The National HVDC Centre

sse

SCOTTISHPOWER

nationalgrid

EPRI ELECTRIC POWER RESEARCH INSTITUTE

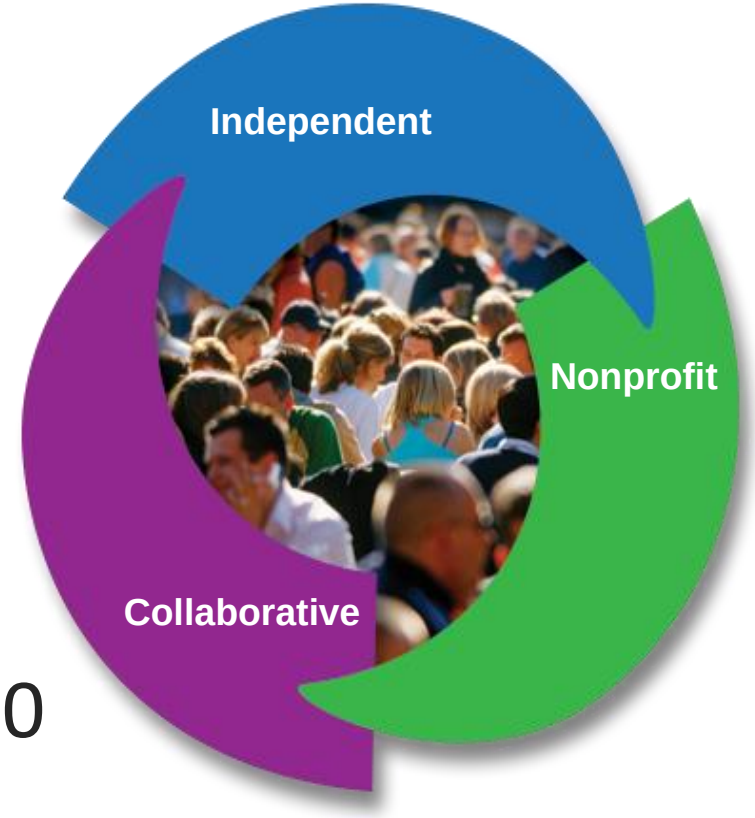
Coordination of AC network protection settings during grid energization from HVDC schemes

LCNI, Glasgow
October 30th, 2019

Jonathan Ruddy
Senior Engineer
EPRI Europe, Dublin

Electric Power Research Institute

- Founded in 1972 as an independent, non-profit center for public interest energy and environmental research
- **European office opened in Dublin in 2013**
- Collaborative resource for the electricity sector
- 450+ participating companies in more than 40 countries



Motivation – Restoration Studies

New Challenges

- New generation mix with wind and solar on transmission and distribution networks
- **Retirement of synchronous plants** and replacement with inverter based resources
- **Lower inertia & fault level** during restoration

Uniqueness

- Necessary capability - must have but hope to never have to deploy
- **Rare events,** (Extreme Weather, etc.) - Hands-on experience may be lacking
- Reliance on capturing all impacts in simulation

