DOE/OE Transmission Reliability Program

Angle Instability Detection in Power Systems with High Wind Penetration Using PMUs

YC Zhang

National Renewable Energy Laboratory

Yingchen.zhang@nrel.gov

27/28 June 2013

Washington, DC

Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

- Project Objective
  - Utilize synchrophasor measurements to estimate the equivalent inertia of a power source such as synchronous generators or wind turbine generators
  - Develop angle instability detection method for a system with high wind penetration using the synchrophasor measurements

Background

- In case of angular instability, some machines will have aperiodic angular separation from the rest of the system and finally lose synchronization. The total system inertia is an essential force to rest the system transient.
- Several types of renewable generation, particularly those with power electronic interfaces, have an inertial response governed by a control function. There is a need to estimate the equivalent inertia available from a renewable generation plant.

Center-of-Inertia

The term Center-of-Inertia (COI) was introduced by Kundur for the convenience of transient instability studies. It essentially describes the center of rotor angles which are weighted by their inertias:

$$\delta_{COI} = \frac{1}{H_T} \sum_{i=1}^{n} H_i \, \delta_i$$

However, real-time generator inertias are typically hard to access

Inertia estimation using PMU measurements

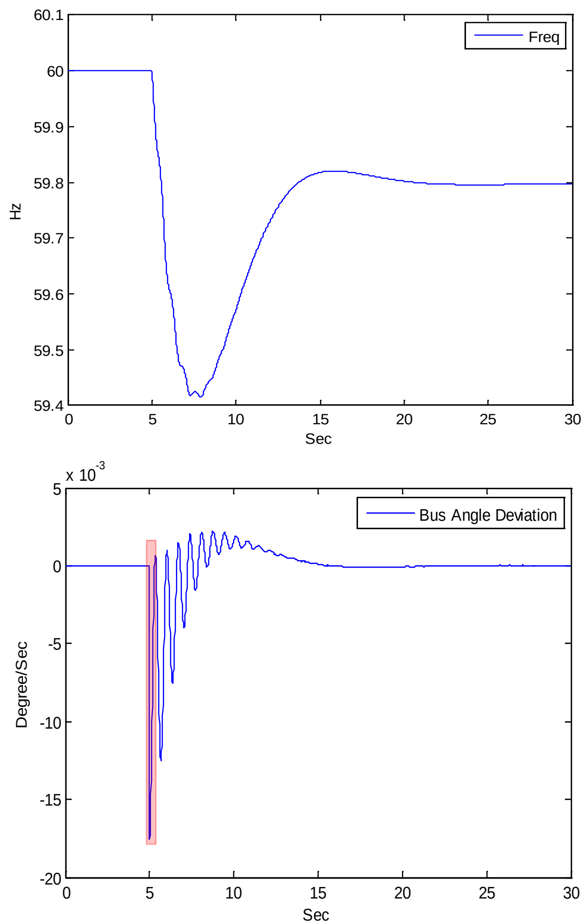
$$\frac{2H}{\omega_0}\frac{\partial^2\Delta\delta}{\partial t^2} = P_M - P_E - K_D\Delta\omega$$

$$\frac{2H}{\omega_0}\frac{\partial^2\Delta\theta}{\partial t^2} = P_M - P_E - K_D\frac{\partial\Delta\theta}{\partial t}$$

$$H\frac{2}{\omega_0}\left(\frac{\partial^2\theta(t+1)}{\partial t} - \frac{\partial^2\theta(t)}{\partial t}\right) = P_{E0} - P_E(t)$$

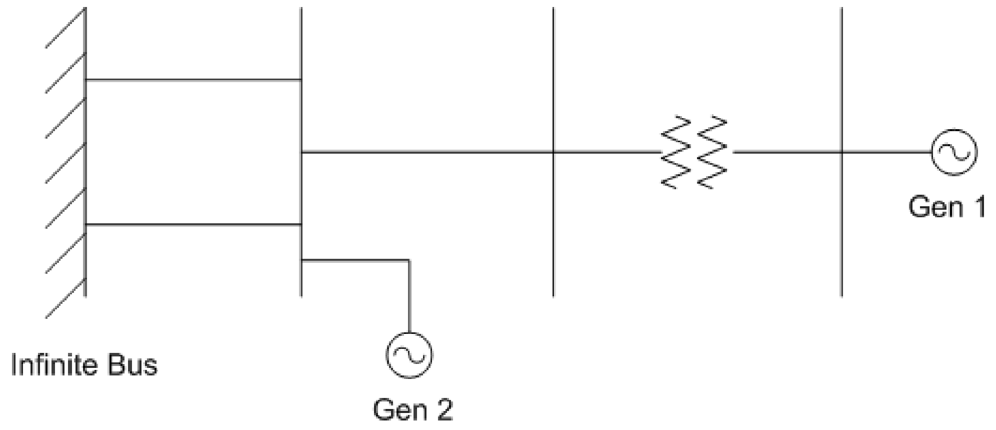
$$H\frac{2}{\omega_0}\left(\frac{\theta(n+3) - 3\theta(n+2) + 3\theta(n+1) - \theta(n)}{Ts^2}\right) = P_{E0} - P_E(n)$$

