TVA Solar Commissioning Experience

September 28, 2022

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Outline

- Interconnection Requirements for IBR Monitoring
- Testing
- Lessons Learned
- Post Commissioning – Operational Issues

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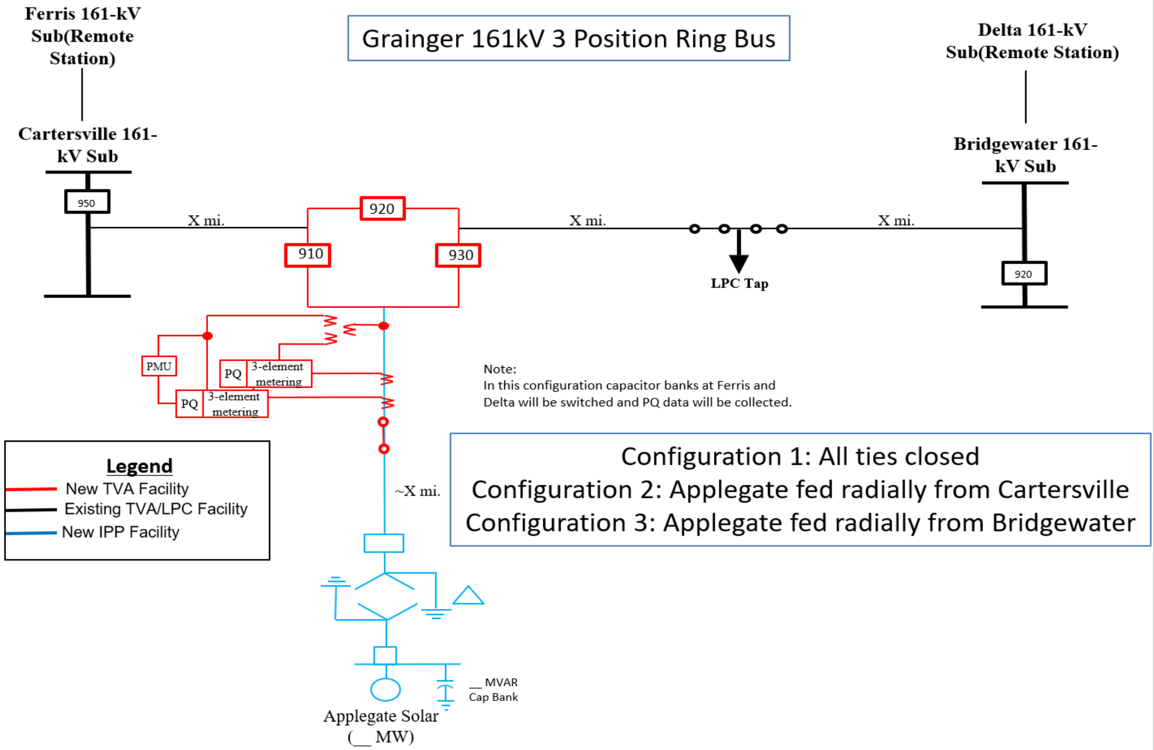
Interconnection Requirements for IBR Monitoring

Existing IBR Monitoring Requirements

- TVA requires a phasor measurement unit and PQ relay for TVA-connected inverter-based ESFs greater than 25MVA.
- For sites with IBRs less than 25MVA, a PQ relay may be required if the located in an area where know PQ issues exist.
- The data is regularly monitored, and the PMU data is sends SCADA alarms to the TVA's Operations group and trips for harmonic voltage distortion or other parameters when necessary

