Estimating Customer Impact of Volt-Watt

Using Only Smart Meter Voltage Data

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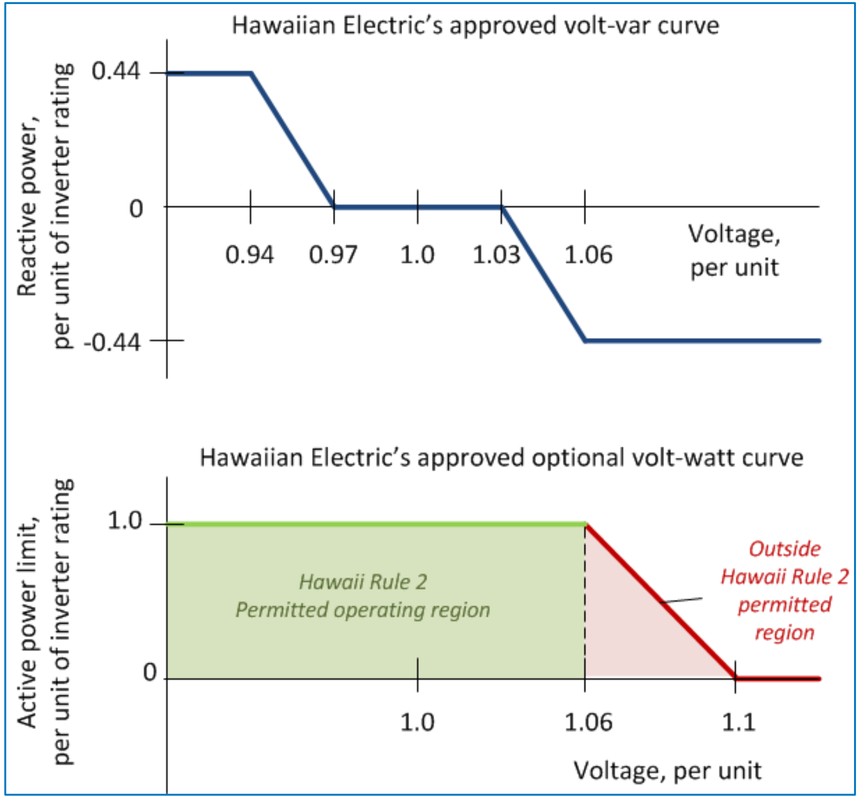
Background and Objective

- **Challenge**
  - Hawaii has more distributed PV than any other U.S. state, as proportion of load
  - DERs play a major part in the plan for 100% renewables by 2045
  - Current levels of PV result in steady-state over-voltage issues
  - Near-term solution: autonomous inverter-based voltage regulation

Autonomous inverter-based voltage response

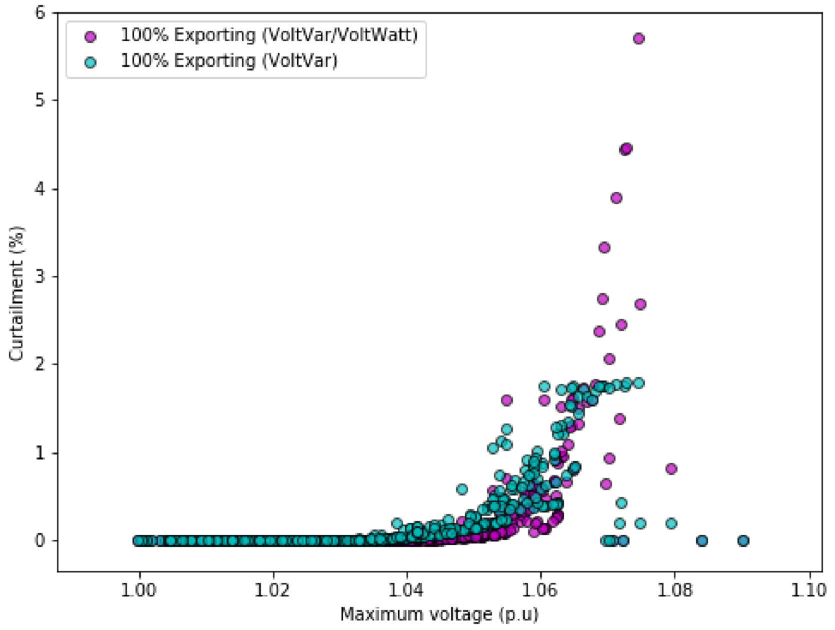
- **Volt-var and volt-watt control**
  - Volt-var control (now required for all new DERs) helps reduce high voltages, but is not 100% effective
  - Volt-watt control serves as a protection against occasional voltages outside ANSI C84.1 ranges (1.05-1.06 pu)



Volt-watt control

*See 2018 NREL Technical Report and Oct 31, 2018, presentation to AITWG for addition details relevant to this slide

- **Volt-watt control is recommended as a backstop to *occasional* high voltages outside ANSI ranges***
  - Because problem voltages often can't be predicted in advance, *system-wide* activation of volt-watt control is required to obtain the benefit
- **Various past NREL studies have found impact of volt-watt control on PV energy production is typically near zero**
  - Confirmed through detailed computer simulations (right) as well as field data
- **In rare cases with voltage *persistently* or *frequently* above 1.06 pu, volt-watt control *can* result in curtailment**
- **In such cases, the utility has a pre-existing obligation to fix the voltage issue. That fix will also bring any volt-watt curtailment near zero.**



- **The DER business process improvement (BPI) is designed to identify problem locations (when possible, before DER is installed)**
  - This will streamline DER interconnections by avoiding the need for detailed secondary modeling/studies
  - System-wide activation of volt-watt allows utility to relax interconnection screens/studies

Mitigation methods for persistently high meter voltages

- **Conventional**
  - Replace or add distribution transformer
  - Replace or add secondary conductors
  - Reconfigure primary or LTC settings
- **Non-wires alternatives**
  - Distributed static var compensators (e.g. Varentec)
  - Add energy storage
  - (Future:) Advanced load control solutions
  - (Future:) Coordinated DER controls
  - Inverter-based solutions (increased grid support) from customer in question and/or neighbors – likely compensated

Autonomous inverter-based solutions for persistently high voltages

- **Replace neighbors' legacy inverters?**
- **Add active power controls or storage to legacy systems?**
- **Use more aggressive volt-var curve?**
- **Use volt-watt and compensate customer for lost production**
    - Key: need reliable estimate of lost production without additional sensors
- **Could also combine multiple of these methods.**

Estimating PV curtailment

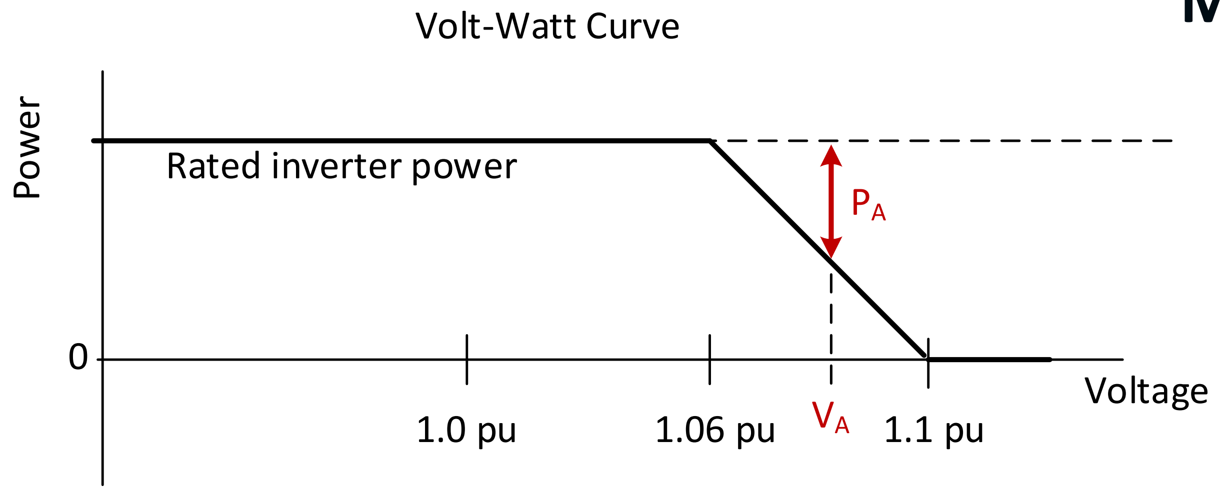
- **Estimating PV curtailment due to volt-watt control without adding any additional sensors**
  - Past NREL-HECO work has estimated curtailment using irradiance sensors with good accuracy, but this is costly and invasive
  - It is likely also possible to estimate curtailment based on inverter data, but this is less accurate, and inverter data is not always available, especially to the utility
- **Goal: estimate curtailment based on AMI (smart meter) voltage data only**
  - AMI data is available for all new DER customers as part of the "BPI" (business process improvement)

