Analysis of Grid Strength for Inverter-Based Generation Resources on Oahu

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What is Grid Strength?

- Grid strength is like a “stiffness” of a power system
- It is specifically for voltage (not frequency)
- Unlike frequency stability, location matters

“Strong Grid”

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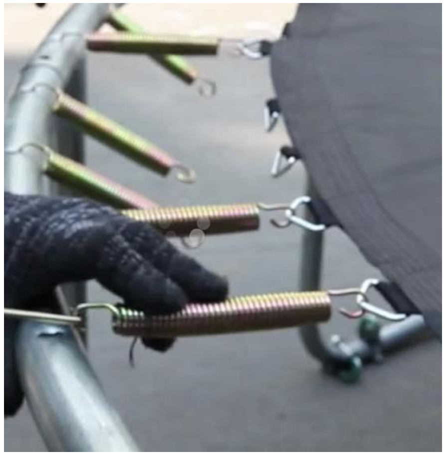
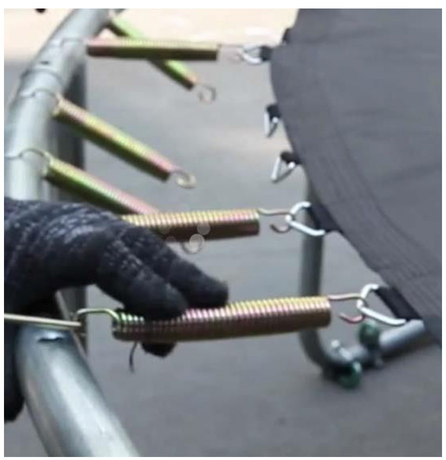


“Weak Grid”

What is Grid Strength?

- Grid strength is like a "stiffness" of a power system
- It is specifically for voltage (not frequency)
- Unlike frequency stability, location matters
- In a strong grid, bus voltages do not change much when the system is 'whacked' by a disturbance like a fault
- In a weak grid, bus voltages change a lot during disturbances like faults

"Strong Grid"



"Weak Grid"

"Impending Fault"

What Contributes to Grid Strength?

- Synchronous machines (generators, condensers)

And what does not?

- Most of today's power electronic-based generation (PV, Wind, HVDC)
- Battery storage
- Loads

Weighted Short Circuit Ratio (WSCR)

What:

- This is a method developed by ERCOT* in 2014 for evaluating the collective grid strength of the CREZ (Western Texas) region, which is considered a weak grid region due to the high penetration of utility-scale wind turbines

$$WSCR = \frac{Weighted \quad S_{SCMVA}}{\sum_{i}^{N} P_{RMWi}} = \frac{\sum_{i}^{N} S_{SCMVAi} * P_{RMWi}}{(\sum_{i}^{N} P_{RMWi})^2}$$

- It was benchmarked by EMT simulations to set a threshold of 1.5 for West Texas. This number is specific to the network, amount, and type of power electronic equipment (controls) installed.

Application to Oahu:

- The approach has been applied to the Oahu system, but the threshold cannot be applied as this is specific to the network & equipment.

- It is an indicator of stability for an aggregated region of the grid that is suitable for looking at the whole grid hour-by-hour, but not bus-by-bus (We have another method for that).

*Panhandle Renewable Energy Zone Study Report, Prepared by ERCOT System Planning, April 2014
http://www.ercot.com/content/news/presentations/2014/Panhandle%20Renewable%20Energy%20Zone%20Study%20Report.pdf

What's Happening in Hawaii...

