NCEMC MICROGRID IMPLEMENTATION REPORT

OCRACOKE ISLAND MICROGRID PROJECT

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PREFACE

PURPOSE

This report provides detailed documentation of the Ocracoke Island microgrid project implementation. It is intended to provide information that can help electric cooperatives design and implement their own microgrid projects.

SCOPE

This report documents NCEMC's experience implementing the Ocracoke Island microgrid. It is not a set of instructions for microgrid implementation. Instead, it outlines how the microgrid on Ocracoke Island was designed and implemented, and shares results from testing different use cases of this project. Future work, possible improvements and opportunities for development are also included for the benefit of the industry.

AUDIENCE

This report is written for key staff, ranging from engineers to board members, at member cooperatives of NRECA.

EXECUTIVE SUMMARY

This report details how NCEMC implemented a microgrid project on Ocracoke Island. It intends to provide reference material for electric cooperatives interested in developing a microgrid on their systems, so as to expedite the development of future projects.

Microgrids are systems that integrate emerging technologies to modernize the electrical grid. A microgrid is a small electric system that combines local energy resources and control technologies to provide power to a defined area. Microgrids typically remain connected to the main grid but can operate independently.

Microgrids can offer benefits to an electric system. By making use of local energy to supply local loads, microgrids can improve resiliency of the system. Microgrids can also optimize deployment of renewable resources. Despite the benefits, there are still obstacles in implementing microgrids, including cost, complex controller design and optimization, complicated engineering design and a lack of established standards and regulations.

The Ocracoke Island microgrid is a pilot program implemented on the Outer Banks of North Carolina, where resiliency of the electrical system is challenged by the remote geographical location and exposure to extreme weather and coastal conditions. NCEMC installed the microgrid pilot to gain operational experience, determine use cases for microgrids and provide benefits to residents of the island. The microgrid comprises a 3MW diesel generator; a 62-panel 15kW solar array on the roof of the diesel generator plant; a 500kW, 1MWh Tesla battery bank; a Schweitzer Engineering Laboratories (SEL) Real-Time Automation Controller (RTAC); 200 Wi-Fi connected thermostats; and 50 water-heater controls. When power from the main grid is interrupted, components of the microgrid can work together to help supply the load of the island. The internet-connected thermostats and water-heater controls can be activated to reduce total load, while the diesel generator, solar array, and batteries provide local power. All components are controlled remotely from the NCEMC Operations Center, where several aspects of the system are monitored in real time.

NCEMC determined six use cases for the microgrid on Ocracoke Island. They include: 1) Demand Response and Energy Arbitrage for cost savings, 2) Ancillary Services to partake in PJM market opportunities, 3) Renewable Integration and Smoothing, 4) Islanding and Resiliency for off-grid operation, 5) Distribution System Asset Deferment, and 6) Power Quality.

This report and all of its sections are specific to the Ocracoke Island microgrid being primarily a research installation. Microgrid operation will not integrate all proposed use cases, and will depend on the intended purpose of the system.

NOMENCLATURE

5CPs – Five Coincident Peaks (PJM)

BTS – Business and Technology Strategies

CHEC – Cape Hatteras Electric Cooperative

DER – Distributed Energy Resource

EMS – Energy Management System

FERC – Federal Energy Regulatory Commission

G&T – Generation and Transmission

NCEMC – North Carolina Electric Membership Corporation

NRECA – National Rural Electric Cooperative Association

PV – Photovoltaic

RTAC – Real-time Automation Controller

RTO – Regional Transmission Organization

SEL – Schweitzer Engineering Laboratories

U.S. DOE – United States Department of Energy

INTRODUCTION TO INVOLVED COMPANIES

NRECA

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. NRECA's members include consumer-owned local distribution systems and 66 generation and transmission (G&T) cooperatives that supply wholesale power to their distribution cooperative owner-members.[1]

Business and Technology Strategies (BTS) is a division of NRECA that works with an extensive network of organizations and partners to conduct collaborative research for electric cooperatives. BTS products, services and technology surveillance address strategic issues in the areas of:

1) Analytics, Resiliency and Reliability
2) Cybersecurity
3) Energy Efficiency
4) Generation, Environment and Carbon[2]

NCEMC

North Carolina Electric Membership Corporation (NCEMC) is one of the largest generation and transmission electric cooperatives in the nation, providing reliable, affordable electricity to its 25 member cooperatives. NCEMC owns power generation assets, purchases electricity through contracts, identifies innovative energy projects, and coordinates transmission resources for its members.[3]

