BTS 91212 | FEBRUARY 2016

Business & Technology Strategies

Field Demonstration: Grid Energy Router

Advanced Device for Voltage Control and Power Quality Management

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Advanced Device for Voltage Control and Power Quality Management

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for

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The National Rural Electric Cooperative Association

NRECA is the national service organization for more than 900 not-for-profit rural electric cooperatives and public power districts providing retail electric service to more than 42 million consumers in 47 states and whose retail sales account for approximately 12 percent of total electricity sales in the United States.

NRECA's members include consumer-owned local distribution systems—the vast majority—and 66 generation and transmission (G&T) cooperatives that supply wholesale power to their distribution cooperative owner-members. Distribution and G&T cooperatives share an obligation to serve their members by providing safe, reliable, and affordable electric service.

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- Analytics, Resiliency, and Reliability
- Cyber Security
- Energy Efficiency
- Generation, Environment, and Carbon
- Renewables and Distributed Generation
- Resource Adequacy and Markets
- Smart Grid Demonstration Project
- Transmission and Distribution

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Field Demonstration: Grid Energy Router

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Questions or Comments

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Field Demonstration: Grid Energy Router

Advanced Device for Voltage Control and Power Quality Management

Introduction

The co-op electrical distribution grid needs a jump-start in technology to meet the growing demands of the smarter grid. Many co-op engineers think "futuristic" when words like "microgrid" are used, but new smart grid technology is necessary if cooperatives are going to be prepared for distributed generation (DG) and microgrids. One of the main problems with the existing infrastructure is that standard electromechanical devices are antiquated and incapable of meeting the solid-state demands of today's advanced electronics.

Co-op engineers need tools and equipment capable of managing not only a smarter grid but all of the challenges associated with maintaining voltage control, customer-site generation, peak generation, renewable DG, and detailed real-time information. The solution could well be advanced electronics installed at decentralized locations with software and communication capabilities to self-monitor, react, and regulate without human intervention.

SCADA is a technology found at 49% of electric co-ops in the United States.[1] This technology has allowed co-ops to monitor and control systems at the substation level, feeder level, and at centralized control points on distribution feeders. The "GER," or Grid Energy Router, is a solid-state device installed at the distribution transformer, potentially feeding multiple consumers. With an estimated 19 million distribution transformers owned by electric co-ops today, precise management of voltage and power factor simultaneously, at the transformer, might be the solution that jump-starts the co-op grid.

> Could the solution be advanced electronics installed at decentralized locations with software and communication capabilities to self-monitor, react, and regulate without human intervention?

> The 'GER,' or Grid Energy Router, is a solid-state device installed at the distribution transformer, allowing precise management of voltage and power factor simultaneously.

History of GridBridge and the GER

The transition to electronic devices on the electrical grid has been evolving for decades, but GER is a unique technology that is alleged to stabilize voltage and power factor and mitigate harmonics at the distribution transformer. NRECA designed a demonstration project to test this new technology that could fundamentally change the utility industry. The project goals were to demonstrate a limited set of capabilities at the distribution transformer level with real-time monitoring and control.

GridBridge, Inc., is a company located in Raleigh, N.C., that developed this new technology called GER. The company has roots to the

[1] Source: 2013 NRECA Market Research Report, "Co-op Technology Survey."

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National Science Foundation's FREEDM Systems Center. FREEDM Systems Center is headquartered at North Carolina State University in Raleigh and has been awarded $40 million over 10 years for electrical grid transformative research using advancements in power electronics.

GridBridge staff met with NRECA representatives and gave presentations to the Cooperative Research Network's Renewable Energy Member Advisory Group in January 2013. Early contributors to the shaping of the product in the sessions that followed were David Gross, PE, Manager of Operations and Engineering Support at Union Power in Monroe, N.C.; Lewis Shaw, PE, Engineering Manager at Brunswick Electric Membership Corporation in Shallotte, N.C.; and Mike Malandro, PE, Manager of Engineering at Prince George Electric Cooperative in Waverly, Va. The goals of collaboration between NRECA and technology companies are to help shape products and standards and provide first access to new technology for electric co-ops.

