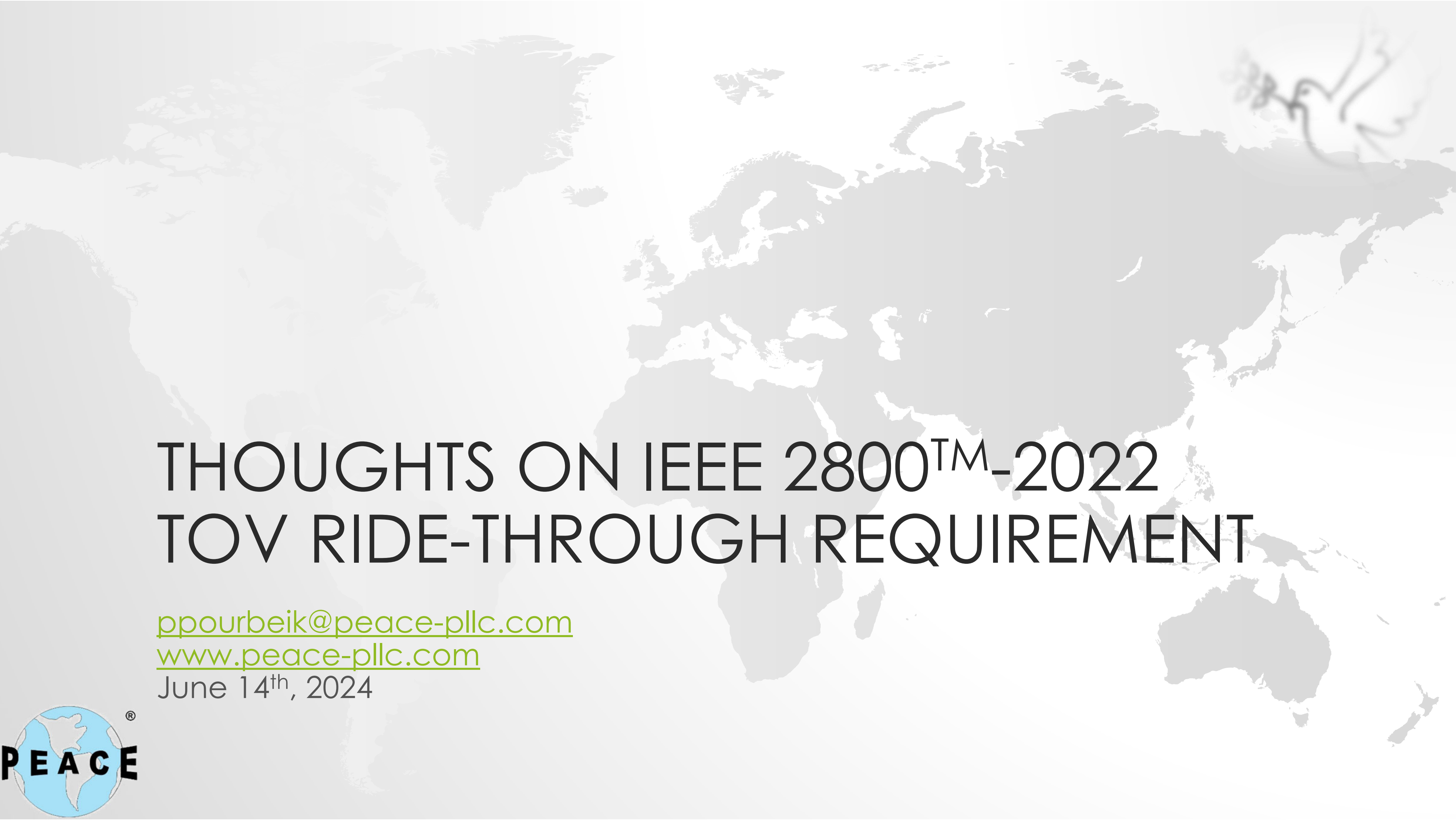

THOUGHTS ON IEEE 2800^{TM}-2022 TOV RIDE-THROUGH REQUIREMENT

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  - Pramod Ghimire, SGRE (SG2 Lead)
  - Rajat Majumder, Invenergy, LLC
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- The slides presented do not necessarily represent the views of the named entities, but rather are a presentation of certain technical facts discussed by individuals within SG2.

