Planning and Modeling IBR-Dominant Systems

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ENERGY SYSTEMS INTEGRATION GROUP

Integrated Planning: Assuring Stability in Modern Systems

Day 2: Session 6

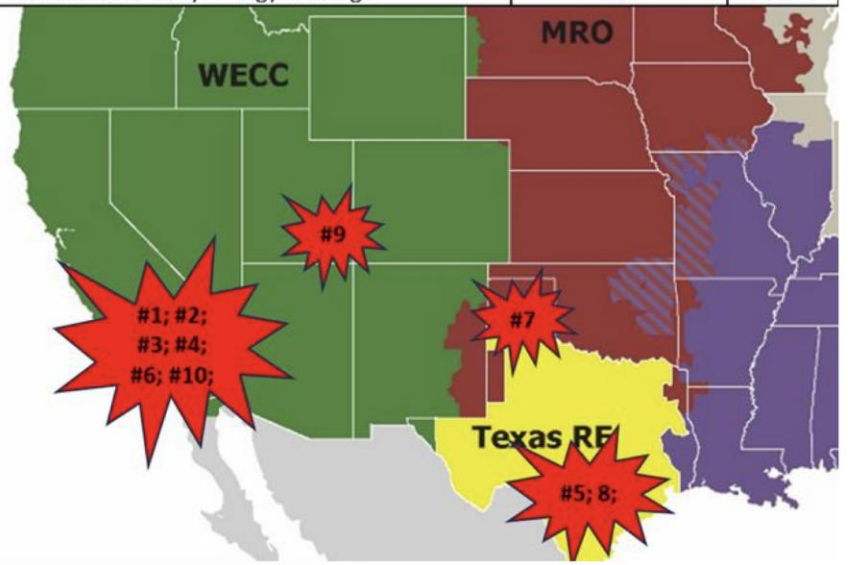
Tuesday September 16, 2025

The Current Paradigm Isn't Working

Reliability improvements begin with understanding the results of the current paradigm:

- 10 major disturbances published by NERC since 2016
  - Totaling **~15,000 MW**
  - These are not ALL events, just those classified in NERC procedure for mandatory release
- **None** of the affected facilities in **any** of these published reports had models which accurately reflected actual performance
- Motivations for IBR interconnection are **not aligned with grid reliability**
- Current regulatory structure promotes disparate, misaligned, and sometimes confusing requirements
- Stakeholder-driven processes **fail to produce sufficient technical minimum requirements**

Reference Number	Disturbance	IBR Reduced (MW)	Year
#1	Blue Cut Fire	1,753	2016
#2	Canyon 2 Fire	1,619	2017
#3	Angeles Forest & Palmdale Roost	1,588	2018
#4	San Fernando	1,205	2020
#5	2021 Odessa	1,112	2021
#6	Victorville & Tumbleweed & Windhub & Lytle Creek Fire	2,464	2021
#7	Panhandle Wind	1,222	2022
#8	2022 Odessa	1,711	2022
#9	Southwest Utah	921	2022
#10	California Battery Energy Strorage	906	2023



Adapted from NERC Ridethrough Technical Conference, Sep. 4 2024

The Current Paradigm Isn't Working

"This report shows that the voluntary recommendations set forth in NERC Guidelines and other publications are not being implemented."

-Inverter-Based Resource Performance Issues Report, NERC, November 2023

- Planning a reliable power system depends on accurate modeling of the system and resources connected to it. This includes accurate modeling of IBR performance, as well as protections or other functions that may take the IBR offline

Table 3.1: Solar PV Tripping and Modeling Capabilities and Practices

Cause of Reduction	Can Be Accurately Modeled in Positive Sequence Simulations?	Can Be Accurately Modeled in EMT Simulations?
Inverter Instantaneous AC Overcurrent	No	Yes
Passive Anti-Islanding (Phase Jump)	Yes[a]	Yes
Inverter Instantaneous AC Overvoltage	No	Yes
Inverter DC Bus Voltage Unbalance	No	Yes
Feeder Underfrequency	No[b]	No[c]
Incorrect Ride-Through Configuration	Yes	Yes

Table 3.1: Solar PV Tripping and Modeling Capabilities and Practices

Cause of Reduction	Can Be Accurately Modeled in Positive Sequence Simulations?	Can Be Accurately Modeled in EMT Simulations?
Plant Controller Interactions	Yes[d]	Yes[e]
Momentary Cessation	Yes	Yes
Inverter Overfrequency	No[b]	Yes
PLL Loss of Synchronism	No	Yes
Feeder AC Overvoltage	Yes[f]	Yes
Inverter Underfrequency	No[b]	Yes

Adapted from: NERC 2022 Odessa Disturbance Report

What's so Different - Technology

Differences between Inverter-Based Resources and Synchronous Generation	
Inverter-Based Resources	**Synchronous Generation**
• Driven by power electronics and software	• Driven by physical machine properties
• No (or little) inertia	• Large rotating inertia
• Very low fault current	• High fault current
• Sensitive power electronic switches	• Rugged equipment tolerant to extremes
• Very fast and flexible ramping	• Slower ramping
• Very fast frequency control	• Inherent inertial response
• Minimal plant auxiliary equipment prone to tripping	• Sensitive auxiliary plant equipment
• Dispatchable based on available power	• Fully dispatchable
• Can provide essential reliability services	• Can provide essential reliability services

Adapted from: NERC's An Introduction to Inverter-Based Resources on the Bulk Power System

