilities; its strength and weakness lies in the fundamental architecture of centralized generation and delivery.

Black-outs and brown-outs (events affecting 50,000 or more consumers) in America have doubled in the period from 2005 to 2010. Immense storms, beginning with Hurricane Sandy, revealed the vulnerabilities of the Grid in the NorthEast (and now in Puerto Rico) and aggressive steps have been taken to examine the ways to decentralize and reconfigure the delivery systems – to "harden the grid." At the heart of these political initiatives was the promulgation of mandates and initiatives to produce community-scaled municipal *microgrids*, creating smaller power generation stations that can isolate themselves from the distribution system when there is a wide-spread electrical black-out/system failure.

The grid is moving towards a more decentralized architecture, yet there are compound problems associated with increasing amounts of renewable power sources being added to the old or "legacy" grid absent a more "standardized" means to "bridge the gap" between yesterday's legacy grid and tomorrow's smart grid.

The work being conducted with a cyber-physical model in a collaboration between DERP Technologies and the National Energy Technology Lab (NETL) "HyPer" Lab centers around a Hybrid Power Generation configuration as an optimal way of creating clean decentralized power generating sources, buttressing the legacy grid and making it more resilient and capable of islanding power to critical loads if and when there is a black-out.

Advanced power controls are the key to optimizing the responsiveness of the generation assets; additionally, making solid oxide fuel cells (SOFC) capable of both enhanced thermal storage and a much longer useful life is a demonstrated outcome of this research and collaboration.

DERP TECH of Hagerstown Maryland has been working to design a family of advanced power controls, branded as the "HEP/DG" family of products, to meet the needs of the utility industry as it faces a future where distributed generation is a key to resiliency. In order to examine the optimum control and fuel platform for the future, DERP TECH entered into a CRADA (Collaborative Research and Development Agreement) with the National Energy Technology Laboratory (NETL).

INTRODUCTION

Hybrid power generation systems integrate several technologies to supply load demands. The SOFC/GT hybrid systems studied in this work consists mainly of a gas turbine hardware component and a cyber physical solid oxide fuel cell. While the gas turbine component is physically connected to the system, the cyber physical solid oxide fuel cell is driven by computational models and real input data from the hardware components. An air plenum and combustor emulate the dynamic responses of a real solid oxide fuel cell and feeds these inputs to a real gas turbine (GT) located on-site at the HyPer Lab at NETL.

Earlier prior research by NETL had yielded strong evidence that -- with the right combination of advanced power controls, power equipment protective devices and other key attributes – a *hybrid configuration of power generation and energy storage* (utilizing natural gas turbines and solid oxide fuel cells at the hybrid system's core) could dramatically increase the active, useful life of fuel cells, *possibly by as much as 4 to 7 times – extending the active life from around 2 years to possibly up to 14 years.* This research, conducted at the HyPer Lab, under the direction of Dr. David Tucker, has the potential of making fuel cell technology far more financially viable for commercial utility-scale applications.
DERP TECH recognized the potential of this potential advance, seeing the need for improved storage and the clean-energy opportunities that the NETL model for hybrid power represented for utility-scale microgrid applications.

Further concurrent research at the NETL HyPer Lab has made it possible to turn-down the natural gas turbine in a hybrid generating plant as much as 90%, thereby making it possible to ramp up production to full capacity at speeds that rival diesel engines, making the natural gas turbines uniquely capable of providing a relatively low-cost spinning reserve in a decentralized distribution power network.

Finally, the collaborative work between DERP TECH and NETL has led to one more key area of research: determining the capacity of SOFC/GT combinations to perform the key function of LOAD FOLLOWING as a small-scale, community-based power plant – providing an "embedded" microgrid application capability that would be highly desirous to the utility industry and private industry.

NOMENCLATURE & BACKGROUND -- CAPABILITIES OF THE HyPer LAB

Terms used in this paper

SOFC/GT = Solid Oxide Fuel Cells /Gas Turbines
HyPer Lab = Hybrid Performance Lab
Load Following (Power Plant) =
A power generating facility (or microgrid) that adjusts its output according to the demand for electricity in real time; this mode of operation is in stark contrast to a typical base-load power plant, which is either "on" or "off."
Microgrid or "embedded" microgrid = a power generating facility that produces and stores electricity close to the end user or load; such a microgrid often operates in parallel with the larger distribution grid under normal conditions, but then performs routines to isolate its power production from the larger grid during grid black-outs – a function that is called "adaptive islanding."

HEP/DG = Hybrid Electric Power / Distributed Generation (a trade name of DERP TECH of Hagerstown, MD)
PCU = Power Continuity Unit (advanced power controller and interconnection device)
Ramp Rate = the amount of power load change over one minute

THE HYBRID PERFORMANCE (HyPer) LAB in Morgantown West Virginia is a unique experimental facility that simulates developing technology, such as fuel cell and thermal energy storage, utilizing a combination of hardware and software. The hardware used for simulating the developing technology (pressure vessels, piping and a burner) is coupled to heat exchangers and a physical gas turbine (GT) in order to evaluate the dynamics of a fully integrated hybrid power system.

