Challenges and Possible Solutions for the Power System of the Future

A Research Perspective

Deepak Ramasubramanian
dramasubramanian@epri.com

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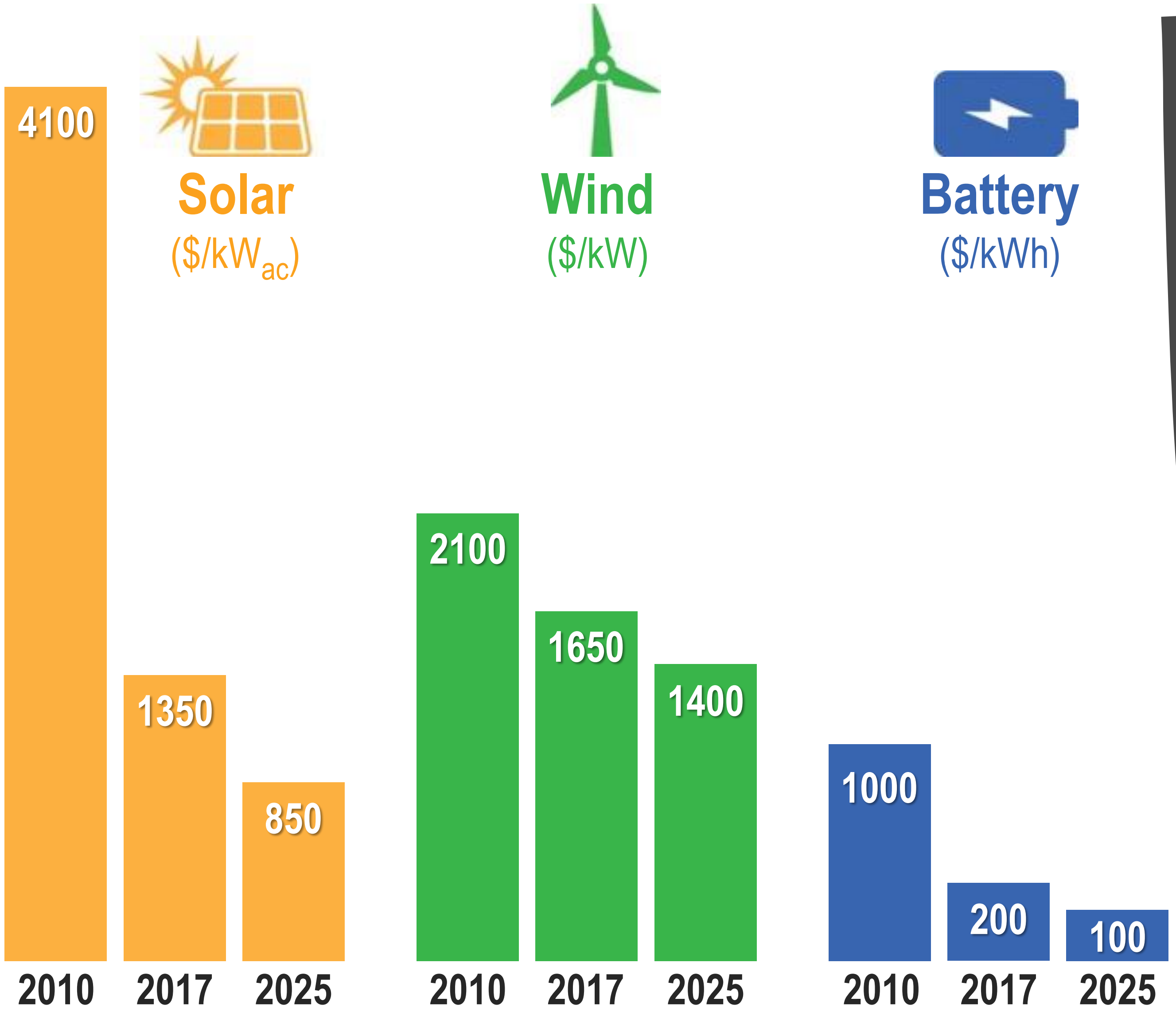
www.epri.com

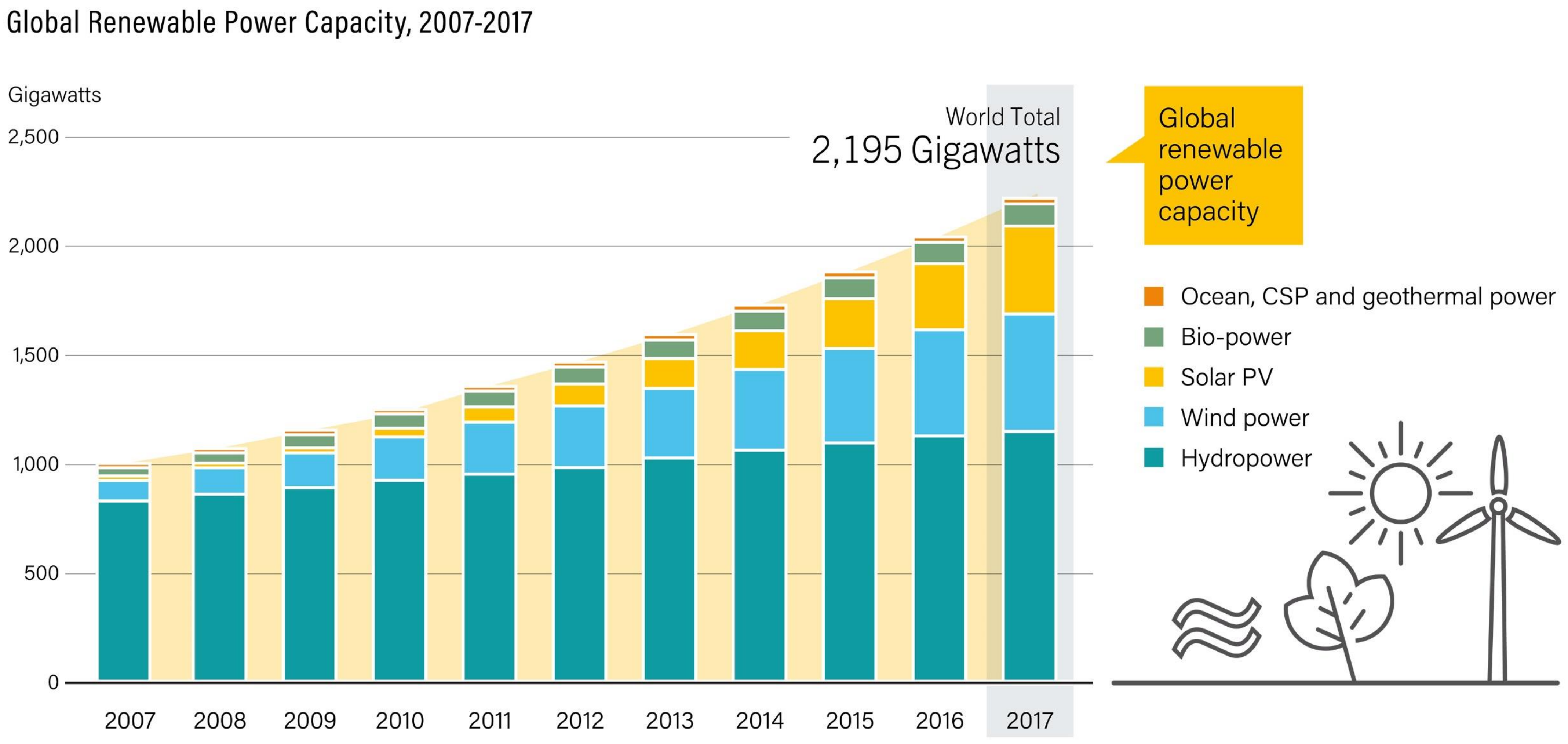
Renewable & Battery Cost Trend: Unlocked Potential by 2025



- Universal Solar PV: ~$0.02/kWh in high solar region but still almost half the cost of rooftop solar
- Wind LCOE: ~ $0.03/kWh in high wind region
- Electric vehicle (~300miles): ~$7,000 decrease
- Commercial building batteries: 2-year payback
- Solar/wind + 4-6 hour storage cost = natural gas power plant

No breakthrough technology needed!

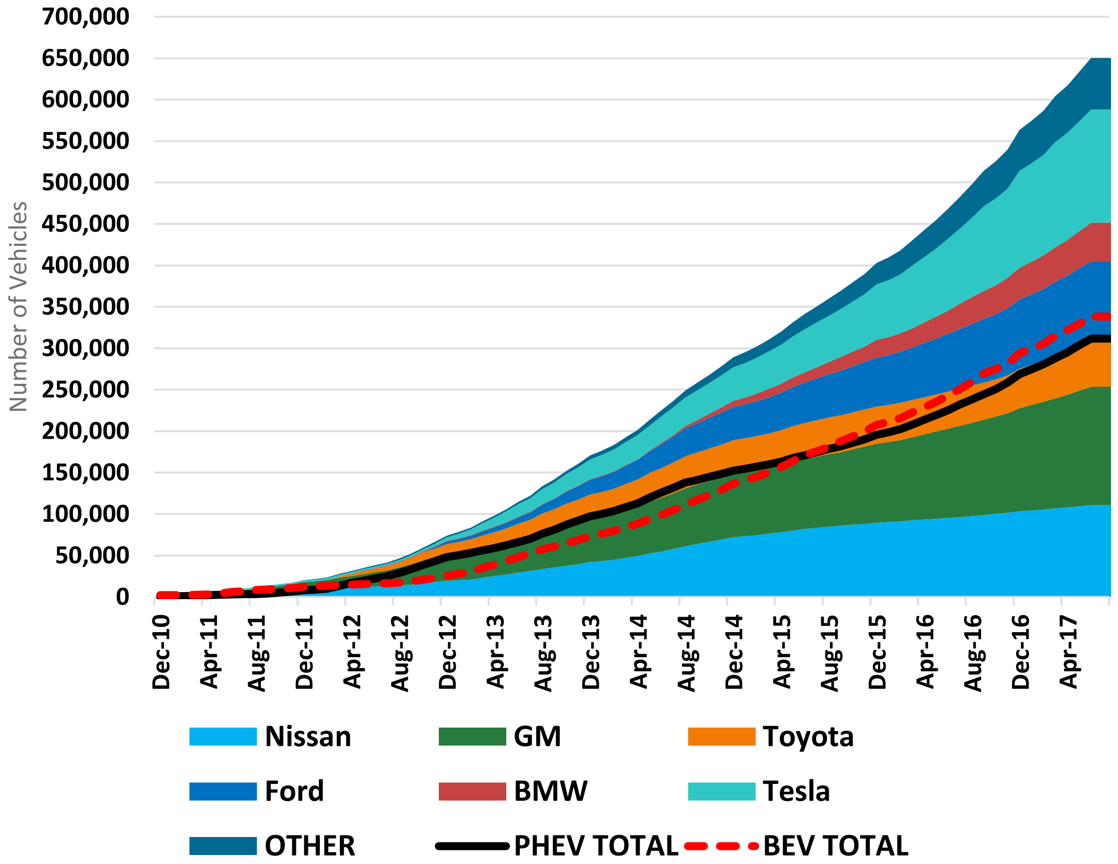
Renewables are increasing…



REN21 RENEWABLES 2018 GLOBAL STATUS REPORT

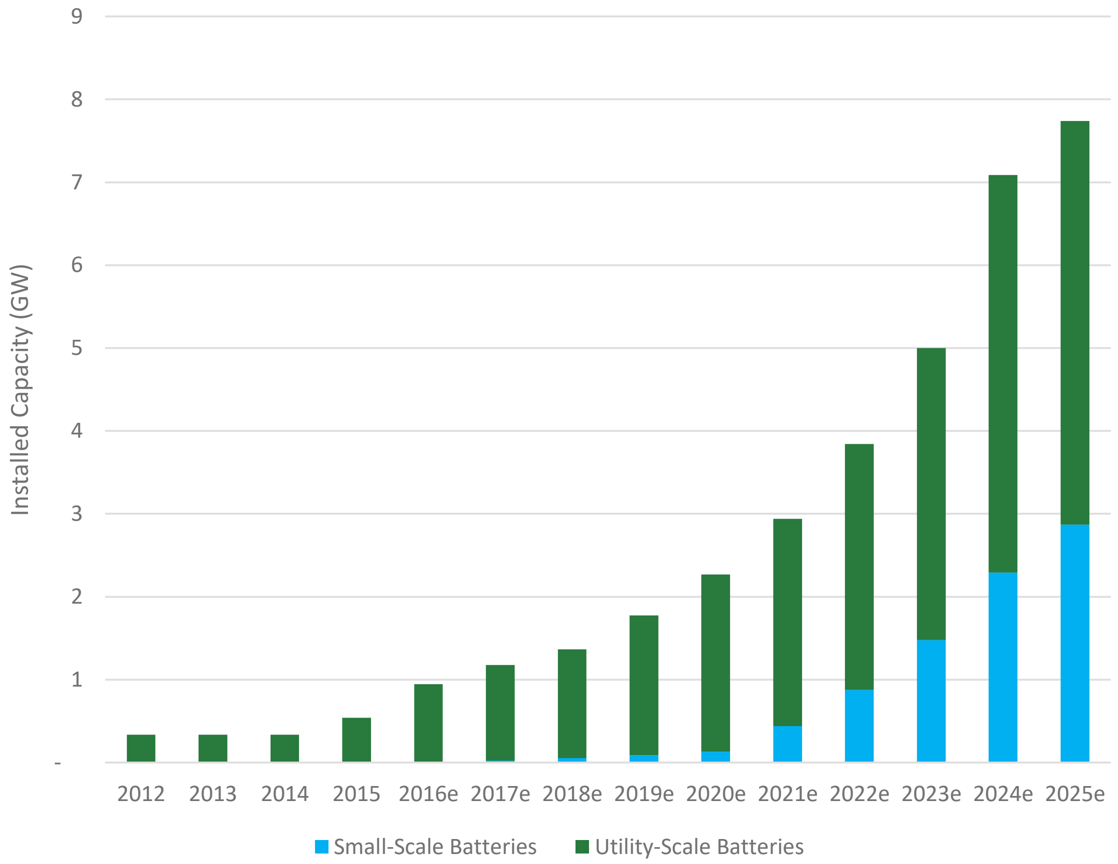
Not just wind and solar PV

Electric Vehicles



Source: EPRI Program on Electric Transportation

Batteries



Source: Bloomberg New Energy Finance, illustrated by EPRI

Inverter Based Resources and Low Short Circuit Systems

What is short circuit ratio (SCR)…?