Driven by service and inspired by innovation, North Carolina's electric cooperatives are building a brighter energy future for 2.5 million residents of North Carolina. Beyond providing electricity, each of the 26 not-for-profit cooperatives is investing in their

[1] https://www.electric.coop/our-organization/
[2] https://www.cooperative.com/public/bts/Pages/default.aspx
[3] http://ncelectriccooperatives.com/who-we-are/#about-us

communities and delivering new energy solutions to improve quality of life for co-op members in 93 of North Carolina's 100 counties.[4]

TIDELAND EMC

Tideland EMC serves more than 22,000 members in Dare, Hyde, Beaufort, Washington, Pamlico and Craven counties.[5] NCEMC and Tideland EMC partnered on the Ocracoke Island microgrid project.

PJM AND DOMINION ENERGY

PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.[6]

Headquartered in Richmond, V.A., Dominion Energy is one of the nation's largest producers and transporters of energy, with a portfolio of approximately 25,700 megawatts of electric generation, 15,000 miles of natural gas transmission, gathering, storage and distribution pipeline and 6,600 miles of electric transmission and distribution lines.[7] Dominion Energy provides some of the power, purchased by NCEMC, that Tideland EMC distributes on Ocracoke Island.

[4] http://ncelectriccooperatives.com/who-we-are/#about-us
[5] http://www.tidelandemc.com/news-info/about-the-co-op/tideland-history
[6] http://www.pjm.com/about-pjm/who-we-are.aspx
[7] https://www.dominionenergy.com/about-us/who-we-are

INTRODUCTION TO MICROGRIDS

WHAT IS A MICROGRID?

NCEMC defines a microgrid as:

> "A small electric system that **combines local energy resources and control technologies** to provide power to a **defined area**. Microgrids typically remain connected to the main grid but **can operate independently**."

The United States Department of Energy (U.S. DOE) defines a microgrid as:

> ''A group of **interconnected loads and distributed energy resources** within clearly defined electrical boundaries that **acts as a single controllable entity** with respect to the grid. A microgrid can **connect and disconnect from the grid** to enable it to operate in both grid-connected or island mode.''

Micrograds can vary in components and scale, and multiple microgrids can exist within a system. This is shown by *Figure 1* below.

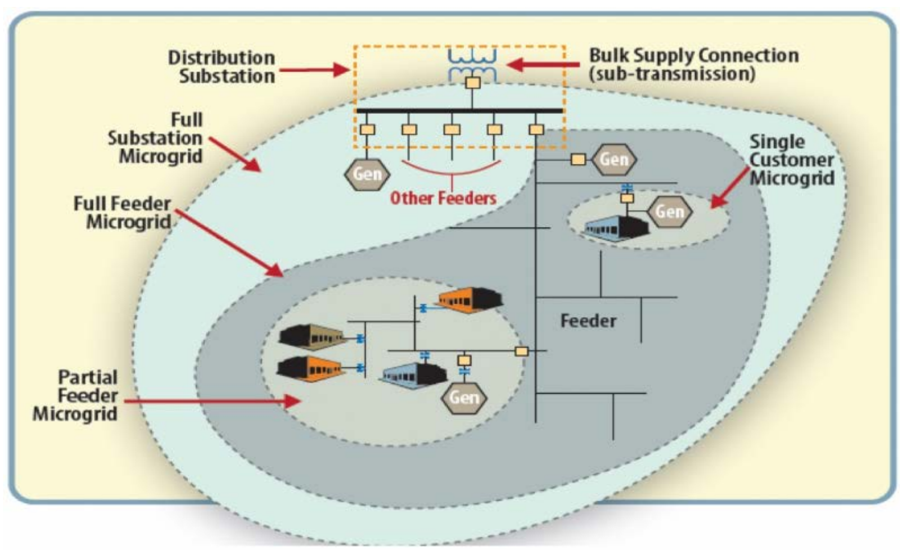

Figure 1 - Generic Microgrid Layout
Source: U.S. DOE | The Role of Microgrids

The Ocracoke Island microgrid described in this report is a partial feeder microgrid, as shown in the figure above. It connects to Tideland EMC's 25kV and 12kV distribution system. This 25kV system is also connected to, or fed from, the neighboring island Cape Hatteras. More details are provided in the *Design* section.

