Nighttime Reactive Power Support from Solar PV Inverters

Aminul Huque, PhD
Program Manager, EPRI

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Motivation and Research Questions

- Proliferation of solar PV and growing adoption of EVs are increasing net load variations, which can make voltage regulation challenging for distribution system operators.
- Distributed Energy Resources, like PV and Energy Storage inverters can provide voltage regulation support by modifying their reactive power output through different control functions including power factor, volt-var, watt-var, and watt-PF.
- Proper understanding of this capability, its associated cost, and real-world demonstrations will help utility planners and operators consider PV inverters as potential resources to address growing voltage management challenges.

- Can solar PV inverter provide continuous voltage regulation support during day and night?
- How much active power a PV inverter or plant need to stay in operation and absorb/inject reactive power during nighttime?

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Laboratory Evaluation

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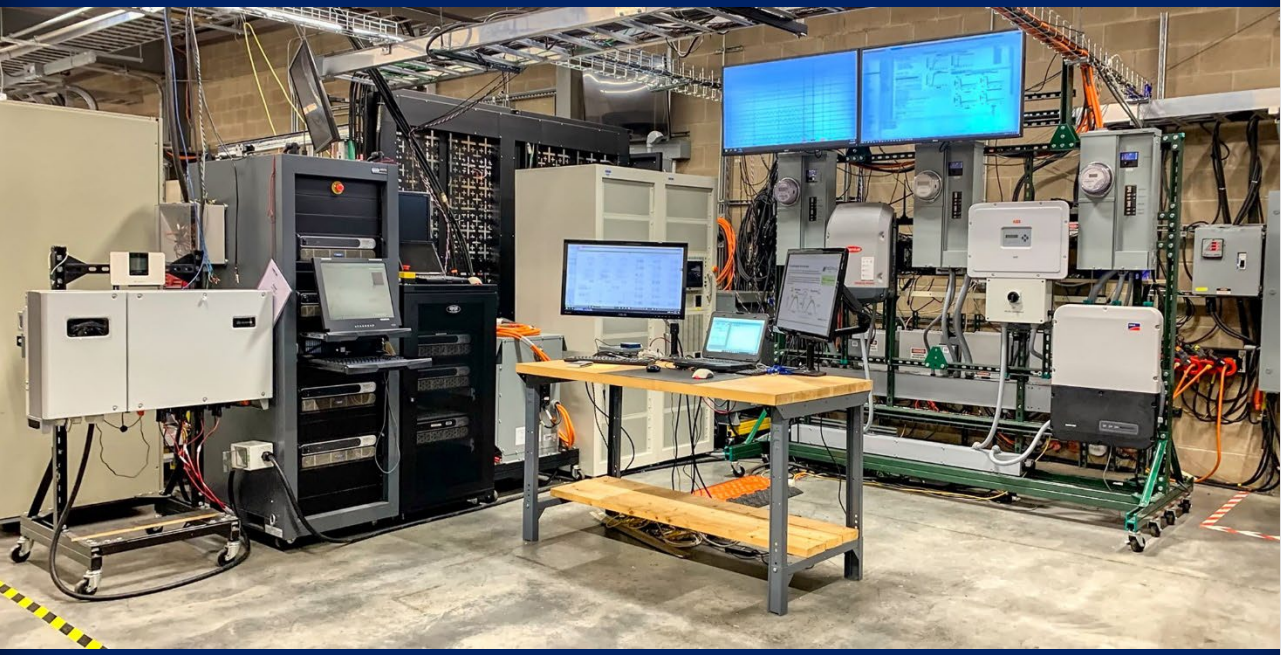
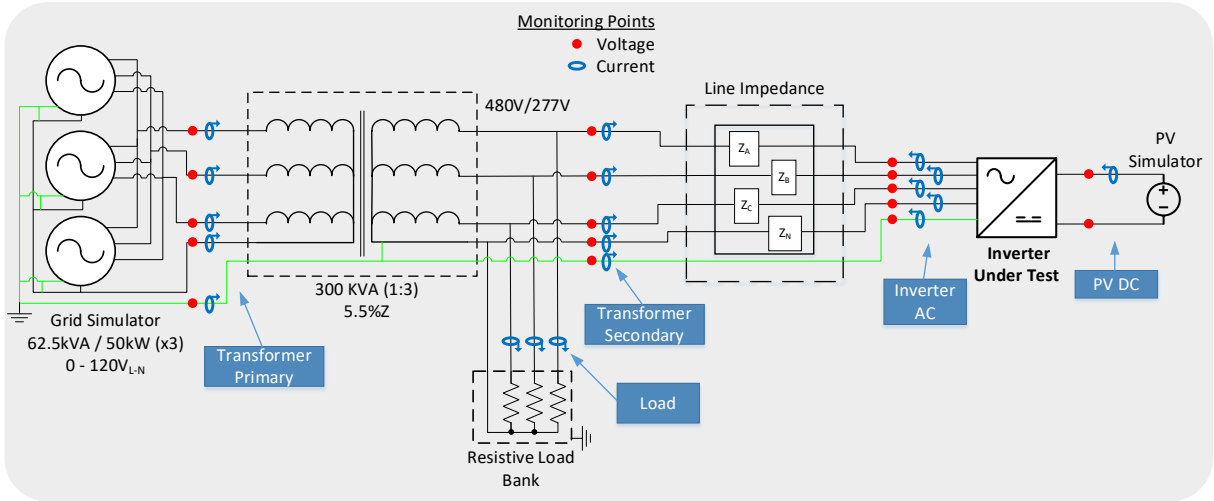
Objectives and Setup



EPRI Laboratory in Knoxville, Tennessee, USA

- A 33kW three-phase solar PV inverter was tested to evaluate its ability to provide reactive power support during nighttime.
- Active power demand to stay active during night and to absorb or inject different magnitudes of reactive power was measured.