Proposed methods

- **Some California stakeholders have proposed using NREL's PVWatts tool**
  - PVWatts is great for forward-looking predictions, but:
    - In the rare very high-voltage cases of interest, curtailment is expected to be a few percent of monthly production – within the margin of error of PVWatts
    - PVWatts uses TMY (typical meteorological year) weather data, not actual weather
    - Geographical granularity is too low to accurately estimate site-specific PV curtailment of a few percent
    - Any shading or other site-specific losses would be misinterpreted as curtailment
- **When voltage is above 1.06 pu, assume PV could have been at full output, and calculate curtailment from volt-watt curve**
  - Subsequent slides describe and evaluate this method

Estimating curtailment from AMI voltage

"Method 1"



- When the voltage is V_A, the maximum possible curtailed power due to volt-watt is P_A
- This assumes the inverter *could have been* at maximum power whenever voltage was above 1.06 pu

Estimating curtailment from AMI voltage

"Method 1"

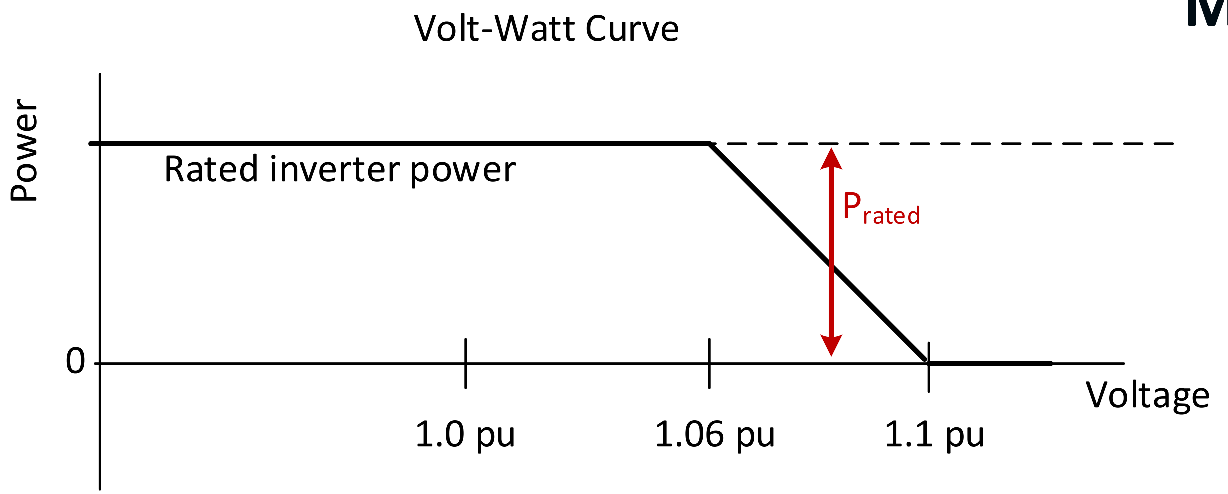
- Expressing it in math:

$$E_{curtailed} = P_{PV} \cdot t_{AMI} \cdot \sum_{v_{AMI}} max\left(\frac{v_{AMI} - 1.06}{1.1 - 1.06}, 0\right)$$

- $E_{curtailed}$ is the maximum possible curtailment due to volt-watt, in kWh, over the time period of interest
- P_{PV} is the rated AC power of the PV system, in kW
- t_{AMI} is the period of the AMI measurements, in hours (so for 15-minute readings, t_{AMI} is 0.25)
- v_{AMI} is the set of AMI voltage readings for the time period between 9am and 3pm, in per unit (pu)

A simpler method?

"Method 2"



- A stakeholder proposed a simpler method that assumes curtailment equal to the inverter rating (P_{rated}) whenever the voltage is above 1.06 pu

A simpler method?

"Method 2"

- Expressing it in math:

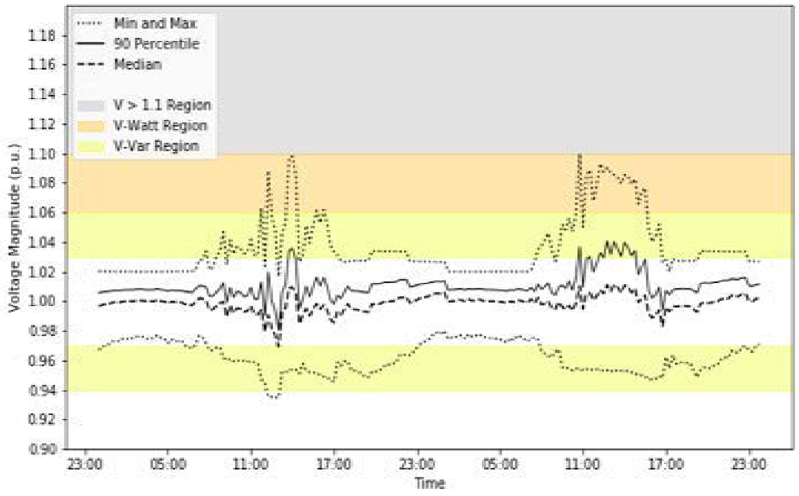
$$E_{curtailed} = \sum_{v_{AMI}} \begin{pmatrix} P_{PV} \cdot t_{AMI}, & v_{AMI} > 1.06 \\ 0, & v_{AMI} \leq 1.06 \end{pmatrix}$$

Evaluating the methods

- **To evaluate accuracy, the two methods were applied to computer simulation (VROS) data and to field data**
  - Method 1
  - Method 2
  - Both methods evaluate volt-watt effects only (not volt-var)
- **The PVWatts-based method was not evaluated**
  - Proposal did not contain sufficient detail to determine how it was intended to be implemented

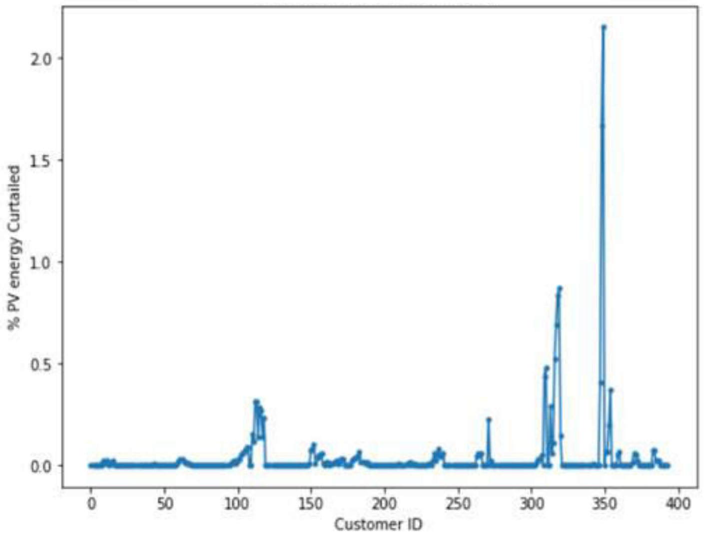
Evaluating the methods – VROS simulation data

- **2017/2018 VROS study simulated a very high penetration Oahu feeder (M34) in a future, even higher penetration state**
  - 6.5 MVA peak load, 2.8 MVA min load
  - 10.9 MW total PV
    - 1.6 MW legacy PV, 5.2 MW FIT, 4.1 MW smart PV
- **VROS quantified curtailment for all customers over time**
- **VROS data from a high-voltage week in June selected for evaluation of curtailment estimation methods**
  - Used “all export” case for worst-case voltages (as opposed to CSS case)

