SPP IBR Integration Challenges

Harvey Scribner

Lead Engineer | Planning Policy & Research

Southwest Power Pool

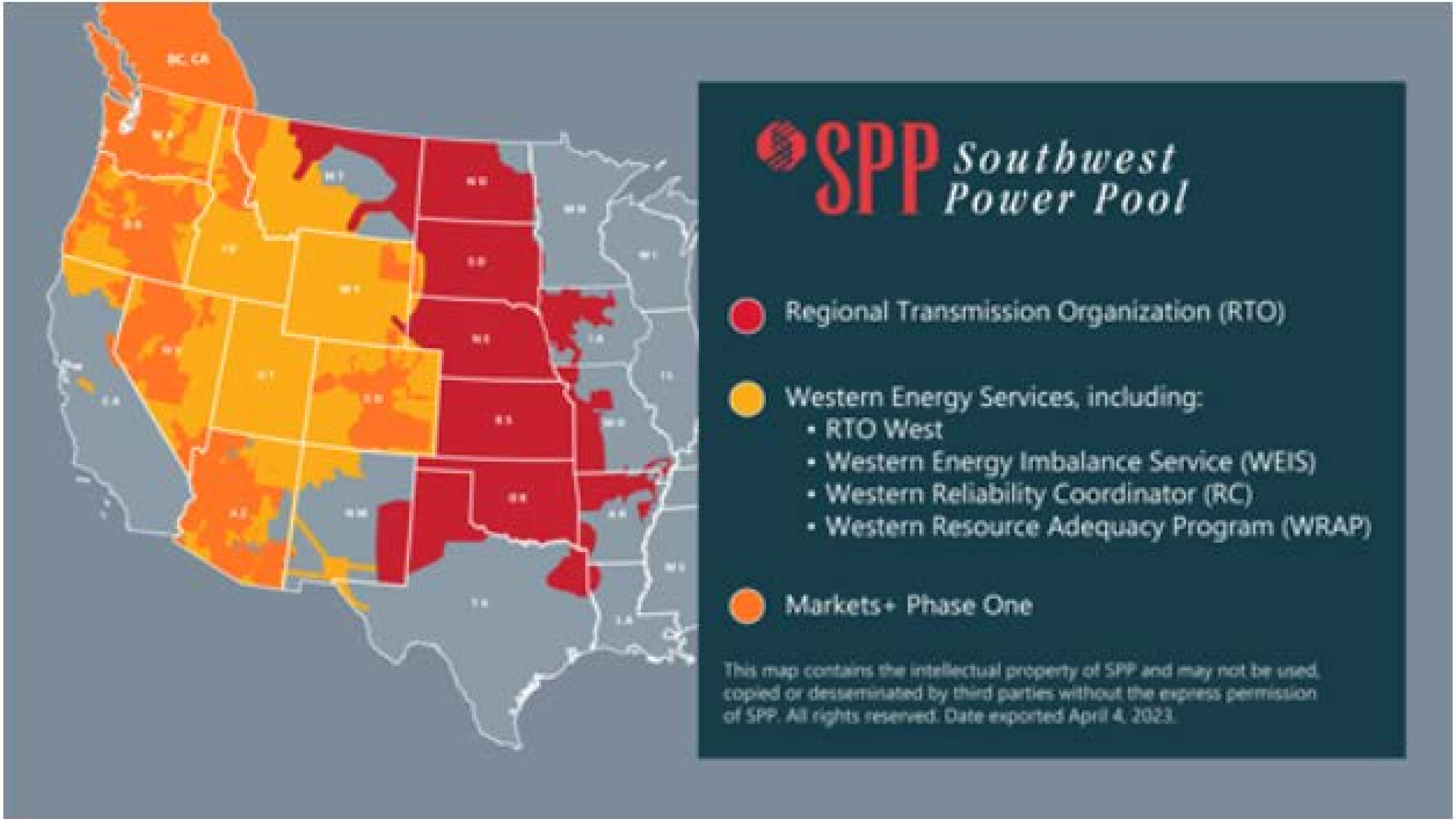
hscribner@spp.org

August 24-25, 2023

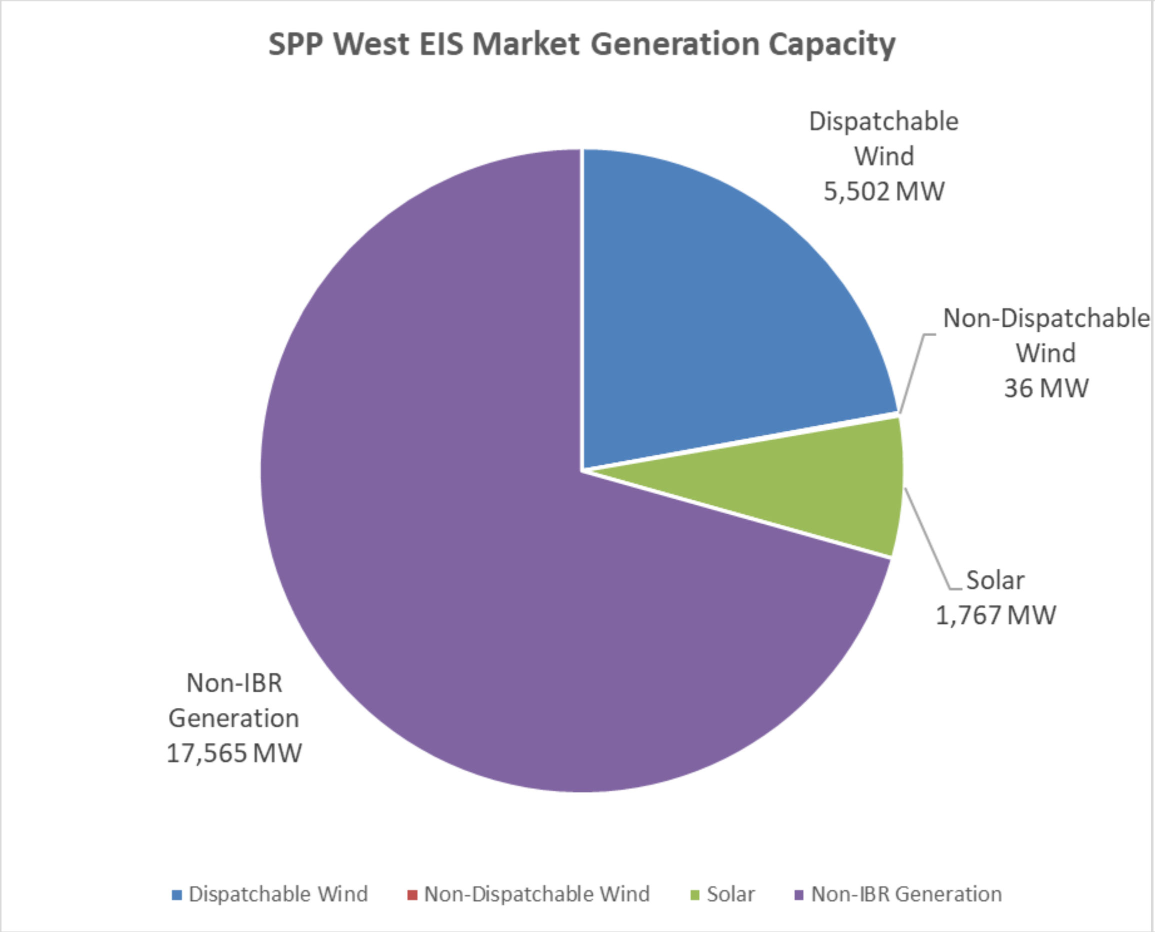
Introduction/Context

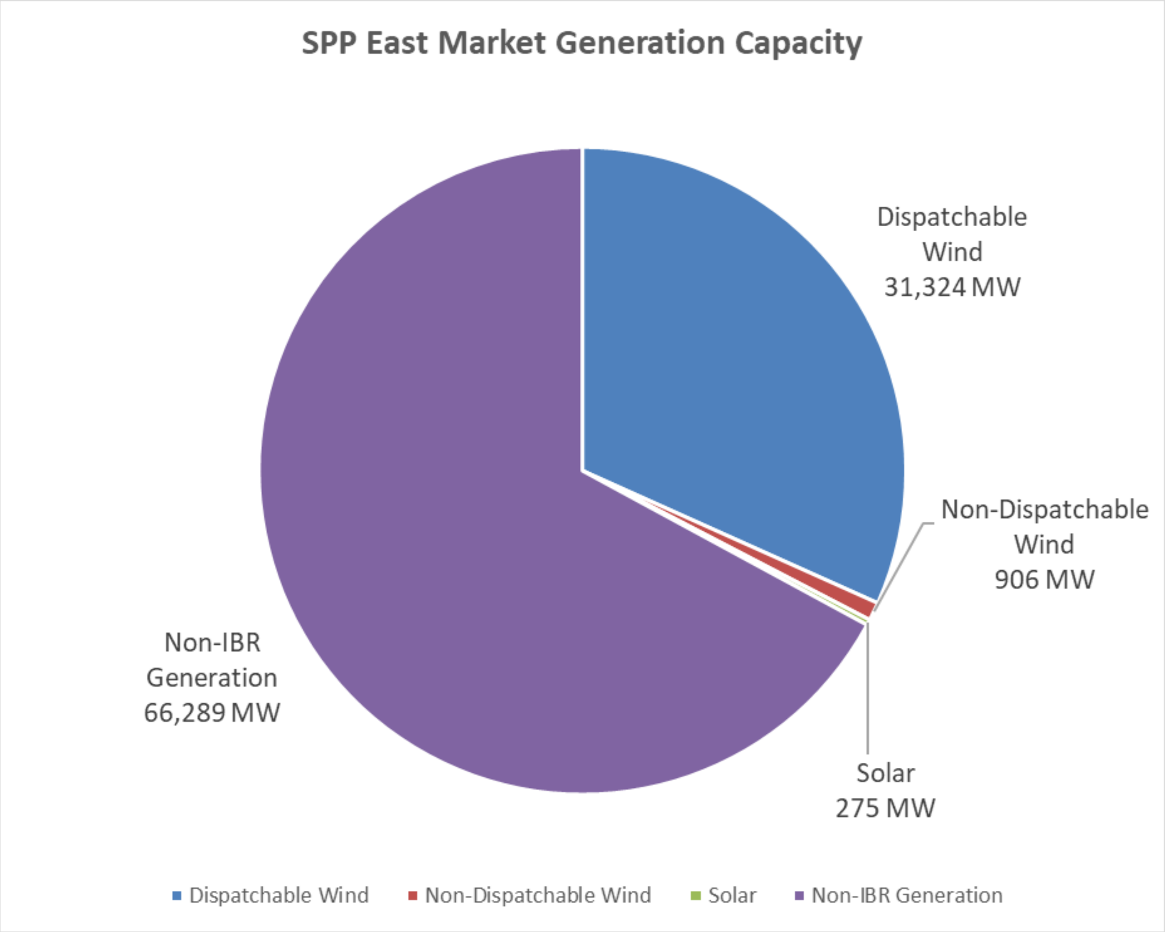
- Inverter-Based Resource (IBR) response to a disturbance can be much faster than that which is shown in standard positive sequence dynamic studies. To capture these responses, Electromagnetic Transient (EMT) studies are necessary. SPP's Generator Interconnection (GI) department are performing these studies using PSCAD software when screening studies reveal further analysis of weak grid conditions is needed.