What's so Different - Technology

- **Software-based** IBR add significantly **more complexity** and uncertainty in both performance and modeling
  - Need to view IBR performance and modeling with a **software-development lens**
  - IBR have significant performance flexibility dictated by software parameters
  - Renewable technology is relatively immature and has not been standardized
    - Efforts are being made to standardize IBR performance but intellectual property and patents are large roadblocks
  - Continuity of data and change management is critical throughout the lifecycle of the IBR plant

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Adapted from: NERC's An Introduction to Inverter-Based Resources on the Bulk Power System

What's so Different - Technology

- Little or no "inertia" and low fault current contribute to the "weakening" of the power system
  - Advanced grid services can help IBR operate at these weaker, or islanded operating points
- Much of the current power system has been designed, planned, and operated with the assumption of significant inertia and fault current
- Changes in inertia and fault current have ripple effects for:
  - Protection design and operation
  - Automatic voltage and frequency control
  - Emergency power system operations (i.e UFLS)
  - Standardization of performance and requirements

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What's so Different – Process and Stakeholders

Synchronous Paradigm

- Often developed by engineering firms with engineering staff
- Reliability standards are the minimum
- Detailed plant information easier to obtain
- Detailed information available sooner in the process
- Differences between studied and real performance typically smaller
- As-built information for modeling is easier to obtain
- Significantly more "operational awareness"

IBR Paradigm

- Often developed by non-engineering firms without engineering staff
- Reliability standards are the maximum
- Detailed plant information more difficult
- Detailed information may not even be available during the interconnection process
- Higher likelihood of large discrepancies in studied and actual performance
- Sometimes difficult to obtain as-built information
- Less "operational awareness"

Why is Modeling IBR So Hard (in general)

Synchronous Machine	Modeling Consideration	Inverter-Based Resource
• More mature • Parameters and controls are standardized • Relatively simple plant construction (generator and main power transformer)	**Technology Maturity and Construction**	• Significantly less mature • Parameters and controls cannot be standardized (*performance can*) • Relatively more complex plant construction (collector cables, collector transformers, multiple manufacturer plants and hybrid resources
• Largely dictated by the physical behavior of a large spinning mass • Relatively small variations in performance from control parameters	**Technology Performance**	• Rarely dictated by the physical behavior of a spinning mass (i.e., Type 1-3 wind) • Relatively extremely high variation in performance from control parameters
• Majority of parameters are standardized and map 1-1 with the equipment • Relatively few model parameters • 1-1 mapping with measurable quantities reduces the number of tunable parameters and makes site-specific modeling easier	**Model Parameters**	• Few models have 1-1 mapping with the equipment • Thousands of parameters • Lack of mapping reduces quality of study inputs and reduces the ability to implement “tuned” site-specific controls

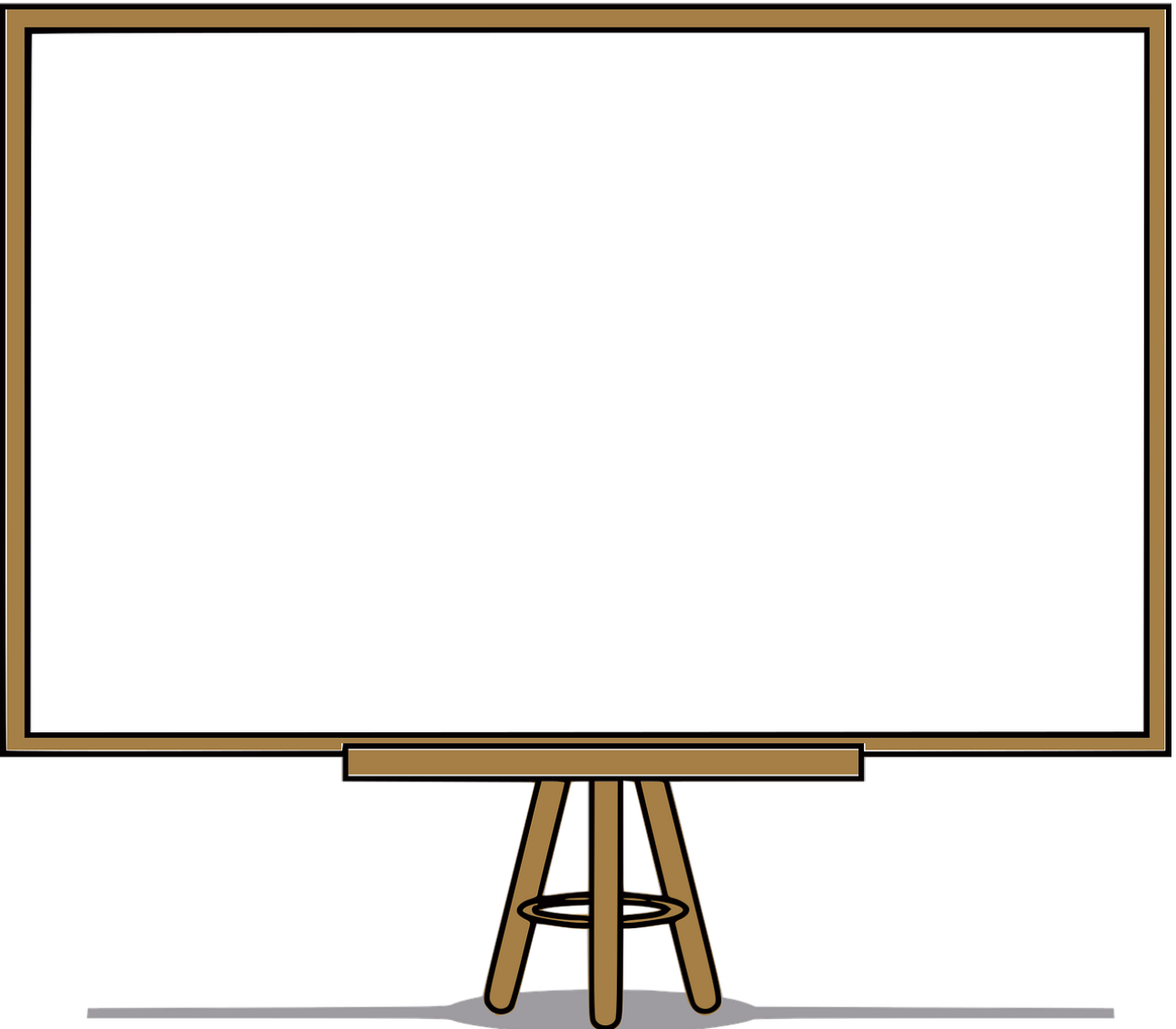
Why is Modeling IBR So Hard (in North America)