New Resources

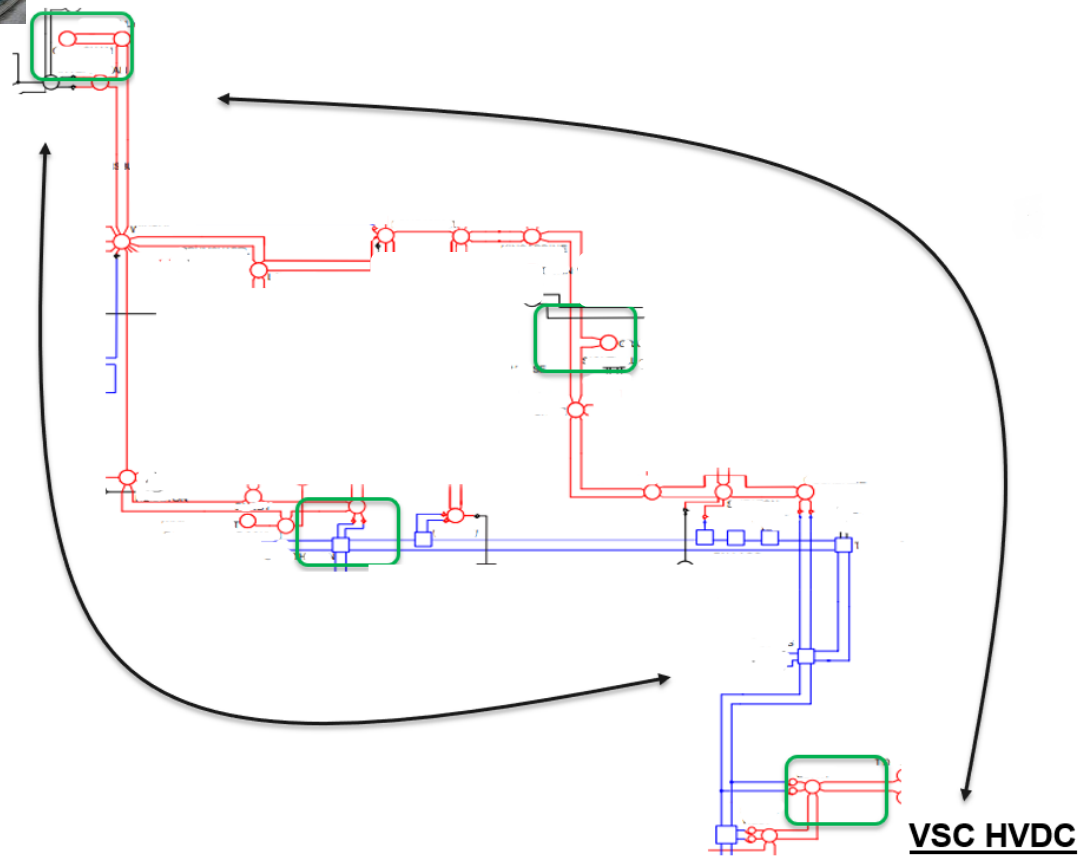
- **New blackstart resources** like DER possible but HVDC has capacity to be most effective
- **VSC HVDC Interconnectors** have inherent controllability & specific modes for blackstart

Need to develop new restoration paths, blackstart resources and expertise to evolve to changing grid conditions

The project case study

- Black start priority: connect black start unit to generation ASAP to grow power islands.
- Power islands expanded towards generation picking up demand along path
- Case illustrates generic MMC HVDC link at Blyth 400 kV (where NSL will connect) energizing a path to Cruachan pumped hydro station
- Detailed path modeled in DIgSILENT EMT using model provided by SPEN
- All detailed vendor specific protection relays modeled along restoration path