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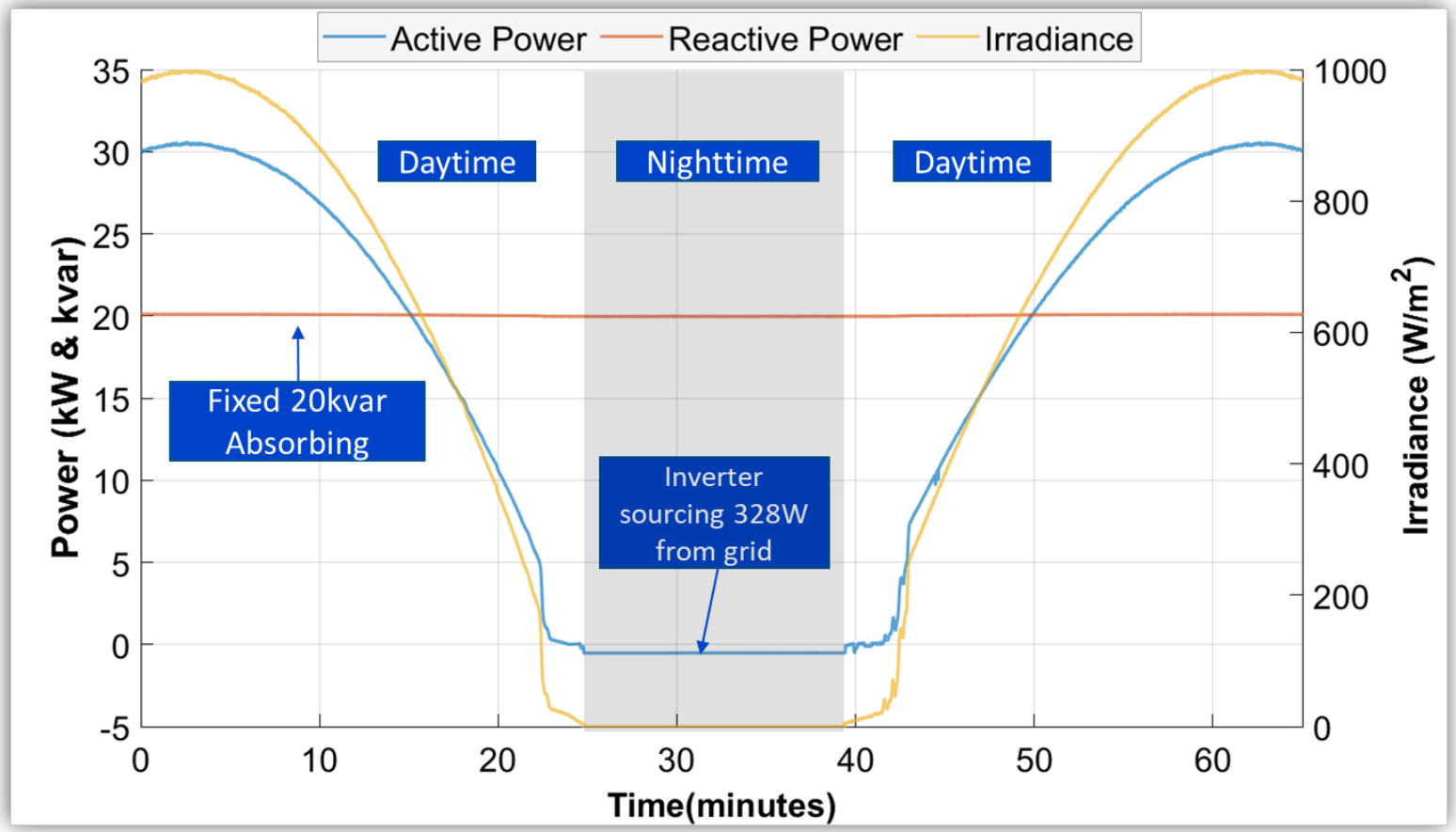
Can a PV Inverter Provide Uninterrupted Q-Support Day and Night?

- A clear sunny day solar profile was condensed into a 60 min test
- "**Reactive power output at night**" setting was enabled to keep the inverter in operation during nighttime
- Was commanded to absorb 20 kvar



The PV inverter tested was able to maintain the reactive power absorption continuously during the daytime to nighttime transition and vice versa

