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August 1, 2023

VIA ELECTRONIC FILING

Ms. A. Shonta Dunston, Chief Clerk
North Carolina Utilities Commission
Dobbs Building
430 North Salisbury Street
Raleigh, North Carolina 27603

Re: ***Duke Energy Carolinas, LLC's and Duke Energy Progress, LLC's Inverter Based Resources Testing Report***
Docket No. E-100, Sub 175

Dear Ms. Dunston:

Enclosed for filing is Duke Energy Carolinas, LLC's ("DEC") and Duke Energy Progress, LLC's ("DEP" and together with DEC, the "Companies" or "Duke Energy") Inverter Based Resources Testing Report ("IBR Testing Report" or the "Report").

The Companies are filing this Report in response to the Commission's *November 22, 2022 Order Establishing Standard Rates and Contract Terms for Qualifying Facilities* in the above-referenced docket, which directed the Companies to conduct a preliminary investigatory study of the operating characteristics of inverter-based resources ("IBRs") at certain of its Duke Energy-owned IBR facilities. The purpose of this study was to understand which ancillary services, if any, each resource or combination of resources can provide. The Commission further directed Duke to file a report on its findings on or before August 1, 2023, and to share the results of the study with the Public Staff and other interested stakeholders prior to filing the Report.

In response to the Commission's directive, the Companies developed a plan to test the operating characteristics of IBRs at their Elm City and Monroe solar facilities and the Asheville Rock Hill standalone battery storage facility. The Companies discussed their test plan with the Public Staff in April 2023 and conducted testing in May 2023 as further described in the Report. After completing the test process and analyzing results, the Companies shared test results, along with their conclusions and recommendations, with the

Public Staff on July 6, 2023 and hosted a meeting with stakeholders to discuss the same on July 25, 2023.[1]

The enclosed IBR Testing Report provides a detailed analysis of the test parameters, execution, and observed results, along with the Companies' assessment of results and recommendations for next steps.

If you have any questions, please do not hesitate to contact me. Thank you for your attention to this matter.

Very truly yours,

/s/ Tracy S. DeMarco

TSD/sbc
Enclosure

[1] The Companies invited all parties granted intervention in the E-100, Sub 175 docket to participate in the stakeholder meeting, and a total of fourteen (14) stakeholder representatives attended.

IBR TESTING REPORT

ACTIVE AND REACTIVE POWER TESTING OF THE ELM CITY AND MONROE SOLAR INVERTER-BASED RESOURCES (IBR) WAS CONDUCTED OVER SEVERAL DAYS. ADDITIONALLY, TESTING OF THE ASHEVILLE ROCK HILL BATTERY RESPONSE TO ACTIVE POWER SETPOINT CONTROL WAS CONDUCTED. THIS REPORT PROVIDES AN OVERVIEW OF THE RESULTS FROM THOSE TESTS AND RESULTING RECOMMENDATIONS

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Executive Summary

Site Information

The sites used for the active and reactive power testing were the Elm City and Monroe solar facilities. Both sites are owned and operated by Duke Energy and each site is located within a different Balancing Authority (BA) in the Carolinas region. Active power testing was conducted with the Asheville Rock Hill battery site in the CPLW Balancing Authority Area of the Duke Energy Progress BA.

Inverter-Based Resources Tested

Standalone Solar

- Elm City Solar (40 MWac)
- Monroe Solar (54.6 MWac)

Standalone Battery Storage

- Asheville Rock Hill Battery (8.8 MWac; 1-hr)

Test Dates and Times

The following dates and times were chosen for the testing:

Active Power Testing

- Friday, May 12, 2023, at 9:00 am - Solar
- Friday, May 12, 2023, at 12:00 pm - Solar
- Friday, June 16, 2023, at 11:30 am - Battery

Reactive Power Testing

- Tuesday, May 23, 2023, from 10:00 am – 5:00 pm – Solar
- Wednesday, May 24, 2023, from 10:00 am – 5:00 pm - Solar

Satellite Views of Cloud Cover for Active Power Testing

Weather for the Elm City active power test was partly cloudy during the morning test with mostly clear skies during the afternoon test. Monroe saw mostly cloudy skies during the morning active power test with some clearing during the afternoon test. Figure 1 and Figure 2 reflect the satellite cloud cover for the Elm City Solar and Monroe Solar sites near the time of the morning and afternoon testing.

