Washington State University
EE 521 Analysis of Power System
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Project 4
State Estimation

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Overview

In power system state estimation, the estimated variables are the voltage magnitude and the voltage phase angles at the system buses. The inputs to the state estimator are the active and reactive powers of the system, measured either at the injection sites or on the transmission lines. The state estimator is designed to give the best estimate of the voltage and phase angles, minimizing the effects of the measurement errors. Another consideration for the state estimator is to determine if a sufficient number of measurements are available to fully estimate the power system. This is the notion of system observability. In this project, we would use the common IEEE 14-Bus system to perform state estimation with least squares method.

Methodology

The first step in the estimation process is to identify and enumerate the unknown states. After the states are identify, the next step in the estimation process is to identify the appropriate function h(x) that correspond to each of the measurements. The first step in the estimation process is to identify and enumerate the unknown states.

$$z - z' = z - Hx' = e - H(x' - x) \qquad (1)$$

Where, z is a vector of actual measurements, h is a vector of function sets. An appropriate weighting factor w is added to the object the objective function f which is shown:

$$F = \sum_{i=1}^{n} w_i e_i^2 \qquad (2)$$

Therefore, we have

$$H^T W e' = H^T W (z - Hx') = 0 \qquad (3)$$

Where, W is the diagonal matrix of weighting factors which have special significance. Also, we have the equation:

$$e' = z - z' = e - HG^{-1}H^T We = [I - HG^{-1}H^T W]e \qquad (4)$$

Where, I is the unit or identity matrix.

Firstly, the actual state was calculated based on the power flow result. The voltage angle and voltage was obtained NR power flow. The power flow result is used to calculate the power injection for each bus and branch for transmission line. Since we get the actual state, the Gaussian distribution random noise has been added. The following is H matrix:

$$H = \begin{bmatrix} \frac{\partial V}{\partial \delta} & \frac{\partial V}{\partial V} \\ \frac{\partial P_i}{\partial \delta} & \frac{\partial P_i}{\partial V} \\ \frac{\partial Q_i}{\partial \delta} & \frac{\partial Q_i}{\partial V} \\ \frac{\partial P_{ij}}{\partial \delta} & \frac{\partial P_{ij}}{\partial V} \\ \frac{\partial Q_{ij}}{\partial \delta} & \frac{\partial Q_{ij}}{\partial V} \\ \frac{\partial P_{ji}}{\partial \delta} & \frac{\partial P_{ji}}{\partial V} \\ \frac{\partial Q_{ji}}{\partial \delta} & \frac{\partial Q_{ji}}{\partial V} \end{bmatrix} \tag{5}$$

According the equation $dx = x' - G^{-1}H^{T}W(z - z')$, the estimated measurement can be found by iterations. If the absolute value of the corrector is smaller than threshold the iteration stops and returns the results.

Also, in this project, we would add 3 bad data detection. Some measurements could be manually assigned extra noises.

Results

By running Matlab, we firstly get true voltage, voltage angle, estimated voltage and estimated voltage angle as the first bad data (Z(10)=4). f=117416.2.

	V	Vangle	VoltageSE	VangleSE
	14x1 double	14x1 double	14x1 double	14x1 double
	1	1	1	1
1	1.0600	0	1.2000	0
2	1.0450	-0.0869	1.1609	-0.0583
3	1.0100	-0.2220	1.0885	-0.1547
4	1.0177	-0.1800	1.0956	-0.1228
5	1.0196	-0.1531	1.1097	-0.1031
6	1.0700	-0.2481	1.1532	-0.1735
7	1.0616	-0.2331	1.1188	-0.1684
8	1.0900	-0.2331	1.1115	-0.1778
9	1.0560	-0.2607	1.1286	-0.1846
10	1.0510	-0.2635	1.1371	-0.1848
11	1.0569	-0.2581	1.1426	-0.1800
12	1.0552	-0.2630	1.1372	-0.1812
13	1.0504	-0.2645	1.1261	-0.1852
14	1.0356	-0.2798	1.1055	-0.1962