- Due to multiple GI Studies being performed in parallel it is imperative that when situations are discovered that require EMT Analysis that the study time be reduced to accelerate GI Customer integration.

Southwest power pool



SPP Generation Capacities

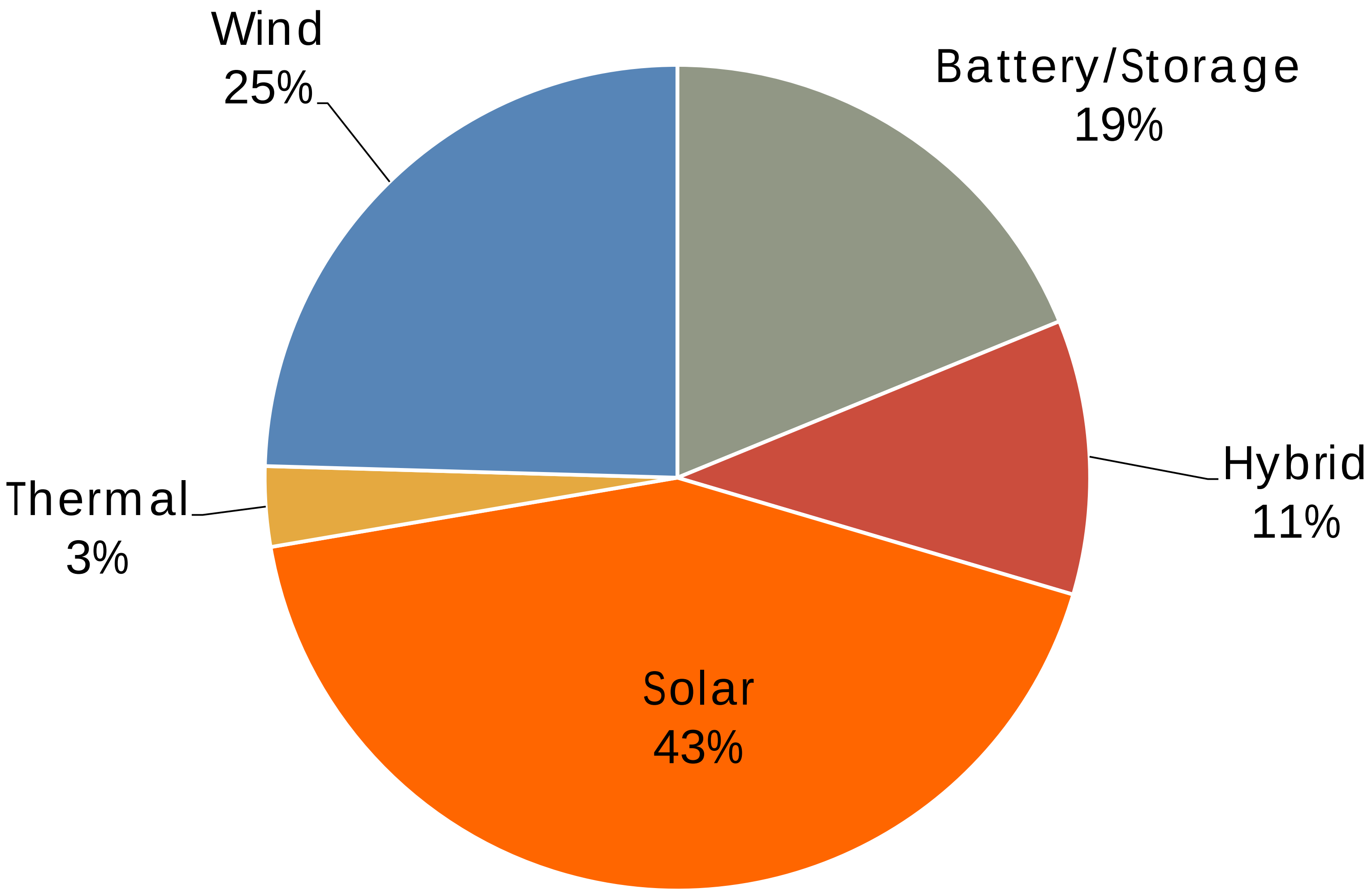




- SPP East Historical Max Wind Penetration (as % of BA Generation): 88.5%

Generator Interconnection Queue Status

GEN TYPE	Requests	GW Capacity
Battery / Storage	144	21 GW
Hybrid	59	12 GW
Solar	223	47.7 GW
Thermal	20	3.5 GW
Wind	115	27.4 GW
TOTAL	**561**	**111.5 GW**