Morning Test

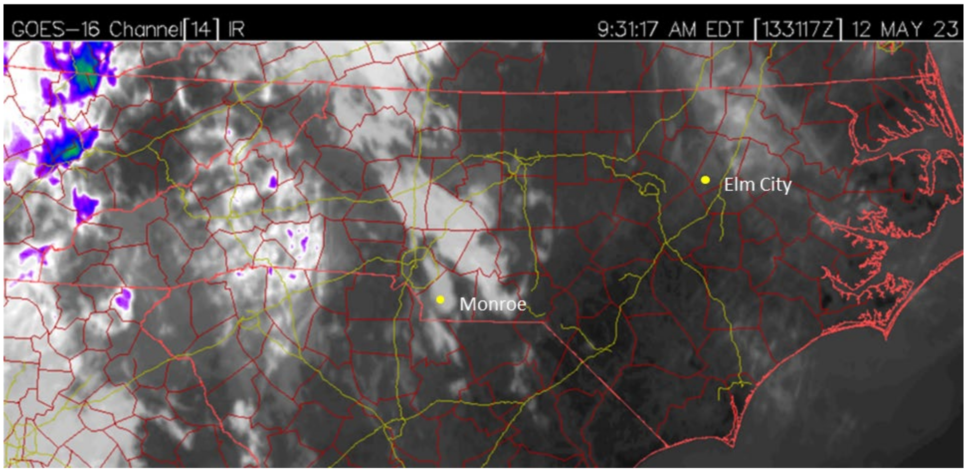

Figure 1 Cloud Cover During Morning Test

Afternoon Test

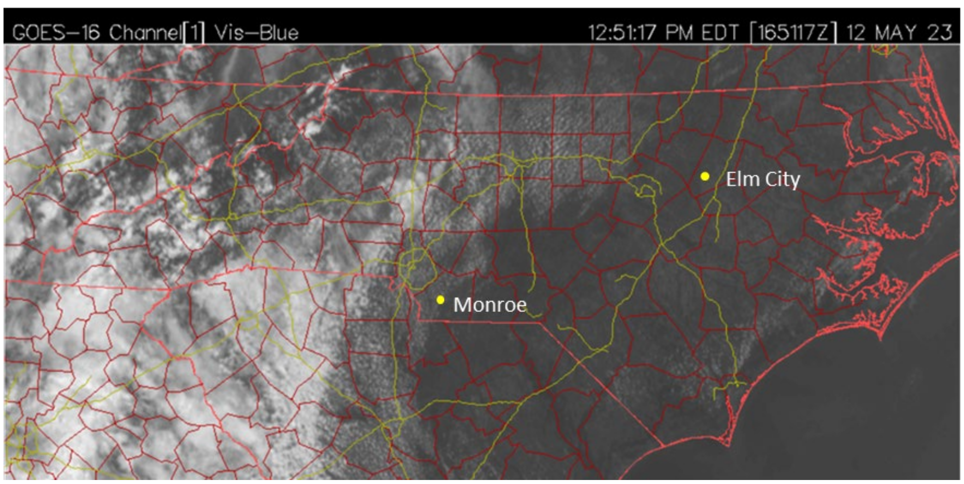

Figure 2 Cloud Cover During Afternoon Test

Introduction

NCUC Docket No. E-100, Sub 175 directed Duke Energy to conduct a preliminary investigatory study of the operating characteristics of IBRs at certain of its own IBR facilities to understand which ancillary services each resource, or combination of resources, can provide. The NCUC Order directed Duke Energy to file a report, on or before August 1, 2023, addressing the potential benefits, if any, to customers of QFs providing ancillary services and whether a pilot program would be worthwhile.

Duke Energy tested the operating characteristics of IBRs at both its Elm City (40 MWac) and Monroe (54.6 MWac) standalone solar facilities and at its Asheville Rock Hill (8.8 MWac; 1-hr) standalone battery storage facility. Elm City is connected to a 115kV transmission facility within the DEP BA, while Monroe is connected to a 100kV transmission facility within the DEC BA. The Asheville Rock Hill battery is connected to a 23kV express feeder out of the Asheville Rock Hill substation in the CPLW Balancing Authority Area (BAA) of the DEP BA.

Test Plan Layout

The test plan for the Duke Energy owned and operated resources involved both active and reactive power testing using setpoint control issued from the Regulated Renewable Operations Center (RROC) or the Distributed Generation Operations Center (DGOC). Test objectives were to determine how the resource would follow an active power setpoint, how it would respond to varying levels of reactive power injections, and how active and reactive power injections interplay with the controller logic and inverter capabilities. Each test occurred on different days where solar energy supported the test objectives.

Active Power Test

Active power testing was designed to create an offset between the actual yield and the estimated yield that would support frequency regulation at varying output levels and characteristics. This was accomplished by manually changing the active power setpoint in the Power Plant Controller (PPC) approximately every 10 seconds to create a ten (10) MW reduction of the actual output from the estimate. Estimated output for the facility is calculated using a model that takes inputs such as irradiance measured at the site, the number of inverters in service, and ambient and back-panel temperatures.

As part of this test, the active power setpoint was additionally offset to mimic frequency regulation by changing the setpoint to respond to deviations in the Area Control Error (ACE) for the respective BAA. ACE is a measure of the deviation of actual tie-line power flows with scheduled tie-line flows and a frequency bias contribution that represents the BA contribution of active power to assist with balancing resources and demand and regulating frequency on the Eastern Interconnection in compliance with NERC Reliability Standard requirements. The active power setpoint was either reduced or increased if ACE went above the high ACE regulation deadband or below the ACE deadband respectively. The ACE regulation deadband used for this test was fifty (50) MW.

Reactive Power Test

Reactive power testing was designed to move the resource's reactive power from zero (0) Megavolt-Amperes Reactive (Mvar) to full reactive absorption in small intervals by switching the resource to var control mode and changing the reactive power setpoint. Once at full reactive power absorption, the active power was then curtailed to determine if the resource could maintain its reactive power at lower active power outputs. The test would also show the sites ability to impact voltage in the local area as the reactive power was modified.

Elm City's voltage schedule is set to operate between 114kV and 119kV with a target of 115kV for every hour of the day. Monroe's voltage schedule is set to operate between 101.7kV and 106.5kV with a target that varies between 103.7kV and 105kV based on the day of the week and time of day.

Voltage support for a standalone battery system will be completed for a transmission-connected facility once available. Coordination would need to be assured between the Asheville Rock Hill battery site and substation voltage regulation devices, other feeders at the substation, and the voltage regulation schemes from the Distribution Management System (DMS) prior to conducting a reactive power test with the Asheville Rock hill battery. For this reason, Duke Energy did not test the voltage regulation capabilities of the Asheville Rock Hill battery resource.

Battery Regulation Test

The Greensmith Energy Management System (GEMS) was used to send setpoints to the Asheville Rock Hill BESS controller every 1-minute from zero (0) active power output to P_{min}, back to zero (0), then to P_{max} and back to zero (0). The facility is normally performing a droop-based frequency response operation if the controller senses a frequency deviation beyond the deadband.

Elm City Testing

Elm City is a standalone solar facility with an active power output interconnection limit of 40 MWac. The facility uses an Emerson/Ovation Power Plant Controller (PPC). It has been set up with a reactive power output limit at 95% power factor at its full interconnection output results in a Mvar limit of ±13.15 Mvar. Elm City is also assigned a voltage schedule in which it is to operate while producing active power into the transmission system.

Active Power Test Parameters

The active power setpoint test of the Elm City Solar facility was started just after 9:15 am, Friday, May 12, 2023. Active power test parameters were to generate a setpoint that reduced the active power output of the facility by ten (10) MWs from the facility's estimated capability based on current facility parameters and weather conditions. The setpoint was additionally offset to mimic frequency regulation by responding to deviations in the CPLE BAA ACE. Implementation of the setpoint within the PPC was done by manually entering the newly calculated setpoint approximately every 10 seconds into the facility's PPC. Setpoint calculation subtracted 10 MWs from the estimated yield calculation and would increase or decrease the result in response to a decrease or increase in ACE in proportion to Elm City's regulation response.