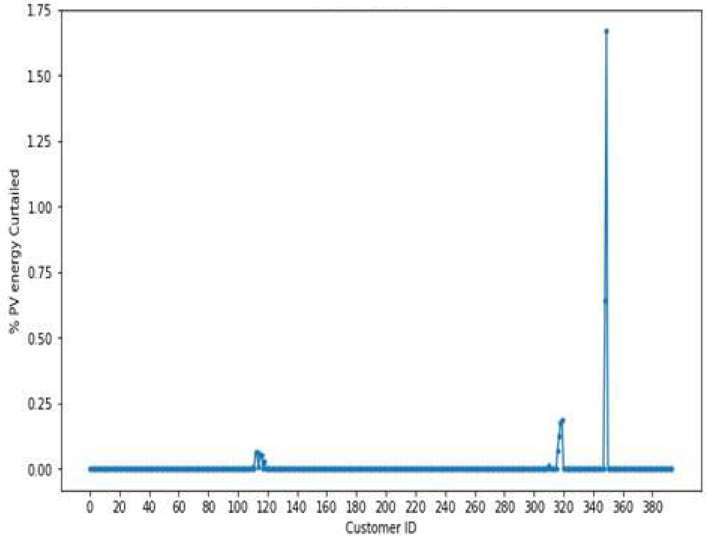


Evaluating the methods – VROS simulation data

VROS – total curtailment



Method 1 – V-W curtailment

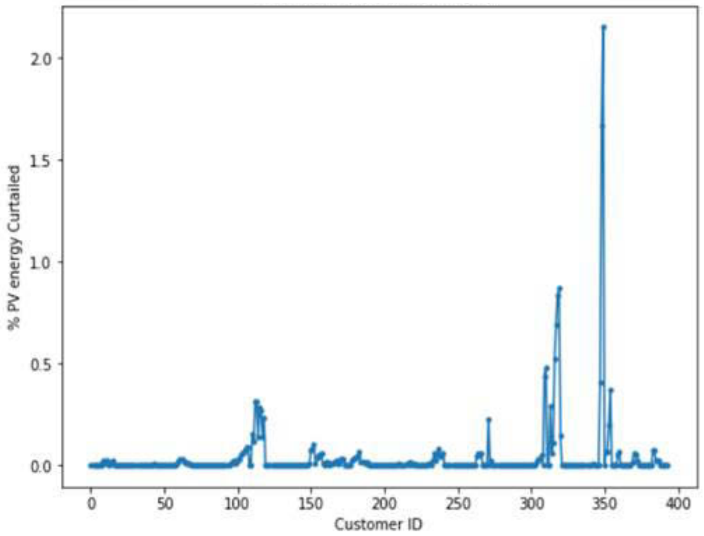


*Note y-axis scales are similar but not identical

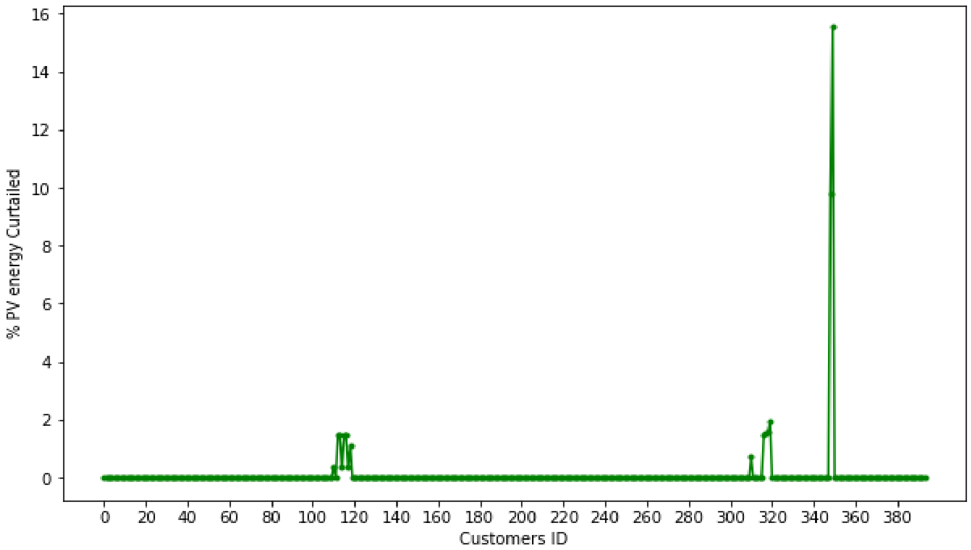
- Results align reasonably well, especially for the most-curtailed customers
- VROS captures all curtailment, not just V-W, so curtailment is more common and percentages are higher
- Method 1 overestimates V-W curtailment, but does not capture volt-var curtailment; these effects counterbalance, resulting in pretty good estimate for customers in V-W region

Evaluating the methods – VROS simulation data

VROS – total curtailment



Method 2– V-W curtailment

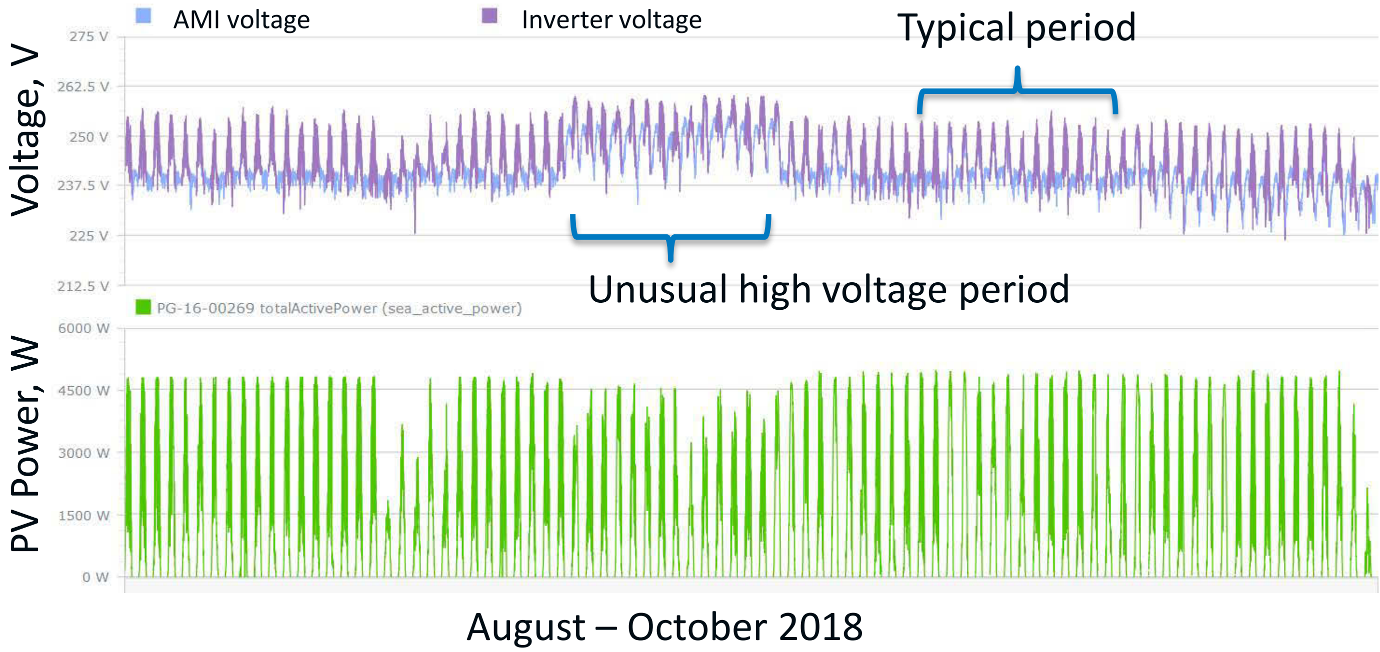


- Method 2 vastly overestimates curtailment

*Note y-axis scales differ by an order of magnitude

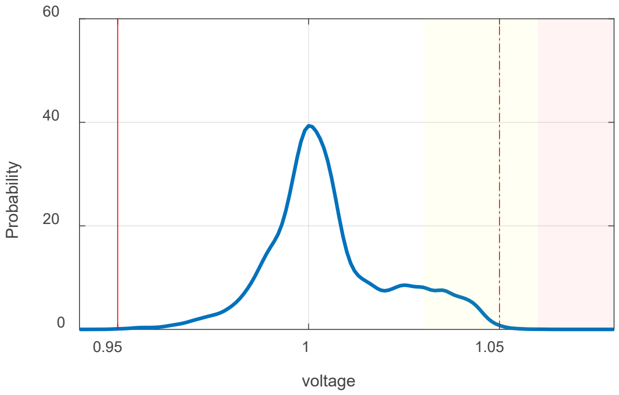
Evaluating the methods – field data

- High-voltage location from advanced inverter pilot: **“Location 3”**
- Analyzed normal period and 15-day period of unusually high voltage