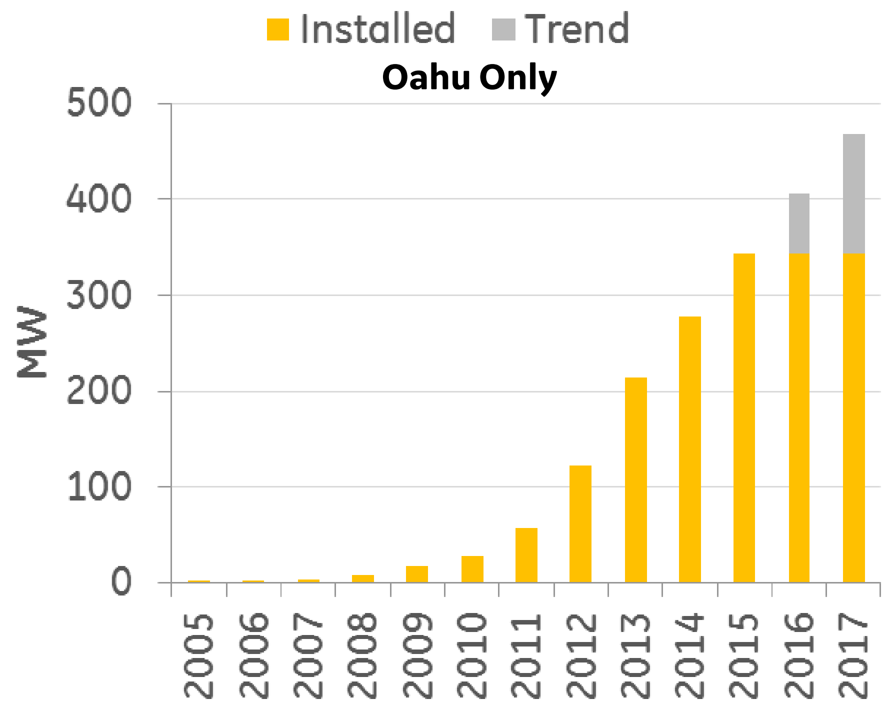
Hawaii's Renewable Portfolio Standard

30% by 2020 → 40% by 2030 → 70% by 2040 → 100% by 2045

Rapid Growth of Distributed PV

5x growth in 5-years

>30% of single family homes



Hawaii is at a nexus for renewable energy development, the industry is moving quickly...
Highlighting a need for technical independent engineering and economic studies

New Methodology & Analytical Process

Production Cost Simulations (GE MAPS) → Selecting System Dispatch Conditions → Short-Circuit Calculations (GE PSLF) → Estimating WSCR Over a Year

Production Cost Modeling

- Economic dispatch of all generation over entire year
- Includes detailed model of generators, operating rules, load and fuel price forecasts

