

GRID EMT

SIMULATION INITIATIVE

Grid Strength Metrics Today & Their Relevance in Planning & Operations

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Introduction

- Inverter-based technologies are increasing across the grid including generation (wind, solar, storage), power-electronic loads (data centers), FACTS, and HVDC systems, while displacing synchronous generation and reducing system strength
- System strength: the ability of the network to maintain a stable voltage under normal and disturbed conditions, and to support stable operation of inverter-based equipment
- Multiple quantitative metrics are in use today, each with distinct assumptions, data requirements, and range of validity
- Scope of this presentation:
 - Overview of prevalent system strength metrics
 - Realm of application of each metric in planning and operations — across generation, load, transmission, and HVDC applications
 - Use of metrics as screening indicators to identify areas requiring EMT simulation
- EMT simulation of an entire interconnection is computationally expensive; planners and operators require systematic, low-cost screening to determine:
 - Where phasor-domain modeling is no longer sufficient
 - Which areas/zones should be represented in EMT detail



Approach

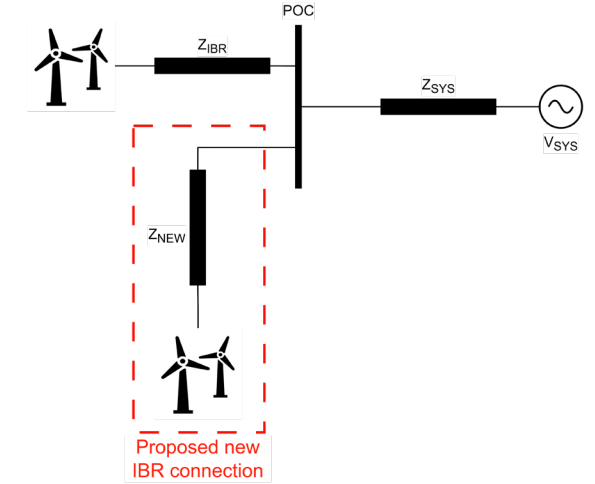
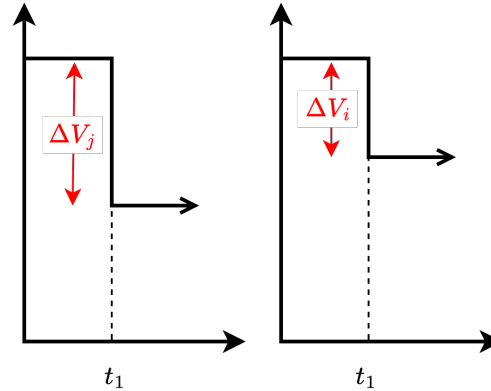
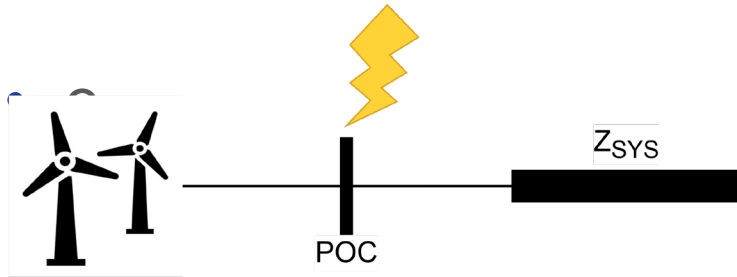
- Survey prevalent system strength metrics in three categories:
 - Short-circuit based: SCR, ESCR, EqSCR, AFL
 - Interaction based: unit IF, multi-infeed IF, multi-infeed voltage IF, harmonic MIIF
 - Other methods: available fault level, voltage sensitivity, advanced critical clearing time
- Characterize each metric by input data requirements, computational burden, and underlying assumptions
- Map each metric to its realm of application in planning and operations studies
- Assess suitability of each metric as a screening indicator for scoping EMT studies, including information SCR-based metrics do not provide

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System Strength Metrics



Short circuit based methods

- SCR
- ESCR
- EqSCR
- AFL
- ...

