Enhanced Network Support Through HVDC

“How to use HVDC to unlock Net Zero”

Razvan Pabat-Stroe,
EPRI International

HVDC Operators’ Forum 2023

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Objective, scientific research leading to progress in reliability, efficiency, affordability, health, safety, and the environment.

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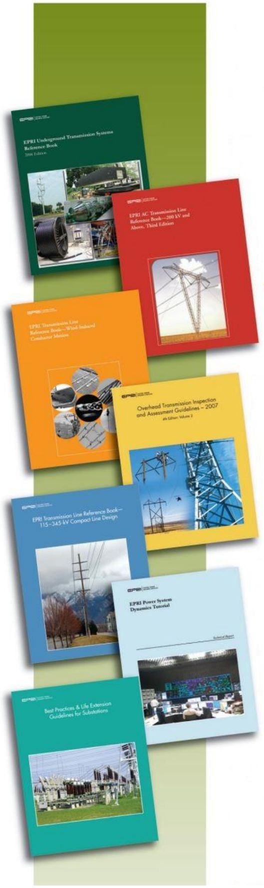
Bring together our members and diverse scientific and technical sectors to shape and drive research and development in the electricity sector.

HVDC LCC SSTI screening

Typical HVDC LCC power or current control bandwidths are in the range of 10 to 30 Hz, aligning with the torsional modes of vibration of typical thermal turbine-generator units.



Relationship used as a **quantitative screening tool** to identify units and system contingencies requiring detailed studies:

$$UIF_i = \frac{MVA_{HVDC}}{MVA_i}\left(1 - \frac{\overline{SC}_i}{SC_{TOT}}\right)^2$$

where:

UIF_i	=	Unit Interaction Factor of ith unit
MVA	=	Rating as per subscript (HVDC or ith unit)
SC_{TOT}	=	Short Circuit Capability at HVDC commutating bus including ith unit
$\overline{SC}_i$	=	Short Circuit capability at HVDC commutating bus excluding ith unit

Units with an interaction factor **less than 0.1** will not have significant interaction and can be neglected in further studies.

Still being used for VSC-HVDC – conservative approach:

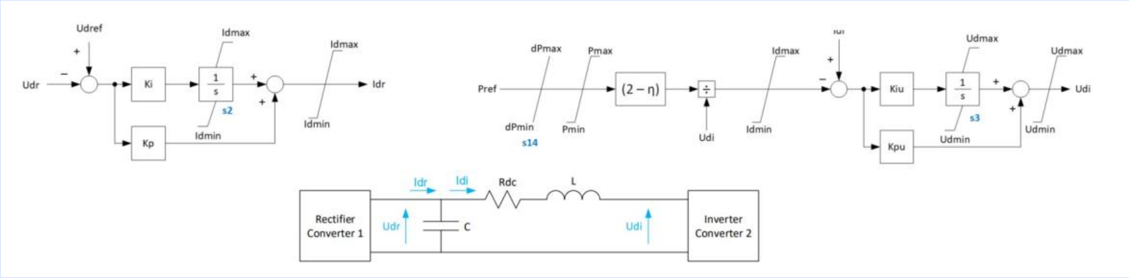
– for interaction factors **above 0.01** → time domain studies are recommended to assess the risk of SSTI

Electric Power Research Institute (EPRI)research project (RP 1425), **1982**

Point-to-point WECC models

Voltage Source Converter HVDC Dynamic Model 1 (*vhvdc1*)

- generic model for high-level stability studies and is not specific to any vendor
- a simple, transparent and portable model
- intended for planning studies in positive-sequence programs such as PSLF, PSS/E, PowerWorld and TSAT, and other similar tools
- VSC-HVDC embedded within an existing AC network, and not for offshore wind or multi-terminal applications
- general and simple representation of DC circuit, control loops and protection to reasonably capture the converter dynamics during AC network faults