BENEFITS OF MICROGRIDS

Microgrids offer several benefits to electric cooperatives.

1) Microgrids make use of **local energy to supply local loads**. Therefore, there is less reliance on long distribution lines that are susceptible to vulnerabilities and that accrue losses.
2) As microgrids can involve storage and active loads, they enable **reduction of peak demand** of the system. Also, peak demand can be supplied, at least in part, by the distributed generation of the microgrid instead of the main grid, which could reduce wholesale energy costs.
3) A microgrid is another way of managing system upgrades. Placing microgrid components downstream in the system can **prolong distribution asset life** by avoiding component upgrades.
4) Microgrids assist with the **optimized deployment of renewable resources**. By enabling more renewable resources, microgrids may help **reduce carbon emissions**.
5) Because new components can be integrated, microgrids are **scalable**.
6) **Resiliency** is the capacity to recover quickly from difficulties. In instances when distribution, or even transmission, service is interrupted, microgrids, as small-scale systems, can enable faster restoration of power in areas served by the microgrid.

MICROGRID CHALLENGES AND DEVELOPMENT

Microgrid design and implementation also present challenges.

1) A **lack of standards and regulations, along with** rapidly-developing microgrid technology, means that there is no universal model for implementation.
2) As each microgrid is unique, **equipment must be custom designed** for each application, meaning system design is less efficient.
3) Microgrids can change the way the electric grid is designed due to the reverse flow of power from the DERs.
4) The controller at the center of each microgrid must be designed for each project’s specific modes of operation. Thus, **controllers are time-consuming to install, integrate and optimize**.

THE OCRACOKE PROJECT

PROJECT GOAL

The Ocracoke Island project is a pilot implementation of a microgrid for research purposes. As microgrids are a relatively new concept, data about performance and life expectancy is scarce. This pilot project will allow for study of multiple potential use cases and how microgrids can best be introduced to the grid. The goal of the project is for NCEMC to gain operational experience, to determine use cases for microgrids, and to provide benefits to cooperative members on and off the island.

ORIGIN

Served by Tideland EMC, Ocracoke Island is part of the string of barrier islands that make up North Carolina's Outer Banks. Its location makes it vulnerable to severe weather events and isolated from central generation sources, like power plants. If the transmission line feeding the island is without service due to storms or other circumstances, the island could be without power.

Figure 2 - Ocracoke Island Location

After implementing several community solar projects in North Carolina, NCEMC saw value in expanding its knowledge about renewables and the interaction of different types of renewable generation. The Ocracoke Island site was selected because its remote location at the end of a transmission line and coastal environment created ideal conditions for pilot testing a microgrid. At the same time, the existing diesel generator was unable to supply peak load during tourist season in the summer if the feeder were to experience an outage. As a result, Ocracoke Island was determined to be the best location to gain operational experience with dispatching microgrid resources.

DESIGN

COMPONENTS

The Ocracoke Island microgrid comprises six components.

1) A 3MW diesel generator that previously existed on the island.
2) A 62-panel 15kW solar array on the roof of the diesel generator plant.
3) A 500kW, 1MWh Tesla PowerPack battery bank.
4) A Schweitzer Electric (SEL) Real-Time Automation Controller (RTAC).
5) 200 Wi-Fi connected thermostats.
6) 50 water-heater controls.

A diagram of components is provided below in *Figure 3.*

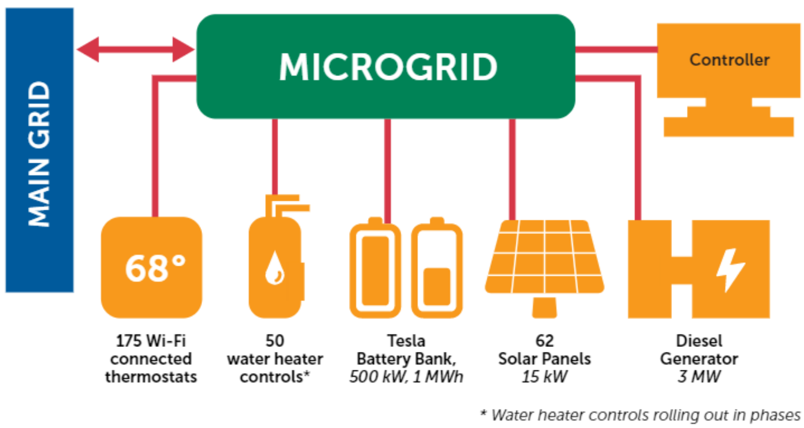

Figure 3 - Ocracoke Island Microgrid Components

Ocracoke Island is connected to the end of a 25kV sub-transmission line from the Hatteras substation. The microgrid is located upstream from the island's load, meaning it is directly connected to the substation where the sub-transmission voltage is stepped down to distribution level. Ideally, a microgrid would be connected downstream to optimize benefits to the system. The microgrid was installed upstream due to space limitations, cost and ease of installation.