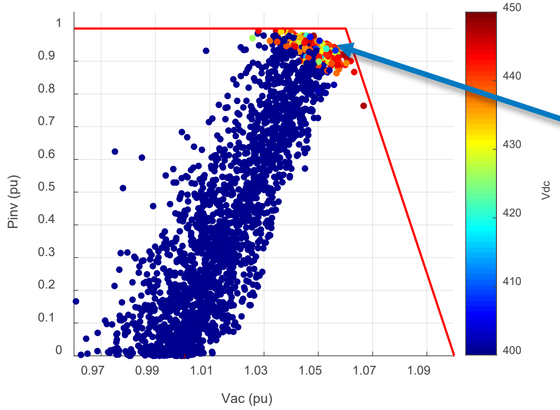


Evaluating the methods – field data: Location 3

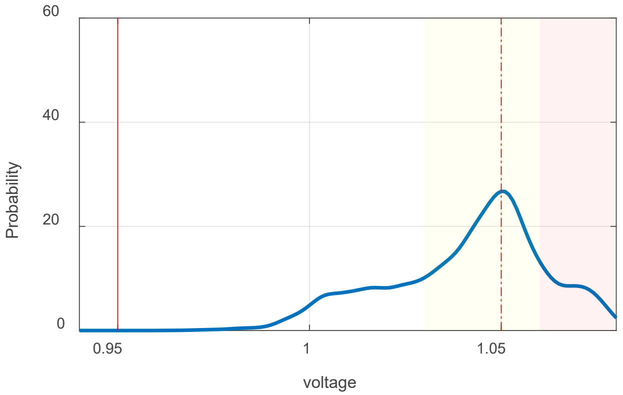
Non-blue dots indicate elevated DC voltage, typically due to curtailment (for this inverter type)



