# Analysis to Inform CA Grid Integration Rules for PV

## *Preliminary Results: Inverter Settings for Distribution System Performance*


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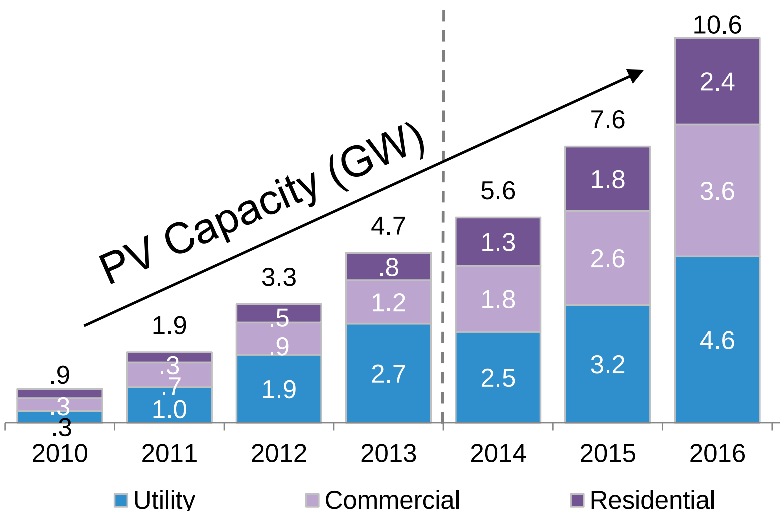
# Project Description

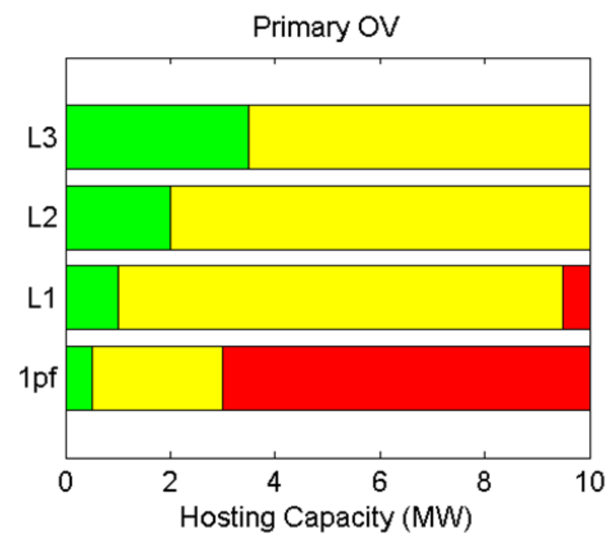
## Industry Challenge

- Landscape is changing
  - 155,000 US installations in 2013
  - 94% connected to distribution
  - Expected to triple by 2016
- New Challenges for Utilities
  - **Accommodate more PV**
  - **Use Advanced Inverters**

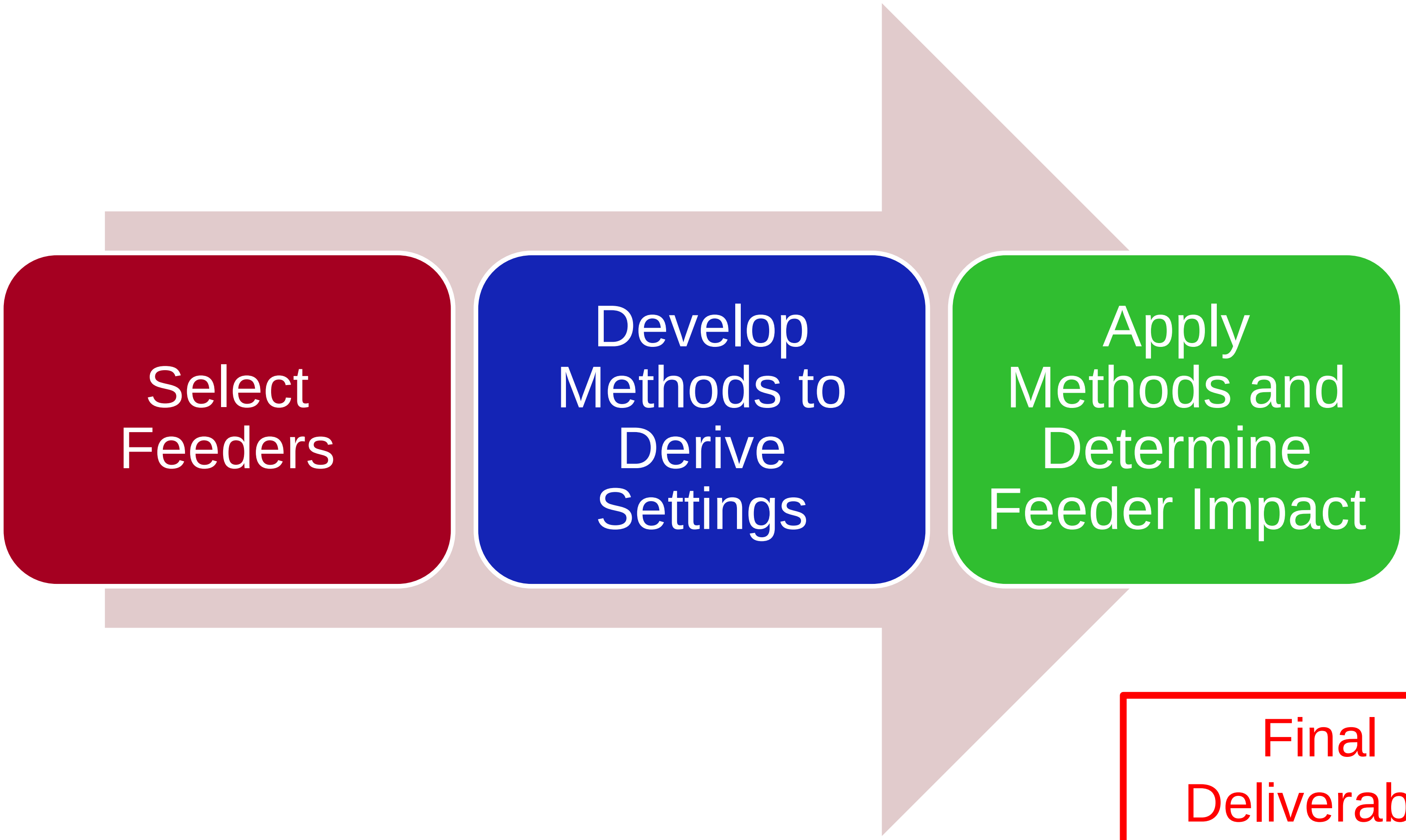
## Project Goal

- Determine advanced inverter settings to accommodate more PV without system upgrades
  - Power factor, volt-var, volt-watt
  - Settings and/or methods to determine settings