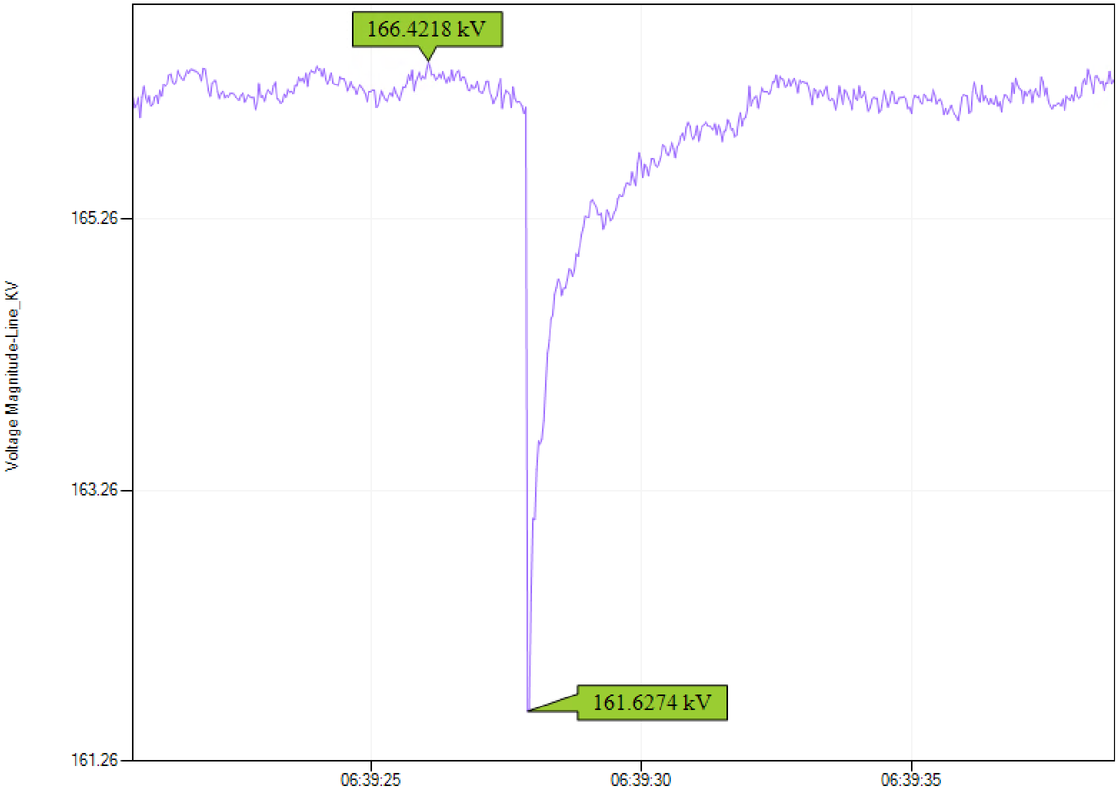


Testing using IBR Monitoring

Part 1: Voltage Flicker Test

- Purpose: To ensure the Facility is designed and operated so the energization of the Main Step-Up Transformer will not induce a voltage sag on the TVA transmission system exceeding 5%.

- Testing: Energize main power transformer and energize one secondary collector system transformer at a time until all secondary transformers are energized.



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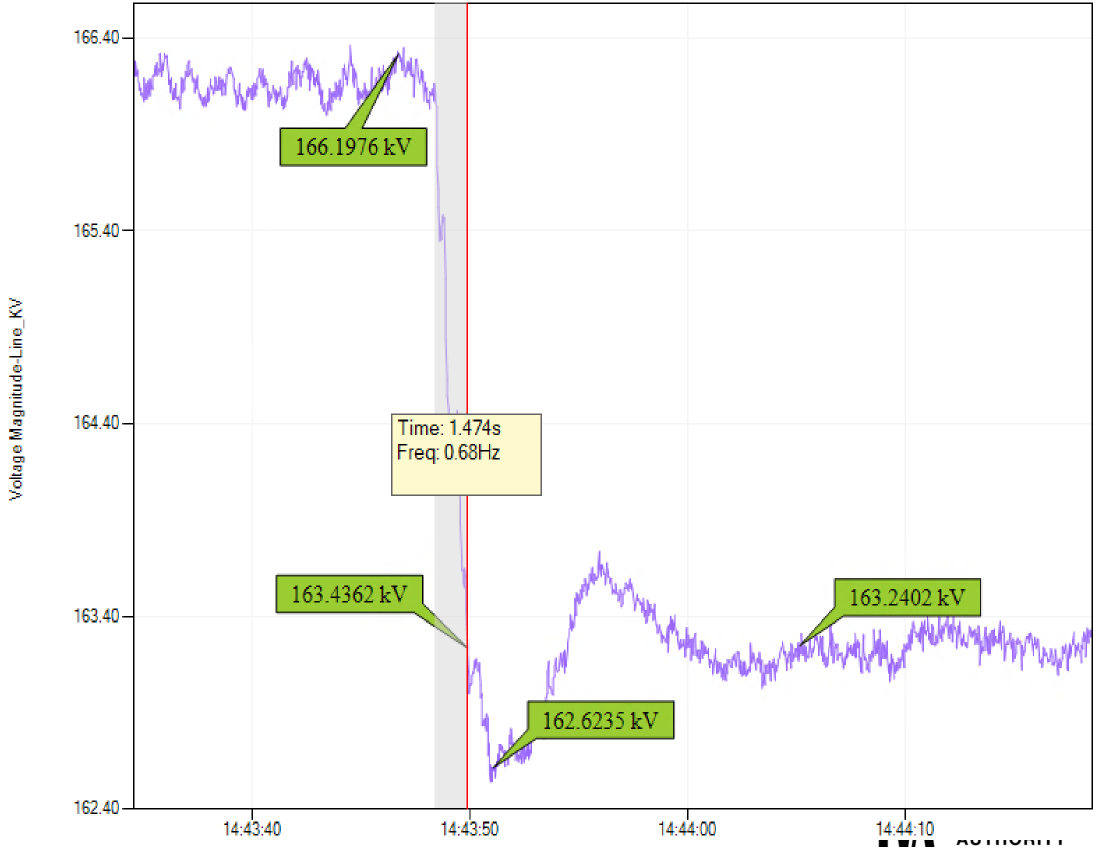
Part 2: Voltage Step Test

- Purpose: Verify the Facility's voltage regulation equipment is sufficient to prevent causing excessive voltage variation on the TVA transmission system.

- Testing: Adjust the automatic voltage regulator set point 4kV above and below the initial set point and verify the voltage control response is less than two seconds for weak system conditions and should not exceed thirty seconds for the all ties closed condition.