MODES OF OPERATION AND CONTROL

Under normal operation when connected to the main grid, the Ocracoke Island microgrid is deployed in two operational modes: for energy arbitrage, and to minimize transmission peaks. Each mode is intended to reduce power costs to the cooperative.

Energy Arbitrage

Energy arbitrage at the Ocracoke microgrid involves charging the battery when energy prices are lowest, and discharging the batteries when prices are highest. This allows the cooperative to save costs by using stored energy rather than peak-priced energy. To determine the charge/discharge schedule, NCEMC Energy Operations and ACES, a nationwide energy management company and NCEMC partner, monitor PJM's day-ahead and real-time prices. ACES compares the real-time prices to the forecasted prices to determine whether a pre-determined price margin has been met to discharge the battery. In this operational mode, the battery is discharged for a maximum of one hour at a time each day to prevent damage to the battery from cycling it too often. More information about energy arbitrage can be found in the *Case Study* section.

Minimizing Peak Demand

Another mission of the microgrid is to capture, and minimize, the transmission peaks of the line, as well as the 5CPs (highest coincident peaks of the load) in the summertime. In this mode of operation, the batteries are discharged during peak hours to achieve peak shaving. Due to managing load expectations for the remainder of the summer, current load forecasts, and forecast uncertainty, these operations can occur 4 to 5 times a month between June and August.

The diesel generator, owned by NCEMC, was installed in 1992 and is part of the PJM market. PJM can call on the generator to dispatch power if needed for economics and reliability.

A diagram of the microgrid operation is provided below in *Figure 4.*

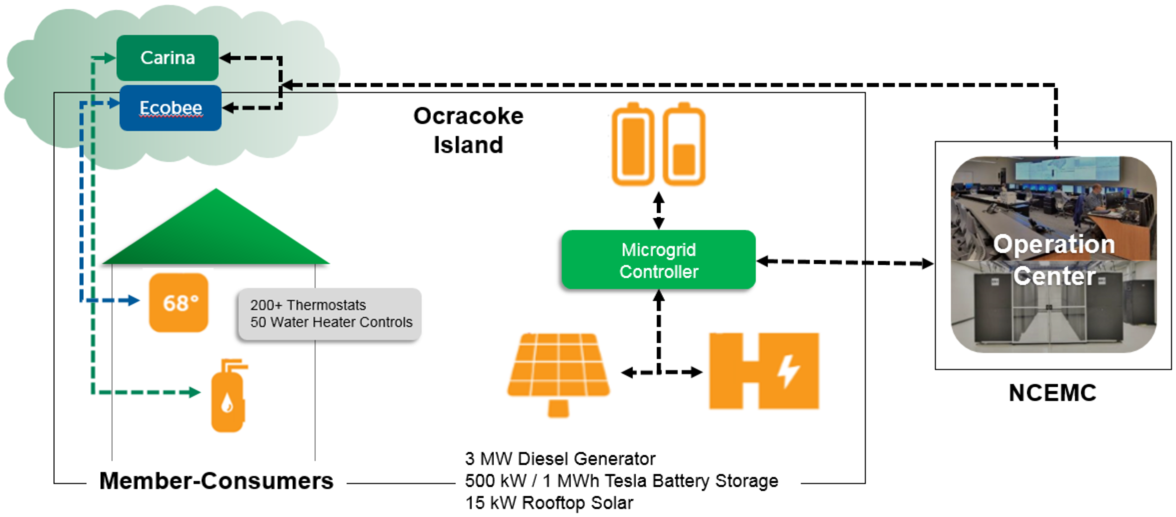

Figure 4 - System Overview

From its Integrated Operations Center, NCEMC can monitor all elements of the microgrid and surrounding grid, including voltage of lines, output levels of the solar and batteries, and the status of reclosers. NCEMC can also control the output of the batteries, and call on the water-heater controls and thermostats for demand response.