At the start of the test the facility was generating 22.1 MW with output increasing as the sun continued to rise. At 9:15 am, the Regulated Renewable Operating Center (RROC) made the first setpoint change from forty (40) MWs to the calculated 12.4 MW and kept changing the value every 10 seconds for the next 17 minutes to follow each new setpoint result. Results of the test are seen in Figure 3 below.

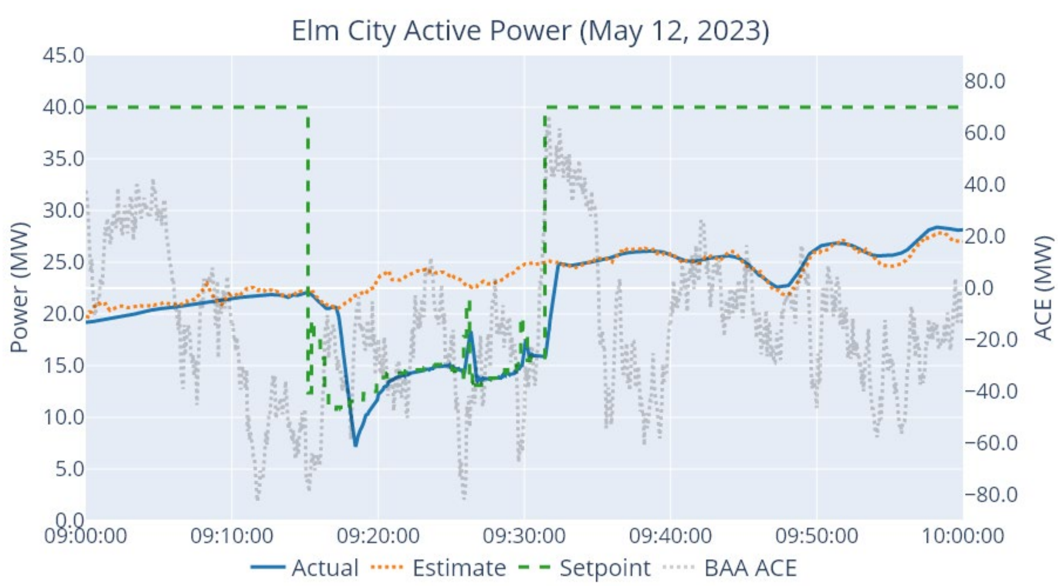

Figure 3 Elm City First Active Power Test - Site-Level Results

It took the PPC just over one (1) minute to start responding, but it then followed the setpoint relatively closely for the duration of the test. This delay was attributed to the starting setpoint being at the

Interconnection Agreement Limit (40 MW) and having to adjust down to the initial setpoint at approximately 12 MW. Also, the effects of the controller time delay and ramp limit are reflected in the response. At 09:24 and 09:29, the CPLE ACE went below the deadband causing the setpoint to increase proportionate with its allocation in response. As discussed above, initial response to the setpoint change was delayed until the PPC was able to overcome the difference between the original setpoint and the adjusted setpoint at the beginning of the test. Once the controller adjusted to this difference, the PPC followed the setpoint with a tight response.

Inverter-level response shows variability between the individual inverters that can be seen with the site-level aggregate active power injection when the facility is not being actively controlled. This variability is due to the size of the respective facilities and weather variations across their footprint along with variations between the inverters and panels themselves. As reflected in Figure 4, the variability mostly reduces once the inverters are controlled to an output below their full capability based on current irradiance.

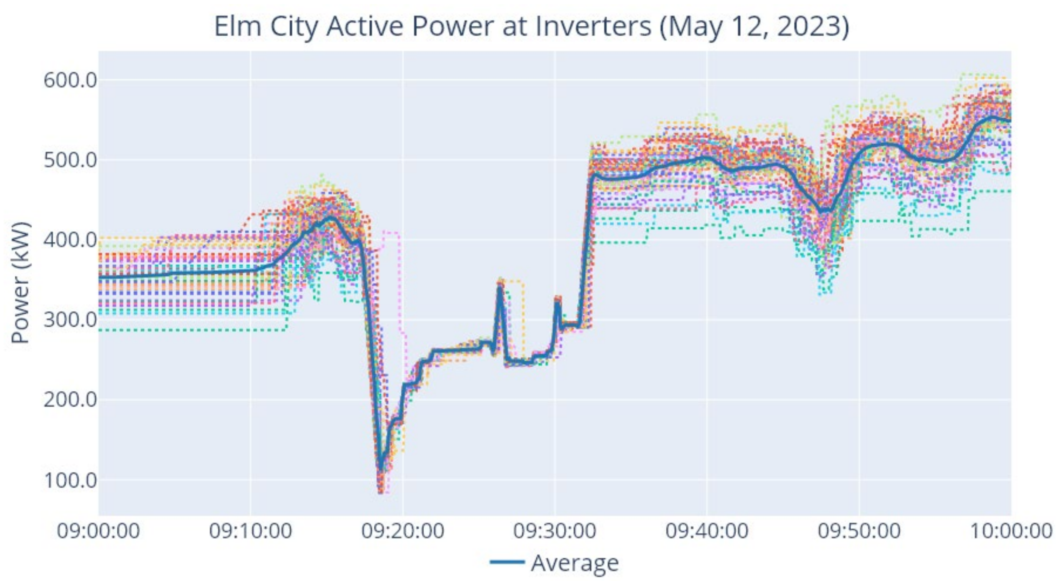

Figure 4 Elm City First Active Power Test - Inverter-Level Results

The second active power control test started at 12:32 with the site at full output as shown in Figure 5. During this test, the setpoint stayed mostly flat at 30 MWs, 10 MWs offset below the site's estimated yield except for small increases in response to ACE going slightly below the lower deadband. Implementation response at the start of the test window had less of a delay than the earlier test as the difference between the initial setpoint and the new setpoint was smaller.