Interconnection and planning requirements in North America do not allow or disincentivize the use of the representative models

- Vendor equipment-specific models are not allowed to be submitted or are disincentivized with extra scrutiny and costs in most interconnections
  - This is out of alignment with the NERC Dynamic Modeling Recommendations and FERC Order 2023
- Manufacturers of IBR equipment do not recommend the use of generic or standard model library models to do site-specific or reliability studies
  - Standard library and generic models are fine for long term, research, or representing machines far from
- Developers are not often willing to do perceived "extra" work that could jeopardize interconnection date

Source: Vestas

Generic Standard Library and Equipment-Specific Modeling – Thought Examples



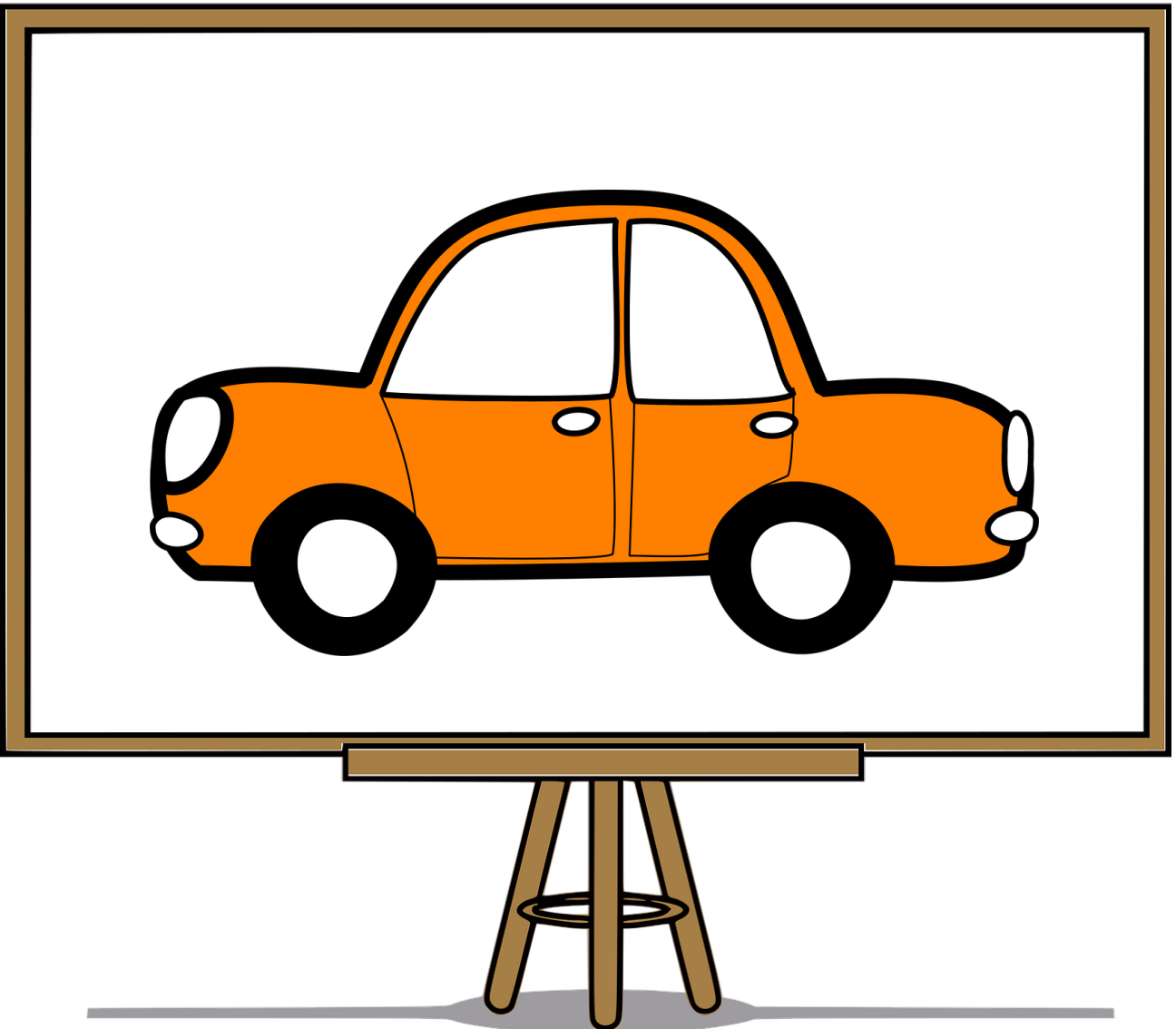
Task: Paint a picture of a vehicle

(represent an IBR plant in general)

