

Direct Non-Iterative State Estimation (DNSE) for Power Systems

B. Fardanesh

NYPA

August 7, 2018

Portland, OR

New Paradigm

- Historically we have used iterative techniques (Least- Squares) to solve the state estimation problem
- A direct one-shot solution for the state estimation is now possible
- Full AC solution-No Simplifications
- No more iterations
- No reliance on the “goodness” of the initial guess
- An envisioned superfast more robust solution

State Estimator problem formulation

- Power Flow equations in Rectangular form
- Naturally in the desired form:

$$\overline{V}_i = a_i + jb_i$$

$$\sum_{i=1}^N \operatorname{Re}(Y_{ij})(a_j a_i + b_j b_i) + \operatorname{Im}(Y_{ij})(a_i b_j - a_j b_i) = P_{G_j} - P_{D_j}$$

$$- \sum_{i=1}^N \operatorname{Re}(Y_{ij})(a_j a_i - a_i b_j) + \operatorname{Im}(Y_{ij})(a_i a_j + b_j b_i) = Q_{G_j} - Q_{D_j} \quad j = 2, \dots, N$$

- Measurement equations have similar form

A Simple Example

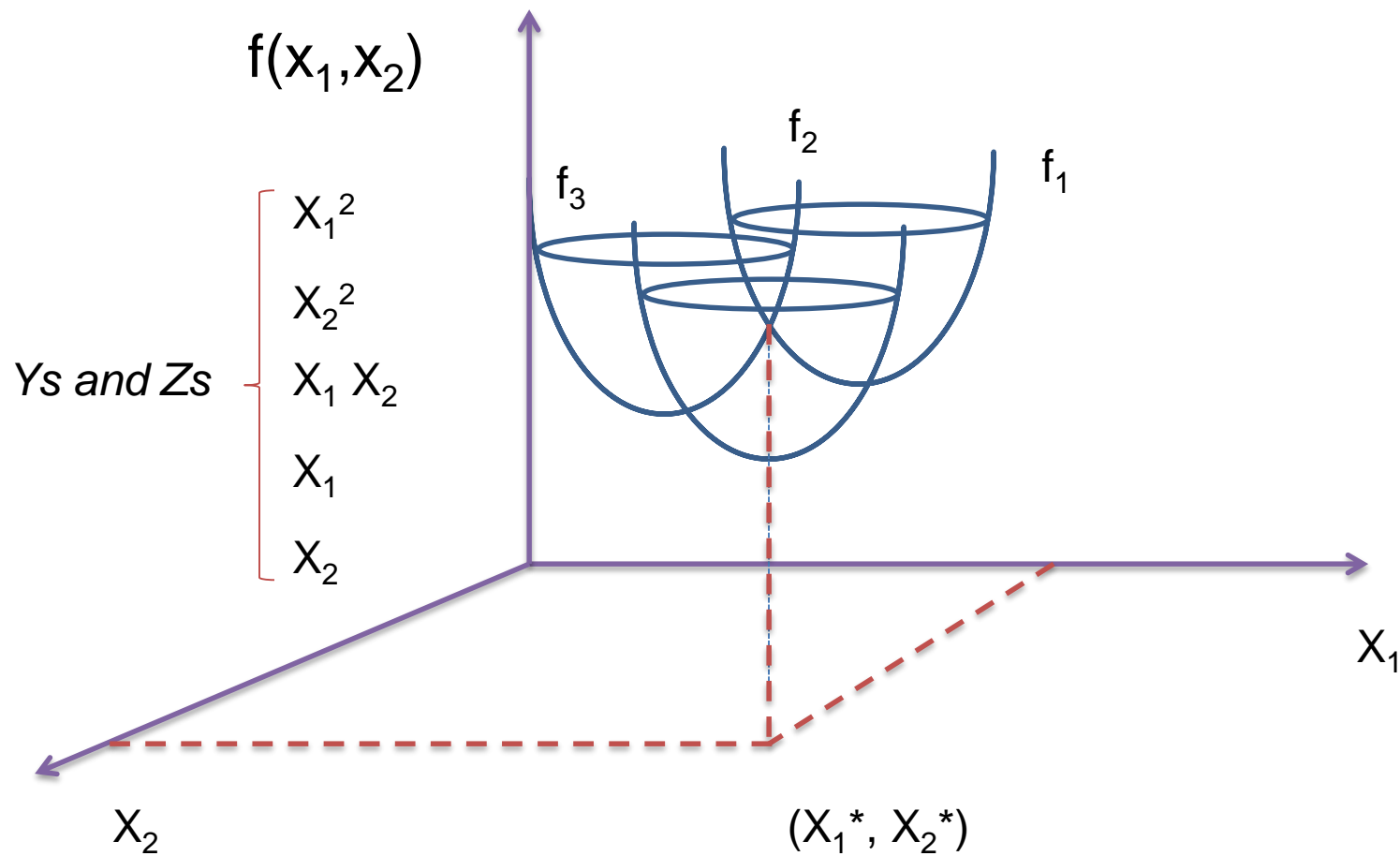
- Redundant Polynomial Equations

$$\begin{array}{rcl}
 x_1^2 - 2x_1x_2 + x_3^2 + x_2 & = & 8 \\