GridBridge began work on a first-generation product, GER, more than four years ago. "GER" is the product name for Grid Energy Routers which essentially control voltage, VAR, and power factor at the distribution transformer, while also directly connecting distributed devices and orchestrating the power flow. The first-generation GER product was developed to be owned by the utility, placed downstream from the substation, and have the ability to monetize benefits of voltage regulation, control power flow, and insert reactive power. The other immediate needs identified by NRECA were to manage smart meter data and energy storage, filter load harmonics, and allow bidirectional DC port capability and direct communications to the device.

NRECA's project was established to test this new technology and demonstrate its capabilities at the distribution transformer level with real-time monitoring and control. The first goals of the product test were to simply buck and boost voltage to dynamically adjustable set points and independently regulate power factor, without capacitor bank or line regulator. The program results are listed to the right.

NRECA Program Goals

- Buck and boost voltage to dynamically adjustable set points for voltage stability
- Independently regulate to a specific power factor
- Demonstrate benefits locally without the need of a capacitor bank or line regulator
- Test the device over a range of environmental factors (low and high temperatures)
- Test the device over a range of electrical factors (low and heavy load, low and high power factors)
- Assess full remote communications and control

NRECA PROGRAM OUTPUTS

- **Full Remote Communications and Control.** Demonstrate GER status collection and system control across a communications infrastructure.
- **Voltage Regulation.** Test the ability to dynamically regulate the voltage on reactive loads with the ANSI-allowed band for sites that have either high-voltage or low-voltage problems, or a wide range of voltage fluctuation.
- **Power Factor Correction.** Exhibit a unity power factor or leading power factor operation at the installation point, providing better asset utilization and improved efficiency.
- **Demand Voltage Reduction Demonstration.** Prove the ability to lower peak demand (at the transformer level) based on real-time remote instructions from the utility control center.
- **Collection of Data and Presentation of Benefits.** Data will be collected from various features and result in a brief report demonstrating the benefits of deploying GER technology.

PRODUCT DETAIL

The GER device is less than 3 cubic feet in size, weighs approximately 200 lb., and is pole-mounted (see **Figure 1**). To meet the goals of the NRECA project, the solid-state GER device

FIGURE 1: Less than 3 cubic feet wide, the 200 lb. GER is mounted on a pole.

was attached to a single-phase overhead distribution transformer. Currently, the GER capacity is one size—up to 50 kVA—and uses a bypass option if the transformer is ever overloaded.

What makes the device most unique is the GER has both AC and DC connection possibilities, an onboard microprocessor, and future capabilities for multiple routers and peer-to-peer communication and coordination. The GER is an intelligent and precise voltage regulator, capacitor, and inverter all in one.

There is no prescribed proactive maintenance required with the electronics-based GER at this time. In discussions with other co-ops, GridBridge is planning to run two internal thermocouples to the tank of the transformer to monitor the transformer performance for proactive maintenance. GridBridge GER was designed to the expected utility standard of a 20-year life and up to a 2-year warranty on the units. The post connectors attached to the GER are standard connectors from HJ Enterprises and, therefore, do not violate NESC or pose threats to animals. Standard raptor protection can be installed for any concerns about birds nesting on them.

Conservation Voltage Reduction (CVR) has proven monetized benefits for distribution networks. What is unique to the GridBridge product approach is CVR at each load point (distribution transformer) instead of at the substation or feeder level. This introduces a targeted effect, pushing CVR to its limits at a location and, therefore, maximizing the benefit to the utility. The graphic user interface (GUI) is web-based and simple (see Figure 2). Users do not require special training and will not be overwhelmed with data.