The HyPer Lab was designed to isolate and independently instrument/monitor each component of the system and is capable of simulations for systems up to 1 megawatt. Recently, a variable load bank was added to the facility to control turbine speed independently from the fuel input – this allows researchers to conduct a wider range of transient simulations and to impose a load profile on the gas turbine in the system. The addition of a dSpace simulator has expanded the lab's simulation capabilities to include spatial resolution of fuel cell and gasifier components in real time.

MICROGRID ADVANCED POWER CONTROLS AND INNOVATION IN DESIGN USING CYBER-PHYSICAL SYSTEMS IN THE NETL HYPER LAB

Previous research performed at the Hyper Performance Facility (HyPer) characterized the load following capabilities of SOFC/GT hybrid systems by feeding different fuel compositions to the SOFC [2]. However, load following of this hybrid system has not been characterized using variations in load on the different components. The fuel composition utilized in this work was a steam reformed methane composition consisting of 6 mol%CH_4, 5.40 mol%CO_2, 10.3 mol% CO, 52.7 mol%H_2, 25.6 mol%H_2O, 0 mol%N_2, and 0 mol%O_2. Ultimately, this study intends to broaden the understanding of the dynamic interdependencies of these two generation technologies and to describe the operational characteristics of SOFG/GT hybrid systems resulting from load fluctuations.

Technical approach

A flexibility analysis of the SOFC/GT hybrid system is conducted based on NETL's daily power load demand profile over a week period, shown in **Fig. 1**. The minimum and peak loads over the week period were 1,277 kW (June 1, 2017 at 4:45 a.m.) and 3,044 kW (June 14, 2017 at 1:30 p.m.), respectively.

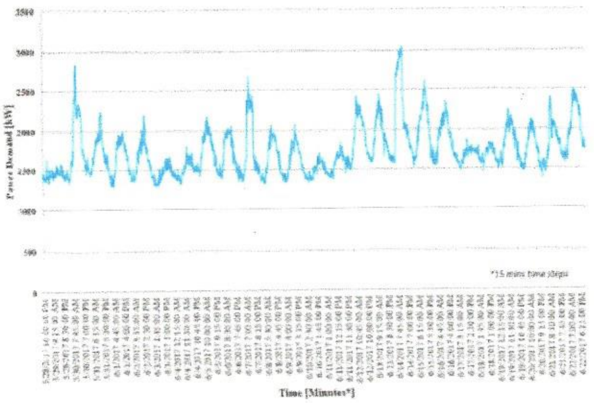

Fig. 1. *NETL load demand profile*

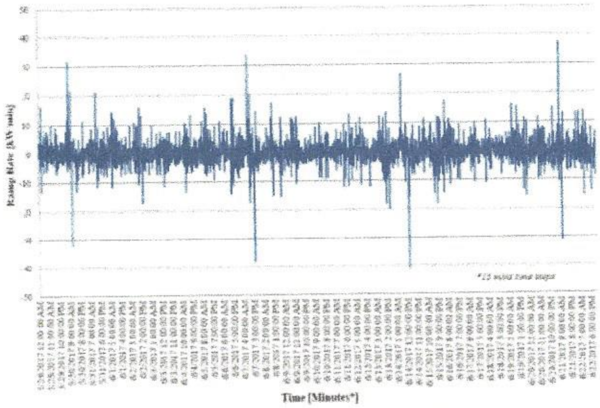

Fig.2. *NETL power demand ramp rate*

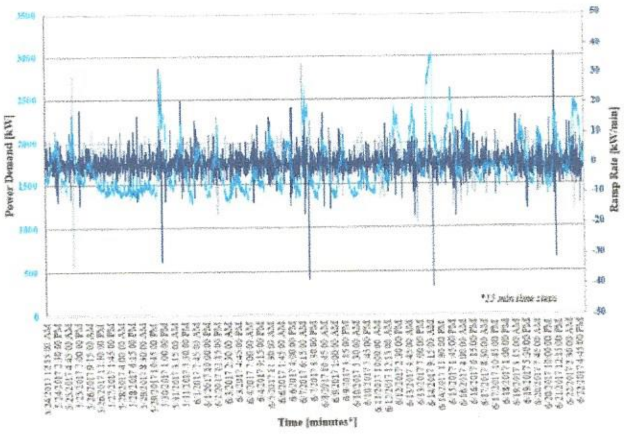

Fig.3. *NETL power demand and ramp rate curves*

The derivative of the power load demand curve represents the amount of power load change over a minute, also known as ramp rate. **Fig. 2** shows the ramp rate in kW/min for the NETL power demand curve. The highest ramp up and ramp down were 37.3 kW/min and 41.2 kW/min, respectively. **Fig. 3** shows both power load demand and ramp rate curves.

In this work, a SOFC/GT hybrid system is considered for a microgrid also consisted of a photovoltaics system and a battery. For this study, the microgrid is operated in island-mode. Because the microgrid would operate with both dispatchable and non-dispatchable generating sources, the effect of the non-dispatchable source (photovoltaics system), must be considered with respect to load fluctuations. The National Renewable Energy Lab's (NERL's) PV Watts data was used ti determine the solar energy profile at the selected location for the corresponding week. The net load fluctuations, originated by incorporating a photovoltaics system to the proposed microgrid is shown in **Fig. 4**. The minimum and peak net loads over the same week are 721.5 kW (May 29, 2017 at 12:15 p.m.) and 2,580.3 kW (June 14, 2017 at 7:00 a.m.), respectively.

