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Believability Evaluation of a State Estimation Result

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Introduction

- **Problems in State Estimation Applications**
  - Accuracy deteriorated by bad data
  - Zero injection constraints
- **How to Evaluate the Believability of a SE Result?**
  - Lab: Compare estimation result with the simulated true power flow
  - Real systems: true state is unknown, how to do?
- **The only known is measurement, How to evaluate SE believability only by measurement**

Existing Problem (1) – Bad Data

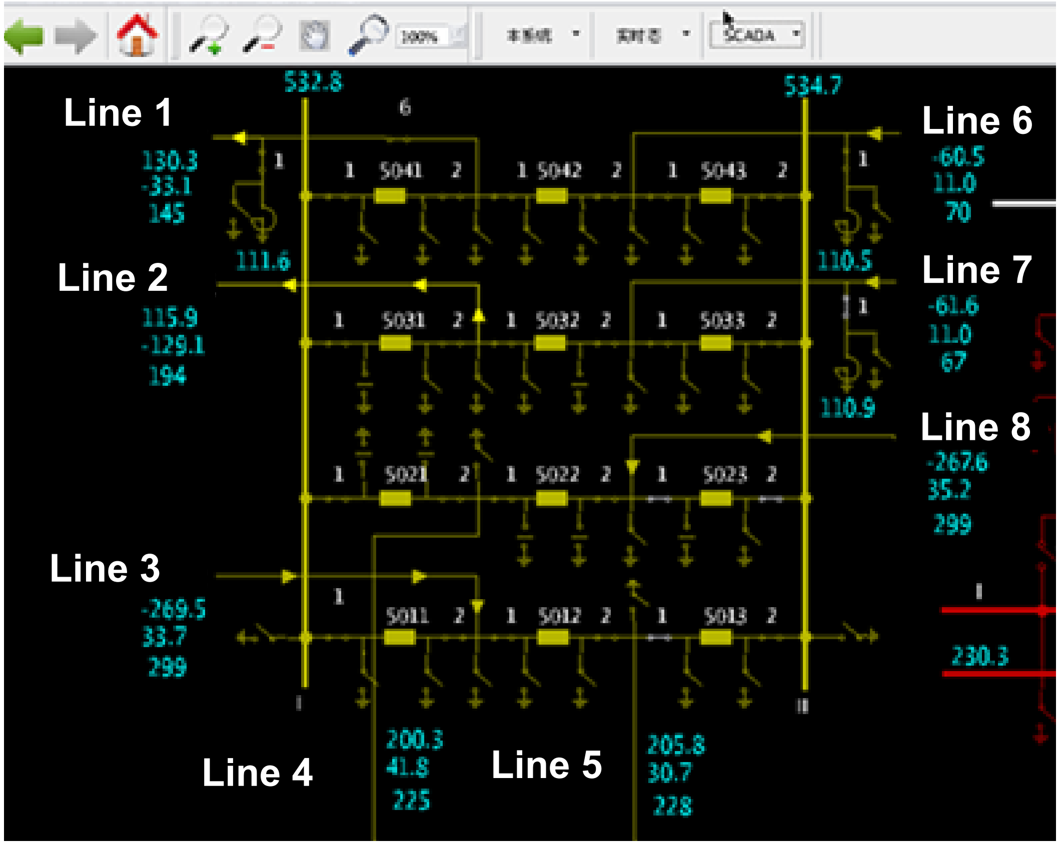
- **Weighted Least Square** (WLS)
  - Assumption: measurement errors accord with Gaussian distribution. not true in real power systems, (GD, BD)
  - Largest Normalized Residual identification, fail especially for conforming BD
- **Robust SE**: WLAV, QC, QL, SHGM (Mili L., 2006), etc
  - Inefficient
  - Empirical
  - Not global differentiable
  - Difficult to identify bad data on leverage points

Existing Problem (2) – Zero Injection Constraint

- **Large Weight Strategy in WLS**:
  - Too large a weight → Numerical problem
  - Too small a weight → KCL not satisfied
- **Problem in Practical Application**
  - A SE result seems OK , but the following Load Flow will stray from SE
  - Following EMS application software can not work normally.
  - It is very common in China EPCC

Existing problem (3) -- Example

A 500 kV ST Example



- SCADA results
- **Q Meas.** (Mvar)