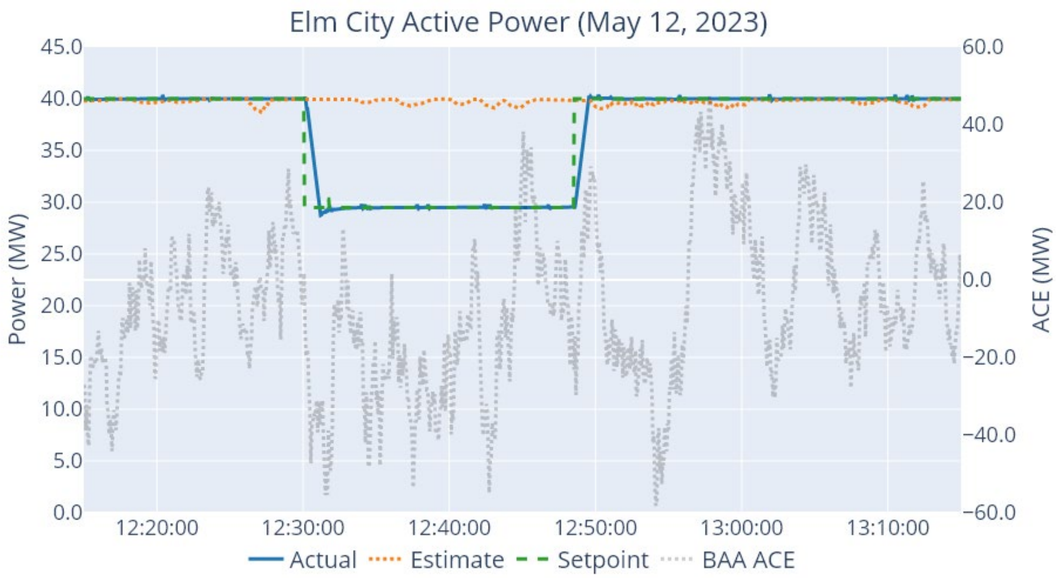

Figure 5 Elm City Second Active Power Test - Site-Level Results

Inverter-level response for the second active power test saw slightly less variability during the active power control window, but a much larger spread outside the test window. Figure 6 shows that some inverters were not able to reach the average yield, with the largest deficiency close to 20% lower than the average. All inverters reached the same active power output during the curtailment window. This larger deviation in inverter output points to the issue being proportional and most likely related to variations in panel and inverter capabilities.

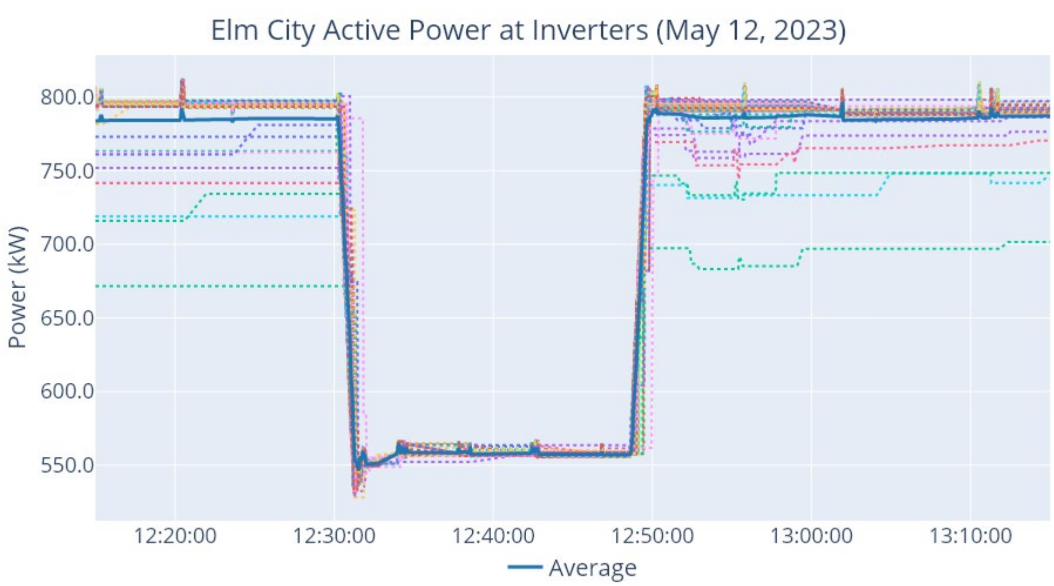

Figure 6 Elm City Second Active Power Test - Inverter-Level Results

Reactive Power Test

The Elm City reactive power test occurred in two (2) parts. The first part of the test was to manually modify the site reactive power output from zero (0) Mvar to full reactive power absorption, and the second was to determine the impact to the reactive power injections when the site active power output was reduced.

Site reactive power was increased from around 10 Mvar leading (absorbing) to zero (0) Mvar for the start of the test. Then the reactive power setpoint was stepped from zero (0) Mvar to 13 Mvar leading in increments of just over 3.1 Mvar. Site reactive power output followed the reactive power setpoint taking almost 2 minute to settle into the new setpoint value after each reactive power setpoint change.

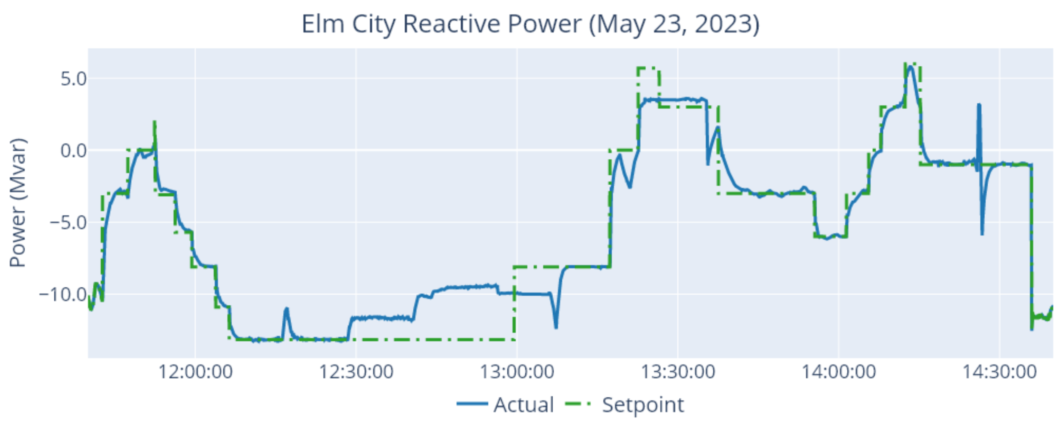

Figure 7 Elm City Reactive Power Response - Site Level

Inverter temperatures during this test rose proportionately until active power began to reduce, remaining in tolerance of the site engineering parameters.