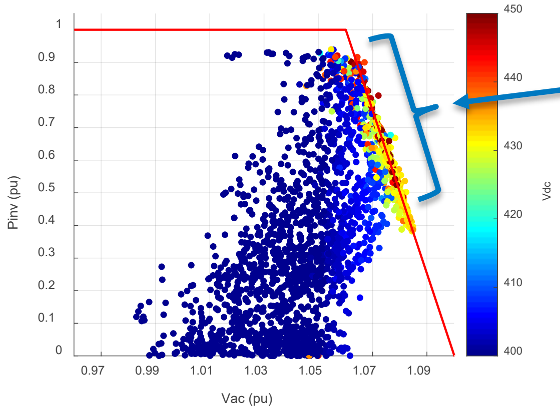
Typical period



Some volt-var curtailment



Unusual high voltage period

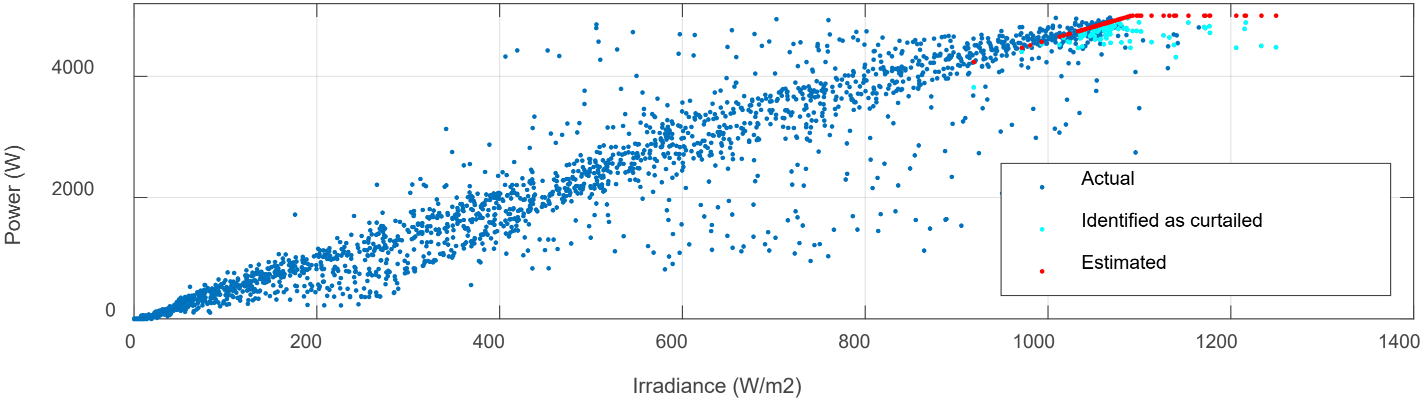


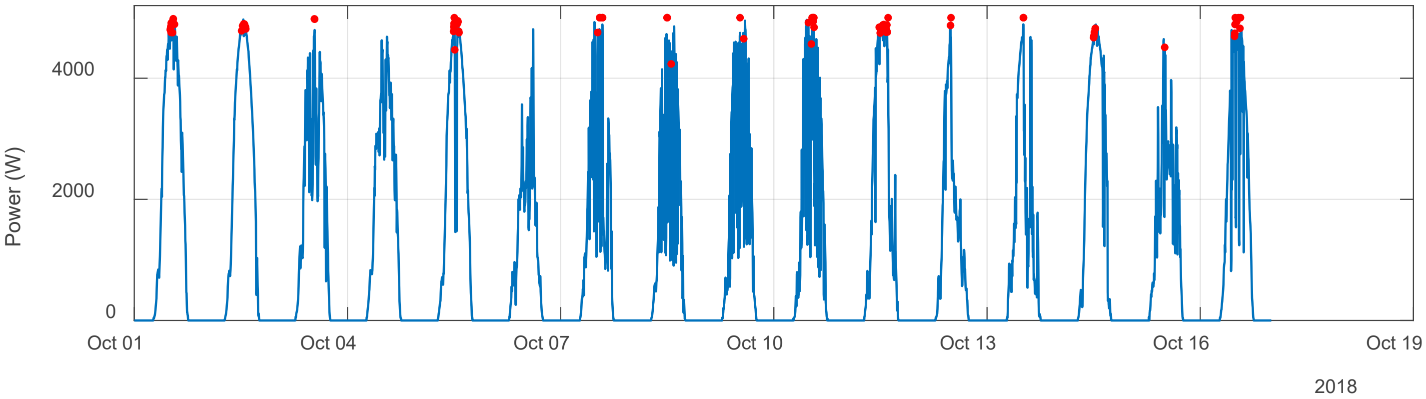
Volt-watt curtailment

Evaluating the methods – finding curtailment in field data

Location 3

Typical period

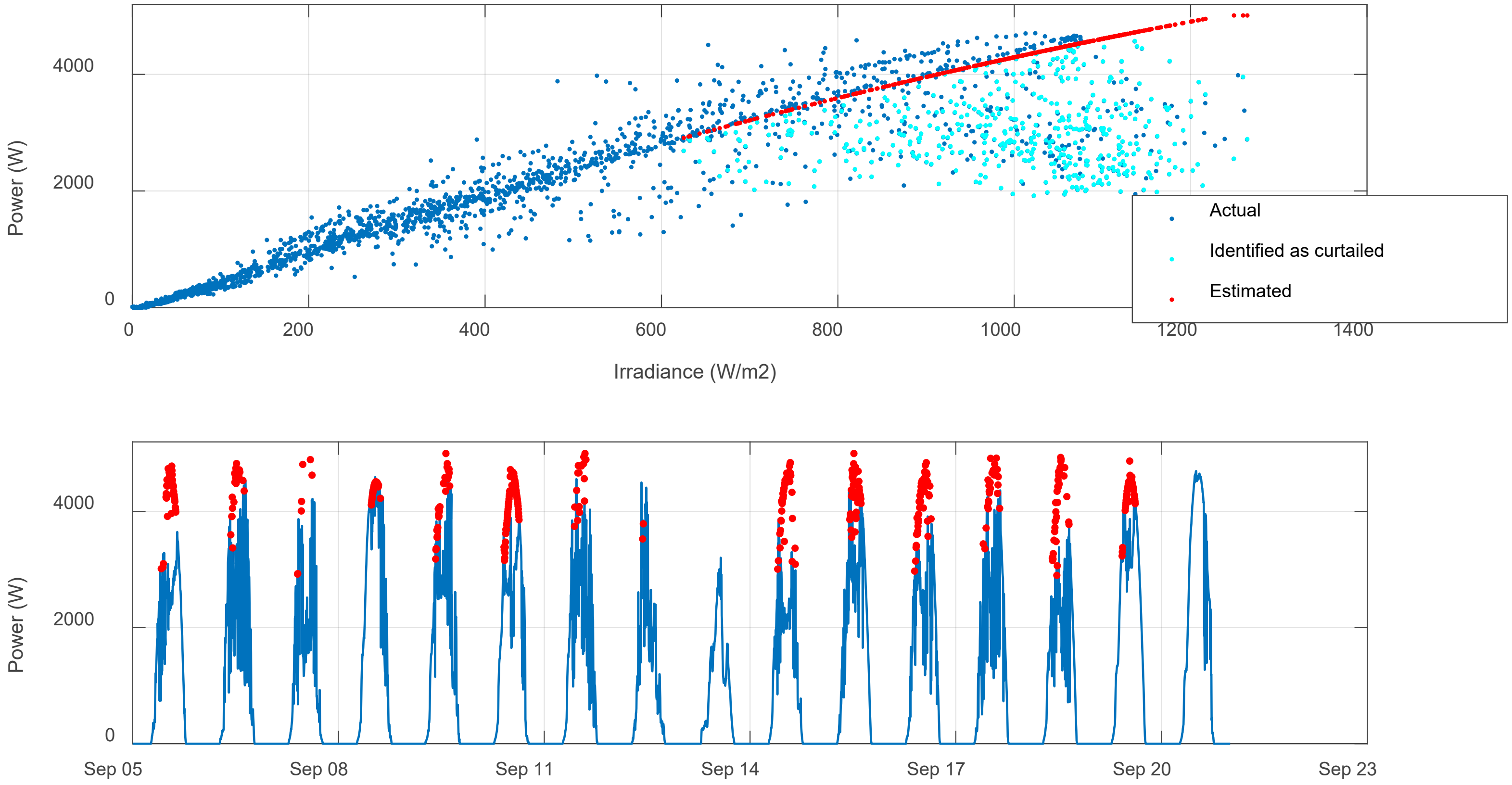




Evaluating the methods – finding curtailment in field data

Location 3

High voltage period



Evaluating the methods – quantifying curtailment – **Location 3**

*As estimated from irradiance curve fit to inverter data

	Measured production (kWh)	Estimated possible production (kWh)*	Actual curtailment (kWh)*	Method 1 - Estimated VW curtailment (kWh)	Method 2 - Estimated VW curtailment (kWh)	Actual curtailment (% of expected energy*)	Method 1 - Estimated VW curtailment (% of expected energy)	Method 2 - Estimated VW curtailment (% of expected energy)
Typical period	425.2	426.5	1.3	0	0	0.30%	0	0
High V period	385.0	431.7	46.7	62.1	271.7	10.81%	14.39%	62.93%

- Method 1 comes out surprisingly close; slightly high
- Method 2 is not close (6x too high)
- Reminder: Actual curtailment includes volt-var *and* volt-watt curtailment
- Side note: *annual* curtailment assuming one high-voltage period such as this per year would be about 1.1%

Evaluating the methods – quantifying curtailment – **Cluster 1**

*As estimated from irradiance curve fit to inverter data

	Measured production (kWh)	Estimated possible production (kWh)*	Actual curtailment (kWh)*	Method 1 - Estimated VW curtailment (kWh)	Method 2 - Estimated VW curtailment (kWh)	Actual curtailment (% of expected energy*)	Method 1 - Estimated VW curtailment (% of expected energy)	Method 2 - Estimated VW curtailment (% of expected energy)
Typical period	197.0	197.0	0.01	0.0	0	0.01%	0	0
High V period	106.8	107.9	1.0	2.8	24.5	0.95%	2.57%	22.71%

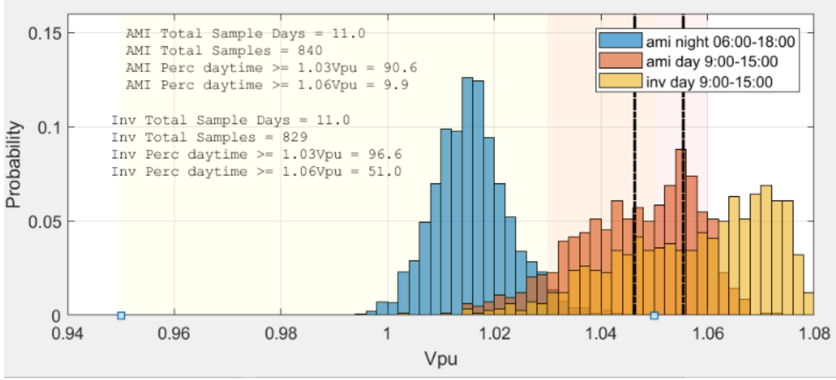
- Method 1 comes out surprisingly close; slightly high
- Method 2 is not close (20x too high)
- Reminder: Actual curtailment includes volt-var *and* volt-watt curtailment
- This location was analyzed in some detail in Oct 31, 2018, AITWG presentation and 2018 IEEE PVSC paper. Curtailment analysis method updated to align with that used for Location 3.

Evaluating the methods – quantifying curtailment – **Location 4**

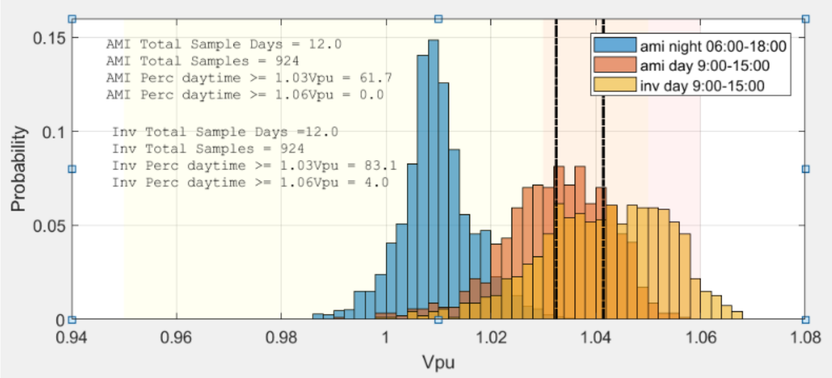
- Highest voltage location from initial pilot
- Significant behind-the-meter voltage rise and high meter voltage
- July 2017: 51% of 9am-3pm *inverter* voltage readings were > 1.06 (top right)
- Installed irradiance sensor in Summer 2018 to estimate curtailment, but…
- After Sept 2017, inverter voltages rarely > 1.06 (July 2018, bottom right)
- Volt-watt curtailment is zero or near zero every month since irradiance sensor installed*

*Unable to quantify exactly due to poor regression fit between inverter power and irradiance measurements. Based on applying Method 1 to *inverter* voltage readings, worst-case curtailment is 0.4%.

Voltage distribution, July 2017



Voltage distribution, July 2018



Conclusions

- **A simple method of estimating lost production due to volt-watt control comes out surprisingly close to reality**
  - **Uses only AMI voltage data (no additional sensors or communications, no need for inverter data)**
  - **Validated against detailed computer simulation for hundreds of customers, and against field data with irradiance sensing and inverter data**
  - **Could be used to estimate curtailment for compensation purposes as a simple non-wires solution for high voltage due to PV**

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Thank you!