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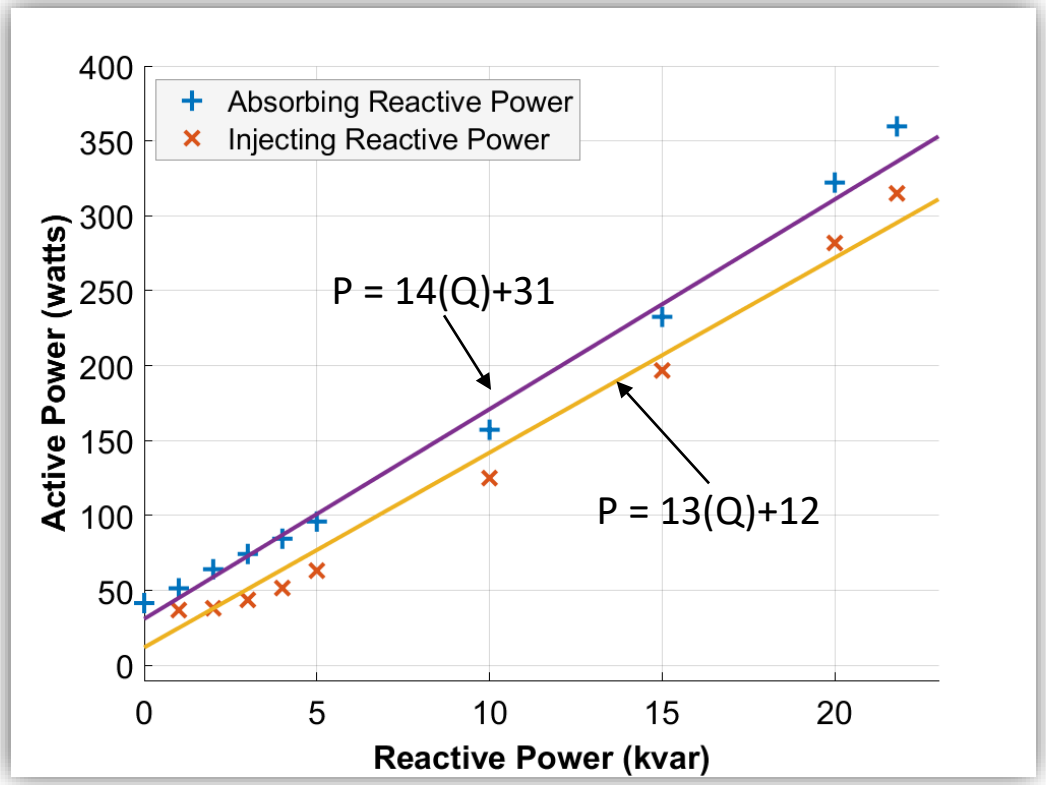
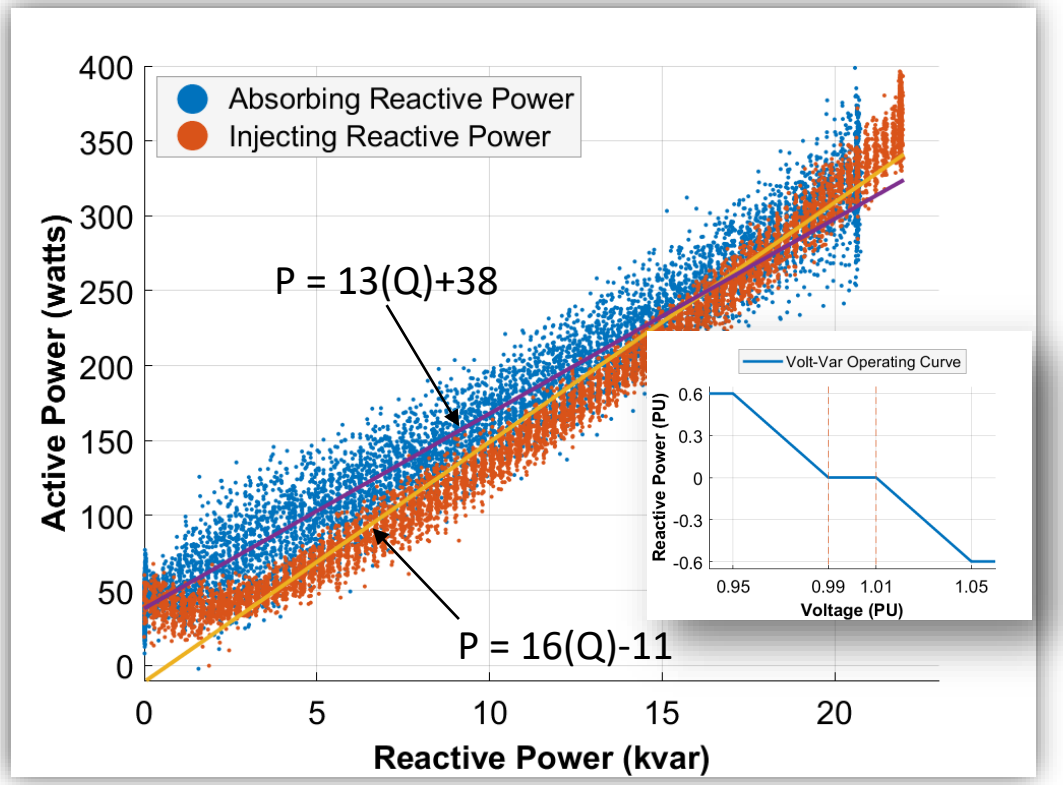
Q at Night – Two Control Modes

Fixed Reactive Power



Volt-Var



- Average active power demand was **35 W + 14 W/kvar** sourced from the grid

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Field Demonstration and Performance Assessment

Reference: Inverter-based Resource Control for Grid Support: Advanced Solar Photovoltaic Plus Energy Storage System Demonstration and Technology Assessment. EPRI, Palo Alto, CA: 2021. 3002023056

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Solar PV Site Specifications

- Located in California, USA
- Connected to 240 kV transmission system.
- 120.09 MW_{DC} and 105.094 MW_{AC}
- 90 MW power injection limit, per interconnection agreement
- Thirty-two power blocks
  - thirty equipped with 3.2 MVA central PV inverters
  - one with thirty-three 100 kVA string inverters
  - one configured with dc-coupled PV plus energy storage for different research objectives

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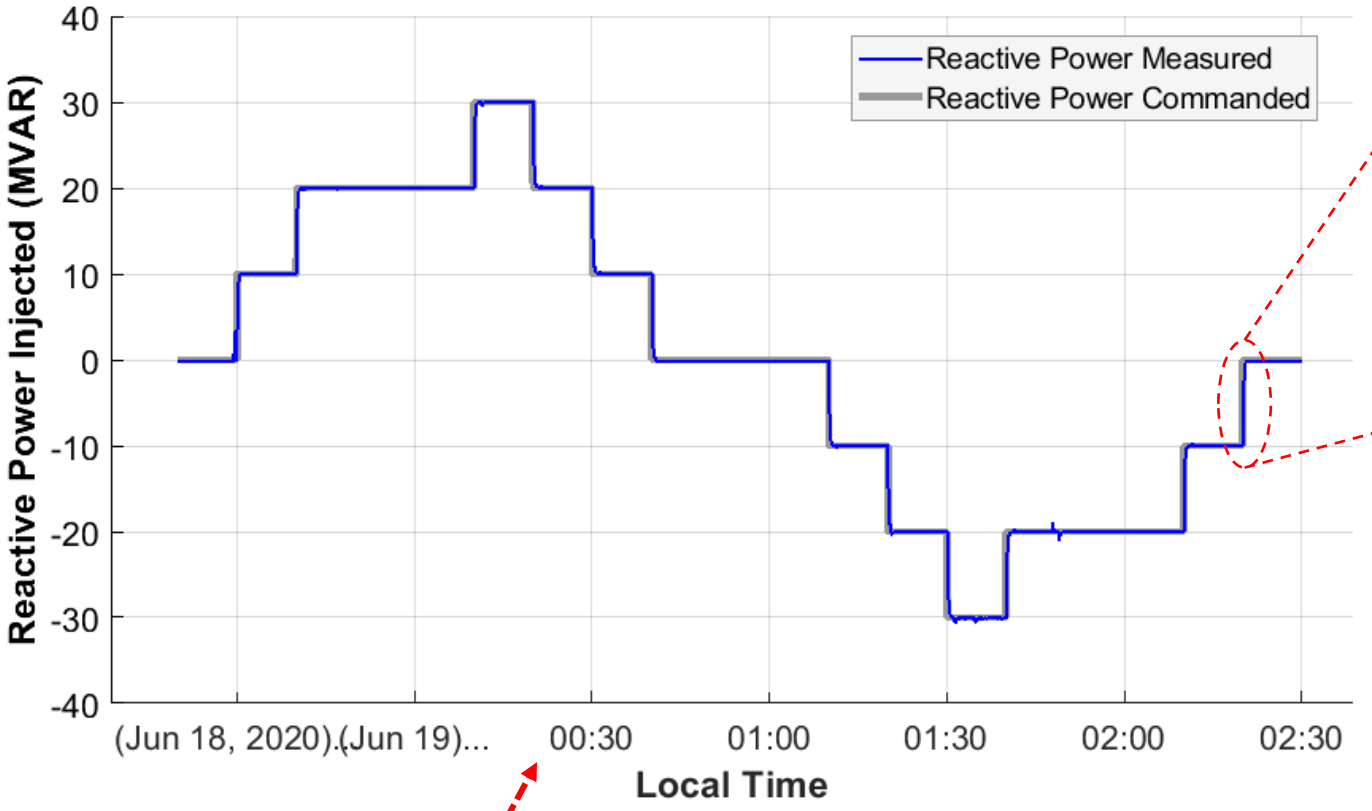
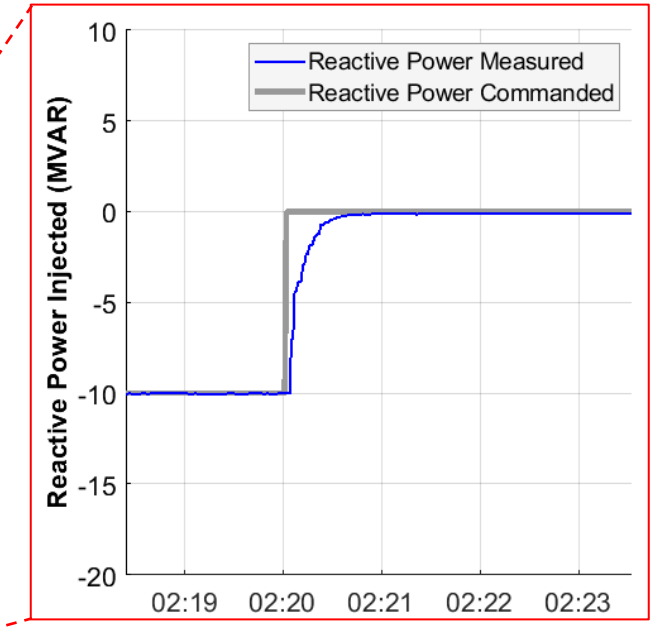
Nighttime Reactive Power Test