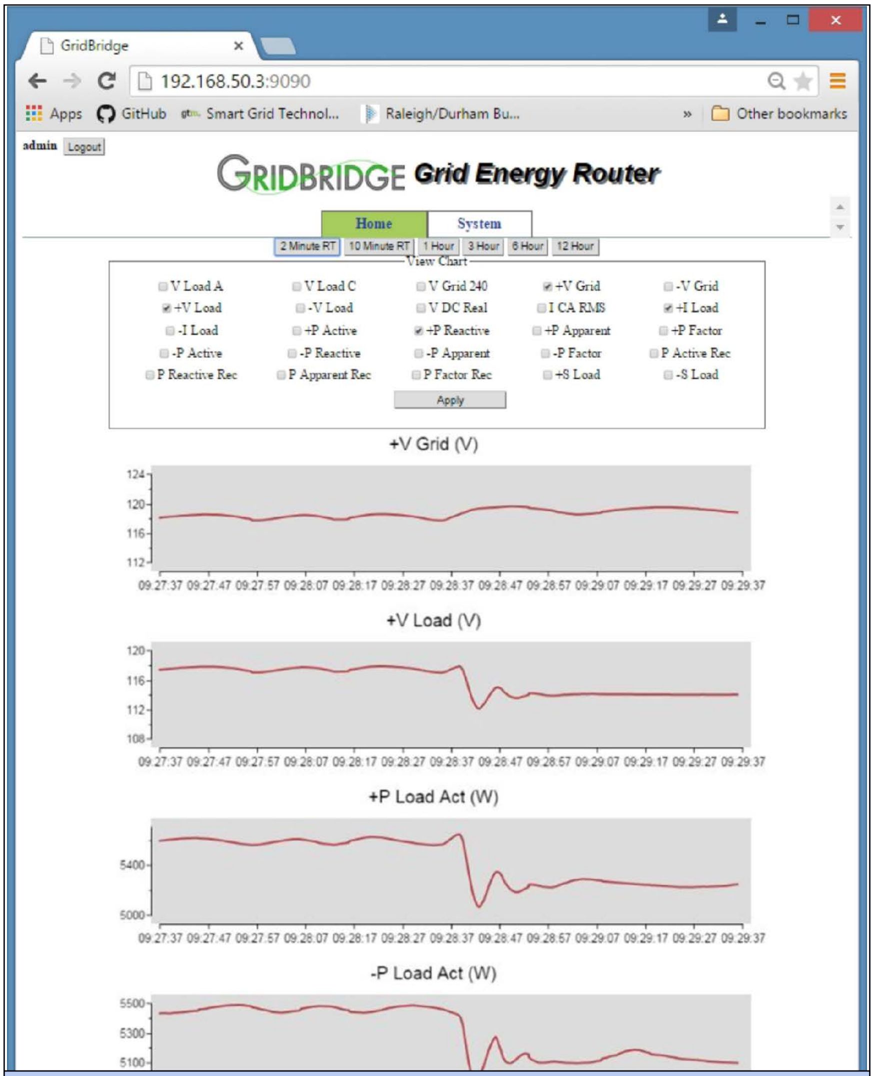

FIGURE 2: The GridBridge GUI used for interface.

Brunswick Electric Membership Corporation Demonstration Project Goals

Brunswick Electric Membership Cooperative (BEMC) agreed to test the GER product at its warehouse facility in Supply, North Carolina, starting in March 2015 (see Figures 3 and 4). The project is still underway, as testing is being performed in multiple stages. Lewis Shaw, Manager of Engineering at BEMC, when asked how the GER can help a typical co-op, stated, “The Grid Energy Router can help mitigate voltage and power factor issues and can help co-ops expand their potential for Conservation Voltage Reduction.”

FIGURE 3: Line workers install a GER device for testing at BEMC’s warehouse.