Generic or Standard Library Model

Equipment Specific Model

Generic Standard Library and Equipment-Specific Modeling – Thought Examples



Task: Paint a picture of a vehicle

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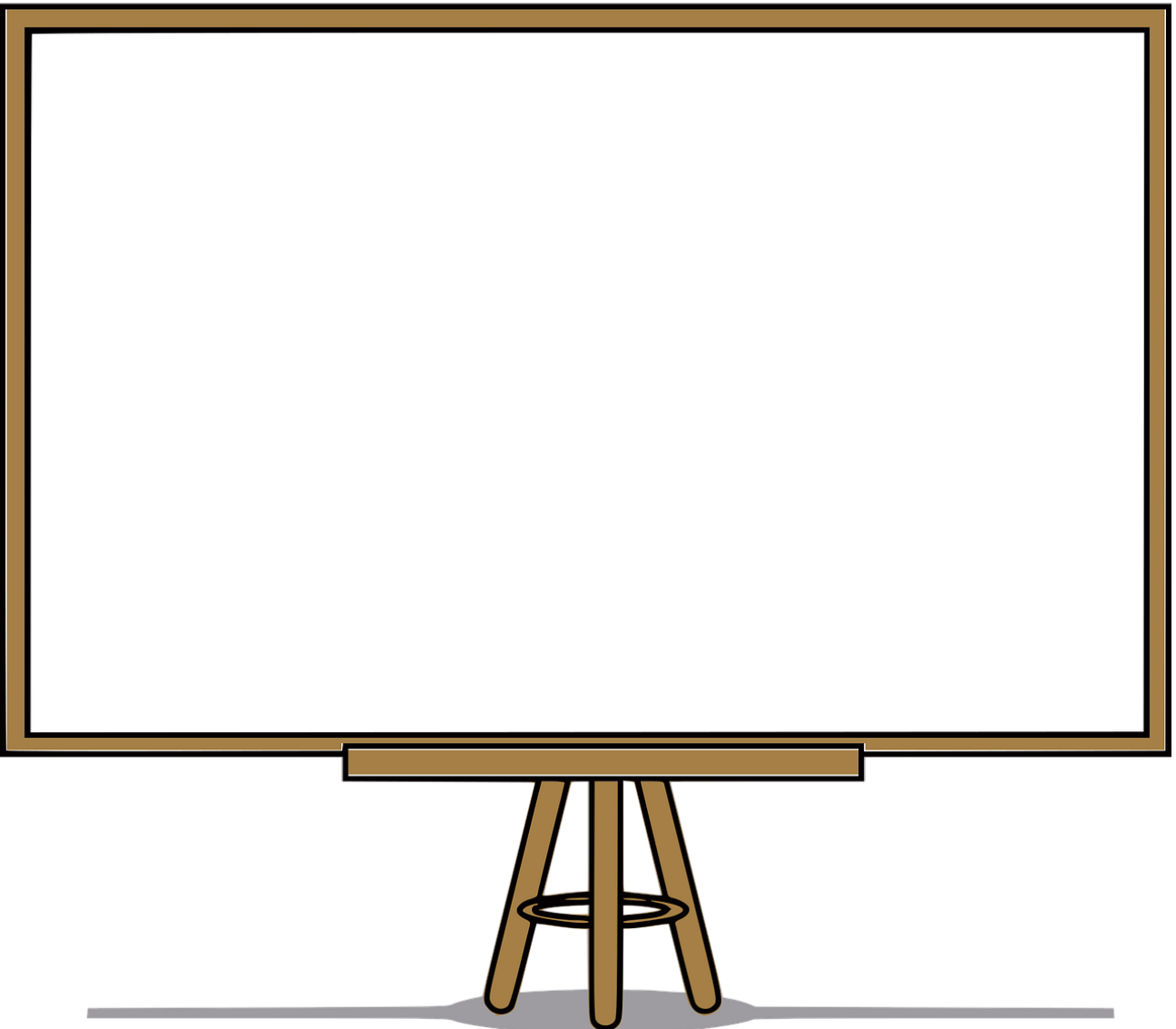

Task: Paint a picture of a van

(represent an IBR plant of a specific type)