# Approach to Derive/Test Recommended Settings/Methods




Final Deliverable Summer 2016

# Select Feeders

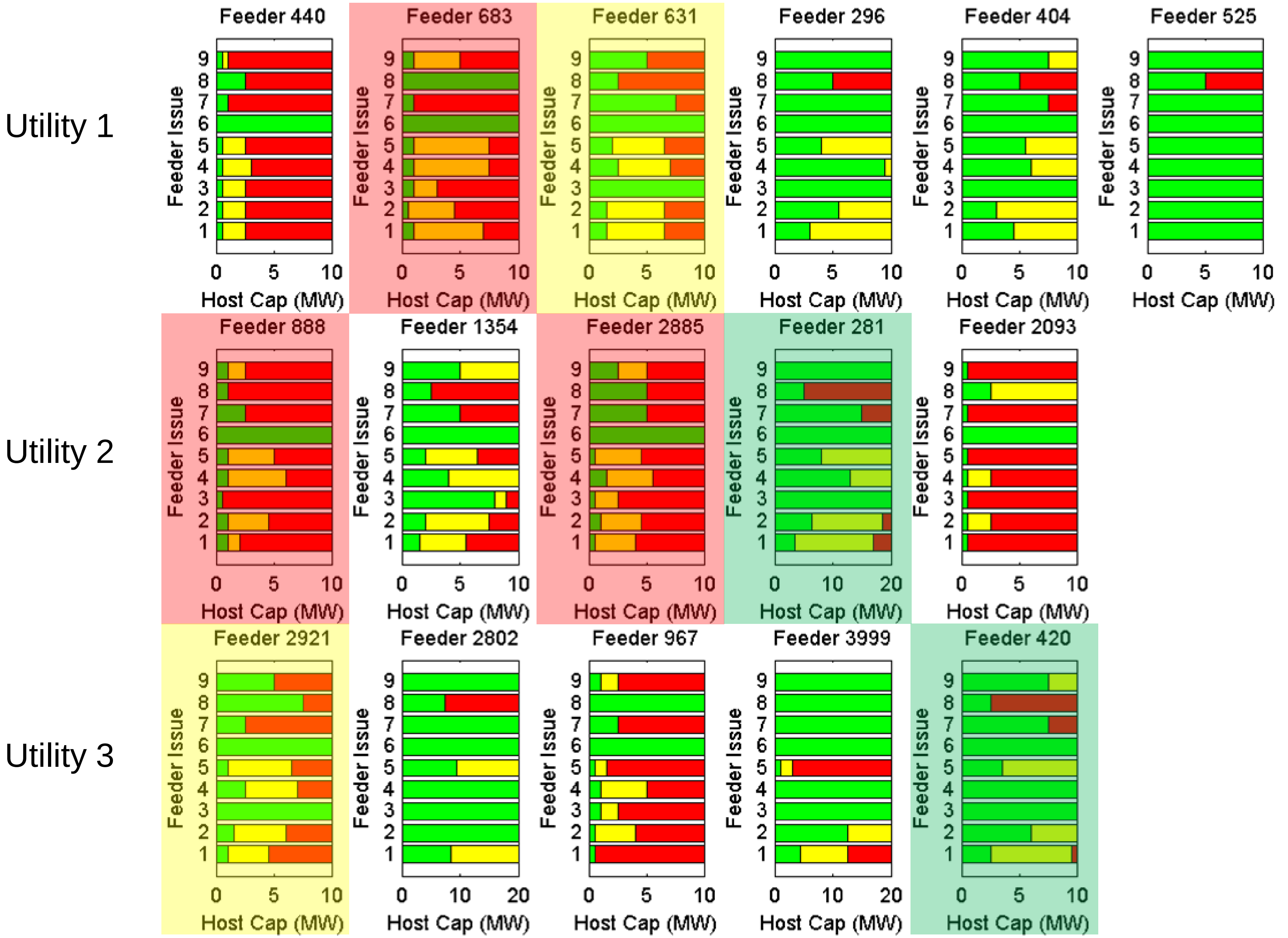
# Feeders Selected from CPUC-CSI3 Analysis

*CPUC-CSI3*
*Alternatives to the 15% Rule: Final Project Summary*. EPRI, Palo Alto, CA: 2015. 3002006594.

Criteria for feeder selection

- Utility
  - 2-3 feeders from each utility
  - Each utility represented in the analysis
- Impact
  - 3 high impact / low hosting capacity feeders
  - 2 moderate impact / moderate hosting capacity feeders
  - 2 low impact / high hosting capacity feeders
- Voltage Class
  - Low/Medium/High
  - Majority of the feeders are in the 12 kV class
- Equipment
  - Certain equipment such as regulators have a direct relationship to low hosting capacity
  - Several feeders chosen have regulators

# CPUC-CSI3 Feeder Hosting Capacity





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# Selected Feeder Details

| Feeder Name | Peak Load (MW) | Farthest 3-phase Bus (km) | PV Hosting Capacity | Nominal Voltage | Line Regs | Switching Caps |
|---|---|---|---|---|---|---|
| 683 | 3.6 | 17.9 | Low | 12 kV | 1 | 1 |
| 631 | 3.4 | 11.7 | Moderate | 12 kV | 0 | 1 |
| 888 | 2.2 | 2.8 | Low | 4 kV | 0 | 0 |
| 2885 | 9.2 | 11.9 | Low | 12 kV | 1 | 6 |
| 281 | 16.7 | 10.3 | High | 21 kV | 0 | 6 |
| 2921 | 6.4 | 15.5 | Moderate | 12 kV | 0 | 6 |
| 420 | 5.0 | 4.7 | High | 12 kV | 0 | 1 |