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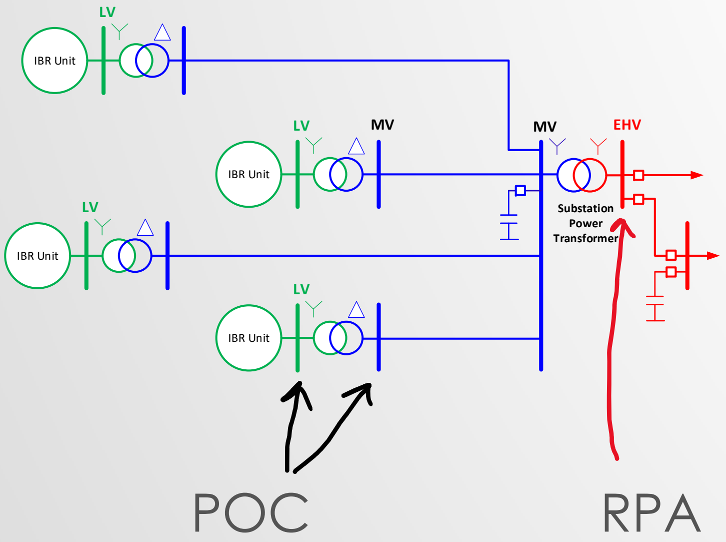
CLAUSE 7.2.3 OF IEEE 2800™-2022

The IBR plant shall ride through transient overvoltage that do not exceed the fundamental-frequency overvoltage ride-through requirements specified in 7.2.2.1 and for which the greater of individual phase-to-phase or phase-to-ground instantaneous voltage magnitudes do not exceed the cumulative durations (minimum time) specified in Table 14. …………..The cumulative duration shall only include the sum of durations for which the instantaneous voltage exceeds the respective threshold over a 1-min time window.

CLAUSE 7.2.3 OF IEEE 2800™-2022

The intent of transient overvoltage ride-through requirements is to help ensure that the *IBR plant* does not trip during switching events in the TS.