Short-Circuit Strength Analysis

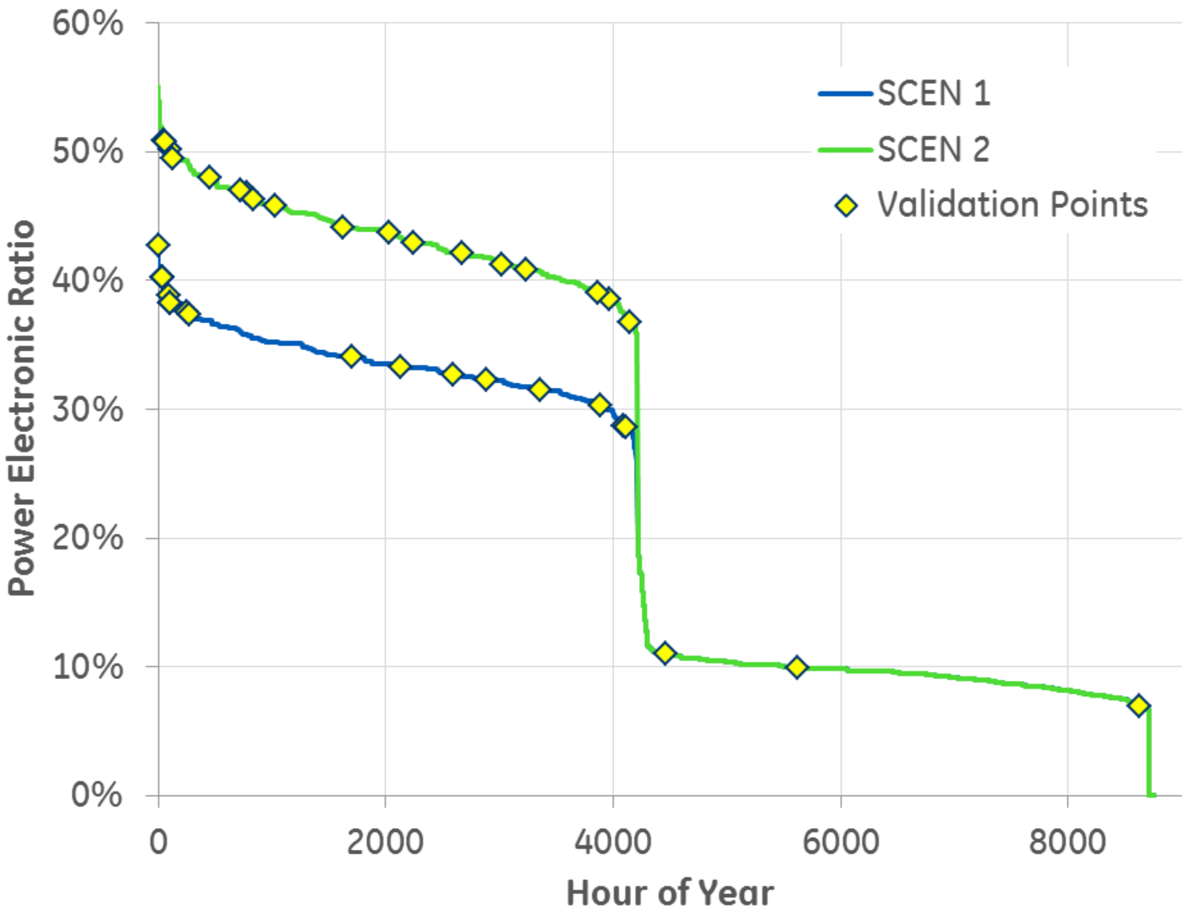
- Simulations used to determine the WSCR of the grid given a dispatch condition

