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

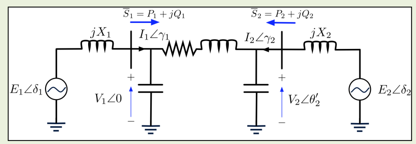
Overview of Research and Hypothesis

- 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-across-system
  - The angle-across-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_1,X_2)
  - The magnitude of the Thevenin voltage source (E_1,E_2) is constant. The angle (δ_1,δ_2) changes along with time.



Parameter Estimation Algorithm

- Kirchhoff's laws give:

$$E_i\angle\delta_{i,t_1} = V_{i,t_1}\angle\theta_{i,t_1} + jX_i I_{i,t_1}\angle\gamma_{i,t_1},\ i=1,2$$

$$E_i\angle\delta_{i,t_2} = V_{i,t_2}\angle\theta_{i,t_2} + jX_i I_{i,t_2}\angle\gamma_{i,t_2},\ i=1,2$$

$V_{i,t}, \theta_{i,t}, I_{i,t}, \gamma_{i,t}$: the measurements on ends i (1 or 2) at time t

- Estimates of parameters in equivalents can be obtained as follows:

$\hat{X}_i$: the positive root of equation

$$(I_{i,t_2}^2 - I_{i,t_1}^2)\hat{X}_i^2 + [2I_{i,t_2}V_{i,t_2}\sin(\theta_{i,t_2} - \gamma_{i,t_2})$$
$$-2I_{i,t_1}V_{i,t_1}\sin(\theta_{i,t_1} - \gamma_{i,t_1})]\hat{X}_i + (V_{i,t_2}^2 - V_{i,t_1}^2) = 0$$

$$\hat{E}_i, \hat{\delta}_{i,t}:\ \hat{E}_i\angle\hat{\delta}_{i,t} = V_{i,t}\angle\theta_{i,t} + j\hat{X}_i I_{i,t}\angle\gamma_{i,t},\ i=1,2$$

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

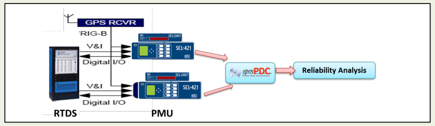
Extension to Transient Stability Analysis

- 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:

$$\hat{H} = \frac{\omega_s \hat{E}_1 \hat{E}_2 \cos(\hat{\delta}_{12})}{8\pi^2 f_{dom}^2 (\hat{X}_1 + X_{line} + \hat{X}_2)}$$

  - After all the parameters are estimated in the equivalents, comprehensive stability analysis can be performed

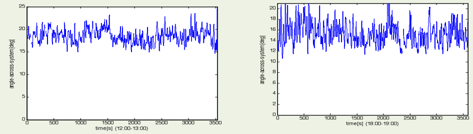
Testbed for Experimental Validation



Illinois Hardware-in-the-loop (HIL) testbed: RTDS+PMUs/PDC

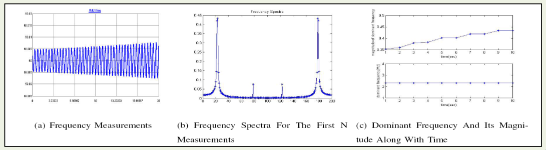
Case Studies

- 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)



The estimated inertia matches with the real inertia in RTDS

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