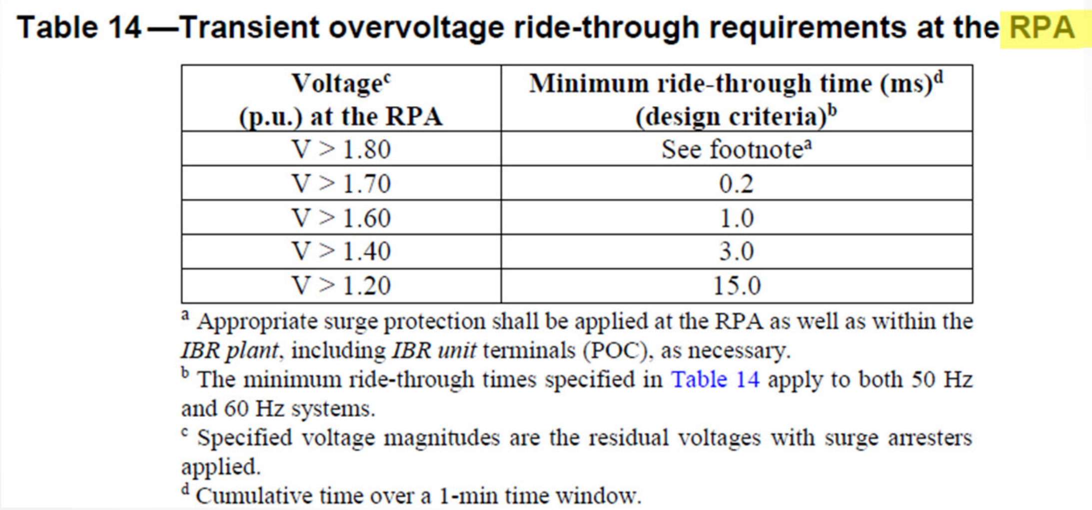


Table 14—Transient overvoltage ride-through requirements at the RPA

Voltage[c] (p.u.) at the RPA	Minimum ride-through time (ms)[d] (design criteria)[b]
V > 1.80	See footnote[a]
V > 1.70	0.2
V > 1.60	1.0
V > 1.40	3.0
V > 1.20	15.0

[a] Appropriate surge protection shall be applied at the RPA as well as within the *IBR plant*, including *IBR unit* terminals (POC), as necessary.

[b] The minimum ride-through times specified in Table 14 apply to both 50 Hz and 60 Hz systems.

[c] Specified voltage magnitudes are the residual voltages with surge arresters applied.

[d] Cumulative time over a 1-min time window.

WHAT KIND OF EVENTS CAN LEAD TO SUCH TOV?

- Lightning: this is a highly researched and documented topic with specific mitigation methods practiced for decades related to substation, transmission line and cable design – insulation coordination (see [1]) **(Defined test procedures for this already exist)**
- Switching Transients: from line energization, line fault and reclosing, reactor switching, transformer switching, capacitor bank switching, etc.; similar to the subject above, however, the wavefronts are slower (see [1])
- Resonance: resonances in the system can potentially lead to extremely damaging, and large, overvoltages, which will be at higher than fundamental frequency, e.g.
  - SSR
  - Ferro-resonance
  - Harmonic resonances
  - Etc.

HOW IS EQUIPMENT PROTECTED?

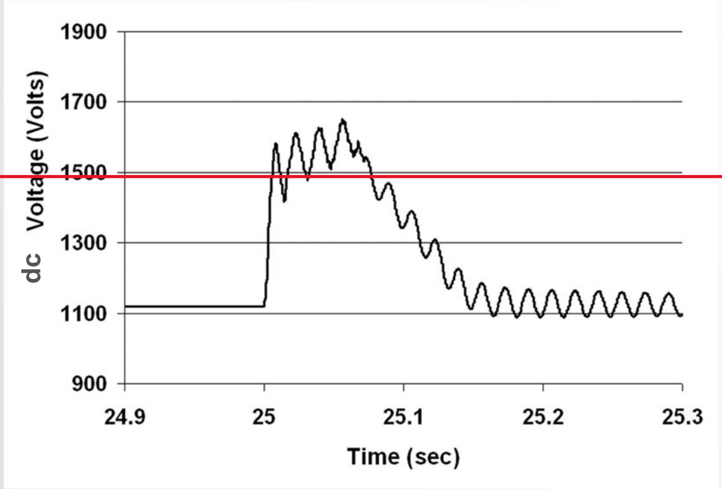
- Balance of Plant:
  - Transformers
  - Cables
  - Switch-gear
  - Shunts
  - Etc.
- Proper insulation coordination and substation/line/cable design, with proper spacing, shield wires, and properly sized and deployed metal oxide varistors (MOVs)

HOW IS EQUIPMENT PROTECTED?