LOCAL COOPERATIVE ENGAGEMENT

NCEMC is the primary operator of the microgrid. For efficiency, employees of local distribution provider Tideland EMC employees are trained to operate and maintain the transformer and recloser at the point of common coupling. NCEMC employees, however, manage the PV array and the Tesla battery bank.

Prior to installation of the microgrid, tests were performed to make sure the microgrid operation would not have adverse effects on Tideland EMC's system.

MEMBER INVOLVEMENT AND DEMAND RESPONSE

In creating the microgrid, NCEMC viewed behind-the-meter demand response as an important element to enable additional control and member engagement. Smart thermostats and water-heater controls were ultimately integrated into the system design.

Wi-Fi-enabled thermostats offered energy-saving potential for participating consumer-members, as well as demand response benefits for the cooperative. Several smart thermostat vendors were considered, and Ecobee was selected as they offered the best interface for utilities to manage their system.

The Ecobee program, which was developed by NCEMC and marketed to cooperative members on the island by Tideland EMC, incentivized Ocracoke residents to buy the smart thermostats at a discounted price. Marketing materials highlighted the potential for energy and cost savings, as well as the added convenience of controlling thermostat settings remotely via smart phone. Tideland EMC enrolled 200 member-consumers in the voluntary program as part of the microgrid pilot. NCEMC can to control each unit's temperature settings through an Ecobee portal, though members can override it at any time if they experience any discomfort.

As water heaters are among the top energy consuming-appliances in a household, NCEMC implemented water-heater controls as a component of the microgrid. Tideland EMC members were offered a financial incentive to have a Carina control device installed on their water heater. The control device cycles water heaters off when needed, with no sacrifice of comfort by members, to reduce load. Tideland EMC enrolled 50 member-consumers in the voluntary program as part of the microgrid pilot.

As illustrated in *Figure 4*, NCEMC can control the thermostats and water heater controls that are part of the microgrid system through a portal. These demand response components are not directly connected to the microgrid controller.

COMMUNICATION

Data is transferred over three different media at Ocracoke: telecom data circuit, Ethernet and fiber.

The telecom data circuit provides a secure way for NCEMC and Ocracoke Island to communicate securely over a distance of 200 miles.

The microgrid and its components on the island are connected by wire. Although Ethernet is the standard way to connect components, as seen in *Figure 5*, the Tideland meter is connected via fiber. Fiber offers better performance over long distances, as well as electrical separation that protects components from damage caused by surges following lightning strikes.

As security measure, the Tesla Master Controller is on a different network than the rest of the components, and has to go through the network's firewall. This allows the third-party vendor, Tesla, to access its product for data retrieval and remote troubleshooting, while preventing its access to the rest of the microgrid. It also prevents vendor security weaknesses from propagating to the microgrid system. Note the simplified diagram below does not show additional security measures such as a firewall.

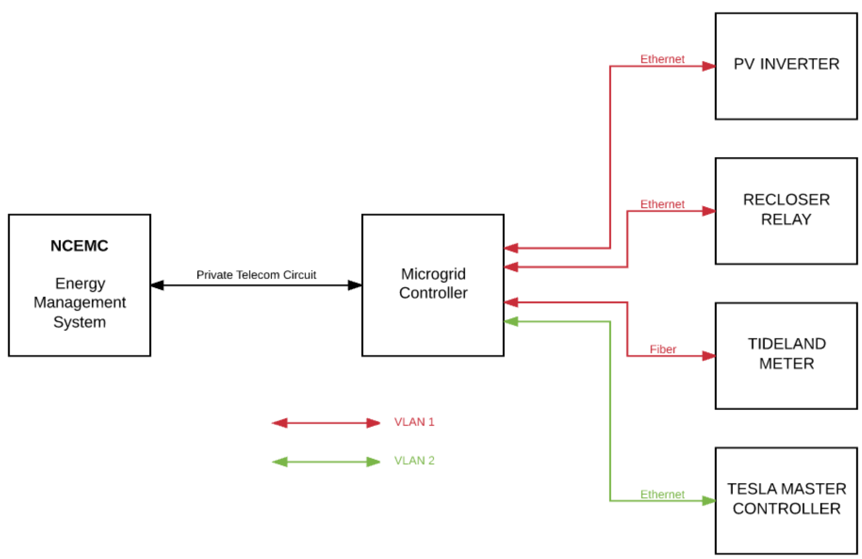

Figure 5 - Communication Diagram

SECURITY

Security at utility facilities involves physical security and network security. Physical security prevents unauthorized individuals from gaining access to the site, while network security blocks unauthorized users from entering the network.