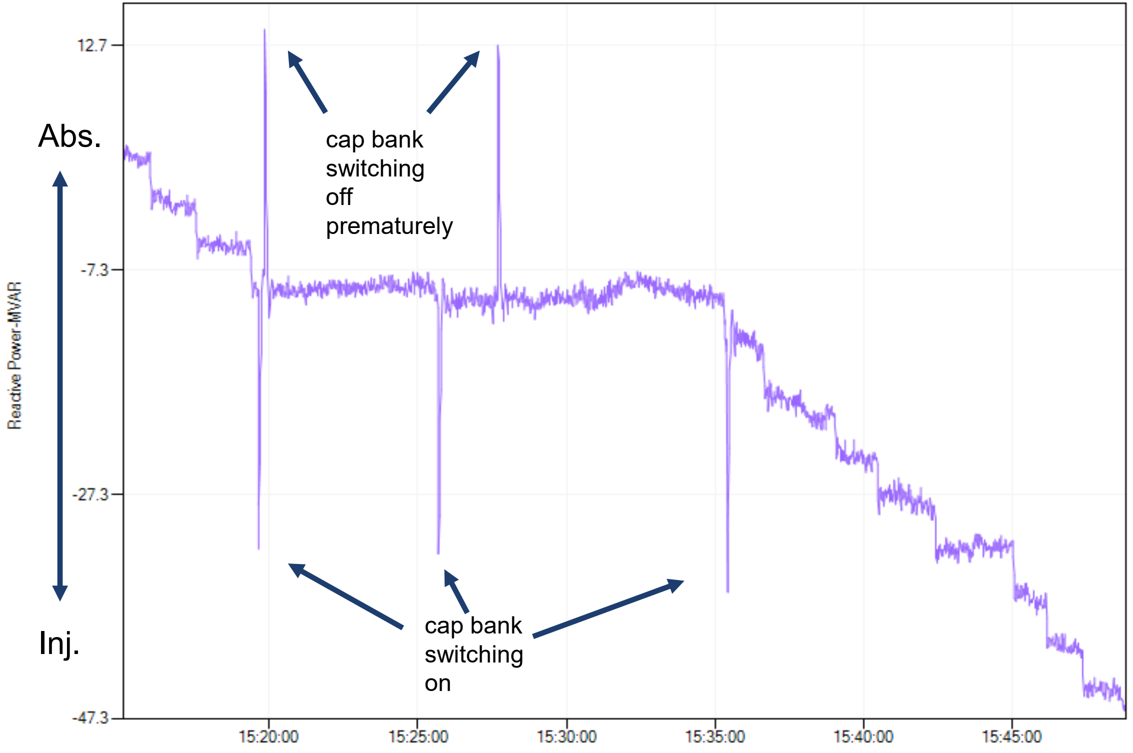
- Overshoot is measured to verify that damping ratio is sufficient



Part 3: Reactive Capability Test

- Purpose: Demonstrate the Facility can provide dynamic reactive power within the range of 0.95 lagging to 0.95 leading at the generator bus at continuous rated power output.

- Testing: Adjust the voltage set point of the Facility in increments of 0.5kV until the required reactive power output/absorption is met.



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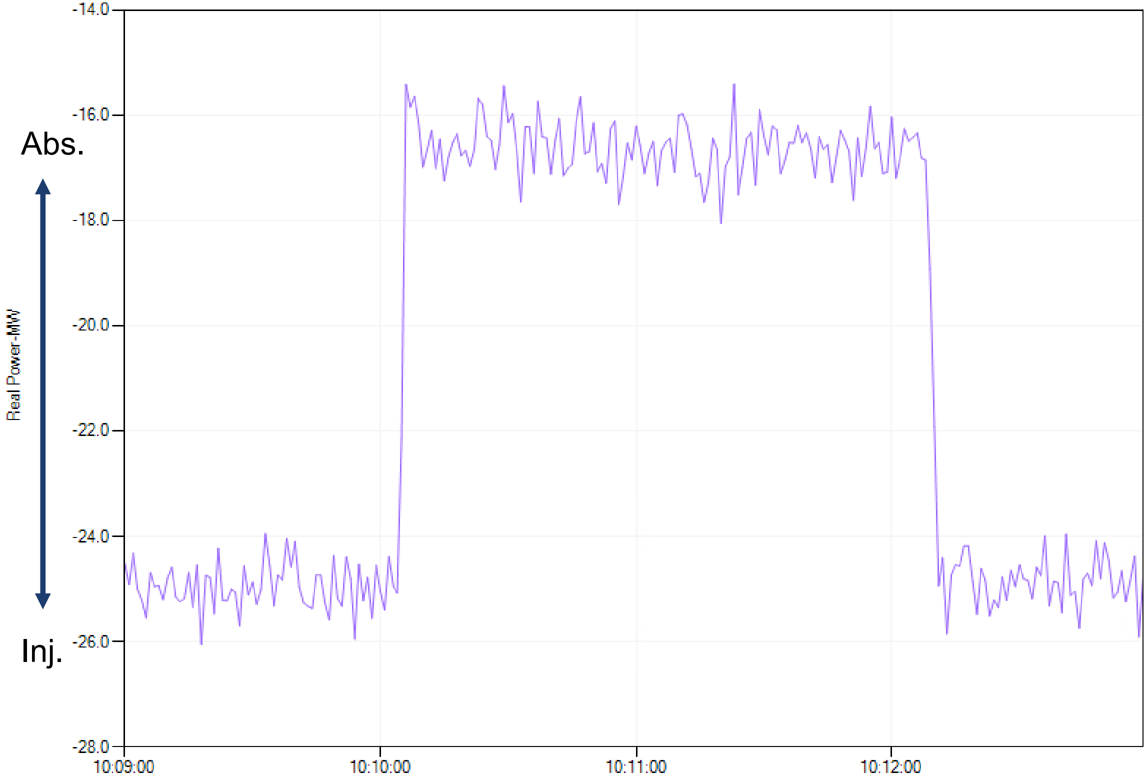
Part 4: Frequency Response Test

- Purpose: Show the Facility can autonomously adjust the real power output within the droop and dead band parameters in the direction needed to correct frequency deviations.