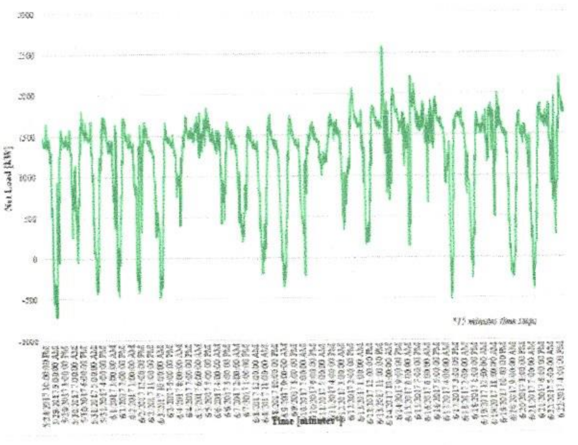

Fig. 4. *NETL net load profile*

The net load ramping for the proposed microgrid is presented in **Fig. 5**. The maximum ramp up and ramp down were 105.4 kW/min and 128 kW/min. The amount of ramping that would be required for the SOFC/GT hybrid system is significantly higher with the incorporation of the variable resource component. Thus, the net load ramping of the microgrid will be assumed in this work, as it represents a worst-case scenario that ensures the hybrid system can provide the amount of ramping associated with variable resources.

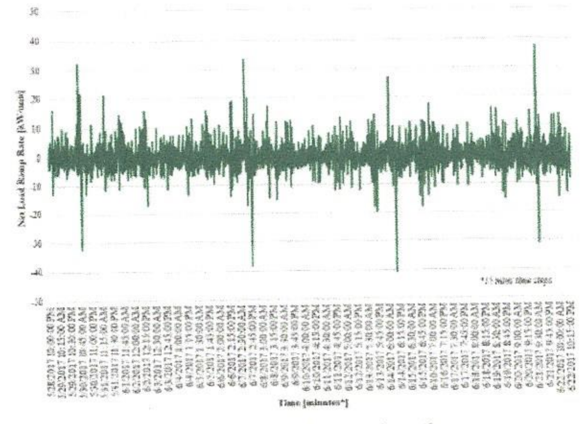

Fig. 5. *NETL net load ramping*

Methodology

To understand how each system component behaves under load stresses and the overall impact of load fluctuations in the individual components, two different tests were performed. In the first test, step changes in the SOFC load were performed. In this test, the gas turbine power load was held constant at 40 kW to determine the dynamic impacts of load changes in the SOFC. The SOFC load was varied from 200 Amps to 190 Amps and from 200 Amps to 210 Amps.

In a second test, the fuel cell load was held constant at 200 Amps and power load changes were executed in the gas turbine. Similarly, two step changes in the gas turbine load were completed. The gas turbine power load varied from 40 kW to 36 kW and from 40 kW to 44 kW. In these preliminary studies, the load step changes performed in the system components are for testing the dynamic response of the hybrid system, and do not necessarily represent the profile in NETL load fluctuations.

Results

Fuel Cell Load Step Changes

The results for the fuel cell current load step changes in the SOFC/GT system are shown in **Fig. 6** and **Fig. 7**. At nominal conditions, the overall power generated by the system is around 368 kW. However, a 5% decrease in fuel cell load resulted in approximately 3.5% decrease in the overall hybrid system power. Similarly, the overall system power increased 3.5% with a 5% increase in the fuel cell load. As expected, the power of the fuel cell component, also known as stack power, changed by 5% with the changes in fuel cell current load.

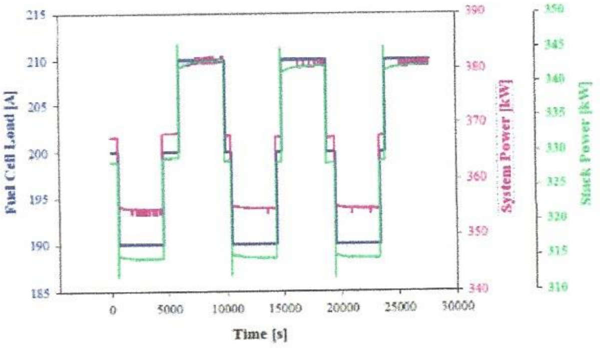

Fig. 6. *Step changes in fuel cell load vs. stack and system power*

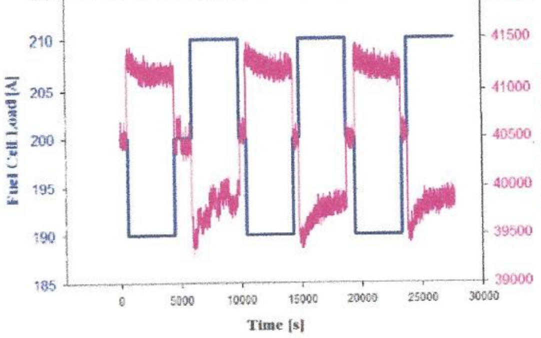

Fig. 7. *Step changes in fuel cell load vs. turbine speed*

On the other hand, the gas turbine speed showed an opposite response to the changes in the fuel cell load. A 5% increment in the fuel cell current load induced a 2% decrease on turbine speed. This is due to the increase in the SOFC fuel utilization that results in less unutilized fuel entering the post-combustor and thus less overall thermal effluent. The thermal effluent directly affects the position of the fuel valve which regulates the amount of thermal energy going into the turbine. As a result, a decrease in thermal effluent causes a decrease in the fuel valve opening and consequently, the turbine speed is reduced.