- Resonances must be avoided/mitigated
  - **SSR** – proper application of protective equipment and supplemental controls to quickly damp SSR, and in extreme cases trip to protect equipment
  - **Ferro-resonance** – ensure circuit topologies that may lead to resonance are avoided in operation, and that there is always a minimum amount of resistive load to heavily damp the resonance circuit (e.g., damping resistor in distribution instrument transformers). This is predominantly a potential issue in distribution systems.
- Sustained resonances cannot be tolerated, they will lead to equipment damage → thus, resonances must be mitigate and equipment protected

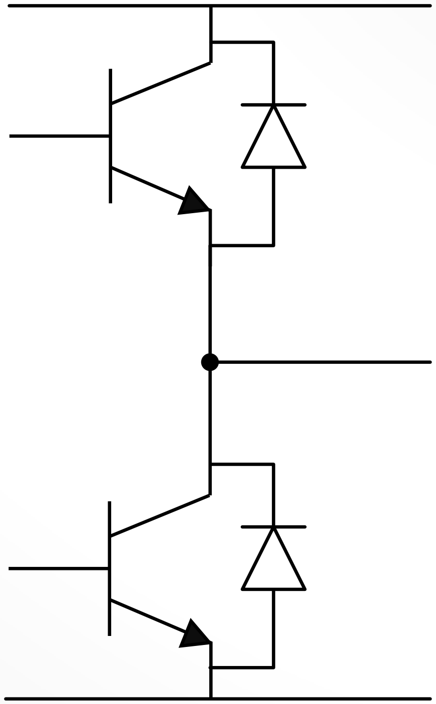
HOW IS EQUIPMENT PROTECTED?

- Power electronic switches (e.g., IGBTs) are sensitive to high-voltage conditions