At 13.1 Mvar leading, the site's active power was reduced from full output of 40 MW in 10 MW increments to determine if the site could maintain the level of Mvar absorption. After stepping active power output to 20 MW, reactive power absorption was reduced by approximately 1.5 Mvar. An additional 2.1 Mvar reduction occurred when the active power was reduced to 4 MW. After 20 minutes at 4 MW output, the site was returned to normal active power output.

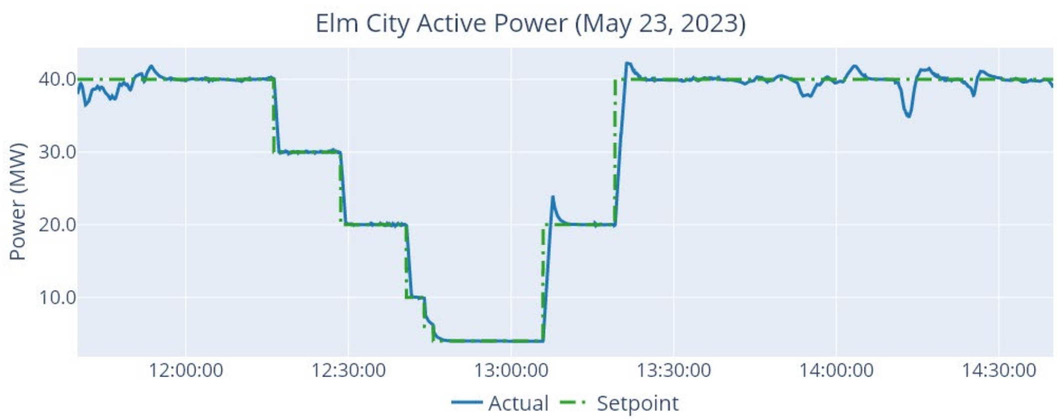

Figure 8 Elm City Active Power Response at Full Reactive Power Absorption

During this reactive power test, voltage trended down within its voltage range about 0.5 kV as expected when reactive power trended down. Bus voltage increased to approximately 1.5 kV as the reactive power moved from 13.1 Mvar leading to 3.5 Mvar lagging. The voltage increase was larger than would have occurred because a capacitor bank was energized in the region just after 12:52.

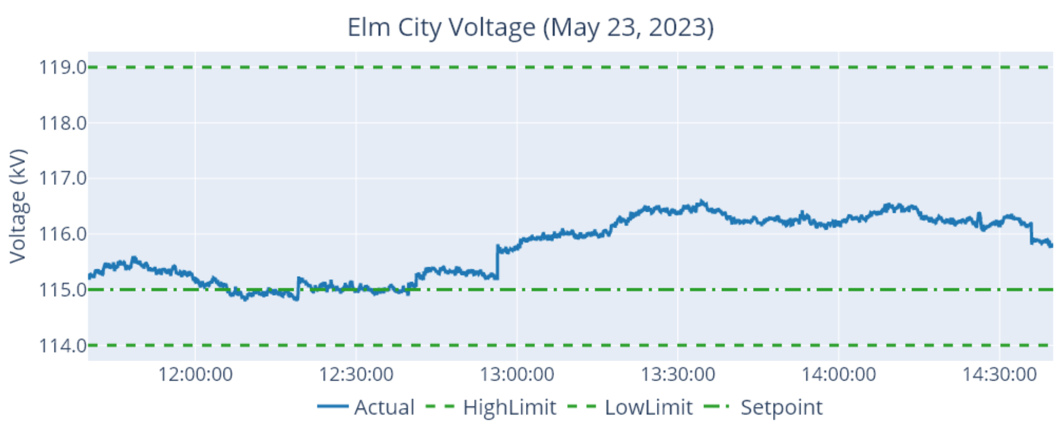

Figure 9 Elm City Voltage During Reactive Power Test

Monroe Testing

Monroe is a standalone solar facility with an active power output interconnection limit of 54.6 MWac and uses a Rockwell PPC. It has been set up with a reactive power output limits at 93% leading and 97% lagging power factor at its full interconnection output resulting a Mvar limit of +21.6/-13.7 Mvar. Monroe is also assigned a voltage schedule in which it is to operate while producing active power into the transmission system. Additionally, Monroe's voltage schedule target adjusts based on the day of the week and time of day to meet system needs as Monroe is connected at 100kV.

Active Power Setpoint Test

The active power setpoint test of the Monroe Solar facility was started just after 9:50 am, Friday, May 12, 2023. The setpoint was additionally offset to mimic frequency regulation by responding to deviations in the DUK BAA's ACE. Implementation of the setpoint was done by manually entering the newly calculated setpoint approximately every 10 seconds into the facility's PPC (PPC). Setpoint calculation subtracted 10 MWs from the estimated yield calculation and would increase or decrease the result in response to a decrease or increase in ACE in proportion to Monroe's regulation response.

At the start of the test the facility was generating 19.0 MW with output increasing as the sun continued to rise and cloud cover moved through the area. At 9:50 am, someone from the Regulated Renewable Operating Center (RROC) made the first setpoint change from forty (54) MWs to the calculated 5.4 MW and kept changing the value every 10 seconds for the next 20 minutes to follow each new setpoint result. Results of the test are seen in Figure 10 below.