Interaction based methods

- Unit IF
- Multi-Infeed IF
- Multi-Infeed Voltage IF
- Harmonic MIIF
- ...

Other methods

- Available fault level
- Voltage sensitivity
- Advanced critical clearing time
- ...

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SCR and Weighted SCR (WSCR)

- Most basic and widely known metric for system strength
- Compares the size of an IBR to the short circuit level at the POC

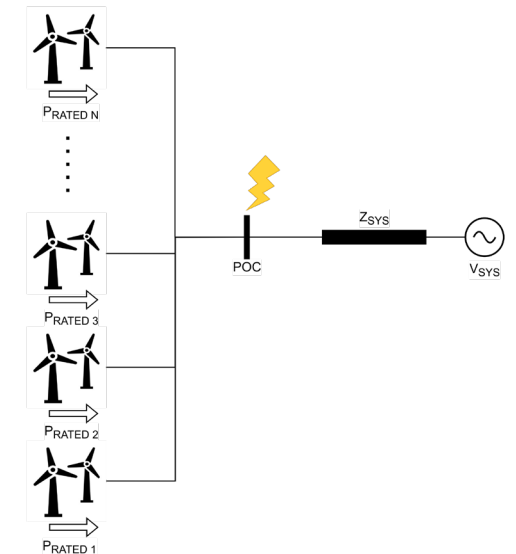
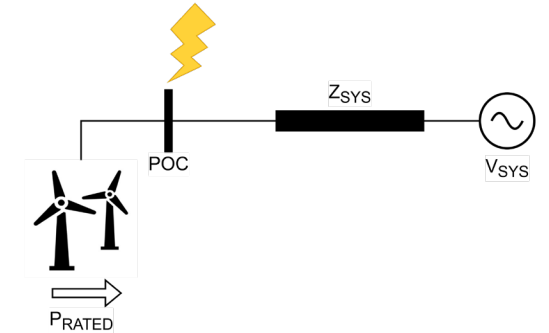
$$SCR = \frac{S_{SC}}{P_{RATED}}$$

S_{SC} is the short circuit MVA at the POC, and P_{RATED} is the rated MW of the IBR

- Considers groups of IBRs with a common POC
- Used by ERCOT for their Panhandle region, also used to determine optimal locations for synchronous condensers

$$WSCR = \frac{\sum_i^N S_{SCi} \cdot P_{RATEDi}}{(\sum_i^N P_{RATEDi})^2}$$

- CIGRE Technical Brochure 671, “Connection of Wind Farms to Weak AC Networks”, WG B4.62, Paris, December 2016.
- ERCOT, “Dynamic Stability Assessment of High Penetration of Renewable Generation in the ERCOT Grid”, ERCOT, Apr. 2018.
- With i IBRs considered in the metric, S_{SC} is the short circuit MVA at bus i .



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Unit Interaction Factor (UIF)

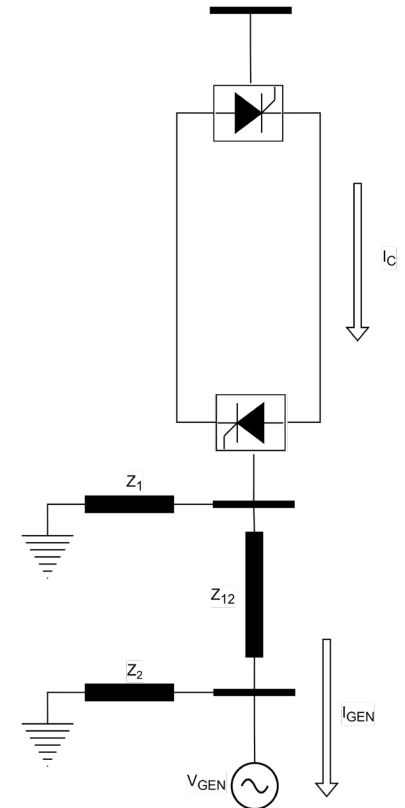
- Traditional method to screen for sub-synchronous torsional interactions (SSTI)

$$UIF_i = \frac{MVA_{HVDC}}{MVA_{GEN}} \cdot \frac{\delta V_C}{\delta V_{GEN}} \cdot \frac{\delta I_{GEN}}{\delta I_C}$$