- SCR – Ratio of short circuit MVA at a source bus to the MW rating of generator
  - High value of SCR implies that the source is ‘small’ relative to the rest of the network.
    - If source moves around a lot, network is minimally impacted.
  - Lower values of SCR implies that source can be ‘comparable’ size with network.
    - Movement of source will impact network

Source: “Integrating Inverter-Based Resources into Weak Power Power Systems”, Andrew Issacs, Electranix Corporation, EPRI-NERC-NATF-ESIG Webinar Series, 2018

Weak grids…

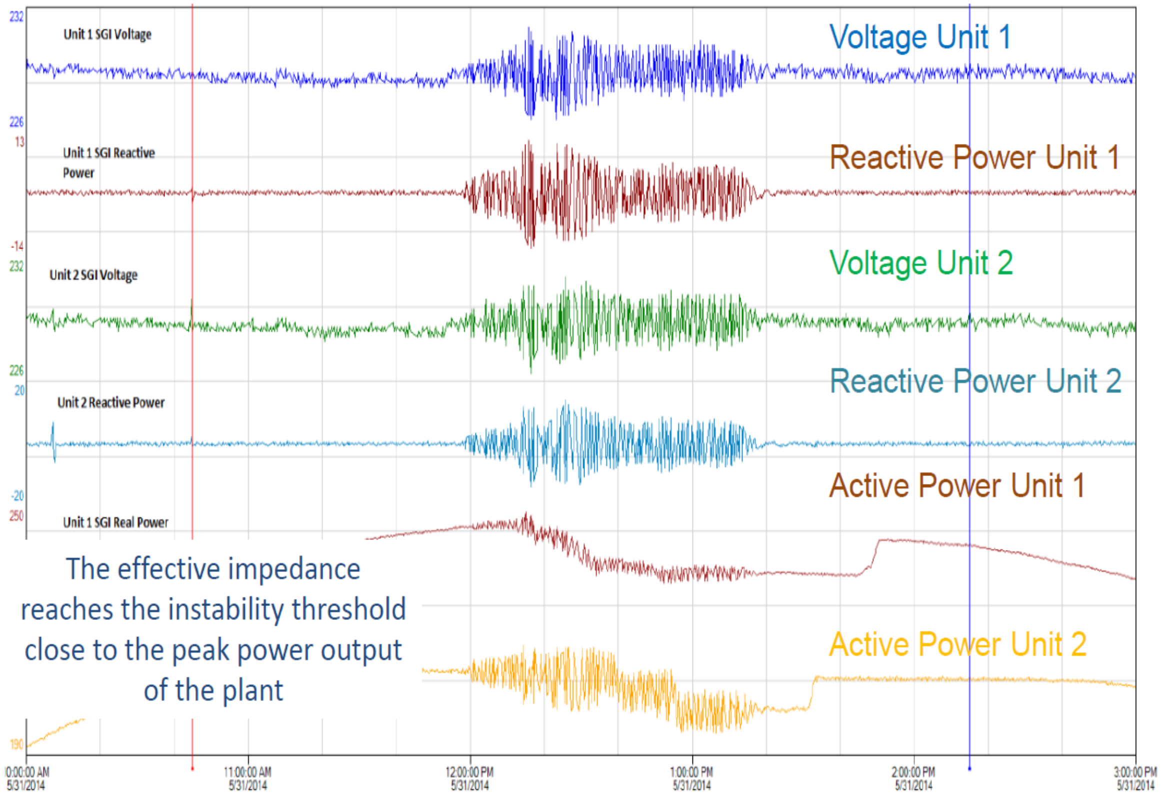
- How does a weak grid arise?
  - There is limited fault current available in the system -> resulting in lower voltages
  - There is large impedance between the source and rest of the network -> resulting in lower voltages

- Why may this be an issue?
  - An inverter uses measured voltage to decide the magnitude and angle of injected current
  - Small variation in current injection can cause large variation in voltages
  - An inverter tries to detect angle and magnitude of phase voltage, and react to this detection in a very fast manner.
  - This can results in an unstable operation.
  - In order to deliver a specific value of P and Q, both magnitude and angle of V should be known in order to decide the value and angle of current

$$I\angle\phi = \frac{P - jQ}{V\angle -\psi}$$

Inverters and Weak Grids

- Wind/Solar interconnections in weak systems are becoming more common
  - Connected farther away from transmission
  - Reduction of available short circuit current
- Contingencies or scheduled outages (e.g. lines under maintenance) may reduce system strength below typical levels expected under normal operating conditions.
  - Changes impedance of system
- Additionally, if such a network situation coincides with ramping up of the plant, the location can become even weaker
  - Injection of higher current through an already weak network
- Converter controller instabilities might occur under weak grid conditions
  - Inherent fast controllers may not be stable



Source: "Deploying Utility-Scale PV Power Plants in Weak Grids", First Solar, 2017 PES General Meeting, Chicago, IL, July 2017

Present Industry Practices to Ascertain Inverter Impact in Low Short Circuit

- No clear industry standard on metrics & associated thresholds to identify a weak area of the system

- Low SCR doesn't necessarily imply converter control instability
  - May re-tune (slowdown) inverter controls

- Other options to deal with low SCR
  - System reinforcement (synchronous condenser, new transmission)
  - Curtail plant output

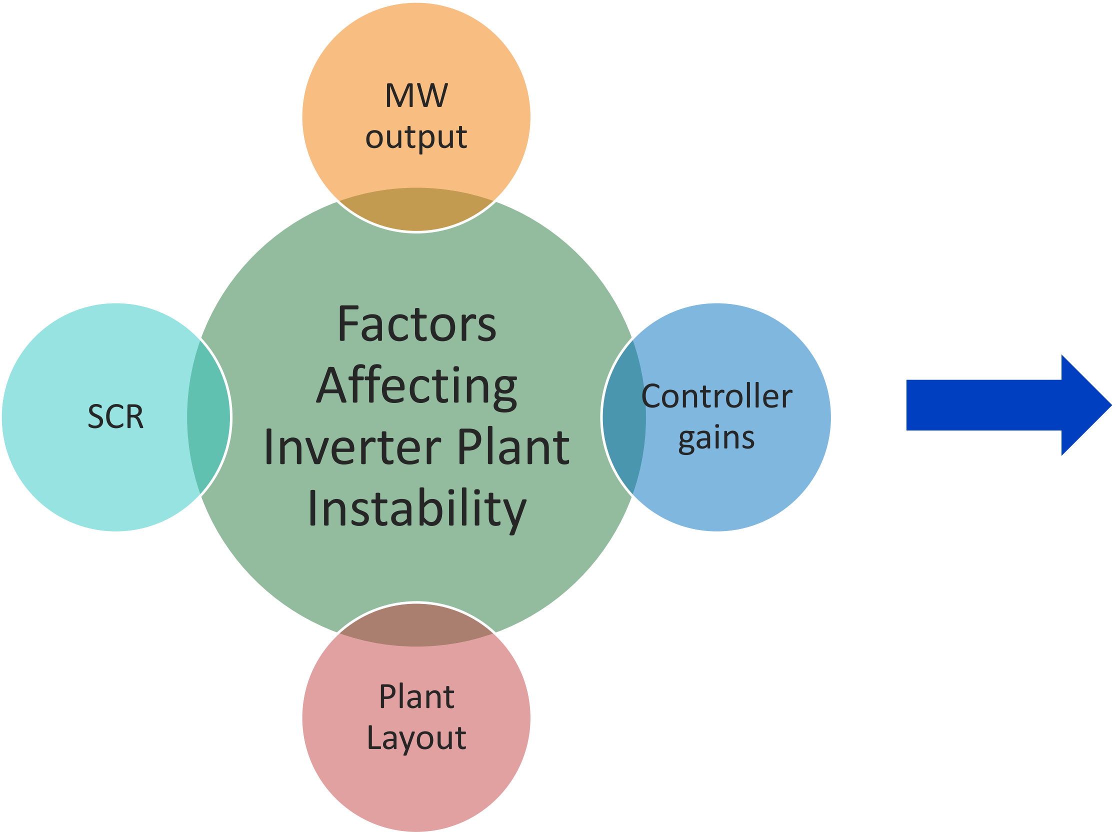
Table 2.1: Comparison of SCR Methods

Metric		Simple calculation using short circuit program	Accounts for nearby inverter based equipment	Provides common metric across a larger group of VER	Accounts for weak electrical coupling between plants within larger group	Considers non-active power inverter capacity*	Able to consider individual sub-plants within larger group
SCR	Short Circuit Ratio	★★	X	X	X	X	X
CSCR	Composite SCR	★	★★	★★	X	X	X
WSCR-MW	Weighted SCR using MW	★	★★	★★	★	X	X
WSCR-MVA	Weighted SCR using MVA	★	★★	★★	★	★★	X
SCRIF	Multi-Infeed SCR	X	★★	X	★★	★★	★★

Source: "Integrating Variable Energy Resources into Weak Power Systems", NERC, June 2017

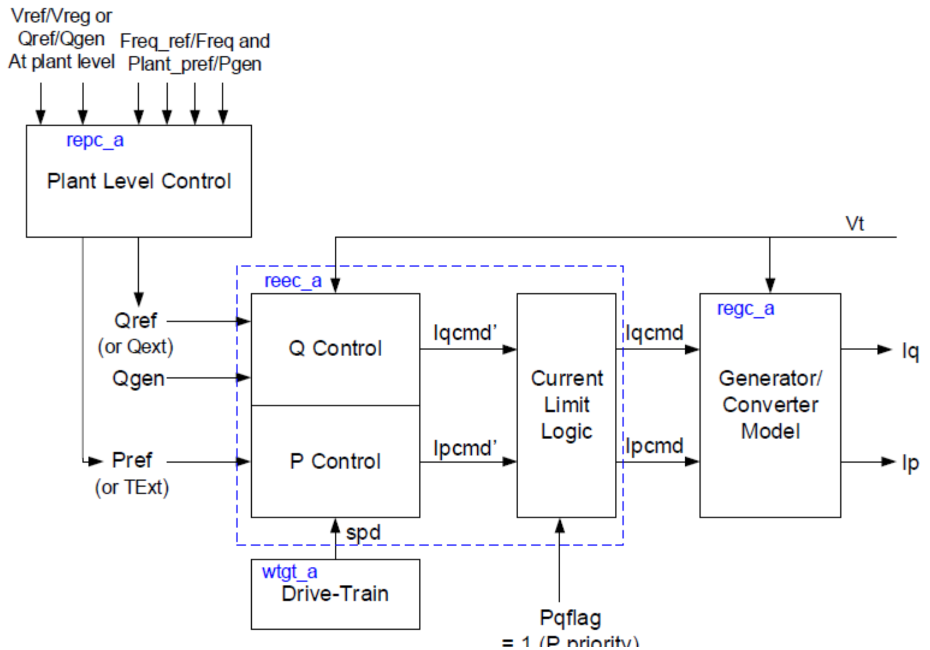
But SCR Does Not Provide The Entire Picture…

- For an inverter plant, a low or high value of SCR may not provide the entire picture about control instability



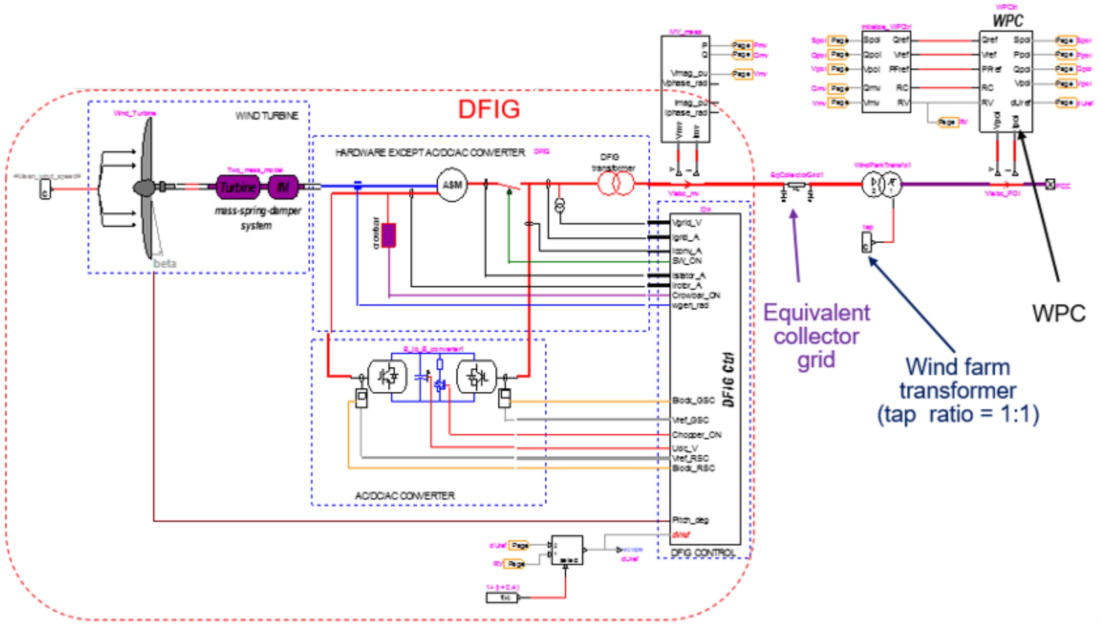
- Controller instability due to extended duration of a fault can be because of:
  - Increased controller effort to maintain respective references during the fault
  - Post contingency system does not provide sufficient damping
  - Saturation of controllers due to large values of gain
- New "Advanced Short-Circuit Strength" metric has been developed
  - For a fault at the POI of an inverter based plant, provides estimate on fault clearing time threshold to prevent controller instability.

