INTERAREA MODEL ESTIMATION FOR RADIAL POWER SYSTEM TRANSFER PATHS USING SYNCHRONIZED PHASOR DATA

Aranya Chakrabortty and Joe H. Chow

Electrical, Computer and Systems Engineering Department, Rensselaer Polytechnic Institute, Troy, NY.

PHASOR MEASUREMENT UNITS
REAL TIME DATA ACQUISITION & CONTROL

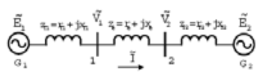
- Synchronized Phasor Measurement Units (PMUs) are digital data recording devices that measure positive sequence current and voltage phasors in a substation and time-stamp these measurements with GPS derived reference

Objective :

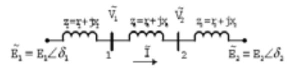
- Our objective is to estimate dynamic model parameters of a 2-area power system using PMU disturbance data.
- We develop an algorithm by which amplitudes of post-disturbance voltage oscillations at intermediate buses are used to extrapolate unknown reactances to machine internal node.
- The algorithm also makes use of the bus angle and frequency data to estimate the machine inertias.
- The method is derived first for a 2-machine system [1] and then extended to a 2-area system [2].
- Simulation results are presented to illustrate the derivations.

DYNAMIC MODEL ESTIMATION
DME PROBLEM FORMULATION FOR A TWO-MACHINE RADIAL POWER SYSTEM

Two machine power system



Classical model representation



Z_{Ti} = Transformer Impedance

$Z_i = Z_{Ti}$ + Direct axis Transient Reactance of G_i

$$\dot{\delta}_i = \Omega \omega_i \qquad (i = 1, 2)$$
$$2H_i \dot{\omega}_i = P_m - P_e - P_{loss}$$

where

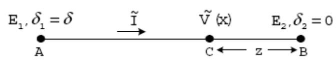
$$P_m = \frac{H_2 P_{m1} - H_1 P_{m2}}{H_s},\quad P_{loss} = \frac{r}{z_m}\frac{H_2 E_1^2 - H_1 E_2^2}{H_s},\quad P_e = \frac{-E_1 E_2}{z_m}\frac{H_2\cos(\delta+\alpha) - H_1\cos(\delta-\alpha)}{H_s}$$

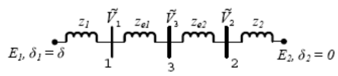
- Assume PMUs are located at Buses 1 and 2
- Available Phasor Variables – $V_1, \theta_1, V_2, \theta_2, I$ & θ_I

DME Problem : Given the available phasor variables, that exhibit a few cycles of oscillations, and assuming E_1 and E_2 to be constant, compute $E_1, \delta_1, E_2, \delta_2, z_1, z_2, z_e, H_1$ & H_2 to completely characterize the dynamic behavior of the 2-machine system.

PARAMETER ESTIMATION USING PMU DATA
TRANSFER REACTANCE EXTRAPOLATION

- **Key idea** : Amplitude of voltage oscillation at any point on the transfer path is a function of its electrical distance from the two fixed voltage sources.





$$\tilde{V}(x,r) = [E_2(1-a) + E_1(a\cos(\delta) - b\sin(\delta))] + j[E_1(b\cos(\delta) + a\sin(\delta)) - bE_2]$$

where, $a = \frac{rr_e' + xx_e'}{r_e'^2 + x_e'^2}$, $b = \frac{xr_e' - rx_e'}{r_e'^2 + x_e'^2}$

- Voltage Magnitude at C : $|V(x,r)| = |\tilde{V}(x,r)| = \sqrt{c + 2E_1E_2(a - a^2 - b^2)\cos(\delta) - b\sin(\delta)}$ where, $c = E_2^2(b^2 + (1-a)^2) + E_1^2(b^2 + a^2)$
- Linearize model about (δ_0, $\omega_0 = 0$, V_{ss}) : $\Delta V(x) = J(a,b,\delta_0)\Delta\delta$
- Assume uniform impedance along transfer path → $a = \frac{x}{x_e}$ and $b = 0$,

$$J(a,0,\delta_0) = \frac{-2E_1E_2\sin(\delta_0)}{V(a,b,\delta_0)}a(1-a) \qquad (*)$$

⇨ • **Note** : $J(x,\delta_0)$ in (*) has a numerator varying with x, and a denominator equal to steady state voltage at C

$J(x,\delta_0)$ can be used to estimate x_1 and x_2 if voltage oscillations are measured at an additional intermediate bus between Bus 1 and 2

- Following a perturbation, let V_{im} = Amplitude of Voltage Swing at Bus i, V_{iss} = Steady-state Voltage at Bus i } **Computed from PMU measurements** ⇨
- From (*) , $V_{in} = V_{im}V_{iss} = A(1-a_i)\,a_i,\quad i = 1, 2, 3$ with $A = 2E_1E_2\sin(\delta_0)$
- x_1 and x_2, and A can now be solved numerically (3 nonlinear equations with 3 unknowns)

MACHINE INERTIA ESTIMATION

- Again use linearization to derive bus frequency and machine speed expressions

$$\xi_1 = \frac{a_1\omega_1 + b_1(\omega_1 + \omega_2)\cos(\delta_1 - \delta_2) + c_1\omega_2}{a_1 + 2b_1\cos(\delta_1 - \delta_2) + c_1}$$

$$\xi_2 = \frac{a_2\omega_1 + b_2(\omega_1 + \omega_2)\cos(\delta_1 - \delta_2) + c_2\omega_2}{a_2 + 2b_2\cos(\delta_1 - \delta_2) + c_2}$$

- ξ_1 & ξ_2 are measured as bus frequencies
- Estimate the generator frequencies ω_1 & ω_2
- Estimate the ratio of machine inertias using $H_1 / H_2 = -\omega_2/\omega_1$

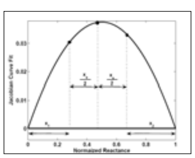
where $a_i = E_1^2(1-r_i)^2$, $b_i = E_1E_2r_i(1-r_i)$, $c_i = E_2^2 r_i^2$ $(i=1, 2)$ and $r_1 = \frac{x_1}{x_1 + x_2 + x_e}$,

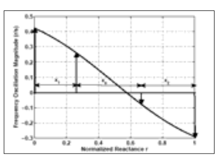
- For a second equation in H_1 and H_2, use the expression for swing frequency

$$f_s = \frac{1}{2\pi}\sqrt{\frac{E_1E_2\cos(\delta_0)\Omega}{2H(x_e + x_1 + x_2)}} \Rightarrow H = \frac{H_1H_2}{H_1 + H_2} = \frac{E_1E_2\cos(\delta_0)\Omega}{2(2\pi f_s)^2(x_e + x_1 + x_2)}$$

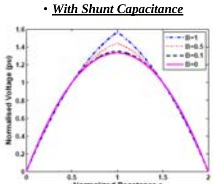
SPATIAL VARIATION OF VOLTAGE AND FREQUENCY

- ***Without Intermediate Voltage Support***

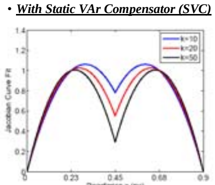




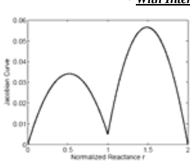
- ***With Shunt Capacitance***



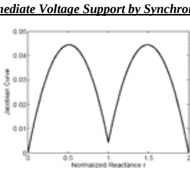
- ***With Static VAr Compensator (SVC)***



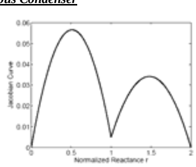
- ***With Intermediate Voltage Support by Synchronous Condenser***



$x_1 < x_2$



$x_1 = x_2$



$x_1 > x_2$

CONCLUSIONS & BIBLIOGRAPHY

- We propose Interarea Model Estimation algorithms for calculating the dynamic model parameters of two-machine power systems using voltage and current phasor data. The main contribution is the novel use of the oscillation amplitude in bus voltages to extrapolate toward the fixed voltage point within a synchronous machine, and the bus frequency oscillations to extrapolate the machine inertias. The algorithm is extended to systems with intermediate voltage support.

References : [1]. J. H. Chow *et al*., accepted in *IEEE Trans. on Power Systems, 2008.* [2]. A. Chakrabortty *et al*., *Technical Report*, RPI, *2007.*
[3]. A. Chakrabortty and J. H. Chow, *in proceedings of IEEE PES GM 2008.*

Rensselaer

CATS Center for Automation Technologies and Systems

NYSTAR