# Develop Methods to Derive Settings

# Methods to Derive Settings

| Level | Complexity | Power Factor | Volt-var | Volt-watt |
|---|---|---|---|---|
| 1 | Low | Based on Feeder X/R Ratio | Feeder Independent Setting | Feeder Independent Setting |
| 2 | Medium | Based on Feeder Model and General PV Location | Based on Feeder Model and General PV Location | NA |
| 3 | High | Based on Feeder Model and Exact PV Location | Based on Feeder Model and Exact PV Location | NA |

# Power Factor Control

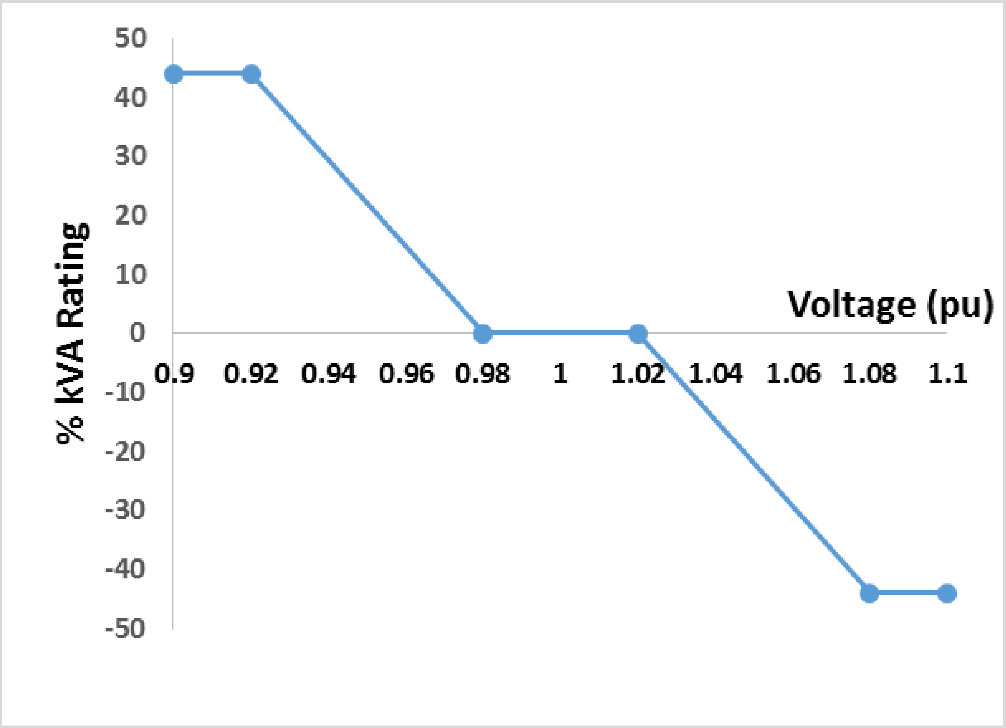
- Level 1 settings:
  - Most simple method required to determine settings
  - Setting is not a default for entire system
  - Setting is feeder specific
  - Setting is based on the Mean X/R ratio on the feeder

| Level | Method | Calculation Method | Data Requirements | Power Factor Setting |
|---|---|---|---|---|
| 1 | **Mean X/R Ratio of 3-phase MV Buses to determine power factor** | Hand calculation | Primary node X/R ratios on feeder, number of phases at each node | Single Setting on each feeder |

$$Power\ factor \cong \frac{\left({}^{X}/_{R}\right)_{mean}}{\sqrt{\left(\left({}^{X}/_{R}\right)_{mean}\right)^2 + 1}}$$

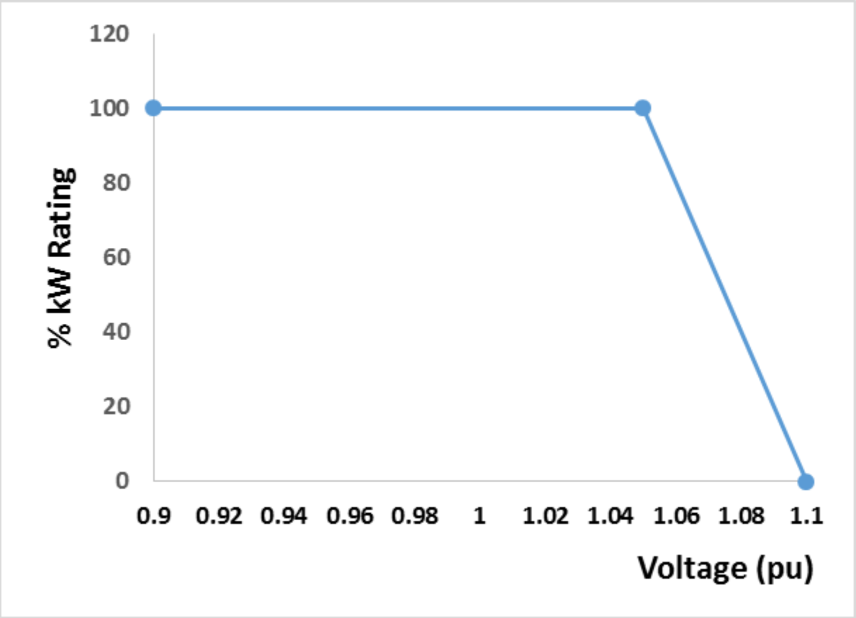
# Volt-var Control

- Level 1 settings:
  - Wide bandwidth (does nothing when within 2% from nominal)
  - Maximum reactive power output equivalent to 90% power factor when real power is at full output (assumed that the inverter is 10% larger than the PV system rating)