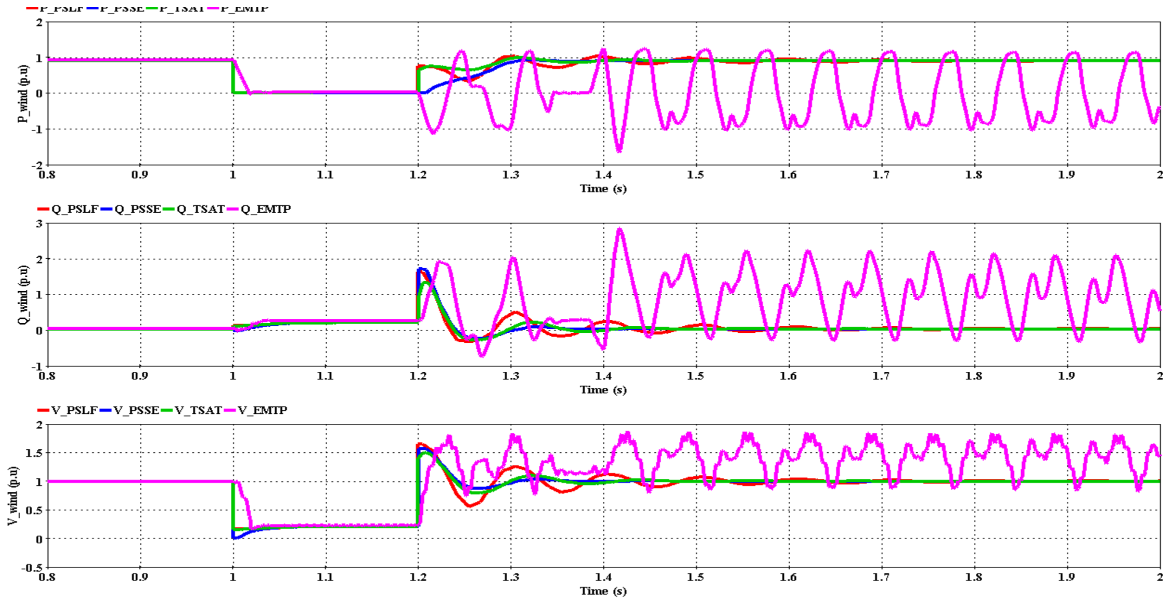
Limitations of Present Converter Positive Sequence Dynamic Models



Generic Positive Sequence Models Limitations

- Models not suitable for capturing fast controller dynamics/interactions
- Models not accurate for studying unbalanced conditions near the converters
- Models not suitable for interconnection studies of a wind/solar power plant to a weak transmission system
- Models not suitable for detailed studies related to phenomena such as sub-synchronous resonance and ferro-resonance





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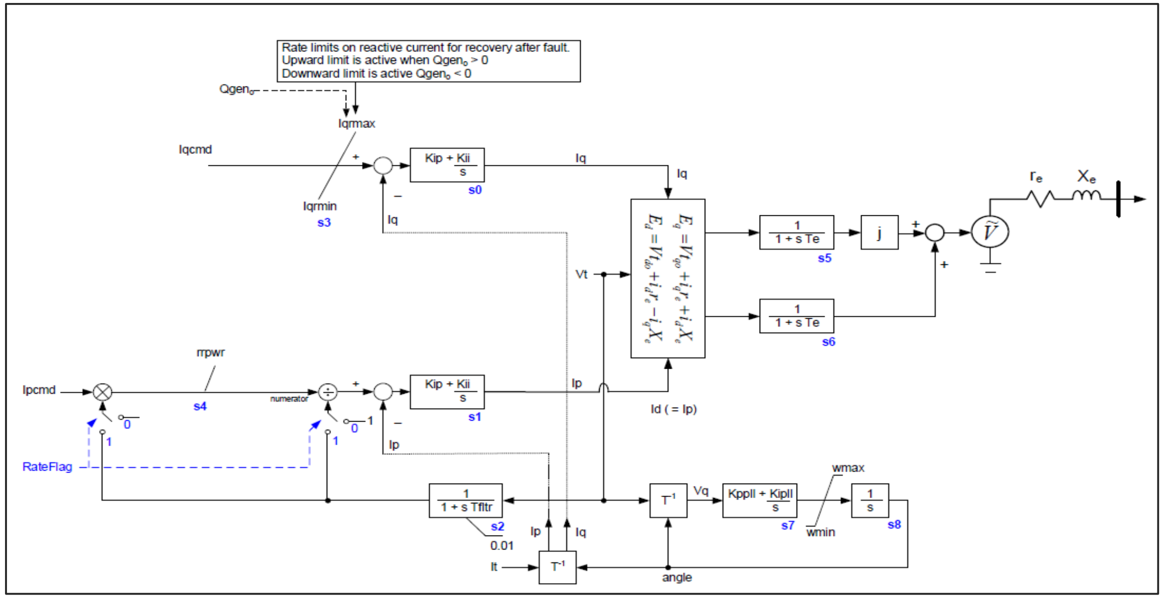
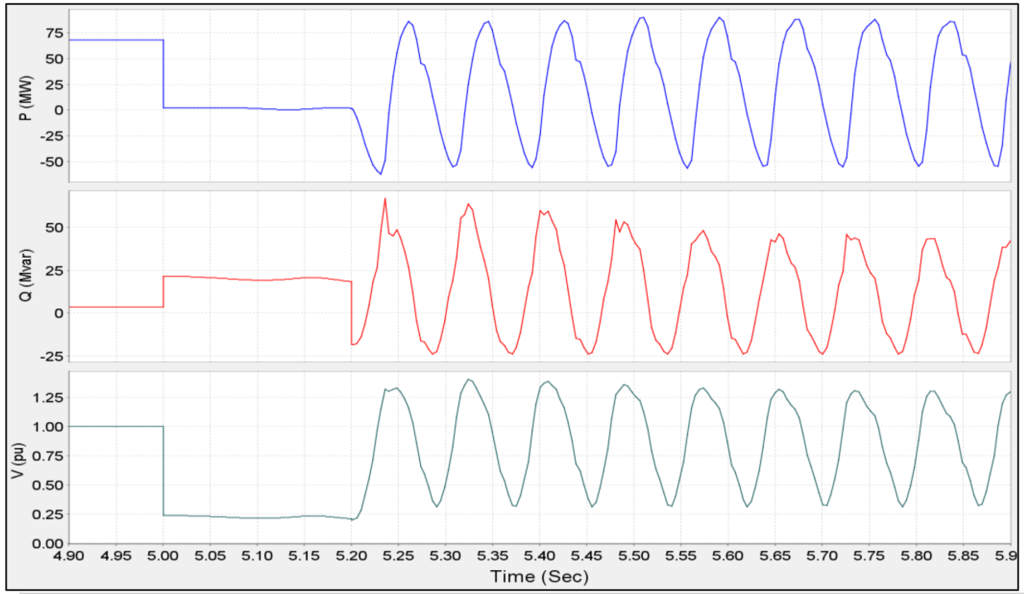
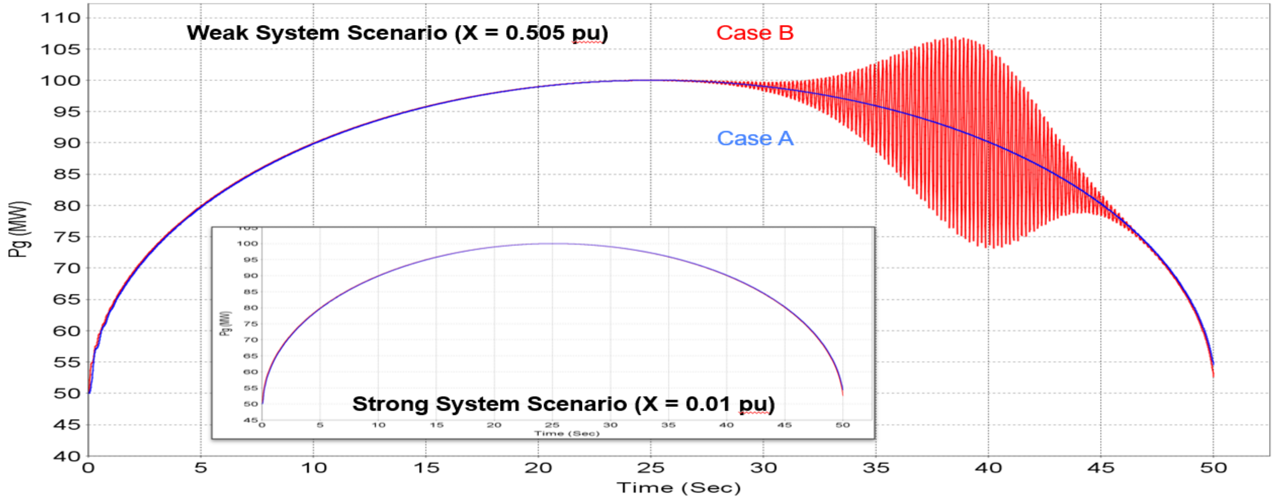
Proposed REGC_C (Positive Sequence Model)

- Representation of PLL and inner current control loop
- Small timestep required (1ms)
- **Improves numerical stability**
- **Suggested to be used for weak grid studies before conducting detailed three-phase EMT studies**
- Update:
  - PSS®E model implementation almost complete
  - Model testing in collaboration with EPRI members



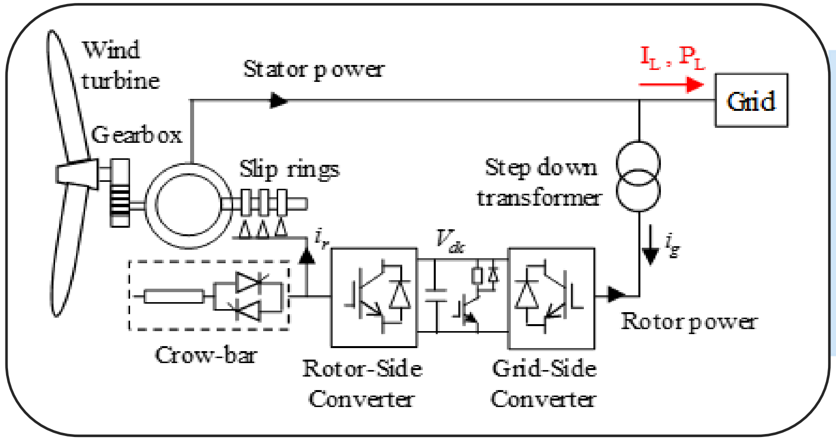




Inverter Based Resource Impact on Protection Relays

Motivation, Challenges & Needs

- Continuously increasing penetration level of inverter interfaced resources, predominantly renewables (Type III, Type IV WTGs & PVs)



Challenge

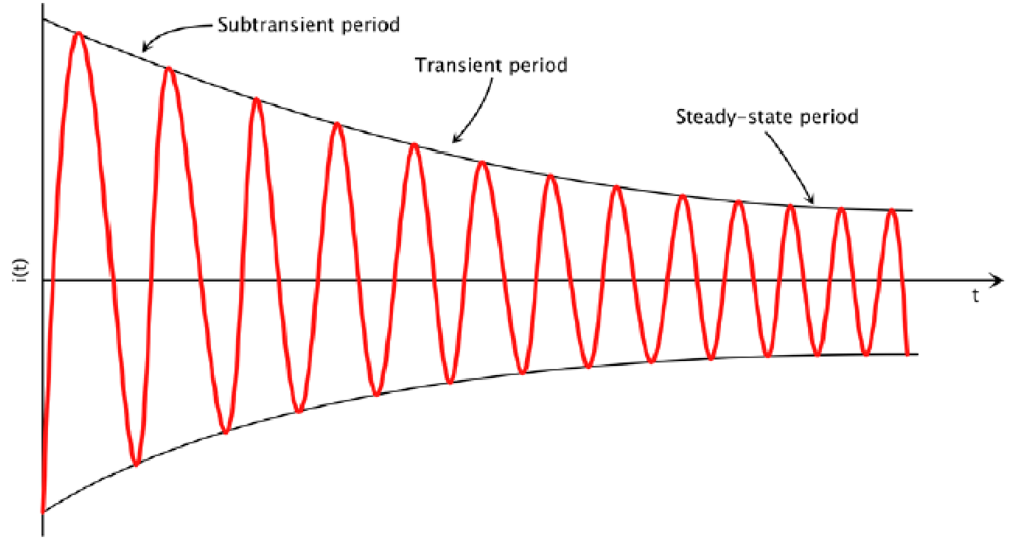
- Complex fault response
- Differs significantly from synchronous short-circuit current contribution (SCC)

Impact on System Protection

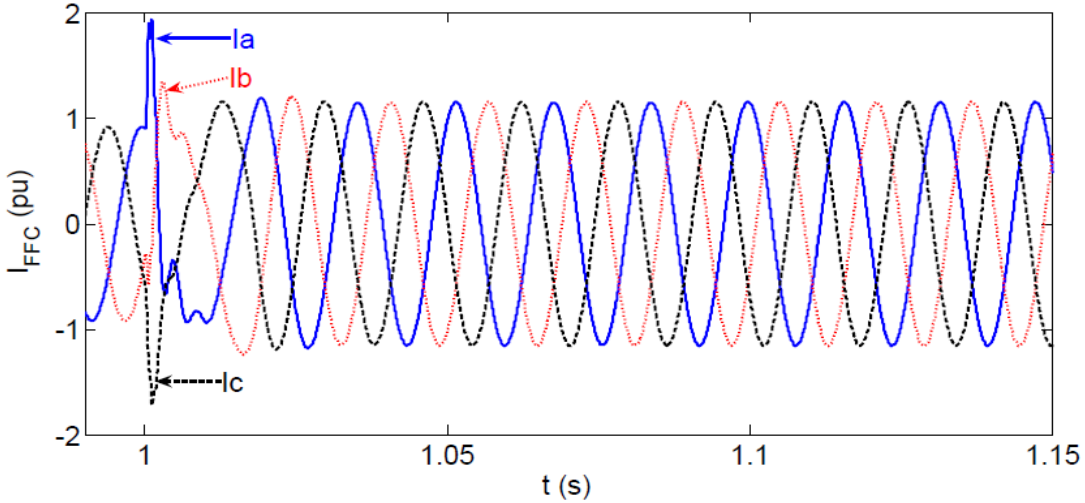
- Accurate short-circuit models for protection/planning studies
- Performance of legacy protection schemes (distance protection etc)

Inverter Based Resources Fault Response Characteristics

Synchronous Generator



Type IV WTG

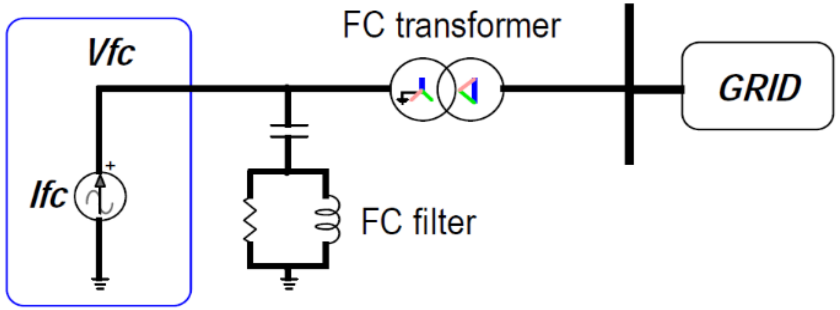


- SCC magnitude close to nominal load current (typically 1.1-1.5 pu)
  - Initial transient (typical duration 0.5 -1.5 cycles) – uncontrolled response – controller “reaction time”
- Fault current can be capacitive, inductive or resistive
- Typically low negative sequence current contribution
- No zero sequence current