Gas Turbine Load Step Changes

The change on the overall system power, stack power and turbine speed during the turbine load step changes are illustrated in **Fig. 8** and **Fig. 9**.

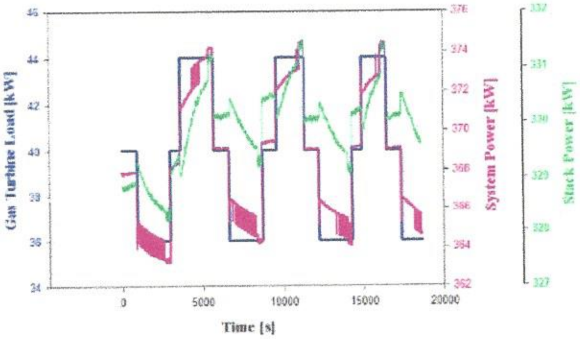

Fig. 8. *Step changes in turbine load vs. stack and system power*

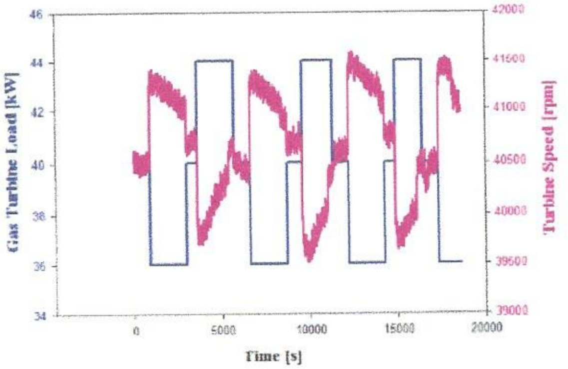

Fig. 9. *Step changes in turbine load vs. turbine speed*

A 10% change in turbine power load produced a 1% change on the opposite direction in the final overall system power output. The stack power profile exhibits a similar response as the overall system power. As seen in **Fig. 9**, the immediate response on turbine speed after the steps is a 2.7% change in the opposite direction. However, as time elapses after the step change, the thermal equilibrium is re-established and the turbine speed is recovered by 1%.

Load-Following Conclusions

A preliminary study was performed on a SOFC/GT hybrid system to investigate the dynamic response characteristics of the system under load changes in the different components. In the current configuration, the HyPer facility demonstrated the capacity to handle 5% load changes in the fuel cell component and 10% changes in the gas turbine component. This study suggests that the hybrid system can increase and decrease the output power up to 15 kW. However, future work is needed to determine the impact of the load changes in fuel cell degradation, fuel utilization rate, fuel flow, and other parameters. Furthermore, research is needed to evaluate the system's capacity to generate higher or lower power output, similar to the ramp rates of typical load profile

HEP-DG Power Protector: A Sub-System to Protect the Generation Assets in a Hybrid Power Plant from Transient Swings

During the hybrid power production operation, various indications of an up-power transient beyond the limitations where the hybrid cycle can transition to a new steady-state may occur, which can lead to system failure. When such an indication is received (by the operator through audible cues) or directly by the Power Protector through audio sensors and processors, through the "Blue Button" circuitry some portion of the oxidant gas is diverted from the compressor outlet to the turbine inlet, until the hybrid system achieves a condition from which sustainable, steady-state operation may be achieved through the mechanically controlled intervention.

The HEP/DG Power Protector controls compressed surge events by providing an oxidant gas to the compressor and withdrawing pressurized oxidant gas to the thermal component in the turbine cycle. In a fuel cell hybrid, for example, the pressurized oxidant gas is delivered to the fuel cell cathode and fuel is delivered to the fuel cell anode, and the cathode and anode exhaust is routed to the post combustor. The thermal exhaust from the coupled system is ported to the gas turbine, which is mechanically coupled to the compressor through a common shaft. (see Figure 10)

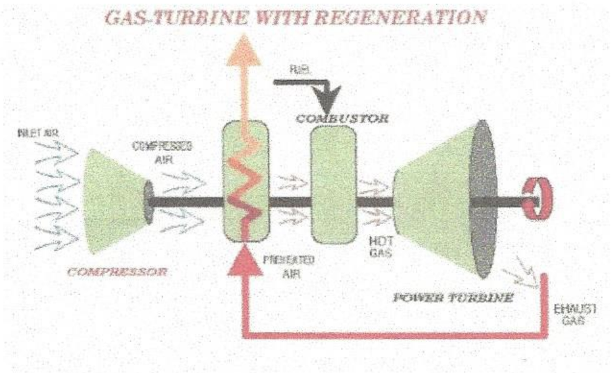

Fig. 10 *Single-shaft alignment*

This Power Protector system maintains the mass flow balance by changing the compressor dynamics and thereby increasing the safety margin of the turbomachinery and it decreases the likelihood of stalls in the hybrid power generation plant. It would work in hybrid systems with and without fuel cell integration.