# Volt-watt Control

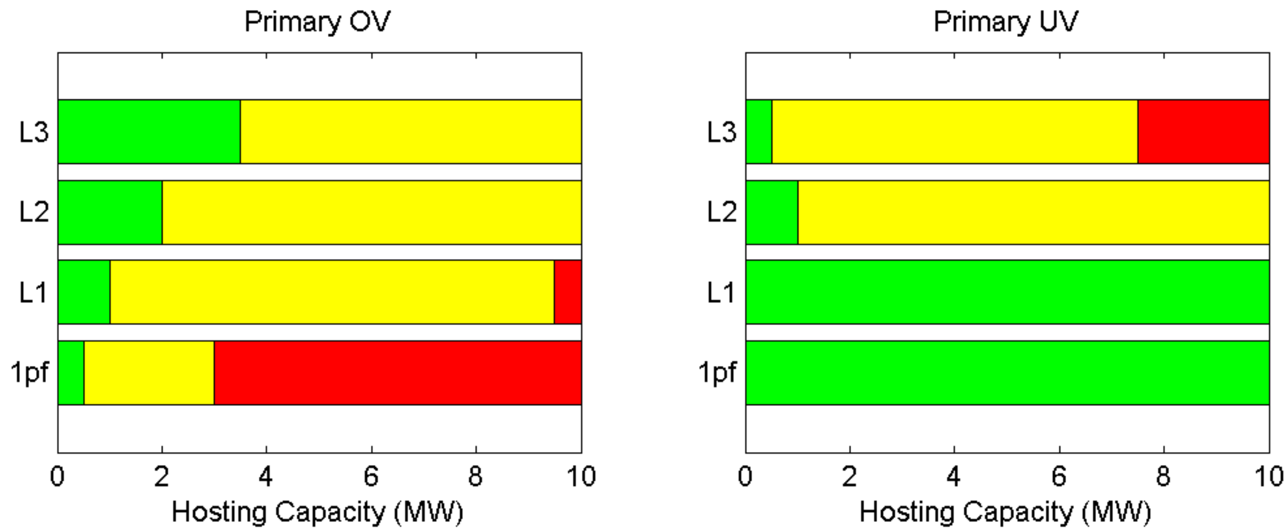
- Level 1 settings:
  - Delayed control (does not curtail power when voltage is within ANSI limits)
  - Real power is only curtailed if the inverter output exceeds the value shown at the specific voltage (i.e., at 1.075 Vpu, the maximum real power output from the inverter can be 50%. If the inverter is at 49% real power output, the inverter does not curtail.
  - Real power curtailed to Zero at 1.1pu voltage
- Basis:
  - If voltages are high without PV, then the inverter should not be limited to what it can produce.
  - Reactive power control functions should be utilized before the inverter voltage reaches the ANSI limit
  - Ideally, reactive power functions would prevent Volt-Watt from being applied
  - **Volt-Watt is more of a last case option**



# Apply Methods and Determine Feeder Impact

# Determine Feeder Impact

- Impact based on same hosting capacity analysis used in CPUC-CSI3 feeder analysis
  - The thousands of stochastic PV scenarios were converted from unity power factor to each of the settings/methods derived
  - Multiple load levels considered





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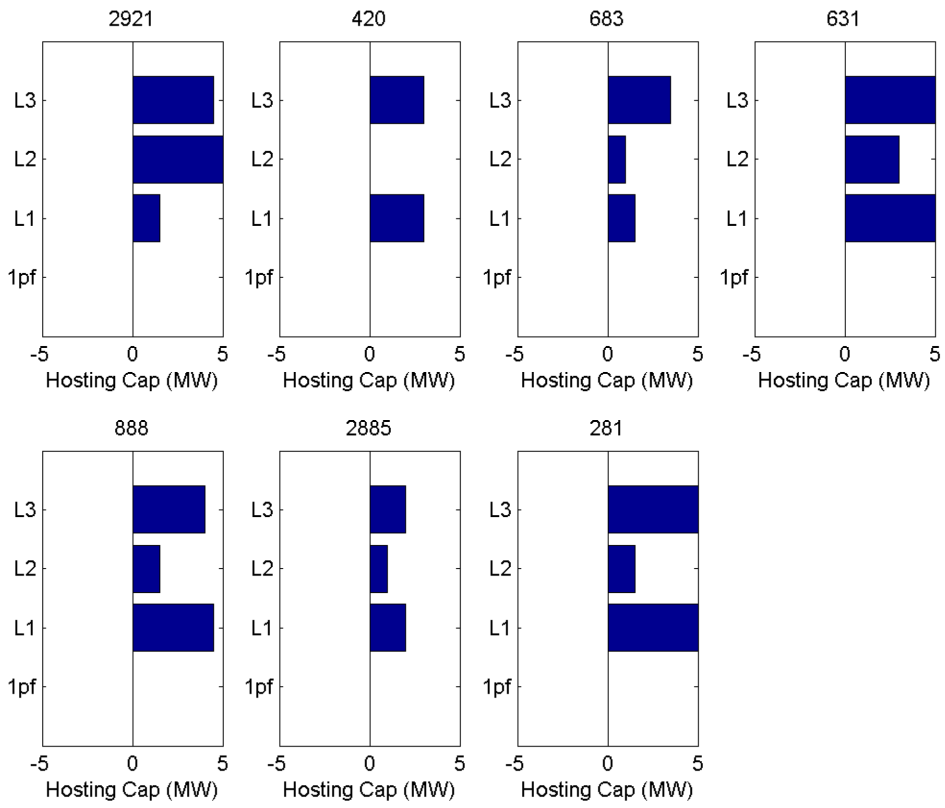
# Power Factor Control
*Hosting Capacity Impact*

Level 1: Feeder X/R Ratio

Level 2: Feeder Model

Level 3: Feeder Model and PV Location

- No methods decrease hosting capacity
- The most simplistic method (L1) performs similarly to more complex L3 on many feeders
- L1 could come at the cost of
  - Excess reactive power demand
  - Excess losses





