Voltage Stability Management:
Voltage Instability Predictor Methodology

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Voltage Related Issues

Voltage Instability: Short- and Long-Term

Fault Induced Delayed Voltage Recovery (FIDVR)
Voltage Stability Monitoring & Assessment

- Dynamic, time-domain simulation tools
  - Voltage Stability Assessment (VSA) based on State Estimation contingency analysis
  - Validate model correctness

- Simple voltage-only measurements may not be a good indicator of proximity to voltage collapse

- Tracking the relative distance from voltage instability continually in real-time:
  - Distance to the nose of the PV curve or SE–based stability boundary (model based)
  - Observing the distance of reactive power level from its’ 100% value when operating the Secondary and Tertiary Voltage Regulations
  - Distance of the load’s apparent impedance to the Thevenin impedance (similar to a relay with an adaptive setting)

Source: ABB
Voltage Instability Detection

- Simple, real time, voltage instability margin detection, e.g. VIP*
- Better than voltage-only methods, but simpler than any other method
  - Much faster than EMS/SE contingency analysis and not model dependent
- Enabling tracking both slow changes and system dynamics using PMUs (10-120 frames/s)
- New Reactive Power Margin Method: Major improvements in accuracy, numerical stability, implementation variants, and ease of use

Maximum power transfer \( \iff |Z_{app}| = |Z_{Thev}| \)

Point of collapse

\[
\begin{align*}
E & \quad Z_{Thev} \\
\text{Thevenin} & \quad Z_{app} \\
\text{Load} &
\end{align*}
\]

New RPM Advantages 1 (2)

- Model-free, fast real-time voltage instability detection method*, independent of state estimation

- Implementation in several variants: bus, load center, transmission line, transmission corridor
  - Calculates Q-margin & other indices for proximity to voltage collapse
  - Stability boundary calculated with real-time PMU data refresh rate

- Easily combined as complementary to other methods and indices
  - Reactive power monitoring
  - Could initiate model-based contingency analysis, e.g. by alarming the operator

New RPM Advantages 2 (2)

- Ability to process data from different sources (PMUs, SCADA, simulation outputs (static and dynamic))
  - Takes immediate advantage of available PMUs
  - Scales up well with increased number of PMUs

- Excellent results from actual system tests on slowly changing system operating conditions (load ramp) and in tracking system dynamics after large disturbances

- Able to distinguish FIDVR from voltage instability even if voltage is very low

- Simple implementation in Control Center tools local and/or IEDs for:
  - Operator tools to increase situational awareness
  - Local automated actions
  - Addition to SIPS

Load center (Source: BPA)
Alarm when measuring real-time Q margins

Realistic PQ-curve slope before and after the disturbance
Comprehensive tests using real-life PMU and SCADA measurements and off-line time-sequence simulation tools

- Ability to detect instability even if voltage close to nominal
  - Accurate results for load centers, transmission lines, and corridors
  - Detection at highly-meshed high voltage systems (e.g. 500 kV) is more difficult
- Results comparable to detailed, model-based off-line QV analysis; very accurate closer to instability boundary
- Discriminates between FIDVR and fast voltage instability
  - FIDVR cases (no voltage collapse) are accurately detected despite the fact the voltage is low for some time
- No false alarms
Present and Future Activities

- Deploying real-time application software based on RPM
- Developing visualization tools to display the Corridor & Load Center results in a control room, including FIDVR detection
- Design monitoring and control strategies based on RPM

Source: SCE