Challenges

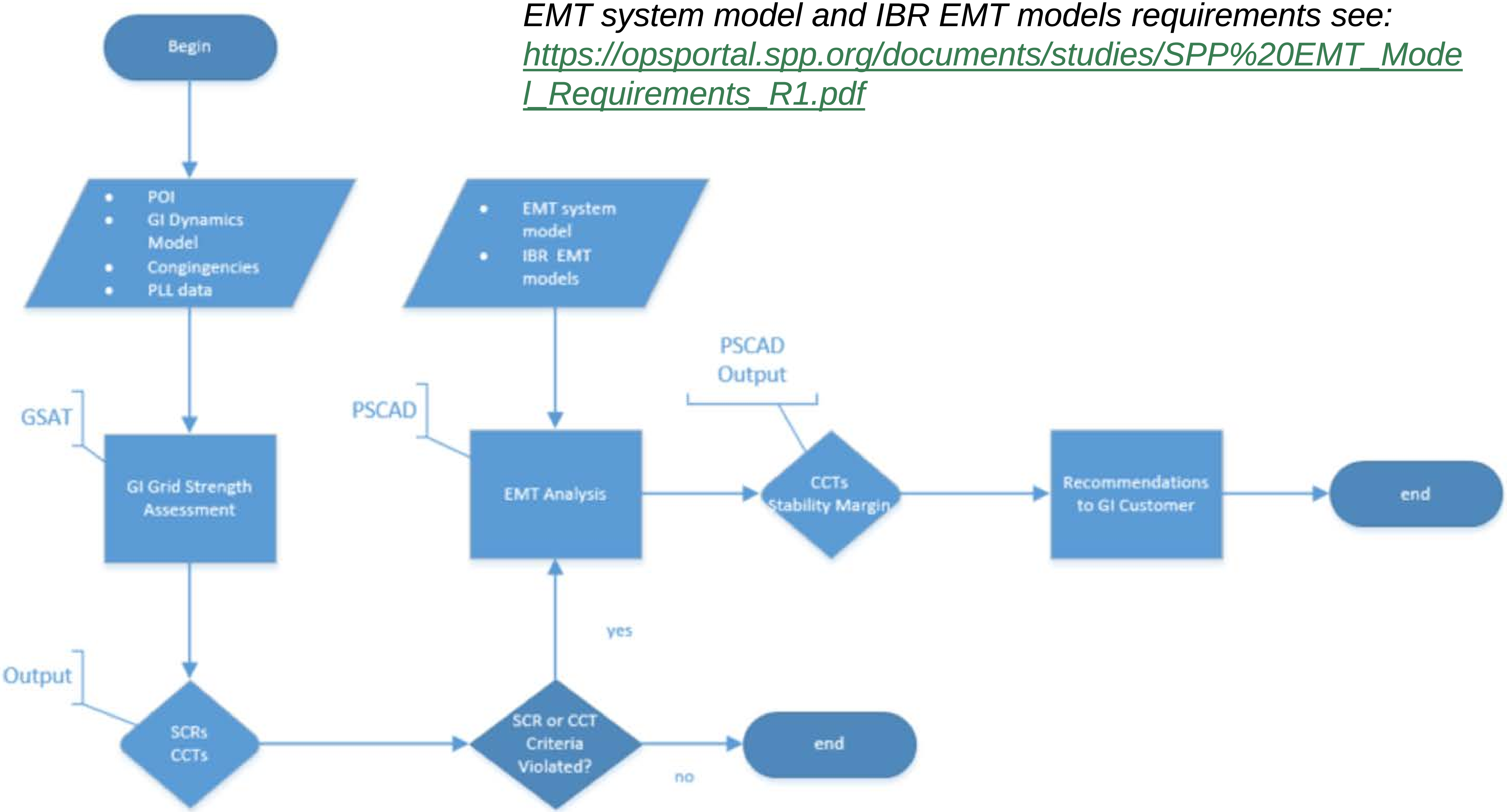
- IBR in remote areas/low SCR
- Retiring thermal fleet
- Current AC 345 kV limit in region
- Low capacity 1300MW Back-to-Back HVDC ties from Eastern Interconnection to WECC
- Computation power required to run EMT and Transient Stability hybrid simulations
- Available resources

Challenges with Phasor-Domain Studies (Transient Stability Studies)

- Interaction between IBR & other power electronics based devices may not be captured in TS studies
- For TS studies, the correct response may not be captured due to reduction of total system inertia with deeper penetration of IBR resulting in weak grid conditions.
- Phasor-domain studies provide a sufficient mechanism for capturing the dynamic response of synchronous machines when the power system experiences faults conditions; however, they do not provide a sufficient picture of the true IBR response due to the slow TS simulation time-step (~4 ms).
  - Some IBR controllers operate much faster. The complete dynamic response cannot be captured using phasor-domain studies.
    - Fast inter-current loop (~200 μs - 1 ms)
    - Phase Lock Loop (~200 μs - 1 ms)
- EMT analysis must be used to overcome these challenges.

SPP Approach: IBR Screening & EMT Simulation for Planning Studies

EMT system model and IBR EMT models requirements see: https://opsportal.spp.org/documents/studies/SPP%20EMT_Model_Requirements_R1.pdf



SPP Approach: IBR Screening & EMT Simulation for Planning Studies (continued)

Short Circuit Ratio:

$$SCR = \frac{Ssc}{MW}$$

Maximum Available Short Circuit Power (MVA) before connection of the resource

Power Rating (MW) of resource to be connected

- Measures the strength (voltage stiffness) at a point (bus) in the power system
- Measured at the POI of a resource to be connected
- Low SCR indicates weakness and additional analysis may be required

SPP Approach: IBR Screening & EMT Simulation for Planning Studies (continued)

Short Circuit Ratio:

$$CSCR = \frac{CSCMVA}{MW_n}$$

Composite Short Circuit Ratio

$$WSCR = \frac{\sum_i^N SCMVA * MW_i}{\sum_i^N {MW_i}^2}$$

Weighted Short Circuit Ratio

- A large concentration of wind plants connected in the vicinity of a transmission node can result in low grid strength
- Ratio calculation becomes more complicated
- Composite and Weighted SCR better measure of Ratio

SPP Approach: IBR Screening & EMT Simulation for Planning Studies (continued)

An Additional Metric.....

- **Critical Clearing Time (CCT)** - the maximum time a fault near the POI of the inverter plant is allowed to remain on the system such that inverter plant remains stable
- GSAT CCT metric can help identify IBRs with **possible** oscillatory instability
- The possibility of inverter instability is governed by,
  - Short circuit current
  - Controller gains
  - MW power output
  - Fault clearing time

Screening Thresholds

- **SCR, WSCR, CSCR = 6.0**
  - **If SCR < 6, bus or bus group is deemed weak (not good)**
- **CCT = 0.15s**
  - **If CCT < 0.15s, clearing time is too low (not good)**
- **Generally, if at least one of the above conditions is true, further study is required***
- **Some Examples:**

SCR	CCT (s)	WSCR	Further Study Required?*
5.2	0.8	7.7	yes
6.6	1.2	4.1	yes
8.8	1.0	na	no
23.0	0.025	17.0	Yes
6.1	0.16	na	Maybe

* Further study may include positive sequence dynamics analysis and / or EMT analysis

Approach: EMT Simulation for Planning Studies (continued)

Model accuracy features:

- *Represent the full detailed inner control loops of the power electronics.*
- *Represent all control features pertinent to the type of study being done.*
- *Represent plant level control,* Power Plant Control (PPC)
- *Represent all pertinent electrical and mechanical configurations* such as filters and specialized transformers.
- *Have all pertinent protections modeled in detail for both balanced and unbalanced fault conditions.*
- *Be configured to match expected site-specific equipment settings.*

SPP Process: Short-circuit ratio critical clearing time (SCRCCT) screening

- All five regions studied, ie, North, Nebraska, Central, SE, and SW
  - N-1 Contingencies three buses deep from each customer POI
  - Dynamics data, and PLL customer data used
- Studied (4) seasons for (5) regions…..(20 simulations)
- Post processing of data for correct formatting
- Will include a sheet of results in the DISIS final report workbook

Process: To Set Up EMT Study in Planning - generation of the planning scenario

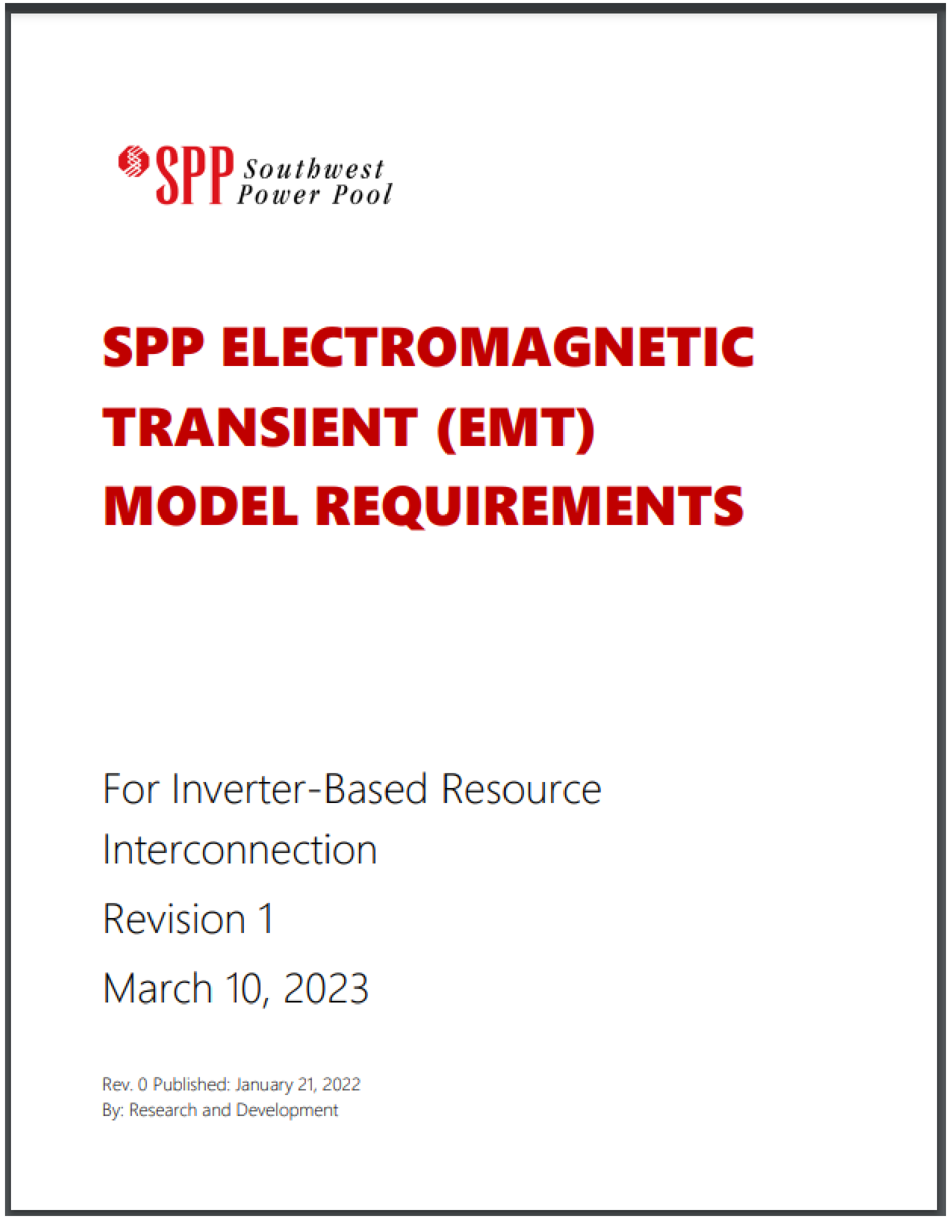
- In order for study engineers to perform system studies and analyze results, the model provided for each facility shall:
  - *Have control or hardware options that are accessible to the user*
  - *Be accurate when running at a simulation time step of 10 μs or higher*
  - *Operate at a range of simulation time* steps (e.g. 10 μs – 20 μs).

Process: To Set Up EMT Study in Planning - generation of the planning scenario (continued)

- *Include documentation and a sample implementation test case.*
  - Test case models must be configured according to the site-specific real equipment configuration up to the Point of Interconnection. This would include (for example): aggregated generator model, aggregated generator transformer, equivalent collector branch, and main step up transformers, gen tie line, power plant controller, and any other static or dynamic reactive resources.
  - Test case must use a single machine infinite bus representation of the system, configured with an appropriate representative SCR. Access to technical support engineers is desirable.

Data: EMT Planning Studies-Data needed to develop the EMT planning study setup

- *EMT system model and IBR EMT models requirements see: https://opsportal.spp.org/documents/studies/SPP%20EMT_Model_Requirements_R1.pdf*