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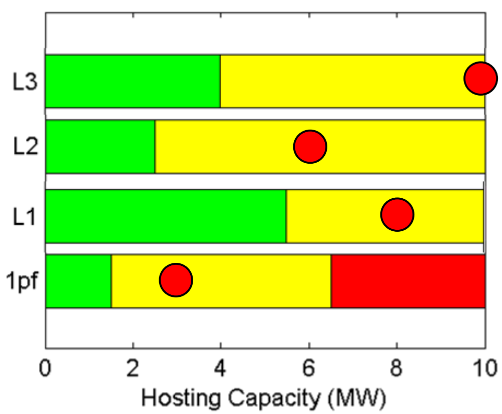
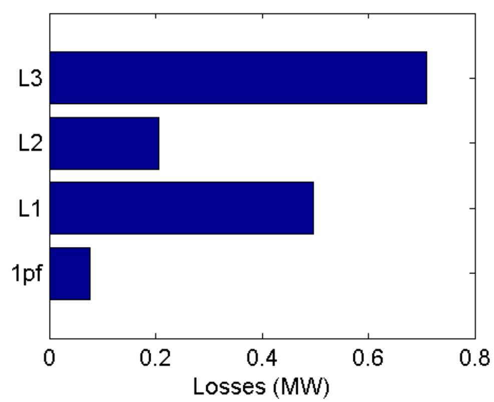
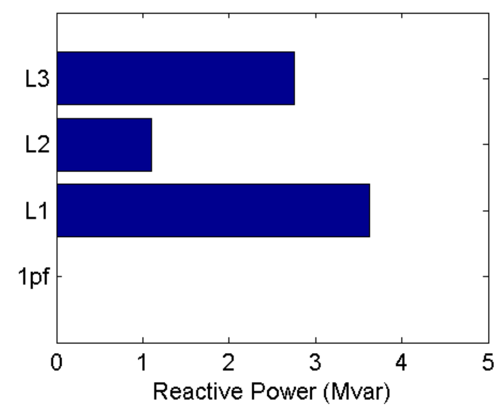
# Quantifying Value from the Method/Setting

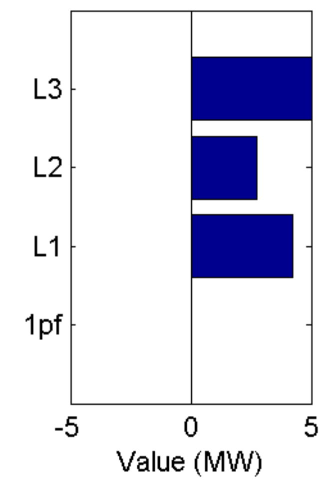
- Impact quantified based on
  - Hosting Capacity for Primary Overvoltage and Undervoltage
  - Losses
  - Reactive Power

Increase in **median** hosting capacity from Unity PF scenario — Increase in losses from Unity PF scenario — Reactive power required derated by 90% = Value





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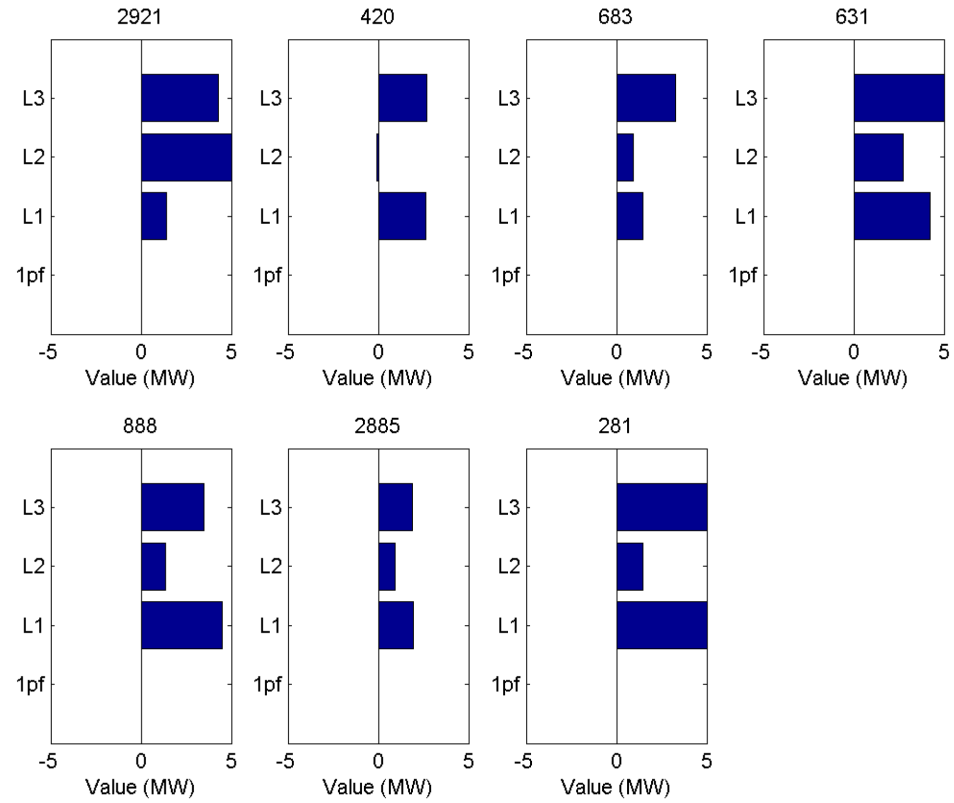
# Power Factor Control

Level 1: Feeder X/R Ratio

Level 2: Feeder Model

Level 3: Feeder Model and PV Location

- Value is the change in hosting capacity, losses, and reactive power
- Level 1
  - Potential for significant value similar to more complex methods on 5 feeders
- Level 2
  - More of a Hit-or-Miss
  - Continued work to be done on this method
- Level 3
  - Consistently a high value





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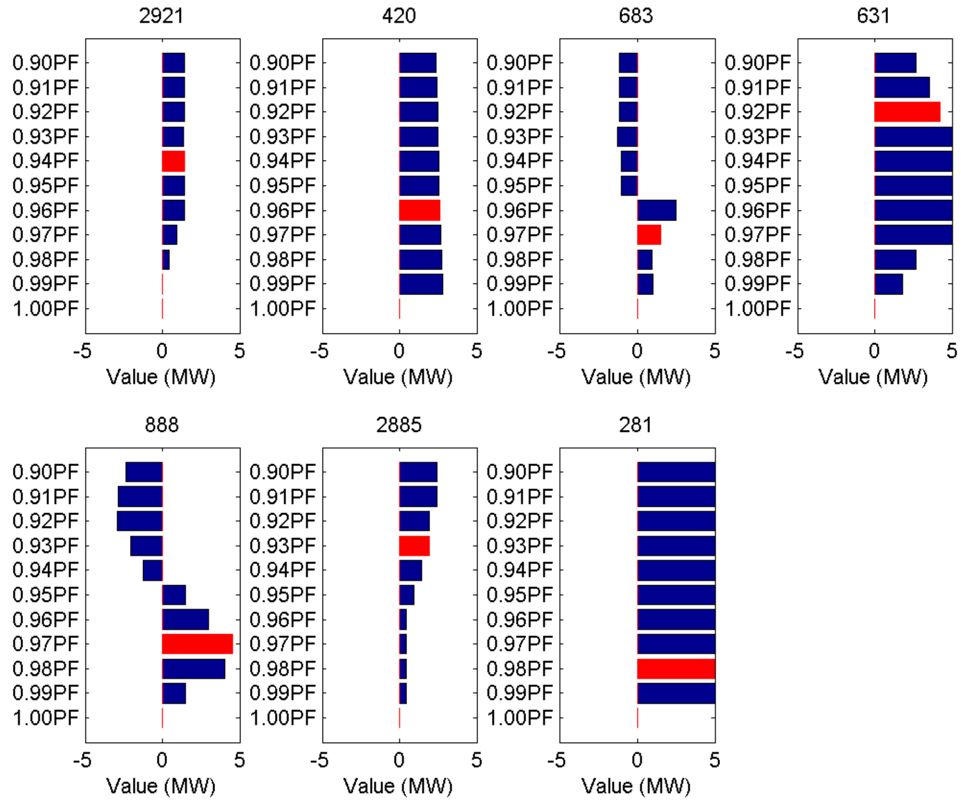
# Power Factor Control Brute Force Sweep