  Line 1: -33.1

  Line 2: -125.1

  Line 3: 33.7

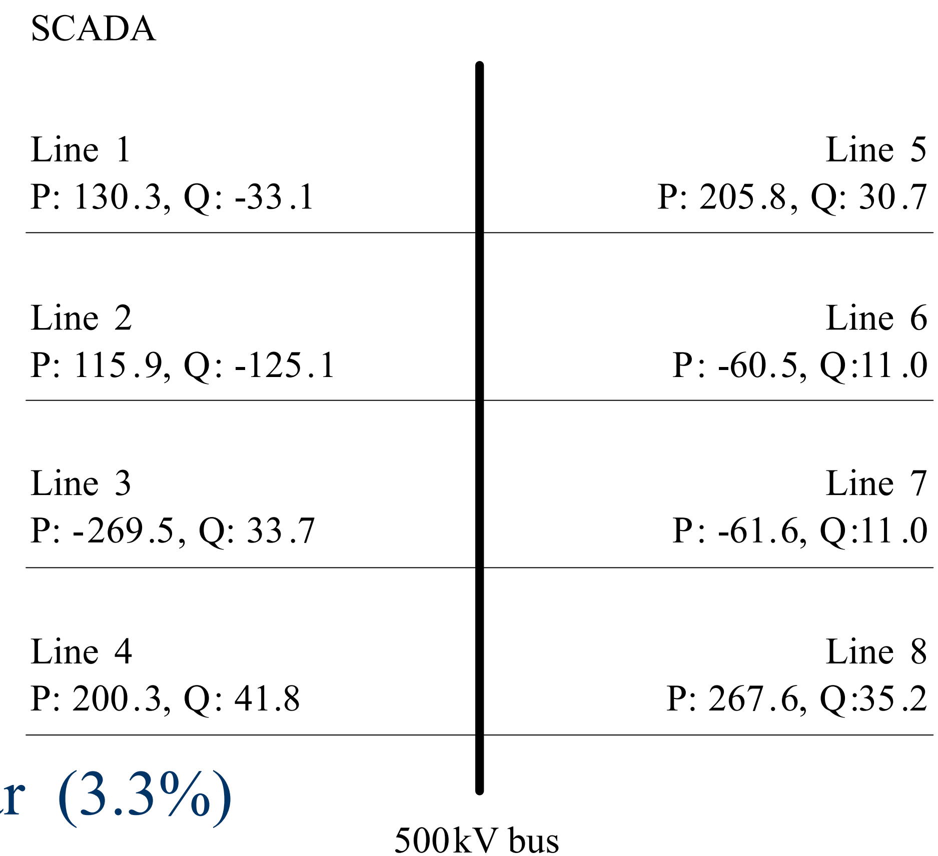
  Line 4: 41.8

  Line 5: 30.7

  Line 6: 11.0

  Line 7: 11.0

  Line 8: 35.2



- ∑SCADA = 5.2 Mvar (3.3%)
- Measurements are good through manually checked

Existing problem (4)

- SE results
- Q Esti./Meas. (MVar)

  Line 1: -53.5/-33.1

  Line 2: -164.3/-125.1

  Line 3: 34.5/33.7

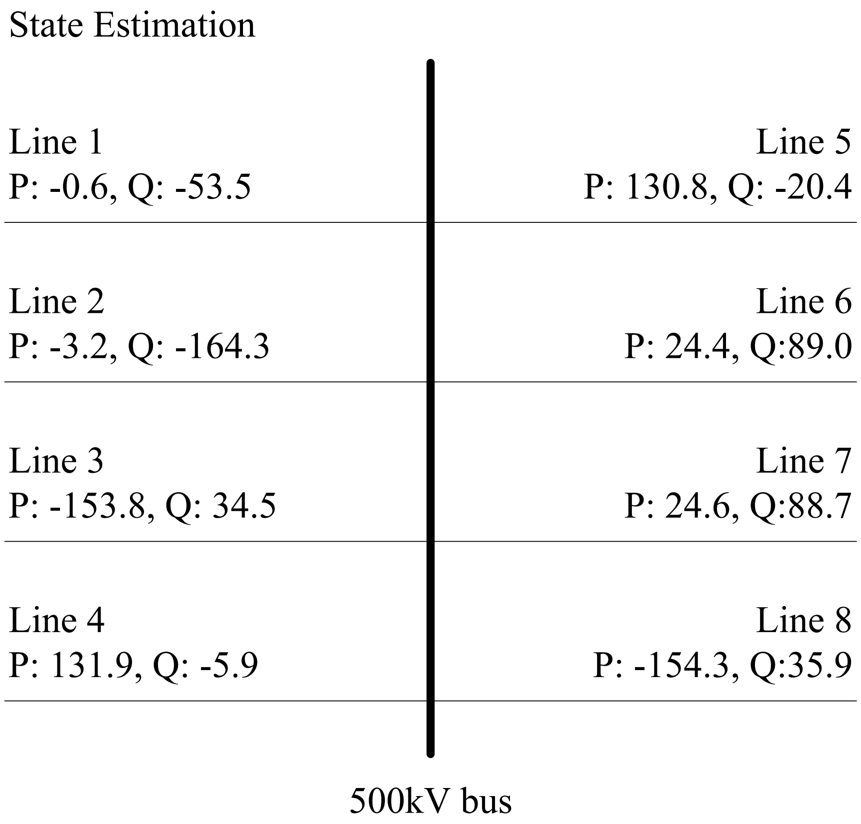
  Line 4: -5.9/41.8

  Line 5: -20.4/30.7

  Line 6: 89.0/11.0

  Line 7: 88.7/11.0

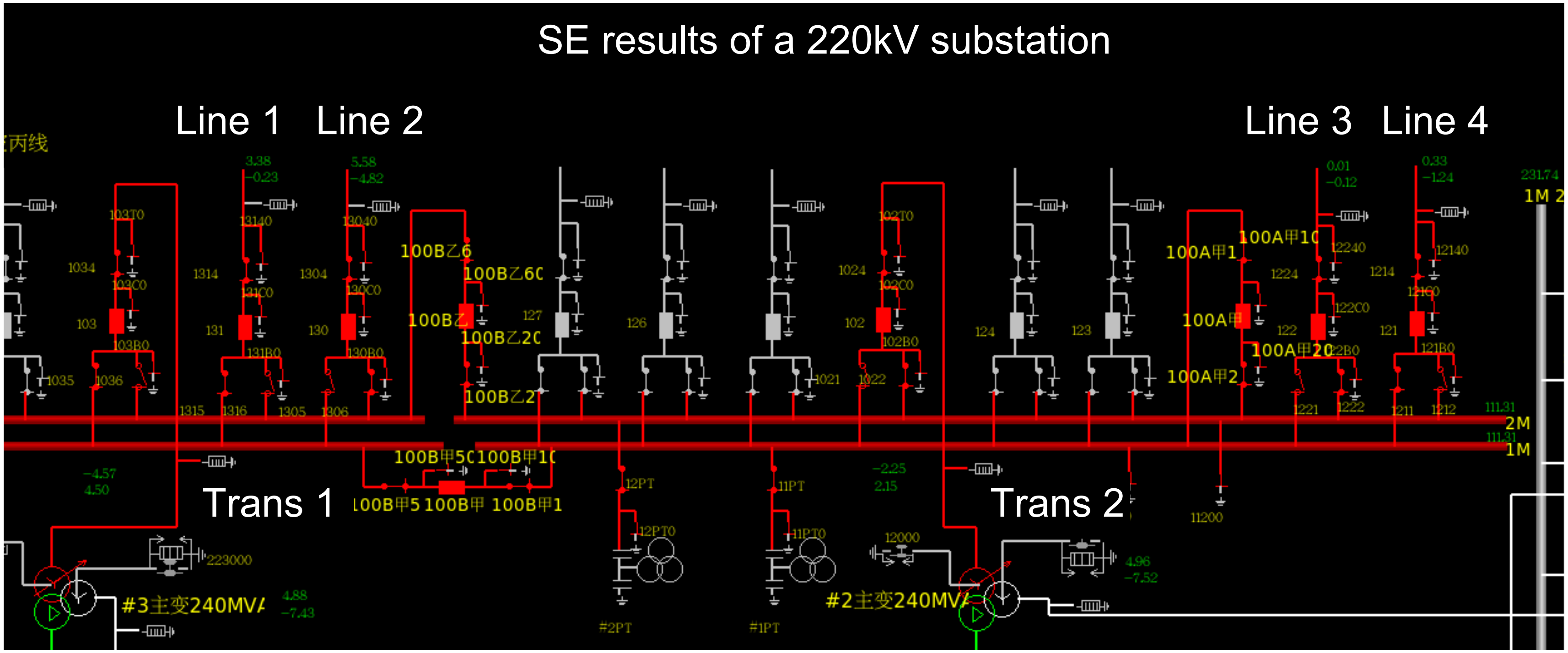
  Line 8: 35.9/35.2



- $\sum SE = 4.0\text{MVar} \neq 0$
- SE results are terribly bad through manually checked

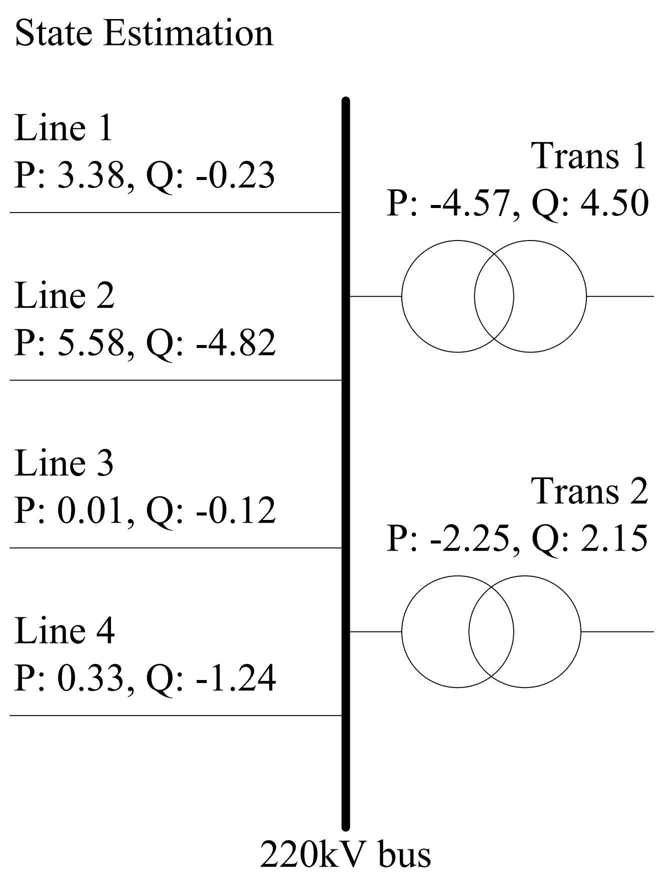
Existing problem (5)

- 220 kV ST Example (another system)



Existing problem (6)

- 220 kV ST Example (to check zero injections constraint)
- Estimated P Meas. (MW)
  - Line 1: 3.38
  - Line 2: 5.58
  - Line 3: 0.01
  - Line 4: 0.33
  - Trans 1: -4.57
  - Trans 2: -2.25



- $\sum = 2.48MW \neq 0$
- SE results are bad

Solution Method

- **For bad data identification problem**, a new robust estimator based on maximum correntropy criterion is developed

  [1]Wu W.C., Guo Y., Zhang B.M., and Sun H.B., Robust state estimation method based on maximum exponential square (MES), *IET Proc. on GTD*, vol. 5, no. 11, pp1165-1172, 2011

- **for zero injection constraints problem**, an efficient approach considering rigorous zero injection constraints is proposed

  [1]Ye Guo, Boming Zhang, etc, An Efficient State Estimation Algorithm Considering Zero Injection Constraints, *IEEE Trans. on PWRS*, vol. 28, no.3, pp. 2651-2659, 2013

Conventional Indices to Evaluate Believability of SE Results

- **No an international standard** until recently
  - Common indices: MAR (Mean of absolute values of residuals), MSR (Mean of square of residuals)
  - The WLS objective value (MSR) is not a good index
- **In China: Acceptance rate**

$$\eta = \frac{n_\xi}{m} \times 100\%$$

  - n_ξ : the number of measurements whose residuals less than given empirical thresholds (e.g. 500kV power measurements: 21.6MW)
  - m: the total number of measurements
  - Plausibility: Yes or No, good or bad measurements
  - Drawbacks: 0-1 manner, empirical thresholds, how much good, how much bad?

Correntropy(COE) based Index (1)

- **Correntropy**: Measure for similarity of two random variables z and $\boldsymbol{h}(\boldsymbol{x})$ in information theory
  - Equivalent to the quadratic Renyi's entropy between z and h(x)
  - Non-parametric estimation, no assumption on error model
- **Map point z and point $\boldsymbol{h}(\boldsymbol{x})$ from measurement space** to a reproduced kernel Hilbert space with kernel function K
  - Use inner product to evaluate the correlation

$$\left\langle \varphi\left(\boldsymbol{z}\right), \varphi(\boldsymbol{h}(\boldsymbol{x})) \right\rangle = K\left(\boldsymbol{z}, \boldsymbol{h}(\boldsymbol{x})\right)$$

  - K is referred to as kernel function, usually use Gauss kernel

$$K\left(\boldsymbol{z}, \boldsymbol{h}(\boldsymbol{x})\right) = \frac{1}{\sqrt{2\pi}\sigma} \sum_{i=1}^{m} \exp\left(-\frac{\left(z_i - h_i(\boldsymbol{x})\right)^2}{2\sigma^2} \right)$$