Can the PV plant accurately respond to control signals issued from utility operation center?



It's after midnight



- Median settling time varied between 10 and 24 seconds between test nights
- Mean absolute error ranged from 0.32% to 1.22%

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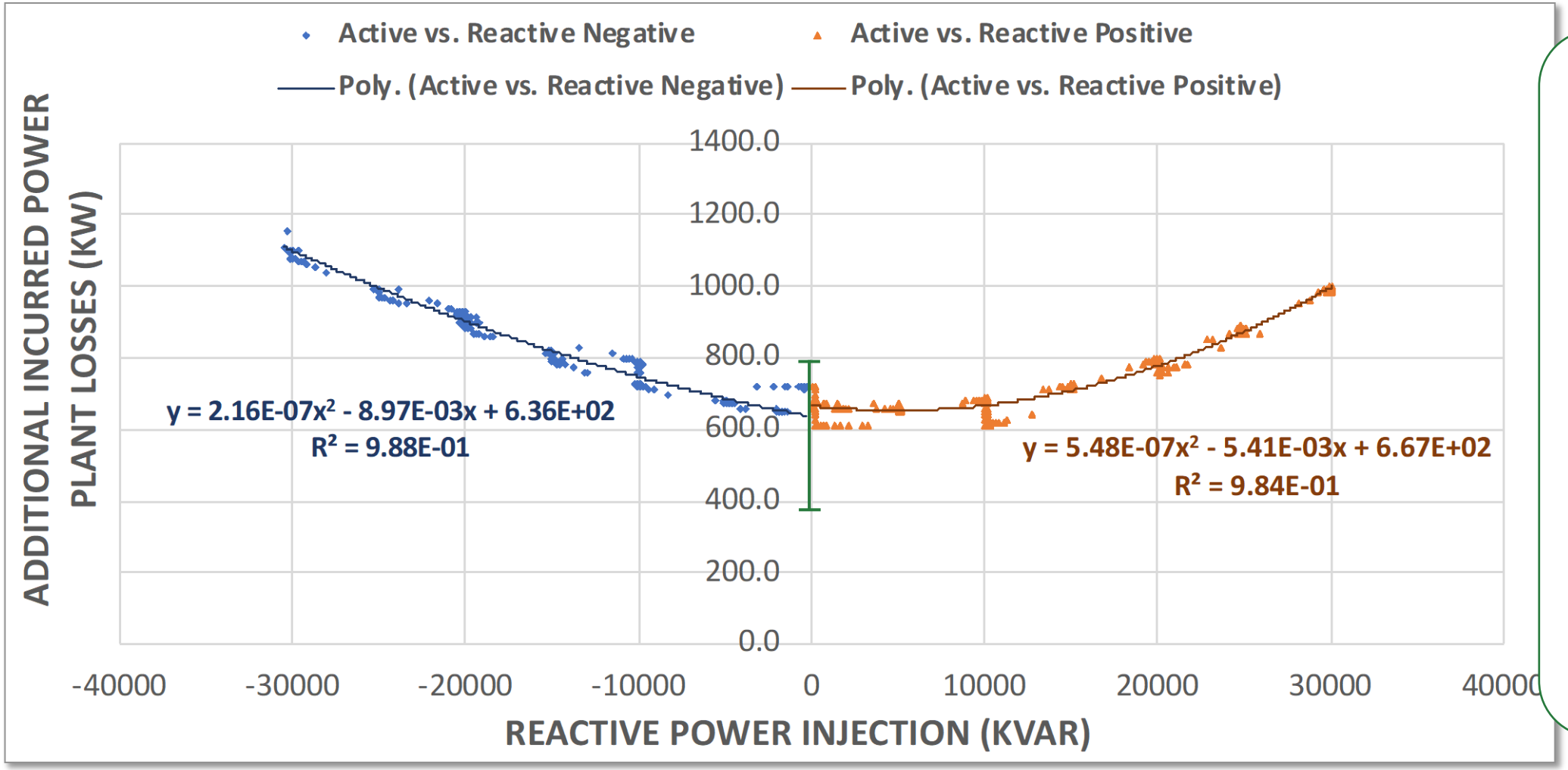
Active Power "Cost" of Q-Support During Nighttime