- Based on the significant value of Level 1 on many feeders, an alternate, more complex, approach was used to examine value of other single power factor settings

- Findings:
  - L1 setting was close to best on many feeders
  - All feeders have positive value with power factor settings greater than or equal to 0.96
  - Voltage constrained feeders (683 and 888) could potentially show negative value
    - Hosting capacity does not change
    - Reactive power demand increases

Highlighted RED is the L1 setting




Voltage constrained feeders could potentially show negative L1 value.

# Power Factor Control
## *More Emphasis on Reactive Power*

Level 1: Feeder X/R Ratio

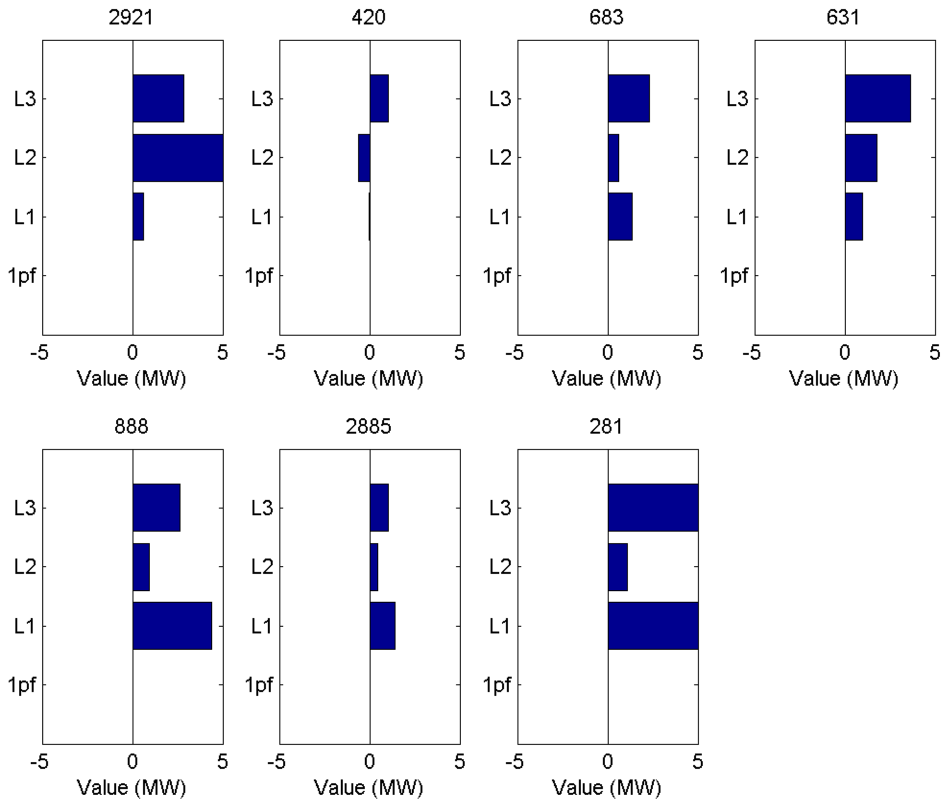
Level 2: Feeder Model

Level 3: Feeder Model and PV Location

- Reactive power deration changed from 90% to 0% to put more emphasis on the use of reactive power (This is an overemphasis for illustration)

- Level 1
  - Less effective due to excess reactive power demand on feeders with low power factor setting (2921 & 631)
  - Method does not take into account PV location

- Level 3
  - More effective use of reactive power
  - Method takes into account feeder model and PV location




Feeders with low L1 power factor settings benefit less if there is more emphasis on reactive power.

