Phase Jump and ROCOF Considerations for IBR – OEM Perspective

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11/10/2023

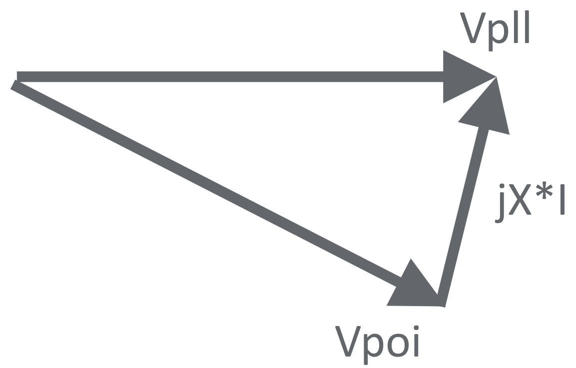
Phase Jump Related Grid Events and Performance Assessment

- Example Grid Events associated with **positive-sequence** phase jumps
  - Line Switching
  - Load Steps
- Other grid events that may results in phase jumps **+ other more dominant dynamics**
  - Grid Faults
  - Reclosing events
  - Islanding of parts of the interconnected system
  - Series capacitor insertion/bypass
- Phase jump compliance usually assessed based on positive-sequence phase jumps events
- Compliance for other grid events evaluated by testing/simulating equipment for the specific type of event

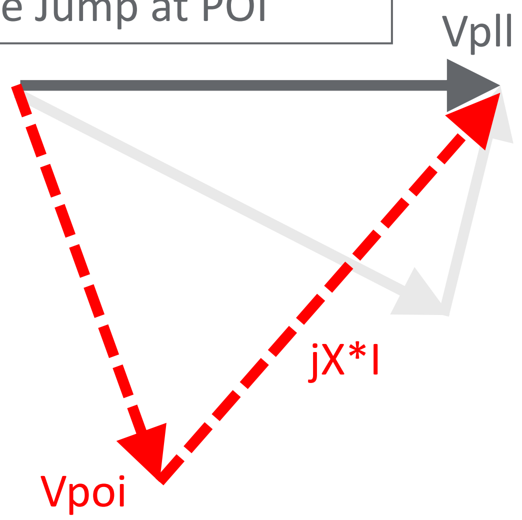
Phase Jump – Equipment and Protection Aspects

- IBR Response
  - Grid phase angle tracked by PLL. Phase jumps appear as sudden jump in PLL error.
  - Upon phase jump event, IBR rapidly adapts its own angle reference to that of the grid (but not instantaneously)
- Equipment Aspects
  - Phase jumps may cause large sub-cycle current transients in IBR depending on magnitude of phase jump
  - May cause offset saturation in xfmrs
  - Phase jumps can also cause large active power and torque transients
- Protection aspects
  - Some IBR may use PLL error signal for phase jump protection
  - Not all IBR have explicit phase jump protection
  - Other protections may act as a result of phase jump events (e.g. overcurrent protection), hence explicit phase jump capability of IBR is complex

Steady-State Phasor Diagram of IBR Plant Connected to POI



Phasor Diagram Immediately After Phase Jump at POI



Phase Jump – Testing Aspects

- Hardware Testing
  - Some state of the art lab testing facilities have power-electronic-based ‘Grid Emulators’
  - These grid emulators create a voltage source with controllable magnitude, frequency, and angle through power electronics at medium voltage level
  - Reflect state of the art testing system for validating phase jump capability, but generally few available
  - Testing carried out on individual IBR units or electrical subsystems
  - Phase jump tests in field (e.g. prototype) impractical due to lack of testing equipment. Deliberate grid events (e.g. line switching) could be a testing option if agreement with TSO/DSO.

ROCOF Equipment and Measurement Aspects

- Voltage-Based Measurement Methods of Frequency
  - Zero crossings of voltage waveforms
  - Phase-locked loop
- Voltage measurements at particular electrical node may be unreliable indicator of overall grid frequency during/after disturbances
  - Algorithms are susceptible to various distortions/transients appearing as large frequency events
- Equipment and Protection Aspects
  - Not all IBR have ROCOF protection
  - Very fast ROCOF requirements influences PLL design
- Testing/Performance Evaluation
  - Grid Emulator Hardware Tests (Single-Unit Testing)

ROCOF Mitigation Approaches and Risks

- Fault-Induced Frequency Events
  - IBRs typically reduce active power if local voltage drops to support voltage
  - If overall system load remains unchanged during fault, grid frequency may temporarily reduce
- Some regional grid requirements have been adopted to mitigate fault-induced grid frequency events, such as
  - Require active power reduction in proportion to voltage drop (e.g. active current priority control)
  - Require fast active power recovery after fault
- Above mitigations increase risk of local voltage stability issues
  - Risks increases in weaker systems
- Past experience indicates best approach to mitigating risks are:
  - Gradual reduction in power based on voltage
  - Prioritization of reactive current/voltage support for deep/close-in faults
  - Ramp in active power back slowly enough to avoid voltage stability issues