- Testing: Adjust frequency offset to simulate a frequency mismatch between the Facility and the TVA transmission system and measure the real output response. Initiate a loss a communication to some of the inverters, adjust the frequency offset and measure the real power output response.

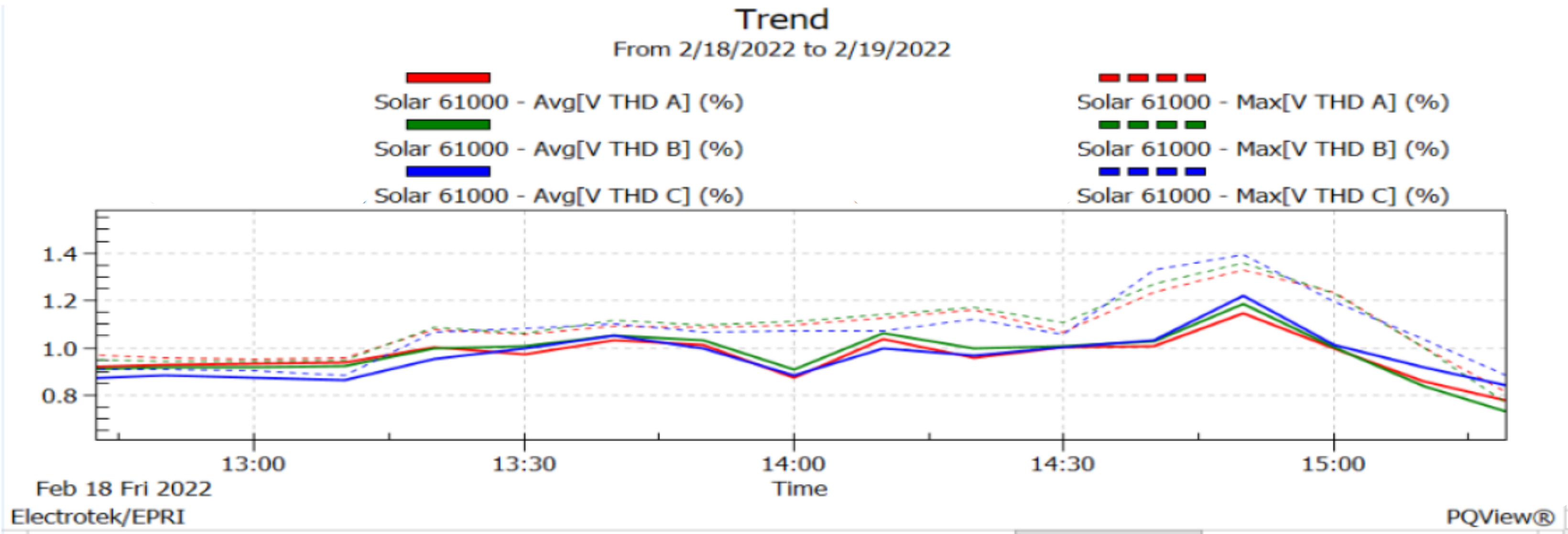
- Overshoot is measured to verify that damping ratio is sufficient.



Part 5: Distortion Test

- Purpose: Validate the Facility's production of total harmonic distortion and individual harmonic distortion injected into the TVA transmission system is below the levels specified in IEEE 519.

- Testing: Switch in local and remote capacitor banks and record the harmonic distortion measured at the point of interconnection.



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Commissioning – Lessons Learned