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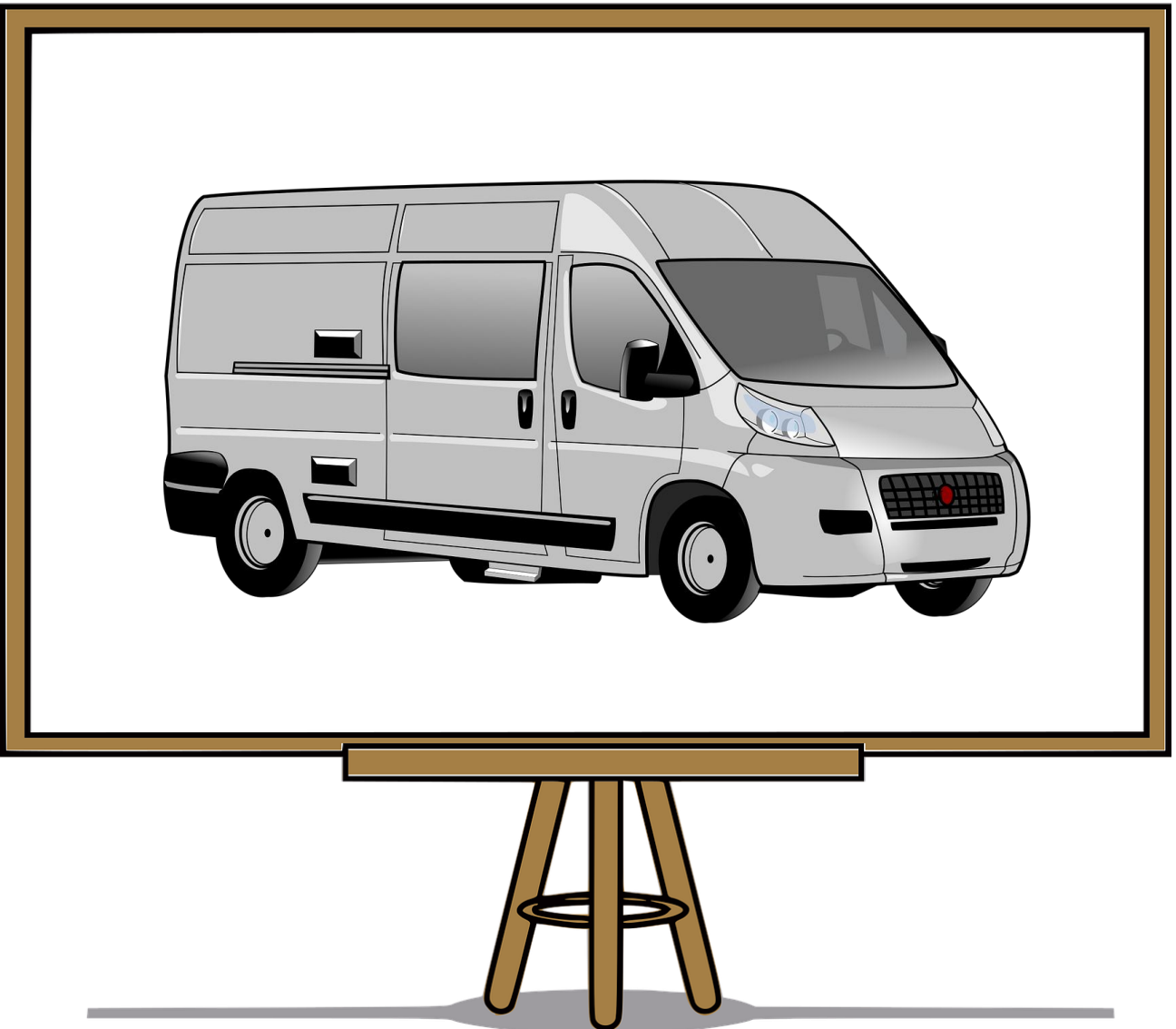

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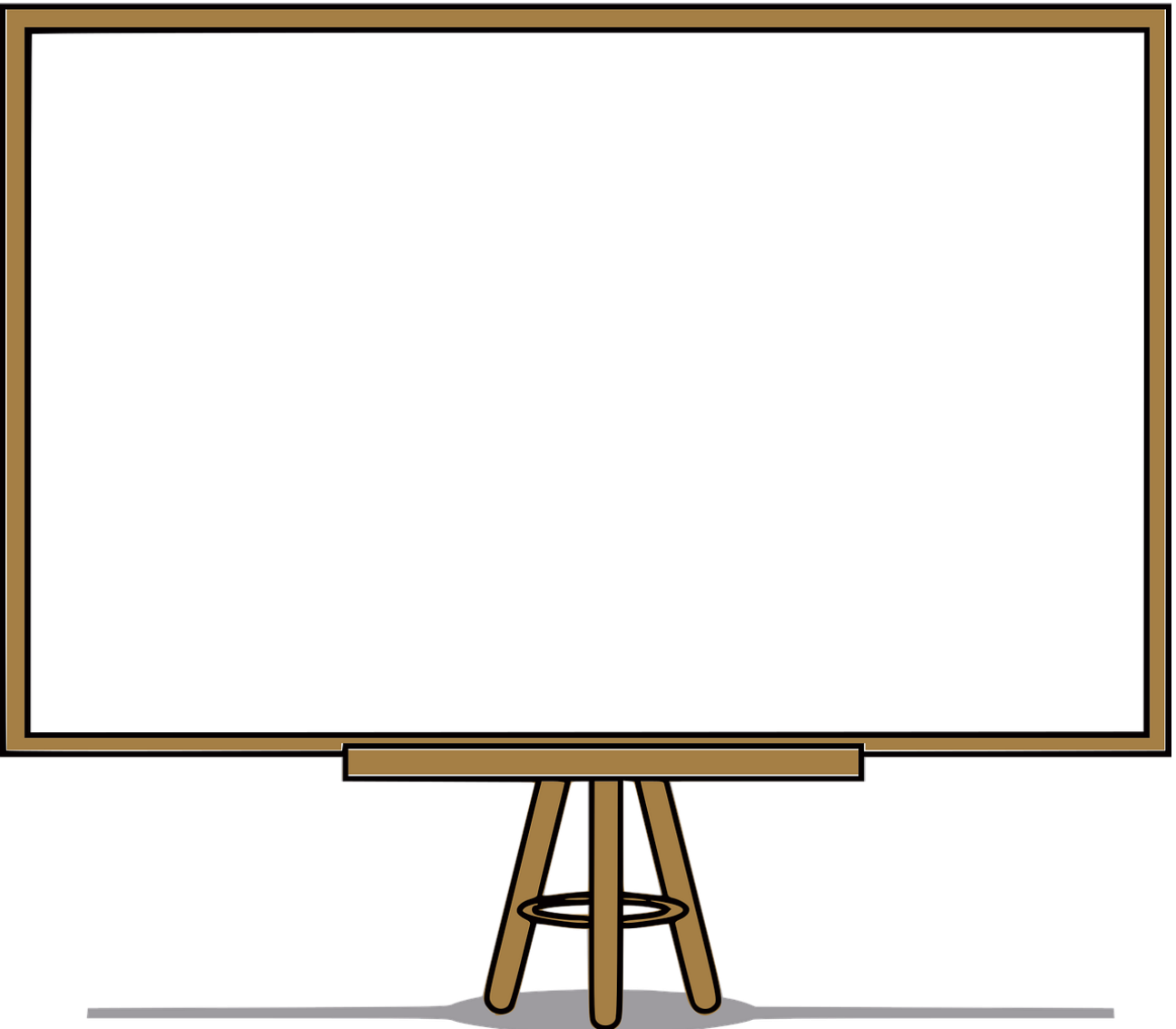