- This can be reduced to an expression dependent on network impedance / admittance

$$UIF_i = \frac{MVA_{HVDC}}{MVA_{GEN}} \cdot \left(\frac{Z_1}{Z_1 + Z_{12}} \right)^2$$

- For LCC systems below 0.1 has been suggested as safe
- For VSC systems uncertainty remains, some references give 0.01 or 0.02
- Assumes an inductive network with a sub-synchronous impedance that changes linearly, should not be utilized in series compensated networks



CIGRE Technical Brochure 909, “Guidelines for Subsynchronous Oscillation Studies in Power Electronics Dominated Power Systems”, WG C4/B4, Paris, June 2023.



Advanced Critical Clearing Time (ACCT)

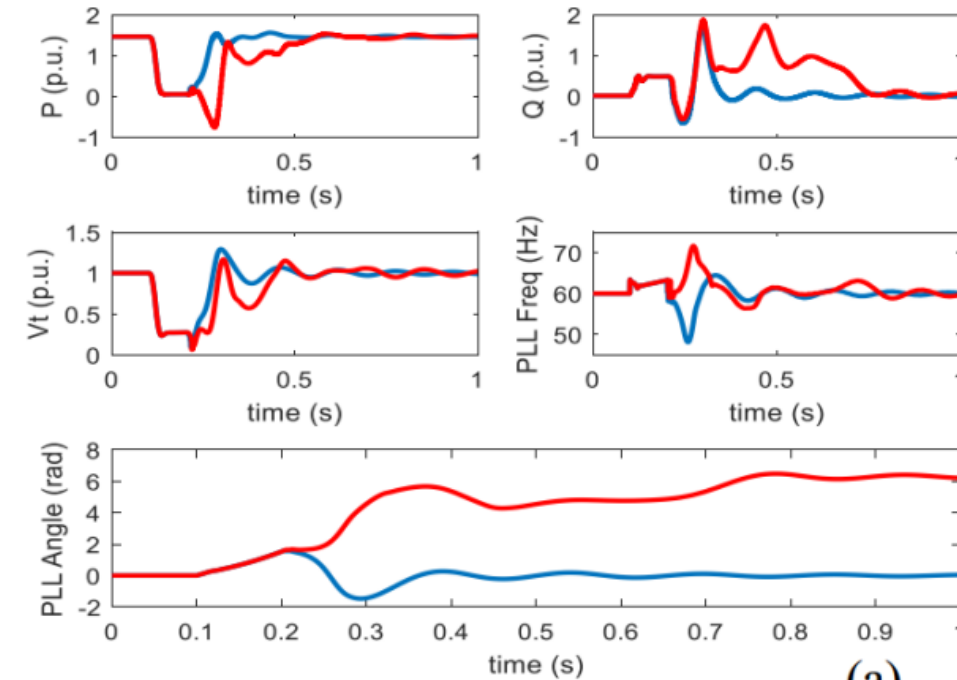
- Metric developed by EPRI – application of critical clearing time for synchronous generators onto IBR's
- Determines the worst case fault ride through scenario for an IBR before the PLL loses stability

$$SM = 100 \cdot \left(\frac{CCT_{IBR} - t_e}{t_e} \right)$$

SM is the stability margin, CCT_{IBR} is the critical clearing time, and t_e is the expected fault clearance time.