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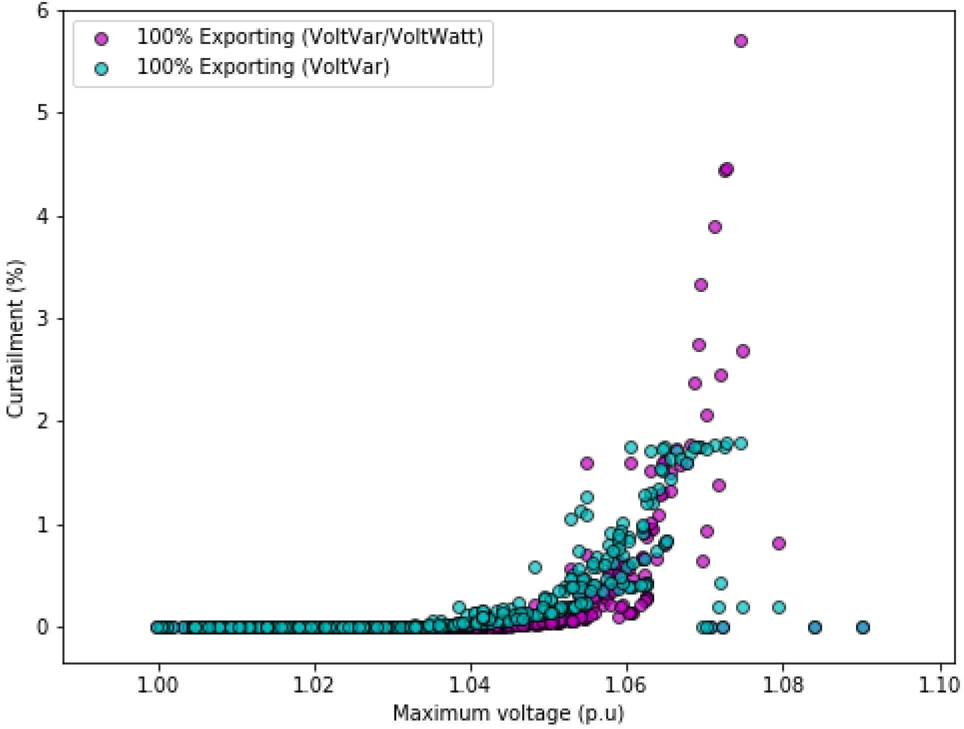
Extra slides

Curtailment is near zero if voltages are inside ANSI C84.1

- Current HECO technical sub-screens identify potential high-curtailment customers that can be monitored while secondary upgrades are underway
- HECO is working on a business process initiative (BPI) to streamline DER interconnections and ensure customers are not experiencing high-voltage conditions
- BPI will leverage the finding that curtailment is near zero in cases where voltage in inside ANSI C84.1

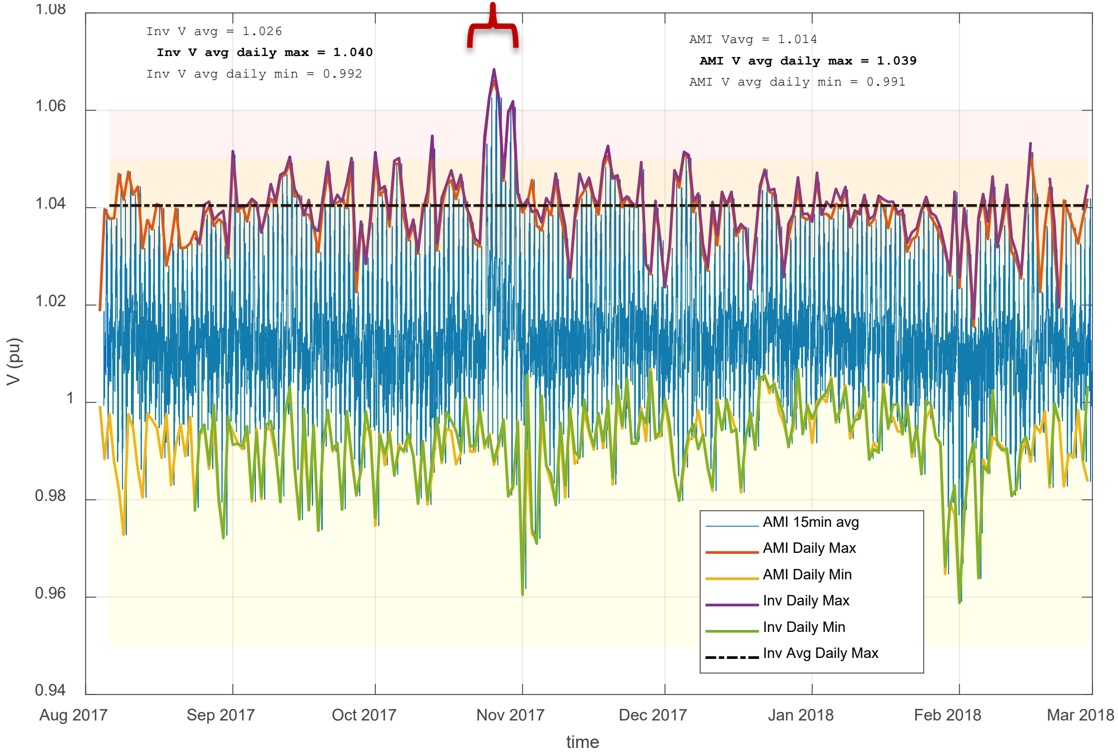


Summary of conclusions (VROS and AI pilot)

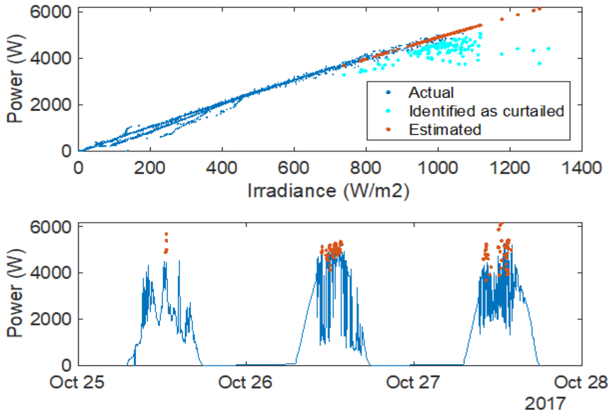
- **Intent of volt/Watt is not to mitigate *persistently* high voltages, but rather to protect against occasional temporary high voltage conditions outside of tariff rules**
  - Because events that occasionally result in high-voltage conditions in the field are very difficult to predict in advance, volt/Watt is only effective as a protection function if enabled system-wide
  - Vast majority of the time, voltages are in normal operating ranges and volt/Watt is not active
- **Simulations and field tests show non-negligible curtailment from volt/VAR and volt/Watt occurs only when voltages are persistently outside of tariff**
  - The utility has an existing obligation to fix out-of-tariff voltages; that fix will also correct any curtailment issue
  - Active monitoring of customer meter voltages both before and after PV installation will ensure such cases are caught and proactively mitigated (BPI initiative)
- **Combined system-wide activation of volt/VAR and volt/Watt control can enable very high levels of PV generation while helping ensure voltages remain within the allowed safe ranges, without significant impact on PV energy production**

Field pilot: Cluster 1 (on M34 feeder)

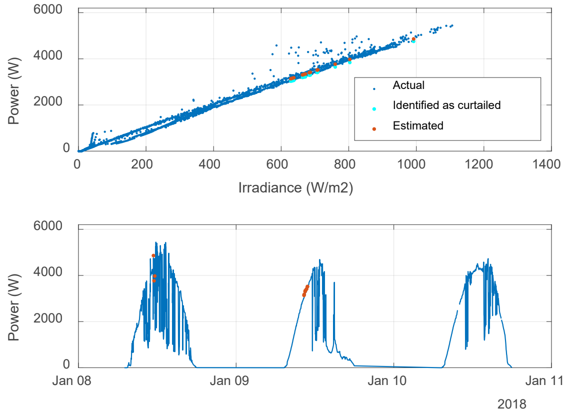
Higher voltages due to temporary primary configuration