Task: Paint a picture of a Mercedes sedan

(represent an IBR plant of a specific type by a specific manufacturer)

Generic or Standard Library Model

Equipment Specific Model

Generic Standard Library and Equipment-Specific Modeling – Thought Examples

Task: Paint a picture of a Mercedes sedan

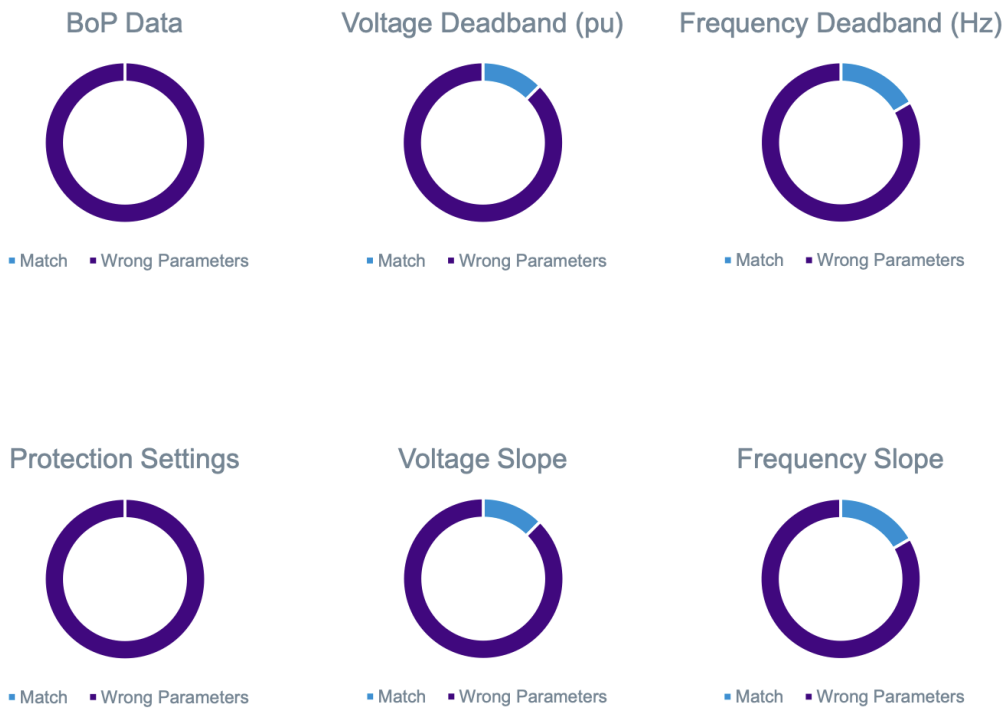
(represent an IBR plant of a specific type by a specific manufacturer)

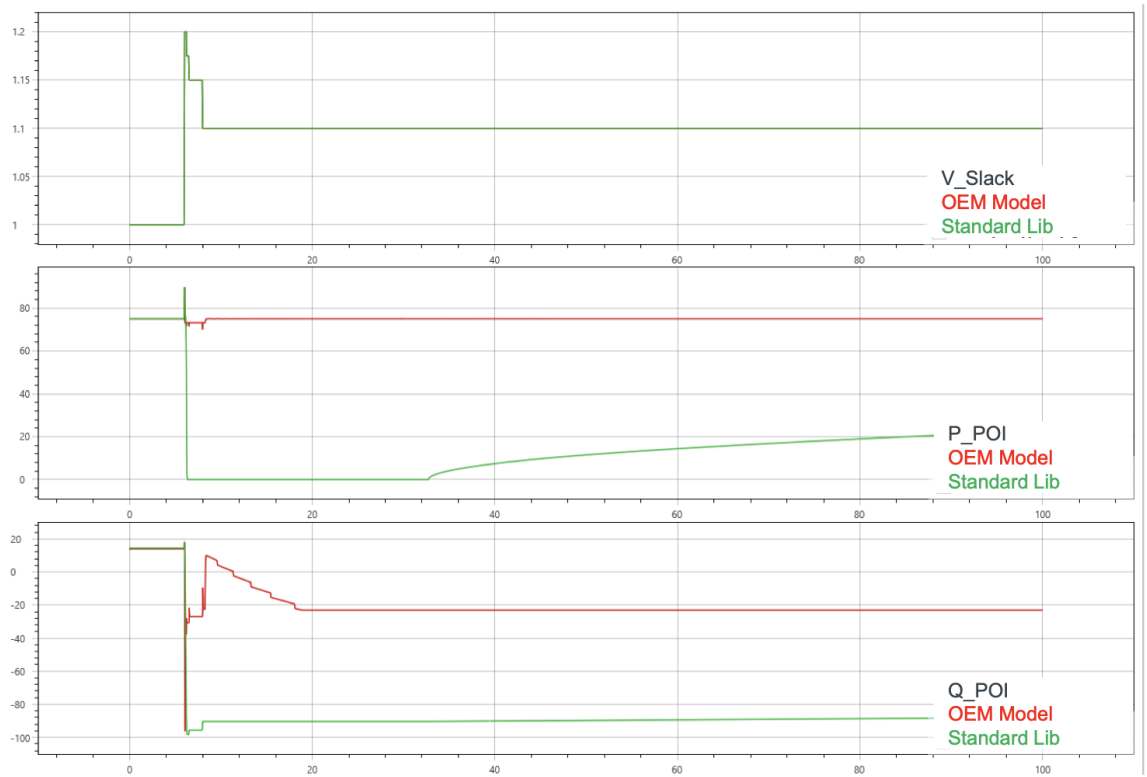
Generic or Standard Library Model

Equipment Specific Model

Generic vs. Equipment Specific – Real World

Vestas Case Study – Comparing Models Used in the Planning and Interconnection Process to Site-Specific Equipment-Specific Models