Statistical Analysis

- Novel approach to estimating stability across a full year of operations

Tight coupling of economic models with stability models

Introducing the Power Electronic Ratio



$$P.E.R. = \frac{Power\ Electronic\ MVA}{Total\ Online\ Capacity\ MVA}$$

Measures the amount of non-synchronous generation online

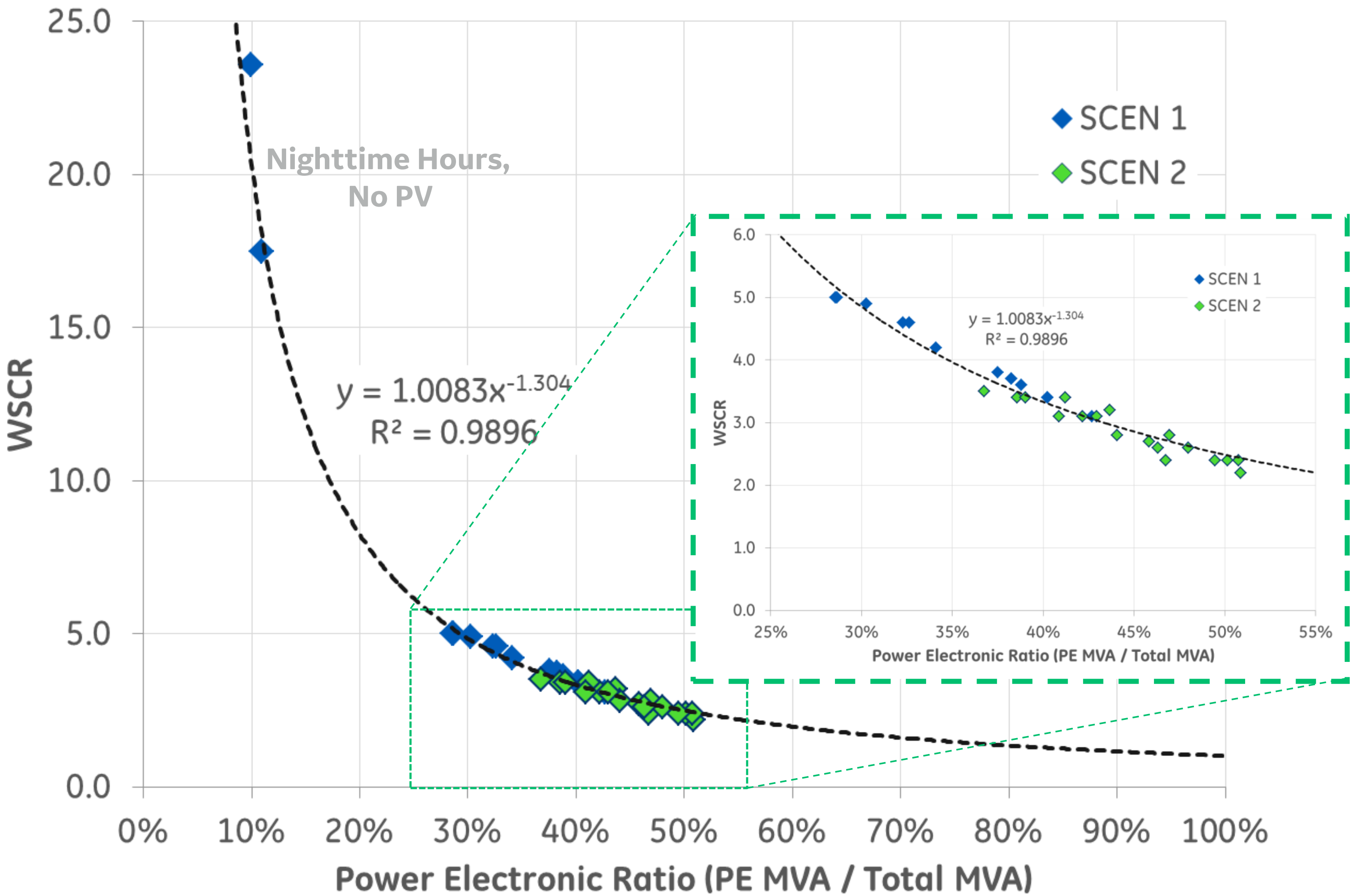
If the unit is online, the full unit capacity (MVA) is counted towards the Power Electronic Ratio

Dispatch and load (MW) do not factor into the equation

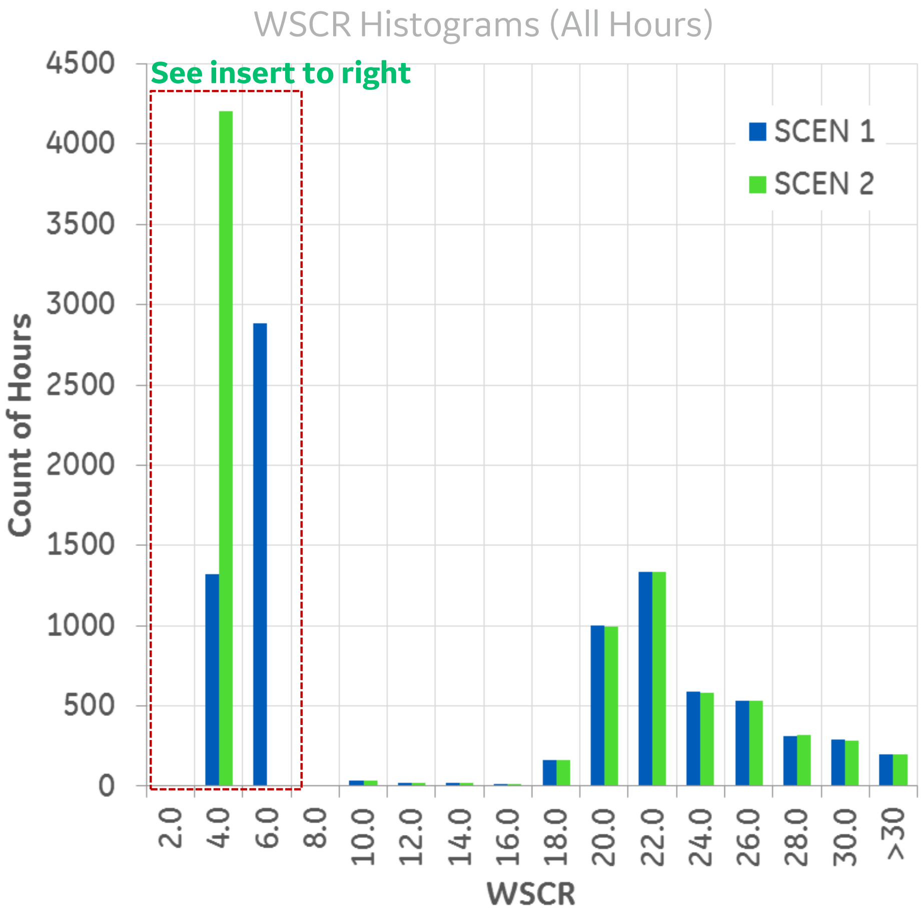
Does NOT equal instantaneous wind and solar penetration of load