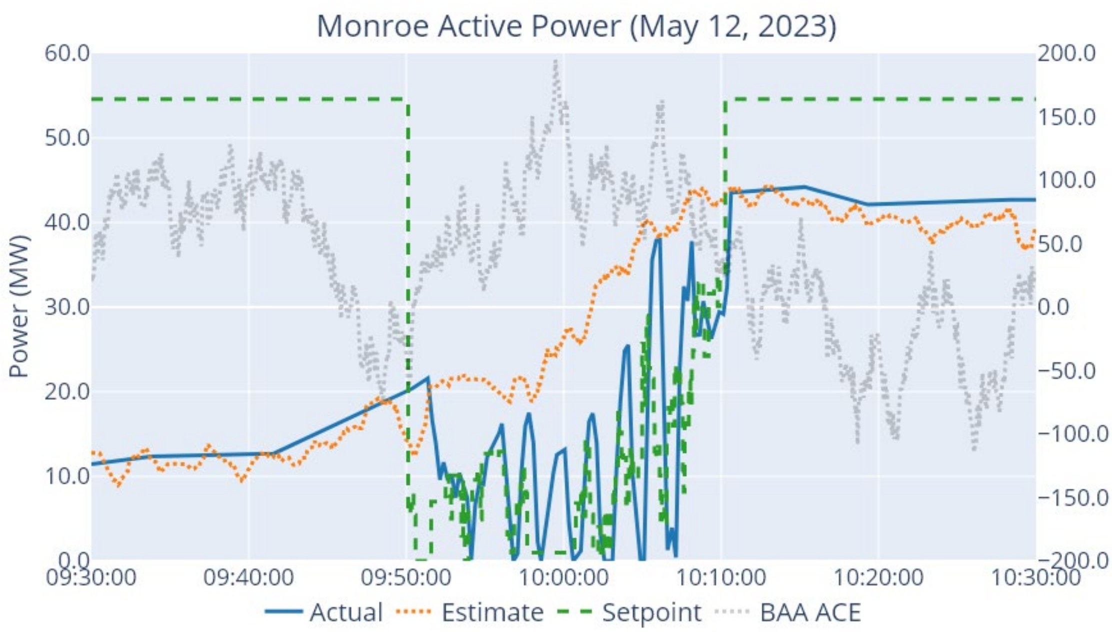

Figure 10 Monroe First Active Power Test - Site-Level Results

Like with the Elm City test, it also took this control over a minute to start responding. From 9:54 through the end of the end of the test window, ACE continually exceeded the upper deadband resulting in the setpoint changing to accommodate regulation response needs. The Monroe controller had some control response lag creating some delay in following the control setpoint. Variability of the weather along with this time delay with the plant controller increased the need for additional regulation response from other conventional resources during this test.

Also like with Elm City, individual inverters had different active power response injections due to the size of the site over many acres and the construction and performance variations between the different inverters and their associated panels. Once the site setpoint was reduced below the actual capability, all inverters maintained the same active power injection but for the small windows where the setpoint was close to the resource output capability. Inverter-level results can be seen in Figure 11.

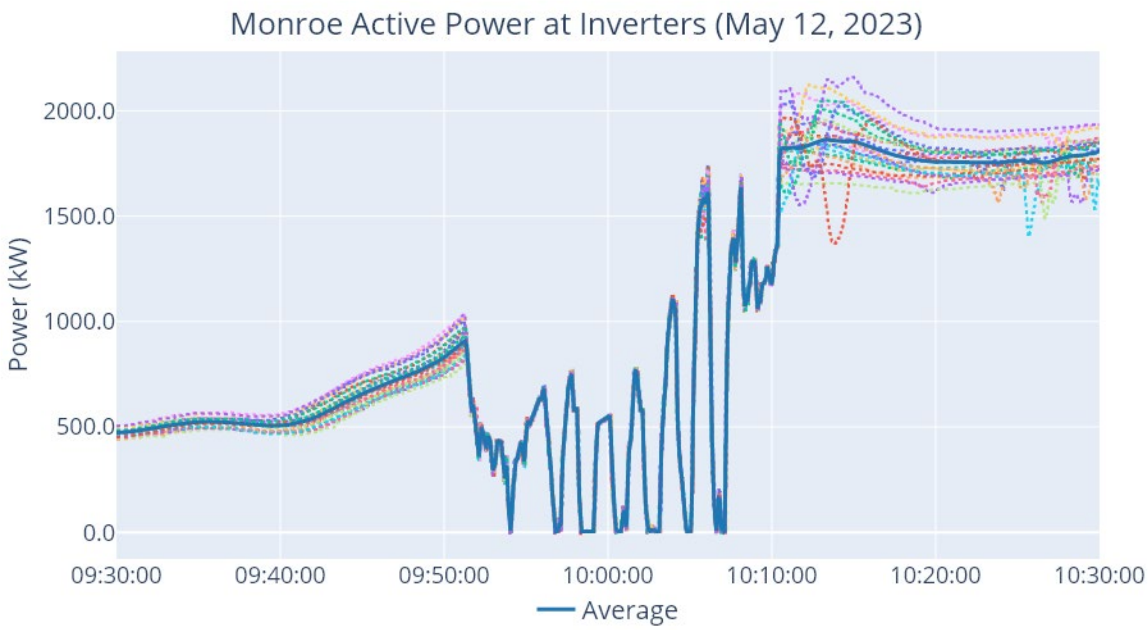

Figure 11 Monroe First Active Power Test - Inverter-Level Results

The second active power control test started at 12:00 with the site almost at full output as reflected with Figure 12. During this test, as with the morning test, the setpoint moved around as it tried to provide frequency regulation and in response to variations in cloud cover. Initially, the 10 MW setpoint was reduced due to ACE exceeding the upper deadband. At this point, the facility began to experience obscuration causing the setpoint to fall further to maintain the 10 MW offset, as frequency regulation was not needed. As the site capability continued to decline, ACE moved beyond the lower limit causing the setpoint to increase to provide regulation response. The variation in site capability due to intermittent cloud cover, coupled with frequency regulation needs continued for the remainder of the test.