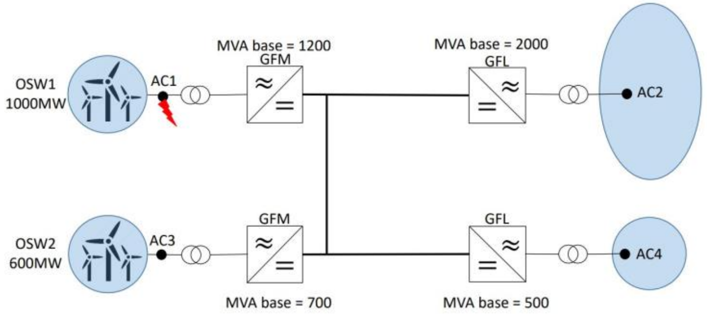


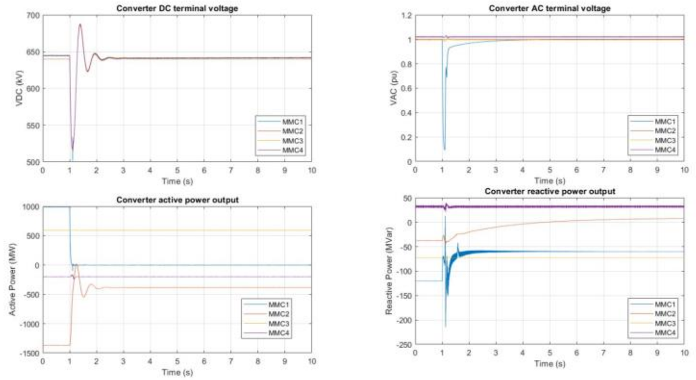
https://www.wecc.org/Reliability/Propose%20Generic%20VSC-HVDC%20Model.pdf

MT-HVDC EMT

The generic PSCAD model developed is intended to support preliminary design analysis in the absence of vendor specific MT-HVDC models.

Various control methods and modes have been included on each terminal to enable the use of the model in a wide range of applications: offshore wind integration, offshore meshed systems and energy island concepts, onshore HVDC bootstraps, onshore MT-HVDC systems collecting remote isolated renewable generation.





3002024854 Multiterminal VSCHVDC Systems (MTDC) for Meshed Onshore and Offshore Applications Development of a Generic Model for Integration Studies

GSAT advanced screening

To **complement SCR-based methods**, EPRI has proposed an advanced screening metric - critical clearing time (CCT). The CCT is from the perspective of the converter and not of a synchronous machine.

Unlike the conventional short-circuit based metrics, the advanced metric **accounts for the effect of different converter control parameters like PLL, terminal and DC link voltage controllers** on the CCT and allows to evaluate how different control parameters influence the stability of the system.

The converter response is represented through differential equations which account for the impact of the PLL and voltage control dynamics on the converter's stability.

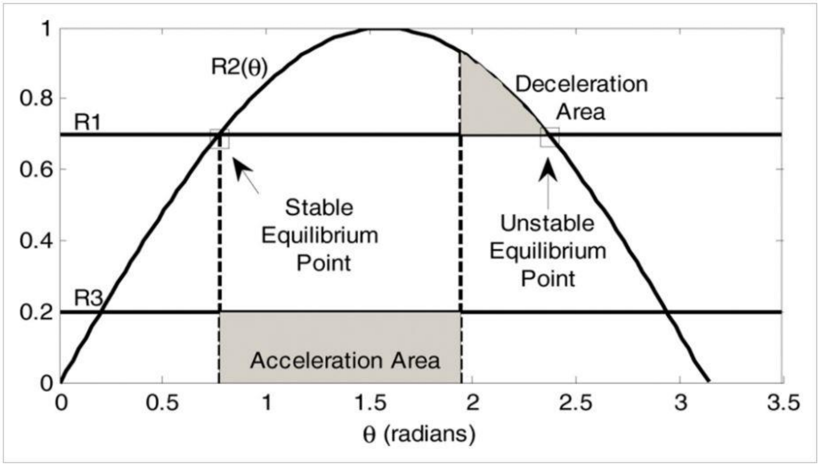
Differential and algebraic equations allow to analyze the effect of PLL and voltage control gains on the transient response of the converter.

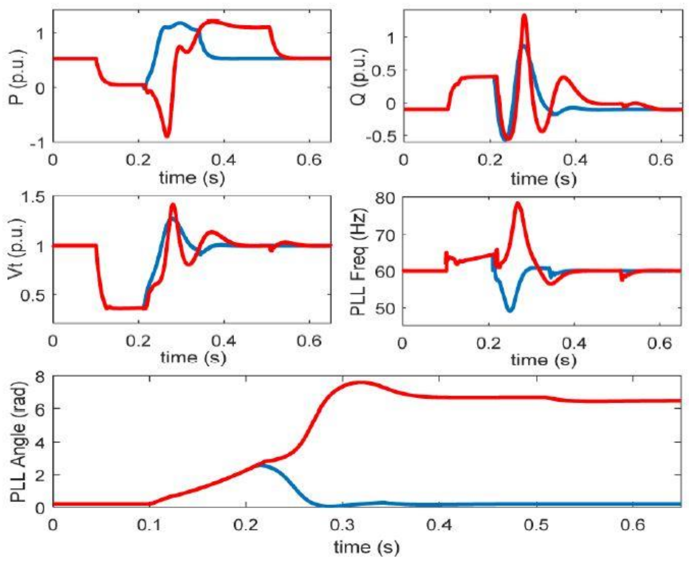
Since the equations are structurally similar to the well-known synchronous machine swing equations, it is proposed the **equal area criterion** can be adopted to analyze the transient stability of the converter.

"Grid Strength Assessment Tool (GSAT)" software tool has been developed by EPRI, which can be used to calculate various system strength metrics at selected nodes in the system:

- calculates the proposed advanced metric expressed as CCT. Small values for the CCT indicate that the system is close to its transient stability limits. Thus, the advanced metric can be used similarly to how the SCR metrics are currently utilisied to **identify converters for further detailed analysis**.
- enables **quick assessment** to investigate the transient and small-signal stability margins using only a steady state snapshot of the system (e.g., power flow and network configuration), without performing dynamic simulations
- calculates classic short-circuit metrics (e.g., short circuit ratio, weighted short circuit ratio, composite short circuit ratio) to give an indication of the small-signal stability margins.

To allow system planners to determine fast and with sufficient accuracy if a converter puts at risk the stability of the network, evaluate the transient stability margin of the converters and coordinate operation of protection schemes.



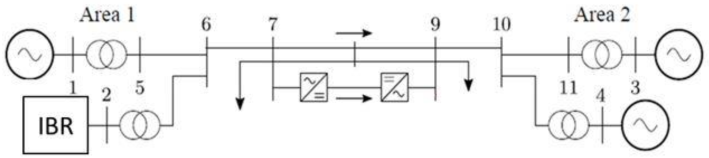


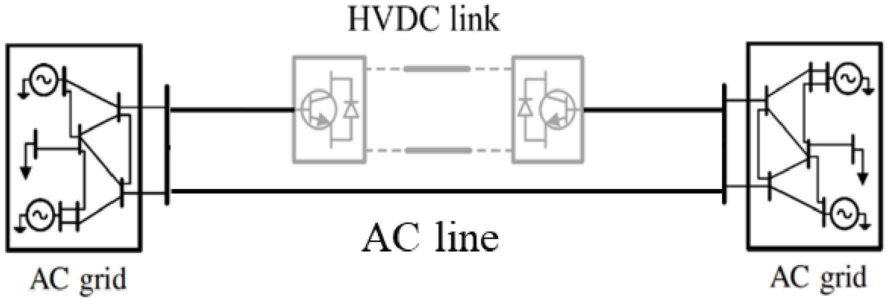
3002024263 Grid Strength Assessment Tool (GSAT) Version 5.0 – Beta. EPRI, Palo Alto, CA: 2022, https://www.epri.com/research/products/000000003002024892
Transient stability analysis and stability margin evaluation of phase-locked loop synchronised converter-based generators - Wang - 2020 - IET Generation, Transmission & Distribution - Wiley Online Library

Embedded VSC-HVDC with Grid-Forming Capability

EMT simulation conducted in PSCAD to investigate how different **operating modes of HVDC converters** can **support** the operation of a power system and **affect** its dynamic stability under various network conditions

- evaluate different stability phenomena of the system, including transient stability, damping of electromechanical oscillations, and converter instabilities that can occur due to inappropriate tuning of parameters and current limiting capability of the power electronic devices
- investigate the critical control parameters of the converters that have predominant effect on system dynamic performance
- aimed at utilities that seek to evaluate how different operating modes and control functionalities of VCS-HVDC links can support the operation of low-inertia and low short circuit ratio networks
- illustrate, by means of a practical example, potential benefits provided when one end of the HVDC link operates in GFM mode
- quantify the impact of different operating modes of the HVDC link on the transient stability of the system
- perform dynamic analysis to evaluate the impact of the system strength on the operation of the converters of the HVDC-link





[Embedded VSC-HVDC with Grid-Forming Capability: Assessment of Challenges and Solutions (epri.com)]

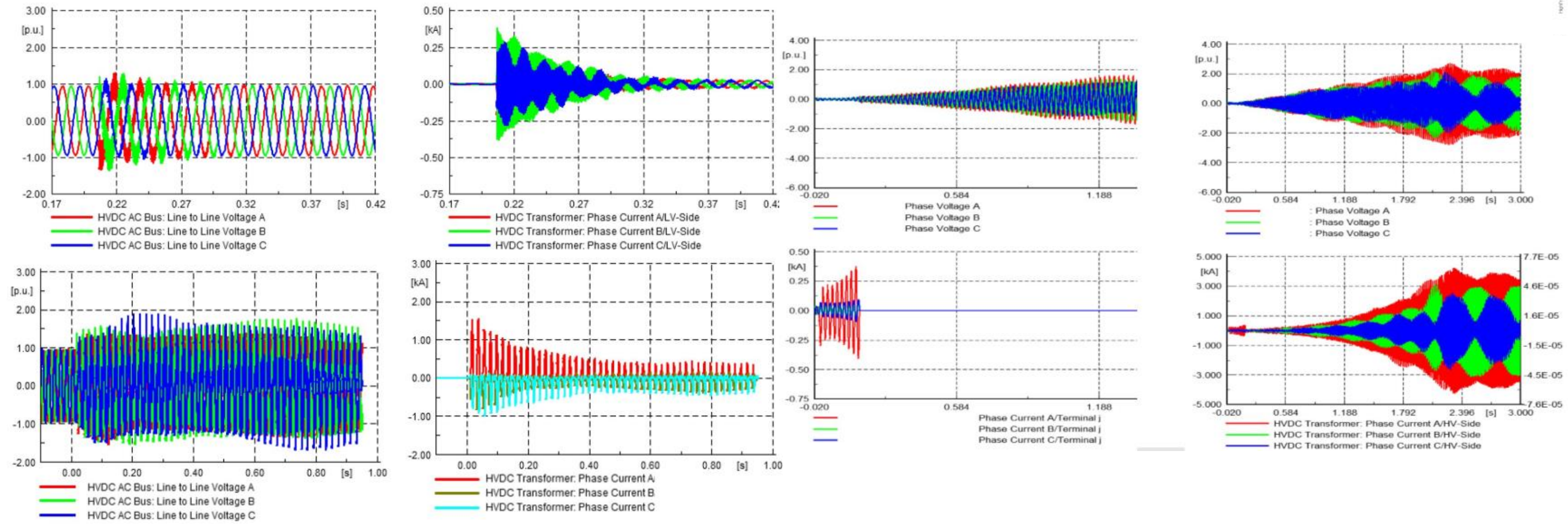
Restoration with LCC and VSC-HVDC

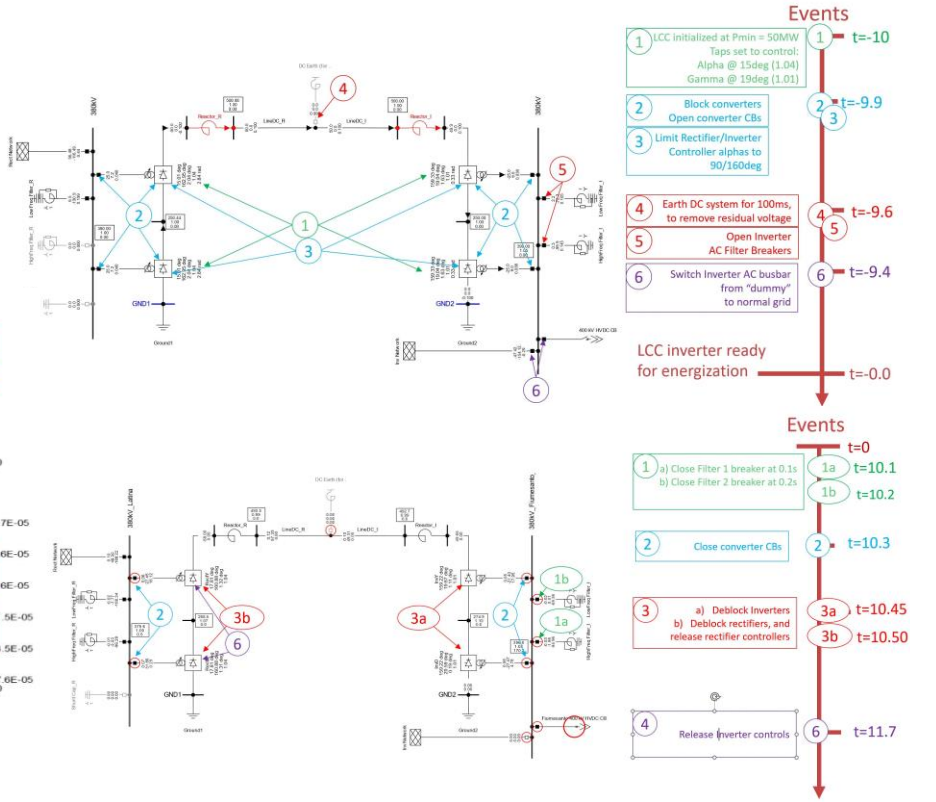
Network protection investigation for restoration from VSC-HVDC

- Protection sensitivity at lower short circuit level
- Impedance calculation with less negative sequence current
- Relay signal processing response to faster phase angle and frequency fluctuations
- Relay ability to track rapidly-varying inputs
- Inverter instability – how does output look like – how does network protection react?