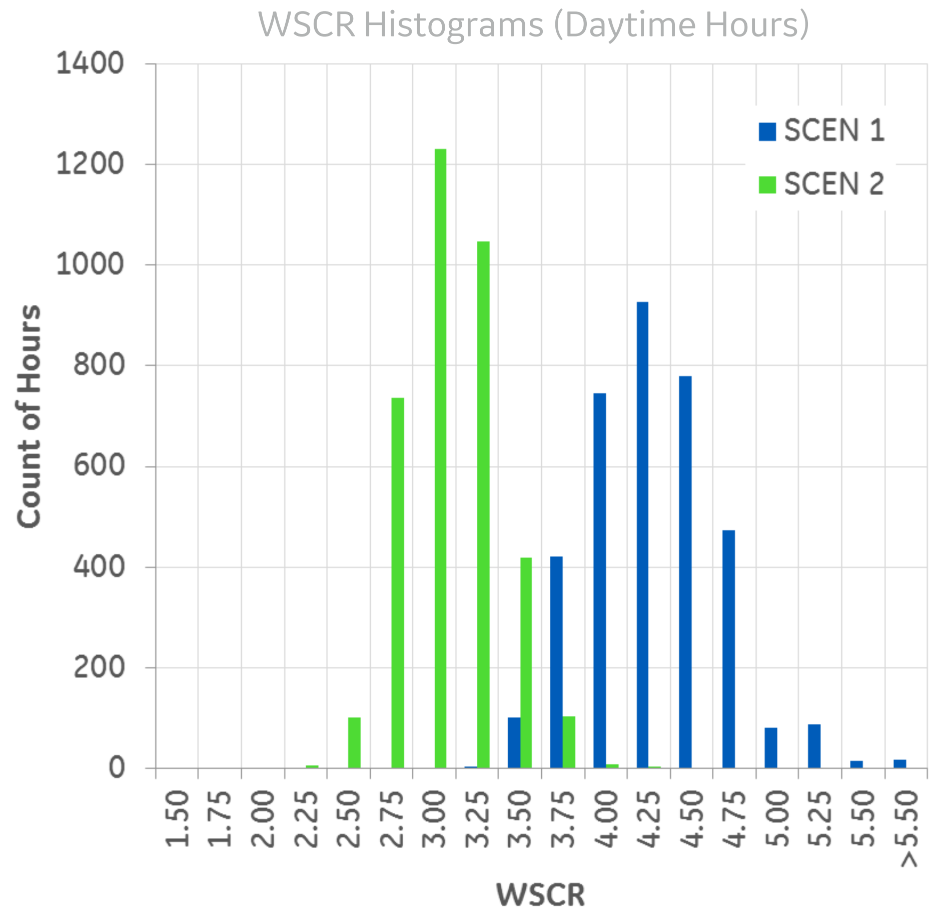
Assumes a power factor rating of 0.95 for wind and solar units

