# A Novel Accurate Non-Divergent State Estimator (SE+)

## (An Offline Backup State Estimator)

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# About Accurate Non-divergent State Estimator (SE+)

0. Accurate Non-divergent state estimator (SE+) can help improve the performance of your state estimator by exactly recovering the true values of bad data.

1. We developed a brand new accurate non-divergent state estimator (SE+) in 2020 with the support from National Science Foundation.

2. It solved the divergence problem suffered by AC power system state estimator for more than 50 years.

3. It has been tested on 25 real-time cases (including unsolved cases) provided by 4 large ISO and power utility companies from North America. The *measurement redundancy ratio* is from 1.23 ~1.91.

# About Accurate Non-divergent State Estimator (SE+)

4. It takes 10 ~ 50 seconds to reach a feasible solution for systems with 2500 buses ~ 7500 buses

5. It shows excellent capability to recover the true values of bad measurements

6. It is Not sensitive to bad measurements with a strong capability to reject all three types of bad data: measurement errors, parameter errors, topology errors

7. It does not use any forms of approximation

8. It solves the problem of Leverage Point

# About Accurate Non-divergent State Estimator (SE+)

9. It is based on a much sharper regression than weighted least square regression

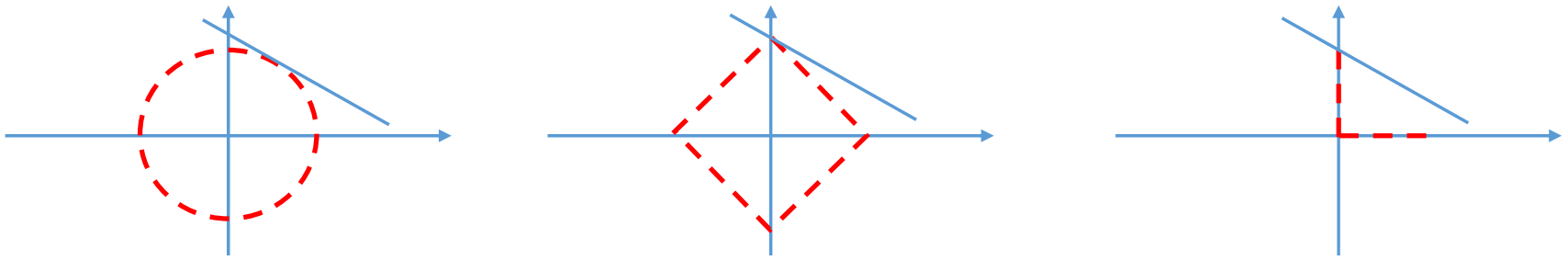
Sharp degree increase: (bad data rejection is increased)

$L_2$ regression $<$ $L_1$ regression $<$ $L_0$ regression

WLS based SE

LAV based SE

Accurate Non-divergent SE



# Testing Results on a Real-time Case

**Raw data information:**

| | |
|---|---|
| Total number of buses: | 3409 |
| Total number of line flow measurements: | 3571 |
| Total number of injection measurements: | 3022 |
| Total number of voltage magnitude measurements: | 1457 |

The real-time case, provided by an company in USA, contains three types of bad data.

**Two situations were tested:**

1) Added 10.0 p.u. on randomly selected 10 real power injection measurements.
2) Added 5.0 p.u. gross errors on randomly selected 10 real power line flow measurements.

**We compared the performance of SE+ and WLS SE:**

1) Detected bad data.
2) Obtained bus voltage solutions.

# Testing Results on a Real-time Case

**Situation #1:**

1) Added 10.0 p.u. on randomly selected 10 injection measurements.

**Results of WLS state estimator:** Diverged without a solution

**Results of Non-divergent state estimator:**

- Converged in 60 seconds with a solution
- 122 bad line flow and injection measurements were detected
- 5 out of 10 intentionally added injection measurements were detected

| Bus_ID | Bus_KV | p_meas_before | p_meas_after | q_meas | p_est_SE+ | q_est_SE+ | Confidence(%) |
|---|---|---|---|---|---|---|---|
| 8 | 1 | 0.0 | 10.0 | 0.0 | 34.24 | -9.58 | 99.0 |
| 10 | 115 | 0.0 | 10.0 | 0.0 | -0.03 | 0.05 | 92.7 |
| 19 | 34.5 | 0.56 | 10.56 | -0.01 | 0.55 | -0.01 | 92.7 |
| 12 | 46 | -0.03 | -10.03 | 0.0 | -0.03 | 0.0 | 92.7 |
| 21 | 34.5 | 0.15 | 10.15 | 0.01 | 0.15 | 0.0 | 92.7 |

5 bad injection measurements were detected and 4 were accurately recovered

# Testing Results on a Real-time Case

**Situation #2:**

2) Added 5.0 p.u. gross errors on randomly selected 10 line flow measurements.

**Results of WLS state estimator:**

- Converged with a solution
- 525 bad data detected including line flow and injection measurements

**Results of SE+:**

- Converged with a solution
- 122 bad data detected including line flow and injection measurements

**Next we will compare the 10 bad data we added.**

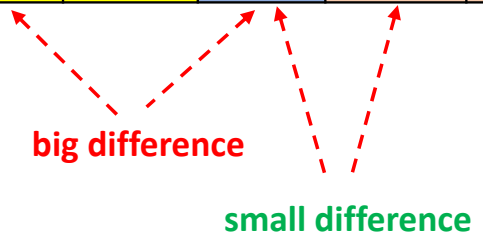
# Testing Results on a Real-time Case

## Situation #2:

2) Added 5.0 p.u. gross errors on randomly selected 10 line flow measurements.

**The detection and recovery of the 10 bad data we added.**

| Line ID | From Bus | To Bus | From_bus KV | To_bus KV | P_meas After | Q meas | P_est WLS SE | Q_est WLS SE | P_meas Before | P_est SE+ | Q_est SE+ | Confidence SE+ (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 4 | 2317 | 345 | 345 | -7.33 | -0.27 | -0.08 | -0.79 | -2.33 | -2.29 | -0.19 | 86.6 |
| 3 | 4 | 3147 | 345 | 345 | 7.78 | -0.05 | 0.1 | 0.14 | 2.78 | 2.76 | -0.13 | 86.5 |
| 40 | 29 | 5 | 115 | 115 | 5.4 | -0.03 | 0.4 | 0.07 | 0.4 | 0.39 | -0.04 | 86.5 |
| 354 | 319 | 5 | 115 | 115 | -5.44 | 0.08 | -0.02 | -0.08 | -0.44 | -0.44 | 0.09 | 86.5 |
| 5 | 4 | 9 | 345 | 345 | -8.61 | -0.09 | -0.14 | -0.69 | -3.61 | -3.61 | -0.03 | 86.5 |
| 27 | 362 | 5 | 115 | 115 | -5.19 | -0.07 | -0.09 | -0.37 | -0.19 | -0.2 | -0.06 | 86.5 |
| 38 | 5 | 29 | 115 | 115 | -5.59 | 0.02 | -0.09 | -0.39 | -0.59 | -0.6 | 0.05 | 86.5 |
| 36 | 5 | 35 | 115 | 115 | 5.2 | 0.07 | 0.11 | 0.4 | 0.2 | 0.24 | 0.05 | 86.4 |
| 1 | 318 | 3146 | 345 | 345 | -8.88 | 0.15 | -0.13 | -0.64 | -3.88 | -4.14 | 0.2 | 85.8 |




## Observation:

- WLS SE cannot recover the bad data
- SE+ is abele to exactly recover the bad measurements

# Testing Results on a Real-time Case

**Situation #2:**

2) Added 5.0 p.u. gross errors on randomly selected 10 line flow measurements.

**Observation:**

- WLS SE cannot recover the true values of bad measurements
- SE+ is able to exactly recover the bad measurements

**Conclusion:**

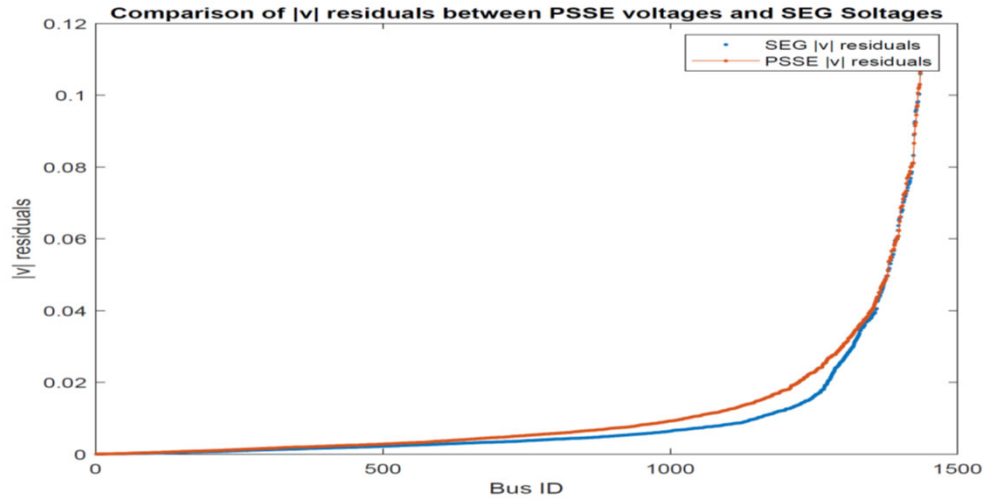
- The bus voltage solution obtained by SE+ should be more accurate than that of WLS state estimator

# Testing Results on a Real-time Case

**Situation #2:**

2) Added 5.0 p.u. gross errors on randomly selected 10 line flow measurements.

**Compare WLS SE voltage solution with SE+ voltage solution to the |v| measurements:**




In order to have a better view, we sorted the |v| measurement residuals. It is clear that the |v| measurement residuals of SE+ is smaller than that of PSSE voltage solution.

$$\sum_{i=1}^{M_v} \left| v_i^{meas} - v_i^{SE+} \right| < \sum_{i=1}^{M_v} \left| v_i^{meas} - v_i^{WLS} \right|$$

**Conclusion:**

- The bus voltage solution obtained by SE+ should be more accurate than that of WLS state estimator

# Why Accurate Non-divergent State Estimator (SE+)?

1. can serve as a backup state estimator to guarantees an accurate feasible solution.
2. can help your SE to obtain a more accurate voltage solution.
3. can accurately detect and **recover** the true values of bad measurements for your state estimator.
4. can solve the divergence issue of post-power flow analysis.
5. Takes ~20 minutes to install.

# Our Promise

1. We will pay you $10,000.00 USD as a reward if SE+ diverges on one of the unsolved cases of your SE.

2. We will pay you $10,000.00 USD as a reward if you can show that SE+ is worse than your state estimator in bad data detection and recovery.

Rules: whoever interested in challenging our SE+ is more than welcome, please contact us and we will sign an agreement before the challenge.

# Any Questions?

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