SPP Southwest Power Pool

SPP ELECTROMAGNETIC TRANSIENT (EMT) MODEL REQUIREMENTS

For Inverter-Based Resource Interconnection

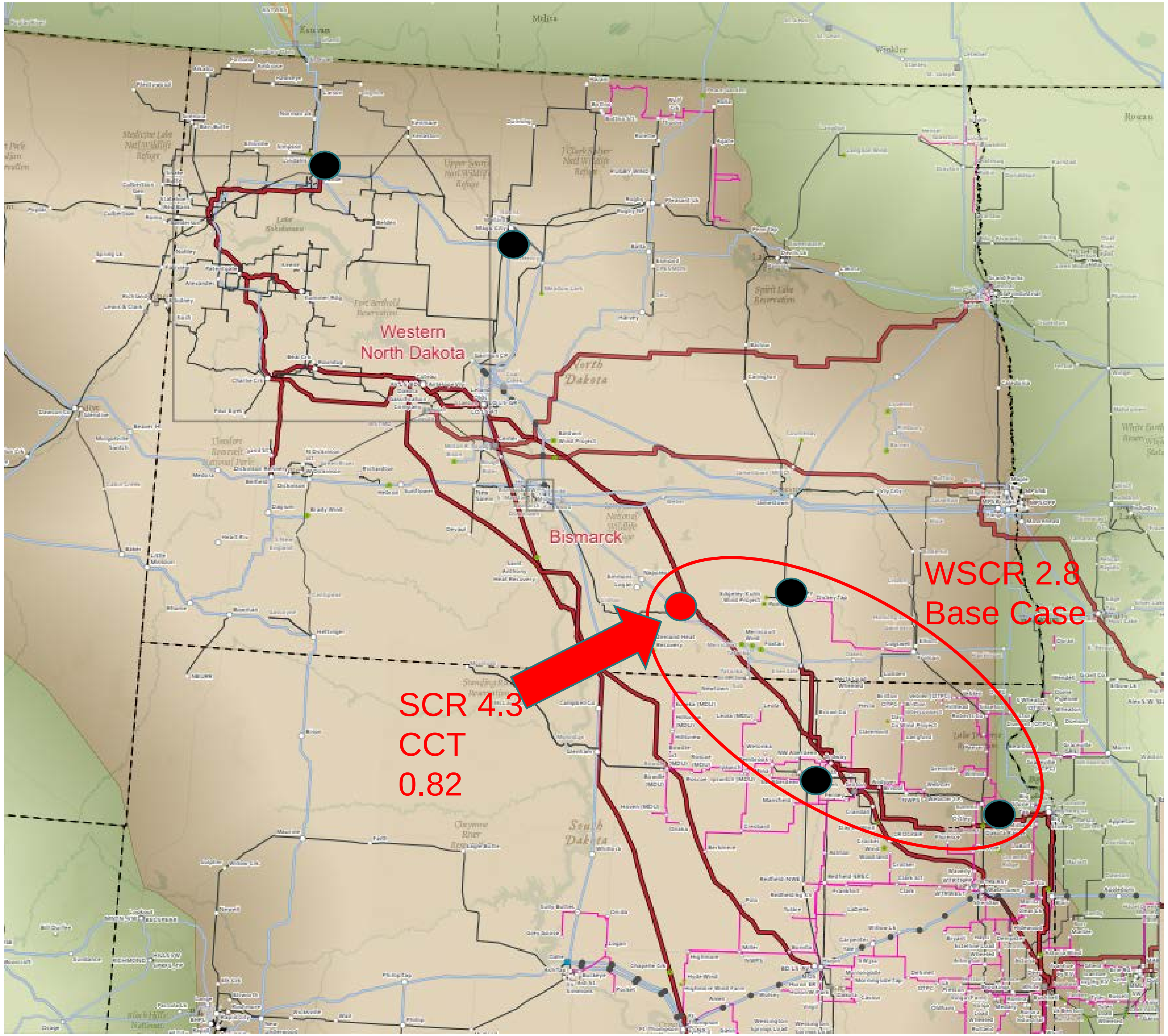
Revision 1

March 10, 2023

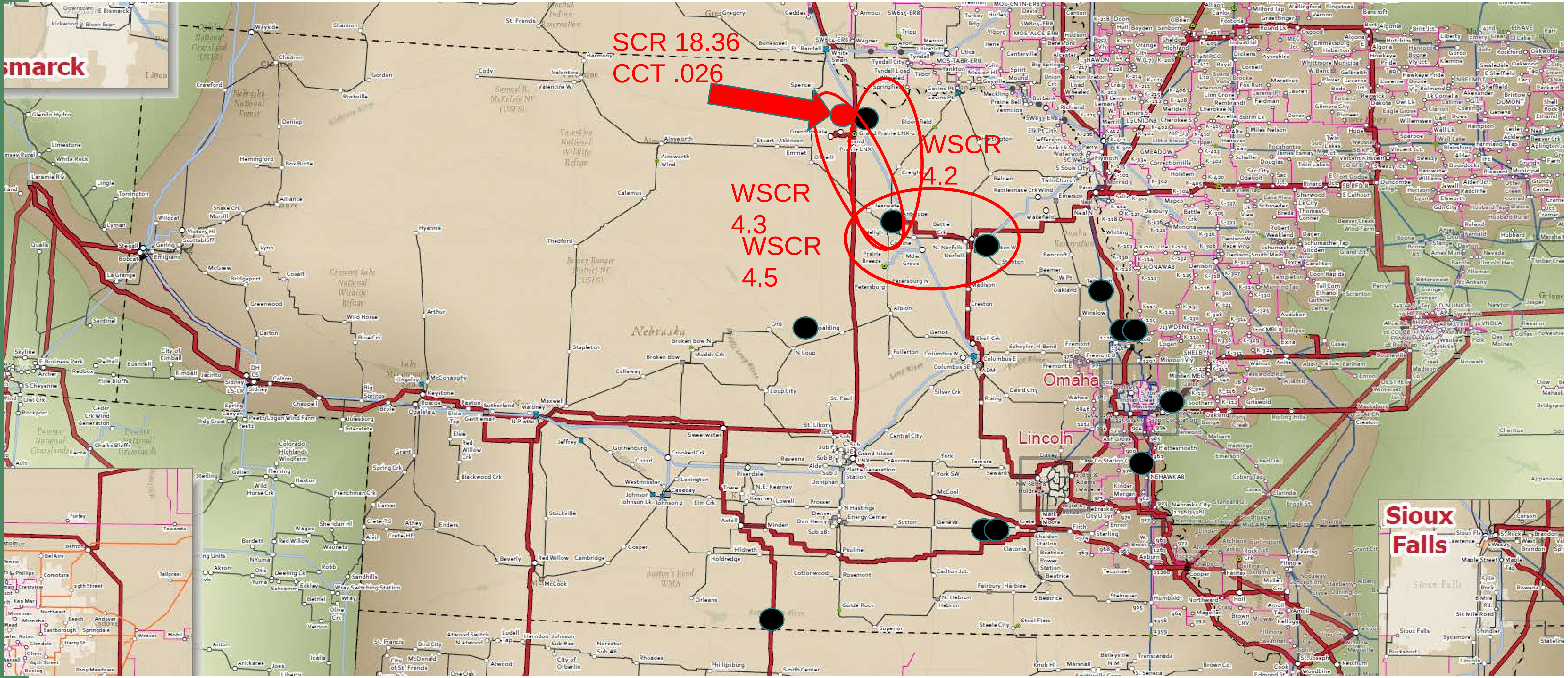
Rev. 0 Published: January 21, 2022
By: Research and Development

Planning Studies Performed

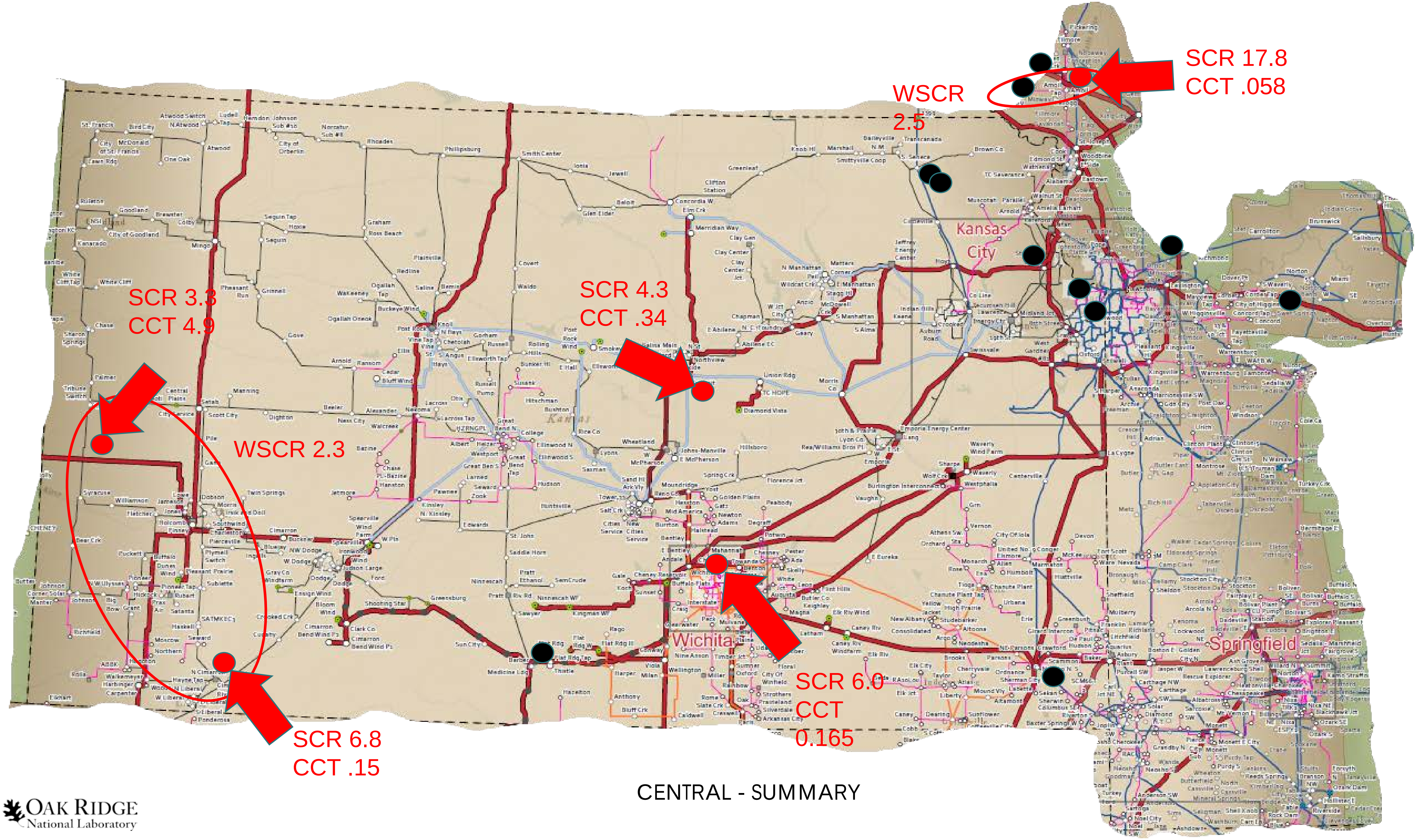
- Legend
  - Black Dots: GI Customers with *no* screening violations
  - Red Dots: GI Customers *with* screening violation
  - Red Ellipse: Customer group *with* screening violation