Physical security methods include:

- Access management – Limit access to the plant to only authorized personnel. Access at all levels is periodically reviewed and based on business needs.
- Visitor log – Register all visitors and purpose of the visit. Visitors should be escorted by authorized personnel. All authorized, unescorted visitors or contractors should be logged and should complete appropriate safety training.
- Perimeter enclosure – Secure the area with fencing. The perimeter can be secured by analyzing weakness in the fencing and by securing any outdoor component accesses by implementing appropriate security controls.

Network security methods include:

- Changing default passwords.
- Implementing two-factor authentication.
- Implementing application whitelisting software to only allow authorized software to run.
- Implementing least-privileged access.
- Turning off unnecessary services.

The National Institute of Standards and Technology (NIST) has developed a general framework to minimize cybersecurity risks. The NIST framework provides guidance in identifying risks and protecting against them, as well as detecting, responding to, and recovering from breaches.

However, the NIST framework does not apply specifically to microgrids. NCEMC is developing a cybersecurity framework specific to microgrids.

PROCESS

This section lists general steps taken in implementing the Ocracoke Island microgrid.

1. Site Selection and Board Approvals
   A team called the Innovative Energy group outlined microgrid location options and built a business case for each. Ocracoke was selected from the proposals, and the project was approved by both the NCEMC and Tideland EMC boards.
2. Owners' Contracts and Environmental
   The roof-mounted solar array was designed and constructed to withstand winds of 140 mph, which required inspection by a structural engineer to ensure the structural stability of the building's roof and to meet code. NCEMC received a variance from the Hyde County Board of Commissioners as the microgrid design exceeded the established limits of the Hyde County Land Development Code.
3. Plant Roof Solar and Batteries
   The installation of the solar panels was contracted to Hannah Solar, which also provided the solar panels. The batteries purchased from Tesla were installed on a 4 ft. concrete base for protection against flooding. The batteries remained above water in October 2016 when floodwaters rose 3 ft. at the microgrid site during Hurricane Matthew. Engineering, procurement and construction (EPC) of the system was done by PowerServices, which was also in charge of acquiring the transformer and recloser for the microgrid.
4. Dispatch Controls/Communications Equipment
   The final step involves component tie-in and functional testing before full operation.

STANDARDS AND REGULATIONS

Standards and regulations that apply specifically to the design and construction of a microgrid do not exist. However, microgrids must follow clearances established in the National Electric Safety Code. There are also U.S. regulations for 25kV construction which include minimum clearance and general safety precautions. Additionally, the National Electric Code applies to the switchgear inside the plant or other ancillary power load centers.

IDEAL VS. ACTUAL

Projects rarely go exactly as planned. At the Ocracoke Island microgrid, adjustments were made to the initial design as the project was implemented.

- The original design of the system incorporated the use of flywheel technology for added storage capacity. However, this technology was ultimately decided to be unfeasible for the project.
- Ideally, the solar array would have been larger in order to charge the battery. However, the island's limited land availability constrained the array to the roof of the generator building. As a result, the batteries are charged by the grid during non-peak hours and make use of the energy arbitrage case study.
- The battery inverters were expected to be grid-forming, but turned out not to be the case. This means that the Ocracoke Island microgrid cannot operate off-grid if the diesel generator (the grid-forming entity), or the main feed, is offline. It is worth noting, however, that Tesla now offers grid-forming inverters.

CHALLENGES

Challenges at the Ocracoke Island site that affected the design of the microgrid included:

- A requirement that structural design of the roof solar array withstand winds of 140 mph.
- A lack of available land to for the solar array.
- The highly corrosive environment due to salt in the air, which can lead to premature failure of installed equipment without proper coatings.

Other challenges came up during construction:

- The isolated location, reachable only by ferry, made it difficult to get crews and equipment on site.
- Construction occurred during tourist season, which caused heavy traffic.
- Hurricane Matthew struck the island during construction, causing evacuations and a 3-week delay.
- The substation feeding the island had to be kept energized.
- The diesel plant had to be available to run at all times.

Challenges during testing included:

- A construction accident at Hatteras Island caused a prolonged power outage at Hatteras and Ocracoke islands, which delayed some scheduled tests.