LCC-HVDC link restart with BESS and synchronous condensers

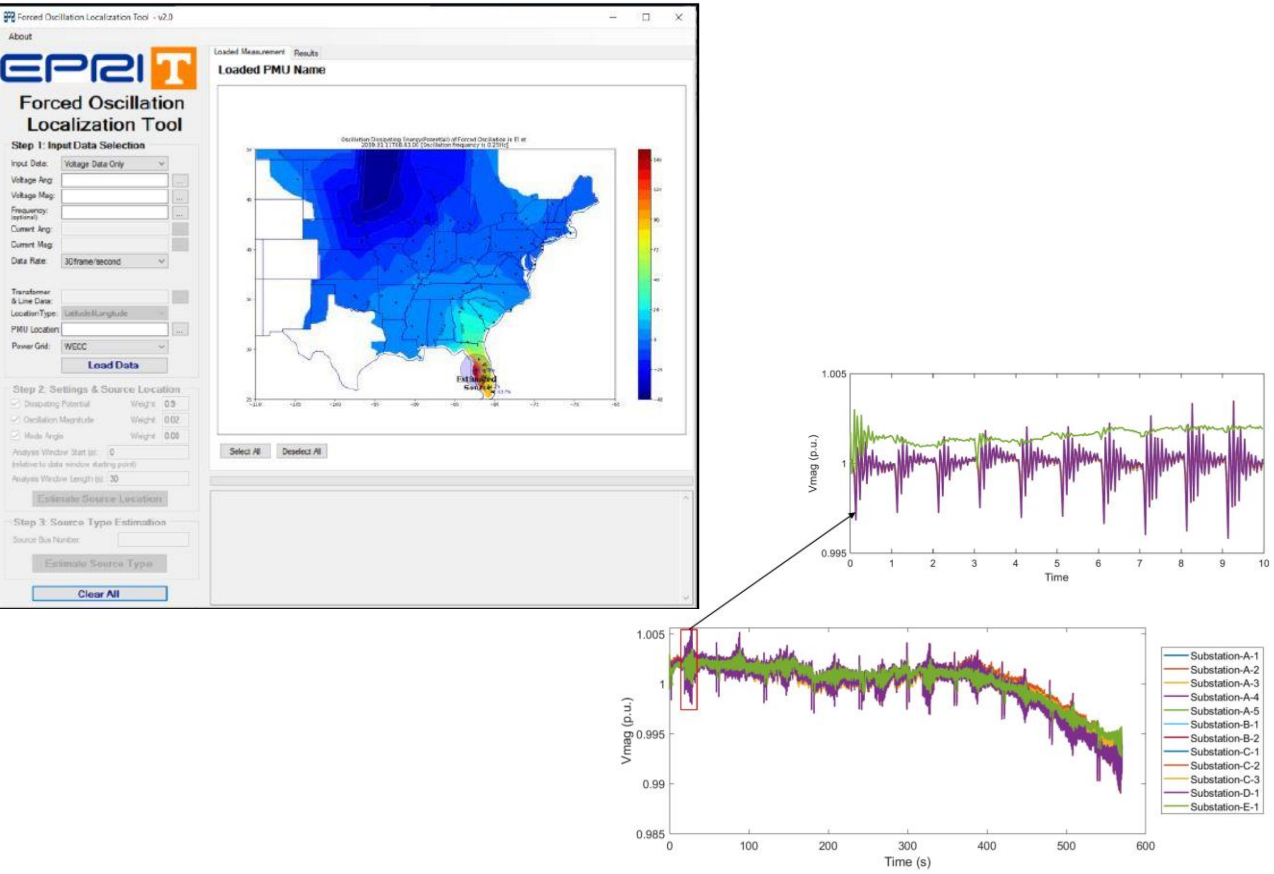
- GFM BESS model to define performance specifications
- Network protection adequacy
- SC start-up
- LCC start-up
- Developed workaround – starting simulation de-energised blocked → internal states didn't initialise correctly and affected simulation





Oscillation detection

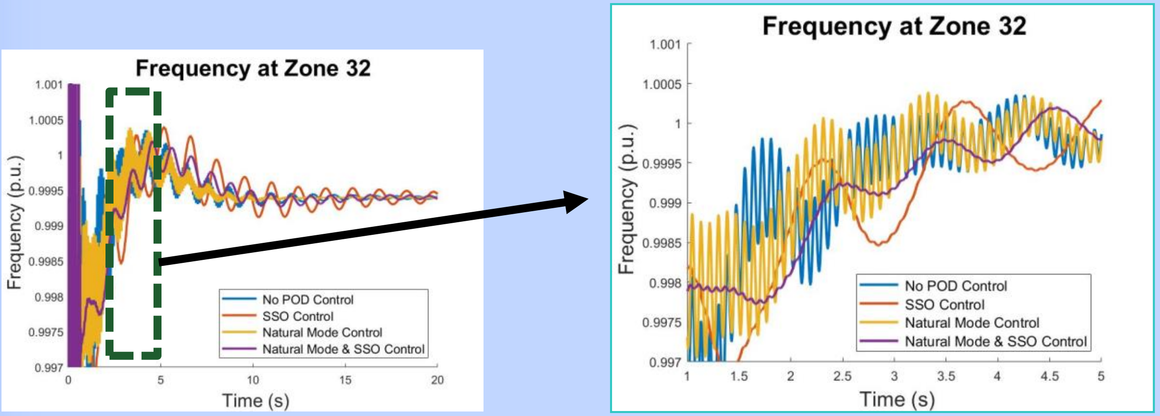
- Three different methods for **source location**
- Source location estimation with confidence index
- Does not rely on system topology
- Does not require entire grid PMU observability