Western
North Dakota
Bismarck
WSCR 2.8
Base Case
SCR 4.3
CCT
0.82

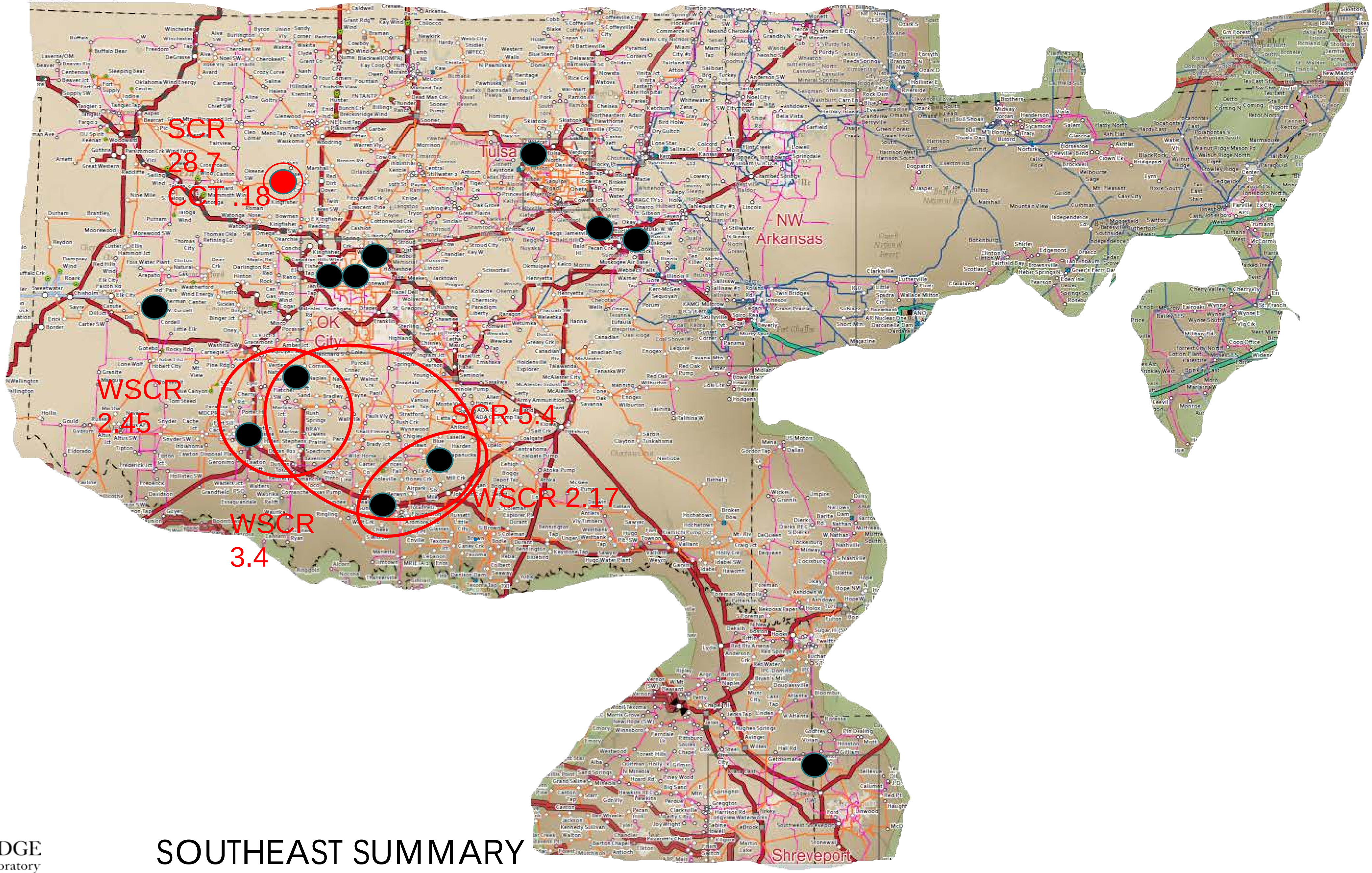
North



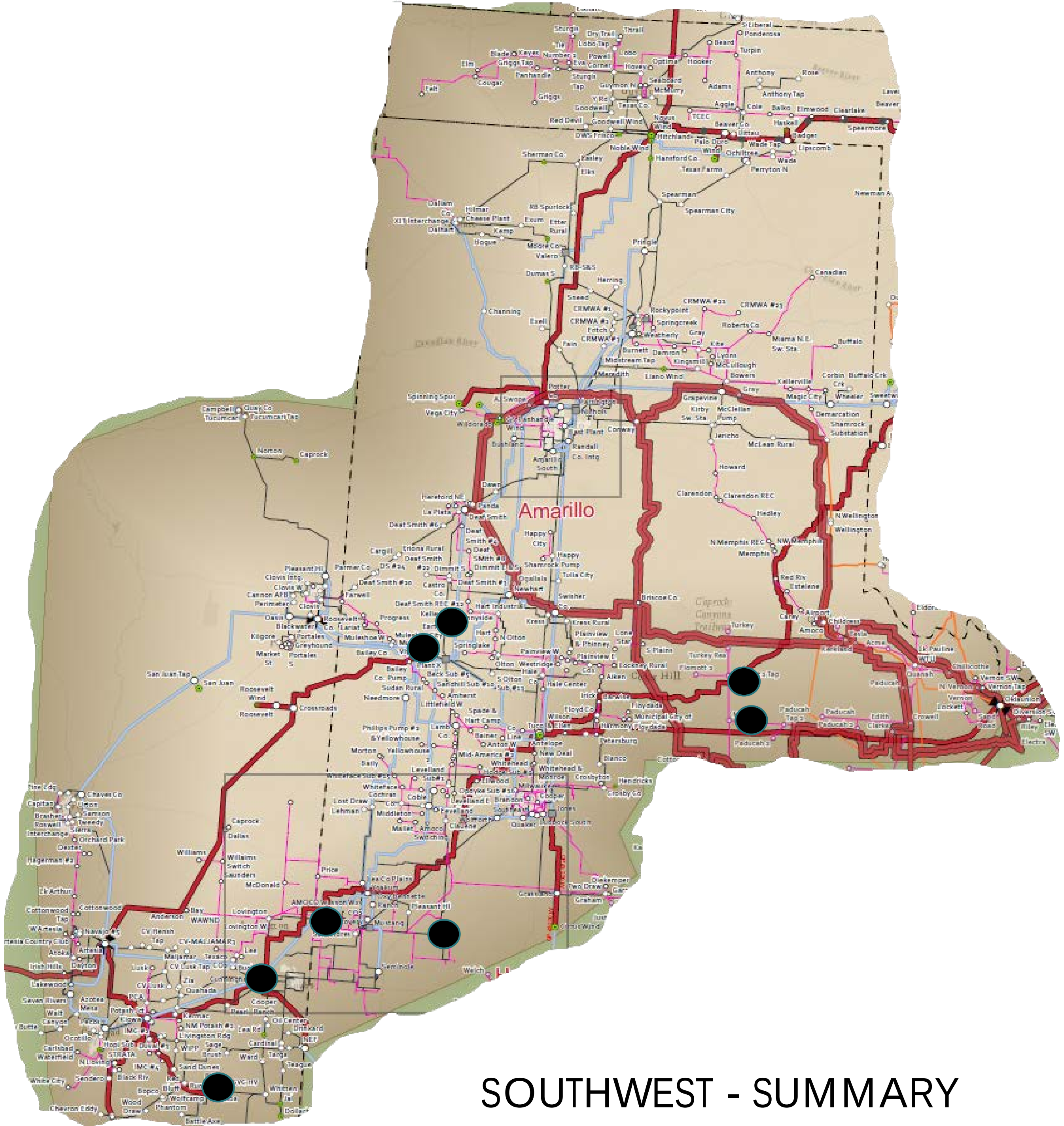
NEBRASKA -
SUMMARY



CENTRAL - SUMMARY



SOUTHEAST SUMMARY



SOUTHWEST - SUMMARY

Lessons

- Screening results may show many weak grid locations that require further EMT investigation
- Automation tools needed to go from screening studies in TS directly into reduced EMT models
- PF/TS/EMT co-simulations need to be automated to handle the complexity of model dimensions and time range
- Generic models needed to handle detailed actual IBR facilities

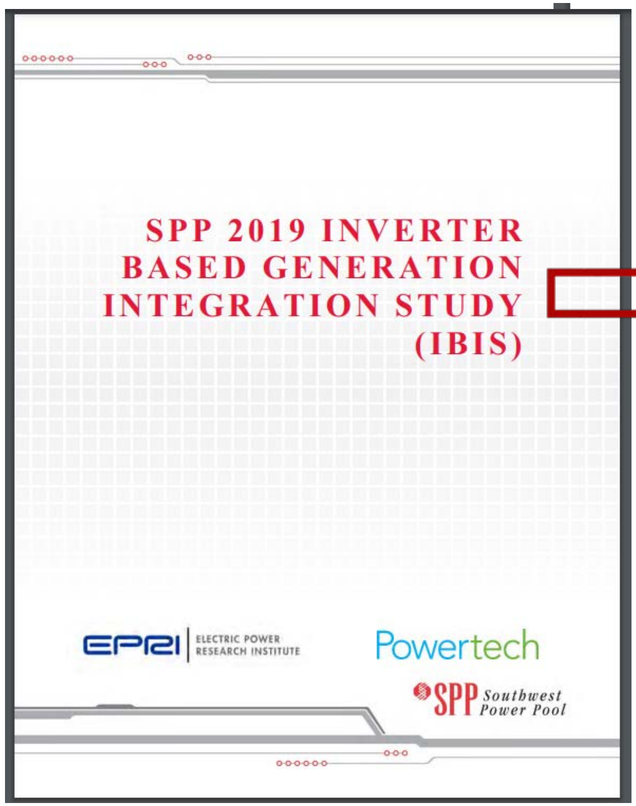
Impact

- Grid Reliability
  - Security concerns should be mitigated while thermal fleet is converted to IBR
  - Adequacy of supply due to variable nature of IBR
  - Role of Storage?
- Just the beginning
  - Electrification of all energy sectors
- Continent wide upper limit of IBR operation and planning for North American Grid should be explored to account for variability of resources continent wide

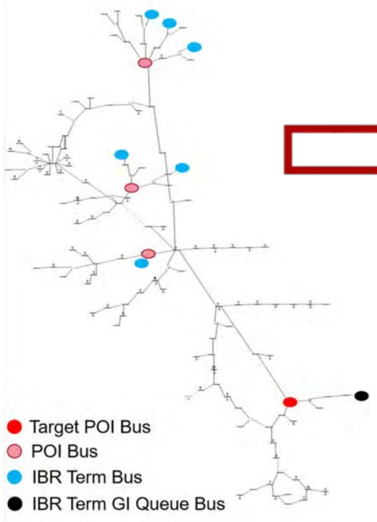
Gaps & Challenges Observed (Not Solved Yet) - Next set of challenges (long-term) that need to be addressed

- DOE Lab(s) digital twin of North American GRID this will facilitate:
  - Model Development/testing/implementation into grid tools
  - Provide a platform to aid in design of future grid as technologies evolve
  - Provide independent source for real time operations security, resilience to threats…
  - Distribute critical computing, testing,… on secure state of the art systems
  - Better prepare North American Grid to integrate and share IBR with other Continents

EMT Screening Development and Benchmark- SPP Inverter Based Resource Integration Study (IBIS)



2019 Inverter Based Generation Integration Study (IBIS)



-line diagram of the resulting system.