FIGURE 4: The grid energy router was tested at BEMC’s warehouse located in Supply, N.C. In addition to electrical conditions, BEMC has tested the GER over a range of environmental conditions, including heavy rains, cold, and heat of summer as it has now been in place for almost a year.

The goals of the demonstration project at BEMC were to demonstrate the capabilities listed below.

Because the GER was located at BEMC’s warehouse, they were able to test the independent power factor correction, voltage regulation, communications, and interface capabilities. The data collected during the project was sufficient to monetize efficiency gains and provide economics to illustrate a payback period. According to Shaw, they did not test the DC port for distributed generation or energy storage or the microgrid capabilities at this time, but look forward to expanding their project when these capabilities are needed in their co-op.

For the demonstration, the GER was easily mounted on a pole below the transformer and connected into the secondary. Because the GER was installed at its warehouse in Supply, North Carolina, BEMC staff had the luxury of using a CAT 5 cable and connecting into a media converter with Internet access. Therefore, they had no connectivity issues during the demonstration project.

GridBridge has designed its communications to accept any TCP/IP connection. In most scenarios, utilities prefer system communications to be provided by integrated 4G/LTE/3G and Wi-Fi 802.11b/g/n wireless radios. The GridBridge team and utility typically jointly monitor the results, as was done at BEMC.

The GER was monitored by a Revolution Power Quality Monitor (PQM) for a period of

GER Capabilities Demonstrated at BEMC

- Bypass Capability
- Voltage Regulation
- Independent Power Factor Correction
- DC Port 400 V Input/Output Bus
- Mitigate or Minimize New Harmonics
- Aggregate Metering
- Communications and Interface
- Monetized Efficiency Gains
- Distributed Generation and Storage Capabilities
- Facilitate MicroGrids and the Power Flow within these Grids

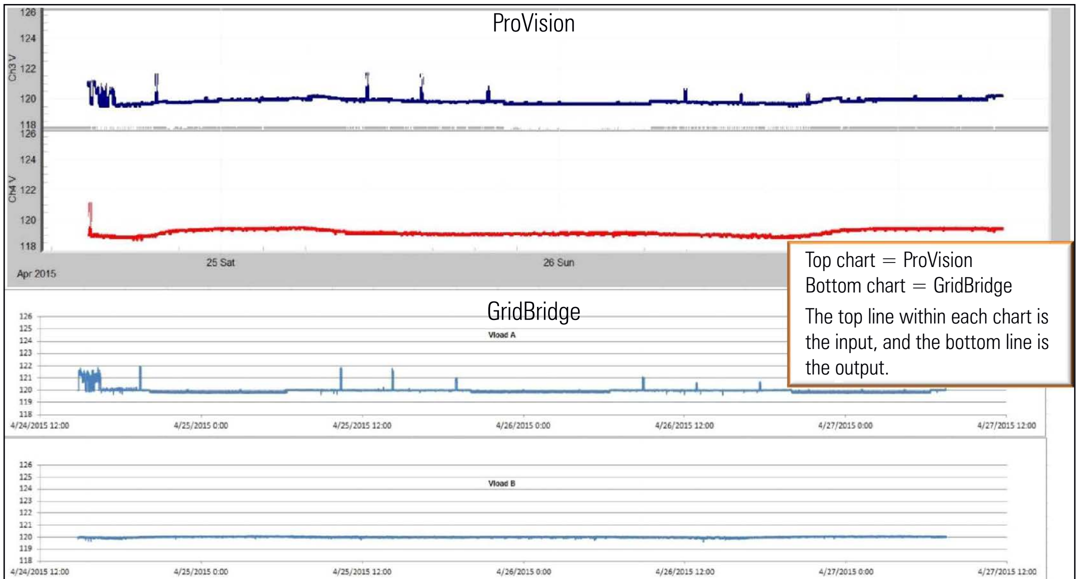

FIGURE 5: GridBridge data versus Revolution PQM data.

