**Title: Variable speed operation in hydroelectric**

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| **Project No.** | | **Project Status** | ACTIVE |
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**Program Code** 8.6 **Program Name** Rural & Community Development

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**Non-Technical Summary**

Hydropower is now increasingly operated outside of original design conditions due to changing water availability and environmental induced operating parameters. Fifty percent of operational hydroelectric dams in the United States are 50 years or older and nearly all were designed to operate steadily as a primary base load resource. Compounding these issues is the increasing prevalence of intermittent power producers such as wind and solar. Because hydropower has a relatively stable supply of "fuel", it can more easily ramp up or down power production quickly as intermittent producers add to or disappear from the power grid. Increasingly, hydropower generators are forced to cycle on and off to accommodate power grid congestion and this cycling results in excessive wear and tear to hydropower mechanical and electrical components.

Standard turbines and generators were designed to operate steadily as baseload suppliers with a narrow range of design operations (water head, flow rate, and turbine speed). Operating outside of these parameters in a traditional generator setup results in poor quality power (voltage and frequency). Therefore, traditional generators must halt power production when design operating conditions do not exist. Modern power electronics will alleviate these problems by providing an electronic, non-mechanical mechanism to match power production to various water head and flow conditions. This project will quantify the range of scalable power achievable across varying flow conditions made possible with power electronics and new generation permanent magnet generators.

By modulating head and flow at a typical hydropower site, this project will test and demonstrate that power electronics can internally maintain quality power production even under variable flow and head conditions. This would likely decrease additional

wear and tear to hydropower drivetrain equipment while adding the ability to maintain power export when a typical generator would be forced offline. Once demonstrated and refined, the processes collected from this research will be deployable to sixty percent of all hydropower sites in the United States allowing greater distributed power generation. Adding the ability to operate under variable conditions will also allow hydroelectric sites to meet environmental and ecological demands while sharing the power grid other power producers.

**Goals / Objectives**

The goals of this project are to evaluate whether modern power electronics will allow hydropower generation under suboptimal conditions such as decreased head and/or flow. A typical hydroelectric generator's voltage and frequency require tight control with relatively narrow operating parameters; and are extremely dependent on rotational speed to maintain synchronization of generator output voltage and frequency to the electric grid. Power electronics such as four quadrant power inverters, also known as variable frequency drives (VFD), maintain grid "synchronization" within the inverter circuitry by converting variable generator voltage and frequency to steady grid quality power. Because power electronics allow variable speed operation (VSO), the project will test the ability to produce and export power using different inverter control mechanisms when: 1) Water flow is reduced through the turbine. This will be accomplished by using variable speed and torque control functions of the inverter. 2) Reducing water elevation (head) to determine what range of head the inverter will allow. All testing will evaluate the VFD ability to internally accommodate variable flow and pressure while still maintaining power export.

**Methods**

This project will compare methods to produce power using variable water flow and head conditions. The efforts will be to demonstrate range of operation and range of head. The project will evaluate the control of variable speed operation.

Demonstrate range of operation: At optimal head, maximum generator output will be measured as flow is reduced through the turbine until grid export ceases. The $kW_{Final}$ to the $kW_{Initial}$, ratio will be the power export range calculated as a percentage. For example, at the test site this may demonstrate scalable reduction in power production from 100kW down to 50kW at which time grid export ceases. In this example, the project would demonstrate a 50% range in power production with reduced flow but continued, useful power production.

Demonstrate range of head: Repeat range of operation test routine but now at decreasing head increments and without adjusting turbine components such as the wicket gates, until power export ceases. This will demonstrate scalability and potential for continued operation in changing hydrologic conditions that drop reservoir levels such as droughts and low rainfall periods.

Evaluate "electronic" control: While maintaining the wicket gate position at maximum flow, use inverter torque control to slow the generator. Recording the power output values at maximum output until power export ceases will then give a range of operation that can be achieved using only electronic control without wear and tear on mechanical drivetrain parts. This test is very important because hydropower is increasingly being dispatched on and off to accommodate other generation sources such as solar and wind power. Rapid cycling of controls like this was never intentioned during the design of typical hydropower mechanical components and damage to equipment is increasingly a problem.

A successful experiment will reveal consistent and reproducible data that determines if our process is feasible, how well it functions, and what power/operating ranges to expect with variable power production under suboptimal head and flow conditions.

**Target Audience**

Due to the short duration of a Phase 1 performance period, the target audience reached is limited but includes our research group, contractors, and student interns. Ultimately the target audience will include market segment such as the greater hydropower community, federal agencies, and the interested public vis a vis publications, conference presentations, news releases, and tours. The project will particularly impact audiences such as rural and small hydropower producers as well as those interested in producing power at non-powered dams and other water flow structures like irrigation conduits, water suppliers, and other non-traditional hydroelectric facilities where untapped power can be produced.

**Products**

The primary product/output planned for this project is data gathered by conducting experiments to determine the range of operation power electronics will allow when tested at a typical low head hydropower site. This project will provide preliminary data suggesting ways forward to optimize variable speed power production under suboptimal head/flow conditions. The data will elucidate methods or techniques that can be used to better operate hydropower sites when site hydrology conditions change

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from normal, when other water flow parameters must be maintained that prevent full flow or require specific partial flow, and possible ways to minimize wear and tear on mechanical parts in the drivetrain. These methods and techniques will likely include inverter programming and integration with site sensors.

Ancillary products also include education of student interns and demonstration of our variable speed process to other interested parties such as DoE, NSF, other hydropower operators, and others who have already expressed an interest in our results. Manuscript development of our research will also begin during the project but due to the short duration of Phase 1, will be extended into Phase 2.

**Expected Outcomes**

The outcomes expected from this project include a change in knowledge:
Determination of range of operation that power electronics will allow in suboptimal head and flow conditions. Specifically, this project will produce estimation of the ranges of head that a typical propeller turbine will operate and still produce power. As a corollary to head range of operation, power production ranges will also be determined.

Identification and refinement of techniques and hurdles to safely obtain maximal power production using internal functions and programming of power electronics without using specialized electrical components, mechanical gear boxes or speed increasers, or unnecessary manipulation of mechanical controls. Power modulation will be accomplished using software and setting changes inside the power electronics control computer.

Identification of adverse effects of variable speed operation such as harmonics, vibration, or yet to be determined operational constraints that power electronics either create or allow to occur during suboptimal head and flow conditions.

Identification of hazards and limits that power electronics may introduce into the system.

**Keywords**

VSO ~grid stability ~hydropower ~renewable energy ~small hydroelectric ~variable speed operation

**Estimated Project FTEs For The Project Duration**

| Role | Non-Students or Faculty | Students with Staffing Roles | | | Computed Total by Role |
|---|---|---|---|---|---|
| | | Undergraduate | Graduate | Post-Doctorate | |
| Scientist | 0.33 | 0.0 | 0.0 | 0.0 | 0.3 |
| Professional | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Technical | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 |
| Administrative | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Other | 0.2 | 0.0 | 0.0 | 0.0 | 0.2 |
| Computed Total | 0.7 | 0.0 | 0.0 | 0.0 | 0.7 |

**Animal Health Component** 0 %

**Activities**

| | |
|---|---|
| **Research** | 90 % |
| **Extension** | 0 % |
| **Education** | 10 % |

**Research Effort Categories**

| | |
|---|---|
| **Basic** | 50 % |
| **Applied** | 50 % |
| **Developmental** | 0 % |

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**Classification**

| Knowledge Area (KA) | Subject of Investigation (SOI) | Field of Science (FOS) | Percent |
|---|---|---|---|
| 402 | 210 | 2050 | 100 |

**Knowledge Area**

402 - Engineering Systems and Equipment

**Subject Of Investigation**

0210 - Water resources

**Field Of Science**

2050 - Hydrology