Inertia estimation using PMU measurements



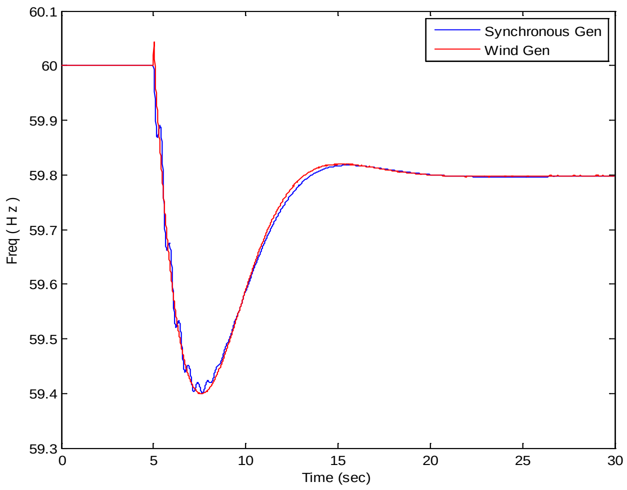
this method can utilize the discrete PMU measurements (bus angles and real power) to estimate the generator inertia in a really short time window after a disturbance

Inertia estimation using PMU measurements



H (Input)	2	4	6	8	10
H (Calc)	2.33	3.84	5.99	7.92	9.67
% Error	16.5	4.0	0.17	1.0	3.3

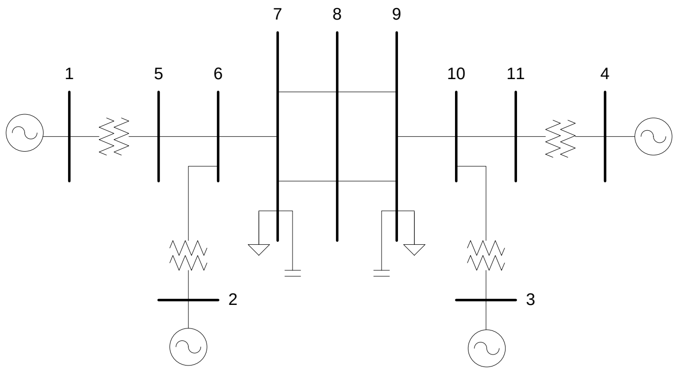
Inertia estimation using PMU measurements

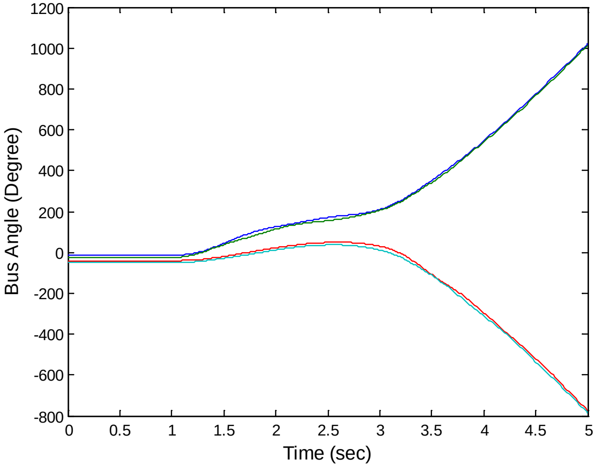


The frequency responses were closely aligned, which indicates a similar inertial support that both generators provided to the system. Thus, the wind generator inertia constant H can be approximated by the synchronous gen generator.