- Study case found SCR=15 had an IBR CCT of less than 60ms, underlining that SCR is not a good indicator of system strength in a high IBR system

- Grid Strength Assessment Tool (GSAT) v8.0, EPRI, Palo Alto, 2026
- Baker, W., Ramasubramanian, D., Val Escudero, M., Farantatos, E., Gaikwad, A., "Application of an Advanced Short Circuit Strength Metric to Evaluate Ireland's High Renewable Penetration Scenarios," The 9th Renewable Power Generation Conference (RPG Dublin Online 2021), Online Conference, 2021, pp. 167-172



Blue trace fault duration = 101.5ms (1/8th of cycle less than IBR CCT), stable response; red trace fault duration = 104.2ms (1/8th of cycle more than IBR CCT), unstable response

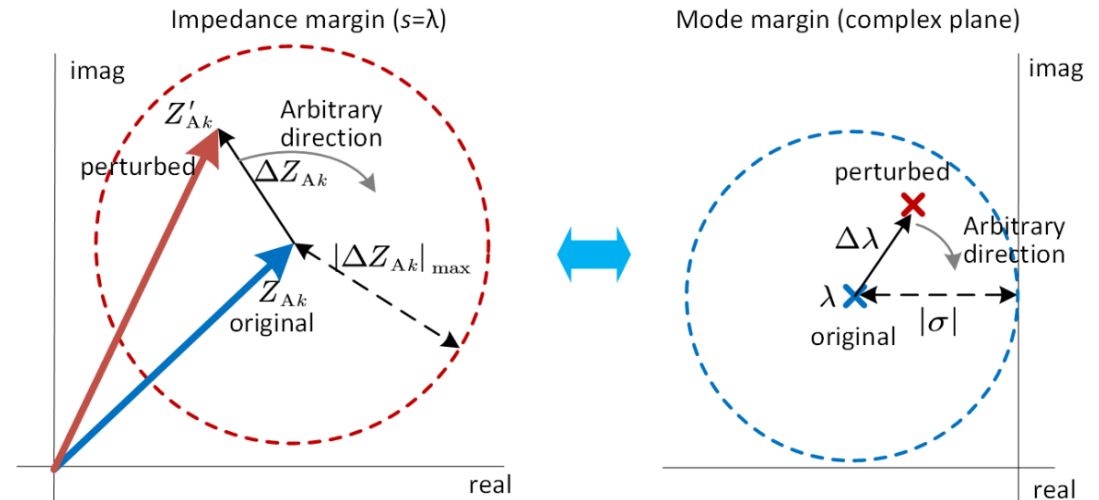


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Impedance Margin Ratio

- Ratio between the maximum allowed variation of the impedance of an IBR in relation to its initial impedance
- Changing the impedance will change its eigenvalues
- If changing the impedance leads to a large change in eigenvalues, there is an increased likelihood of instability
- Derived either analytically through modelling, or through data analysis

