Impact of Reactive Power Control Functions on Active Power Generation

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Background

- Fixed power factor (PF) and Volt-Var are the most commonly used smart inverter voltage regulation support functions.
- Several studies showed the effectiveness of these functions to assist voltage regulation on circuits with higher penetration of DGs.
- However, stakeholders may raise questions regarding how these functions may impact PV plant's active power generation and economics.

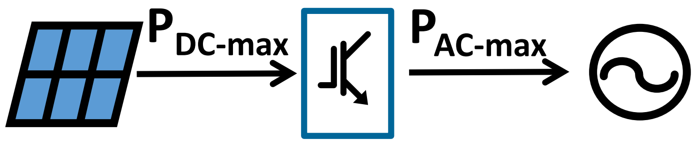
Factors Impacting Energy Loss

Factors Impacting PV Generation

Factors impacting PV generation:

- PV system design (DC-to-AC ratio)
- Inverter design - kVA rating vs kW rating
- Voltage control modes – power factor vs volt-var
- Function settings
  - power factor setpoints (for example 1.0 or 0.95 vs 0.9)
  - volt-var characteristics: with or without dead-band, width of dead-band, and Q/V gradient

PV System Design



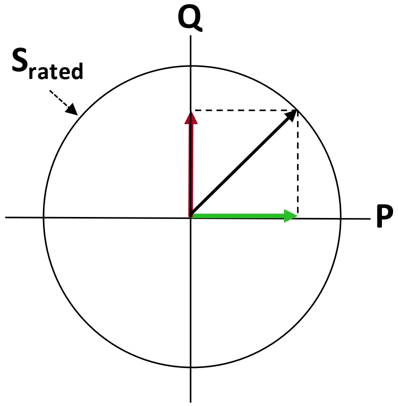
$$\frac{P_{DC\text{-}max}}{P_{AC\text{-}max}} = \text{DC-to-AC ratio}$$

Inverter Design

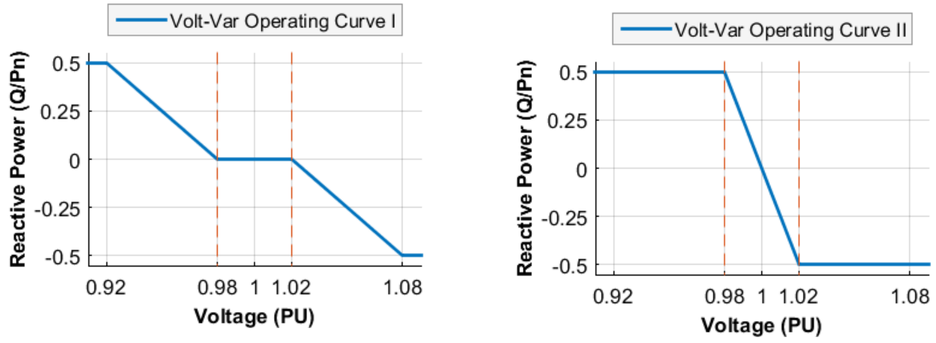
$P_{rated} = S_{rated}$

Or

$P_{rated} < S_{rated}$



Control Modes and Settings

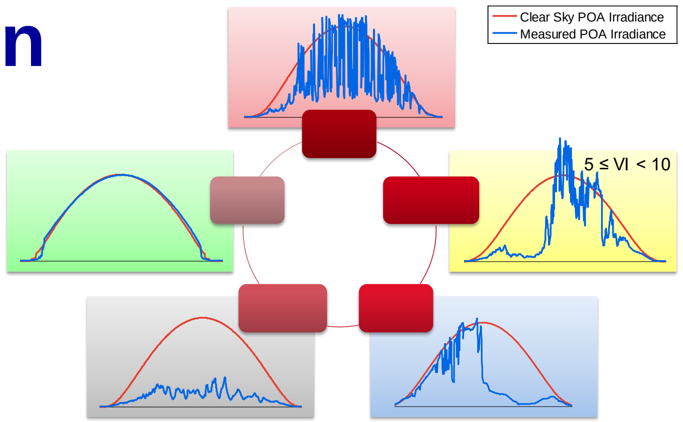


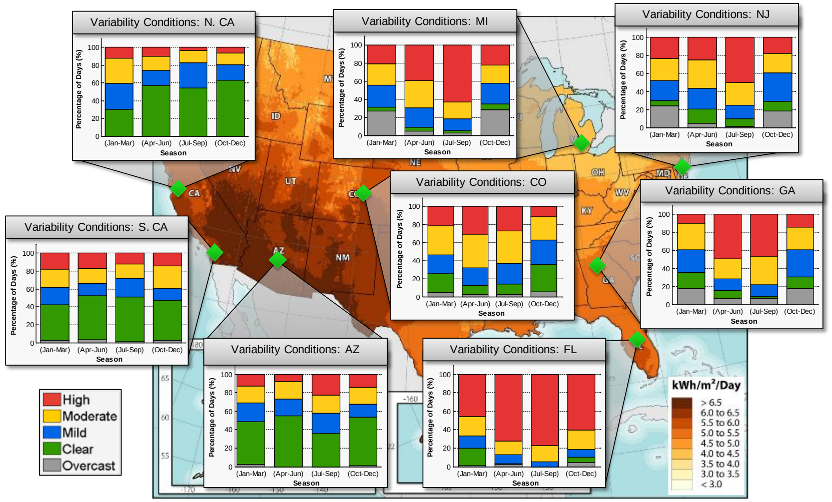
PF { 1.0, 0.95, 0.9 }

Factors Impacting PV Generation

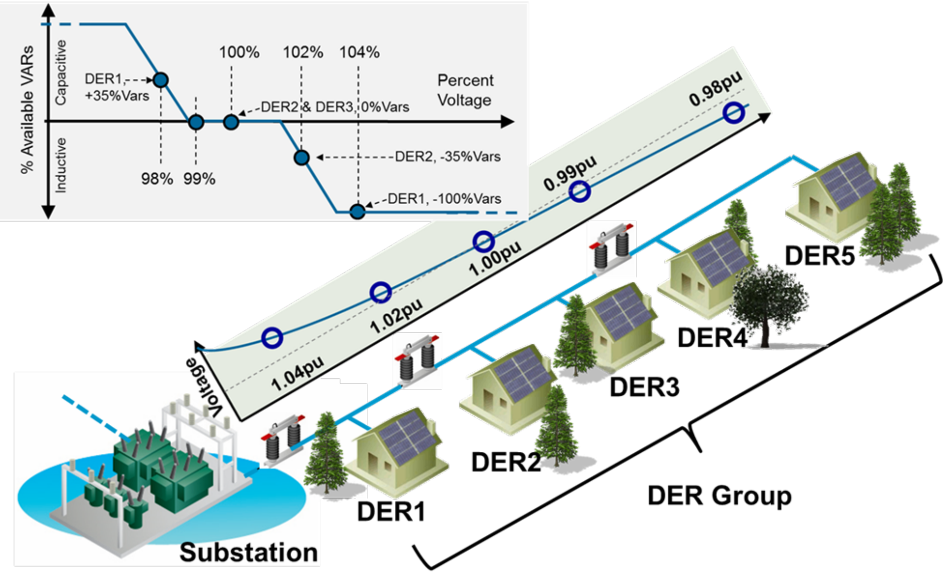
Other factors include:

- Solar irradiance profile – clear vs overcast vs high variability days
- Geographic location – some areas may have more clear and sunny days, while other areas may have more overcast or high variability days