7 days, using a variety of scenarios, to meet the goals of the demonstration project. Some of the scenarios were cycling of heaters, with an average load of approximately 10 kW and peak loads up to 35 kW. A set point of 120 Volts was chosen. The team chose to keep the voltage constant, although it could be changed remotely. The GridBridge GUI was proven to be as accurate as the PQM, as shown in Figure 5.

TABLE 1: Average Load (kW) With the GER Over a 7-Day Field Test

Average Load Without GER Over 7-Day Period	10.1 kW
Average Load With GER Over 7-Day Period	9.5 kW
Average Voltage Delta (set at 120 V)	3.47 V
Average % Difference Witnessed Over 7-Day Period	5.3%
Kilowatt-Hours Saved in 1 Hour	0.63 kWh
Annualized	5,490 kWh

BEMC TEST RESULTS FROM STAGE 1 FIELD TEST DEMONSTRATION

The results of the First Pass Voltage Optimization Demonstration Test for 7 Days are summarized in Table 1 and Figure 6. Measurements were taken on the high- and low-side of the Grid Energy Router. Apparent, Reactive, and Real power measurements are available on the line- and load-sides of the energy router. The co-op can choose which variable to demonstrate, i.e., savings of power on the utility-side, or reduction of power consumed by the member. The difference is demonstrated by the GER's ability to simultaneously manage voltage and increase the power factor to unity on the line-side.

Figure 6 shows the results of Volt/VAR control and difference in power. With the power factor set to 1.0, during a 7-hour sampling, an 11–12% power difference was recorded (red line).

Within this first demonstration pass, the voltage was set to 120 V and power factor remained unaffected. Various time frames were sampled to capture performance periods during low versus high load, along with varied grid power factor. Since the GridBridge GUI and data logging was proven to be as accurate as the Revolution PQM, the on-board measurements were exported to Excel for the GER analysis.