Fig 1. Actual solution and estimated solution for the first bad data

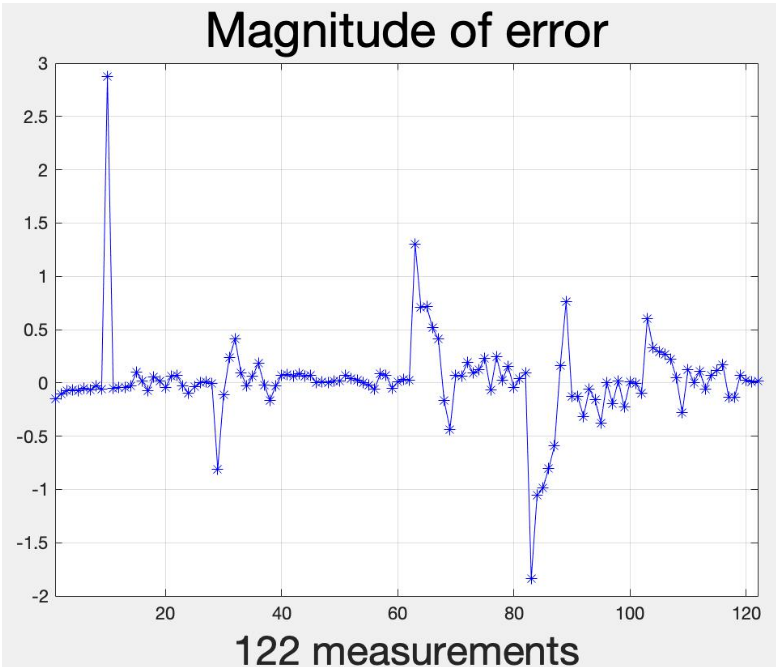

Fig 2. Bad data point for the first bad data

Then, we add the second bad data z(55)=5, we can get the related estimated voltage and voltage angle. f=131461.8

	V	Vangle	VoltageSE	VangleSE
	14x1 double	14x1 double	14x1 double	14x1 double
	1	1	1	1
1	1.0600	0	1.1094	0
2	1.0450	-0.0869	1.0648	-0.0694
3	1.0100	-0.2220	1.0113	-0.1814
4	1.0177	-0.1800	0.9715	-0.1466
5	1.0196	-0.1531	0.9481	-0.1172
6	1.0700	-0.2481	0.6096	-0.3450
7	1.0616	-0.2331	1.0135	-0.2127
8	1.0900	-0.2331	1.0860	-0.2152
9	1.0560	-0.2607	0.9470	-0.2554
10	1.0510	-0.2635	0.9214	-0.2514
11	1.0569	-0.2581	0.8258	-0.2584
12	1.0552	-0.2630	0.5797	-0.4546
13	1.0504	-0.2645	0.2692	-0.8667
14	1.0356	-0.2798	0.6989	-0.3483