PV Commissioning – Lessons Learned

Commissioning Experience to Date

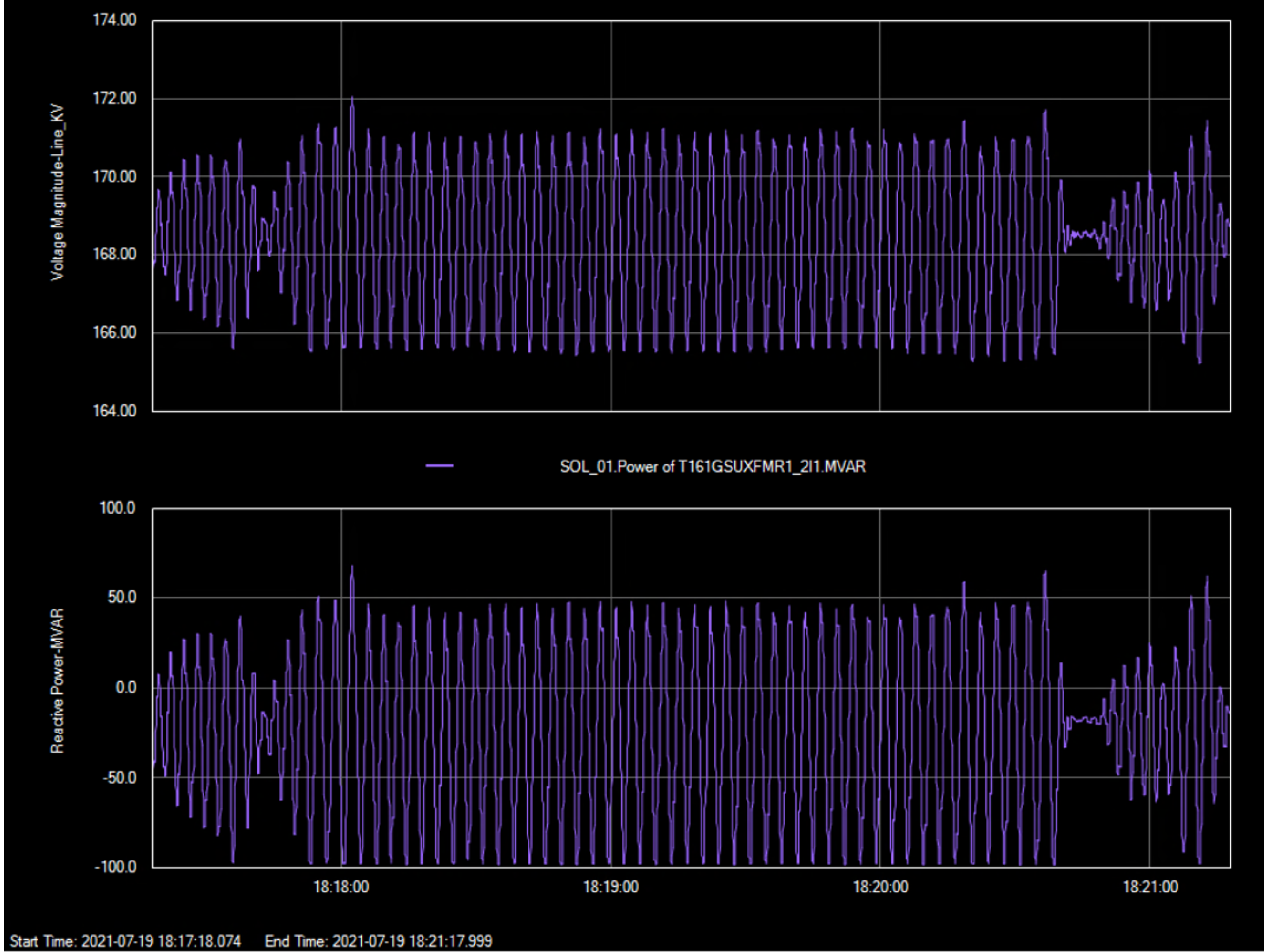
- Commissioning / testing procedures revised in 2021
- Two plants have completed the new process:
  - Plant 1: 227 MW PV (September 2021)
  - Plant 2: 150 MW PV (March 2022)
  - Both plants are connected to a 161-kV line with the feed from one direction being significantly stronger than the other.
- Test procedures were refined for Plant 2 to incorporate lessons learned from Plant 1

PV Commissioning – Lessons Learned

Plant 1

- PSCAD model for PPC did not match installed equipment.
- Numerous modeling parameters for inverter and PPC did not align with installed equipment. Signal time delays not incorporated.
- Performance issues were observed <u>before</u> testing began.
- Issues noted before testing:
  - Reactive power oscillations
  - Real power oscillations (or pulsing)