The ”Standard Lib” represents NERC MOD validated models used in current reliability processes

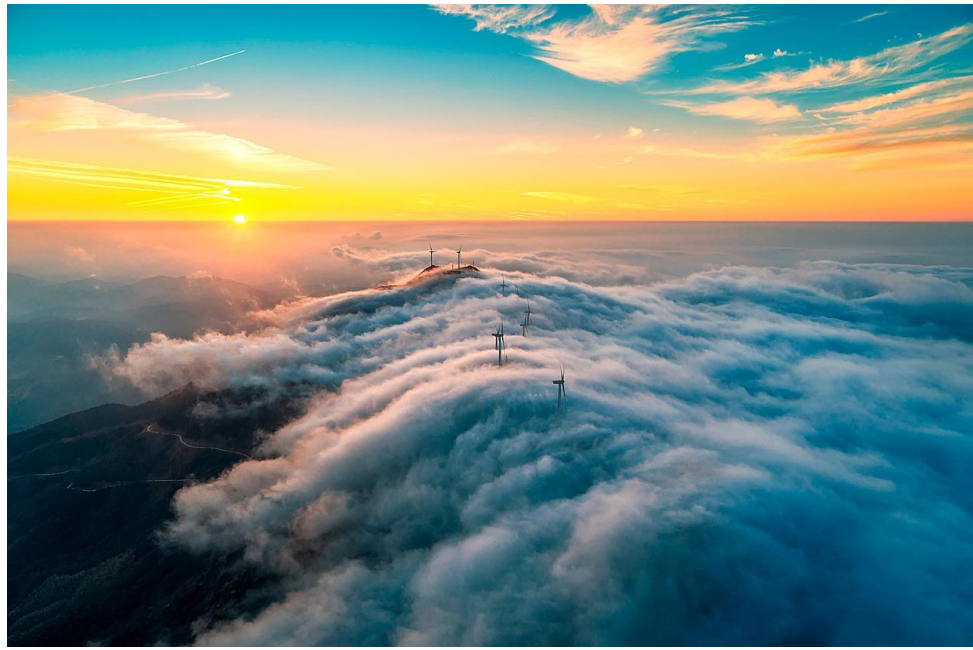
Classification: Public

Vestas

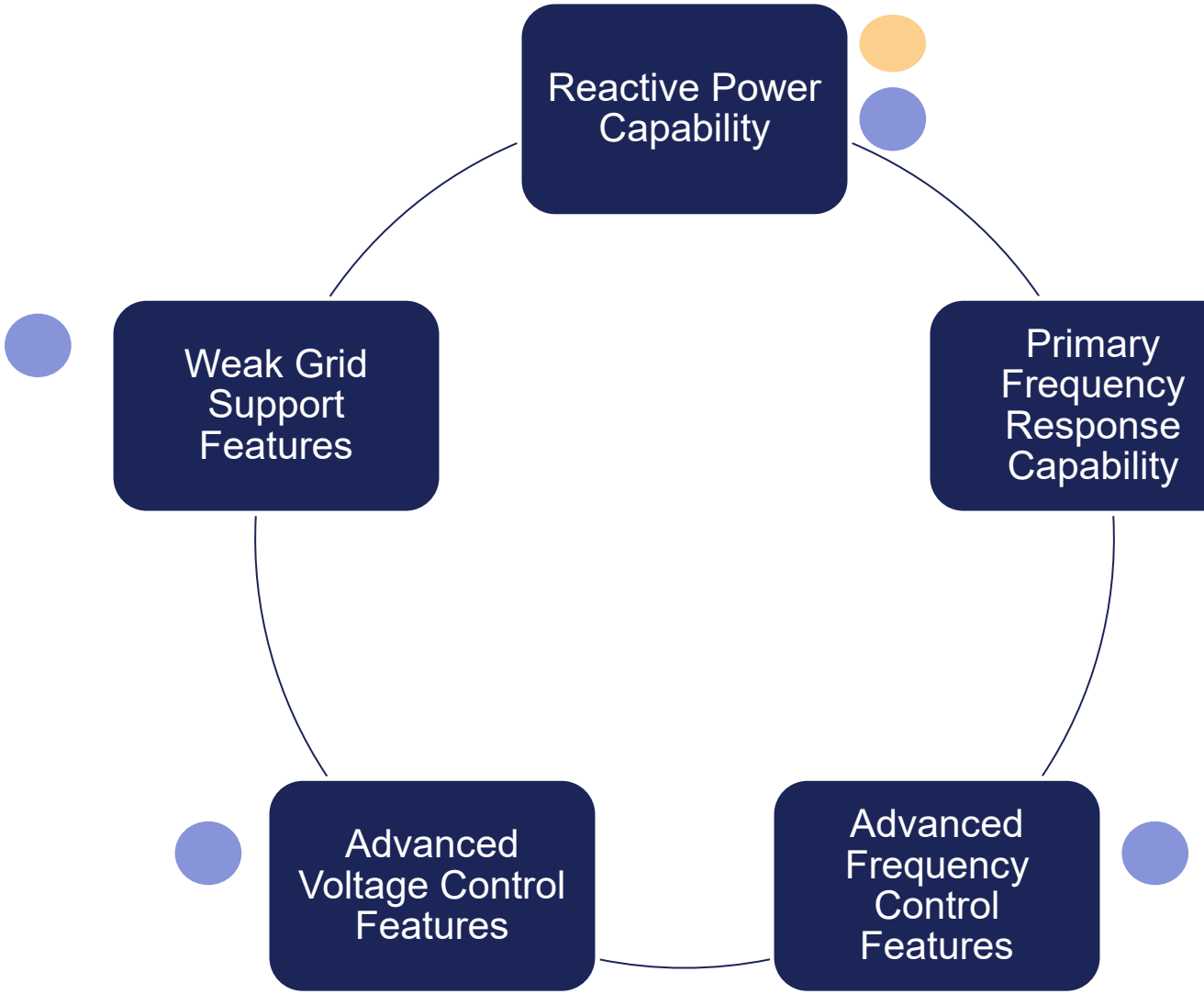
Source: Vestas

Why is IBR Modeling Detail So Important?

- The power system is **evolving rapidly**, and the current **stability margin is being reduced** by current IBR interconnection and planning processes
- Transmission enhancements are on a significantly slower time scale than IBR interconnections
- IBR have significantly **underutilized capabilities**
  - Enabling these capabilities (which are only available in equipment-specific models) is essential to the efficient use of the current power system and to inform efficient future grid enhancements
- Utilizing "advanced" IBR capabilities will be **essential to maintaining** grid reliability and avoiding **erroneous transmission upgrades**
- Reliance on generic and standard library models ensures that interconnection and planning studies **will always be wrong** when compared to actual performance
  - "Wrong" in this case is neither conservative nor optimistic
  - Generic and standard library models give **both false positives and negatives**



What is Being Underutilized?



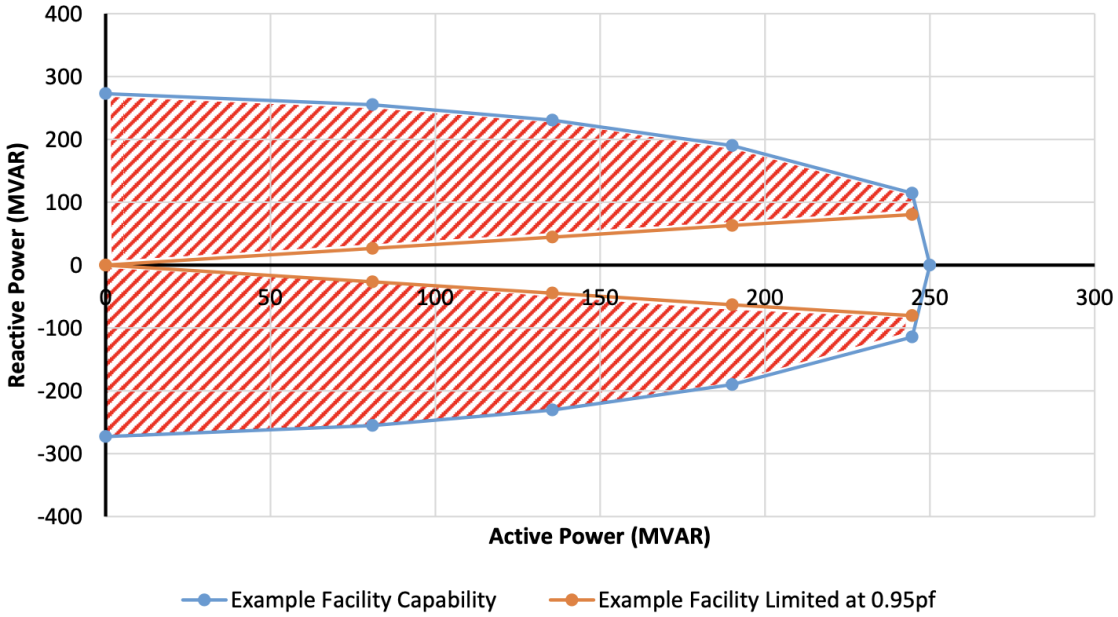
Federal Regulatory Impediments

Generic Model Limitations

Federal Regulatory Impediments – An Example

Language with unexpected interpretations in FERC Order 827 limits reactive power capability