Map Power Electronic Ratio to WSCR



Estimating WSCR across the year





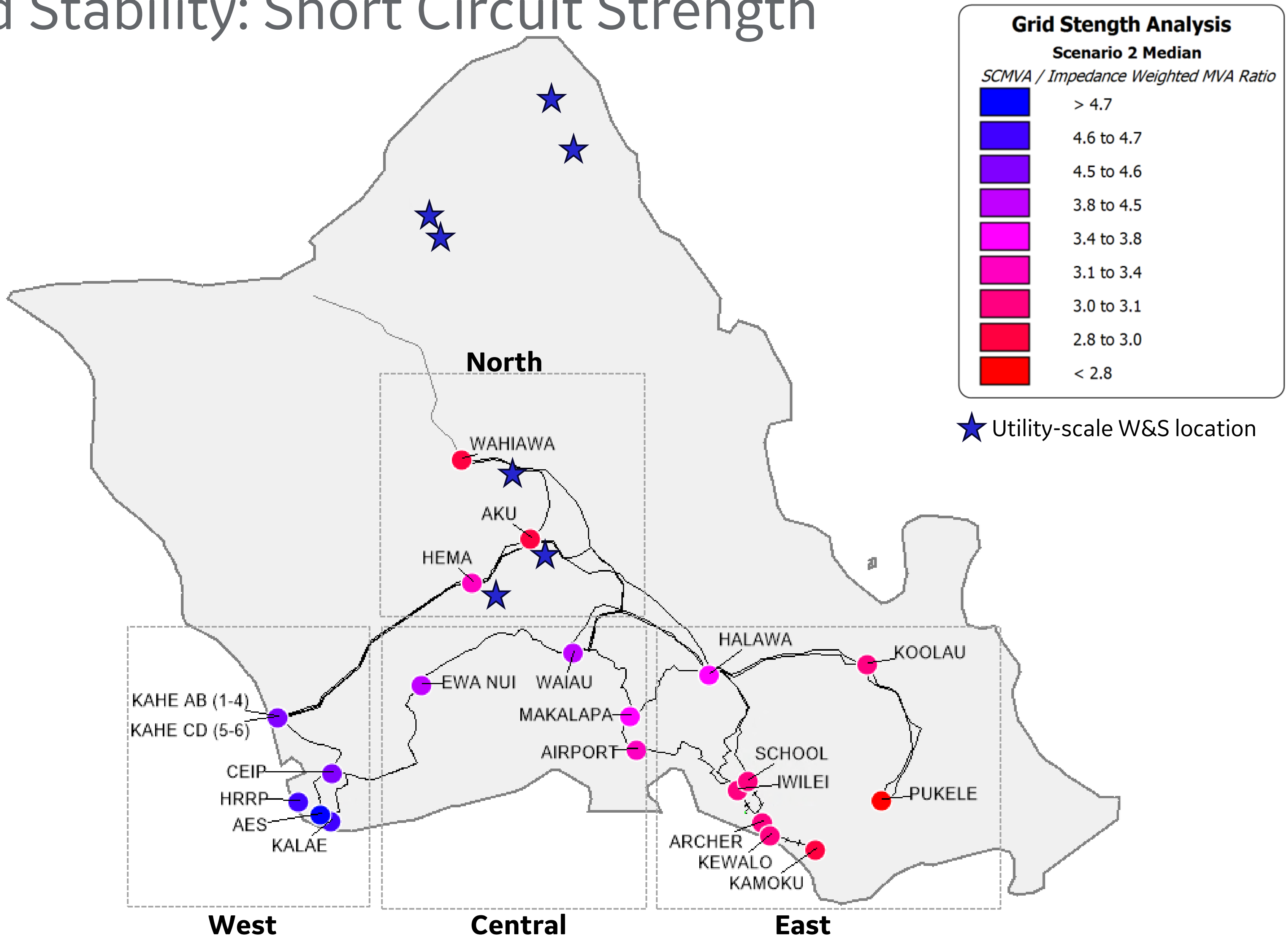
Grid Strength Evaluation by Bus

- Location Matters!
  - Amount of synchronous generation
  - Amount of power electronic equipment
  - Amount of transmission network connectivity