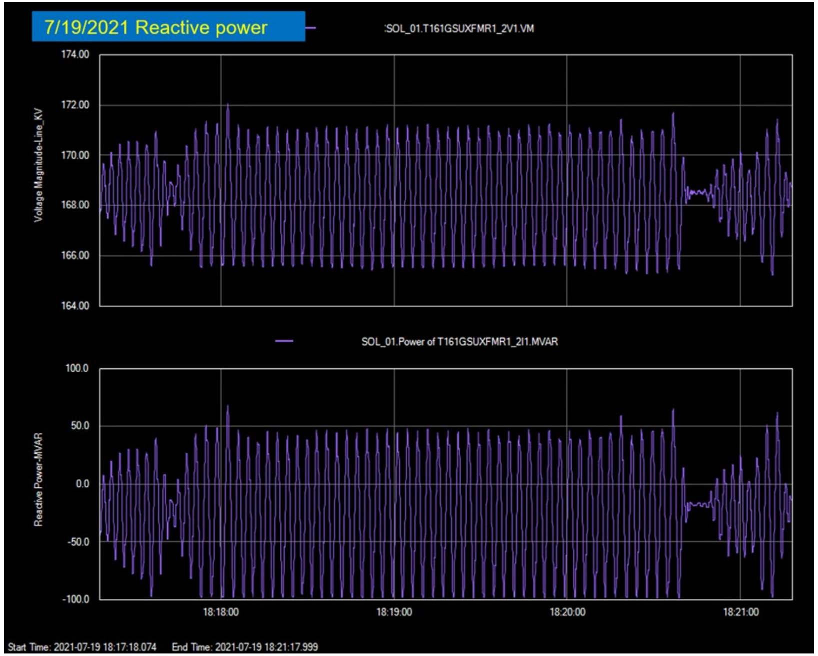
7/19/2021 Reactive power

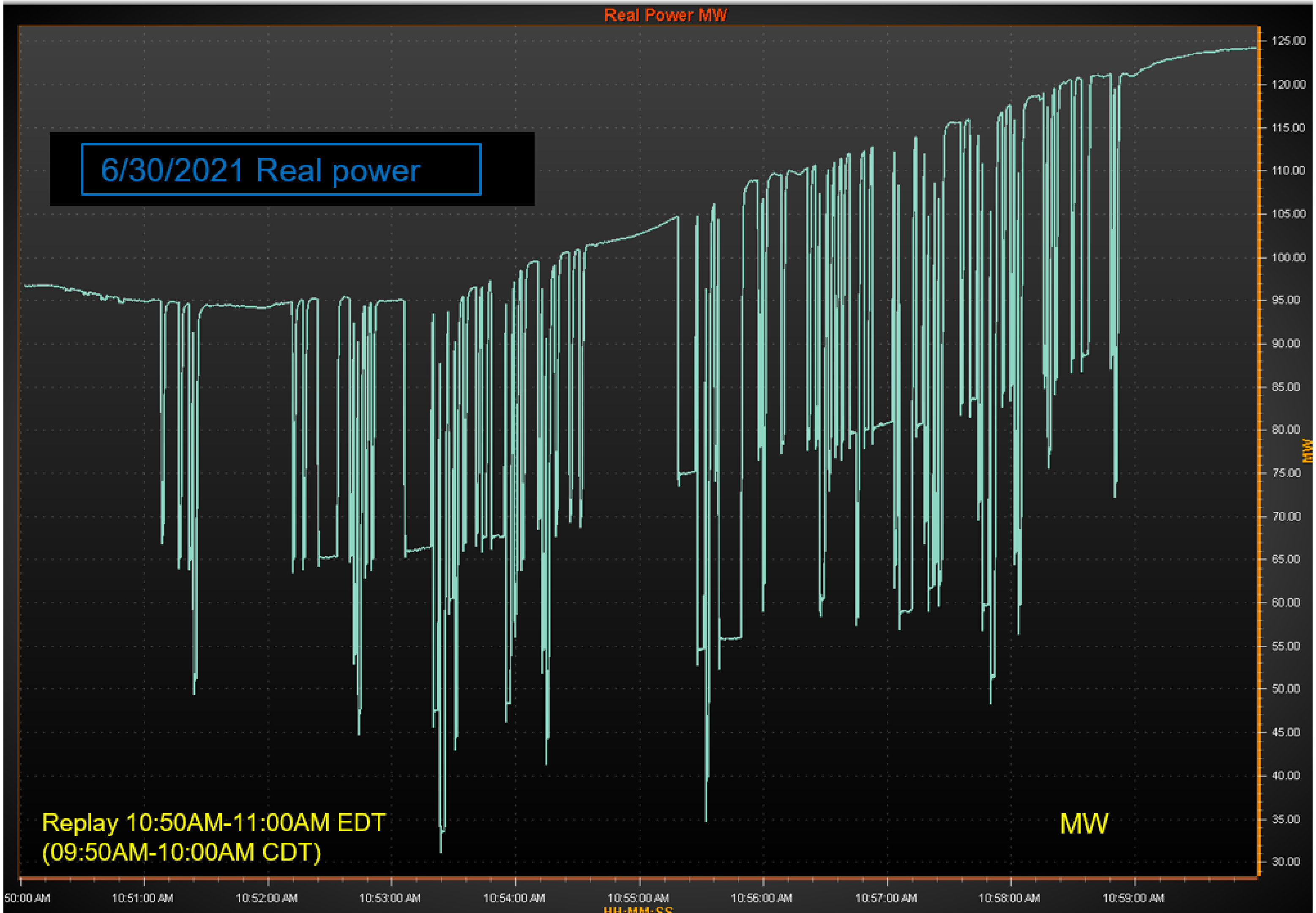


PV Commissioning – Lessons Learned

Plant 1 - Reactive Power Oscillations

- Caused by aggressive tuning to meet 2 second rise time requirement for voltage step test.
- Oscillations occurred during normal configuration (all ties closed)
- Weaker configurations, such as strong-source out, were not considered during plant tuning.
- Plant retuned voltage controller for 2 second rise time during weak condition with strong-source out. Note this resulted in a 20 second rise time for normal conditions.



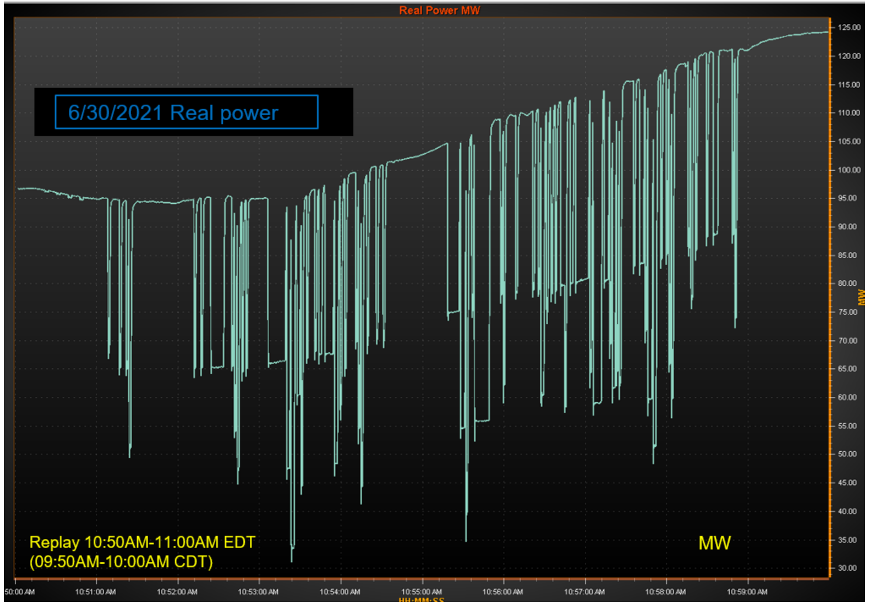


Real Power MW
6/30/2021 Real power
125.00
120.00
115.00
110.00
105.00
100.00
95.00
90.00
85.00
80.00
75.00
70.00
65.00
60.00
55.00
50.00
45.00
40.00
35.00
30.00
MW
Replay 10:50AM-11:00AM EDT
(09:50AM-10:00AM CDT)
MW
50:00 AM
10:51:00 AM
10:52:00 AM
10:53:00 AM
10:54:00 AM
10:55:00 AM
10:56:00 AM
10:57:00 AM
10:58:00 AM
10:59:00 AM