Within the 7-day data set, a subset of 24 hours

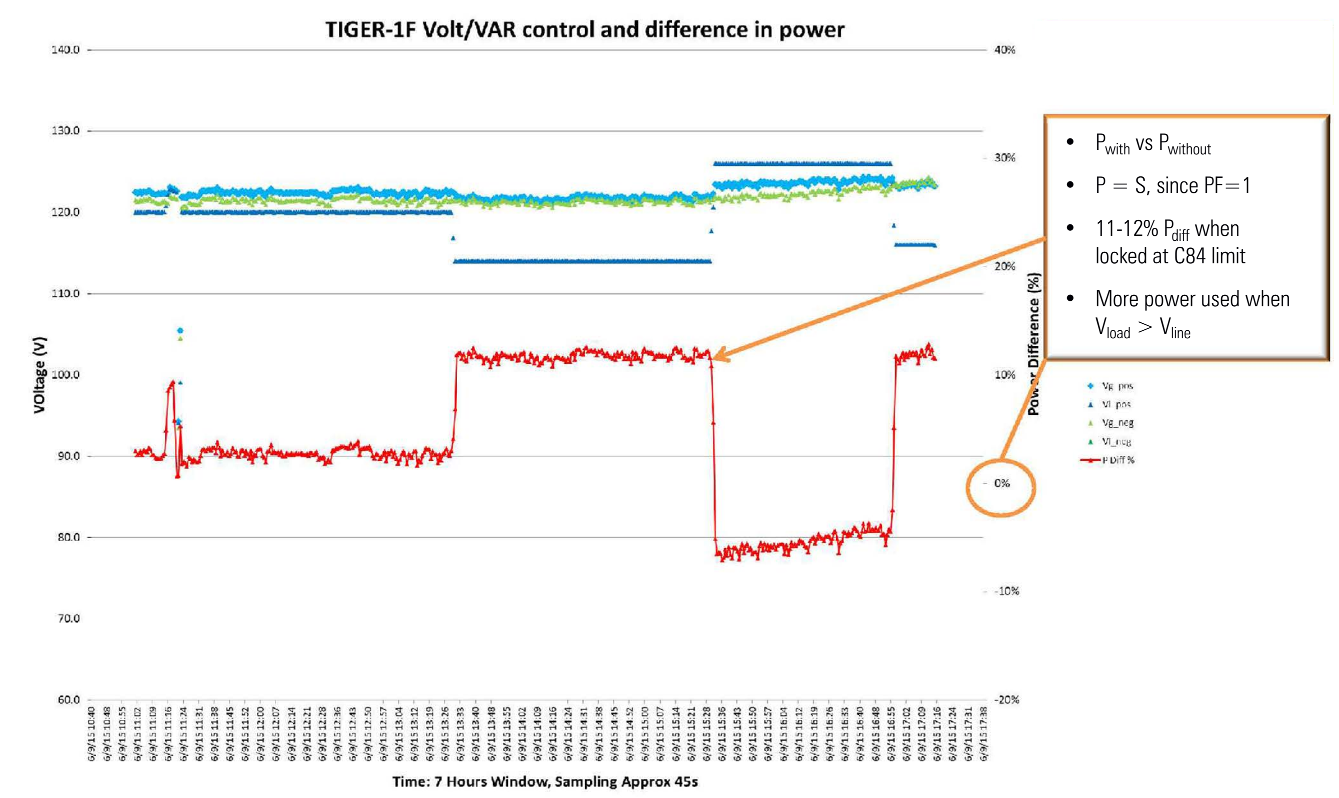

FIGURE 6: A 7-hour sampling and difference in power ("P")

TABLE 2: Average Load (kW) With the GER Over a 24-Hour Field Test	
Average Load Without GER Over 24 Hours	20.8 kW
Average Load With GER Over 24 Hours	19.6 kW
Average Voltage Delta	3.0 V
Average % Difference Witnessed Over 24 Hours	4.0%
Average Power Without GER (8am–9am)	16.7 kWh
Average Power With GER (8am–9am)	15.7 kWh
Real Power Delta	0.98 kWh

was chosen for more specific granular information and is summarized in Table 2.

The team next concentrated on maximizing CVR benefits at a location and established a set point at the lower end of ANSI C84.1 limits (114 V). Additionally, in this demonstration, the power factor was independently set to 1.0. The GER data was sampled for a smaller period of time, approximately 12 hours, for ease of data management. A 2-hour subset of that data was used to isolate the benefit of voltage reduction.

The voltage set-point was changed 4 times at 2-hour intervals: 120 V, 114 V, 126 V, and 118 V. Again, since the GridBridge GUI and data logging were proven to be as accurate as the Revolution PQM, the onboard measurements were exported to Excel for the GER analysis. Unity power factor was demonstrated at BEMC, but was not quantified in terms of payback or savings. **Table 3** includes actual load data in the first column, as well as an extrapolation to utilization at nameplate rating of the GER.

TABLE 3: GER Voltage Optimization Results

	Actual	If Used at Nameplate Capacity
Average Load Without GER Over 2 Hours	10.8 kW	50 kW
Average Load With GER Over 2 Hours	9.6 kW	44 kW
Difference	1.3 kW	5.9 kW
Average Voltage Delta	7.45 V	
Average % Difference Witnessed Over 2 Hours	11.7%	11.7%
Average Load Without GER Over Period	10.9 kW	50 kW
Average Load With GER Over Same Period	9.6 kW	44 kW
Difference	1.3 kW	5.9 kW
Average Voltage Delta	7.48 V	
Average % Difference Witnessed Over Period	11.8%	11.8%

The GER is still installed at BEMC, with additional tests still underway:

- On/off testing over varied periods,
- Survivability (consider recent rains, heat of summer),
- Successful remote update of operating system,
- Handling during surge cycling, and
- Knowledge of unique situations/scenarios on power system not otherwise witnessed.