 2x_2x_3 - x_2^2 + 2x_1 & = & 10 \\
 5x_1x_3 - x_1x_2 + 3x_3 + x_2^2 & = & 26 \\
 7x_1^2 - 2x_2x_3 + x_3^2 - 5x_3 & = & -11 \\
 x_1^2 - x_2^2 - 5x_2x_3 + 12x_1 & = & -13
 \end{array}
 \left[\begin{array}{cccc|cccc}
 1 & -2 & 1 & 1 & 0 & 0 & 0 & 0 \\
 0 & 0 & 0 & 0 & 2 & -1 & 2 & 0 \\
 0 & -1 & 0 & 0 & 0 & 1 & 0 & 5 \\
 7 & 0 & 1 & 0 & -2 & 0 & 0 & -5 \\
 1 & 0 & 0 & 0 & -5 & -1 & 12 & 0
 \end{array} \right]
 \begin{array}{l}
 y_{11} \\
 y_{12} \\
 y_{33} \\
 y_{20} \\
 \underline{y_{23}} \\
 z_1 \\
 z_2 \\
 z_3 \\
 z_4
 \end{array}
 =
 \begin{array}{l}
 8 \\
 10 \\
 26 \\
 -11 \\
 -13
 \end{array}$$

$$[M \mid T] \begin{bmatrix} Y \\ Z \end{bmatrix} = [R] \quad Y = M^{-1}(R - TZ)$$

Solve for the y_s in terms of the z_s

Basics of the Re-Linearization Method



Basics of the Re-Linearization Method

Form new quadratic
Surfaces in term of Z_s

$$y_{ij} y_{mn} = y_{im} y_{jn} = \dots = y_{in} y_{jm}$$

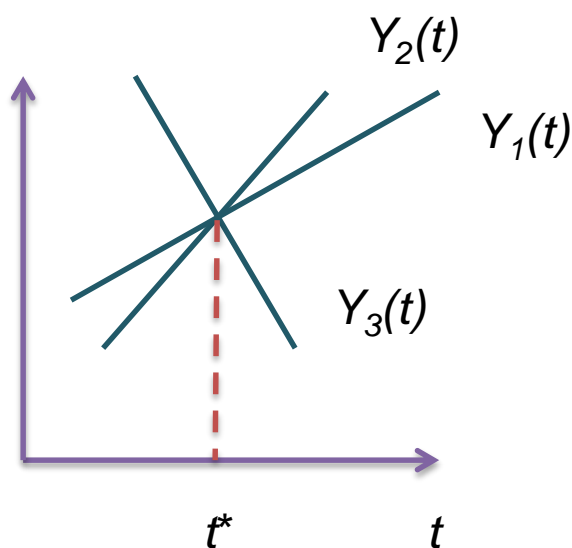
and change variables to t_s :

$$\left[z_1 \ z_2 \ z_3 \ z_4 \ z_1 z_2 \ z_1 z_3 \ z_1 z_4 \ z_2 z_3 \ z_2 z_4 \ z_3 z_4 \ z_1^2 \ z_2^2 \ z_3^2 \ z_4^2 \right]$$