- The most affected buses are those with a combination of the lowest SCMVA and the highest penetration of power electronic sources in the local area.
- For each bus, this is determined by taking the ratio of SCMVA (synchronous generator contribution at the bus) to impedance-weighted power rating of renewables at that bus.
- Completed for the 38 validation cases and the buses were ranked according to their median value across all 38 hours.

Grid Stability: Short Circuit Strength

Map created with ABB Velocity Suite



Options for Dealing with Low Grid Strength

Synchronous Machine Support

By Operational Dispatch

- Immediately-available option... keep more sync units online to support grid strength
- Expensive ... to run and can lead to renewables curtailment

By Synchronous Condenser

- Conversions of existing equipment
- New equipment is a significant expense, consumes some power

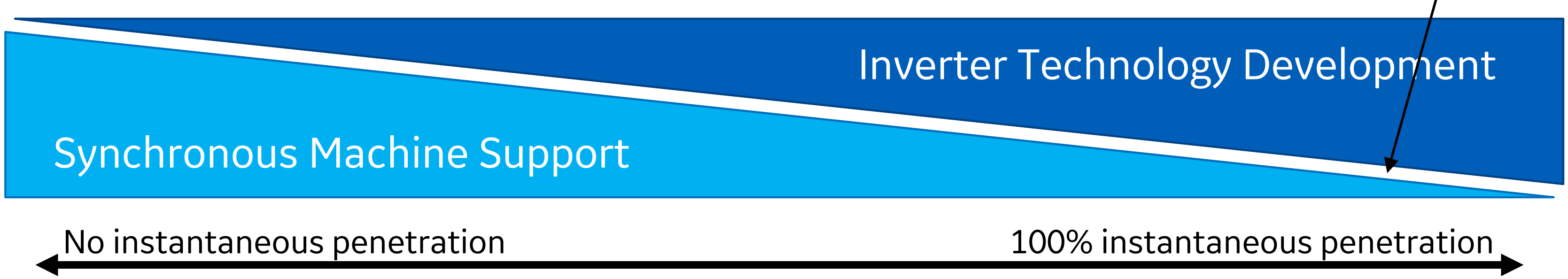
Inverter Technology Development

Advanced controls exists for utility-scale wind

- Has enabled high penetration in ERCOT
- No "laws of physics" prevent operation of a 100% inverter-based power system

Challenges

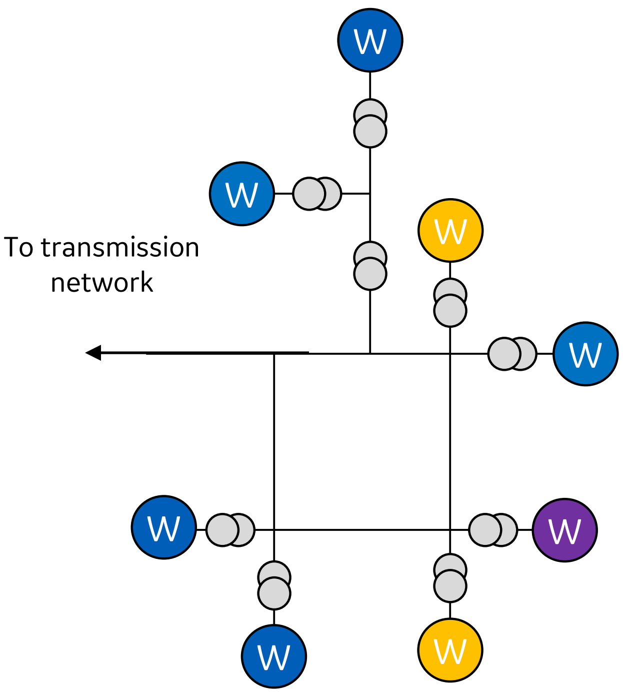
- Many individual inverters and many OEMs of inverters
- Weak grid / controls stability challenge is generally not on DPV OEMs' radar