The equivalent inertia constant was calculated as 1.832

Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

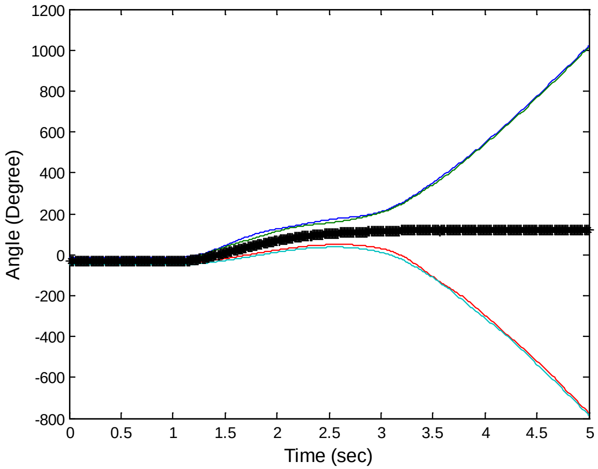


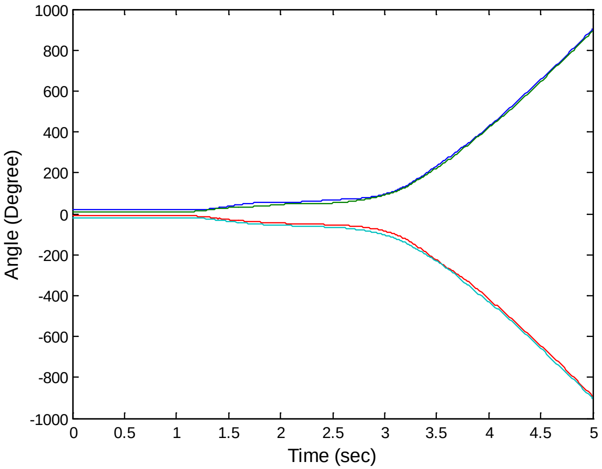


Test system and bus angle separation

Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

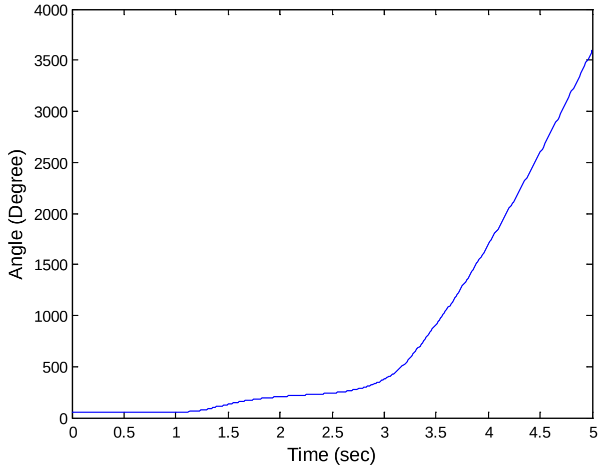
$$\delta_{CBA} = \frac{1}{H_T} \sum_{i=1}^{n} H_i \, \delta_{bi}$$

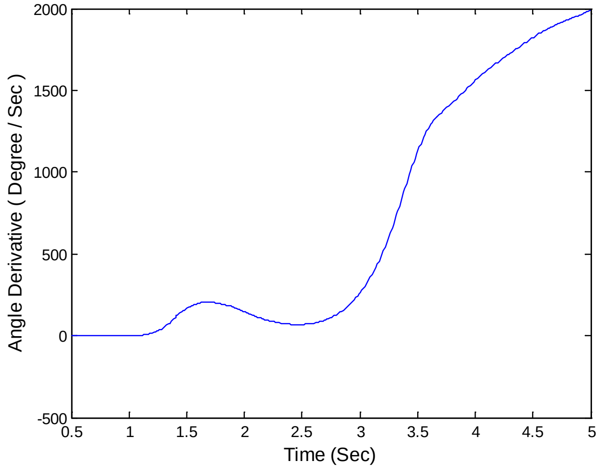




Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

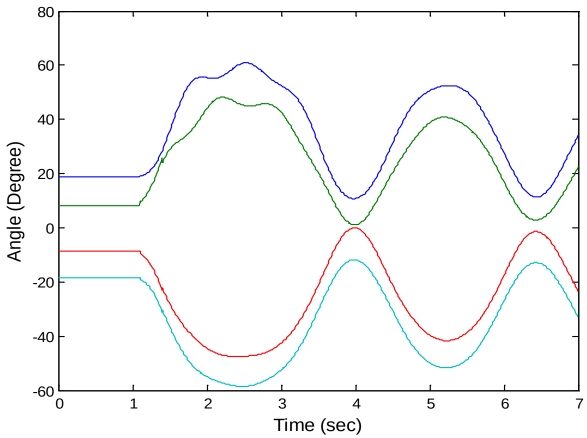
$$\delta_{TAS} = \sum_{i=1}^{n} |\delta_{bi} - \delta_{CBA}| \qquad Derivative\ of\ \delta_{TAS} = \frac{d\delta_{TAS}}{dt}$$