Curtailment during high voltage period: 1.6%



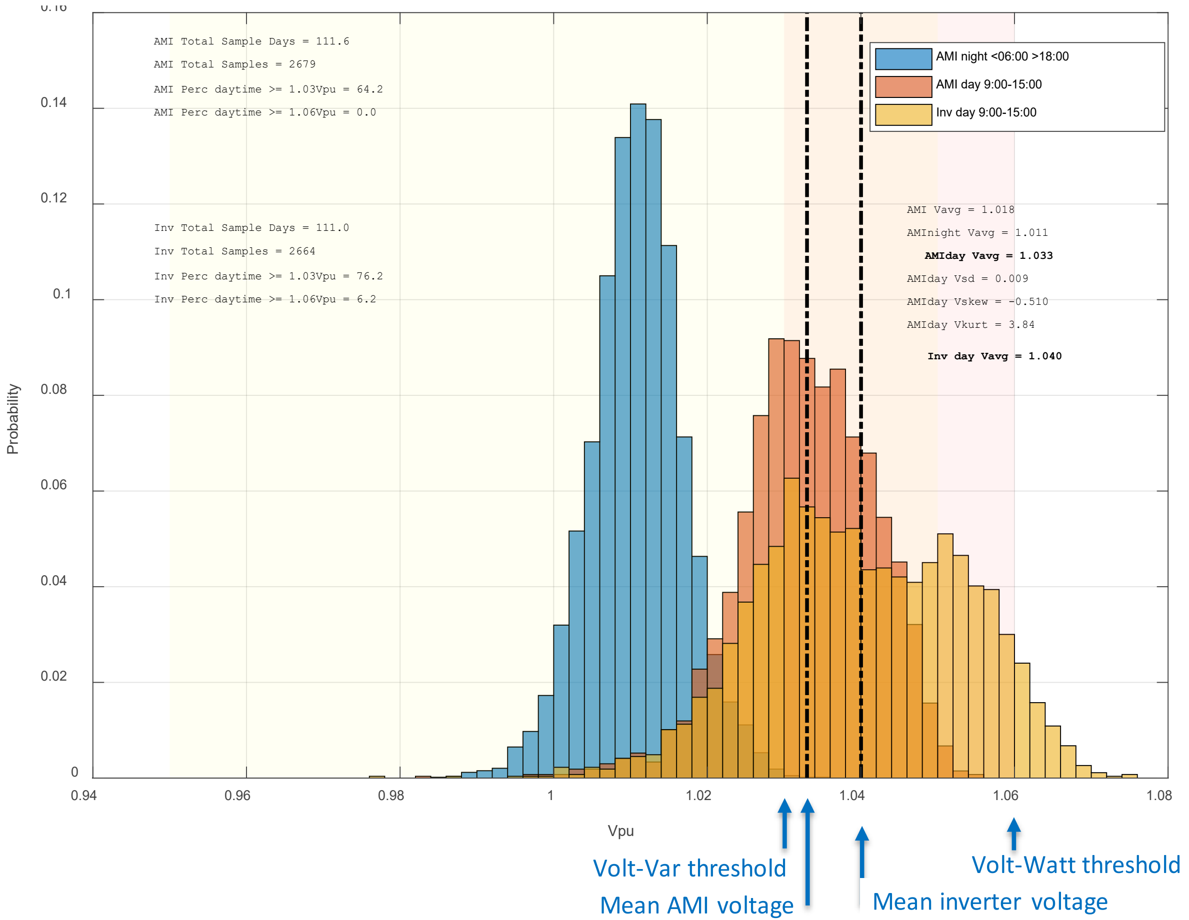
Curtailment during typical period: 0.04%



Field pilot: Cluster 1 (on M34 feeder)

- **Key take-aways from previous slide**
  - Despite relatively high voltage (peaking around 1.04-1.05 daily), annual curtailment impact is negligible (<<1% of annual energy production)
  - Temporary higher voltage condition illustrates intended purpose of volt/Watt: backstop against temporary high voltage conditions outside ANSI range

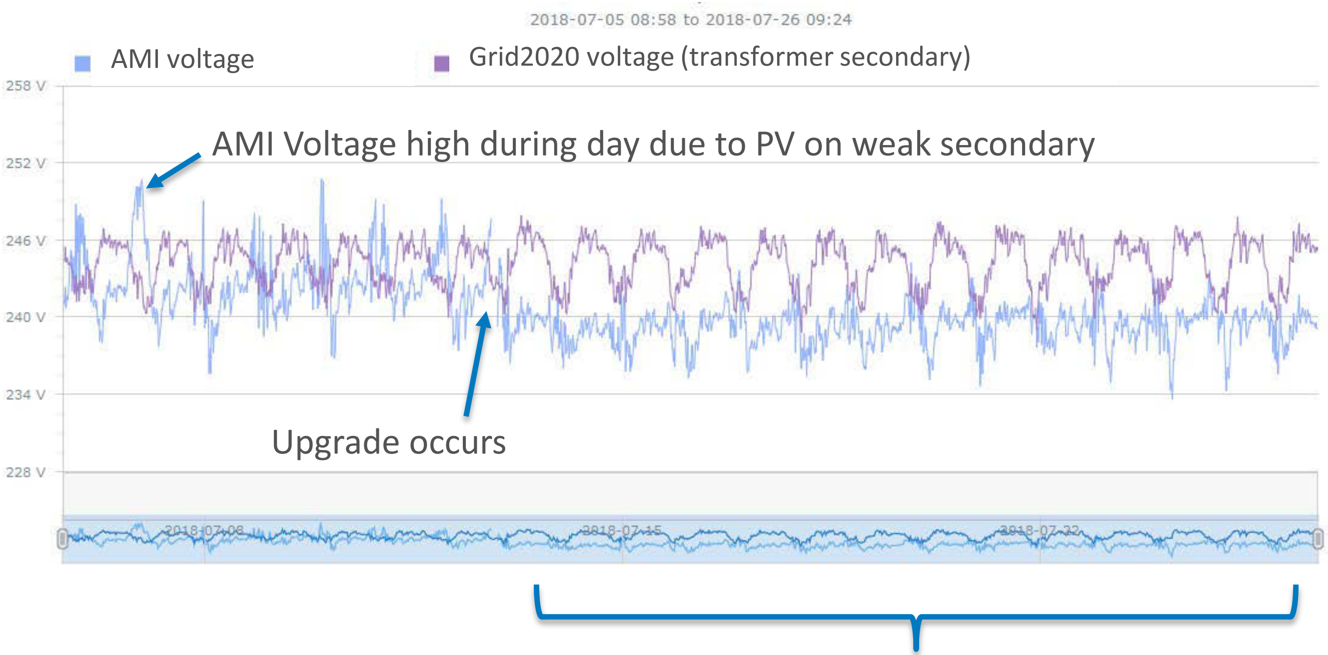
Field pilot: Highest voltage location



- Inverter daytime voltage persistently high
- Irradiance sensor recently installed at this location.
- Curtailment may be non-negligible
- Customer was scheduled for a secondary circuit upgrade prior to pilot. Upgrade will bring voltage down and mitigate curtailment.

Field pilot: Example of mitigation

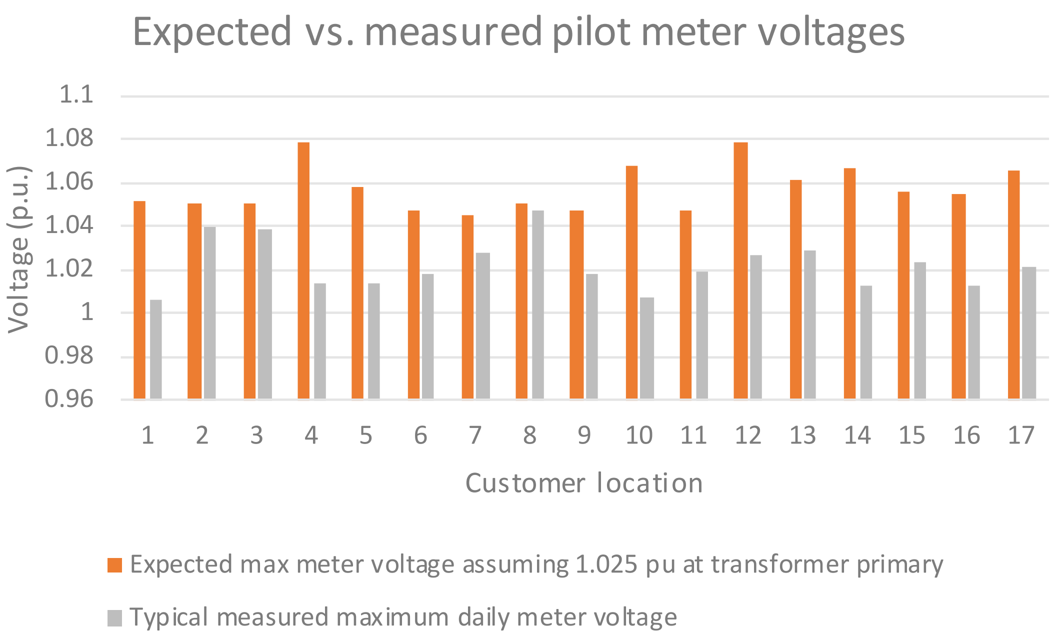
- Cluster 1 secondary upgrade completed July 12, 2018
- Voltage now peaks below 1.02 pu
- Was upgrade necessary?



- AMI voltage significantly lower due to strengthened secondary
- Transformer voltage unchanged

Field pilot: Expected vs measured voltages

- Measured max voltages consistently lower than expected from detailed screen
- Distribution planners do not have information needed to accurately predict customer voltages; must make assumptions
- Leads to more systems than necessary being identified as problems
- Is there a better way?