Establishing a Threshold

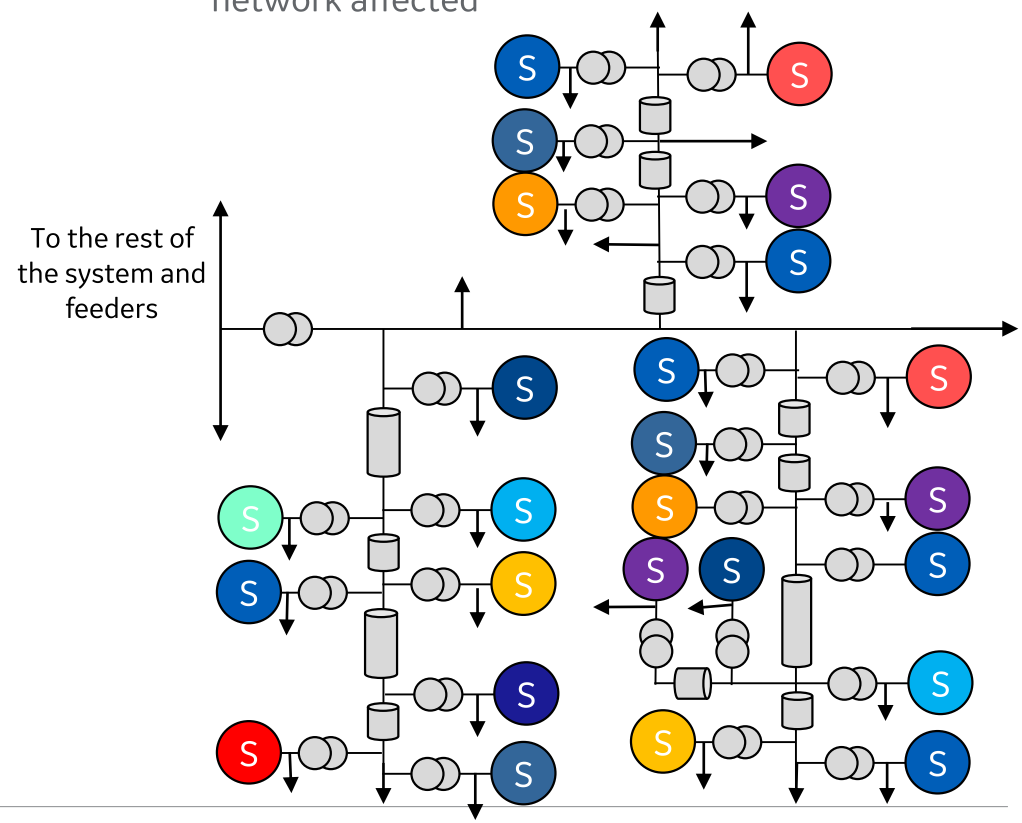
ERCOT established a threshold based on a model like: this

- Dozens of wind plants
- A few varieties
- High-fidelity models readily available
- Relatively small transmission network affected



In Oahu, a similar approach quickly becomes intractable

- Hundreds/thousands of inverters
- Dozens of varieties, controller vintages
- High-fidelity models not readily available
- Complex transmission and distribution network affected



Key Findings

This is an emerging issue in the industry and not an exact science…

- Trends are clear - increasing inverter penetration significantly reduces WSCR
- Industry has reasonably good understanding of weak system performance for utility-scale wind and solar PV power plants. In ERCOT, WSCR of 2 or 1.5 is often ok with appropriate control design and tuning – but this is system specific
- Much less is known about performance of DPV, and performance may be less predictable. There are no standards for this issue yet.

Questions?

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