Future Capabilities for GER

DC PORT

The DC port option, with direct connection of solar PV or other renewable distributed generation, could be a major benefit to co-ops. Maintaining stable voltage at the distribution transformer as power is generated from unstable renewable energy sources is ground-breaking technology.

GridBridge demonstrated powering of AC and DC loads in its lab. Although the concept of DC completely replacing AC at the residential or co-op member level seems distant, having products with the capability to handle AC and DC homes at the same transformer is an exciting concept.

To date, the damaging effects of solar penetration on the co-op grid has not been quantified. If the effects of asset depreciation from reactive power can be minimized at the distribution transformer, co-ops will have one less worry from the saturation of consumer-level renewable DG.

Field testing of GER technology on solar inverters at the utility level to manage any detrimental voltage/VAR effects they cause will solve a complex problem. Plans for the next generation GER will have the capability to connect multiple DC-based sources and loads while providing traditional AC power to homes and businesses, all while managing the detrimental effects inherent with intermittent solar generation caused by cloud cover, for example.

DISTRIBUTED GENERATION

Integration of distributed generation and energy storage is critical and the technology to support this integration is needed first. Distributed generation has doubled in the last decade worldwide. Clearly, electric co-ops need solutions to integrate renewable energy and energy storage to member loads.

Currently, residential-owned distributed generation is tied to the grid through consumer-owned inverters. Each consumer with a DC-based device (solar PV, wind, etc.) has at least one inverter—in some cases, multiple inverters—to convert from DC to AC. It is hoped the GER can eliminate multiple inverters by plugging DC directly into the device at the transformer.

Although not deployed yet, GridBridge has studied that conversion at the transformer offers savings greater than those from installation of both the transformer and the inverter. The DC port has the potential to eliminate the need for an inverter and make PV installation more affordable to the consumer.

The goal is to eliminate redundant inverters, which decreases member installation costs. DC integration will aid in the control of battery storage charge-and-discharge operations, but via utility control.

PREVIOUS VIEW

GridBridge is looking for future demonstration projects of the GER in order to exhibit additional features that are valuable to co-ops. One promising project is designed to integrate a solar array to have a direct connection to the distribution transformer. This could be done with a typical residential installation or a 20- to 50-kW community solar array. The project can also be enhanced to include community energy storage and demonstrate the successful orchestration of power.

Other future demonstration projects could compare the losses of the DC-to-grid connection versus the DC-to-inverter-to-grid connection. The overall efficiency of the GER system has been referenced as 99%. The DC-to-grid connection is in line with industry standards, pointing to 97% maximum efficiency.

PEER-TO-PEER COMMUNICATIONS

With another intelligent point downstream, can the GER help facilitate microgrid deployments? Intelligent microgrids have the capability to integrate DC-based generation and energy storage. Peer-to-peer communication between grid devices is a critical component to this success.

The GridBridge GUI and software interface promises to include peer-to-peer communication. Intelligent microgrids can be achieved through multiple installations of grid energy routers. Lewis Shaw, Engineering Manager at BEMC, explained, "Whether it is a microgrid or a normal co-op circuit, the grid energy router can help solve isolated voltage issues. The telemetry possibilities also open the door for greater operating efficiencies and improved decision making."

HARMONIC FILTERING

GER is designed to be in compliance with IEEE harmonic standards, with the future promise of filtering other harmonics in the distribution network. Fifth and seventh harmonics are the primary targets for future deployments. BEMC did not attempt to mitigate harmonics during the pilot project.

Conclusions

Co-op grids need innovative products to help solve the complex issues in today's digital grid. It is not practical to replace the major components of today's distribution electrical system with all new solid-state equipment.

The GER is a product with a promise to change the co-op grid. The electronic capabilities, on-board software, and direct communications allow the device to make automatic decisions based on pre-set points, react, and control downstream from the substation, which could revolutionize the distribution grid.