OCRACOKE CASE STUDY

NCEMC considered several use cases for the Ocracoke Island microgrid. These cases include:

1. Demand Response and Energy Arbitrage
2. Ancillary Services
3. Renewable Integration and Smoothing
4. Islanding and Resiliency
5. Distribution System Upgrade Deferment
6. Power Quality

It is to be noted that these use cases are for research purposes only. It is unlikely a microgrid can be operated to meet of all these use cases.

1 – DEMAND RESPONSE AND ENERGY ARBITRAGE

Demand response involves battery storage and behind-the-meter devices, such as thermostats and water-heater controls that can be dispatched to reduce load during peak hours. Energy arbitrage, in this case, is the ability to charge the microgrid battery when the cost of power is low, and discharge it when the cost is high (during the peak hours).

"Peak hours" are the times of the day when energy prices are highest. By reducing load during peak hours, cooperatives can reduce peak energy expenses.

Through demand response and energy arbitrage at Ocracoke, NCEMC can reduce its wholesale power costs, which benefits NCEMC's member co-ops and their member-consumers. The effectiveness of energy arbitrage depends on how widely prices vary throughout the day. Potential impact caused by this kind of battery operation should be weighed against the potential for cost savings.

2 – ANCILLARY SERVICES

FERC defines ancillary services as "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system." Microgrids, and more specifically batteries, have been cited as excellent resources for providing ancillary services to the grid. Ancillary service from battery storage provides stability to the grid by adjusting unit output very quickly and is preferable to traditional turbine generation.

There is an opportunity to generate revenue by entering the microgrid into market to sell energy. This requires that some control of the microgrid operation is ceded to the electric utilities purchasing the power.

3 – RENEWABLE INTEGRATION AND SMOOTHING

Output of a solar array varies with cloud cover and other environmental effects, a phenomenon known as “flicker”. As renewable resources are added to a cooperative’s distribution system, these resources could negatively impact distribution assets due to their non-dispatchable (uncontrollable) nature. Using battery storage to support output shortfalls and to absorb excess generation could prove to be a critical part of integrating renewable resources into a cooperative’s distribution grid.

4 – ISLANDING AND RESILIENCY

The most fundamental definition of a microgrid is the synchronization of load and generation to safely and reliably satisfy the electrical needs of those who are hosting it. Ocracoke presents an excellent environment to create this balanced system. During low load periods, the combination of supply-side resources (3 MW generator, battery storage, and solar) and demand-side resources (battery demand-response, thermostats, and water heaters) should be able to manage the power needs of the island. During storms or other emergencies when loads are reduced, the microgrid can improve reliability and resiliency of power delivery on the island.

5 – DISTRIBUTION SYSTEM UPGRADE DEFERMENT

A compelling argument for storage and the microgrid is that these resources can be used to defer or avoid upgrades to transmission or distribution equipment. Asset deferral or life extension would be accomplished by adding a microgrid or storage asset electrically “downstream” from the affected equipment. The microgrid could be deployed to relieve some portion of the asset’s load-carrying capacity during extreme peaking periods. The asset could be a transformer, conductor or other equipment that is approaching its maximum load and/or expected life.

6 – POWER QUALITY

The service territories of distribution cooperatives continue to be desirable locations for distributed energy resources (DER), particularly solar PV generation. However, these non-dispatchable resources can negatively impact rural distribution systems that were designed for one-way flow of power. This microgrid provides information about how solar inverters can support grid operations by reprograming units to provide reactive power. Reactive power control enables more operating flexibility and increased reliability. Understanding how these inverters can be reprogramed, or dynamically operated, as a grid resource will be part of microgrid and distribution operations in the future and will ensure that DER growth contributes in rural distribution systems.

CONCLUSION AND RECOMMENDATIONS

NCEMC is constantly working to improve the microgrid process. This report provides information and lessons learned by NCEMC in designing and implementing a microgrid. The Ocracoke project was installed for research and development purposes, and many applications were studied to produce results about feasibility in the marketplace. Lessons learned throughout the development process have been mentioned for other cooperatives to consider.

The Ocracoke Island microgrid is a step toward modernization of the electrical grid. Results showed that though microgrid implementation is expensive, the benefits in system management and data collection far outweigh the costs. Prices of microgrid components, including batteries and solar, are always changing, making the outlook for microgrids promising.

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Thank you to the project team for helping with either providing or reviewing content throughout this project.

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