IBR fault response depends on inverter control scheme

IBR Short Circuit Models

Synchronous generator classical short circuit model (voltage source behind an impedance) is not applicable



- Voltage controlled current source
- Iterative solution (nonlinear behavior)
  - considers the impact of controls on the short circuit response
  - respects inverter current limits

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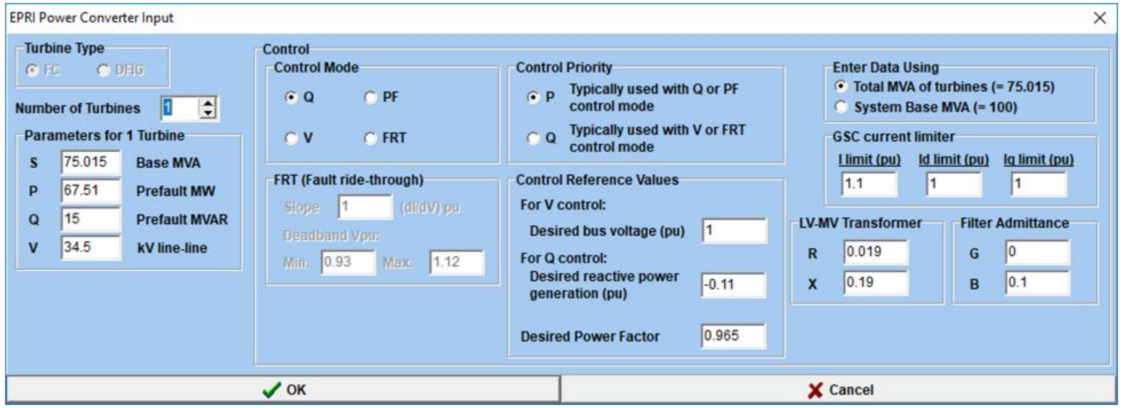
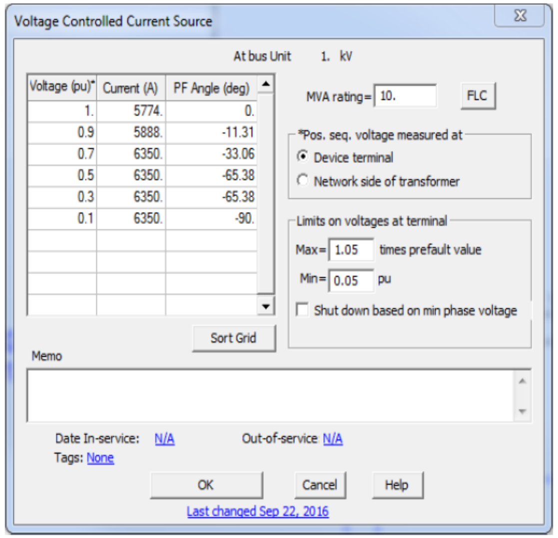


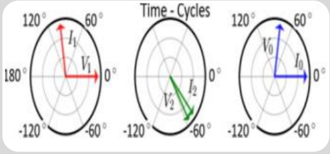
ASPEN OneLiner v14



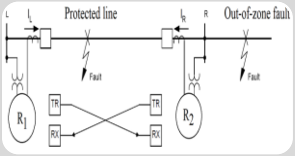
IEEE PSRC C24 WG

Time frame 1 (seconds or cycles)		Fault Type:
Positive sequence voltage (pu)	Positive sequence current (pu)	Positive sequence current angle with respect to positive sequence voltage (deg)
0.9		
0.7		
0.5		
0.3		
0.1		

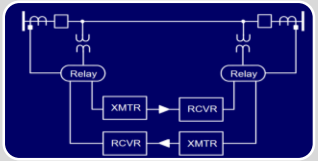
Protection System Performance Evaluation



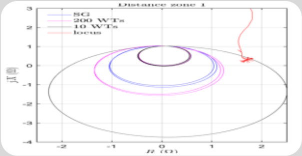
Negative Sequence Based Protection



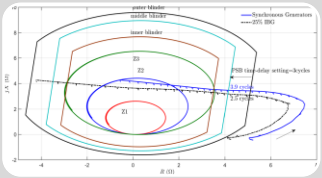
Line Differential Protection



Communication Assisted Protection



Line Distance Protection



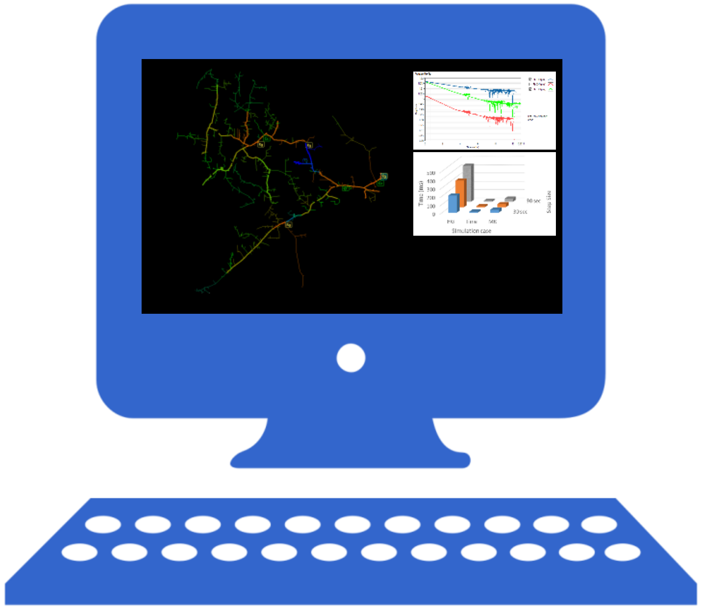
Power Swings Protection

- Investigate relays response & identify potential misoperation scenarios
- Provide recommendations and study practices to protection engineers when conducting protection studies to prevent relay misoperation & miscoordination
- **Related Industry Efforts:**
  - IEEE PES - NERC Technical Report “Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance”
  - DOE Project “Inverter Based Resource (IBR) Negative Sequence Current (I2) Injection Study”

Next Generation Tools for Distribution Planning

Distribution System Analysis Tools

Present day tools

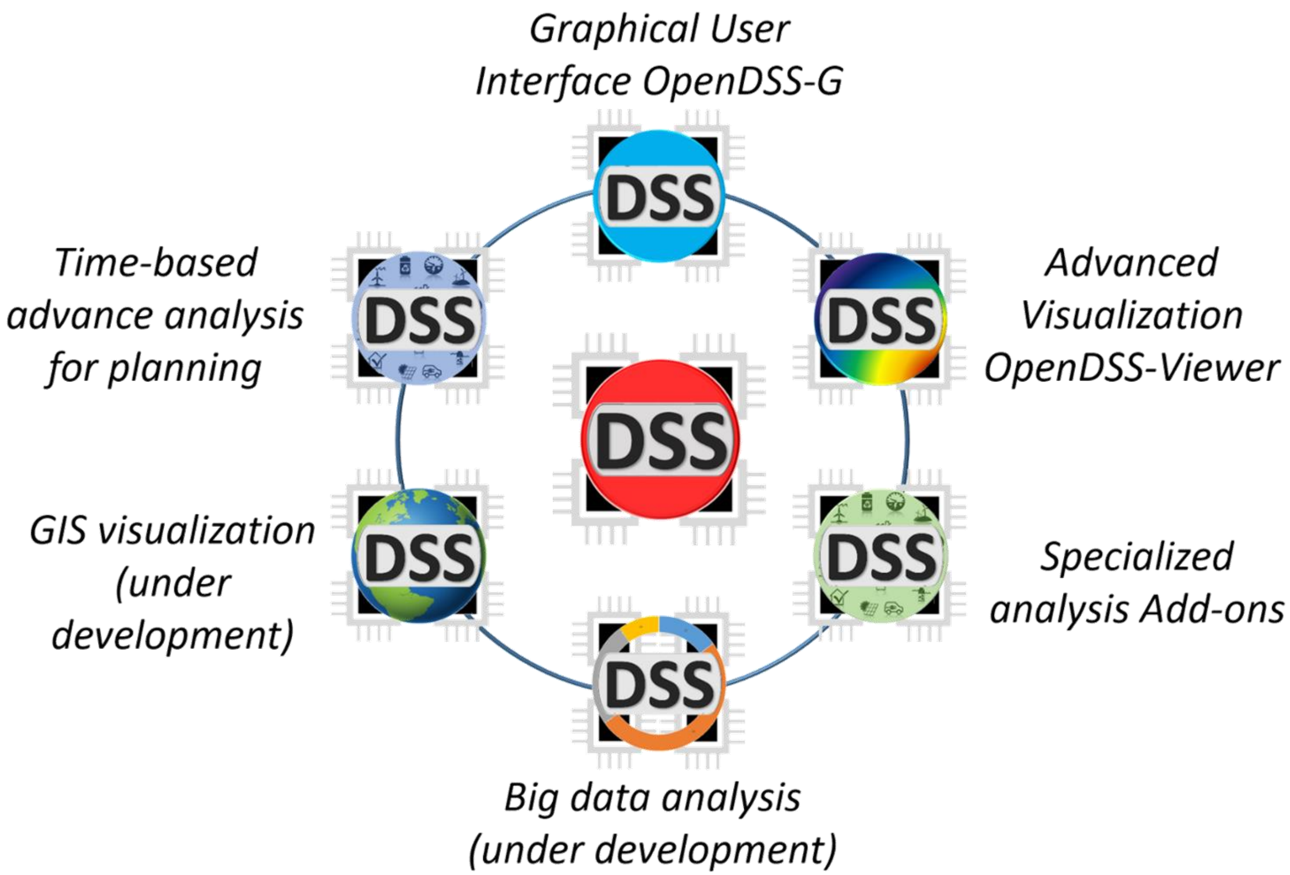


- Snap shot simulation
  - Extreme values
- Simple and efficient
- Seemed to have everything

Requirements for future tools

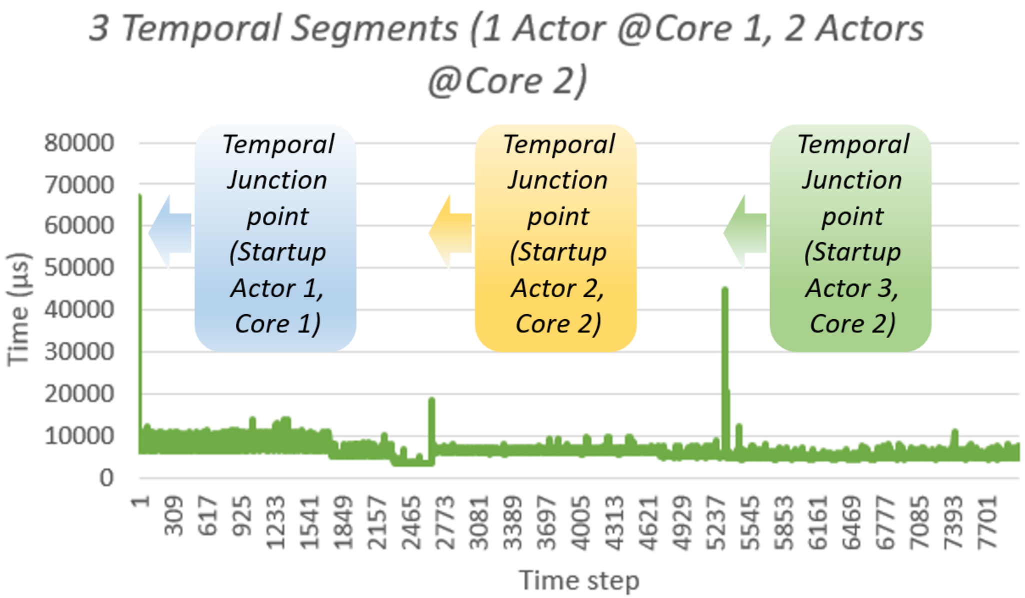
- Accelerate advanced analysis
- Varying operational conditions
  - Big data processing
- The evolution is happening

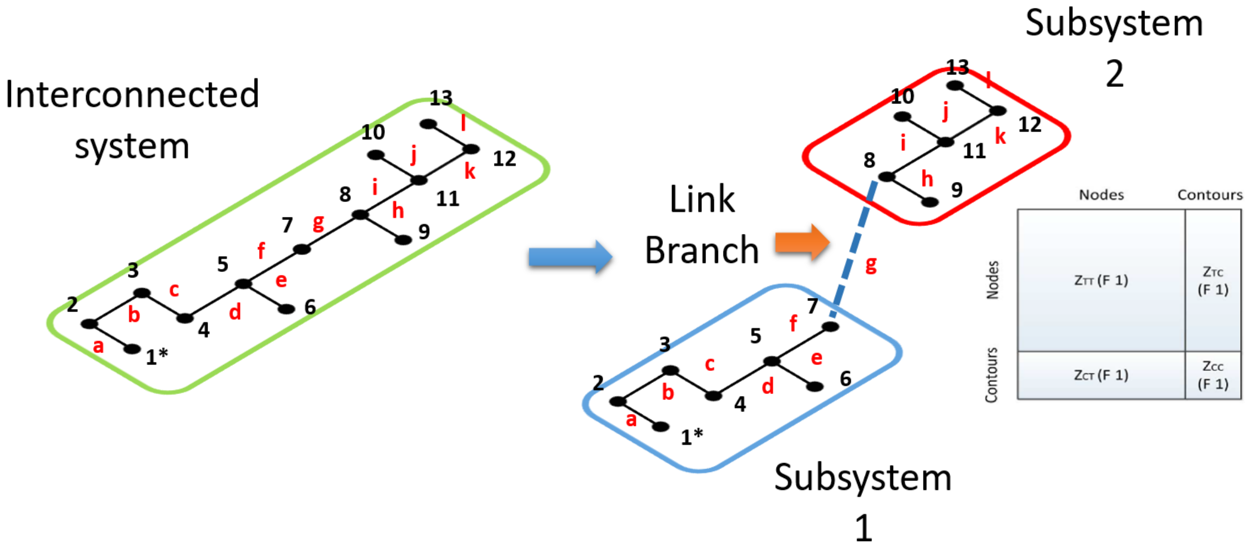
The Next Generation of Distribution Analysis Tools



The Next Generation of Distribution Analysis Tools

- Accelerating simulations

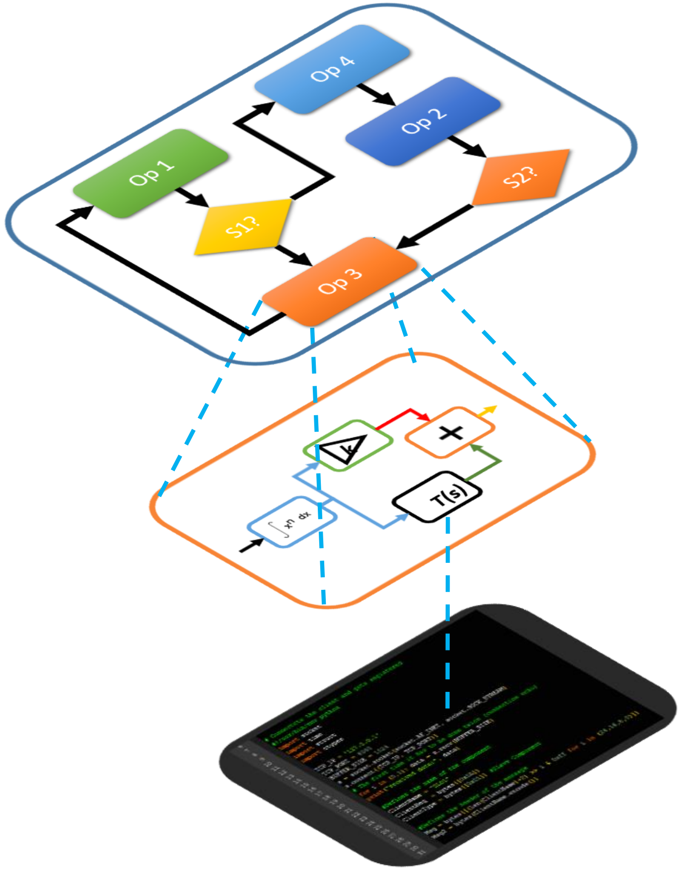




And other techniques that can be used to take advantage of multicore computers when using OpenDSS

The Next Generation of Distribution Analysis Tools

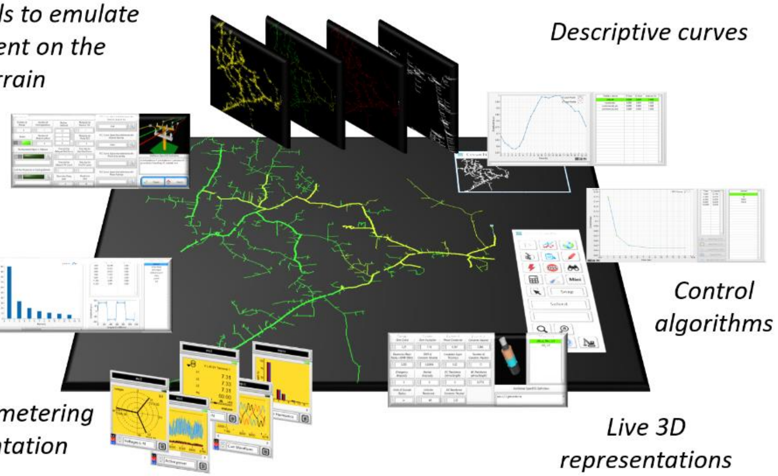
- Simplifying Complex Processes and Data



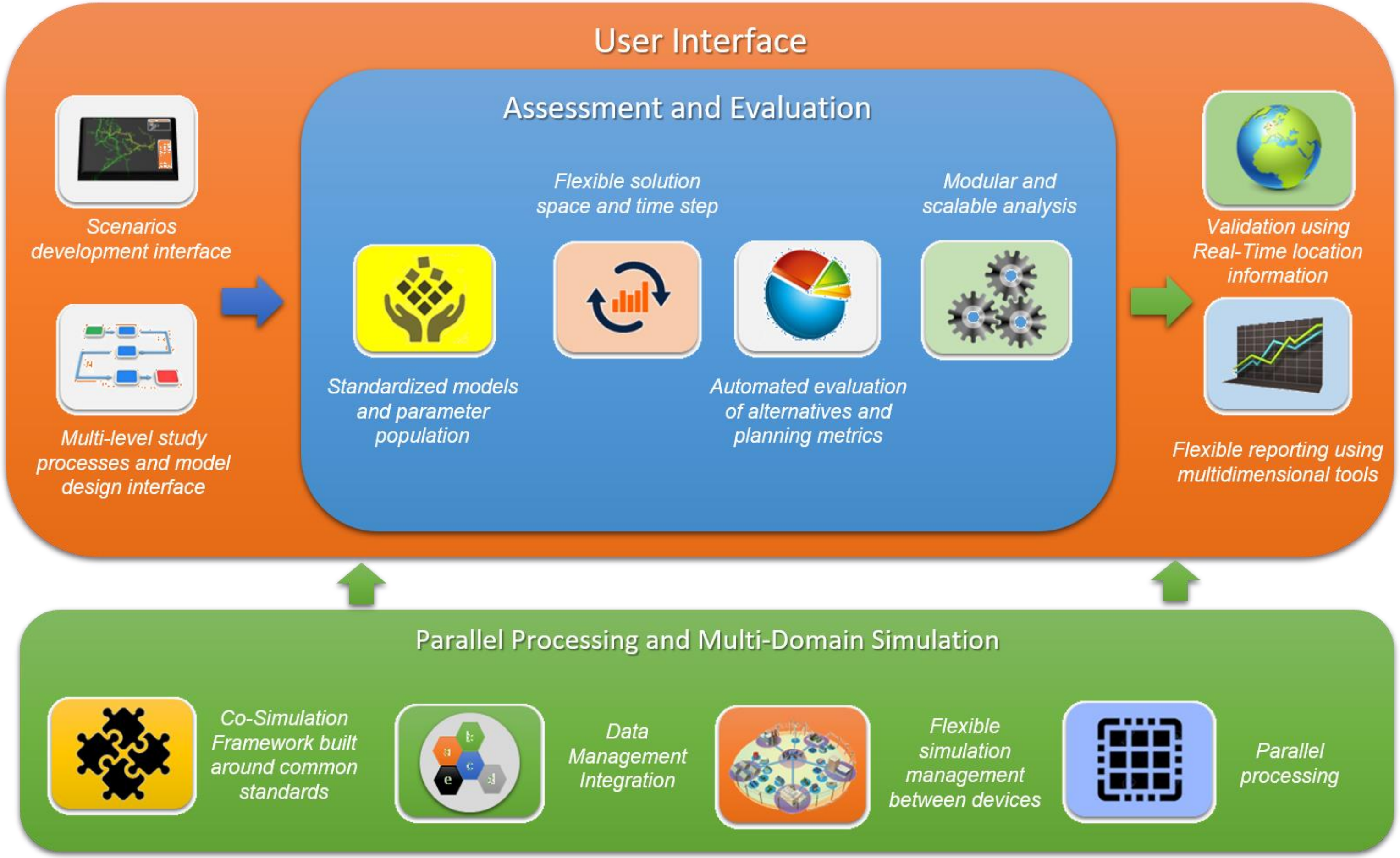
High level interface, describes the simulation process and global considerations of the planning study

Medium level interface, describes customized equipment using pre-existing functions

Low level interface, describes customized functionalities as new components for the simulation



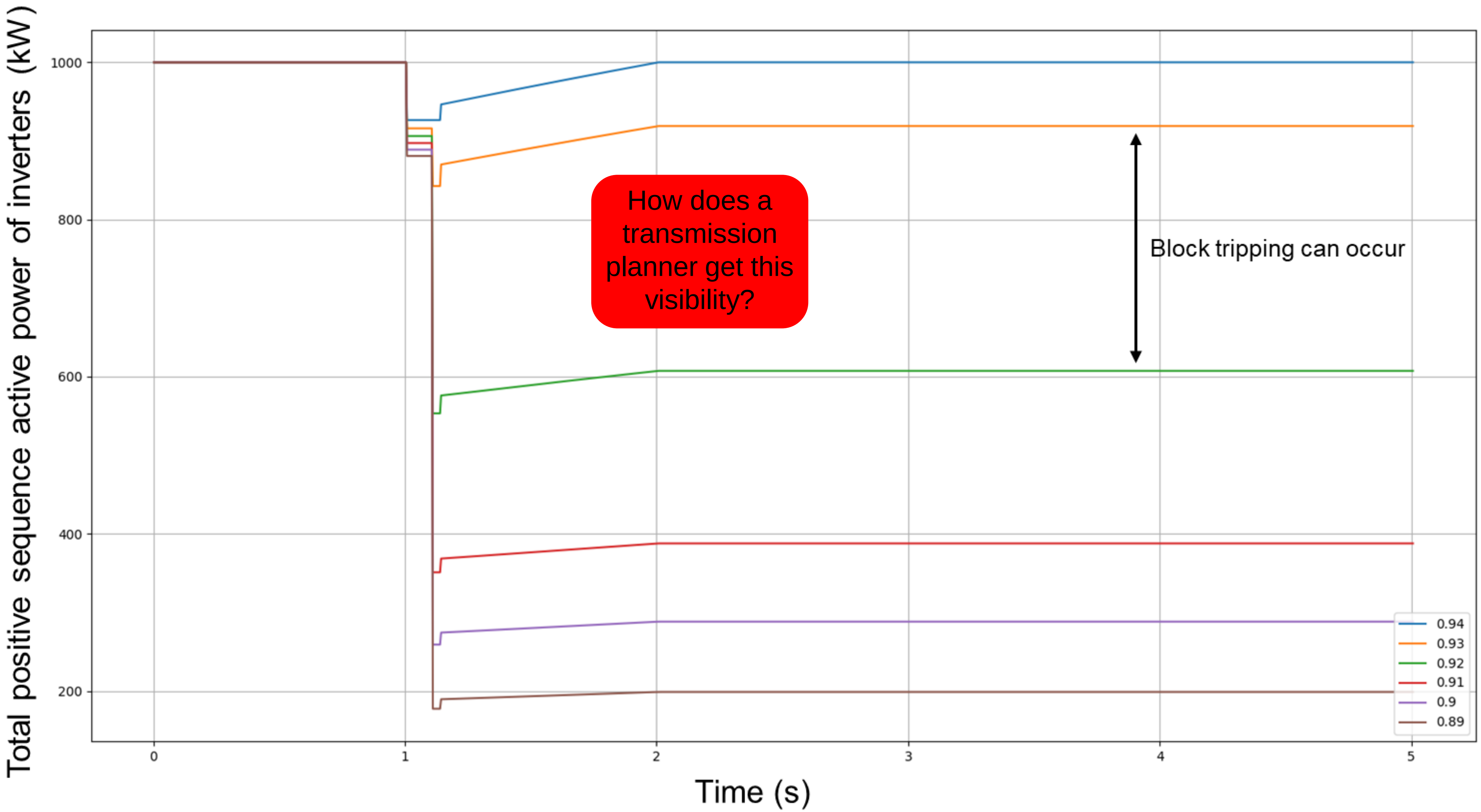
Conclusions



Distributed Energy Resources (DER) Impact on Bulk Power System

Why should DER be modeled explicitly…?

<ins>Block tripping of DERs can be a concern to system stability</ins>



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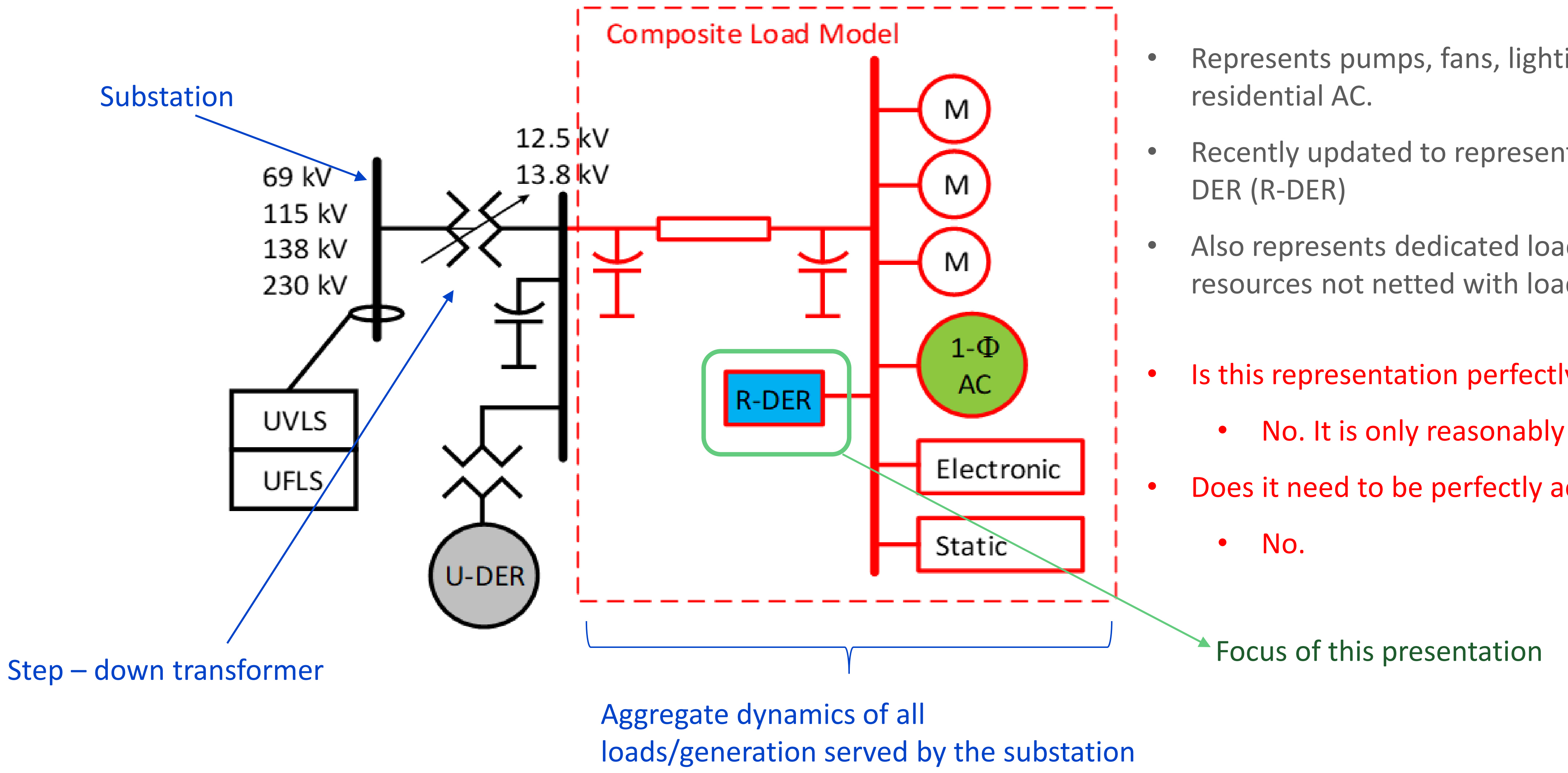
A solution for DER to be modeled for bulk power system planning studies…