- PV system location on the feeder will impact the voltage w/wo generation



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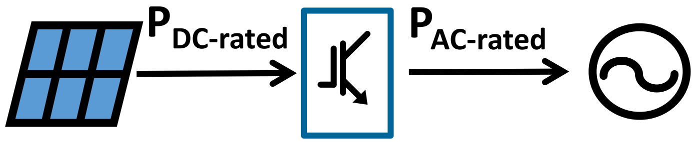
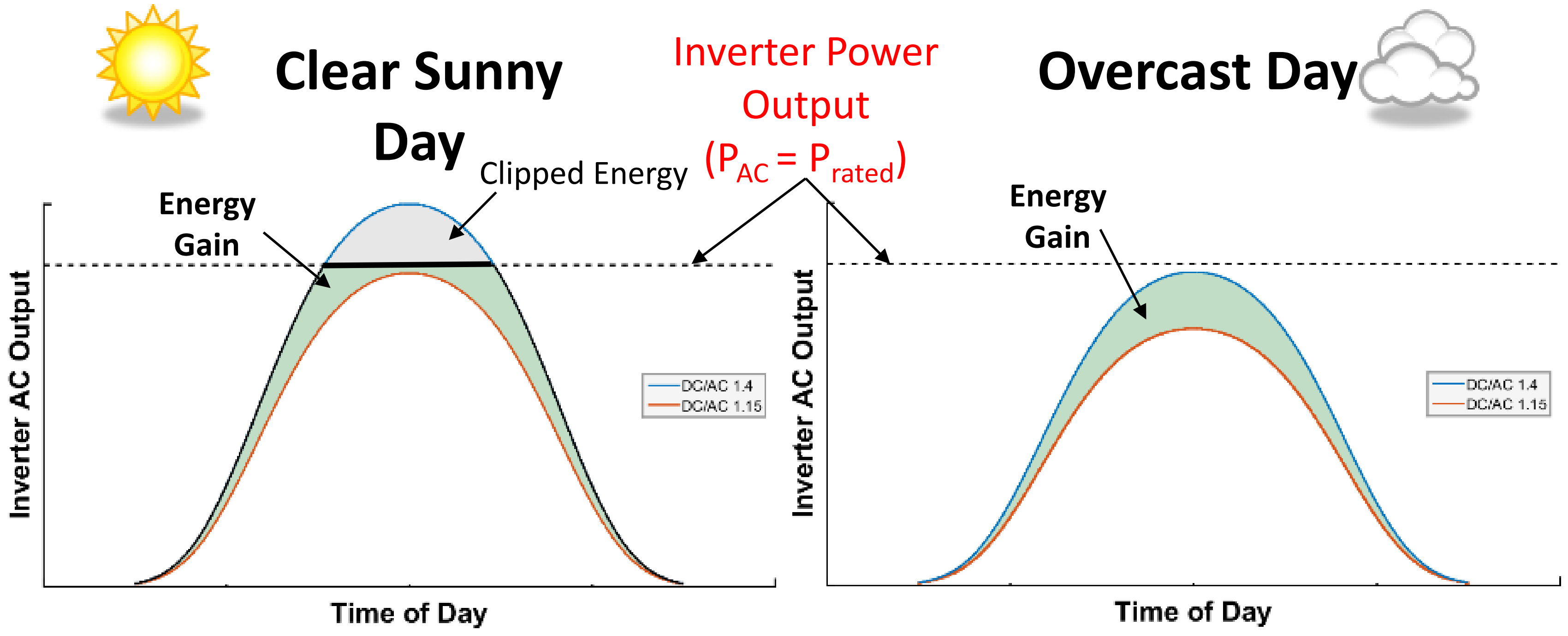
PV system design: DC-to-AC Ratio



$$\frac{P_{DC\text{-}rated}}{P_{AC\text{-}rated}} = \text{DC-to-AC ratio}$$

- In a PV system with higher DC-to-AC ratio, inverter(s) will generate more active power/energy.
- PV system's AC power output should not exceed the aggregate AC power ratings of the inverters.



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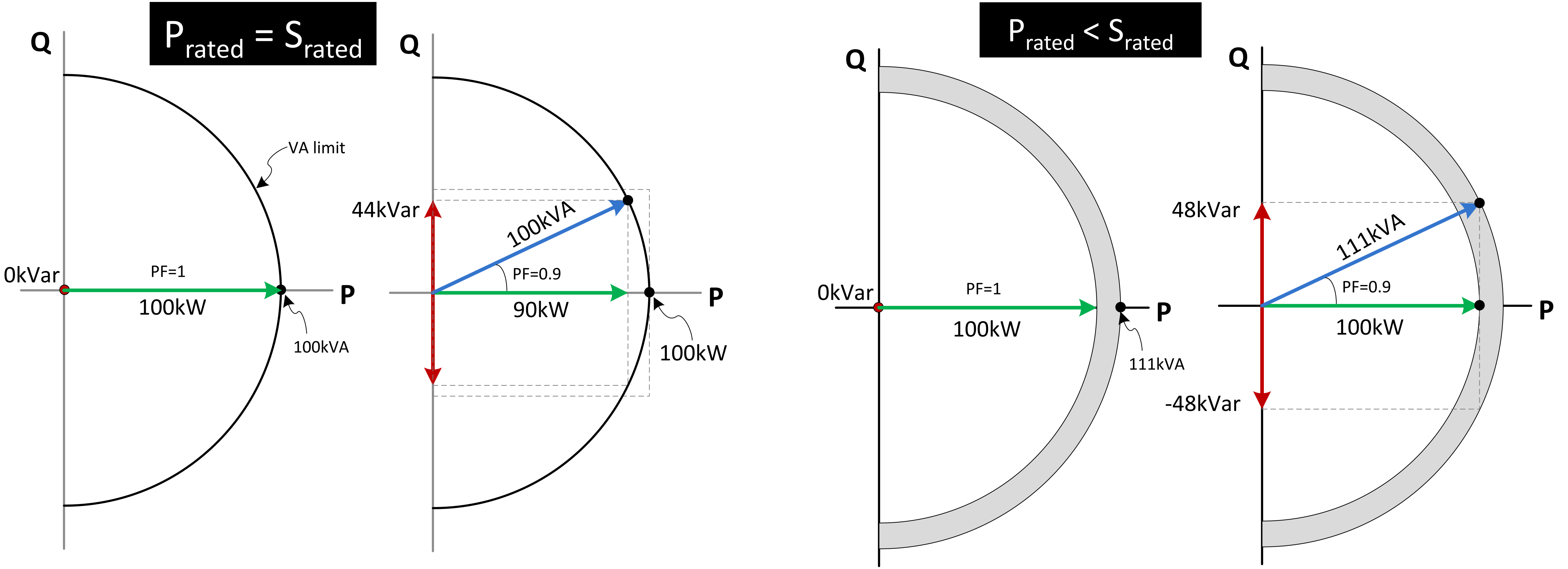
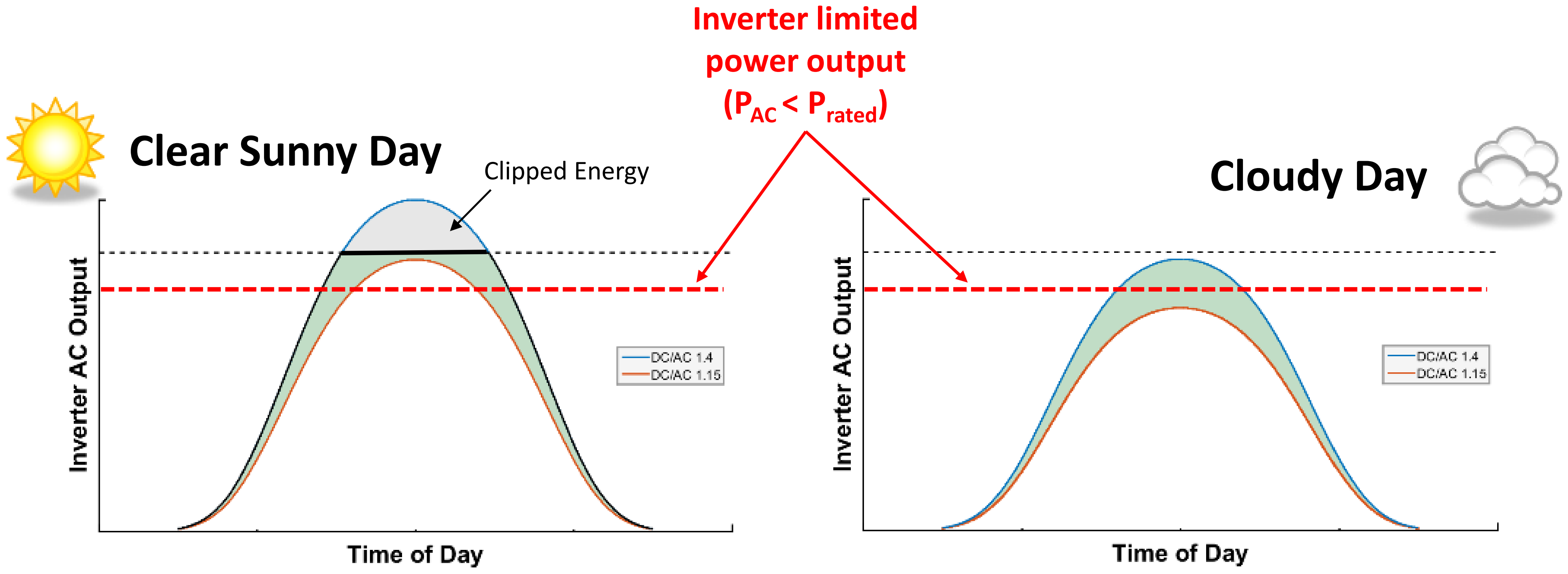
Inverter design - kVA vs kW Rating

- By design, inverters are volt-ampere (VA) limited device.
- Figures bellow show the transition of inverter operation from rated power at unity power factor to 0.9 power factor for two different inverter designs.



PV system design: DC-to-AC Ratio

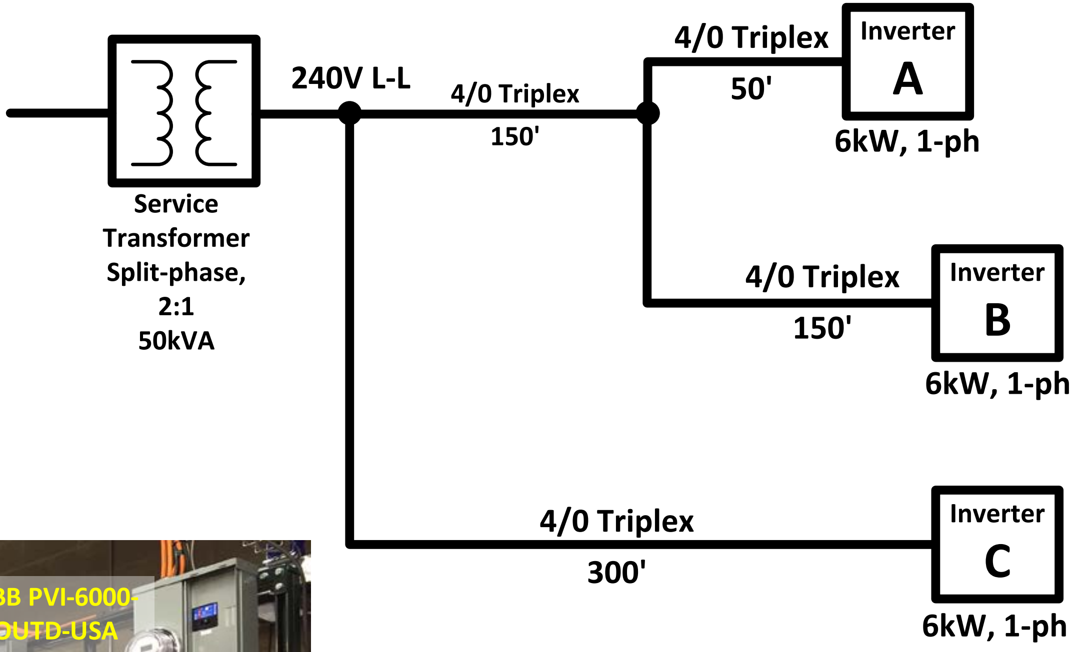
- If the inverter needs to limit it's active power output to generate reactive power (in case of kVA=kW ratings) required by the voltage control function, energy loss will be higher for systems with higher DC-to-AC ratio.



Example results from a specific test scenario

Test Scenario

Encanterra, San Tan Valley, AZ



House	A	B	C
DC/AC Ratio	1.0	1.0	1.0
DC/AC Ratio	1.3	1.4	1.2

Smart inverter test setup at EPRI Knoxville, TN laboratory

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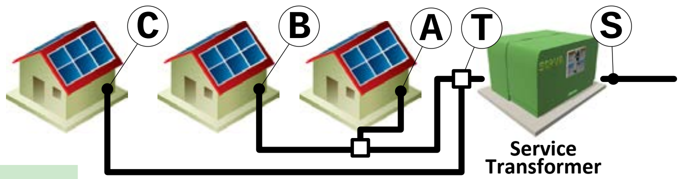
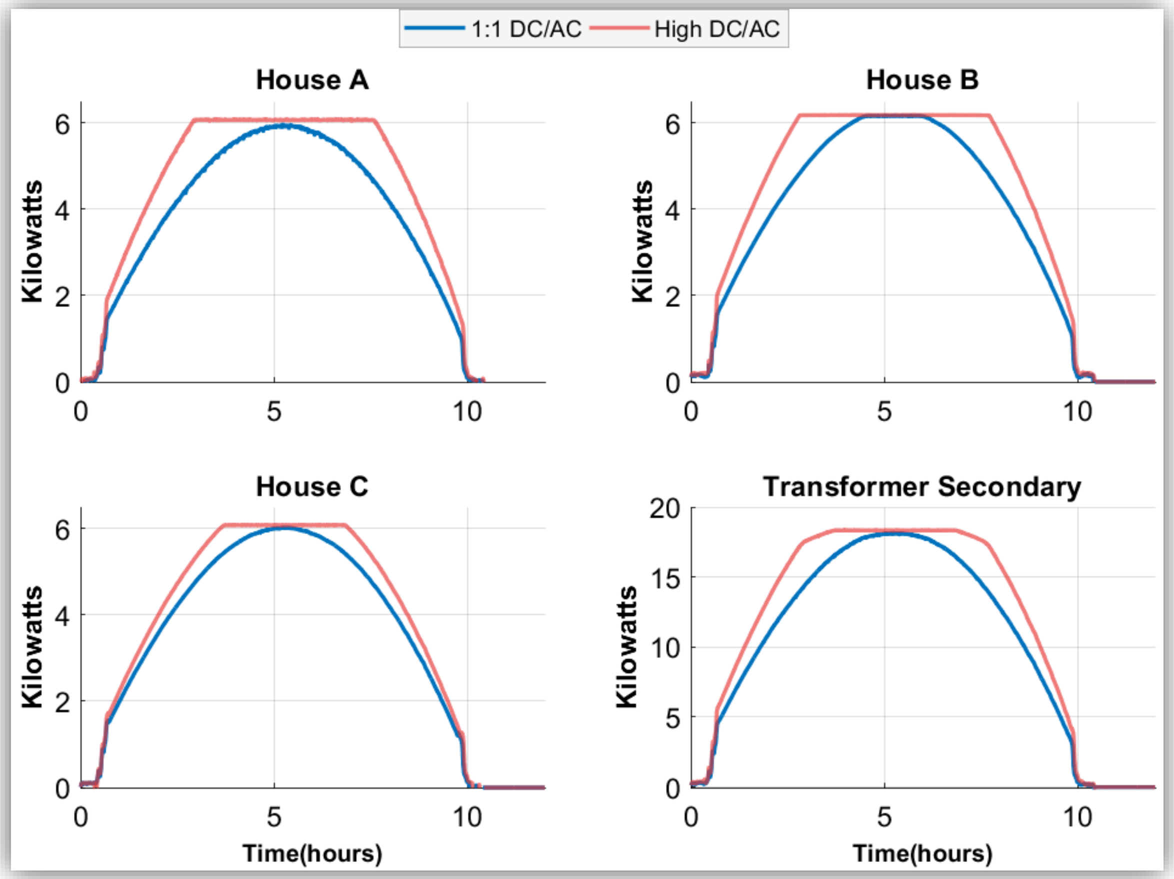
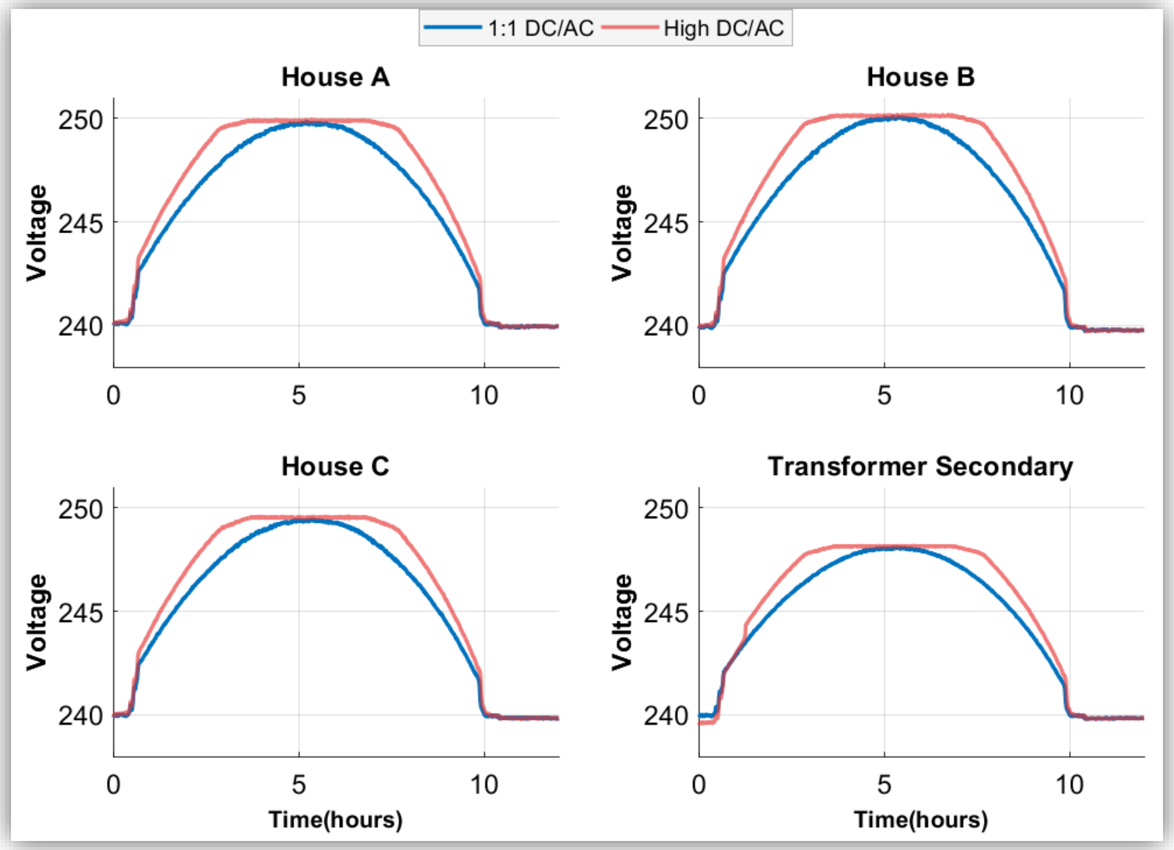
Why Oversize the PV Array?



- **Inverters operating at unity PF mode**

House	A	B	C
DC/AC Ratio	1.0	1.0	1.0
DC/AC Ratio	1.3	1.4	1.2





- PV system owners install additional modules for economic reason – up to certain DC-to-AC ratio, additional energy value will higher than the cost of additional modules.

- **System impact – higher voltage for longer period.**

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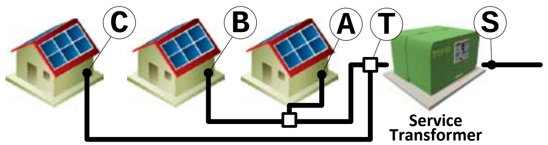
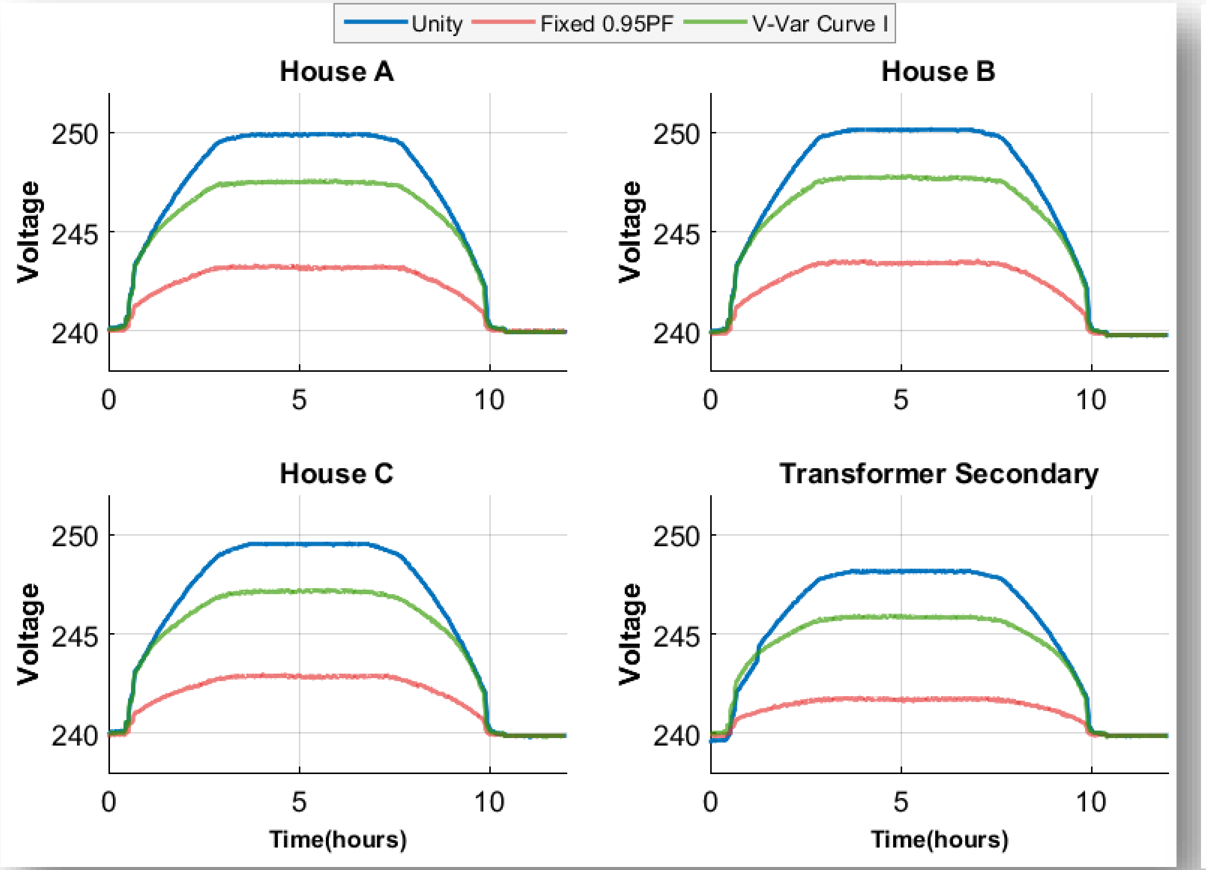
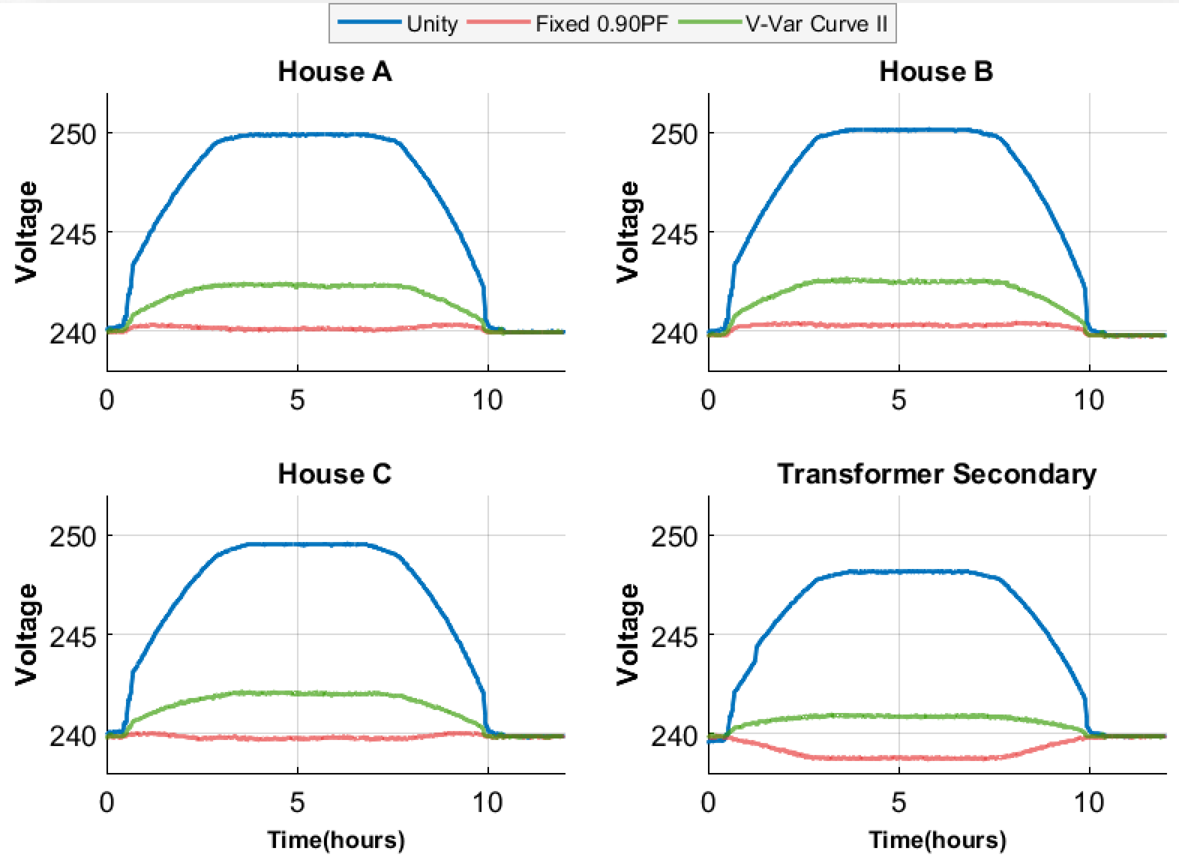
Impact on Voltages

Clear Day; High DC/AC Ratio

House	A	B	C
DC/AC Ratio	1.3	1.4	1.2





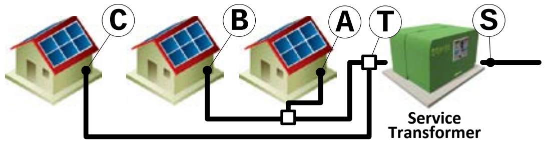


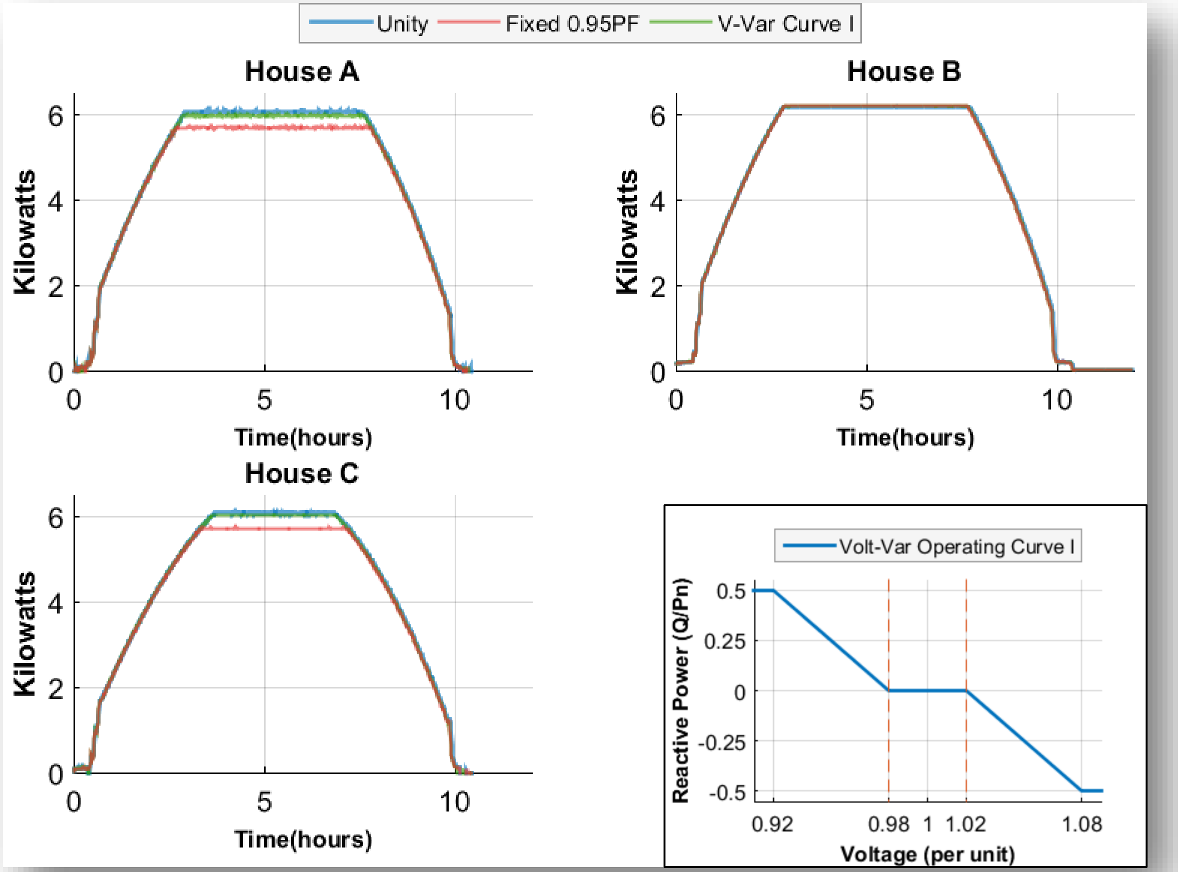
- Even with higher DC-to-AC ratios, maximum ac power output from each inverter is limited to its rating of 6kW. Hence the maximum voltages observed here are same as what were observed for 1:1 DC/AC ratio scenario.
- In this test scenario, since inverters operate at rated power for longer duration, elevated voltages were observed for longer durations.

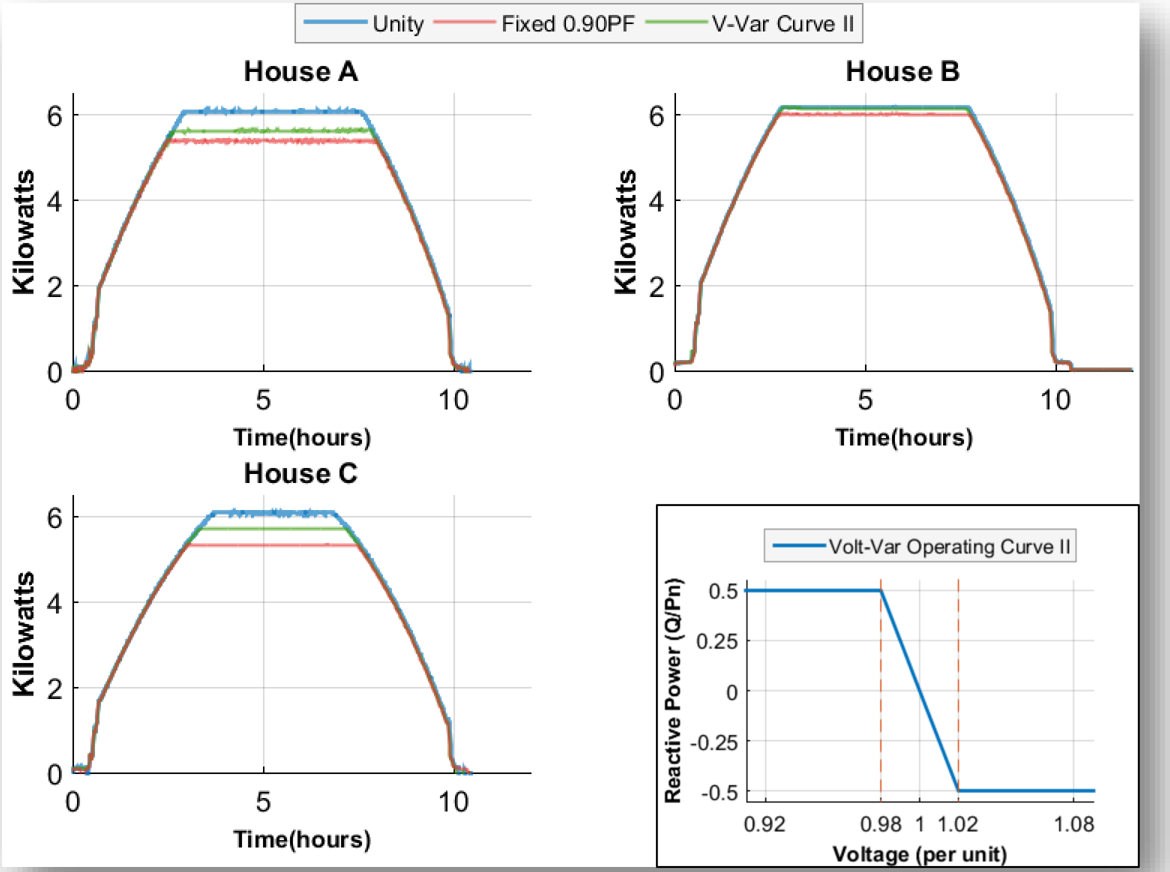
Impact on Active Power

Clear Day; High DC/AC Ratio

House	A	B	C
DC/AC Ratio	1.3	1.4	1.2





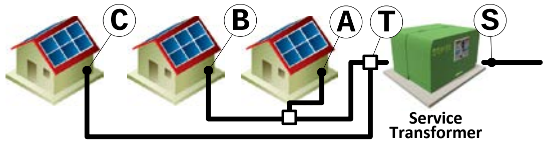


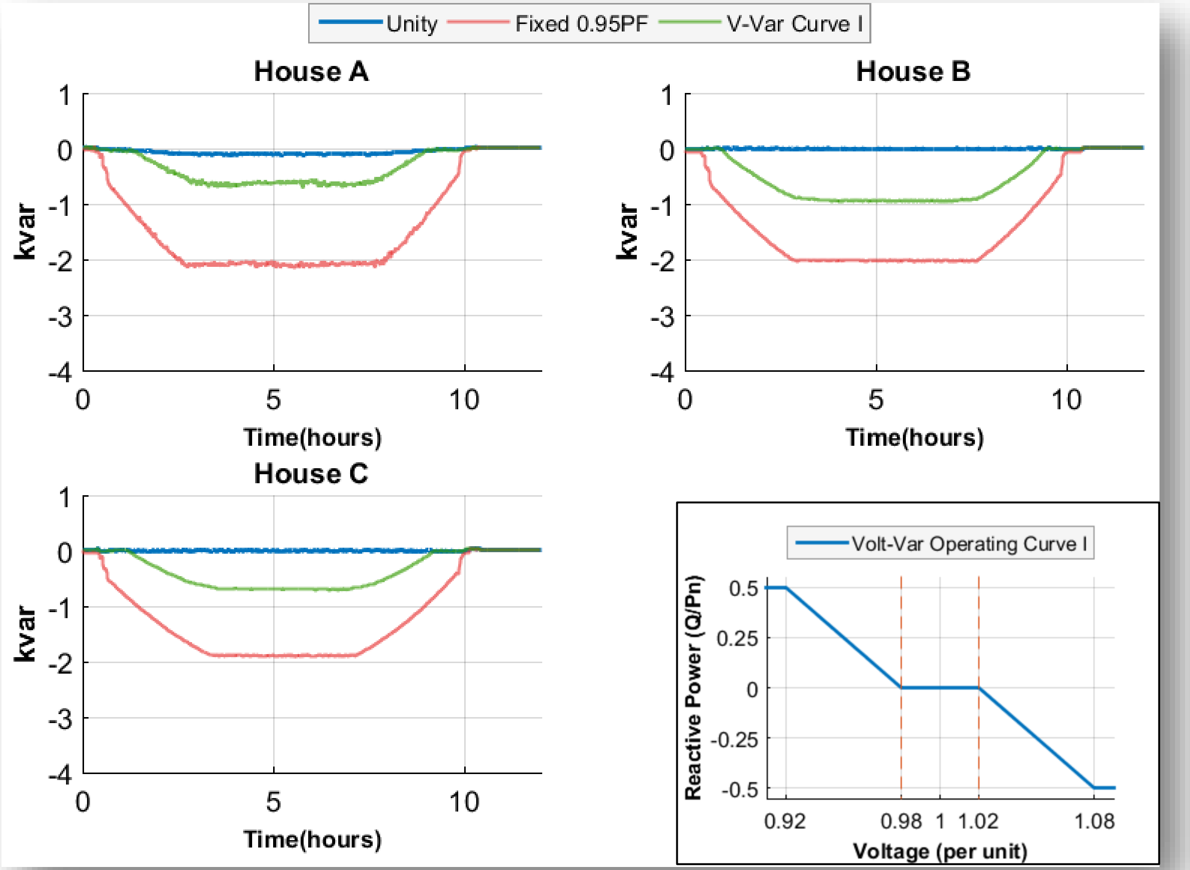
- House B has the minimum reduction in active power generation. Inverter at this house has higher kVA rating than its kW rating, hence was able to absorb more reactive power before needing to limit active power generation.
- **Volt-var I** setting has almost no impact on the PV generation.

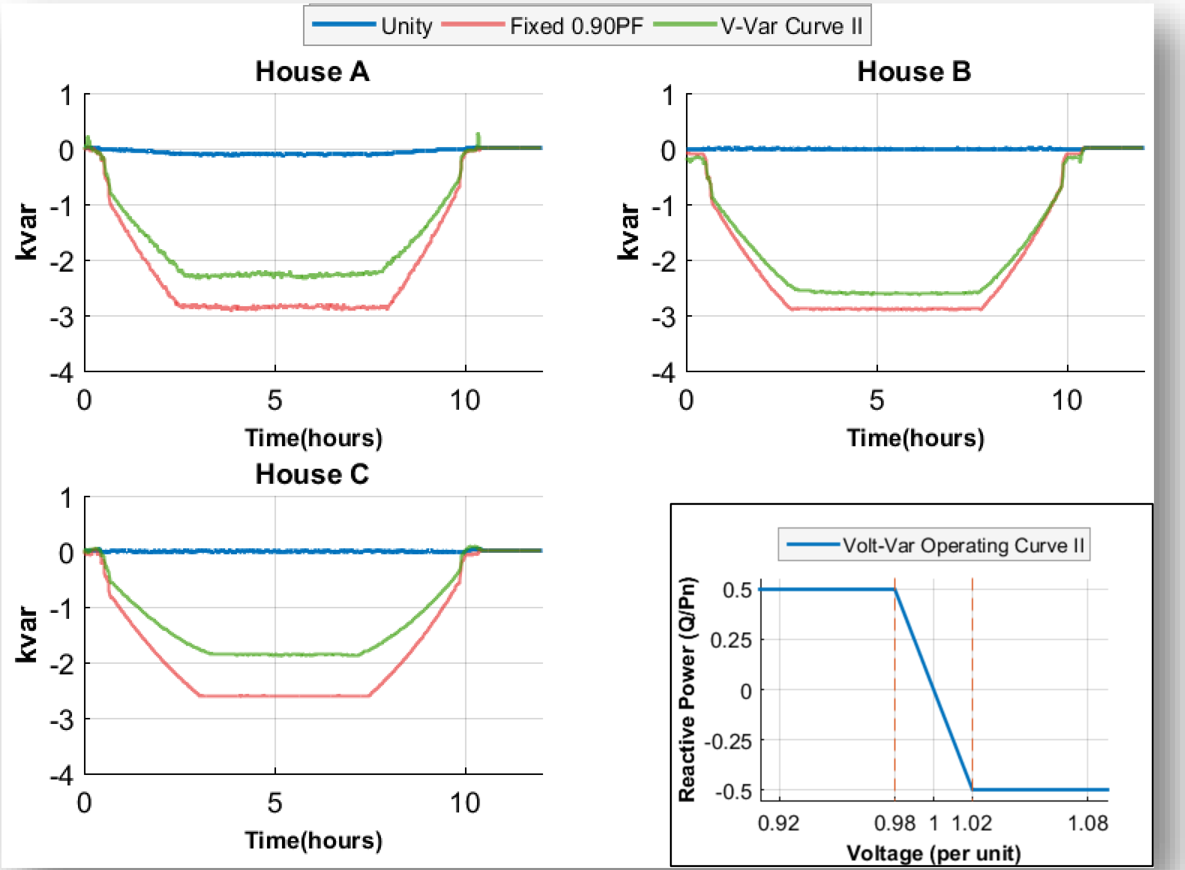
Impact on Reactive Power

Clear Day; High DC/AC Ratio

House	A	B	C
DC/AC Ratio	1.3	1.4	1.2





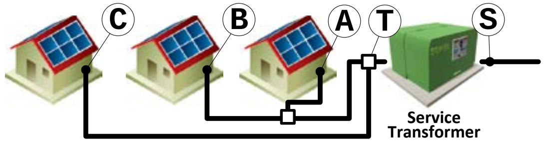


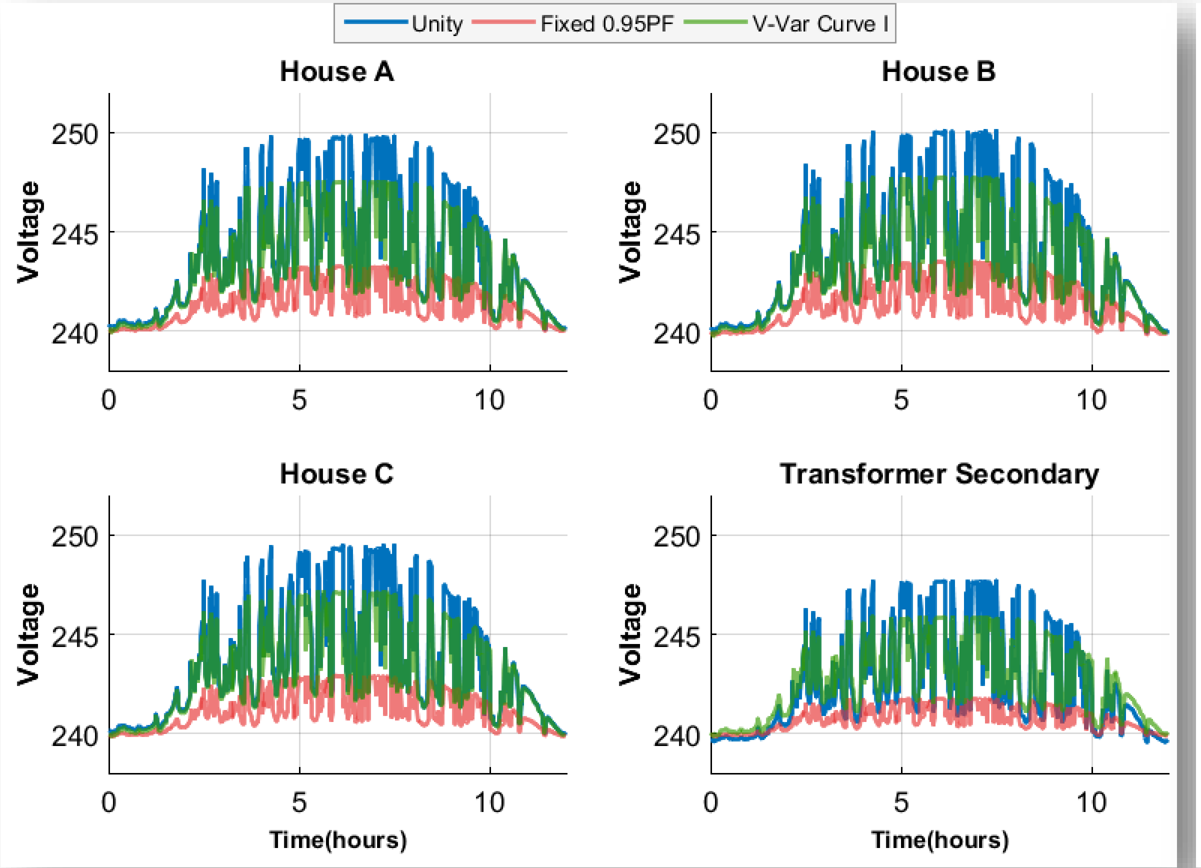
- All three inverters absorbed more reactive power in fixed PF mode compared to volt-var mode.
- In volt-var I control mode, inverters started absorbing reactive power when their terminal voltages exceeded the dead-band voltage upper limit (1.02 pu). Since volt-var II control did not have any dead-band, reactive power absorption started immediately when PV generation started to push voltages higher than 1 pu.

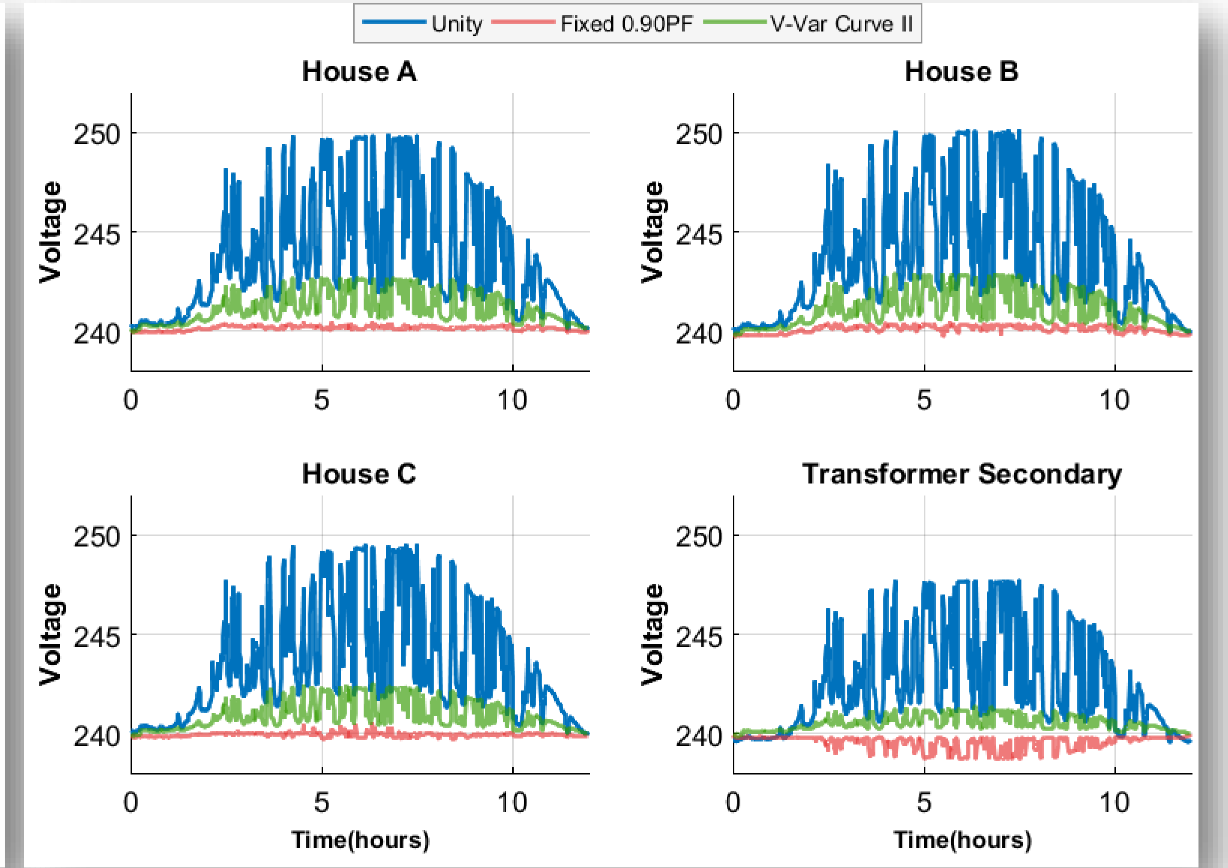
Impact on Voltages

High Variability Day; High DC/AC Ratio

House	A	B	C
DC/AC Ratio	1.3	1.4	1.2

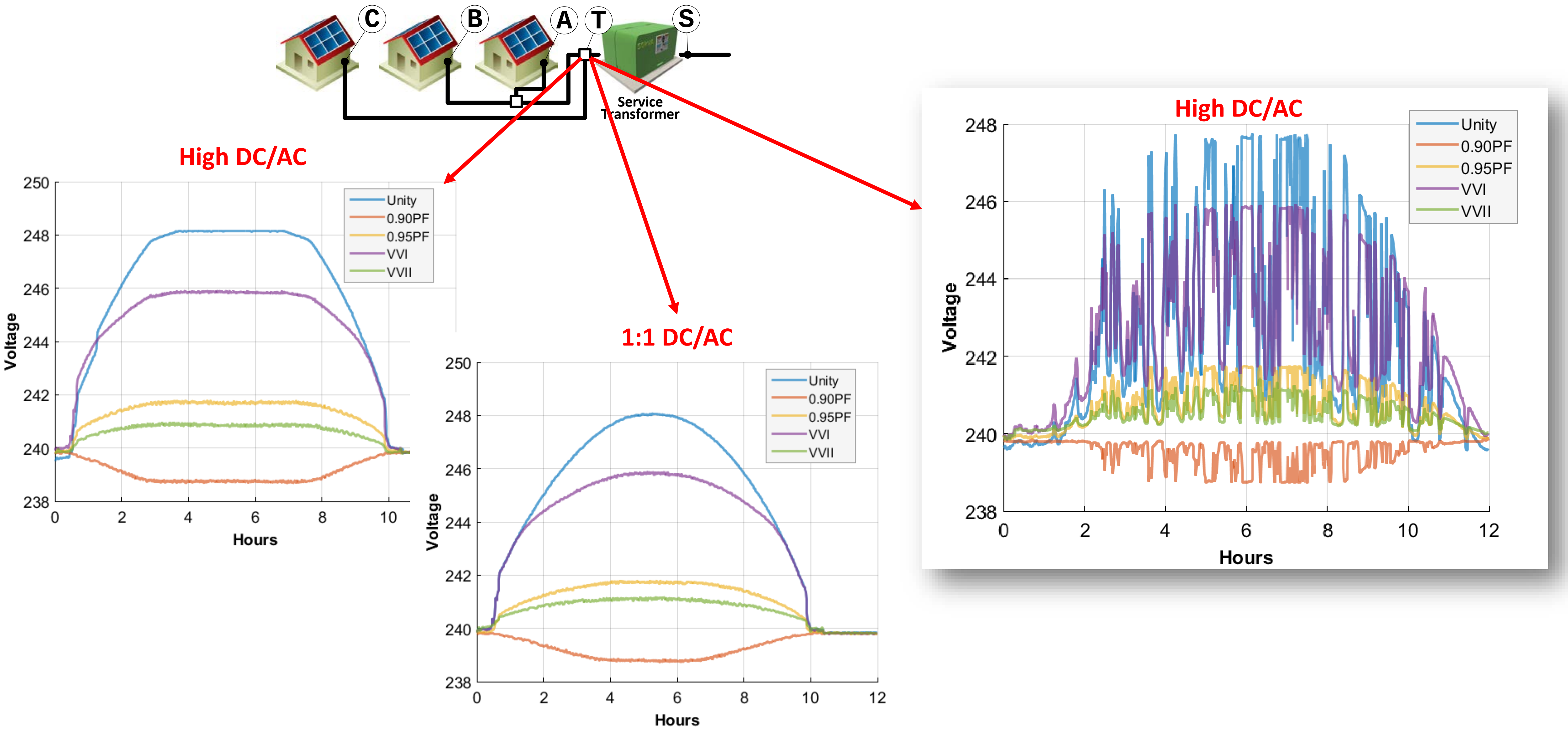






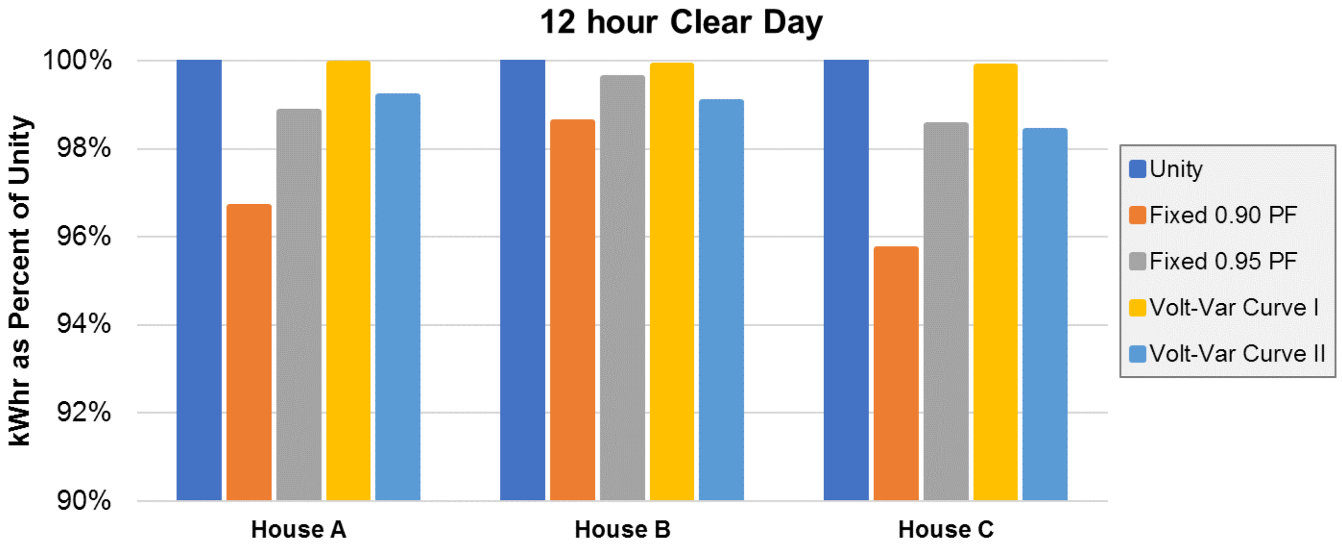
- With higher DC-to-AC ratio, inverters reached to their maximum generation limit more often than 1:1 DC-to-AC.
- All three inverters, in non unity PF (absorbing var) and volt-var control modes, limited the voltage increases at the houses and transformer level. Voltage variability is also reduced at the houses and transformer.

Impact on Transformer Secondary Voltage

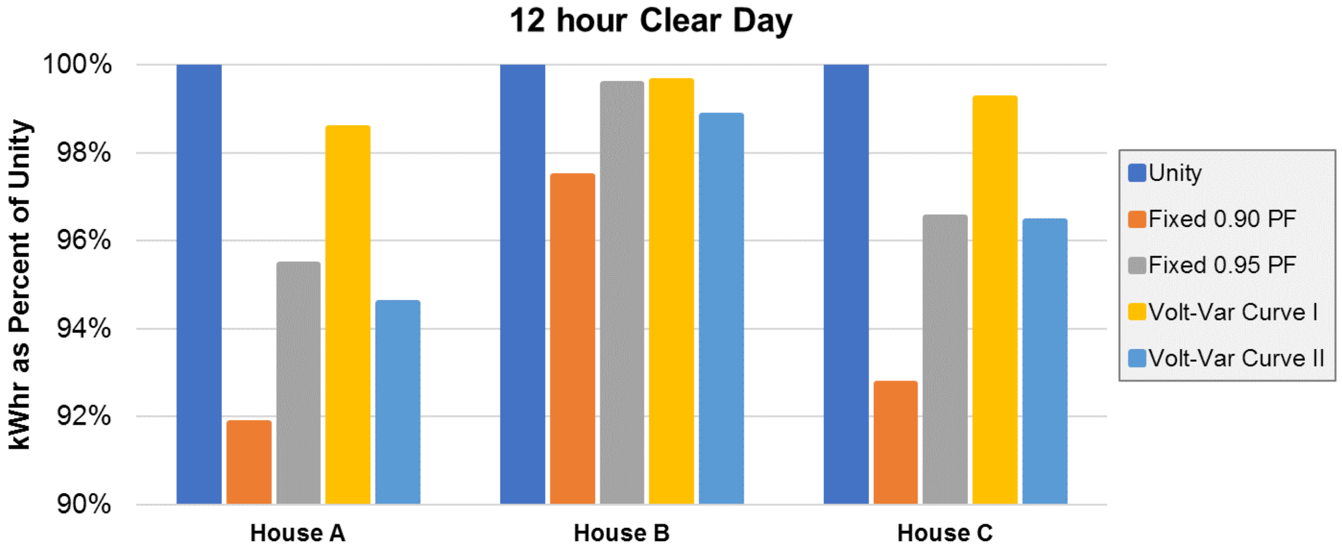


Comparisons – Clear Day

House	DC/AC Ratio
A	1.0
B	1.0
C	1.0



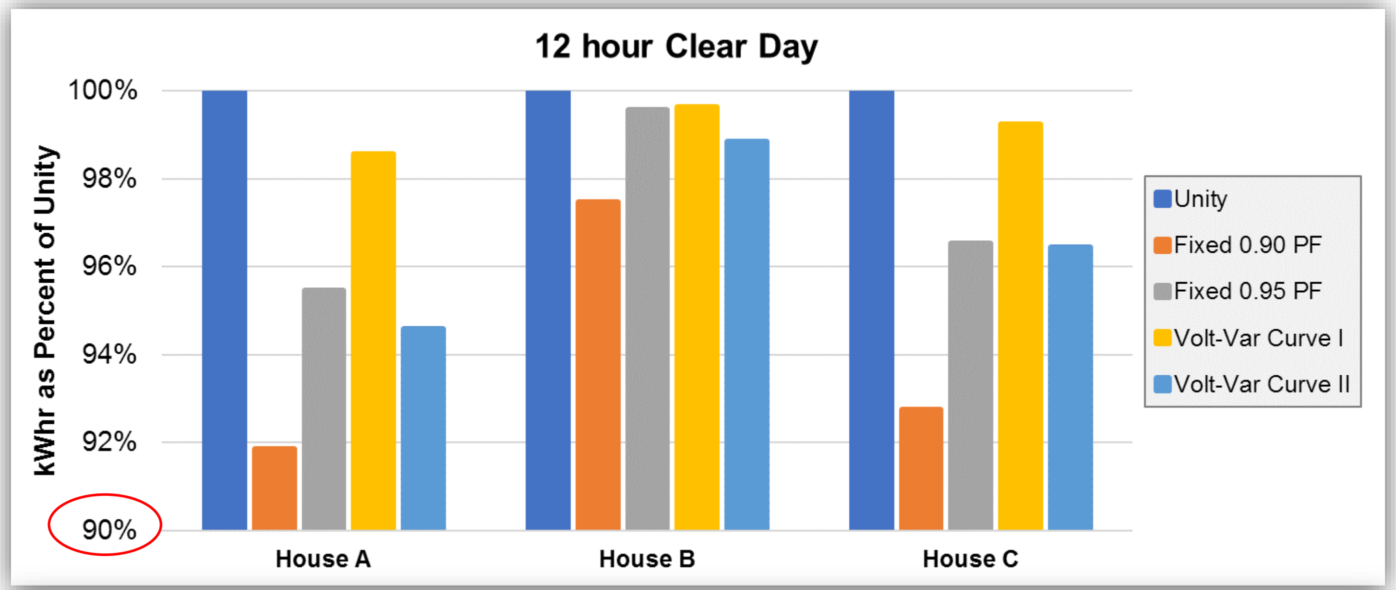
House	DC/AC Ratio
A	1.3
B	1.4
C	1.2

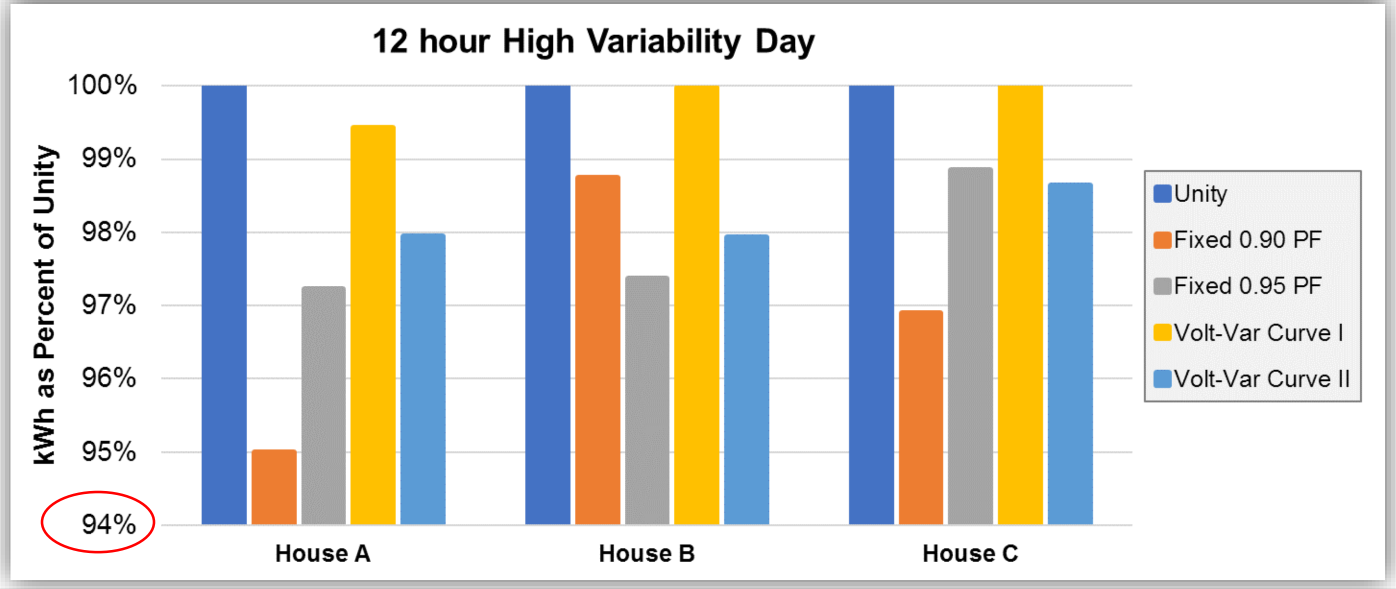


- House B active energy loss was minimum because of it's inverter with larger kVA rating than kW rating
- Volt-Var (±0.02 pu dead band and benign ΔQ/ΔV gradient) have negligible impact on inverter's active power generation.
- More aggressive(like PF ≈ 0.9) settings can increase the energy loss.

Comparisons – Clear Day vs Highly Variable Day

House	DC/AC Ratio
A	1.3
B	1.4
C	1.2





- Loss will be higher on clear days compared to other types of solar days

Conclusion

- Smart inverter voltage regulation impact on PV generation depends on many factors including inverter choice, relative size of PV array to inverter, control function mode/settings, weather condition, and circuit voltage.
- In general, Volt-Var control mode has smaller impact on the active power generation compared to comparable fixed power factor control mode.
- In PV system design, if inverters with slightly higher (for example 5~10%) kVA rating than its kW rating is used, then most of the energy loss due to PF or volt-var function can be avoided.

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