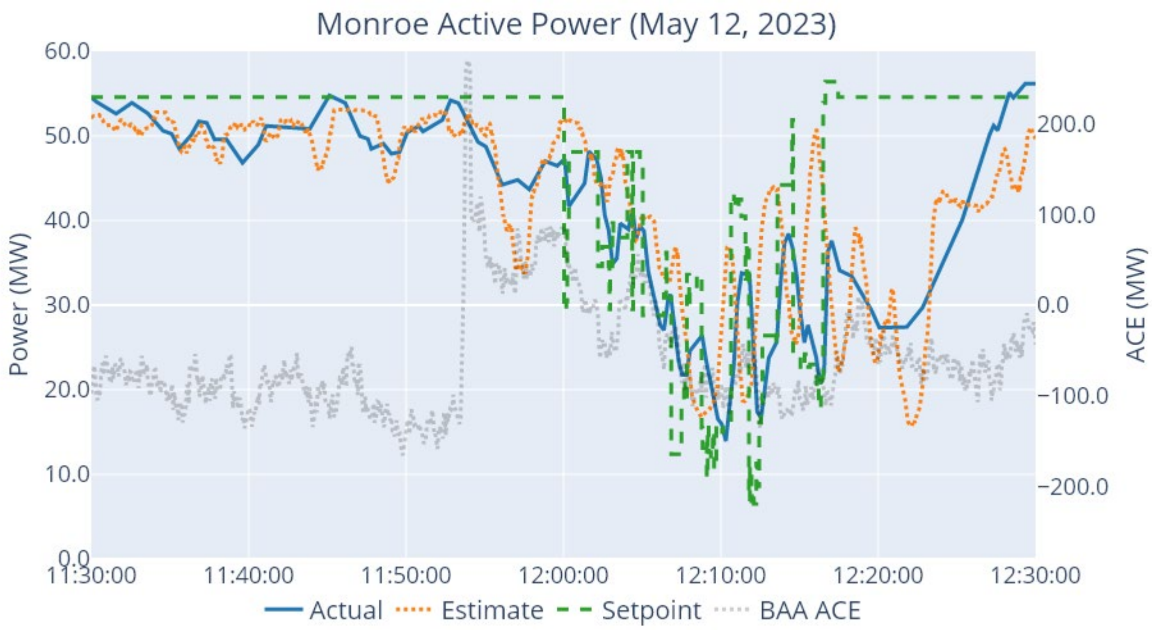

Figure 12 Monroe Second Active Power Test - Site-Level Results

Inverter-level response for the second active power test saw significant variability both during and outside the active power control window. It can be seen in Figure 13 that output between inverters varied significantly as well as response characteristics. Many of the inverters saw variations as large as 70%. This larger variation was predominantly related to variations in cloud cover.

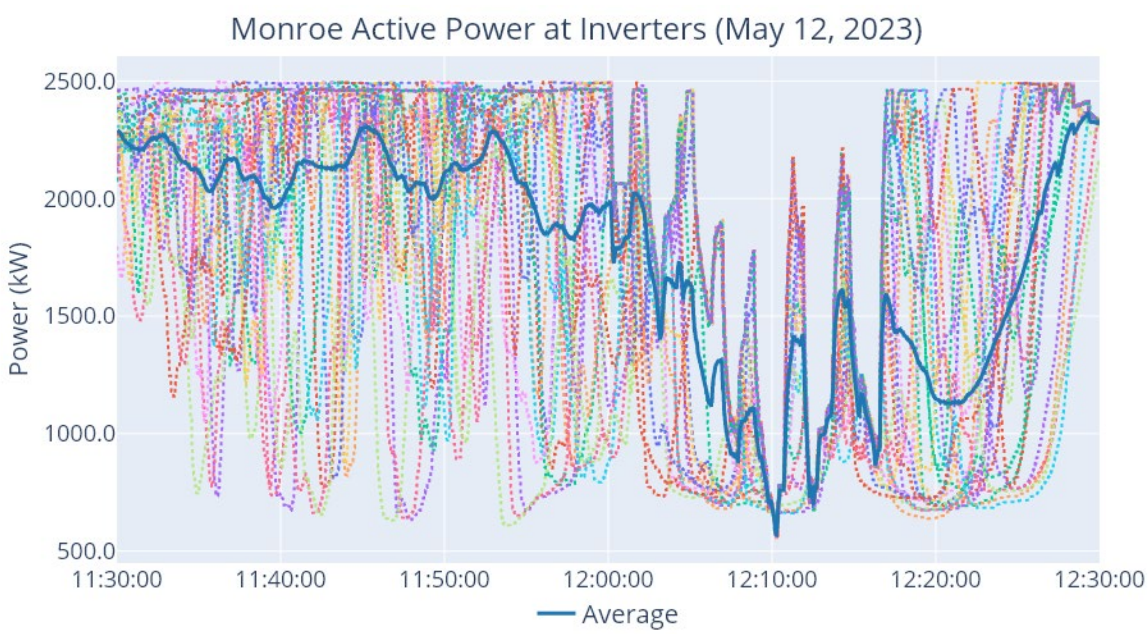

Figure 13 Monroe Second Active Power Test - Inverter-Level Results

Reactive Power Setpoint Test

On May 24, 2023, Duke Energy started to test the reactive power capabilities of the Monroe Solar site like the Elm City reactive power testing. However, the reactive power response was not properly following the manual setpoint signals being sent from RROC to the controller, so the testing was cancelled

The capability of the reactive power, Q-controller for the Monroe Solar facility was observed with PI data on May 28, 2023, to ensure the controller was still properly responding with Mvar injection/absorption for local voltage support. Figure 14 reflects this observation and concludes the Q-controller was operating properly for providing voltage support.

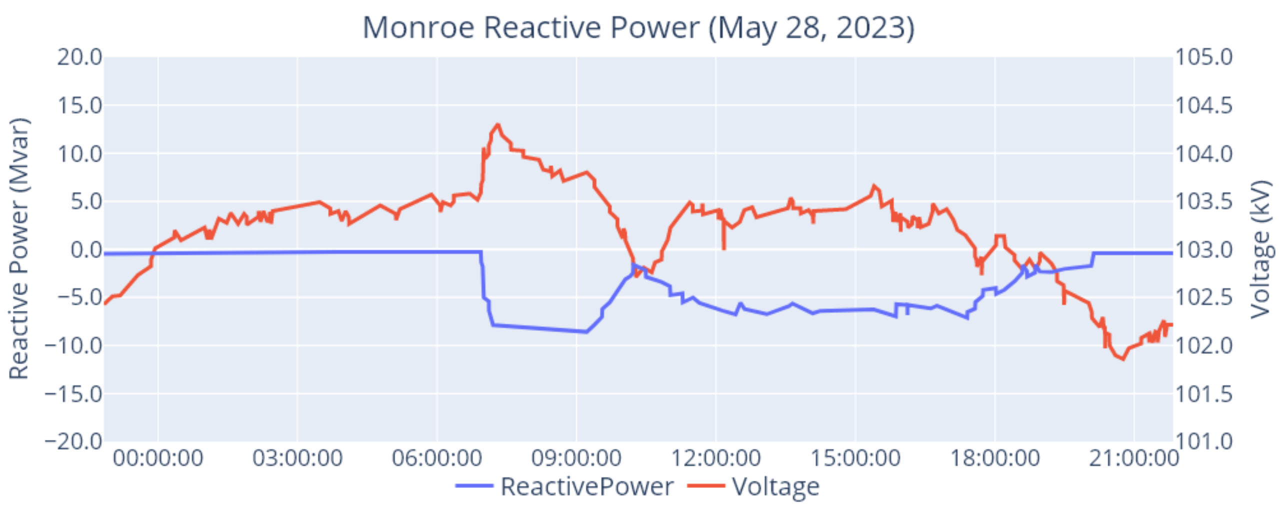

Figure 14 PI Data Reflecting Verification of Monroe Q-Controller Performance (+) Mvar = Absorbing