PV Commissioning – Lessons Learned

Plant 1 - Real Power Oscillations

- Caused by algorithm used to account for unconnected inverters for primary frequency response.
- Problem would occur when system frequency would go above 60.036 Hz (upper deadband). When this happened, the plant controller would activate curtailment mode and assume that non-communicating inverters were at full output to prevent exceeding curtailment limits.
- Contributing to the problem was a cut fiber line to inverters.
- This issue occurred multiple times and lasted for extended durations (10+ minutes)
- Could have been a major impact to local chemical plant if strong source had been out of service during event.
- A solution was worked out to ramp inverters down to zero for loss of communications and temporarily disable PFR during the ramp down.



PV Commissioning – Lessons Learned

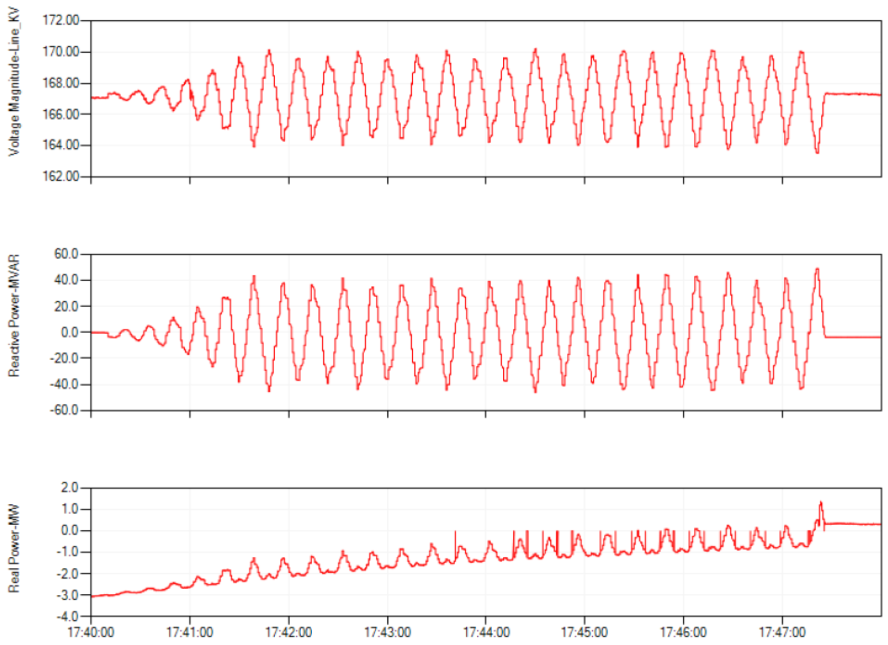
Plant 2

- PSCAD model for PPC did not match installed equipment.
- Some modeling parameters for inverter and PPC did not align with installed equipment.
- Issues noted during testing:
  - Frequency response not activated unless plant is curtailed
  - Cap bank pre-maturely tripping
  - Sluggish voltage response required retuning
  - Improper voltage regulation calibration. No line drop compensation for gen-tie line.
  - Frequency response overshoot
  - Reactive power oscillations at startup and shutdown

PV Commissioning – Lessons Learned

Plant 2 - Reactive Power Oscillations (March 2022)

- Occurred during evening when solar output winding down (3 MW)
- Occurred three days in a row during burn-in period
- Problem addressed by greatly restricting the reactive power ramp rate for low power outputs



Post Commissioning – Operational Issues

Post Commissioning Issues

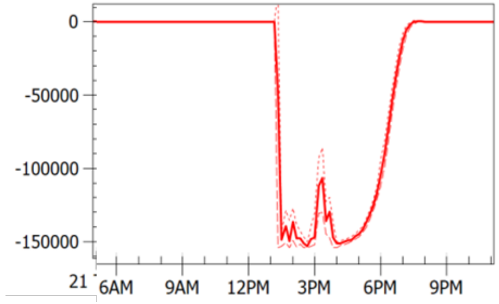
Plant 1 Output Reduction and Delayed Recovery for Nearby Ground Fault

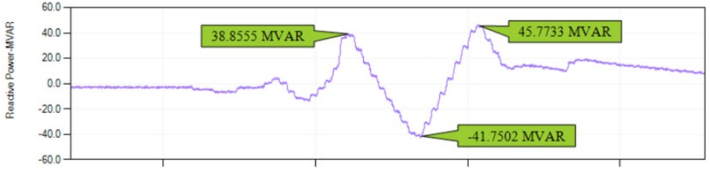
- A normally cleared phase-to-ground fault occurred on the 161kV system about 40 miles from POI
- Plant 1 was operating at about 15% output and reduced power from 34 MW to 24 MW and took about 15 seconds to recover
- POI voltage did not fall below LVRT threshold and plant did not report entering LVRT
- PSCAD model shows near immediate recovery
- Working with GO and OEM to address both plant performance and modeling issues

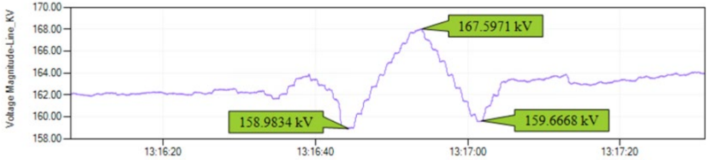
Post Commissioning Issues

Plant 2 Reactive Power Oscillations (Apr 2022)

- Primary Frequency Response (PFR) was enabled during plant startup as frequency was below lower deadband 59.964
- PFR is set to disable ramp rate and latches for 4 seconds.
- After 4 seconds, there is a pause until frequency goes below deadband again.
- Still being investigated, but it appears the high ramp rate may have triggered a reactive power oscillation.