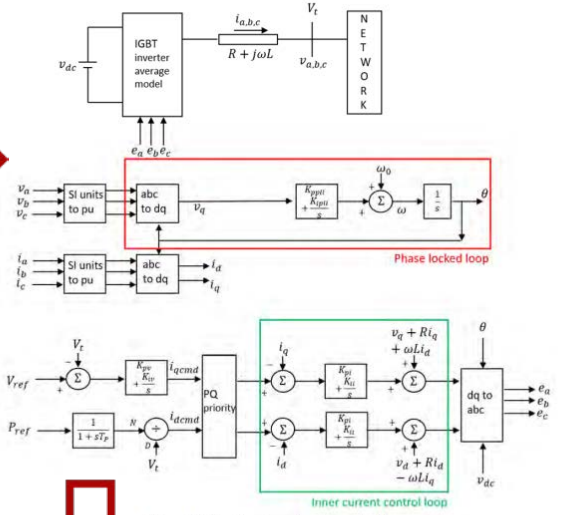


Figure 10.4.3: Structure of entire control loop.

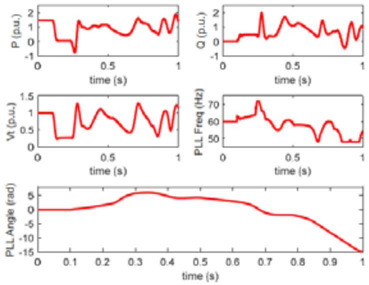


Figure 10.5.2: Response of WTG at bus G0322G0420G1 for a solid three-phase fault at its POI (WTH WF 4). (Fault duration 0.1308s, unstable)

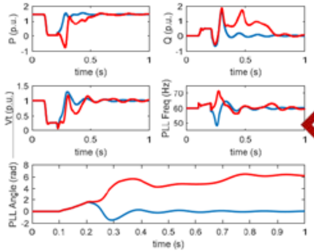


Figure 10.5.1: Response of WTG at bus G0322G0420G1 for a solid three-phase fault at its POI (WTH WF 4). (blue curve: fault duration 0.1015s, stable; red curve: fault duration 0.1042s, unstable).

Gen bus Name	POI bus Name	Fault bus Name	CCT_GSAT	CCT_PSCAD	Error (CCT_GSAT - CCT_PSCAD)	Actual Field Setting Clearing Time
REDHILLS WF	RHWIND4	RHWIND4	0.2607s	0.2318s	0.0289s	0.083s
RKYRDGW1-2WG RKYRDGW1-1WG (Group 1)	RKY_RDG4	RKY_RDG4	0.1326s	0.131s	0.0016s	0.0917s
ROARK1 DEMPSEY1 ELK_CITY_WG1 (Group 2)	SWEETWT6	SWEETWT6	0.1711s	0.1475s	0.0236s	0.0917s

Table 10.5.1: Comparison of the calculated and simulated CCTs

- https://spp.org/documents/64834/20190828%20-%20spp%202019%20inverter%20based%20generation%20integration%20study.pdf

EPRI Grid Strength Assessment Tool

Deepak Ramasubramanian
dramasubramanian@epri.com

August 2023

www.epri.com

Grid Strength Assessment Tool (GSAT)

Value	Evaluates	Compatibility
Provide insights on • Network locations/conditions which could be susceptible to issues related to weak grid conditions • The need for detailed studies	• Generic SCR • Weighted SCR • Composite SCR • Minimum available SCC • Advanced EPRI metric	• Siemens PTI PSS®E • GE-PSLF™ • DIgSILENT PowerFactory

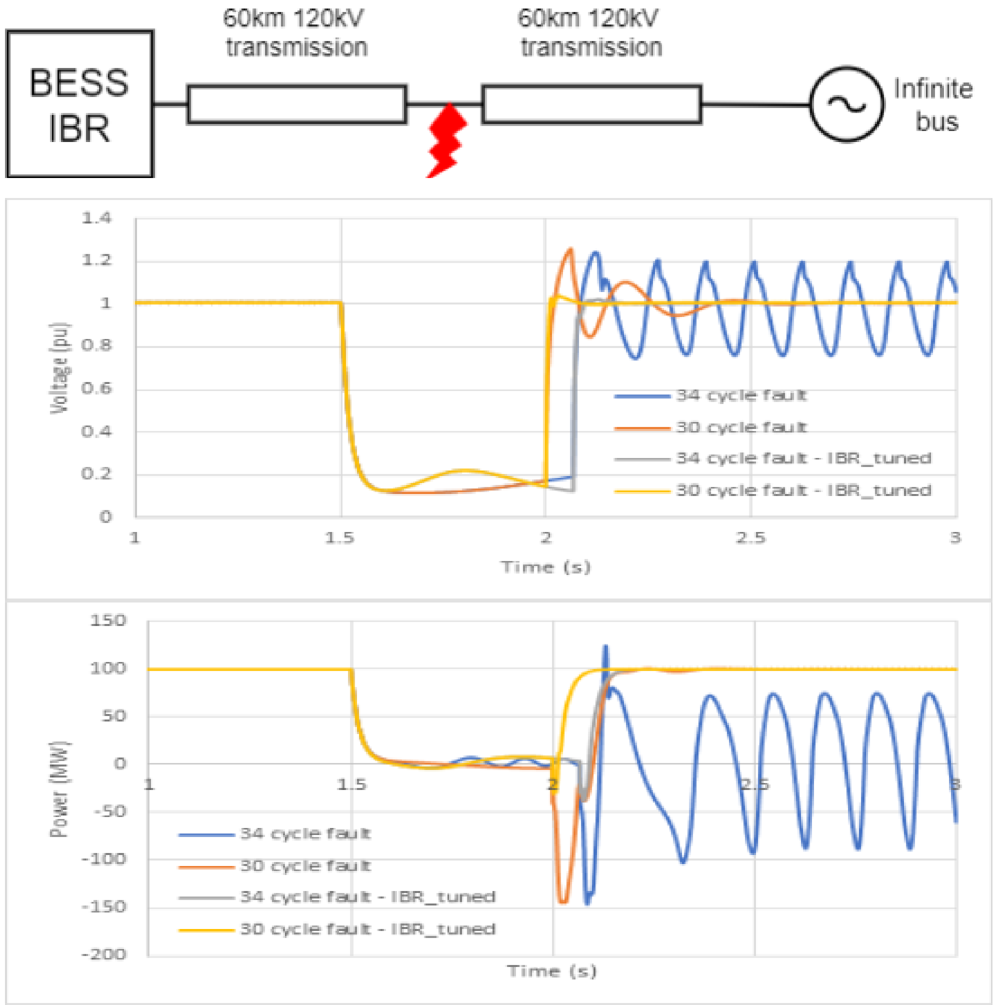
- Minimum available SCC
  - Provides insight into potential locations of instability based on impact of other IBRs in the network
  - Can be used to determine an initial rating of system strengthening devices that are required
- EPRI's advanced metric
  - Completely analytical, and no requirement of a dynamic run
  - Uses few dynamic data values (e.g. controller gains, time constants) of the IBR
  - Is expressed as critical clearing time before converter instability
- Data requirements
  - Powerflow case files, contingency definitions, locations for evaluation, few dynamic performance data

EPRI

OAK RIDGE National Laboratory

GSAT's Critical Clearing Time (G-CCT)

- G-CCT is not related to acceleration/deceleration energy from conventional CCT perspective
- If appropriately tuned, stability of IBRs can be invariant to fault duration
  - Doesn't necessarily imply that CCT may not be a valid metric
- G-CCT provides another metric to understand potential dynamic behavior of IBRs



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