Pumped Hydro

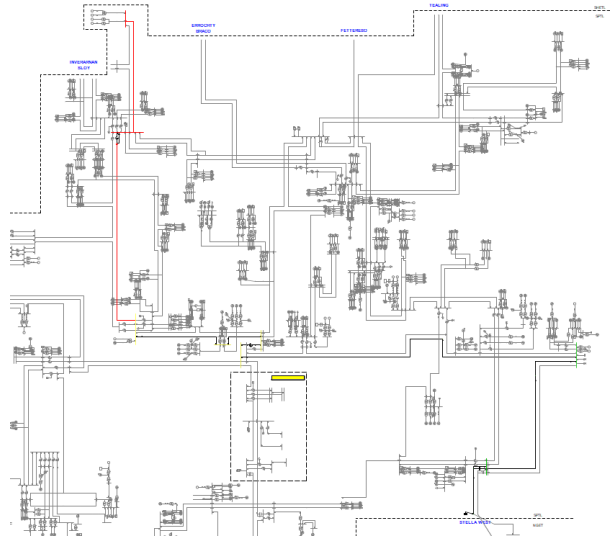


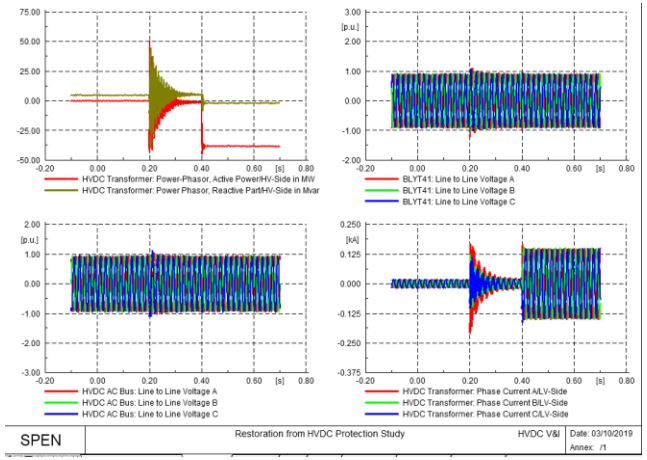
VSC HVDC

EPRI ELECTRIC POWER RESEARCH INSTITUTE | The National HVDC Centre | SCOTTISHPOWER | sse | nationalgrid

Project steps

- Review algorithms of protection relays on the network
- Use PowerFactory simulations to perform restoration studies
  - Grid restoration from VSC HVDC with/without faults
  - Transformer energization
  - Cold load pickup
  - Controlled and uncontrolled resynchronization of HVDC island grid to another blackstart island or other grid.
- Hardware testing of specific relays in HVDC Centre Lab
  - Study relay response to specific, triggered events





What are the protection issues?

Issues to consider with inverter-dominated grids?

Some obvious issues:

- Lower short circuit level – protection sensitivity
- Much less negative sequence current – impact on impedance calculation
- Insensitivity of output power to frequency changes

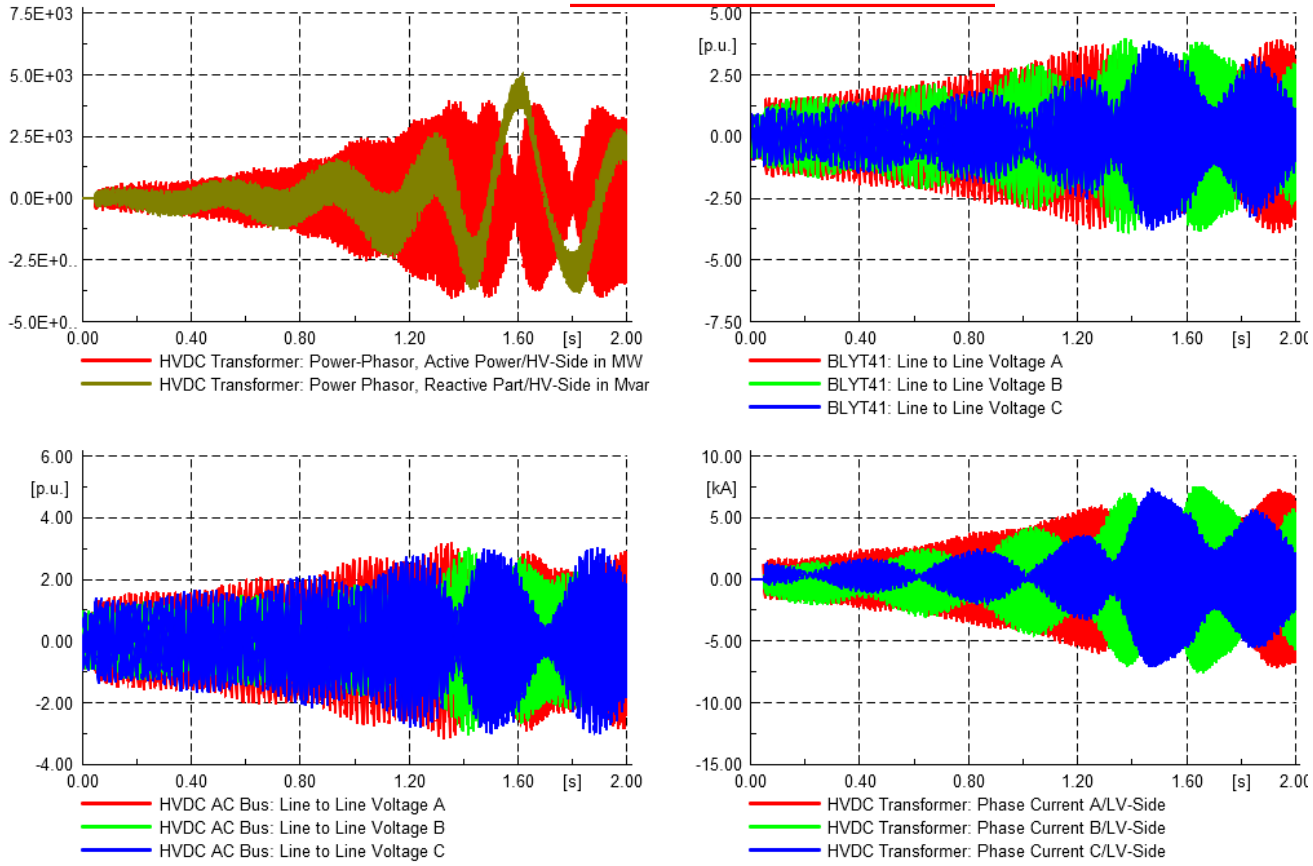
Some less obvious issues:

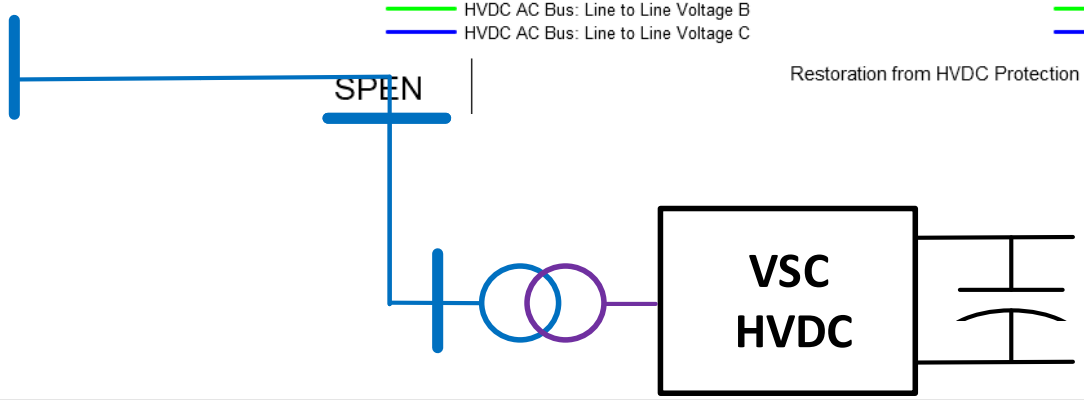
- Fast-acting inverter controls – relay signal processing response to faster phase angle and frequency fluctuations
- What does an unstable inverter output look like?
- Relay ability to track rapidly-varying inputs

How to Energize restoration path

- Traditional switching – set HVDC voltage to nominal & switch in each component
- Each switching action creates inrush currents and voltage fluctuations that the HVDC must **control**, **damp**, and **ride-through**
- Undamped resonance condition may occur if insufficient load is available early on in restoration to assist damping
- Resonant frequencies vary from circuit to circuit
- Options to mitigate:
  - Damping controls on HVDC
  - Pick up load
  - Soft Start HVDC

ILLUSTRATIVE RESULT

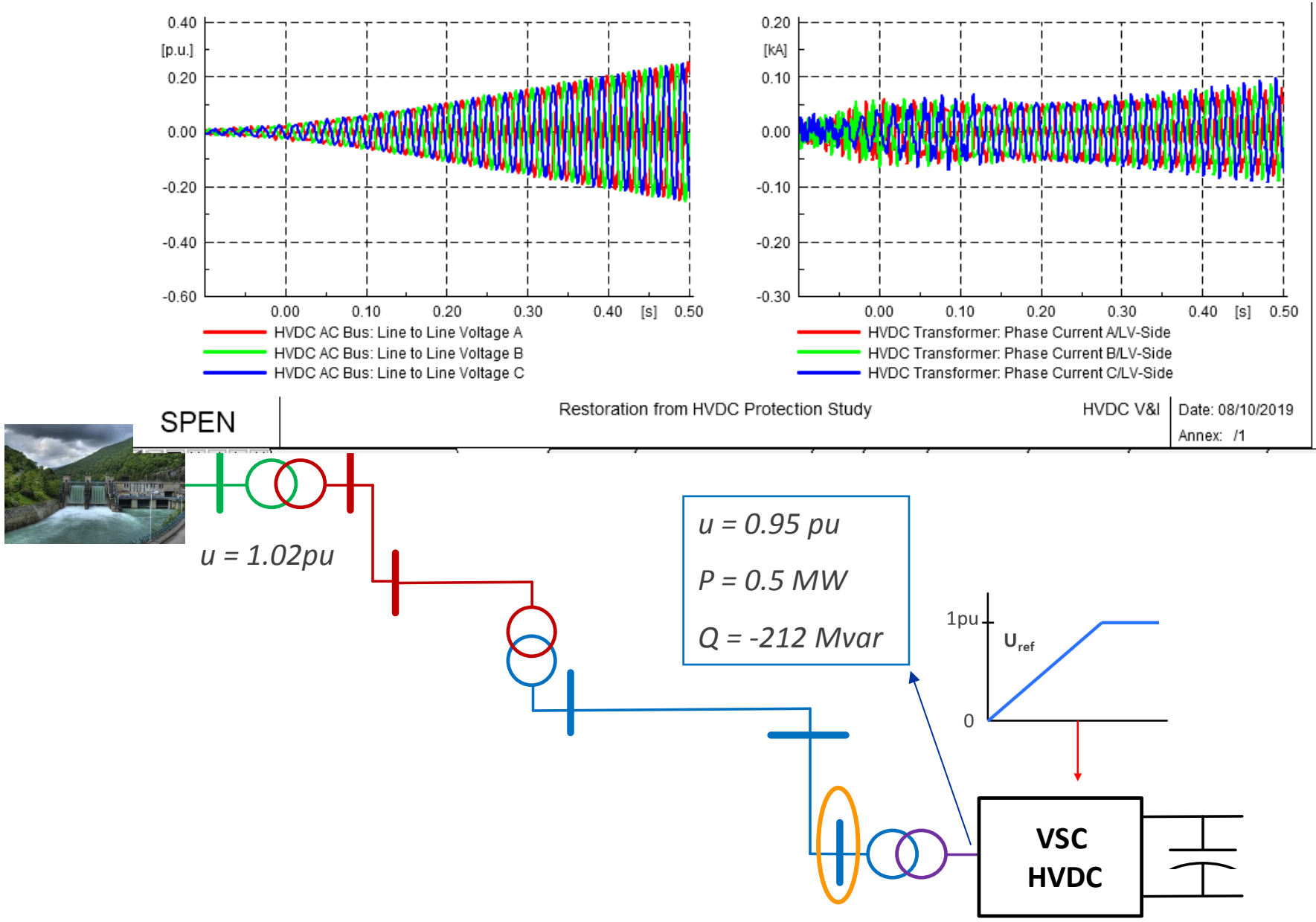




Restoration from HVDC Protection Study | HVDC V&I | Date: 03/10/2019 | Annex: /1

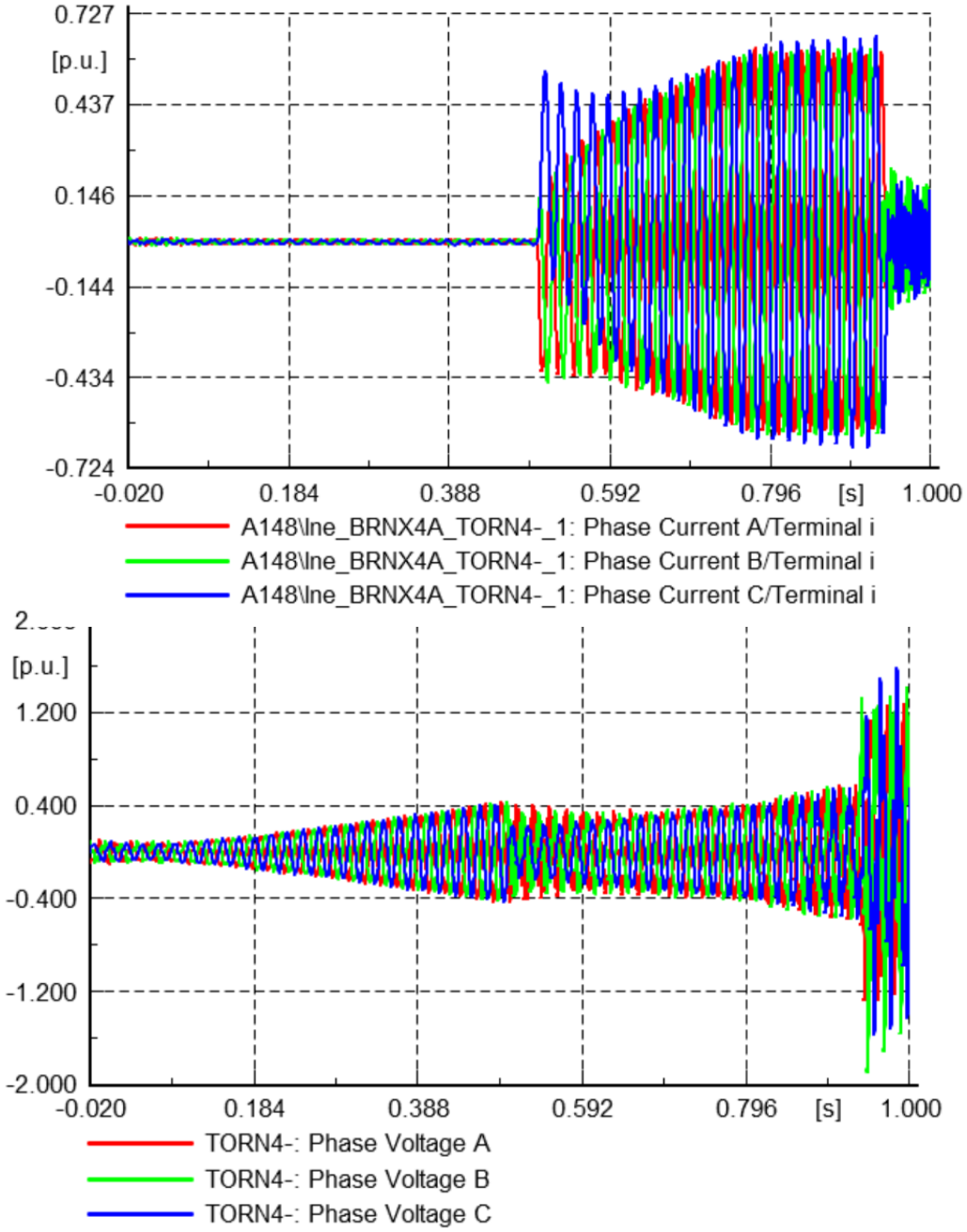
Soft Start HVDC method

- Full blackstart path energized via soft start
- HVDC as only source
- Soft start ramp minimises transients and inrush currents
- ~1400 MVA HVDC has plenty of capacity left to begin:
  - connecting more central Scotland 400 kV, 275 kV network
  - connecting load
  - Synchronizing to pumped hydro and rest of grid



Protection Implications

- Implications of soft starting on protection
  - Low fault level at early stages of ramp
  - Unit protection won't trip until fault current high enough
  - Under-voltage protection will need to be deactivated if ramp is slow
  - Risk of exciting resonance and temporary over-voltages causing over-voltage protection to trip if ramp rate is too fast
- Challenging to configure HVDC controller to detect faults during ramp
- Pre-existing permanent faults are greatest risk



Project outputs & Conclusion

- Using case study, identify key results and areas of consideration for effective black start using HVDC
- Recommendations for protection settings, algorithms and relay configuration during blackstart from VSC HVDC
- Recommendations for mitigation of low grid strength issues during blackstart/restoration
  - Up-to-date models for future studies
- Control system design considerations for design of the VSC HVDC incorporating blackstart capability
- Industry webcasts and workshop at HVDC Centre (Q1 2019) if interested please contact jruddy@epri.com, Bharath.Ponnalagan@sse.com or simon.marshall@sse.com
  - Go through results, findings, and lessons learned
  - Ensure knowledge is shared and not lost

Together...Shaping the Future of Electricity