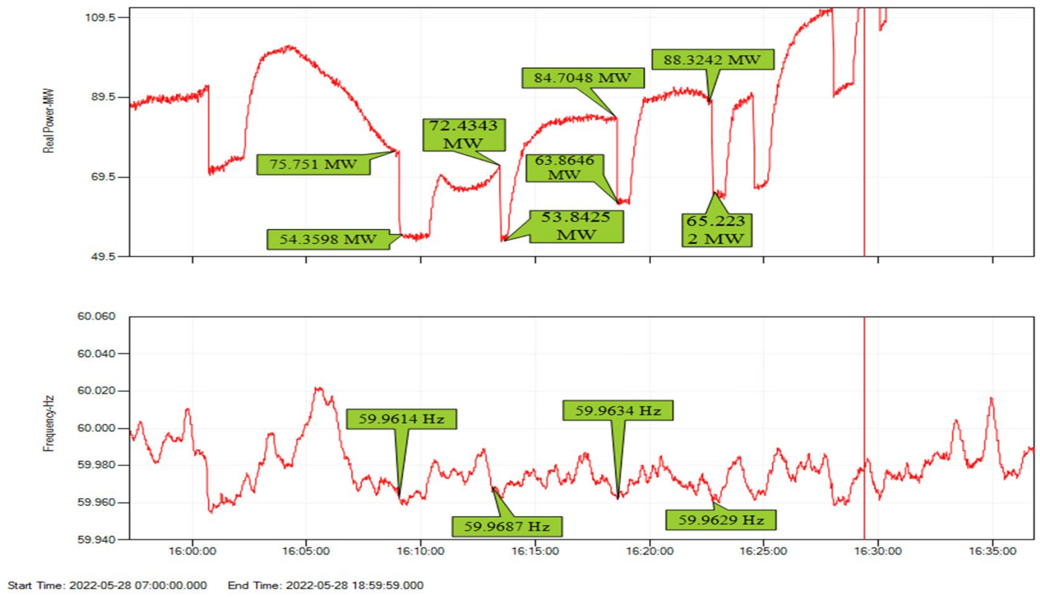




Post Commissioning Issues

Plant 2 Primary Frequency Response Issues (May 2022)

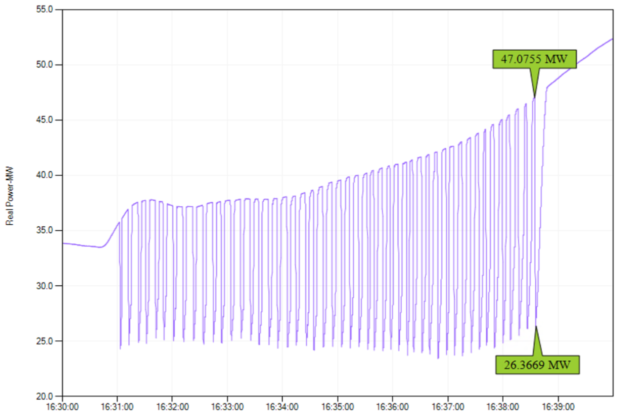
- Problem: It appears there is potentially an issue with the way the inverter controls respond when it measures a system frequency below 59.964Hz. The drops should be an increase in real power and only be a fraction of a MW, but the plant is reducing power in the 20-25MW range.
- Solution: GO reprogrammed PFR controller. TVA has not retested new controls.

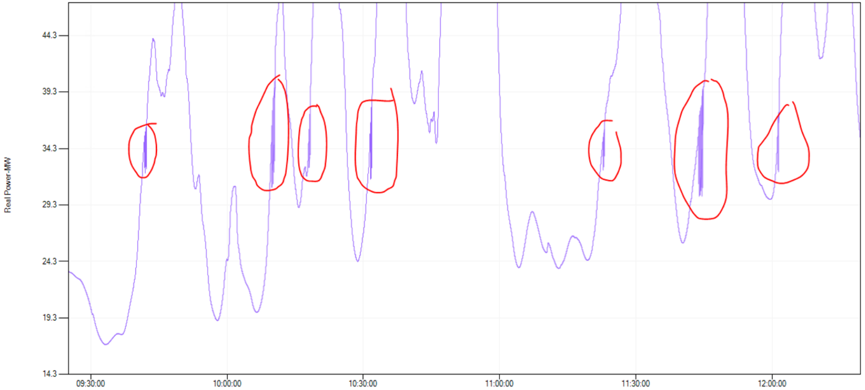


Post Commissioning Issues

Plant 0 Real Power Oscillations

- Plant 0 is a 75 MW solar plant that has been operating for several years
- Operational data has shown frequent 20 MW power swings occurring for a duration of about 10 seconds
- Appears to occur while plant is ramping up and crossing the 50% power threshold
- Unknown how long this condition has been present as it is just beneath our threshold for alarming.
- GO is presently looking into this issue.





Questions?

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