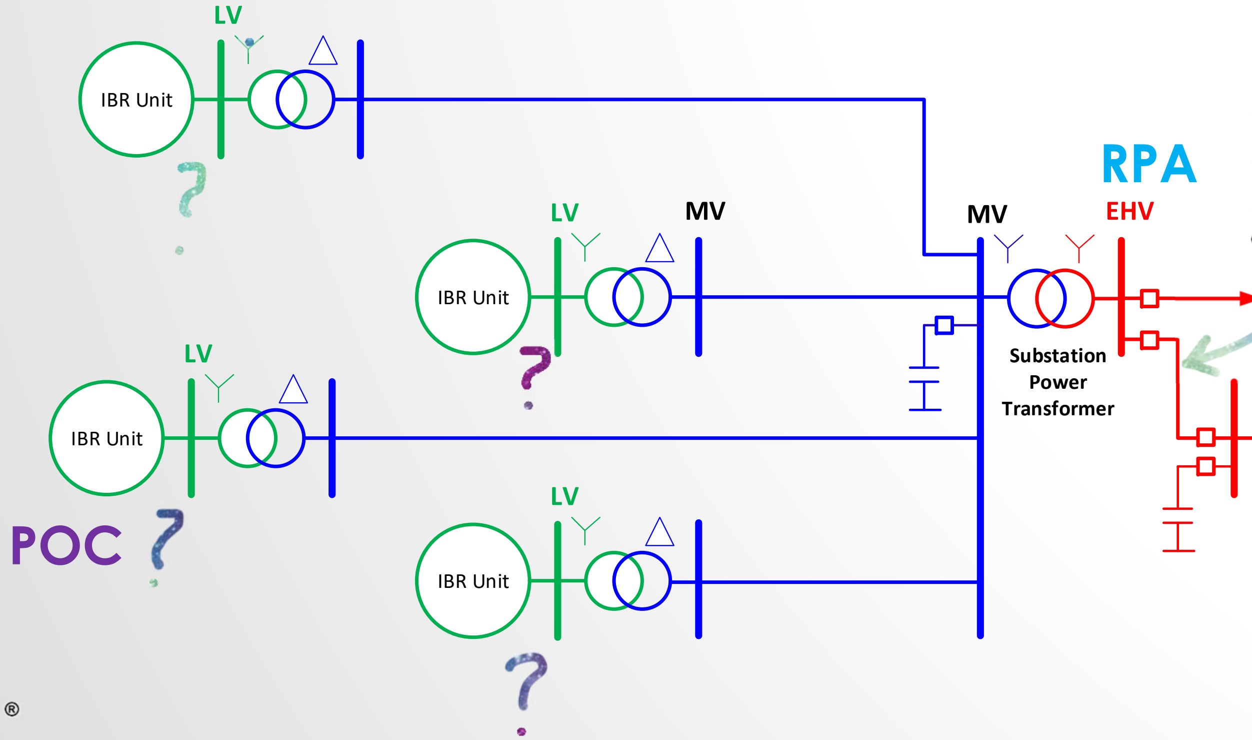


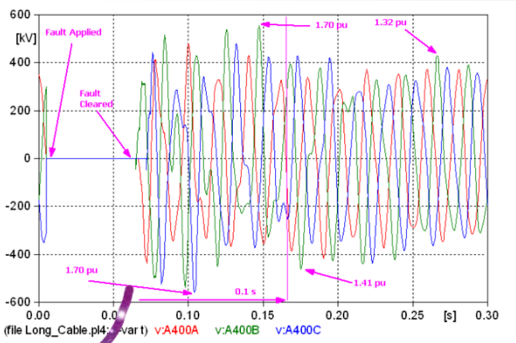
Just as an example

(with permission from presentation slides of reference [2])



CRITERIA IS DEFINED AT RPA





Example from [3] for illustrative purposes (not applicable to all systems)

WHAT ARE THE PROBLEMS?

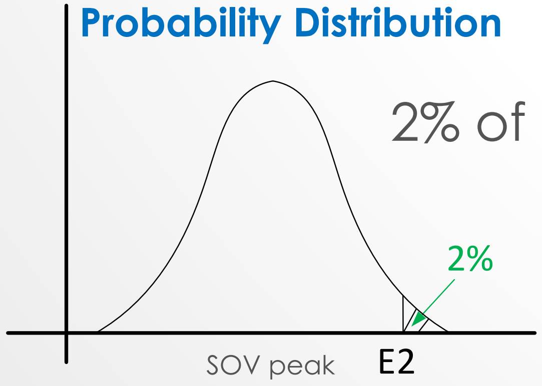
- TOV at RPA tells us very little about actual TOV seen by individual IBRs in the plant at the inverter terminals (POC)
- To see the TOV at each IBR unit's terminals (POC) one needs:
  - A detailed disaggregated model of the plant
  - All electrical equipment modeled including MOVs
  - All elements modeled with proper frequency-dependent models (including transformers)
  - Statistical analysis (hundreds of simulations for each switching event at random point on wave)
  - This is a VERY complex model and EXTREMELY computationally intensive
- TOV is a fast transient wave-form – it cannot be approximated; we must simulate actual statistical switching events to see possible maximum TOV events

WHAT ARE THE PROBLEMS?

- Criteria says "*for which the greater of individual phase-to-phase or phase-to-ground instantaneous voltage magnitudes do not exceed…*"
- *Thus, would have to calculate both for all statistical simulations!*