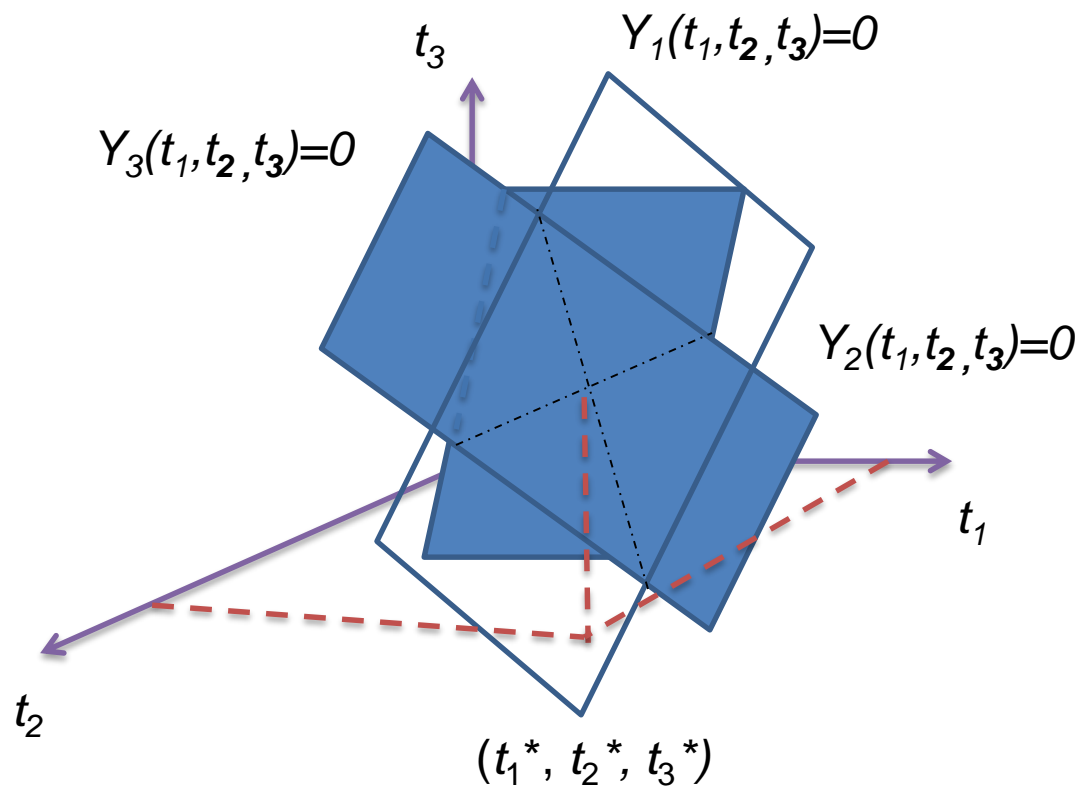
$$\begin{bmatrix} -241.5 & 2849 & 0 & 60 & 337 & 0 & 7.5 & 0 & -85 & 0 & -14.25 & -1989 & -1 & 0 \\ 64 & 0 & 260 & 156 & -17 & -10 & -6 & 0 & 0 & -30 & 0.5 & 0 & -25 & -9 \\ -163.5 & 1667 & -120 & -12 & 321 & -15 & -1.5 & 175 & 20 & 0 & -15 & -1700 & 0 & 0 \\ -13.5 & 97 & -26 & 0 & 10 & 1 & 0 & 0 & 0 & 3 & -0.75 & -17 & 5 & 0 \\ -90 & 10 & 0 & 0 & 118 & 0 & 5 & 0 & 0 & 0 & -9.75 & -1 & 0 & 0 \\ 0 & -85 & 0 & 0 & -9.5 & 0 & 0 & 0 & 5 & -1 & 0 & 117 & 0 & 0 \\ 0 & 0 & 29 & 26 & 0 & 10 & -1 & -100 & 0 & -4 & 0 & 0 & 10 & -3 \\ 0 & 5 & 0 & 26 & 0.5 & 0 & -1 & 0 & 0 & -5 & 0 & -1 & 0 & -3 \\ -162 & 3042 & 430 & 385 & -117 & 48 & 23.5 & -586 & -351 & -25 & 9.5 & 0 & 0 & -15 \\ 1125.5 & -11893 & 850 & -55 & -2120 & 95 & -40 & -1170 & 382 & -50 & 95 & 11700 & 0 & -5 \\ 231 & -2600 & 115 & -61 & 101 & -60 & -31 & 500 & 300 & -35 & -10 & 0 & -50 & -3 \\ 8 & -26 & -25 & -15 & 1 & -1.5 & -1.5 & 5 & 3 & 0 & -0.5 & 0 & 0 & 0 \\ -64.5 & 529 & -50 & -5 & 60 & -5 & 0.5 & 10 & 1 & 0 & -5 & -100 & 0 & 0 \\ 0 & 0 & 0 & -12 & 0 & 0 & -1.5 & 1 & 17 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ t_3 \\ t_4 \\ t_5 \\ t_6 \\ t_7 \\ t_8 \\ t_9 \\ t_{10} \\ t_{11} \\ t_{12} \\ t_{13} \\ t_{14} \end{bmatrix} = \begin{bmatrix} 1020 \\ 676 \\ 348 \\ 60 \\ 25 \\ 0 \\ 0 \\ 0 \\ 2210 \\ -2465 \\ -754 \\ -130 \\ 145 \\ 0 \end{bmatrix}$$