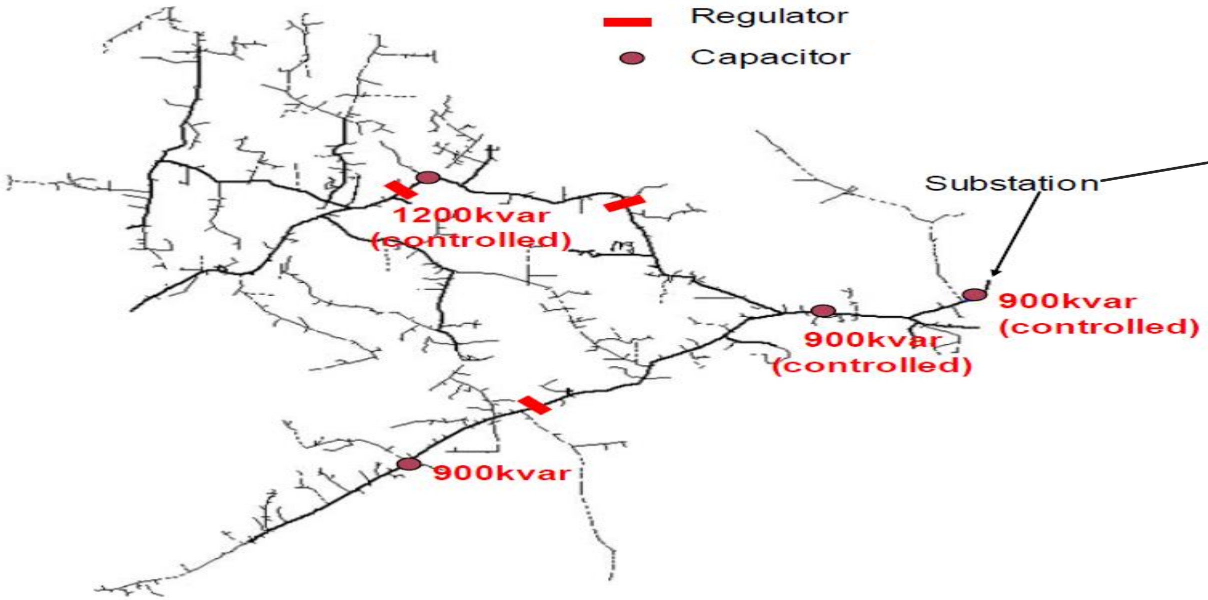


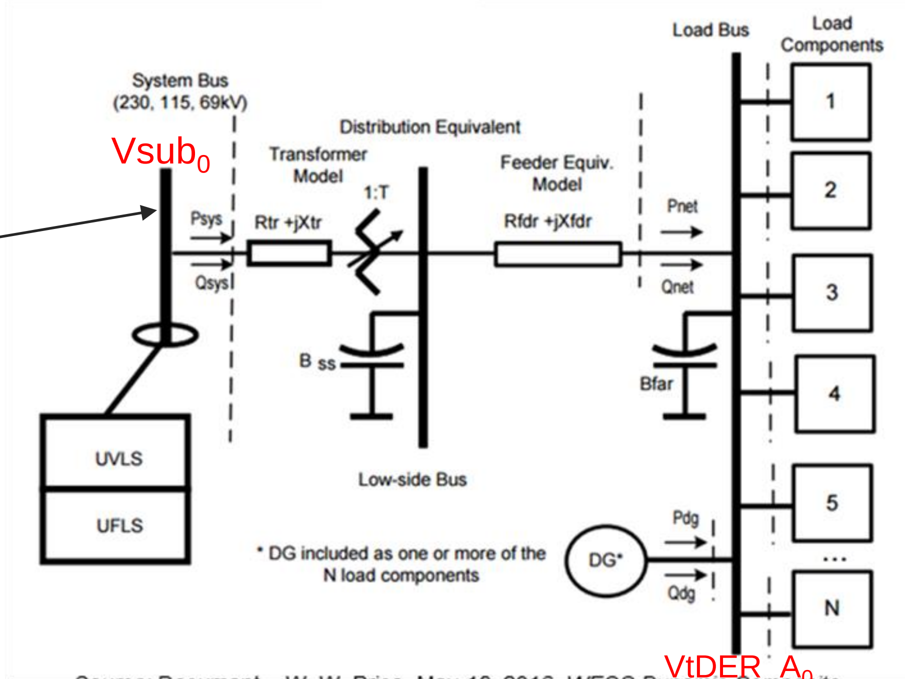
- Represents pumps, fans, lighting, HVAC systems, residential AC.
- Recently updated to represent behind the meter DER (R-DER)
- Also represents dedicated load serving DER resources not netted with load

- Is this representation perfectly accurate?
  - No. It is only reasonably accurate
- Does it need to be perfectly accurate?
  - No.

If the decision to be made from studies does not change whether one uses detailed models or aggregated models, then aggregate models are sufficient

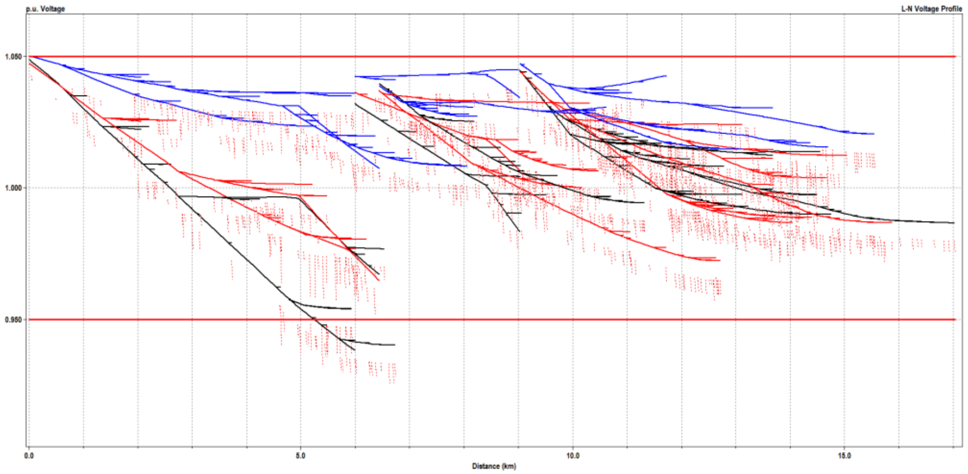
The modeling challenge still persists though…



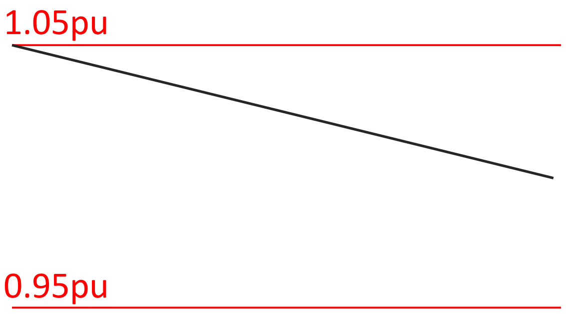


Source: Document – W. W. Price, May 18, 2016, *WECC Dynamic Composite Load Model (2nd Generation) Proposed Structure*

Entire load on a substation modeled as a single equivalent



Complete three phase voltage profile represented by single RMS profile



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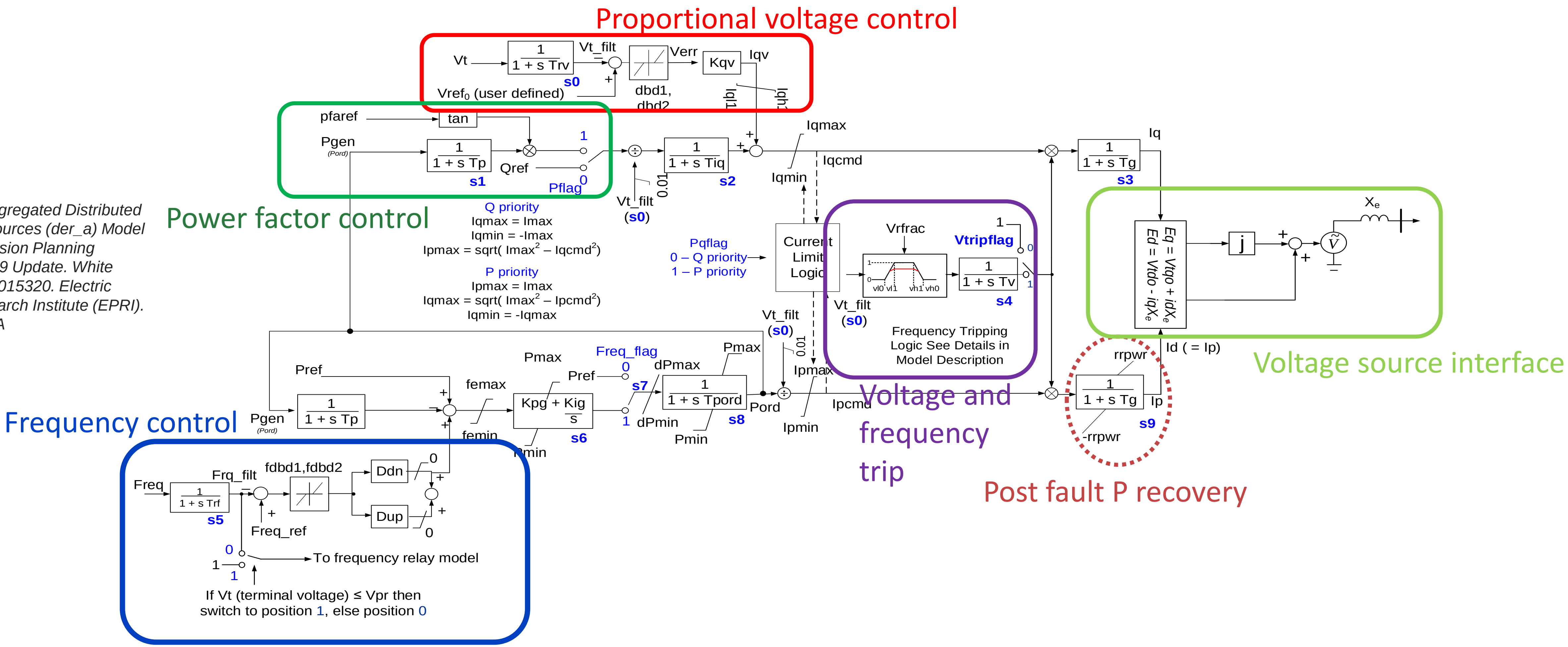
Aggregated model to represent the dynamic behavior of DER…

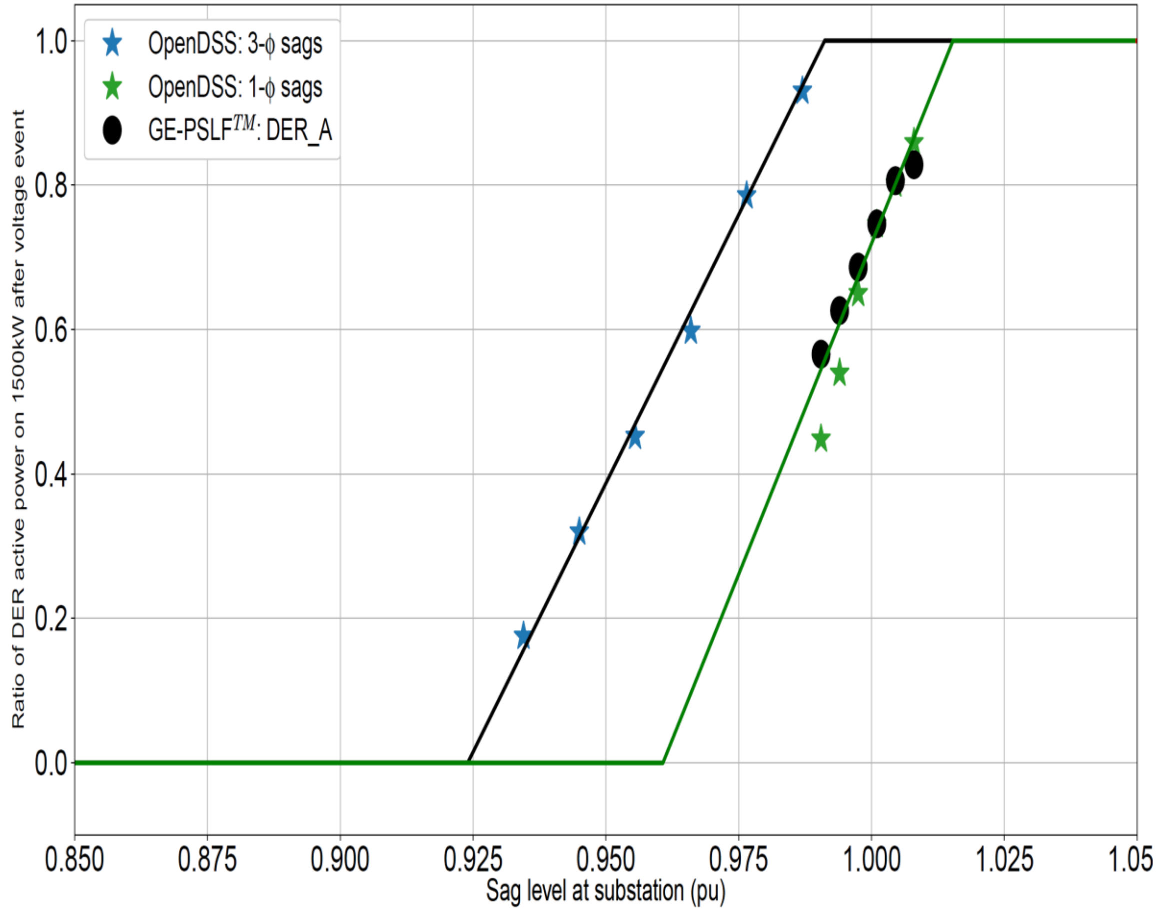
Reference:

The New Aggregated Distributed Energy Resources (der_a) Model for Transmission Planning Studies. 2019 Update. White Paper. 3002015320. Electric Power Research Institute (EPRI). Palo Alto, CA

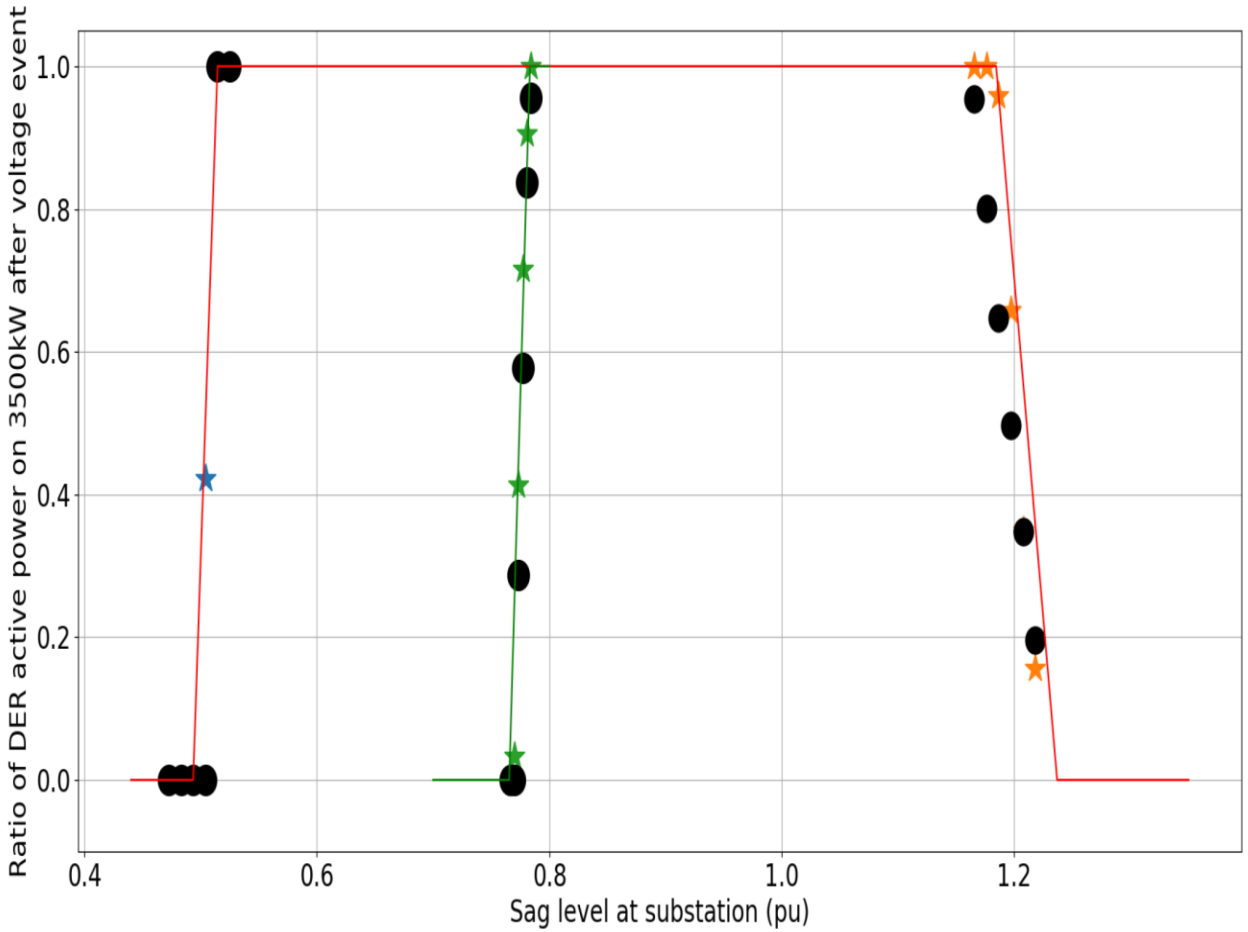


How to find parameter values for the model? Present focus is on voltage thresholds.

Partial trip of DER based on voltage magnitude…



Individual DER Vtrip = 0.88pu

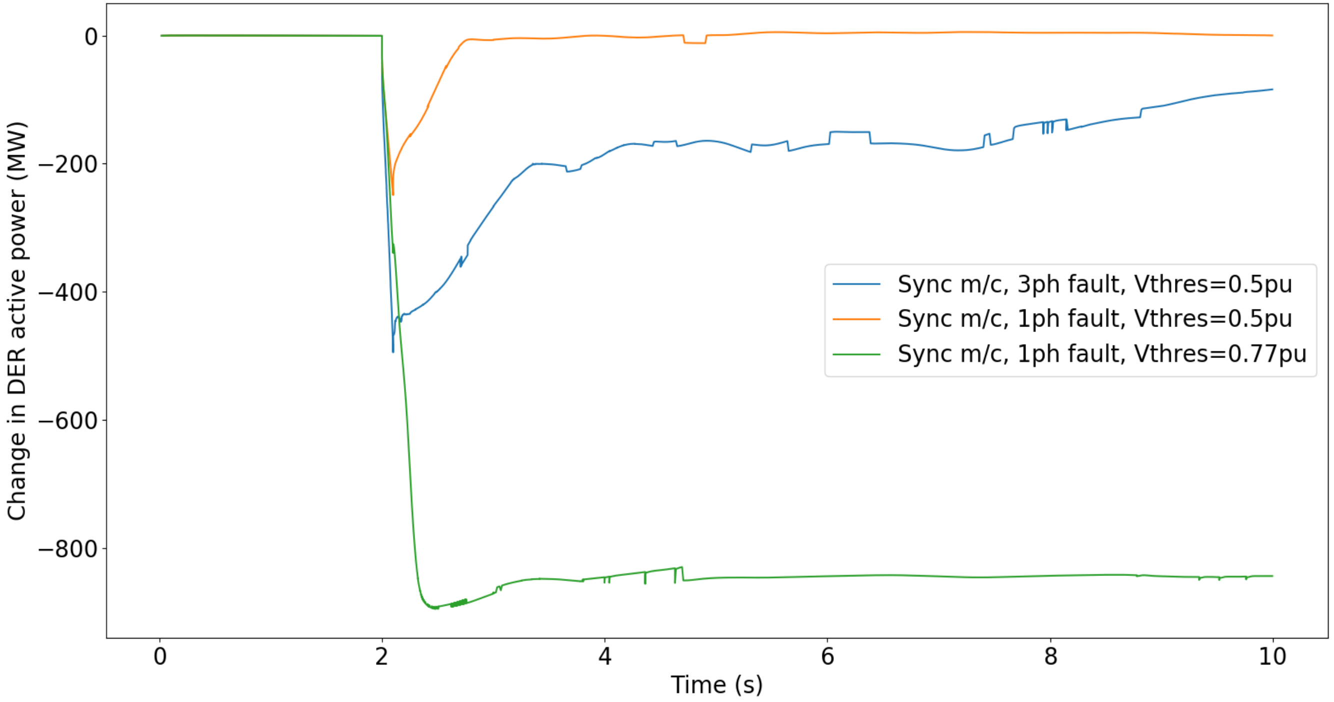


Individual DER Vtrip = 0.5pu

Reference: Deepak Ramasubramanian, Inalvis Alvarez-Fernandez, Parag Mitra, Anish Gaikwad and Jens C. Boemer, “Ability of Positive Sequence Aggregated Distributed Energy Resource Model to Represent Unbalanced Tripping of Distribution Inverters,” 2019 IEEE Power & Energy Society General Meeting (PES), Atlanta, GA, 2019

Impact on bulk power system...

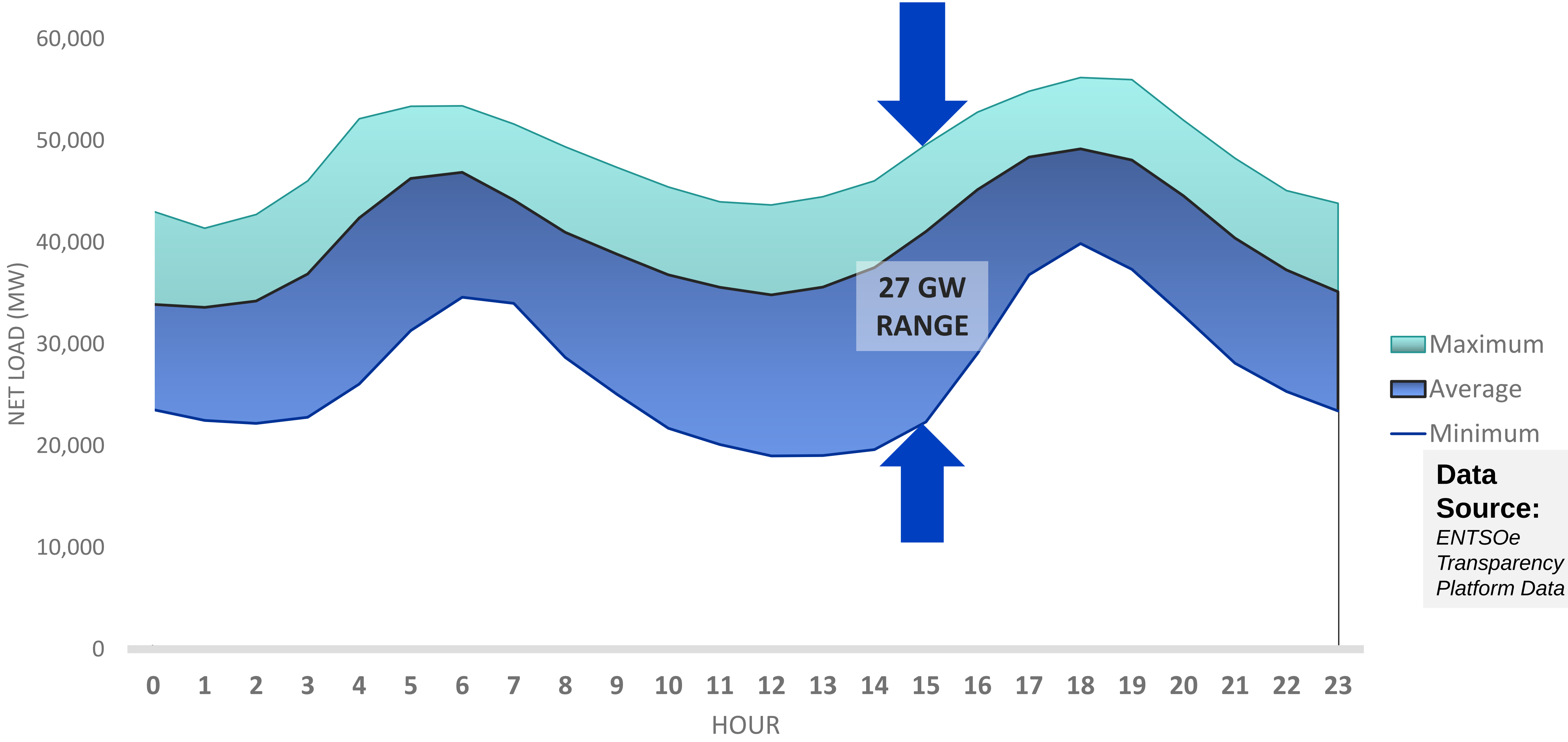
- Simulation premise
  - System generation is 69 GW, gross load is 81 GW, DER is 14 GW
  - Fault applied in the middle of transmission line, and subsequently line is cleared in 6 cycles
  - Load dynamics are considered along with DER dynamics



Without the parallel trip characteristic, there could be a huge misrepresentation of amount of DER that ride through a single phase fault