Asheville Rock Hill Test

During this test, the BESS active power setpoint was changed from zero (0) MW to -6.4 MW, then back to zero (0) MW, then 6.4 MW and back to zero (0) MW. These setpoint changes were implemented on 0.5 MW steps for the duration of the test. There was a control signal latency of 45 seconds identified from the time of the setpoint change to the time the response was measured. The results of this test are reflected in Figure 15.

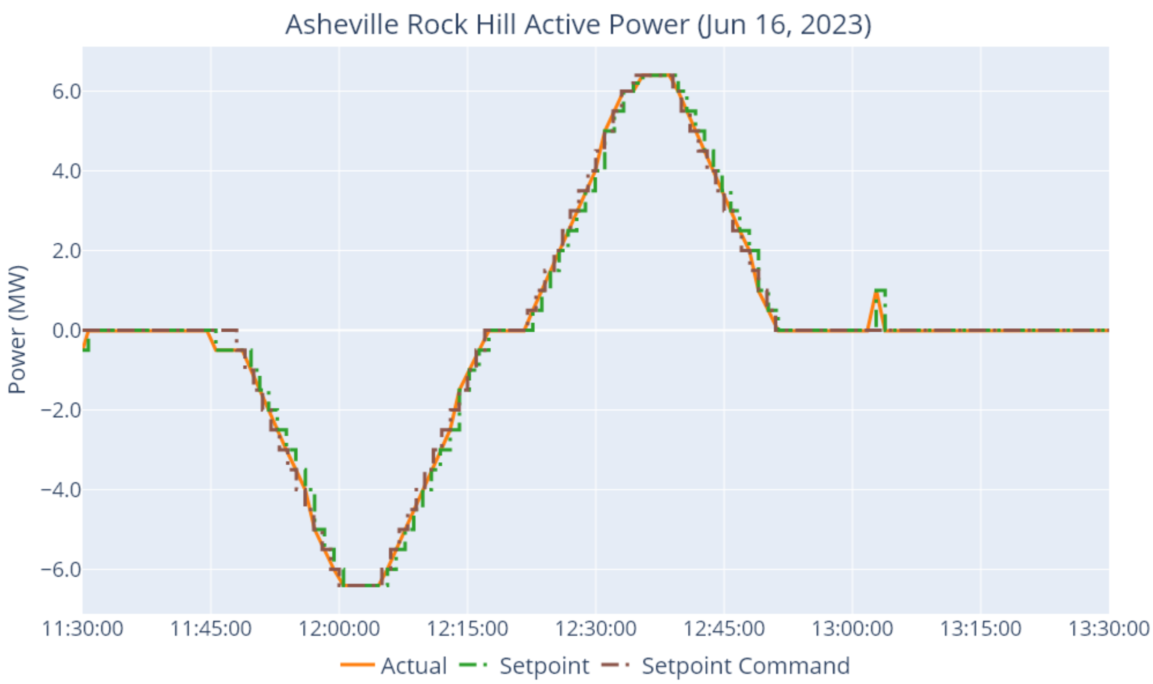

Figure 15 Asheville Rock Hill Active Power Response to Setpoint Control

Conclusions

1. While some IBRs are suitable for providing regulation, maintaining a regulation range with standalone solar on partly cloudy to mostly cloudy days is infeasible. Based on the Monroe Solar active power testing, trying to maintain the 10 MW regulation range during the intermittency created by cloud cover created the need for more regulation from conventional resources.
2. With respect to controllers, the Elm City Solar controller appeared to perform better than the Monroe Solar controller. It was observed that suboptimal control tuning can lead to a poor control system response. Parameters for IBR controls need to be tuned, verified, and tested to ensure the proper response and dampening. This control functionality comes at a cost for the testing itself, control system tuning engineers, telecommunications improvements, etc.
3. This testing highlights the importance of commissioning and monitoring of IBRs with respect to control system stability and capability to provide acceptable active power management and voltage support.
4. Reactive power management/voltage support is a service based on locational needs. This service has been provided successfully by transmission connected solar following a voltage schedule within power factor limits for several years now and will continue to be utilized from transmission-connected IBRs in the future to some degree as the locational need is determined by Transmission Planners.

Recommendations

Based on the short timeline (January – June 2023) to design and conduct the testing , additional testing with different, larger Duke-owned IBR resource types (standalone batteries and solar plus storage) could allow for design of the testing with plans to record more parameters for post testing data analytics to thoroughly evaluate the capabilities of IBRs to provide certain ancillary services. Additional testing would also allow for assessing the costs for the testing and the IBR design/modifications needed to provide the ancillary service. Duke Energy believes that further study and testing of different Duke-owned IBR resource types such as standalone batteries and solar plus storage, (resource types that will be significant in the future resource mix), will help determine whether a pilot program would be worthwhile.

This testing further illustrates that the industry must move forward with implementing enhanced commissioning and monitoring requirements for IBRs. And where monitoring reveals subpar performance, additional testing will be conducted, and recommended solutions will be provided.

CERTIFICATE OF SERVICE

I hereby certify that a copy of *Duke Energy Carolinas, LLC's and Duke Energy Progress, LLC's Inverter Based Resources Testing Report* filed in Docket No. E-100, Sub 175 was served electronically or via U.S. mail, first class postage prepaid, upon all parties of records.

This the 1st day of August, 2023.

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