Nighttime loss

When in sleep mode: **317 kW**

When active but not abs/inj Q: **575 to 725 kW more**

PV Plants Can Absorb/Inject Reactive Power During, but comes with "cost" to keep the plant operational

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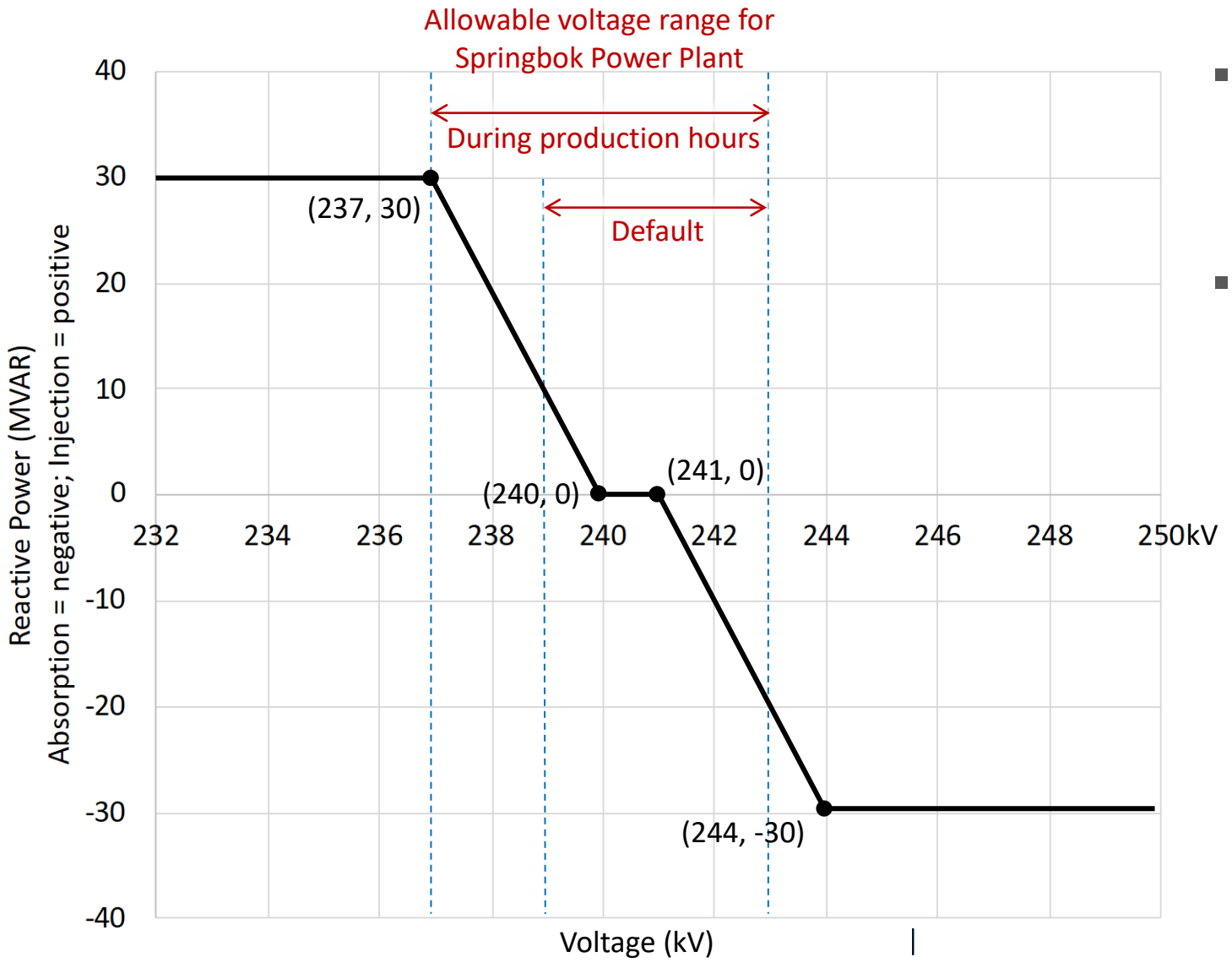
Can PV Plants Provide 24/7 Voltage Regulation Support?



- Volt-var settings used for the continuous voltage regulation support test
- Plant performance was evaluated over three test periods lasting 8, 10, and 6 days

PPC Parameter	Argument
Voltage Setpoint	240500 (V)
Undervoltage Max VAR	30000 (kVAR)
Undervoltage DeadBand	0.208 (%)
Undervoltage Droop	1.46 (%)
Overvoltage Max VAR	30000 (kVAR)
Overvoltage DeadBand	0.208 (%)
Overvoltage Droop	1.46 (%)