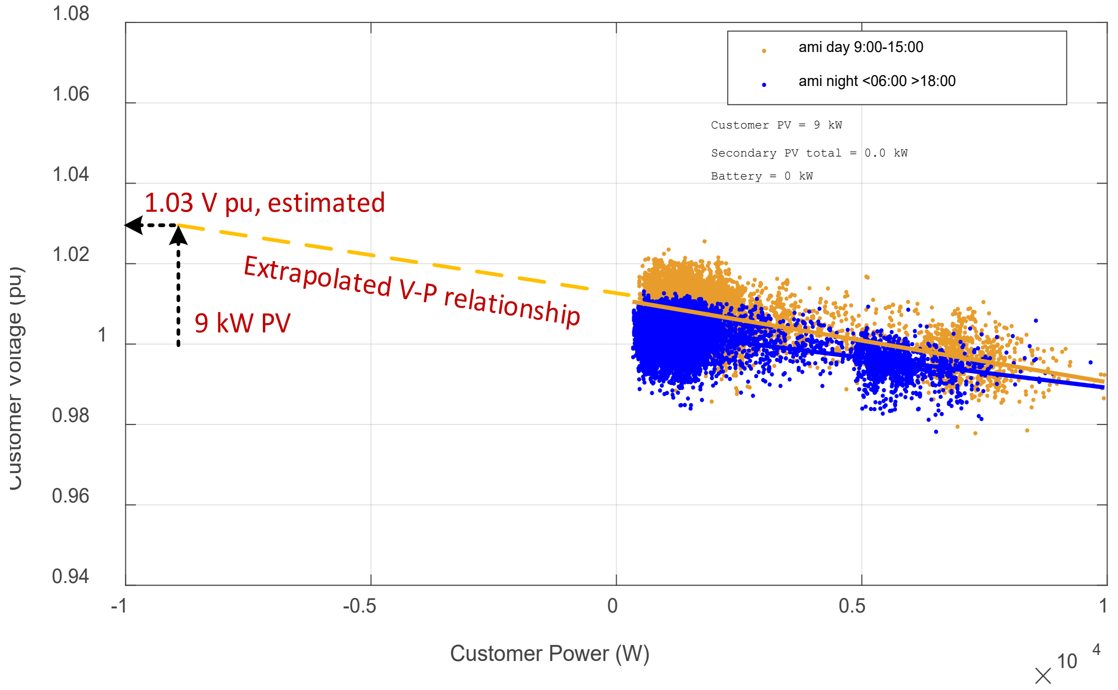


Operationalizing pilot methods

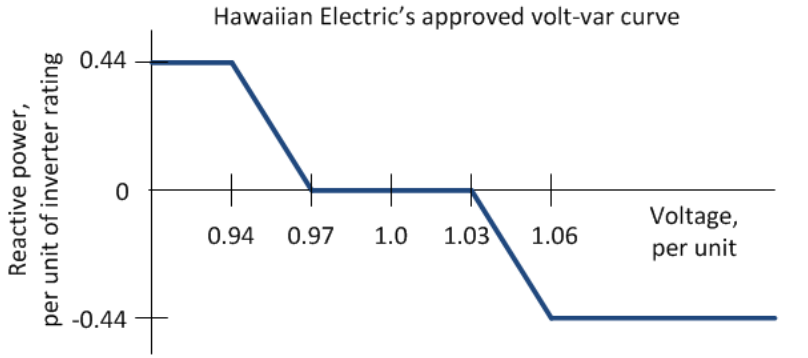
- Key missing information: customer voltage data
- Solution (business process improvement): install AMI upon receipt of interconnection application
- Identify potential problems early
- Can problems be identified *before* DER is installed?

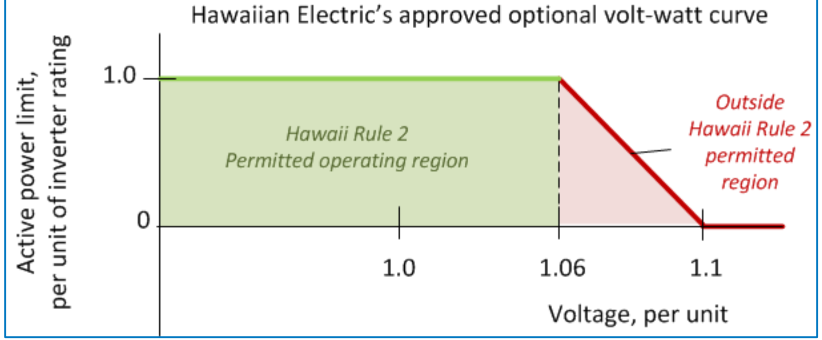
BPI: Predicting voltage issues before DER is installed

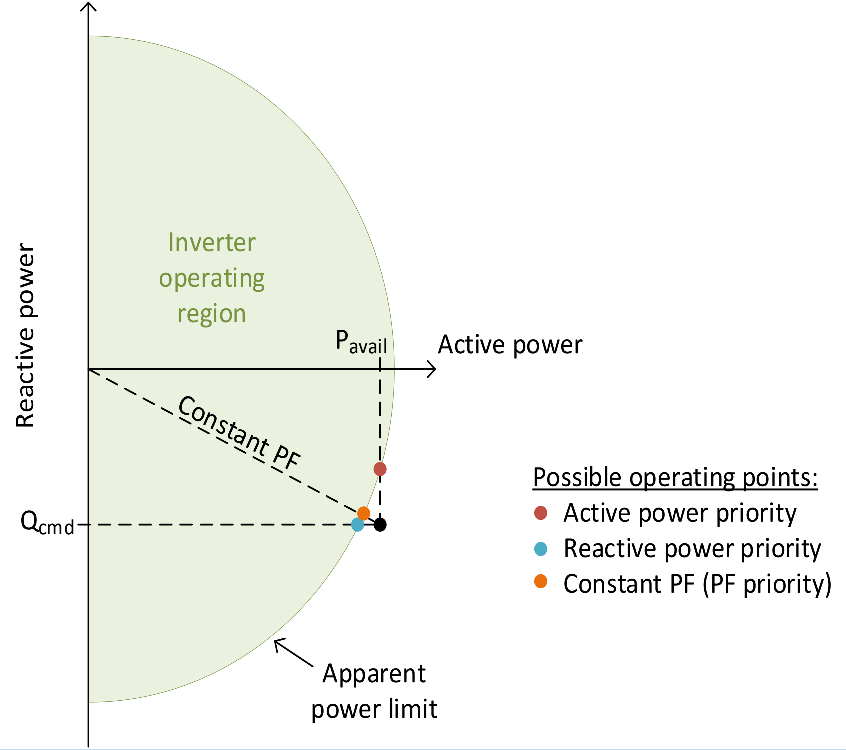
- Analyze AMI data to estimate relationship between power and voltage
- Extrapolate to negative power (PV export) to predict voltage rise
- Flag problem locations for mitigation
- Simple example shown here; reality is more complex
- HECO working with NREL to develop analytics for early identification of problem locations



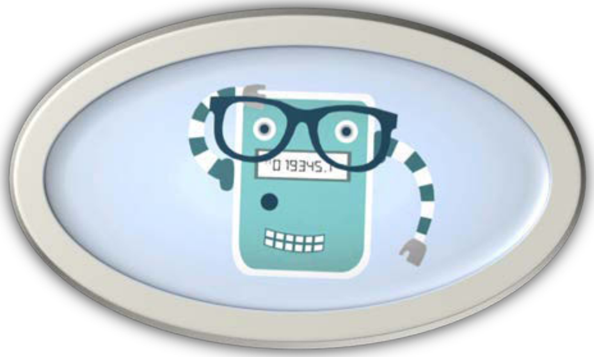
Cheat sheet – advanced inverters







Key findings from report



- **It is difficult for anyone (utility, customers, PV installers) to accurately predict in advance whether a given location will experience high voltage issues (and resulting PV energy curtailment) before PV has been installed**
  - Absence of smart meters in most Hawaii locations and the lack of customer inverter data available to utility planners makes this task even harder
- **Weekly curtailment of energy production is negligible as long as typical peak voltages are inside the ranges specified in American National Standards Institute (ANSI) Standard C84.1**
  - For any location where curtailment would be a problem, voltage is high enough that it would likely require mitigation even if curtailment were not a concern
- **HECO has embarked on a new business process improvement to streamline the interconnection of DER systems by integrating new methods, including early deployment of smart meters, to proactively identify and address problem locations**