1. Detecting and Preventing Severe Up-Power Transients

Integrating fuel-cells with gas turbines and other components for transient operations increases the risk for equipment exposure to rapid and significant changes in process dynamics and performance that are primarily associated with fuel cell thermal management and compressor surge. Without rick management through advanced power controls, this situation can lead to severe fuel cell failure, shaft overspeed, and gas turbine damage. Sufficient dynamic control architectures need to be made to mitigate undesirable outcomes and that is why the "Blue Button" valve control has been introduced.

The indication of the up-power transient which provides the trigger point for the "Blue Button" compressor flue controls are likely to be: (1) an observed ramp-rate, (2) an automated or manual observation of a compressor surge, (3) a decrease in turbine speed, which drops below an expected value during normal operation, (4) operation outside of a stable envelope (as defined by a dynamic controller), and/or (5) other indicators as yet to be determined.

2. HEP/DG Power Protection with "Blue Button" Manual Control Components – A Working Prototype

Fig. 11 *The Control Panel*

The basic control panel, including the above-referenced "Blue Button" manual control (located in the upper-right hand corner), is shown in Figure 11. (Shown is a working prototype.) The basic control panel is designed for manual operation and requires a human operator to be present and to be responsive to indicators of turbine/compressor imbalance as indicated in the above paragraph.

In the "advanced model," various ancillary components would be added to the Power Protection system; these addition components would include acoustic sensors and a high data acquisition system that would in effect automate the "blue button" function and reduce the need for oversight by a human operator on-site.

Other ancillary components for the installation include adaptations to the valve and by-pass line that would be inserted in the turbine cycle, along with a wiring harness that would connect the control panel (figure 11) with the valve (or flue) controls.

In Figure 12, the dynamic of the compressor (represented by the "pressure ratio" represented in the "Y" axis (compressor inlet and outlet pressure) follow a certain path that goes far away from the red "danger" line (the oblique line on the left).

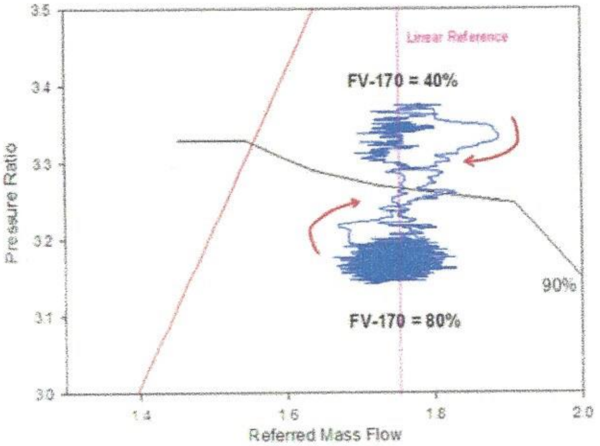

Fig. 12

When the Power Protector's "Blue Button" (valve controller) is activated, the mass flow through the compressor, which is generally kept constant, goes from 40% to 80% – this allows the safety margin to be increased while the flow balance through the compressor does not change.

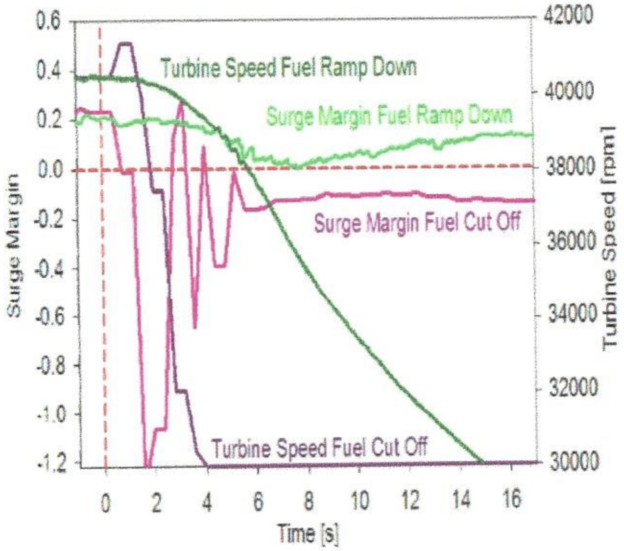

Fig. 13

A test from the lab shows the EMERGENCY SHUTDOWN of the generation system with and without the actuation of the "Blue Button" (Valve Controller).

Figures 12 and 13 illustrate the successful operational results of the HEP/DG Power Protector while being tested in a lab environment.

The collaboration between DERP TECH and the HyPer Lab will continue to optimize the means by which both Distributed Generation and Microgrids can become integral and standardized components in the nation's emerging Smart Grid. Further research is anticipated by DERP TECH in the arena of SCADA communications and interfaces with the distribution substation architecture.