Forced Oscillation Localization Tool (FOLT) v2.0 Beta https://www.epri.com/research/products/000000003002024714

Adaptive oscillation damping

- Select POD parameters from look-up table
- Update POD parameters using transfer function model derived from ambient and ring-down measurements
- Adaptive POD performance tested and validated in PowerFactory and HiL in RTDS
- The parameters of the inner current control loop controller, outer voltage controller, and PLL are tuned to produce SSO
- Developed POD controller can **suppress natural oscillations and SSO** using VSC-HVDC active and reactive power modulation



Adaptive HVDC Control System and Power Oscillation Damping Methods: Theoretical Developments
https://www.epri.com/research/products/000000000001024321
https://www.hvdccentre.com/innovation-projects/pod_project/

Impact on Real-time Ops. from increase in HVDC penetration

- Changes in the way the power systems is operated and restored
  - Response and behavior governed by sophisticated black-boxed control systems **difficult to represent and understand in real time operations environment**
- Changes in the way power systems fail
  - **Different** type of contingencies e.g., control system misbehaving without any apparent system fault or external event
  - **Lower margin** for error – **less time** to assess and react – **limited corelation** between cause and effect
- Gap in operational experience and expertise
  - Highly experienced power system operators use mental models when making critical decisions
  - **Mental models** are built on their vast operational experience – **synchronous machine dominated systems**
  - In novel situations – no previous similar experience – **expert decision makers may operate at novice level**
  - The operator’s ability to understand the state of the system and anticipate possible problems may be impaired
  - **Good foundation** necessary to perform well in novel situations

Real-time operation is already very **complex**

- Should planning and real-time capabilities evolve to handle more complicated concepts/difficult to understand processes
- Find solutions to take abstract and difficult to visualize formats and turn to something that can be intuitively understood (cause and effect)

Impact on Real-time Ops. from increase in HVDC penetration

Define **questions** worth answering – relevant to real-time operator training

Determine the **level of detail** for the answer – sufficient to inform skilful questioning and decision-making process

Example: SSTI or SSCI with VSC-HVDC

- In what control operating mode (AC and DC side) is more likely to introduce negative electrical damping due to its controls?
- Does operating in DC voltage control rather than Power control increase probability of introducing negative damping?
- For steam turbines → higher active power output = higher mechanical damping.
- For VSC-HVDC does the magnitude and direction of active and reactive power affect damping level?
- For SSCI – in what operating mode is more likely for VSC-HVDC to exhibit unwanted interactions with nearby devices?

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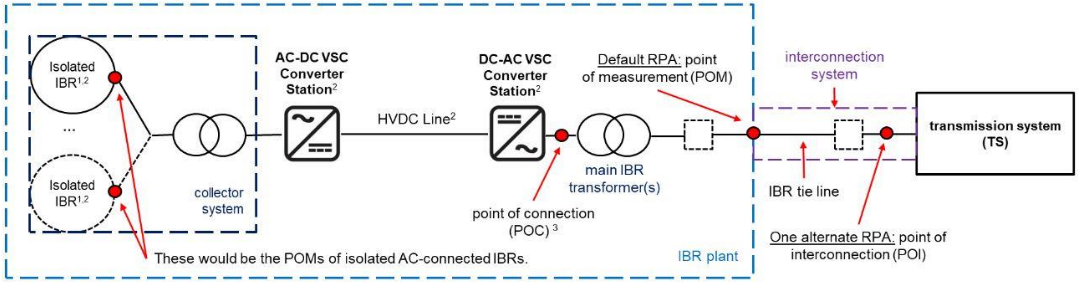
IEEE Std 2800-2022

Establish the required interconnection **capability and performance criteria** for connection of inverter-based resources to the transmissio system.