The top idea applications for the GER include:

- **On-Demand Reserve.** 5 to 15% reserve capacity at each location.
- **Efficiency Gains.** By setting voltage and power factor.
- **Real-Time Spot Load Knowledge and Capability.** By gathering power quality data at each transformer, co-ops can couple feeder knowledge and capability to control set points.
- **Readiness for DC Devices.** Managing the variability caused by distributed generation directly connected to the grid.

The demonstration project at BEMC is still underway, but results are positive. As shown in **Table 4** and **Figure 7,** the GER has a 2- to 3-year payback when installed on a 50-kVA transformer operating at half load.

Lewis Shaw hopes in the future to see the GER expand to a pad-mounted version rated at 75 kVA. Chad Eckhardt, President and CEO of GridBridge, noted that, "Nothing within the design precludes us from scaling power levels or increasing from single to three-phase. Up to 50 kVA was chosen as a market starting point because it was the most common co-op distribution transformer."

In addition to the quantified results of the testing at BEMC, other unique results of the installation of the GER at co-op distribution transformers are:

- Thermal profiling of the transformer to determine transformer wellness,
- Aggregate metering function coupled with meter data to locate losses,
- Deployment on feeders where existing CVR programs can't be implemented,

TABLE 4: GER Loading as a Percentage [50 kVA] Nameplate					
	20%	**40%**	**60%**	**80%**	**100%**
Average Load over Period (kW)	10.8	20	30	40	50
Average Load with GER over Period (kW)	9.6	18	26	35	44
Difference (kW)	1.3	2.3	3.5	4.7	5.9
Average Voltage Delta (V)	7.45	7.45	7.45	7.45	7.45
Average % Diff. Witnessed over Period	11.7%	11.7%	11.7%	11.7%	11.7%
Per Year (kWh)	11,141	20,571	30,857	41,143	51,428
Annual Savings	$891	$1,646	$2,469	$3,291	$4,114
Payback (Years)	**6.6**	3.6	2.4	1.8	1.4

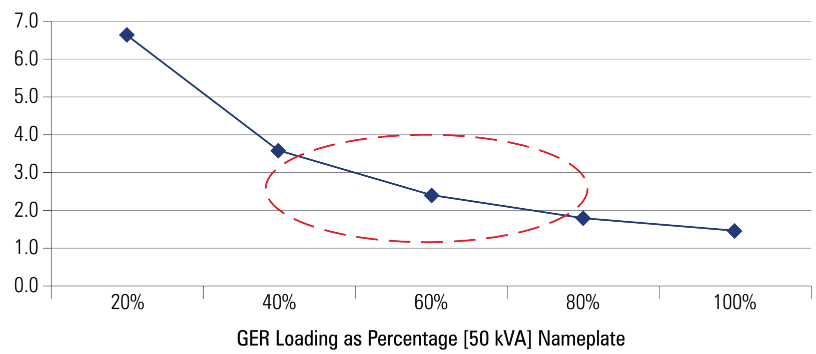

FIGURE 7: Payback in Years of GER Use

- Capacity reserve at each location of 5% to 15%, and
- Power Quality at every location.

The benefits of unity power factor at the transformer, with simultaneous management of voltage/VAR effects, substantiated that intelligent voltage management can offset the expense of the GER at this time. Introduction of intelligent, self-correcting devices downstream from existing co-op SCADA points provide promise for the future of microgrids.

The promising component of the GER is the DC port option with direct connection to solar PV or energy storage and ultimate elimination of DC to AC inverters. This allows the utility to control consumer-owned renewable generation. Since the inverters are eliminated, this decreases the maintenance points and it becomes a utility-controllable component, which improves safety.

Eckhardt summarizes the promise of the GER product for co-ops. “Having the capability to connect distributed devices (AC or DC), sense the various power parameters, and control the power flow is a core function of a smaller grid operating inside the larger,” he says. “The grid energy router can do all three.”