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GRID
MODERNIZATION
LABORATORY
CONSORTIUM
U.S. Department of Energy

Smart Microgrids with Hybrid Assets and Storage for Grid Resiliency

Topic 2 Energy Storage and System Flexibility

Subtopic 2: Network Microgrids

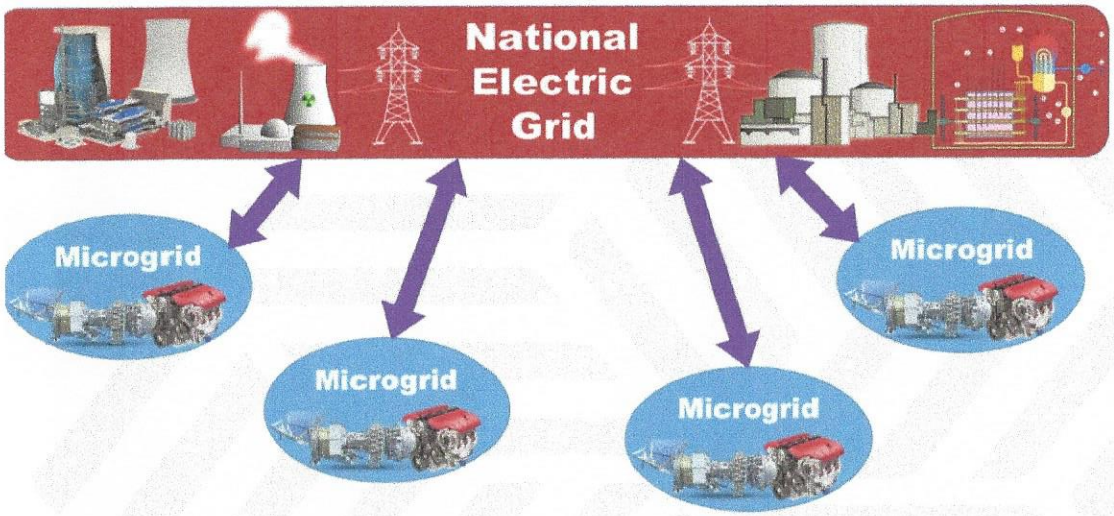
DOE 2019 Grid Modernization Lab Call

Dr. David Tucker

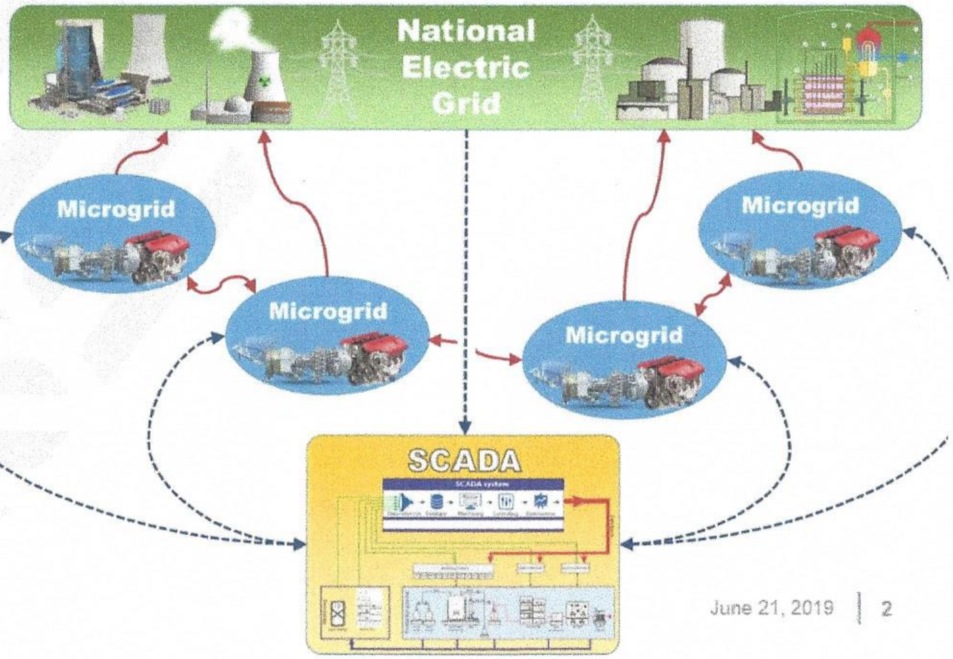
National Energy Technology Laboratory

June 21, 2019

Objectives

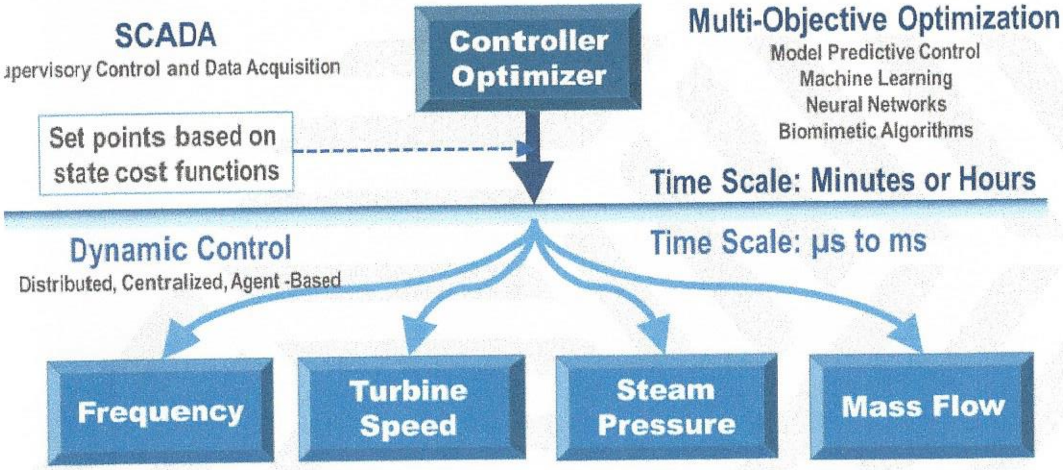


- **Overview and Problem Statement**
  - ✓ Balance supply and demand over multiple tim
    scales using energy storage and controls to improve system flexibility, resilience, and security of the bulk power system.



