Real-Time PMU-Based Tools for Monitoring Operational Reliability  
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**Project Objectives**
- The objective of this project is to develop real-time PMU-based tools for operational reliability monitoring
- In particular, this project will address the following problems:
  i) Small-signal stability monitoring
  ii) Transient stability monitoring
- A key feature of this project is to use the PMU data together with limited knowledge of the system topology

**Relevance**
- PMUs have been acknowledged as an enabling technology for transforming real-time power system operations
- Despite this potential, their utilization in real-time applications has been limited so far
- The research has the potential to provide tools for system operators and assist them with operational reliability issues
- The research leverages data and information for real-time wide-area monitoring tools, which have been researched and prototyped under CERTS for NERC, FERC, and DOE

**Overview of Research and Hypothesis**
- Hypothesis: it is possible to monitor small-signal stability conditions from phasor information, across certain transmission lines, collected in real-time by PMUs, without having an accurate model of the system
- Hypothesis: for transient stability monitoring, for every monitored line, phasor information can be used to estimate two-machine system dynamic equivalent models as seen from both ends of the line
- We envision that it is possible to conduct all computations in a distributed manner using the PMU processors
- No need to push the data to a centralized location
- A key of the research is to provide theoretical grounds to justify these hypotheses

**Research approach**

**System Equivalents**
- For stability monitoring, it is necessary to obtain an estimate of the angle of the ac-system
  - The ac-system can be calculated after obtaining two external system equivalents as seen from both ends of the monitored transmission line
- These external equivalents are two simple per-phase Thevenin equivalents, where it is assumed that
  - The Thevenin impedance is purely imaginary \(X_L, X_C\)
  - The magnitude of the Thevenin voltage source \(E_L, E_C\) is constant. The angle \(\angle X_L, \angle X_C\) changes along with time.

**Parameter Estimation Algorithm**
- Kirchhoff’s laws give:
  \[
  E_i \angle \delta_i = V_i \angle \theta_i + j X_i I_i \angle \gamma_i, \quad i = 1, 2
  \]
- \(V_i, I_i, E_i, \gamma_i\): the measurements on ends \(1\) or \(2\) at time \(t\)
- Estimates of parameters in equivalents can be obtained as follows:
  \[
  \hat{X}_i: \text{the positive root of equation (1.2)} - j \hat{X}_i \angle \delta_i + j (V_i \angle \gamma_i - \gamma_i)
  \]
  \[
  \hat{E}_i, \hat{\delta}_i: \quad \hat{E}_i \angle \hat{\delta}_i = \hat{V}_i \angle \hat{\gamma}_i + j \hat{X}_i I_i \angle \gamma_i, \quad i = 1, 2
  \]

**Hypothesis:** angle-across system provides an indicator of closeness to small-signal instability
- Ongoing theoretical and simulation analysis to verify this hypothesis
- Postulation of multi-port equivalents that consider several PMUs and partial information of the system model structure

**Future Work**
- Modify estimation filter parameters, e.g., window size to improve the precision of the estimates
- Conduct transient stability analysis based on the equivalent model and verify this approach in other real and simulated cases

**Extension to Transient Stability Analysis**
- For transient stability, it is necessary to obtain an estimate of the equivalent generator inertia
  - The inertia can be estimated based on the measurement frequency spectra:
    \[
    \dot{H} = \frac{\alpha E \dot{E} \cos(\dot{\delta})}{2\pi f_m^2 (\dot{X}_L + X_{mea} + X_C)}
    \]
  - After all the parameters are estimated in the equivalents, comprehensive stability analysis can be performed

**Testbed for Experimental Validation**
- Illinois Hardware-in-the-loop (HIL) testbed: RTDS+PMUs/PDC

**Case Studies**
- Small-Signal Stability: Angle-across-system
  - Data: 08/17/2011
  - (a) work period (12:00-13:00)
  - (b) off-work period (18:00-19:00)
  - The power system is more stressed during the work period
  - Measurements’ Frequency Spectra (preliminary result)

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