Basics of the Re-Linearization Method

If only one Z

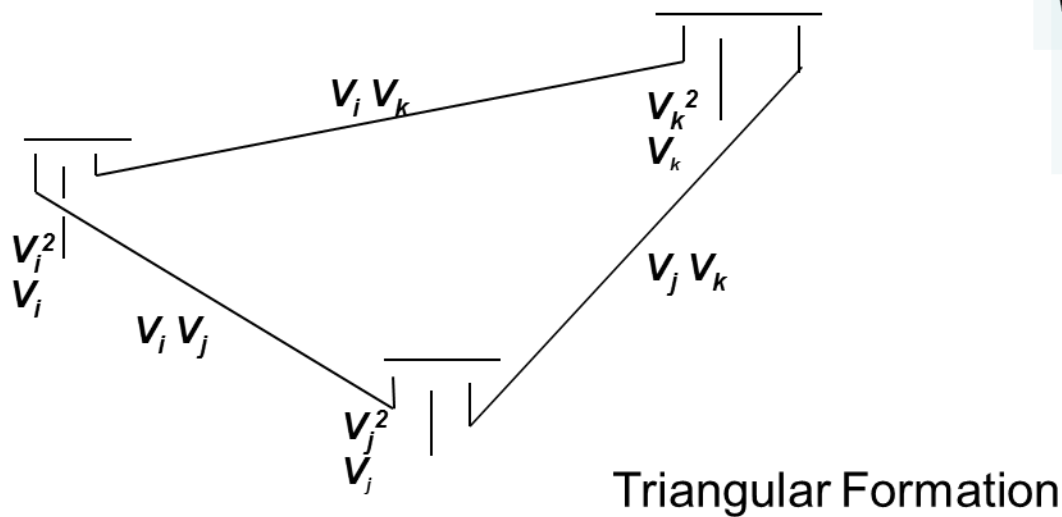
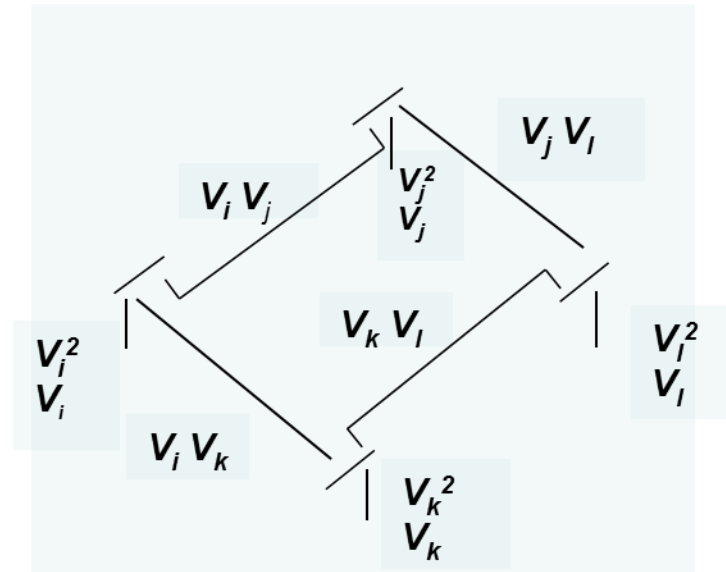
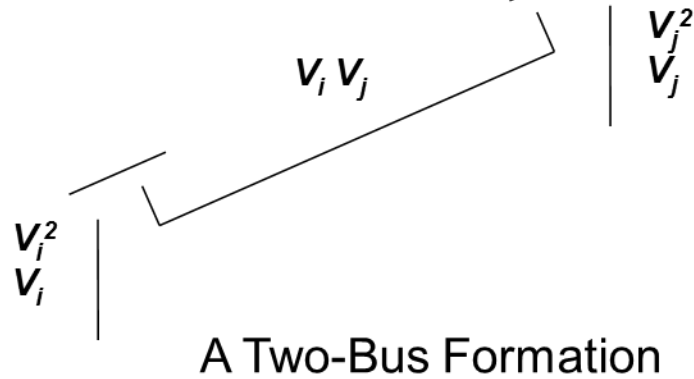


If Z_1 and Z_2 , we will have five ts ;
Assuming only three ts are present:



Dual Transformation and Direct One-Shot Solution

Relation to Network Topology



Benefits

- Direct State Estimation/Solution
- More robust— No more iterations
- No reliance on the initial guess
- Can accept both measurement types from the system at the control center—SCADA and PMU—Hybrid SE
- Fast— Perhaps limited only by the communication links' latency
- A much more “dynamic” assessment of the system conditions and behavior
- Potential for ultimate use in closed-loop and automatic control of power systems

DOE funded Project—Pre-Commercial Demonstration Quanta Technologies and EPG working with NYPA

- Pre-Commercial Demonstration of Direct Non-Iterative State Estimator (DNSE+)
- Award number: DE-OE0000704
- \$998,890 DOE share
- \$1,052,978 Cost share
- \$2,051,868 Total project value

Project Accomplishment for DNSE+

- Successfully demonstrated DNSE+ at New York Power Authority (NYPA):
 - Used both SCADA and synchrophasor data simultaneously to obtain the complete state of the entire NYPA operating model at rates close to the phasor data rates, and without iterations.
 - Developed input/output adapters based on standards (IEEE 37.118 for streaming synchrophasor data, ICCP and SQL for SCADA exchange and CIM to export the EMS model data)
- Proved that DNSE+ is a commercially viable application by successful integration with commercial products (EMS and RTDMS)
 - RTDMS has been enhanced as part of the project
 - Enhanced C37.118-5 to include large data frames
 - Showed that DNSE+ is ready for use at other utilities or ISOs to address a common need for “clean and trustworthy” operational data for synchrophasor applications

DNSE+ Conceptual System Architecture