- **Objectives of Project**
  - ✓ Demonstration of self-assembling microgrids for resilient power in support of grid stability and accelerated restart through smaller scale self-assembling nanogrids (<100kW).
  - ✓ Assessment of chemical, thermal, and electric storage to improve flexible operability of the microgrid network

Innovation and Impact



SCADA

upervisory Control and Data Acquisition

Set points based on state cost functions

Controller Optimizer

Multi-Objective Optimization

Model Predictive Control
Machine Learning
Neural Networks
Biomimetic Algorithms

Time Scale: Minutes or Hours

Dynamic Control

Distributed, Centralized, Agent -Based

Time Scale: µs to ms

Frequency

Turbine Speed

Steam Pressure

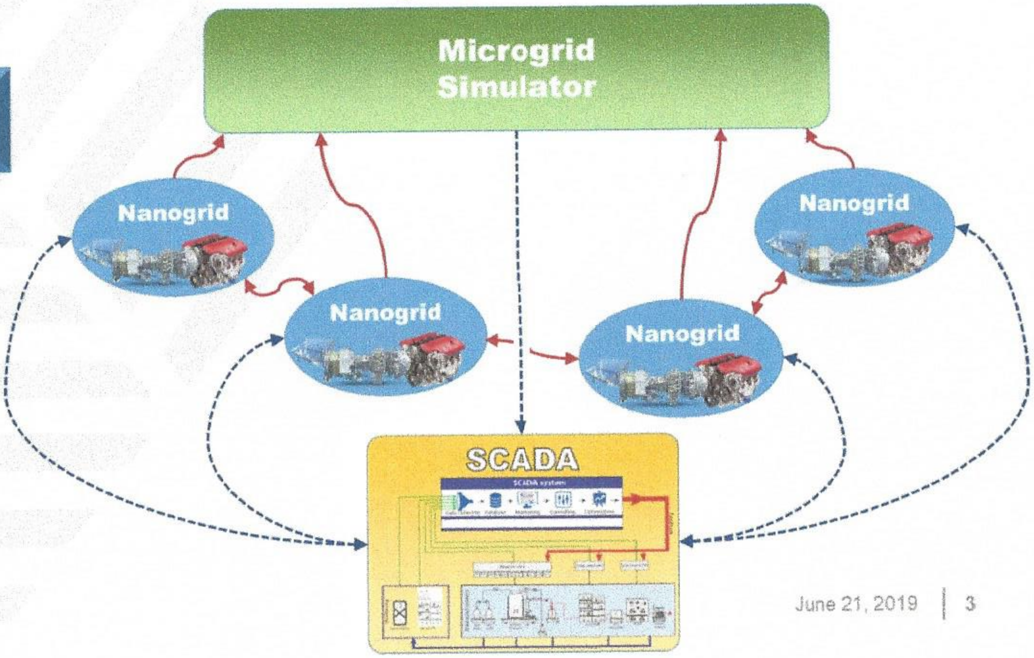
Mass Flow

Impact

- ✓ Development of a smart microgrid composed of four highly coupled nanogrids with electric, chemical, and thermal storage as well as renewable generation assets capable of supporting load management through grid instabilities and blackouts or failures will directly support Energy Storage and System Flexibility applied to the grid.

Innovation

- ✓ Supervisory and dynamic controls will be developed to form a single smart microgrid that will be applied more broadly to a system of microgrids supporting the regional power distribution grid.



Technical Approach

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Control Architecture and Asset Development-

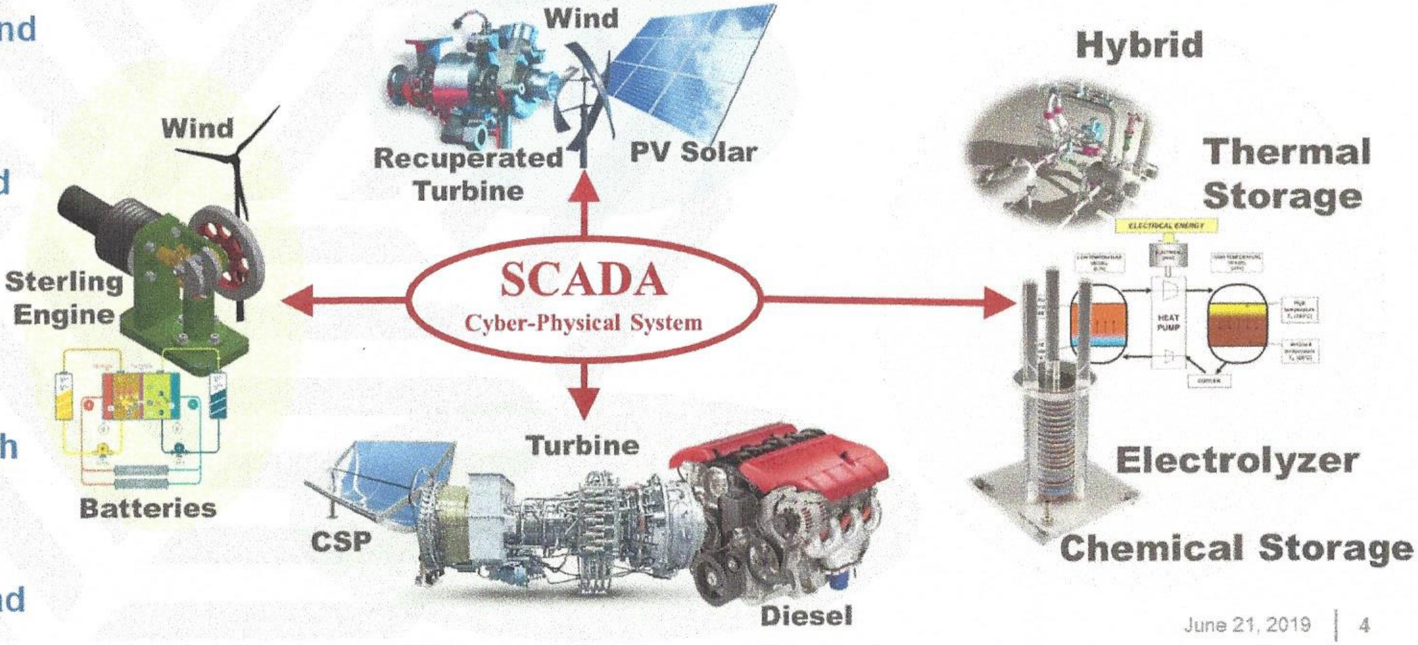
- Each nanogrid will be developed with renewable assets or storage so that the impact of intermittency and storage can be evaluated on system operability during load transients.
- Establish real-time links for bulk grid assessment and develop cyber-physical assets for future technology impact.
- Develop transfer functions for empirical models of NREL electrolyzer for dynamic control and supervisory control.

Installation/Coupling of Nanogrids and Cyber-Physical Systems

- The nanogrid assets and cyber-physical systems will be installed and coupled by the end of the second year.

Demonstration of Supervisory and Dynamic Control

- The SCADA will be optimized with weighting for intelligent performance.
- Testing and demonstration of load ramp for grid stabilization.



Team and Resources

Laboratories

- National Energy Technology Laboratory
- Ames Laboratory
- National Renewable Energy Laboratory
- Sandia National Laboraories

Partners

- DERP Tech, LLC.
- Georgia Institute of Technology
- (Under discussion)
  - Pepco
  - Baltimore Gas and Electric
  - Entergy

Proposed Budget Range: $4 to 6 million

Connection to 2019 Grid Mod Lab Call principles, GMLC MYPP and GMLC Projects

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- **Primary: Topic 2, Subtopic 2 Network Microgrids**
- **The proposed work would support the other subtopics under Topic 2**
  - Subtopic 1- Dynamic controls would enable flexible operation.
  - Subtopic 3- Load ramp capability would support black starts.
  - Subtopic 4- Dynamic real-time controls will enable optimal performance over a large range of states.
- **The proposed work would support the other subtopics under Topic 6**
  - Subtopic 2- Novel micro-scale generation technologies can be tested using cyber-physical system and performance evaluated.
  - Subtopic 5- Load ramp capability would support event recovery.
  - Subtopic 6- Interdependencies of a variety of generation assets will be evaluated as a matter of course in controls development.

Concept Maturity and Risk

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- Remaining concept development needs between now and final August presentation that reflect challenges or areas of risk-
  - Agreements with the partner utility will need to be established.
  - Leverage of NETL CRADA with the University of Genoa and availability of their microgrid for the project will need to be finalized.
- Identify questions for DOE regarding issues facing the project or alternatives considered

Smart Microgrids with Hybrid Assets and Storage for Grid Resiliency

High Level Summary

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Project Description

- ✓ The project will build and demonstrate a smart microgrid with hybrid assets and storage for load following and surplus load for stabilizing the grid during events and component failure.
- ✓ The smart microgrid will be composed of nanogrids capable of supporting each other during component failure to minimize grid instabilities.

Value Proposition

- ✓ Balance supply and demand over multiple time scales using energy storage and controls to improve system flexibility, resilience, and security of the bulk power system.
- ✓ Supervisory and dynamic controls will be developed to form a single smart microgrid that will be applied more broadly to a system of microgrids supporting the regional power distribution grid.
- ✓ Development of a smart microgrid composed of four highly coupled nanogrids with electric, chemical, and thermal storage as well as renewable generation assets capable of supporting load management through grid instabilities and blackouts or failures will directly support Energy Storage and System Flexibility applied to the grid.

Team Partners

- ✓ Dr. David Tucker, NETL
- ✓ Ames Laboratory
- ✓ National Renewable Energy Laboratory
- ✓ DERP Tech, LLC.
- ✓ Georgia Tech
- ✓ (Under Discussion)
  - ✓ Pepco
  - ✓ Baltimore Gas and Electric
  - ✓ Entergy

Project Objectives

- ✓ The project will focus on the demonstration of self-assembling microgrids for resilient power in support of grid stability and accelerated restart through smaller scale self-assembling nanogrids (<100kW).
- ✓ Assessment of chemical, thermal, and electric storage to improve flexible operability of the microgrid network wil also be accomplished.

Insert Technical Team Area