- Voltage and frequency ride-through
- Active and reactive power control
- Dynamic support during abnormal network conditions
- Power quality
- Negative phase sequence current injection
- System protection

Provide guidance and recommended practices on **conformance tests** and **verification procedures** for connecting inverter-based resources to the transmission system

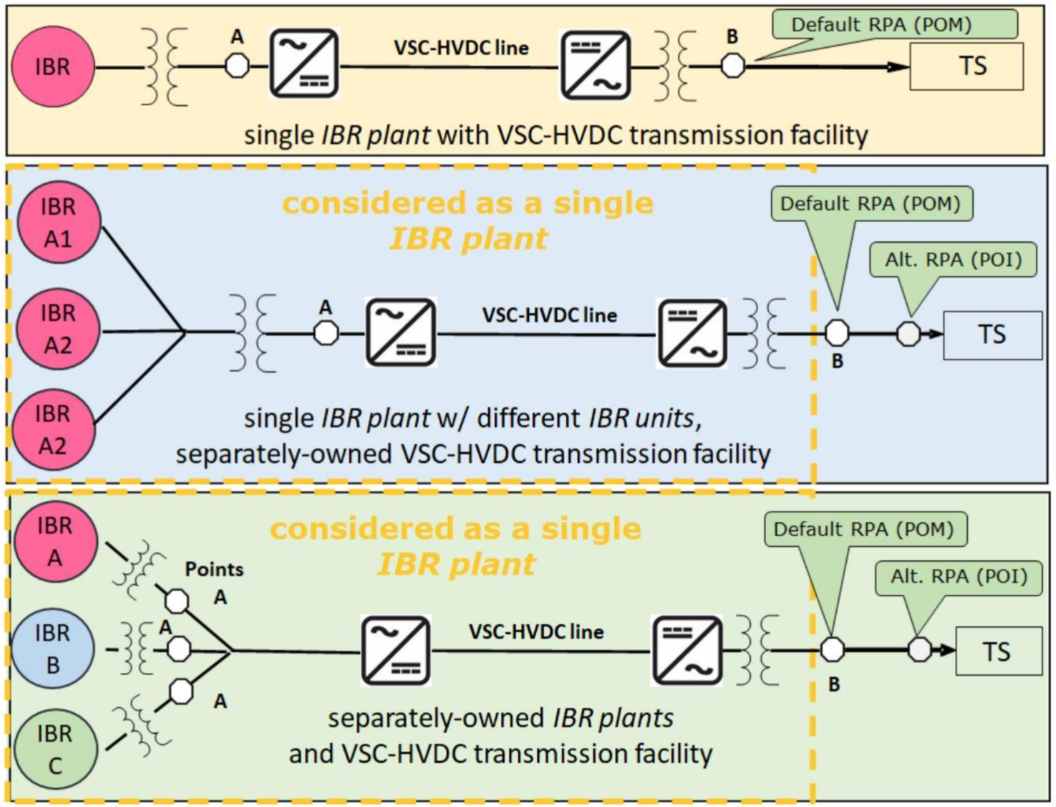
The standard applies to inverter-based resources connected via dedicated **VSC-HVDC** transmission facilities.



[1] Includes IBR units like type IV wind turbine generators

[2] May serve as a supplemental IBR device that is necessary for the IBR plant with VSC-HVDC to meet the requirements of this standard at the RPA

[3] Depending on design, the POC may be on the TS side of the main IBR transformer.



2800-2022 - IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems