Technical Assistance Request

The overall goal of this research is functional testing of the Phase-EQ, a power electronics device designed to help utilities mitigate operational challenges caused by single-phase solar generation connected to the electrical grid. The device is intended for deployment on primary distribution systems, and was engineered for the most common voltage and configuration found in the U.S., 15kV wye grounded. The table to the right includes additional specifications for the Phase-EQ. This non-destructive testing will provide a critical opportunity to operate the Phase-EQ using a real, utility-grade power system to verify baseline performance, safe operation, and thermal stability of the equipment. NREL's National Wind Technology Center (Flatirons Campus) is one of only a few facilities in the U.S. with the infrastructure and expertise to provide this type of testing.

POWER ELECTRONICS RATINGS		
Model Number	EQ-15k066	EQ-15k133
Current Rating	66 A	133 A
Interconnection Voltage	15kV 3 Phase	
Power Rating at 15kV	1.7 MVA	3.5 MVA
Operating Voltage	11-14kV	
System Configuration	Wye, Wye Grounded	
Operating Frequency	60 Hz	
Ramp to 100% Power	< 2 cycles	
BIL Rating	95kV	

Table 1. *Phase-EQ Specifications*

Key Objectives

1. **Static Points Test –** Hit static operating points for balancing power between three phases. This will run through a variety of power set points across the operating range of the device, and include solving for different types of imbalance, with different voltage imbalances present. The goal of this test will be to identify any limitations in the operating behavior of the device.
2. **Dynamic Range Test –** One of the most compelling benefits of this device is its ability to dynamically balance the grid, reacting to changes in system conditions and being able to move from point-to-point to smooth out the imbalance. Initially, this will include jumps from operating point to operating point: 0% to 25% all the way up to 0% to 100%. After this, we will follow a simulated signal for a period of 2 minutes.
3. **Thermal Test –** Run the unit for an extended period of time to verify functionality of the thermal management system. This will require running the device at full rated power and seeing the thermal management system come to steady state.
4. **Fault Handling Test –** Simulate grid faults to test the system's safety requirements and ability to disconnect/reconnect. The device will be designed to disconnect from the grid outside of certain nominal voltage and frequency settings (i.e. +-5% voltage and +-.1 Hz). After 1 minute of nominal grid conditions, the device should reconnect and begin balancing again.

The complete Phase-EQ will come with the ability to balance the power locally, or virtually based upon the needs of the distribution system. This will be accomplished by using a remote sensor to relay information to the device about the needs of the distribution circuit in real time to the Phase-EQ device. Making sure that the device behaves across all operating conditions, with a wide range of inputs, and ensuring that the device responds properly to faults is imperative, especially with an automated device like this. **The proposed R&D will confirm the functionality of the first commercial technology capable of dynamically exchanging real power between phases.** We have engaged a utility that is interested in installing the device on their existing distribution system. Commissioning that pilot project is dependent upon successful third-party testing of our equipment, which will be accomplished in this scope.

Technical Background: Phase-EQ (PEQ)

The Phase-EQ will evenly distribute solar generation across distribution systems, by using power electronics to route power from phase-to-phase. This allows more rooftop solar to connect to the grid without causing system imbalances that lead to bad power quality, nuisance trips, and costly system upgrades. The benefits of the Phase-EQ are shared between the utility and the user: utilities enjoy reduced line losses, reduced nuisance trips, and lower operational expenditures; while customers enjoy lower costs for connecting more solar, better efficiency for three-phase loads, and enhanced power quality.

As distributed solar generation grows, problems caused by phase imbalance will increase in severity. If successful, the proposed innovation will achieve an unprecedented level of control over primary distribution networks and automate phase-balancing, a costly and tedious process that utilities currently have to perform manually as part of their system planning and operations. Through talking to utilities and solar developers today, we learned that interconnection costs are one of the leading obstacles to building a project. When a solar project is studied to see how it will affect the grid, the voltage imbalance and the current limit of the wires are two of the key criteria. As each solar project is connected, this re-balancing may need to be performed. The Phase-EQ will eliminate this need while providing dynamic phase balancing in response to changes at the grid edge from one moment to the next. Switched Source's Phase-EQ allows more solar to connect to the grid by balancing out the solar generation across the three phases.

This technology is an offshoot of a power flow control technology that was originally supported by ARPA-E for power flow control between distribution circuits. The prototype for this power flow control technology is shown in *Figure 1*. Switched Source interviewed over 16 utilities in a customer discovery process. The takeaways from those interviews was that the most manually intensive process and one that was going to be made worse with solar generation adoption was phase balancing. This was especially painful for utilities in suburban and rural areas.

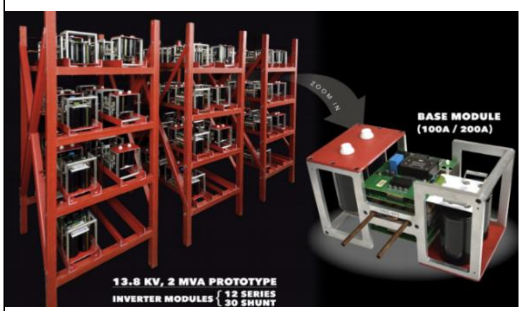

Figure 1*. Prototype Unified Power Flow Controller ("Tie Controller")*

Once this problem was identified, Switched Source set out to see if there was a way to "bend" the technology that was originally supported by ARPA-E to address this use case. In this effort, we found that there were several different potential topologies that leveraged IP from the power flow controller that had the potential to be re-engineered for utility phase balancing applications. One of these topologies, which has become the Phase-EQ, was a particularly good fit, because its design had a reduced complexity and it achieved the best results for grounded-wye systems, the most common type of grid configuration for three-phase systems.

Switched Source immediately sought out support to prove the system impact of this technology and found a partner in the New York Stated Energy Research and Development Authority. NYSERDA supported R&D efforts for the technology through a stage gate process which to-date has supported proving out the theory and basic required control laws for the different topologies as well as determining the potential impact on solar hosting through power systems modeling with researchers at Binghamton University.

As part of the research at Binghamton University, the device was modeled in MATLAB alongside a system model in OpenDSS. **Results showed that the Phase-EQ device could increase solar hosting capacity on a distribution feeder by 2-3X,** depending on the location of solar generation in relation to device placement. These simulated results will be proven out during the first utility partner pilot deployment for which Switched Source has received a letter of commitment.