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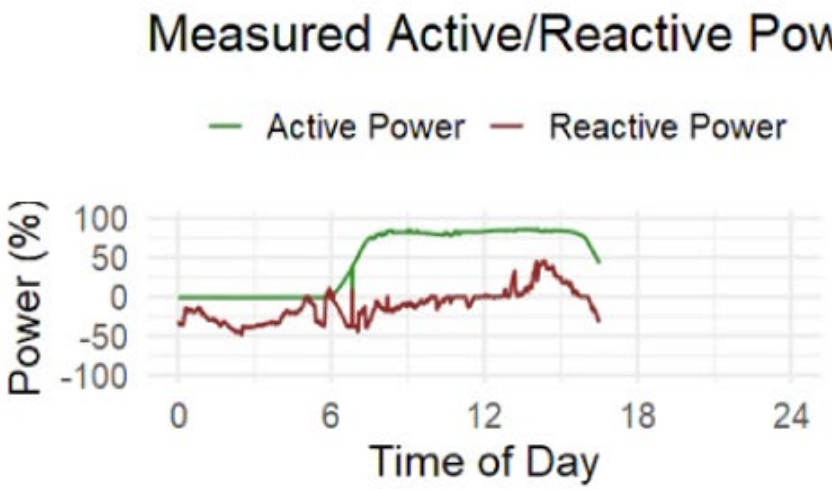
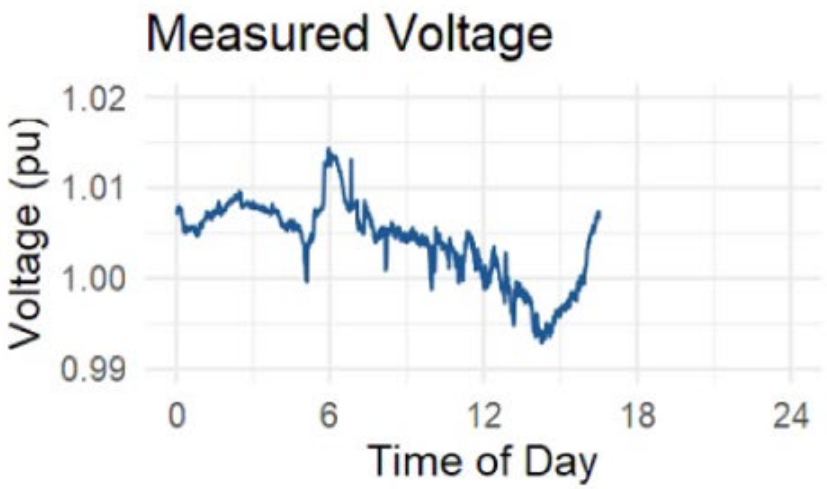
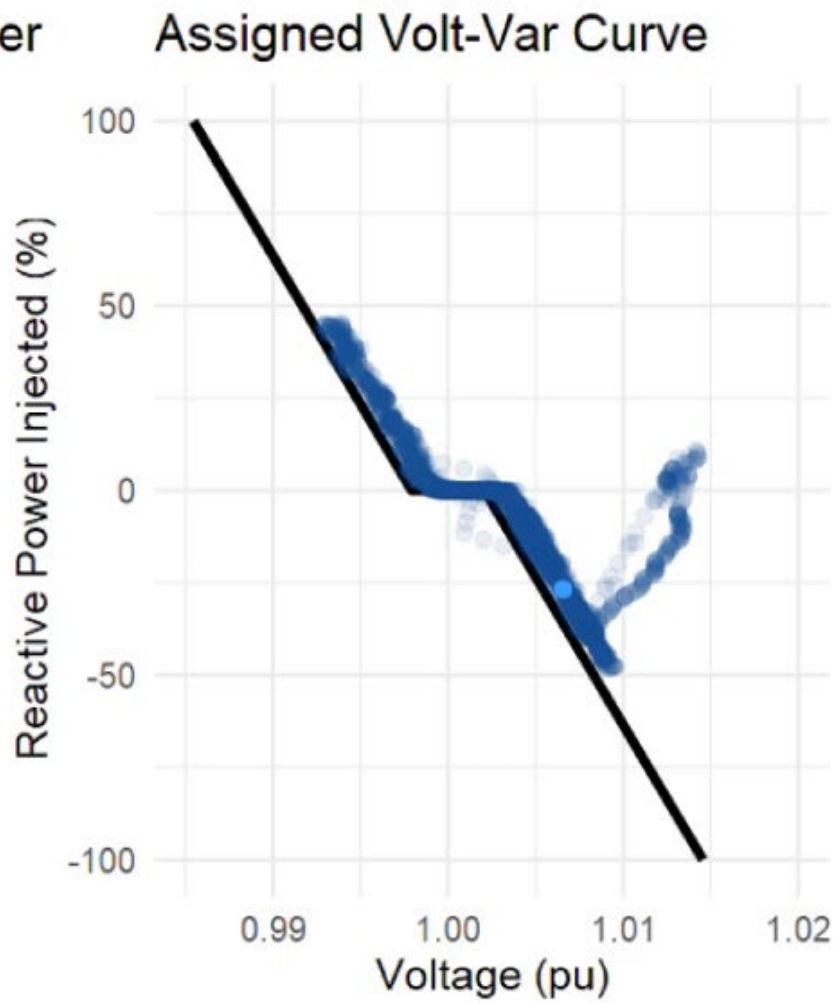
A Test Day Performance with Volt-Var Function Active







The PV Plant executed the volt-VAR function with reasonable accuracy except few exceptions

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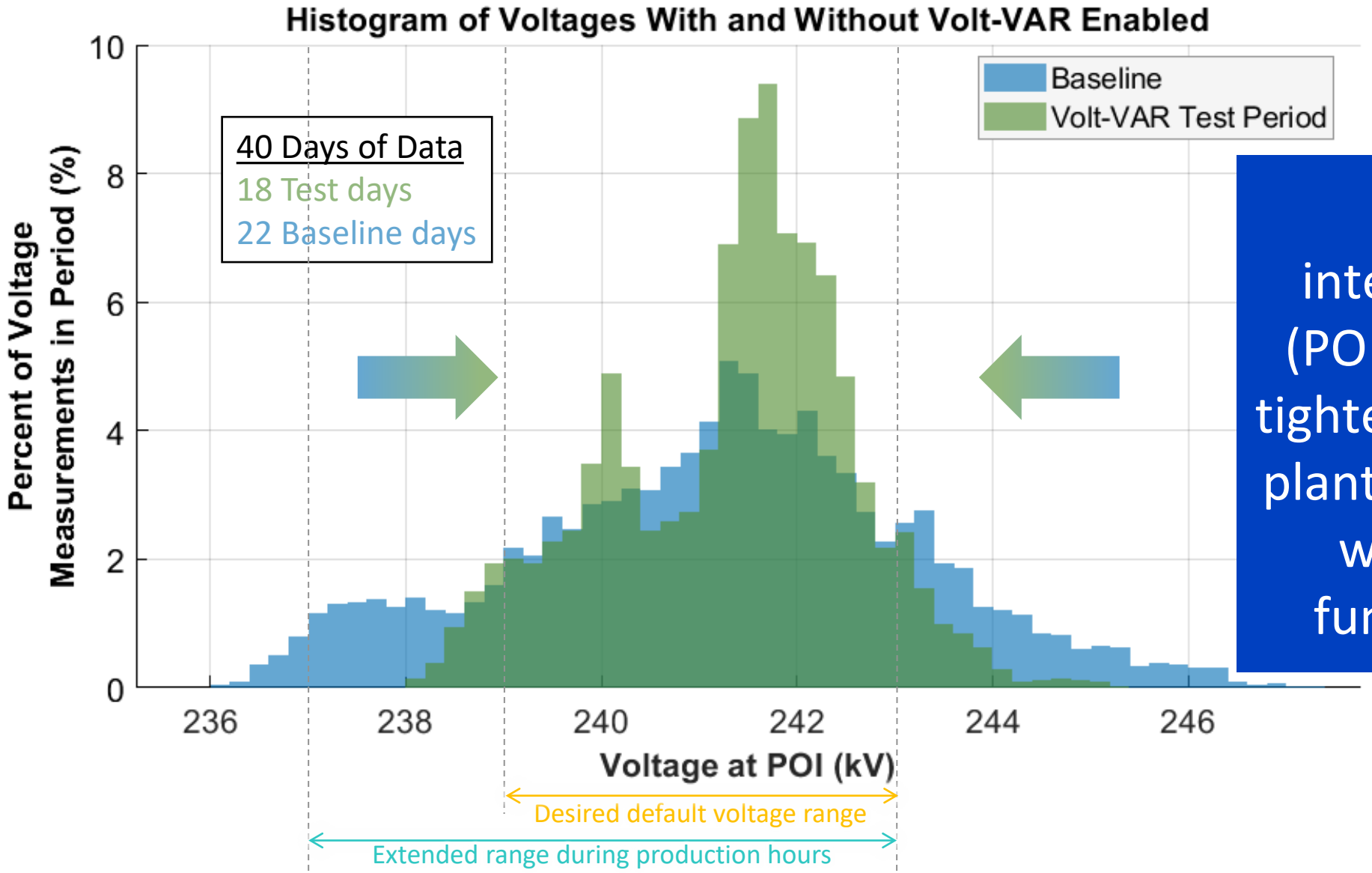
Volt-VAR Function's Impact on Plant POI Voltage