Fig 3. Actual solution and estimated solution for the second bad data

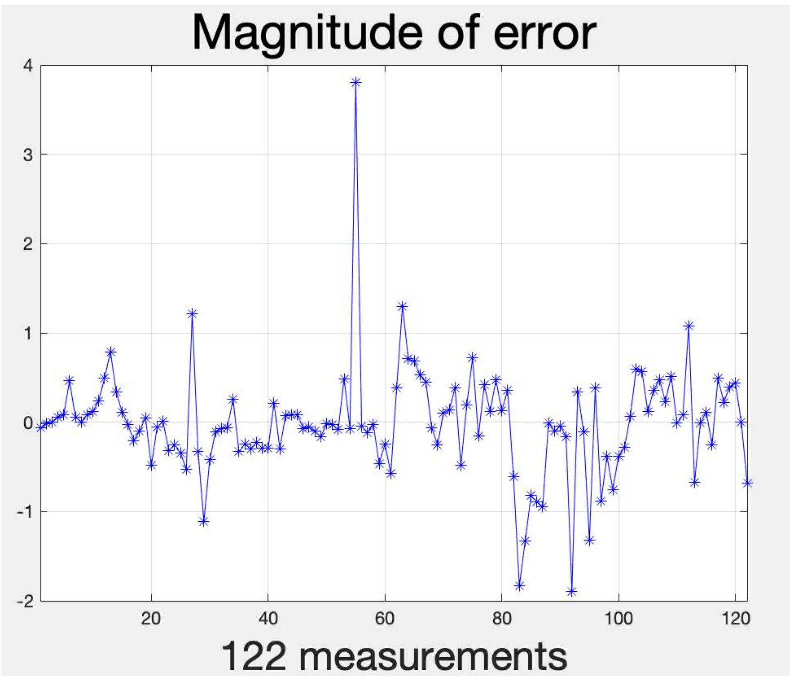

Fig 4. Bad data point for the second bad data

Finally, we add the second bad data z(105)=6, we can get the related estimated voltage and voltage angle. f=256201.2

	V	Vangle	VoltageSE	VangleSE
	14x1 double	14x1 double	14x1 double	14x1 double
	1	1	1	1
1	1.0600	0	0.9444	0
2	1.0450	-0.0869	0.8060	-0.0896
3	1.0100	-0.2220	0.1384	-1.0740
4	1.0177	-0.1800	0.7508	-0.2236
5	1.0196	-0.1531	0.8456	-0.1784
6	1.0700	-0.2481	1.0490	-0.2047
7	1.0616	-0.2331	0.9384	-0.2174
8	1.0900	-0.2331	0.9932	-0.2175
9	1.0560	-0.2607	0.9727	-0.2264
10	1.0510	-0.2635	1.0022	-0.2274
11	1.0569	-0.2581	1.0407	-0.2170
12	1.0552	-0.2630	1.0827	-0.2164
13	1.0504	-0.2645	1.0601	-0.2178
14	1.0356	-0.2798	1.0242	-0.2367

Fig 5. Actual solution and estimated solution for the third bad data

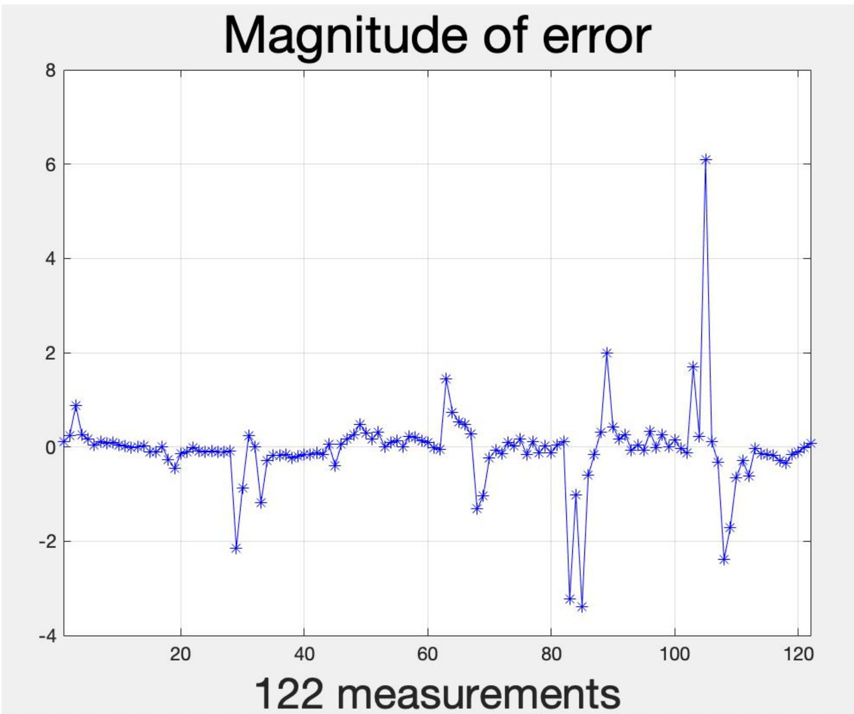

Fig 6. Bad data point for third bad data