- FERC Order 827 states to "(...) maintain a composite power delivery at continuous rated power output at the high-side of the generator substation **within the range of 0.95 leading and 0.95 lagging**, unless the Transmission Provider has established a **different power factor range** (...)"
- This is similar, but not identical, to the IBR operating points that contributed to the Iberian blackout
  - IBR were operated at a **fixed power factor**
    - No matter the grid condition, the plant will deliver a fixed reactive power for a given active power
  - FERC Order 827 dictates a **power factor limited** operation
    - The direction of reactive power (leading or lagging) may change, but is still limited to +/- 0.95



NERC Level 2 Alert data shows 35% of the currently installed IBR are operating in this limited mode

Conclusions

Modeling IBR is hard, data and evidence shows the current paradigm is insufficient, but regulatory enhancements are needed to close gaps and enhance North American Modeling Practices

- Major events comprised of unexpected IBR tripping show that the current modeling paradigm is insufficient
- Many of the modeling challenges have solutions internationally
- There is strong best practice available for IBR modeling in North America
  - This best practice is often at odds with current regulatory processes
- Regulatory processes need enhancements to allow stakeholders to perform best practice
- Process enhancements must have strong industry consensus technical foundation (i.e. IEEE 2800-2022, P2800.2, etc.)
- Stakeholder driven processes need enhancement to prevent gaming, lobbying, and misinformed comments and ballots

THANK YOU