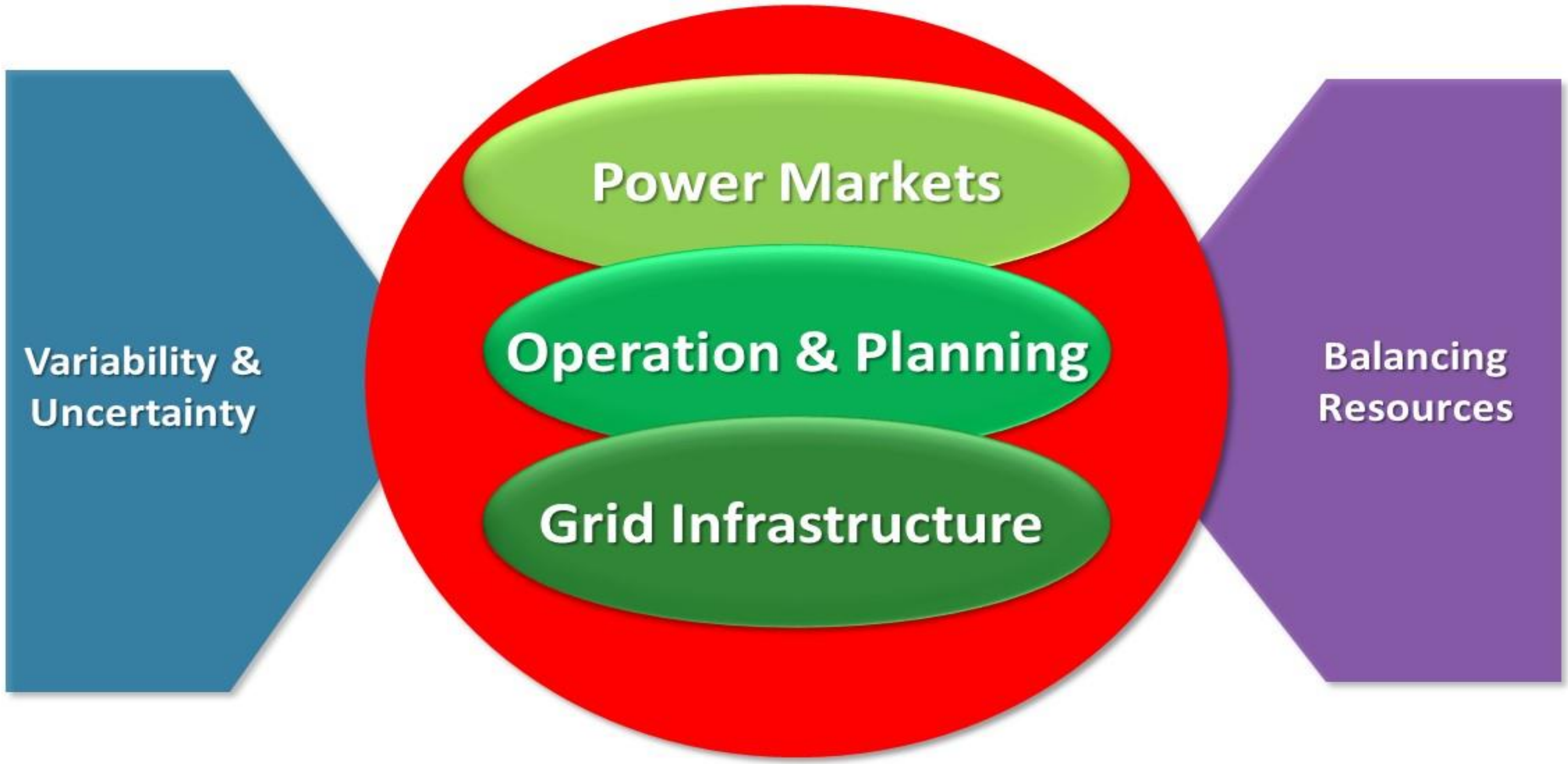
Flexibility and Resource Uncertainty

German Hourly Net Load Range – August Workdays, 2019



Data Source: *ENTSOe Transparency Platform Data*

Carbon Reduction Necessitates Enabling Flexiblity



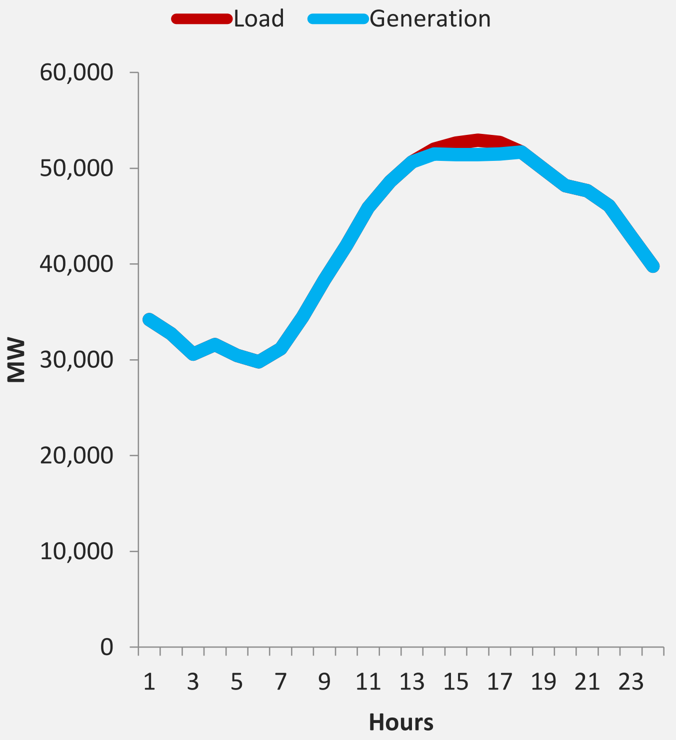
Source: *Harnessing Variable Renewables -- A Guide to the Balancing Challenge*, International Energy Agency, 2011

Long-Term Planning Needs –What "Type" of Capacity is Needed?

Traditional "Generic Capacity" Metrics

$\text{LOLE}_{\text{GENERIC-CAPACITY}}$

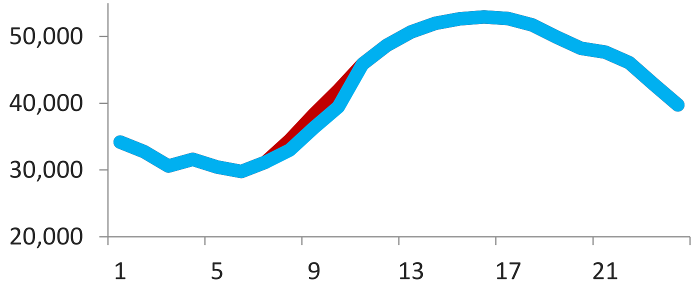
Traditional metric to capture events that occur due to capacity shortfalls in peak conditions



New "Flexible Capacity" Metrics

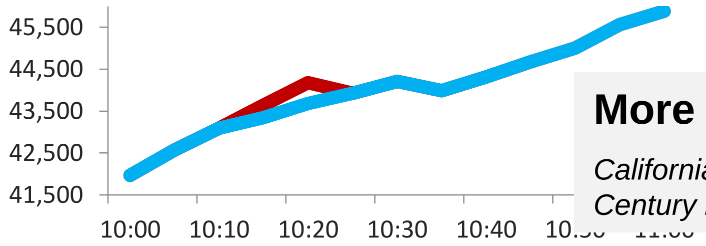
$\text{LOLE}_{\text{MULTI-HOUR}}$

New metric to capture events due to system ramping deficiencies of longer than one hour in duration



$\text{LOLE}_{\text{INTRA-HOUR}}$

New metric to capture events due to system ramping deficiencies inside a single hour



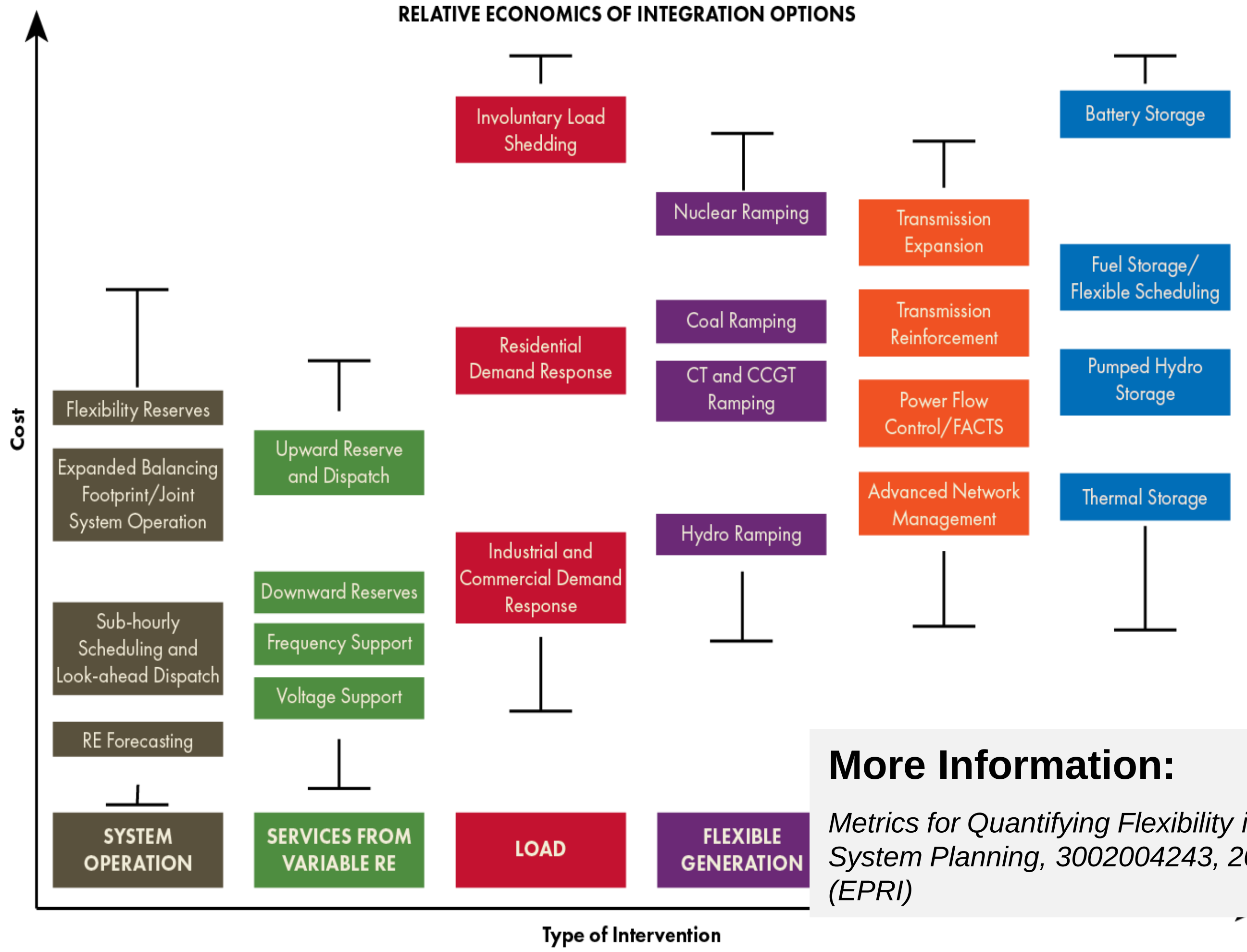
More Information:

California Energy Systems for the 21st Century Flexibility Metrics Project (2017)

New need to ensure flexibility adequacy in long-term planning?

Flexibility Will Become More Valuable

- Increasing variability and uncertainty will require flexibility on all time scales and at different spatial scales
- Different resources may contribute
  - DER, storage and inverter based resources may provide some of the needed flexibility services
  - Retrofits and altered operational practices

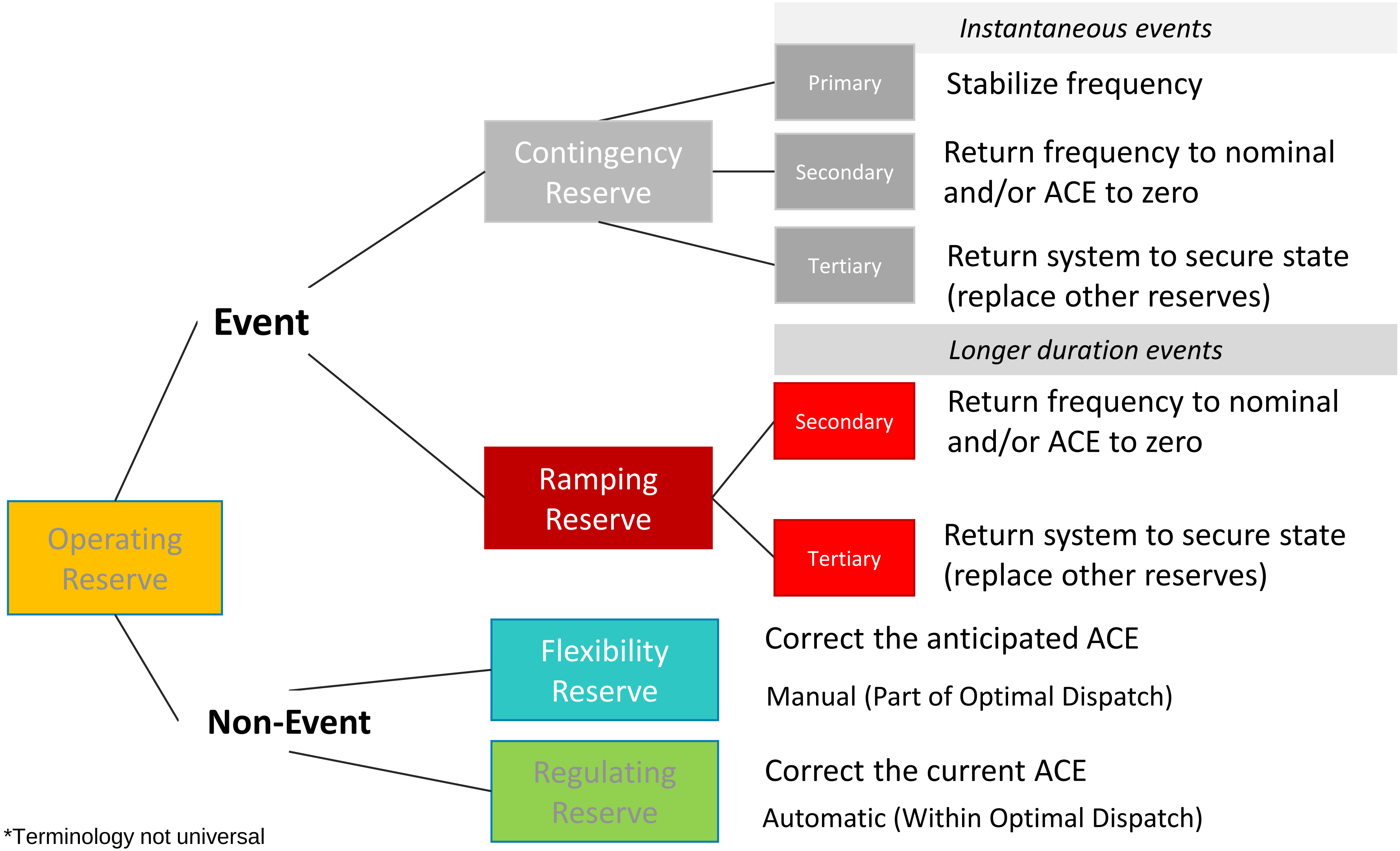


More Information:

Metrics for Quantifying Flexibility in Power System Planning, 3002004243, 2014 (EPRI)

EPRI working on flexibility tools and metrics to assess long term resource adequacy impacts

Short-term Operational Needs – Impact on Operating Reserve



*Terminology not universal

Few industry working groups in relation to these topics…

- CIGRE JWG C2/C4.41 Impact of high penetration of inverter-based generation on system inertia of networks
- CIGRE WG C4.56 on Electromagnetic transient simulation models for large-scale system impact studies in power systems having a high penetration of inverter-based resources
- CIGRE WG B5.65 Enhancing Protection System Performance by Optimizing the Response of Inverter-Based Sources
- IEEE/CIGRE B4.82 Working Group on Use of Real Code in EMT Models for Power System Analysis
- IEEE PSDP Task Force on Modeling and Simulation of Large Power Systems with High Penetration of Inverter-Based Generation
- IEEE PSRC C32 WG Protection Challenges and Practices for the Interconnection of Inverter Based Generation to Utility Transmission Systems.
- WECC Modeling and Validation Work Group (MVWG)
  - WECC Load Modeling Task Force (LMTF)
  - WECC Renewable Energy Modeling Task Force (REMTF)
- NERC Inverter Based Resource Performance Task Force (IRPTF)
- NERC Load Modeling Task Force (LMTF)
- NERC System Planning Impacts from Distributed Energy Resources Working Group (SPIDERWG)

Questions, comments, and suggestions..?

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