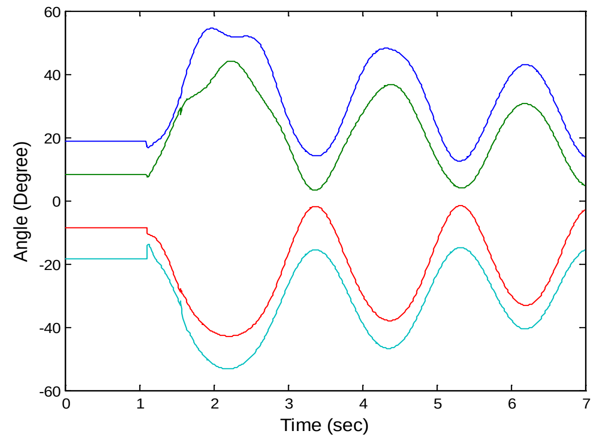




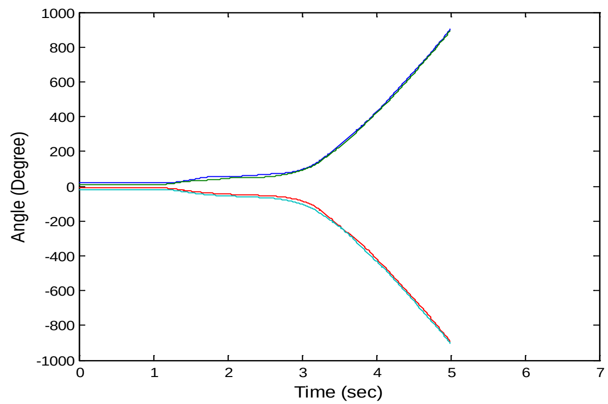
Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

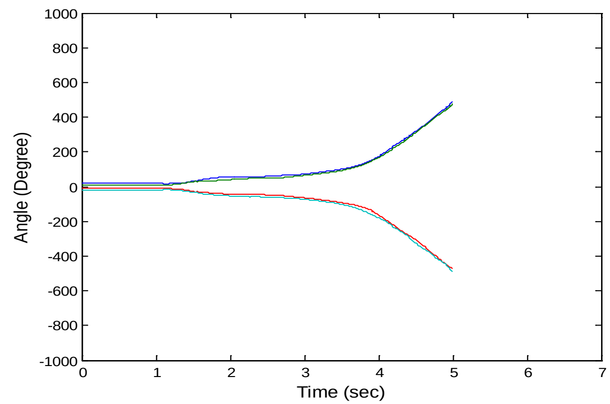
	Fault on	Stable clearing	Unstable clearing
Without WPP	1.1 sec	1.4 Sec	1.41 sec
With WPP	1.1 sec	1.55 sec	1.56 sec

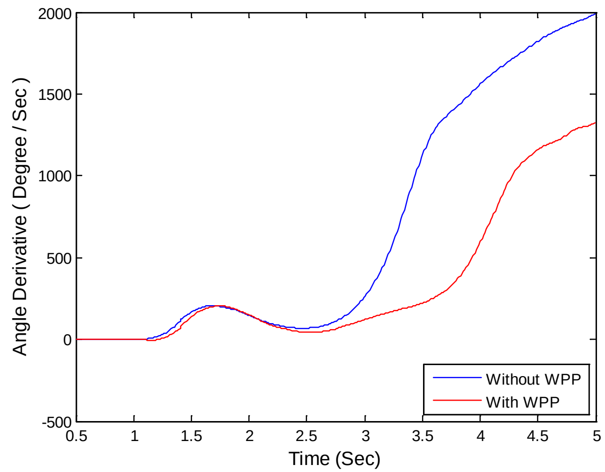




Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements







Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

- Major technical accomplishments

  Theoretical study and test with simulation
- Deliverables and schedule for activities to be completed under FY13 funding

Y. Zhang, et al. "Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements, " IEEE Journal of Emerging and Selected Topics in Power Electronics, pp. 1–8, 2013, in process

Angle Instability Detection in Power Systems with High Wind Penetration Using Synchrophasor Measurements

- Risk factors affecting timely completion of planned activities as well as movement through RD&D cycle

  Real system test and PMU data requirement

- Early thoughts on follow-on work that should be considered for funding in FY14

  High renewable's impact on system stability margin and real-time stability margin estimation using PMUs