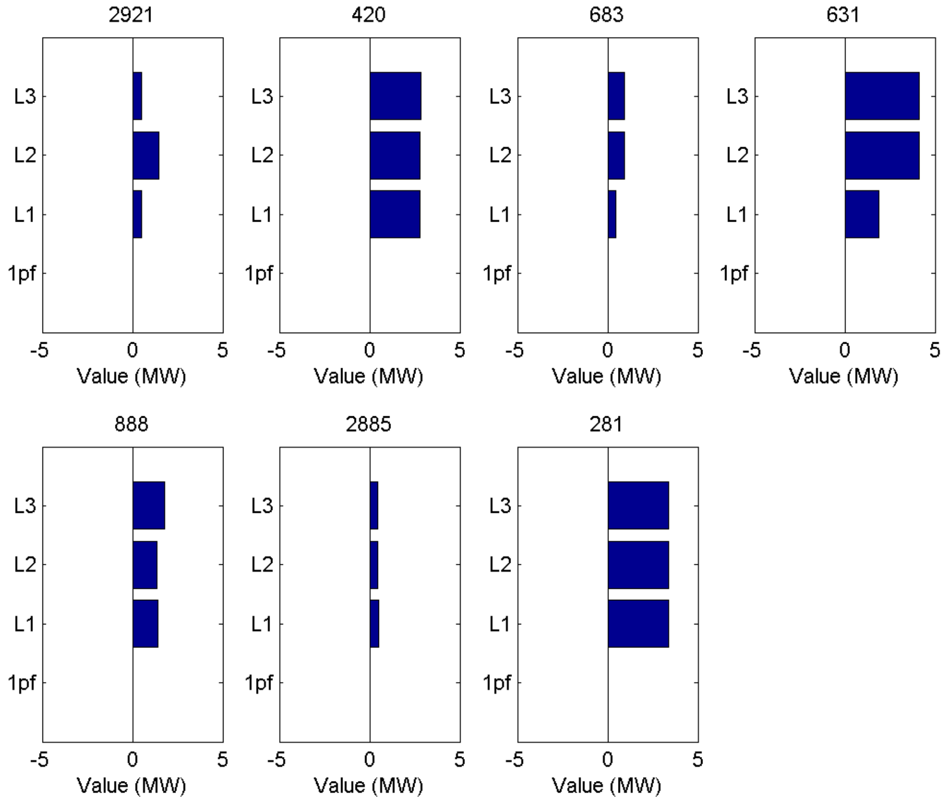
# Volt-var Control

Level 1: Feeder Independent Setting

Level 2: Feeder Model

Level 3: Feeder Model and PV Location

- Level 1
  - There is potential for significant value similar to more complex methods on 5 feeders
- Level 2
  - Slightly higher value than Level 1
  - Setting is more aggressive yet tuned to the feeder model
  - More effective use of reactive power
- Level 3
  - Slightly higher value than Level 1
  - Setting is more aggressive yet tuned to the feeder model and PV location
  - Most effective use of reactive power





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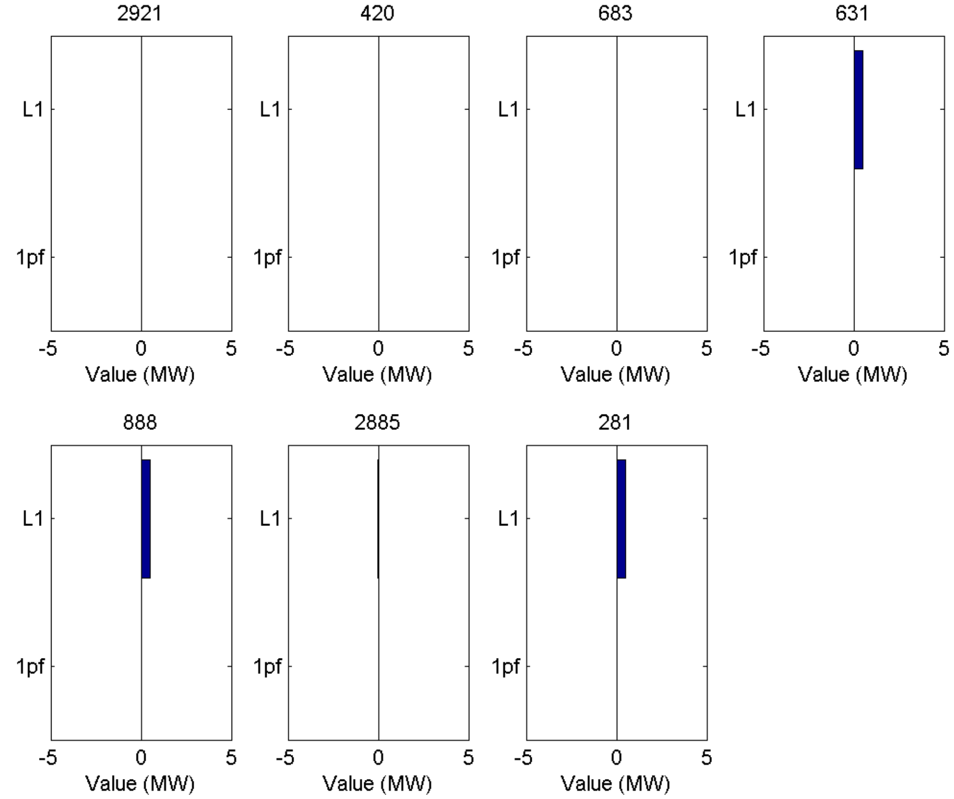
# Volt-watt Control

Level 1: Feeder Independent Setting

- Level 1
  - Only slight value based on design
  - This control would be better utilized in conjunction with volt-var





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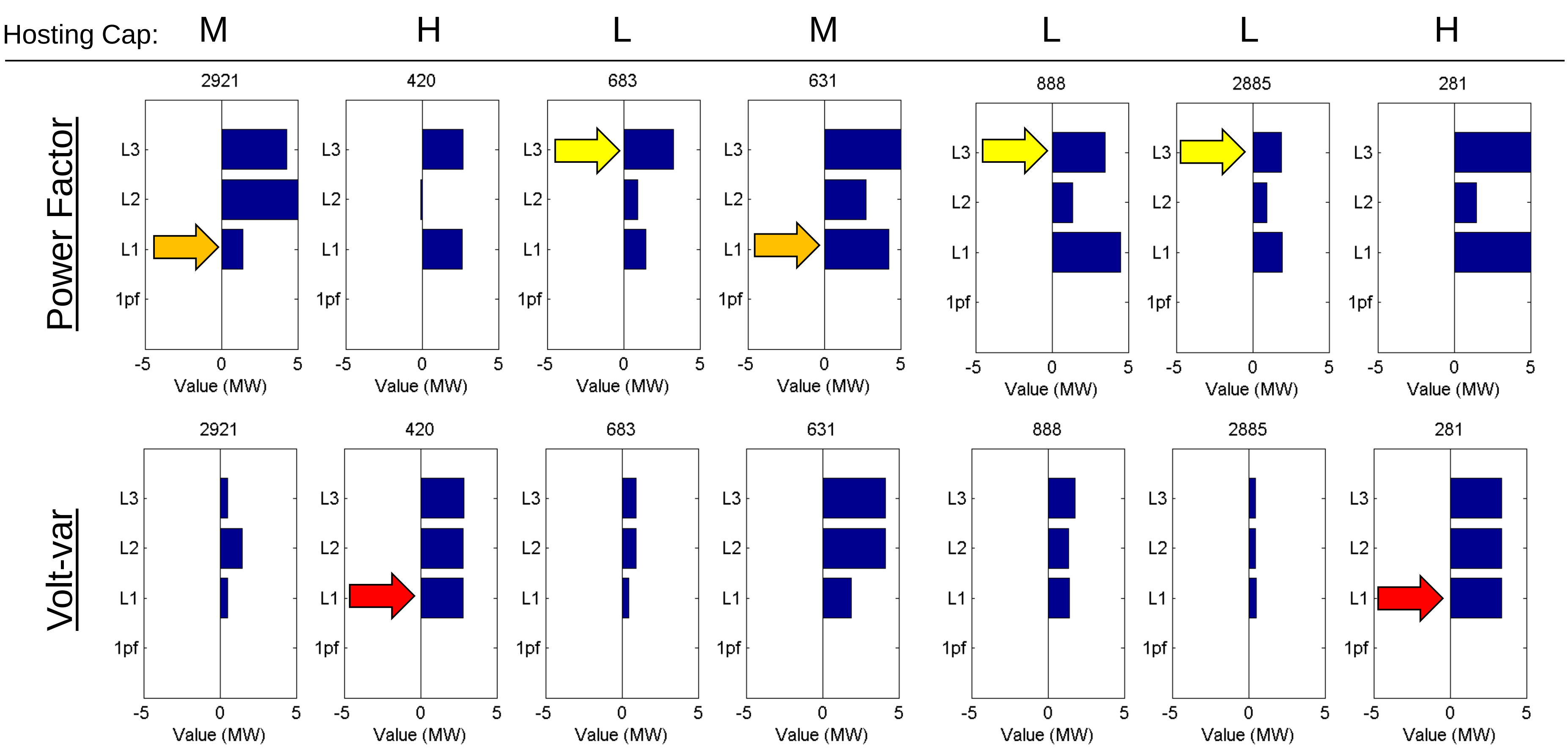
# Comparison of all Control Functions