Point-of-interconnection (POI) voltage was tighter when the PV plant was operated with volt-var function active

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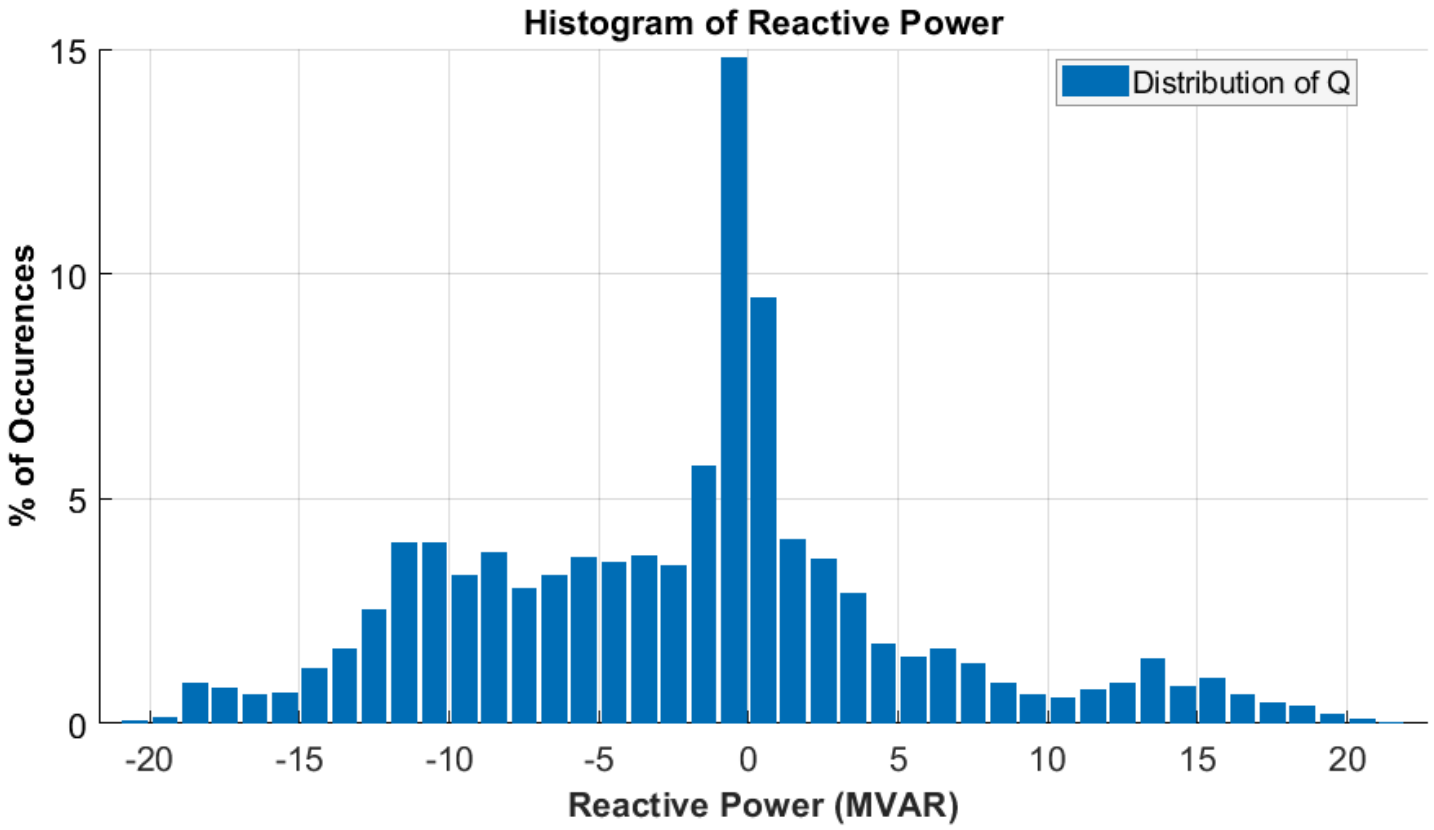
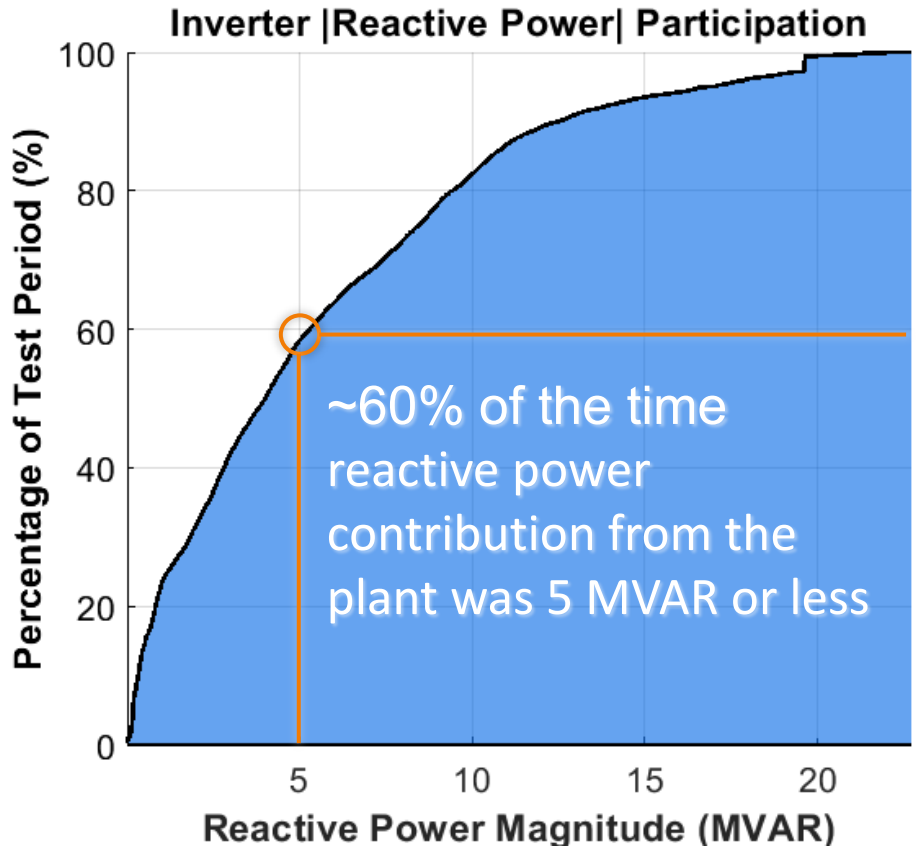
Reactive Power Injection/Absorption Distribution