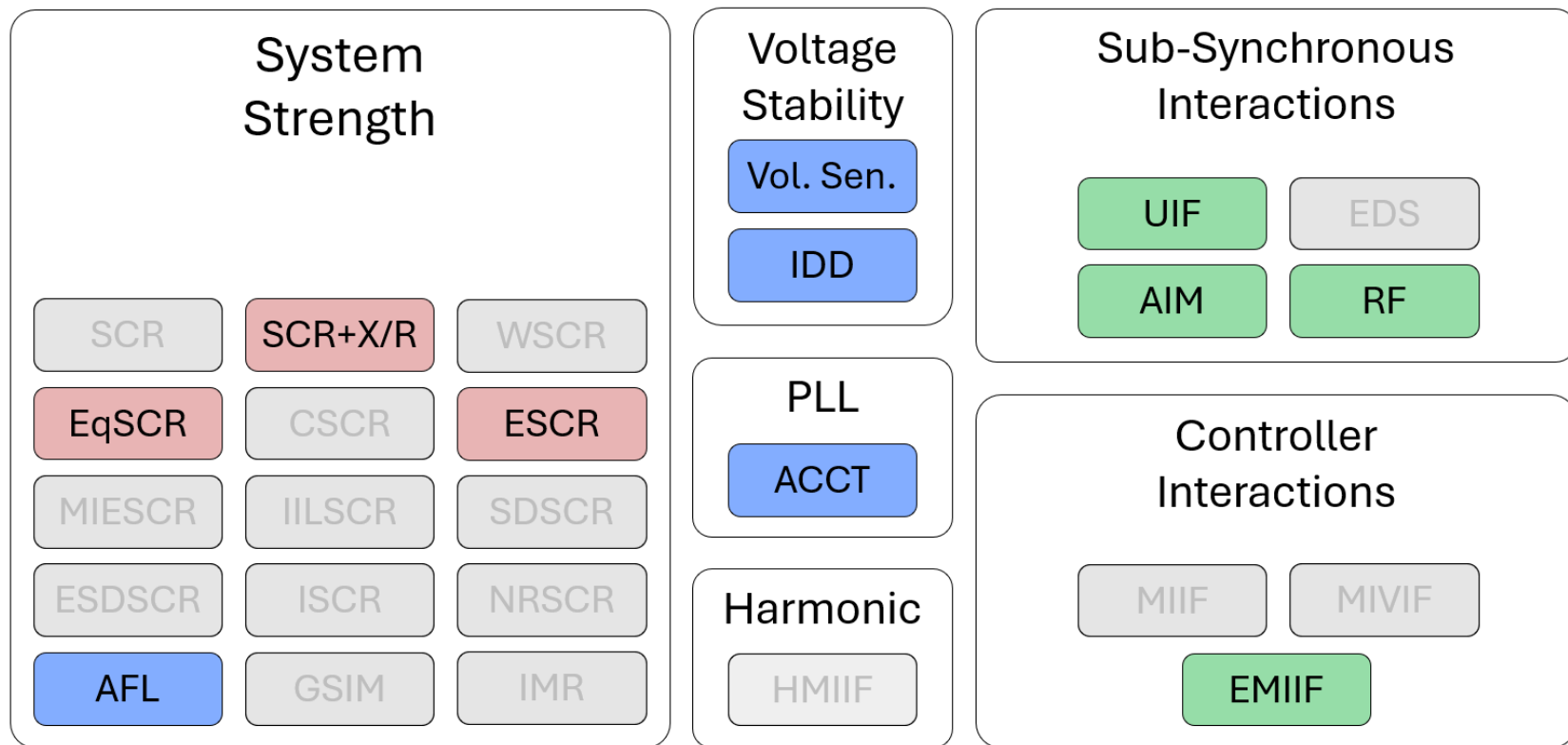


Y. Zhu, T. C. Green, X. Zhou, Y. Li, D. Kong and Y. Gu, "Impedance Margin Ratio: a New Metric for Small-Signal System Strength," in IEEE Transactions on Power Systems, doi: 10.1109/TPWRS.2024.3371231.



Grid strength metrics suitable for interconnection + planning

- Metrics selected based on:
 - Should cover both long-term planning and interconnections
 - Simple to calculate – simple metric preferable, but not prohibitive in the planning domain
 - Used in industry – preferable to utilize metrics that are tried and tested in other TSOs
 - Metrics should cover all areas of interest in system strength and stability