- Power Factor outperforms volt-var on each feeder
- Simple volt-var methods effective on feeders with high hosting capacity
- Simple power factor methods effective on feeders with moderate hosting capacity
- Complex power factor methods effective on feeders with low hosting capacity feeders
- **In lieu of any model or analysis, Volt-var Level 1 Feeder Independent Settings show positive value**



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# Conclusions

- Improved system performance shown for the various methods to set inverters
- Simple Level 1 settings provide significant value in most cases
- More complex methods increase value, and that value increases further with greater emphasis on reactive power

- Additional Work: Refinement of Power Factor and Volt-var L2 and L3 Methods

# Together…Shaping the Future of Electricity


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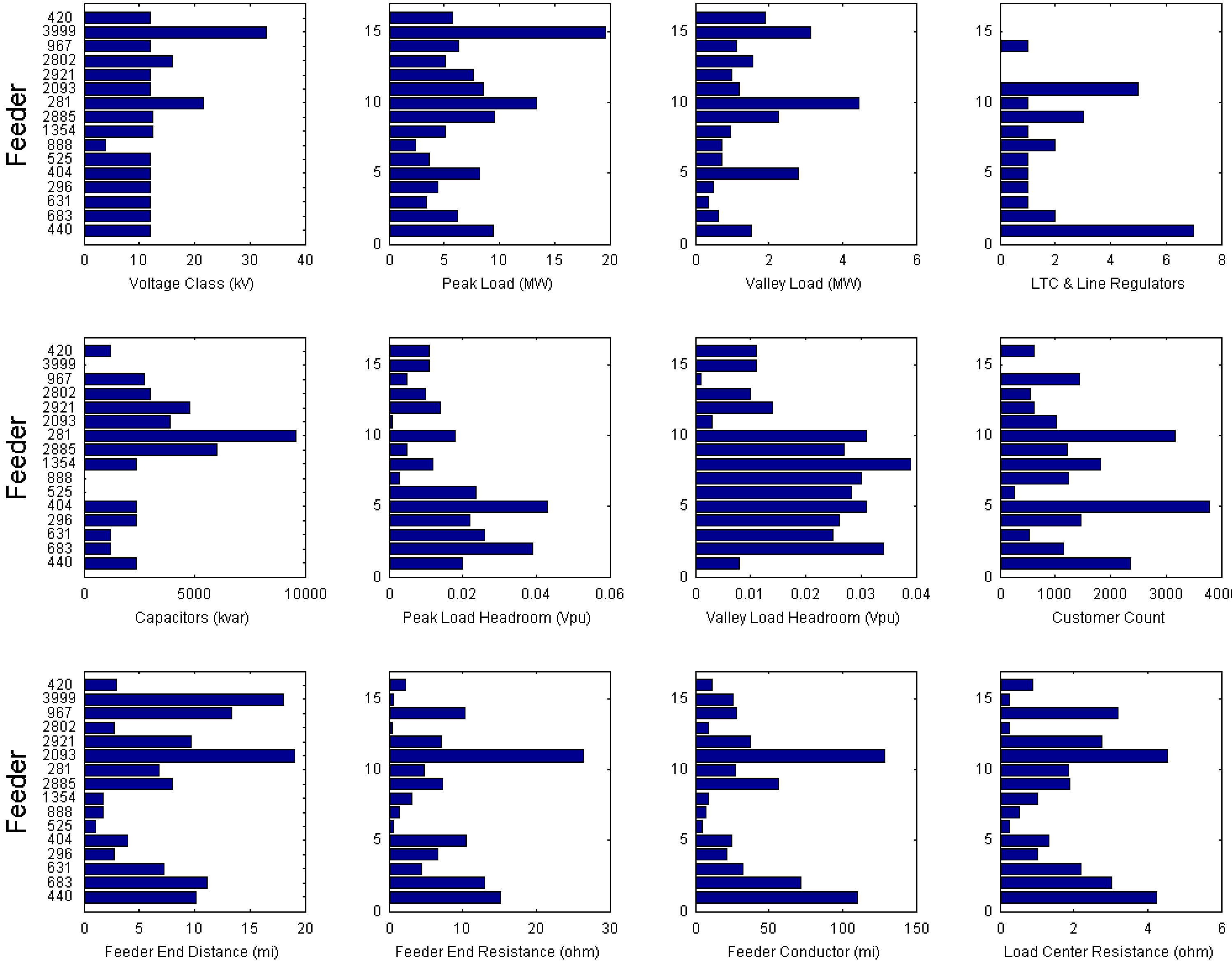
# Backup Slides

# Feeder Characteristics from CSI3





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