Correntropy based Index(2)

$$\xi = \frac{1}{m}\sum_{i=1}^{m}\exp\left[-\frac{\left(z_i - h_i\left(\hat{\boldsymbol{x}}\right)\right)^2}{2\delta_i^2}\right]\times 100\%$$

	Acceptance rate (AR)	Correntropy based index(COE)
Theoretical basis	Empirical	Similarity measure in information theory
Measurement partition	0-1, either good or bad	Score each meas. continuously according to its residual
Thresholds	Empirical	not needed

Correntropy based Index(3)

- **Zero injection constraints must be satisfied strictly**
- Count mean MW/Mvar mismatches for 0-injection bus

$$\Delta = \frac{1}{n_Z}\left(\sum_{i \in Z}|P_i| + \sum_{i \in Z}|Q_i|\right)$$

  - Z: zero injection bus set
  - n_Z: number of zero injection buses

  - **If Large Δ** : SE results do not yield to KCL, erroneous state estimate
  - **High COE index & small Δ** = believable SE result
  - **Low COE index | large Δ** = unbelievable SE result

Numerical tests: 9-bus test system

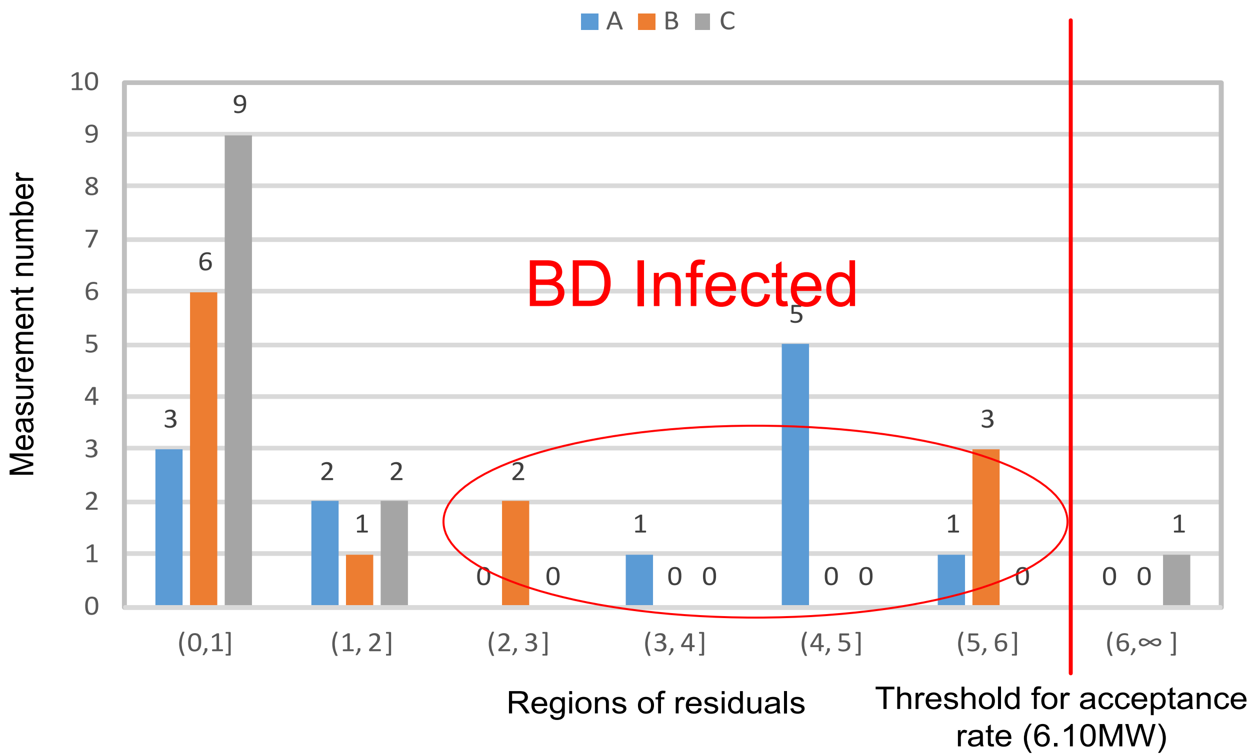
- Three SE results produced by different estimators
  - **A**: WLS estimator with large weights for zero injections.
  - **B**: WLS estimator with small weights for zero injections(significant power mismatches)
  - **C**: Robust estimator considering rigorous zero injection constraints

Indices	A	B	C
Acceptance rate (%)	100%	100%	91.67%
COE Index (%)	83.74%	90.65%	91.15%
Mean power mismatches of zero injection buses (p.u.)	0.0053	0.0445	7.13e-5
Mean estimation error (p.u.)	0.0047	0.0042	7.44e-4

- Acceptance rate gives erroneous conclusions on SE accuracy
- Zero injection examination is necessary

Numerical tests: 9-bus test system

- **Distribution of residuals**
  - A & B: Several meas. reside in the middle residual regions
  - C: One identified as bad data, all others have small residuals



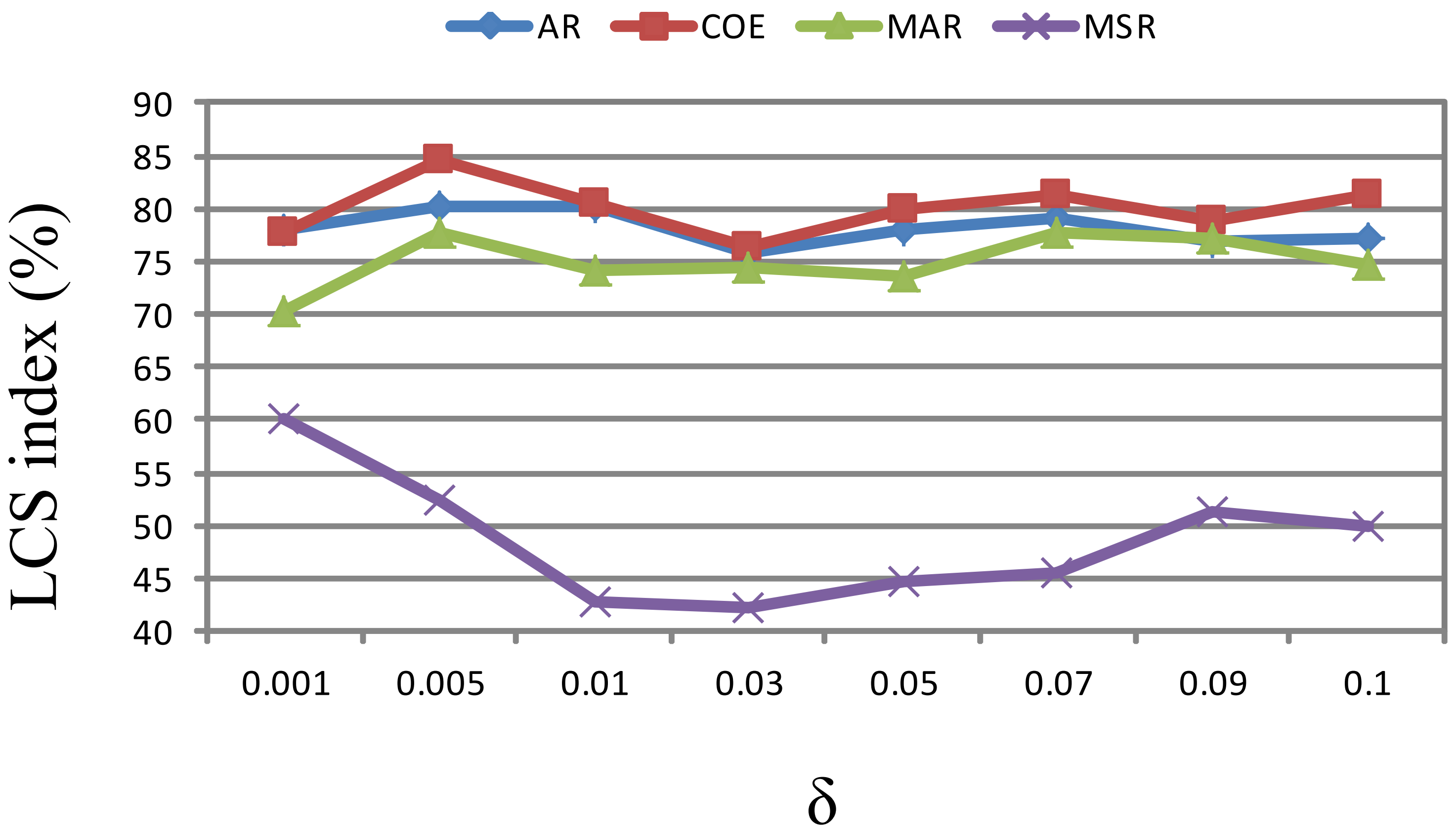
Numerical tests: 118-bus test system

- **Comprehensive comparison**
  - Four indices: **Acceptance rate** (**AR**), **Correntropy** (**COE**), **Mean Absolute value of Residuals** (**MAR**), **Mean Square of Residuals** (**MSR**)
  - Change measurement errors, for each point of measurement error, 100 different measurement sets are generated.
  - For each measurement set, 10 different SE results are obtained by different estimators
  - Count the mean values of the longest common sequence (LCS)

$$LCS\ index = l_{LCS} / 10 \times 100\%$$

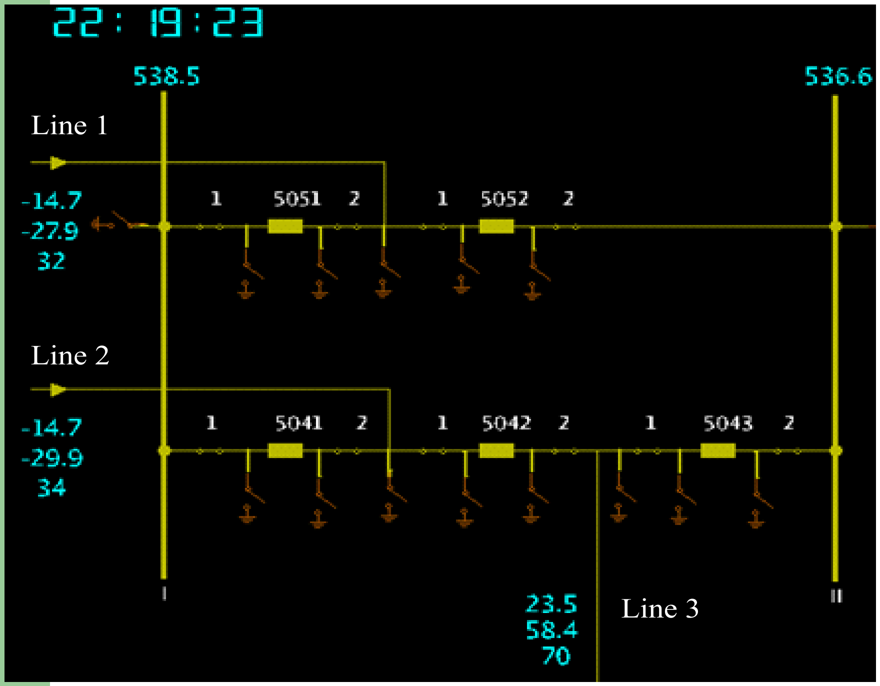
Numerical tests: 118-bus test system

COE>AR>MAR>MSR

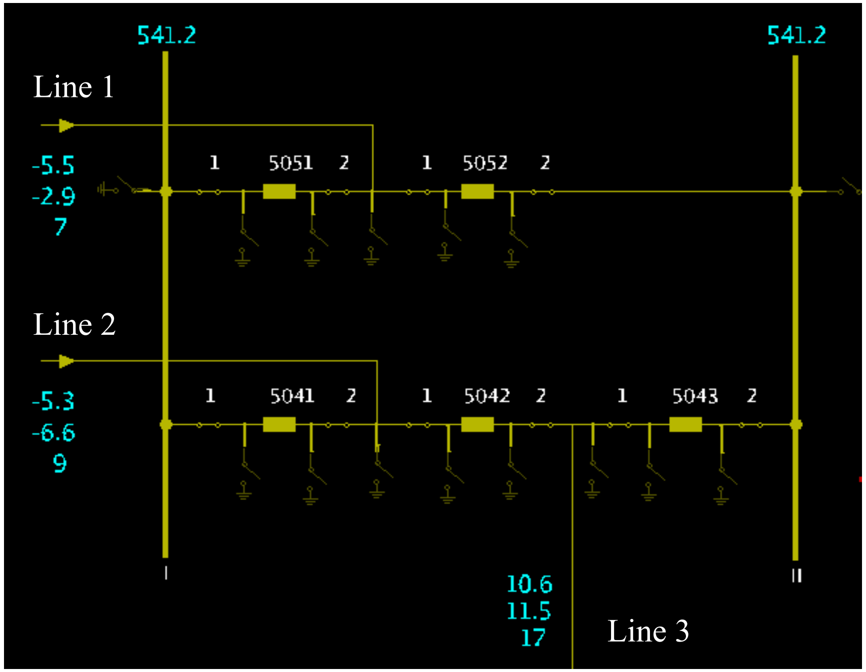


Numerical tests: a practical system

- **A selected 500kV ST - Detail**



SCADA



State Estimation

Numerical tests: a practical system

Q Meas./Estimated (MVar)

Line 1: -27.9/-2.9

Line 2: -29.9/-6.6

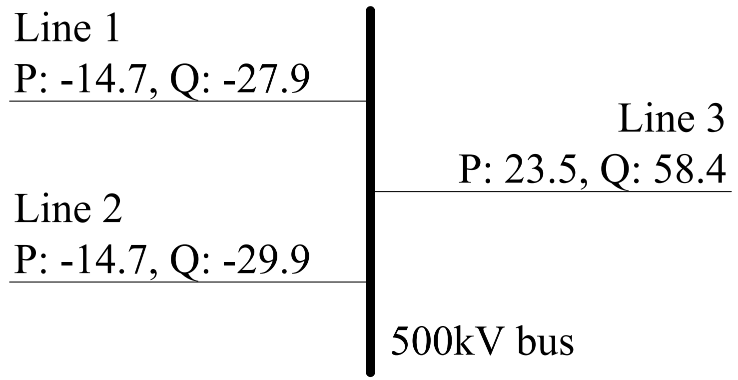
Line 3: 58.4/11.5

∑SCADA = 0.6MVar (good)

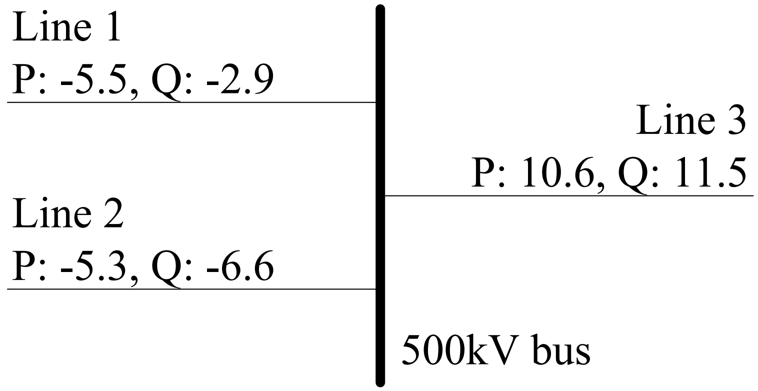
∑SE = 2.0MVar (bad)

- SE result is not believable
- KCL is not satisfied

SCADA



State Estimation

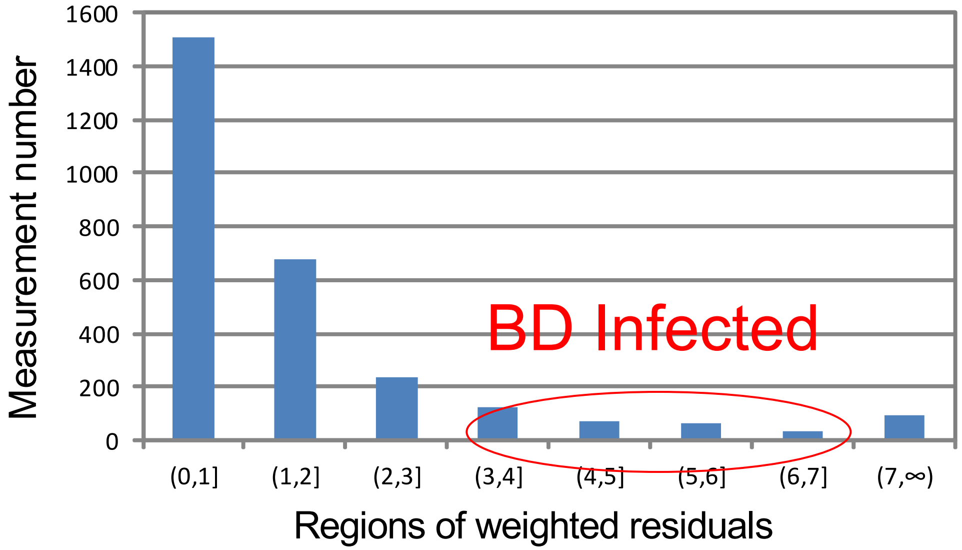


Numerical tests: a practical system

- **A provincial system in China**
- **Some indices**
  - High acceptance rate
  - Low COE Index
  - High zero injection mismatch

Acceptance Rate	99%	High
COE Index	77.40%	Low
Mismatches of zero injections	2.08MVA	Large

- **Distribution of weighted residuals**
  - Many measurements are infected!
  - Inaccurate SE results!



Conclusions

- Problems in SE application
  - Bad data
  - Zero injection
- How to assess the Believability of a SE result
  - Conventional: MAR, MSR, Acceptance rate are not reliable
  - Correntropy (COE) based index

    + Zero injection constraints checking

  Is a reasonable solution.

Thank You!