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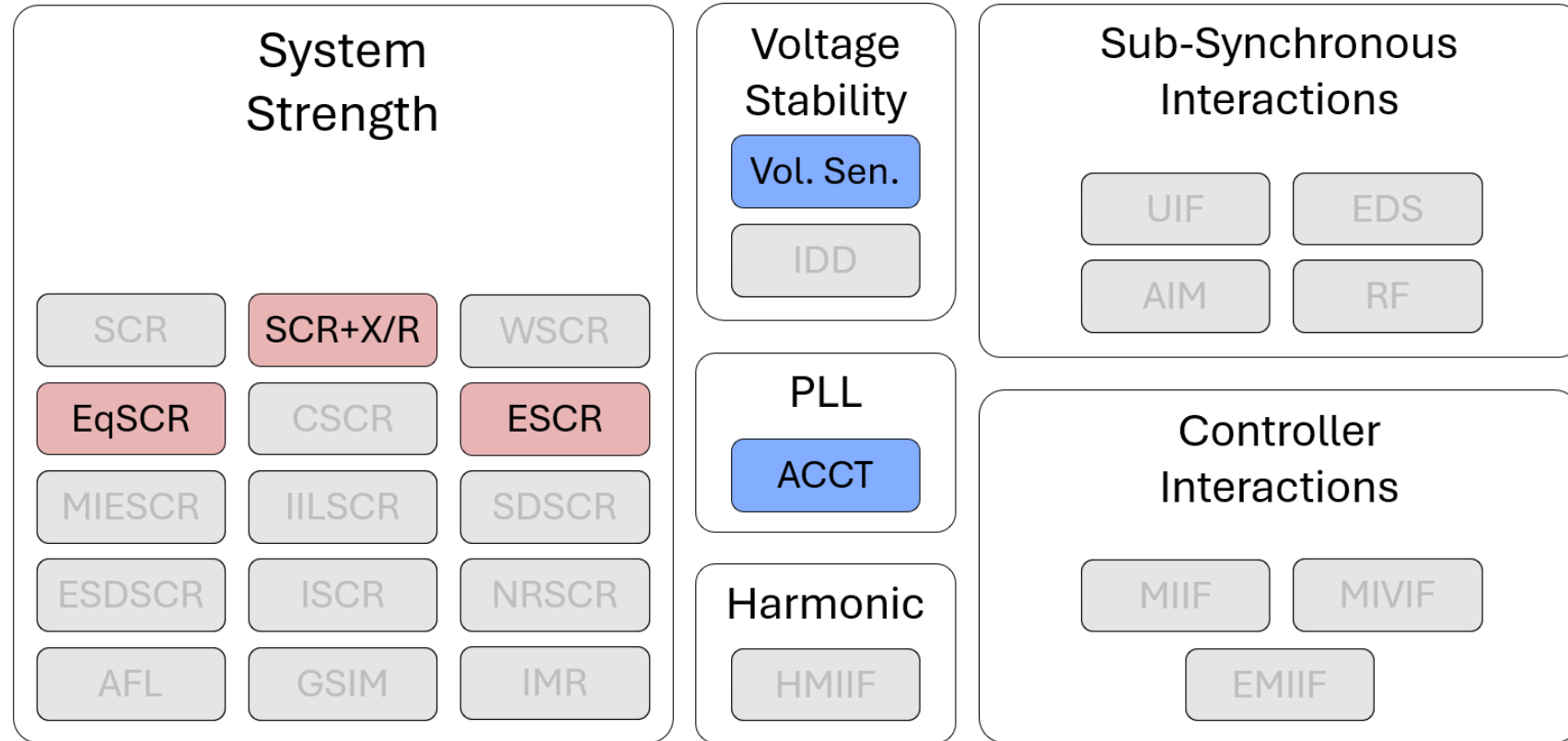
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Grid strength metrics suitable for operation

- Metrics selected based on:

- Applicable to operations: time taken to run should be very quick
- Simple to calculate: easy to run, and easy to understand quickly for an operator to take an action if required
- Used in industry: preferable to utilize metrics that are tried and tested in other TSOs
- Metrics should cover all areas of interest in system strength and stability



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Limitations of Grid Strength Metrics

- Metrics are steady-state or small-signal proxies; do not characterize time-domain dynamic behavior:
 - No information on oscillation modes, frequencies, or damping of control interactions
 - No prediction of fault ride-through performance or post-disturbance recovery trajectories
- Calculated for a static network condition; do not capture control-mode transitions, protection actions, or nonlinearities
- Do not represent vendor-specific IBR control implementations
- Threshold values are largely empirical and are dependent on specific system and operating scenario
- **Implication: metrics indicate where EMT study is required; they cannot substitute EMT simulations in characterizing system behavior**



Observations & Conclusions

- Short-circuit metrics:
 - simple and widely available, but may overestimate strength at high IBR penetration
- Interaction-based metrics:
 - capture multi-infeed coupling, but require more data
- No single metric is sufficient across all conditions
- Metrics are screening tools not substitutes for detailed EMT analysis
- Recommended workflow:
 - screen with metrics → flag low-strength zones → targeted EMT simulation

Reach out to EPRI if you are interested to know more about how to identify regions for EMT studies



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