An estimated 9.5 MWh of additional energy per day was consumed by the plant to provide the voltage regulation support

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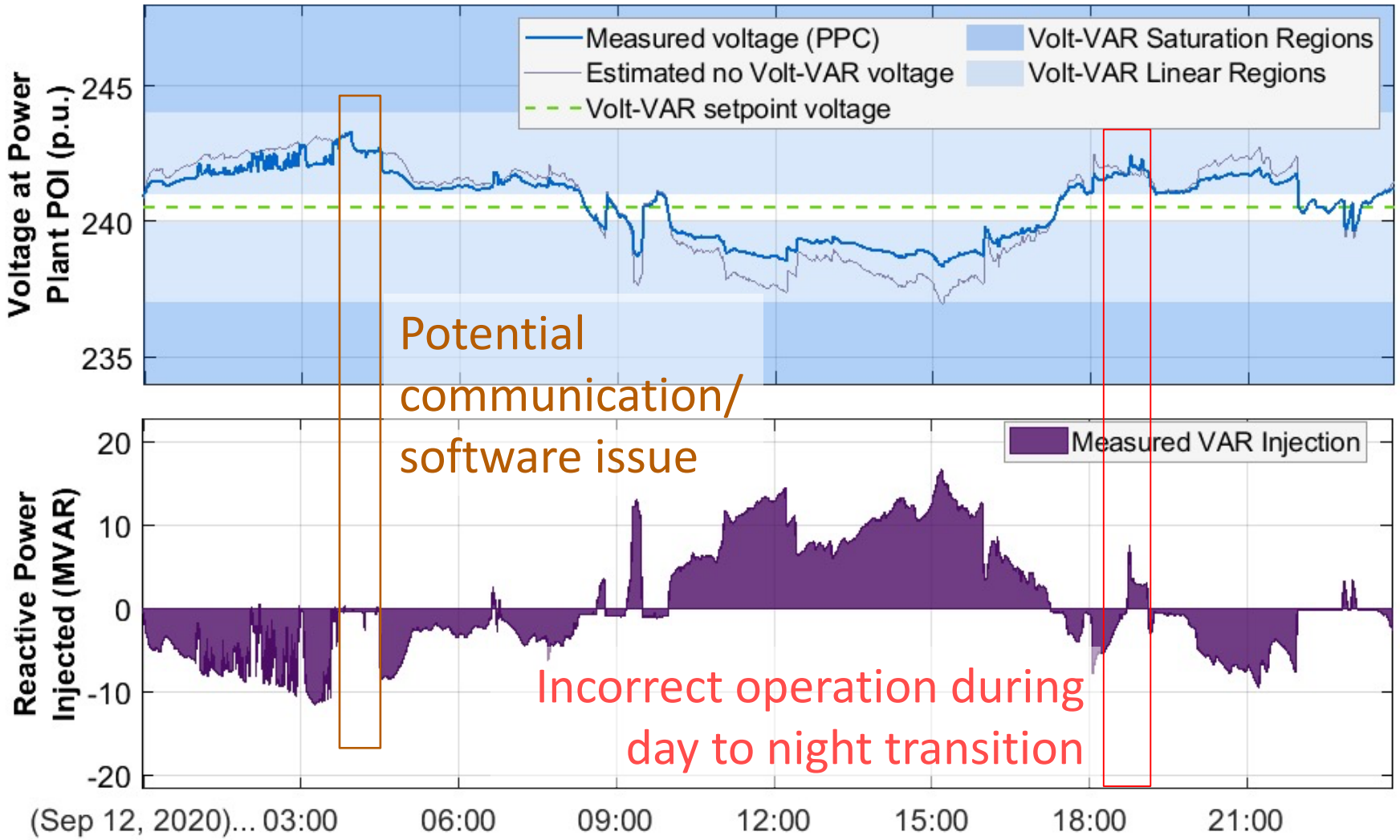
Room for Performance Improvement



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Summary

- Nighttime reactive power support from PV inverters and plants is possible but comes with “cost” to keep the plant operational instead of going to sleep mode to reduce losses.
- PV systems can provide 24/7 voltage regulation support if designed and configured accordingly.
- Need reliable performance to build confidence in power system operators to rely on these resources.

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Future Work

- Investigate impacts of increased daily operating hours (from 10 - 14 to 24 hours) on inverter life expectancy and associated business models.
- Reliable and repeatable real-world demonstrations of nighttime (preferably 24/7) voltage regulation support from solar PV inverters and plants.
- Updating existing interconnection and certification standards to define and incorporate the STATCOM-like voltage regulation support capability.
- Business model to compensate for the energy cost to keep the PV plants operational and provide reactive power support during nighttime and the voltage regulation support service rendered.

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Contact Info:

Aminul Huque, PhD
Program Manager, DER Integration, EPRI
mhuque@epri.com; 865-218-8051

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