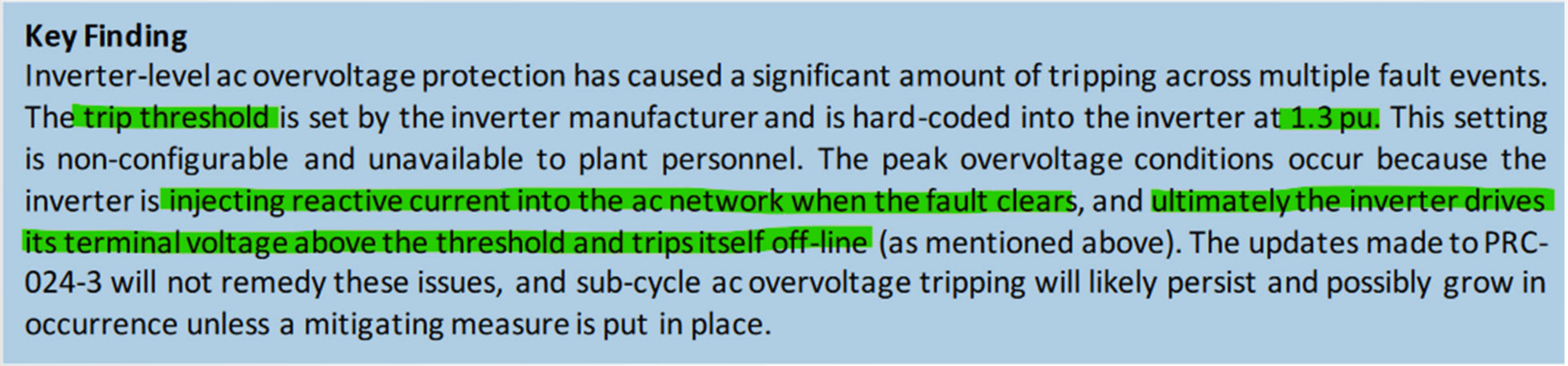
LET US LOOK AT SOME BASIC INFORMATION

- In general, for a fault and high-speed reclosing event on an EHV line typically E2 is between 1.8 to 2.8 pu ([1], pg. 103)
  - E2 = 1.8 pu is with pre-insertion resistors
  - E2 = 2.8 pu is without pre-insertion resistors
- E2 is the statistical switching overvoltage peak in pu of the maximum crest of the line-neutral voltage



2% of all events lead to SOV ≥ E2

ASIDE NOTE: ODESSA REPORT



Key Finding

Inverter-level ac overvoltage protection has caused a significant amount of tripping across multiple fault events. The trip threshold is set by the inverter manufacturer and is hard-coded into the inverter at 1.3 pu. This setting is non-configurable and unavailable to plant personnel. The peak overvoltage conditions occur because the inverter is injecting reactive current into the ac network when the fault clears, and ultimately the inverter drives its terminal voltage above the threshold and trips itself off-line (as mentioned above). The updates made to PRC-024-3 will not remedy these issues, and sub-cycle ac overvoltage tripping will likely persist and possibly grow in occurrence unless a mitigating measure is put in place.

(source: reference [4])

- This is NOT a TOV from a switching transient – it is poor PPC/Inverter FRT coordination, resulting in the PPC pushing the inverter to over-voltage following a fault; this should be captured and fixed in the design evaluation of a plant
- IEEE P2800.2 SG3 Design Evaluation is looking at these issues through fault simulations (LVRT/HVRT)

CONCLUSION

- A TOV criteria at the RPA tells us nothing about TOV experienced by the inverters in the plant (at POC)
- The IEEE 2800$^{\text{TM}}$-2022 TOV criteria as written is not truly testable in a EUT type test or with a simple simulation test
- Resonant phenomena must be mitigated, and Lightning protection is already addressed by existing standards
- Transmission switching transients can lead to TOVs; likely < 2% of such events may lead to TOVs > 1.8 pu (depends of topology and breakers)
- Let us address the "*low-hanging fruit*": PPC + Inverter FRT coordination → during design evaluation this will be caught through LVRT/HVRT simulations
- For TOV OEM should simply specify:
  - Are they using an instantaneous voltage trip point, if so at what value?
  - Is the above part of an active anti-islanding protection?
  - What is their equipment's capability in terms of TOV withstand?
  - Do they have a flag/protection log that can indicate if the IBR tripped on instantaneous excessive dc voltage?

REFERENCES

[1] A. R. Hileman, *Insulation Coordination for Power Systems*, CRC, 1999

[2] P. Pourbeik, R. J. Koessler, D. Dickmander and W. Wong, "Integration of Large Wind Farms into Utility Grids (Part 2 - Performance Issues)", Proceedings of IEEE PES General Meeting, July 2003. [*Diagram from Presentation Slides from the IEEE PES GM 2003*]

[3] CIGRE Technical Brochure 556, *Power System Technical Performance Issues Related to the Application of Long HVAC Cables*, October 2013

[4] NERC, *Odessa Disturbance Report*, September 2021
https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf