# Metering Accuracy and State Estimator Performance

A model approach to quantify the effects of metering accuracy and density in a model on State Estimation.

# Model Development

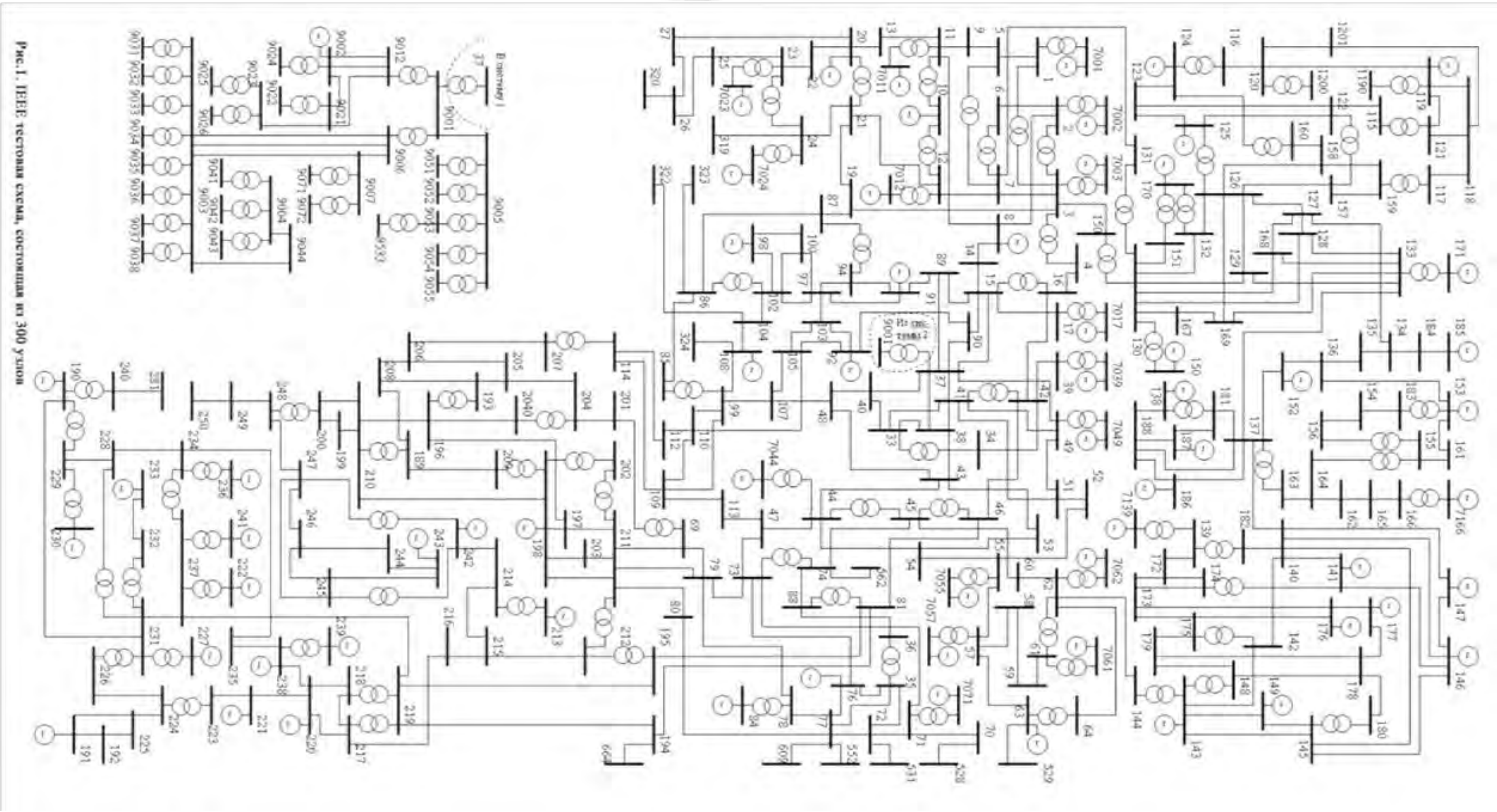
Shaun Murphy : MATLAB Programming

John Baranowski : Model Behavior

Ryan Nice : Meter Behavior and Analysis

- To **quantify the effects of metering/telemetry accuracy** on State Estimation for PJM and members, a model of SE was built.
- MATLAB model of IEEE 300 bus test case assumed functionally equivalent to a portion of PJM's Spectrum model of PJM territory.
- Introduced various degrees of and kinds of telemetry inaccuracy to test for differences in State Estimation behavior.
- Approximately 5000 State Estimator runs/solutions for each error model, with telemetry errors randomized each run.

# Methodology: IEEE 300 Bus Test Case



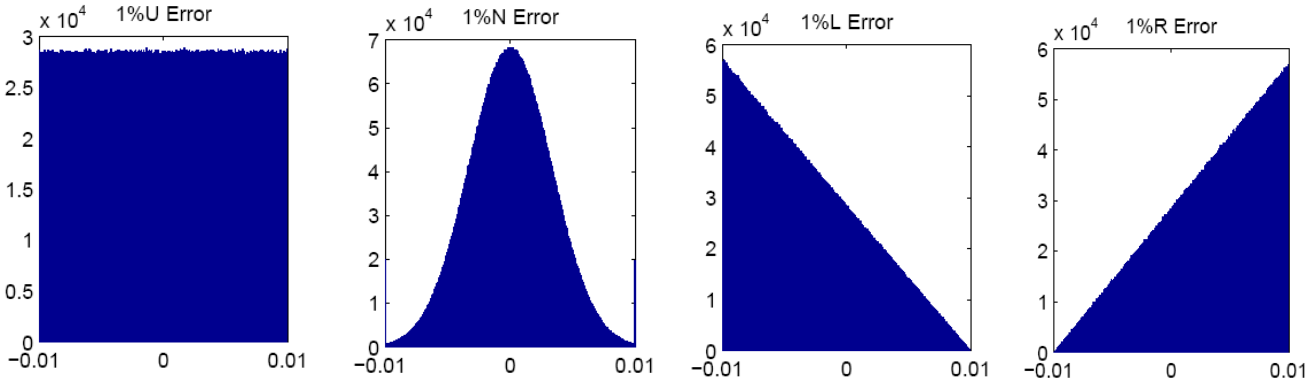
# Methodology: IEEE 300 Bus Test Case

- To cover the amount of available telemetry and usable telemetry typical for the PJM EMS, analyzed system at different percentages of measurement quality in the model:
  - From 100% good measurements to 10% good measurements
  - Used measurement high or low weighting to simulate good or bad/missing measurements respectively.

# Methodology: Input Meter Accuracy

- Analyzed system at five different meter accuracy ranges:
  - ± 1%, high accuracy metering
  - ± 2%, general PJM requirement
  - ± 3%
  - ± 4%, accuracy of protection duty equipment
  - ± 5%

- Analyzed each meter accuracy range with four different error distributions:
  - Uniform
  - Bell Curve
  - Linear Low Bias
  - Linear High Bias



# Methodology: Runs and Data Capture

- Focused on MW (from branch) flows as the primary measurement trended.
- Each of the 5000 runs has every measurement randomized within the specific accuracy range and distribution type.
- The results for each bus flow over the 5000 runs noted for max, min, avg. and std. deviation. Those results were trended to look for patterns.

**Caveat Emptor:**

- In reality, enterprise grade AIX Siemens Spectrum hardware/firmware/software *versus* MATLAB on standard computing device.
- In reality 15437 bus model, *versus* 300 bus model.
- No statistical differentiation or special consideration for higher or lower voltage levels.
- MVAR or other measurements could pose other or more complex problems.

# Methodology: Limitations, Approximations and Assumptions

- In reality meters will often be biased high or low and tend to stay that way in most conditions, *versus* randomized accuracy across all measurements within the accuracy range and distribution.
- In reality the same meters read ever-changing analog values which are consumed by SE each run, *versus* the same true flow values estimated 5000 different meter error models. In other words, **the metrics describe 5000 different combinations of all metering behavior within the accuracy range and distribution fed into the same model at the same moment in time**.

# Methodology: Limitations, Approximations and Assumptions

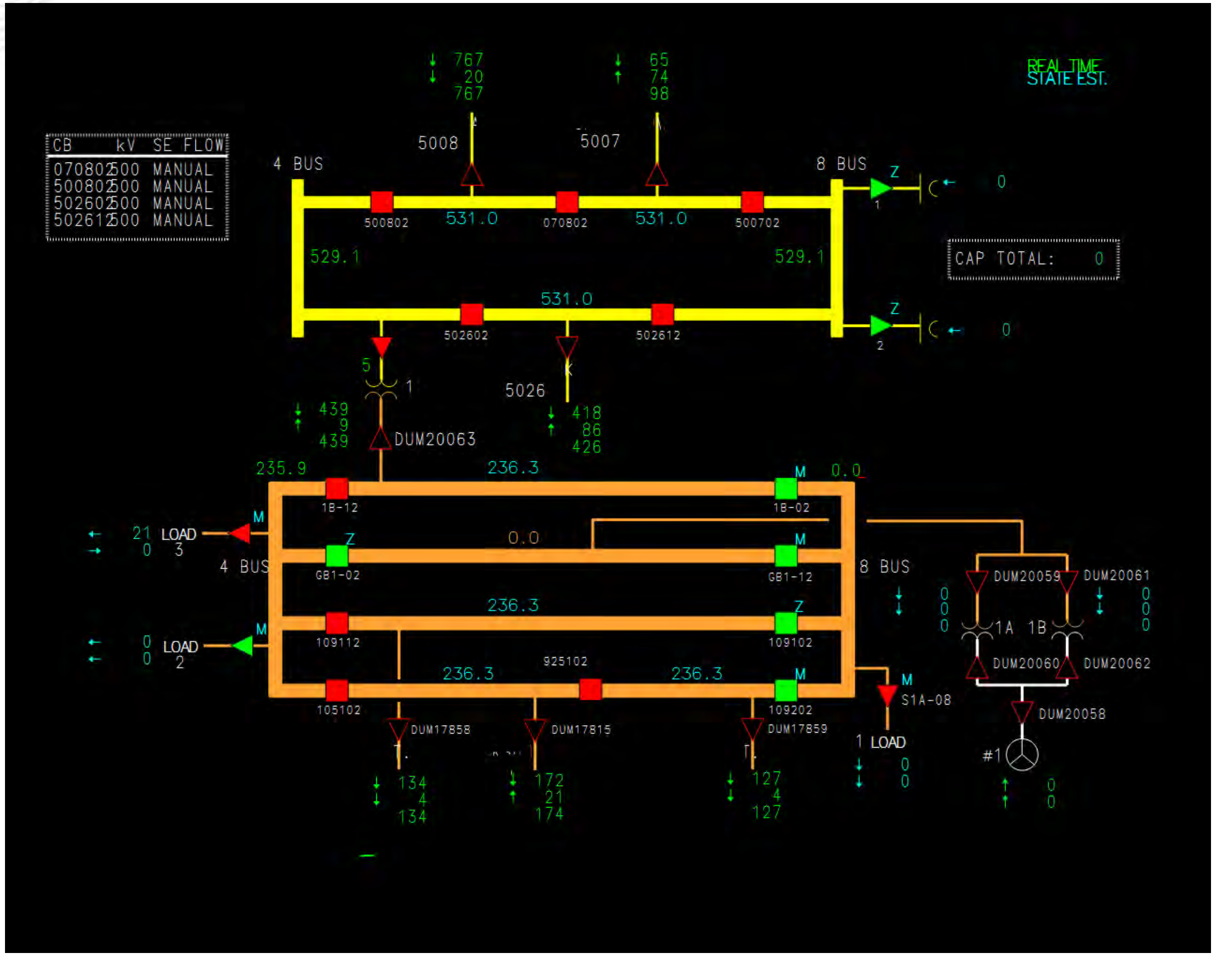
- In reality PJM uses measurement weighting on a scale, and does not have telemetry for all possible measurements, *versus* using a full weighting or nearly zero weighting to mimic both good/bad telemetry and also available/not-available telemetry.

# Methodology: Limitations, Approximations and Assumptions

- In reality, the weighting of individual measurements will be done with human intelligence that would tend to minimize bad or risky measurements and maximize good or trusted measurements, versus the weighting and accuracy being assigned with no correlation.
  – A second model was developed where measurements assigned “good” weighting also were assigned a smaller error range, to simulate that heavier weighted measurements would tend to be better measurements.

# Methodology: Limitations, Approximations and Assumptions

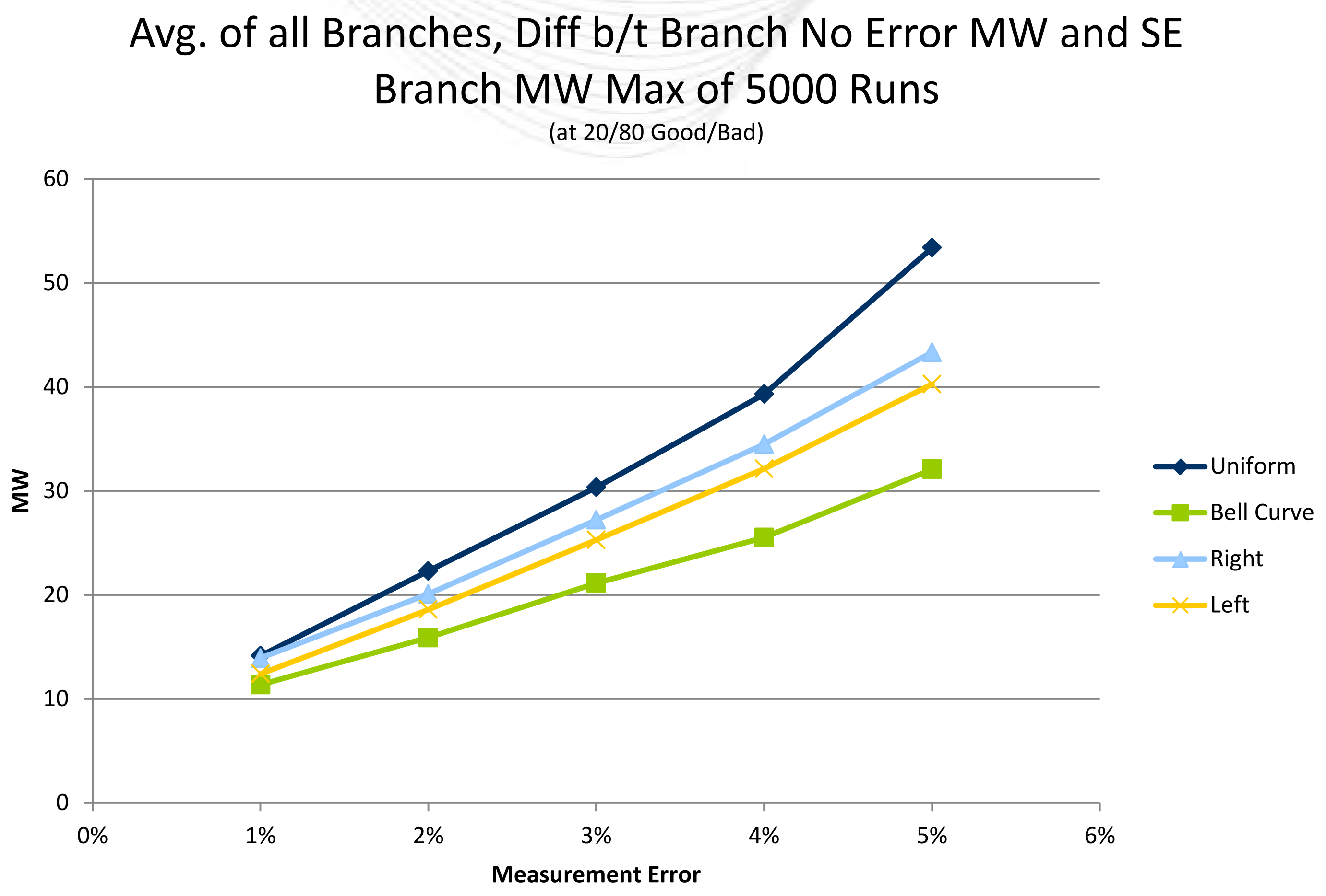
- In the model, the "good" telemetry is randomly distributed, where real telemetry is intelligently distributed for best observability.
- Difficult to compare the ratio of good/bad data in the model to SE.



# Methodology: Limitations, Approximations and Assumptions

Therefore, conclusions drawn from this model cannot be directly applied to the actual metering, telemetry and SE infrastructure of PJM. However, the general principles and trends can be usefully applied when supported by existing engineering understanding, relevant experience, and other related evidence.

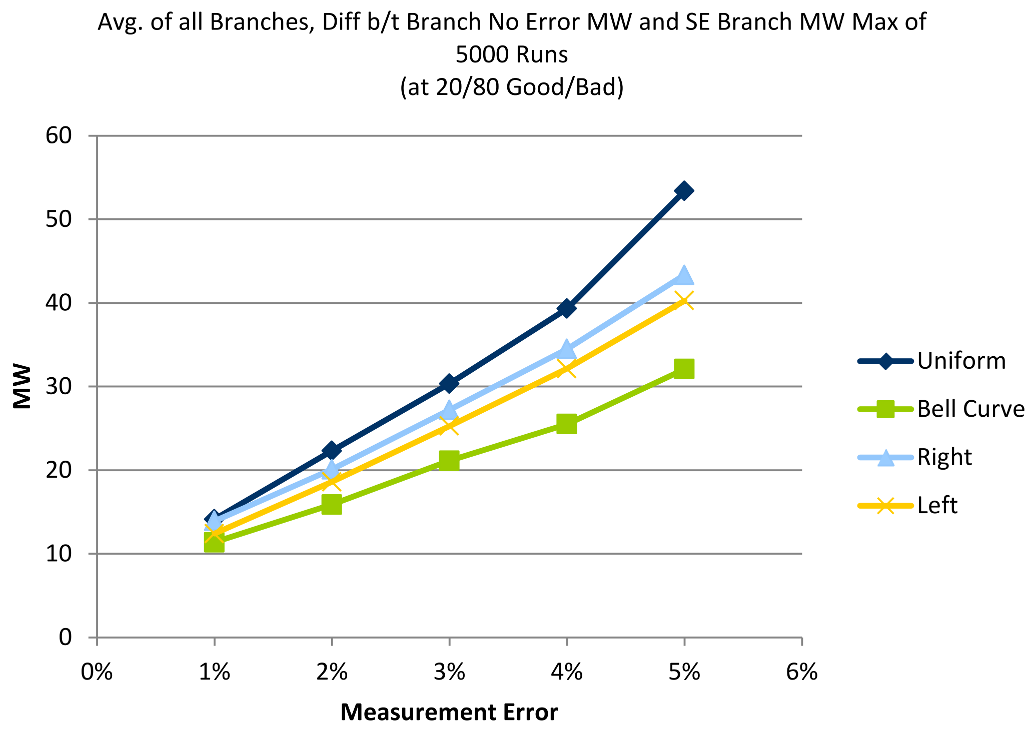
# Results and Conclusions (1st model)



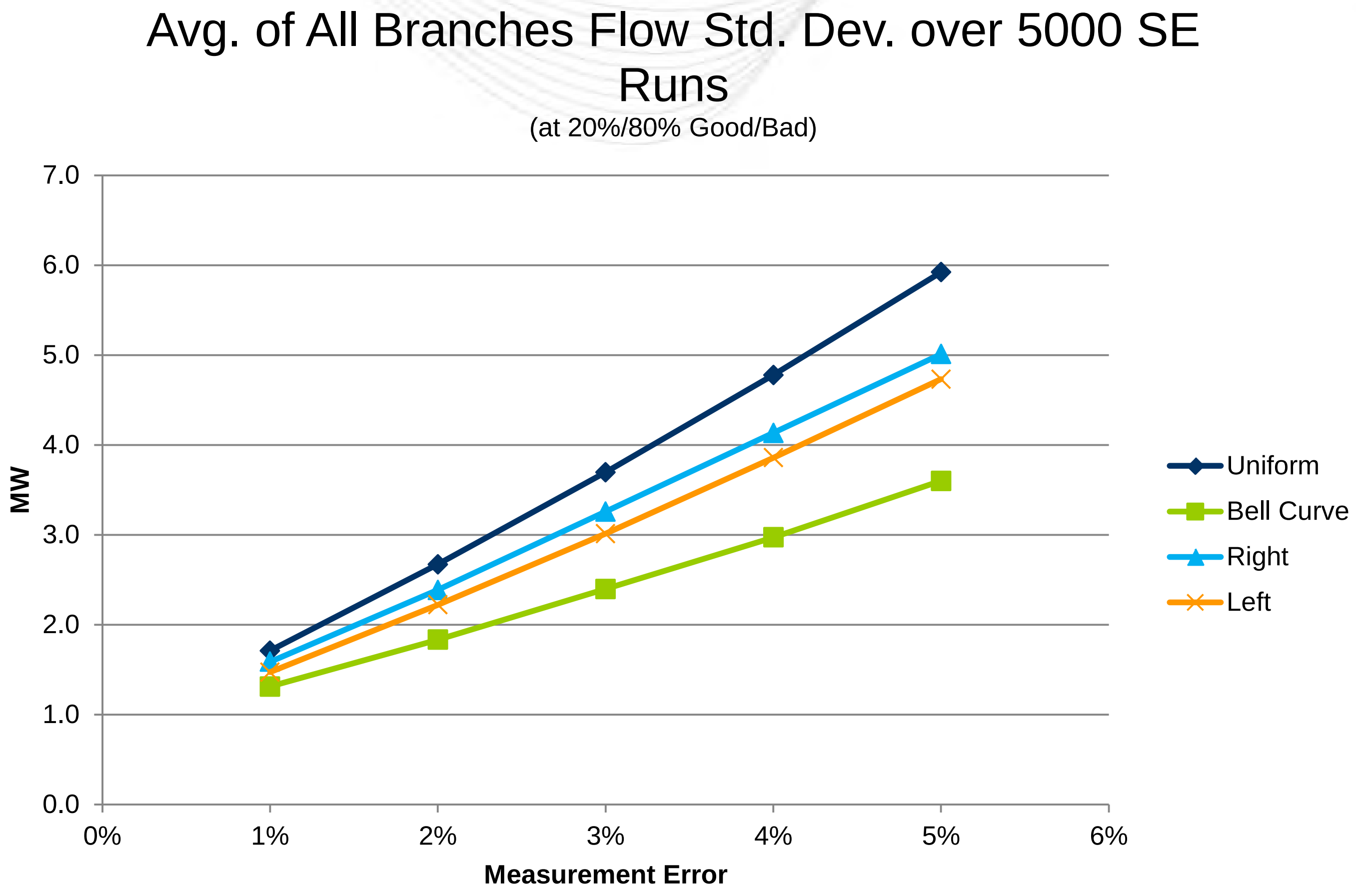
# Results and Conclusions (1st model)

Conclusion:

- As range of meter error increases, the average difference between a true MW flow and the max SE solved MW flow increases.



# Results and Conclusions (1st model)

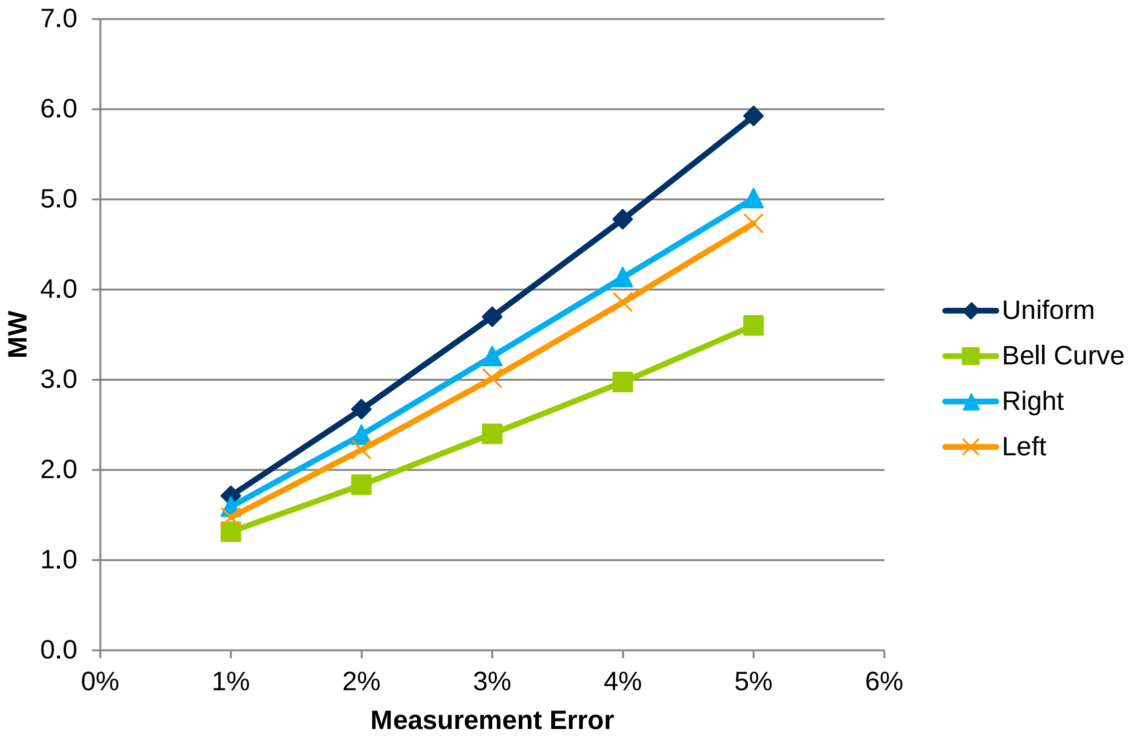


# Results and Conclusions (1st model)

Conclusion:

- Similarly, as meter error range increases, the SE solved value also spreads and disperses further.

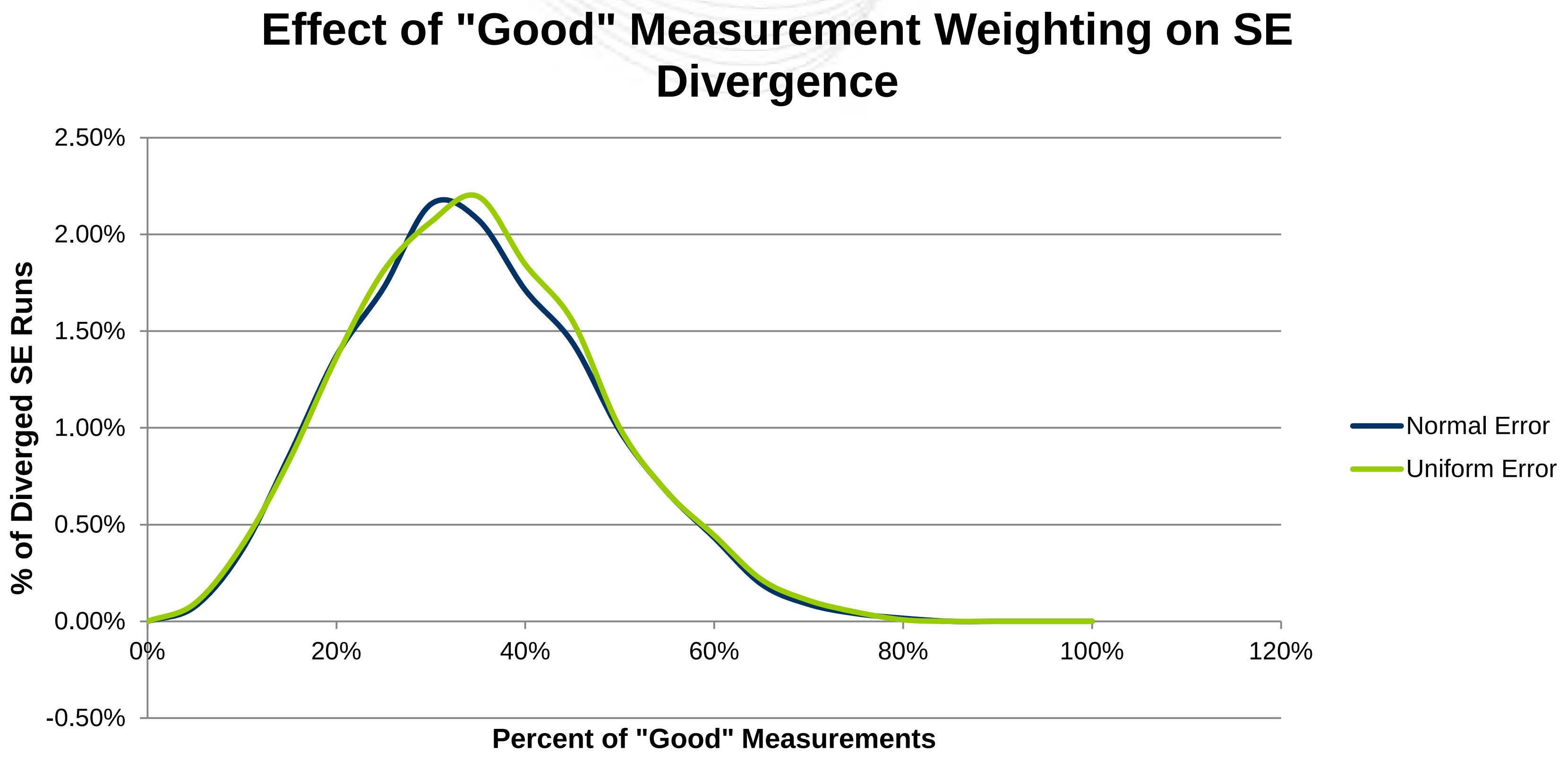
Avg. of All Branches Flow Std. Dev. over 5000 SE Runs
(at 20%/80% Good/Bad)



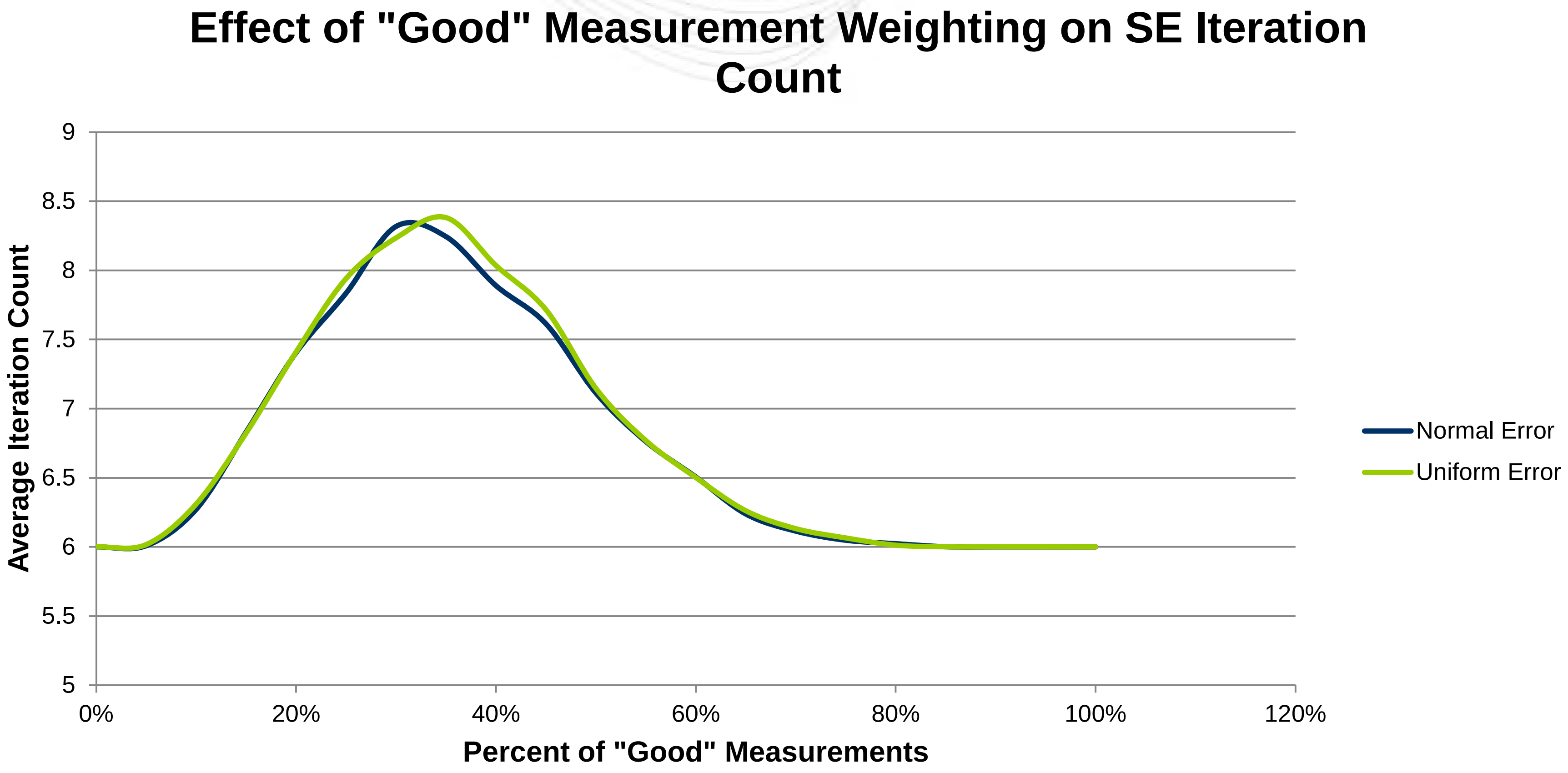
# Results and Conclusions (2nd model)

- A second model was developed and run that had three additional features:
  - SE iteration counts and non-convergence counts were captured.
  - Measurements weighted heavier tend to have better accuracy, and measurements weighted lighter tend to have lower accuracy, to account for the human intelligence of weighting good and trusted measurements higher and suspect or less important measurements lower.
  - Metrics focused on a single line, Line 394 at 1210.0 MW, instead of the entire model.

# Results and Conclusions (2nd model)



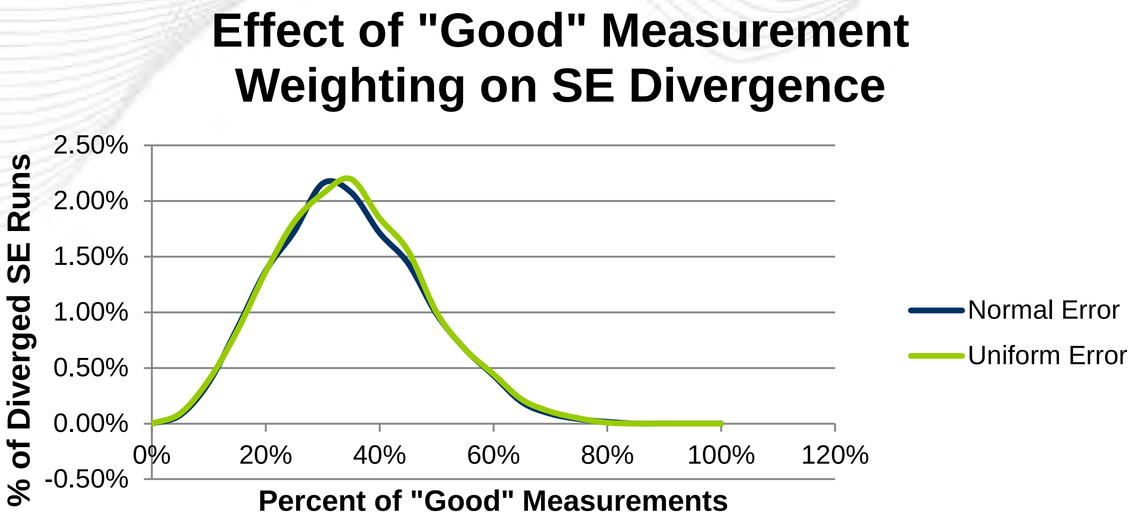
# Results and Conclusions (2nd model)

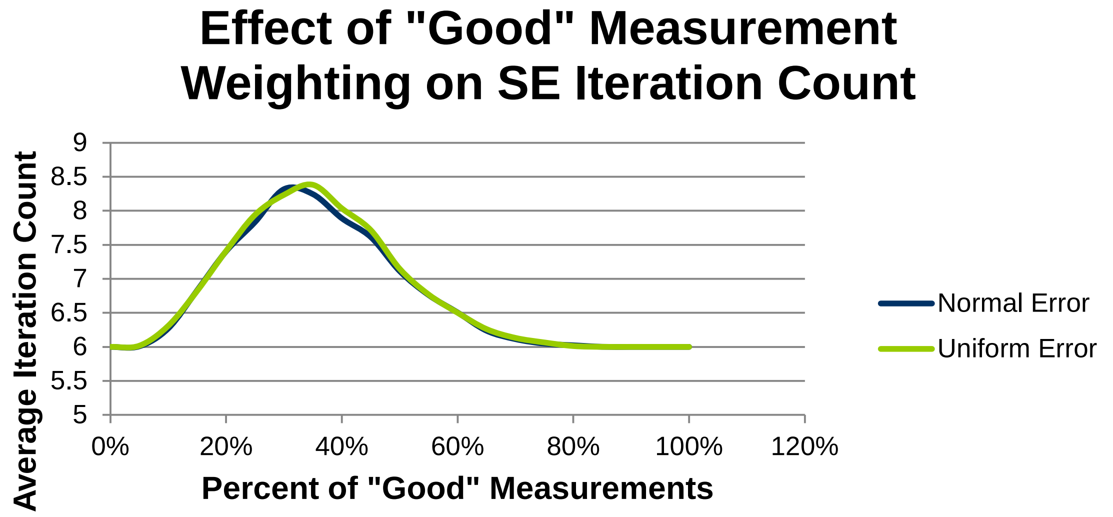


# Results and Conclusions (2nd model)

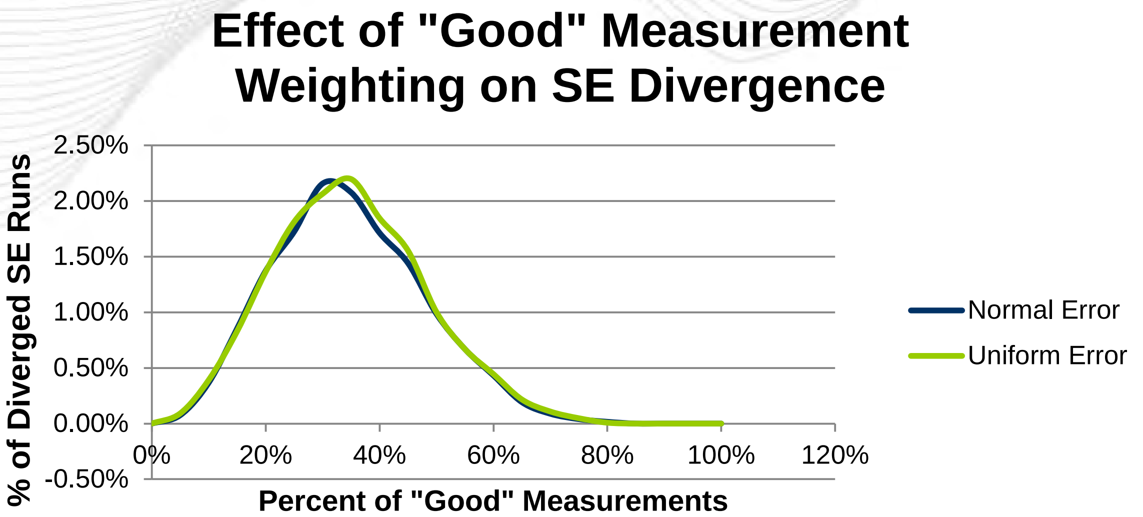
Conclusion:

- There is a tipping point at 30% good measurements, where lower SE works less hard (maybe b/c it is easier to solve with so many free variables), and above SE works less hard (maybe b/c of more good data and less computational load).



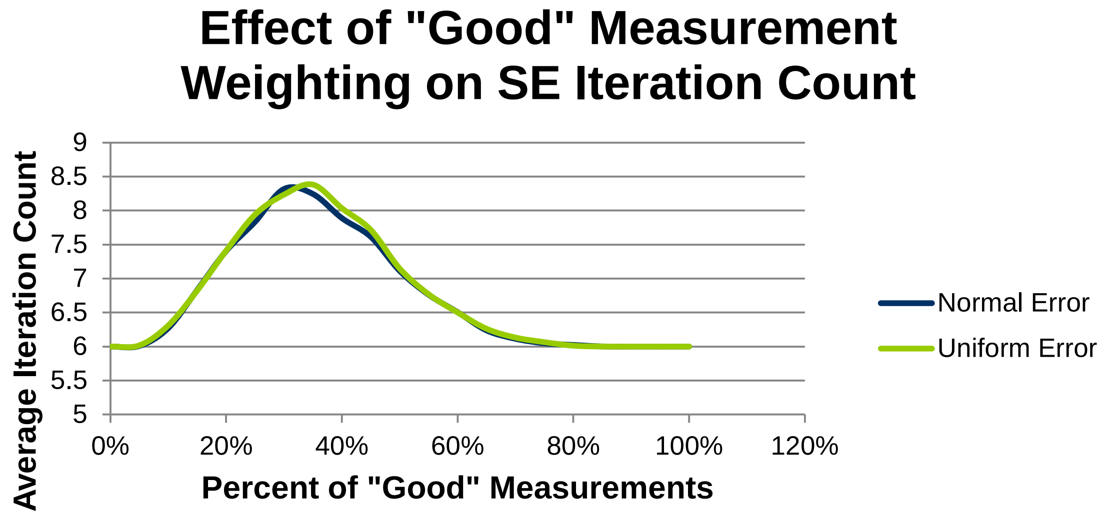



# Results and Conclusions (2nd model)

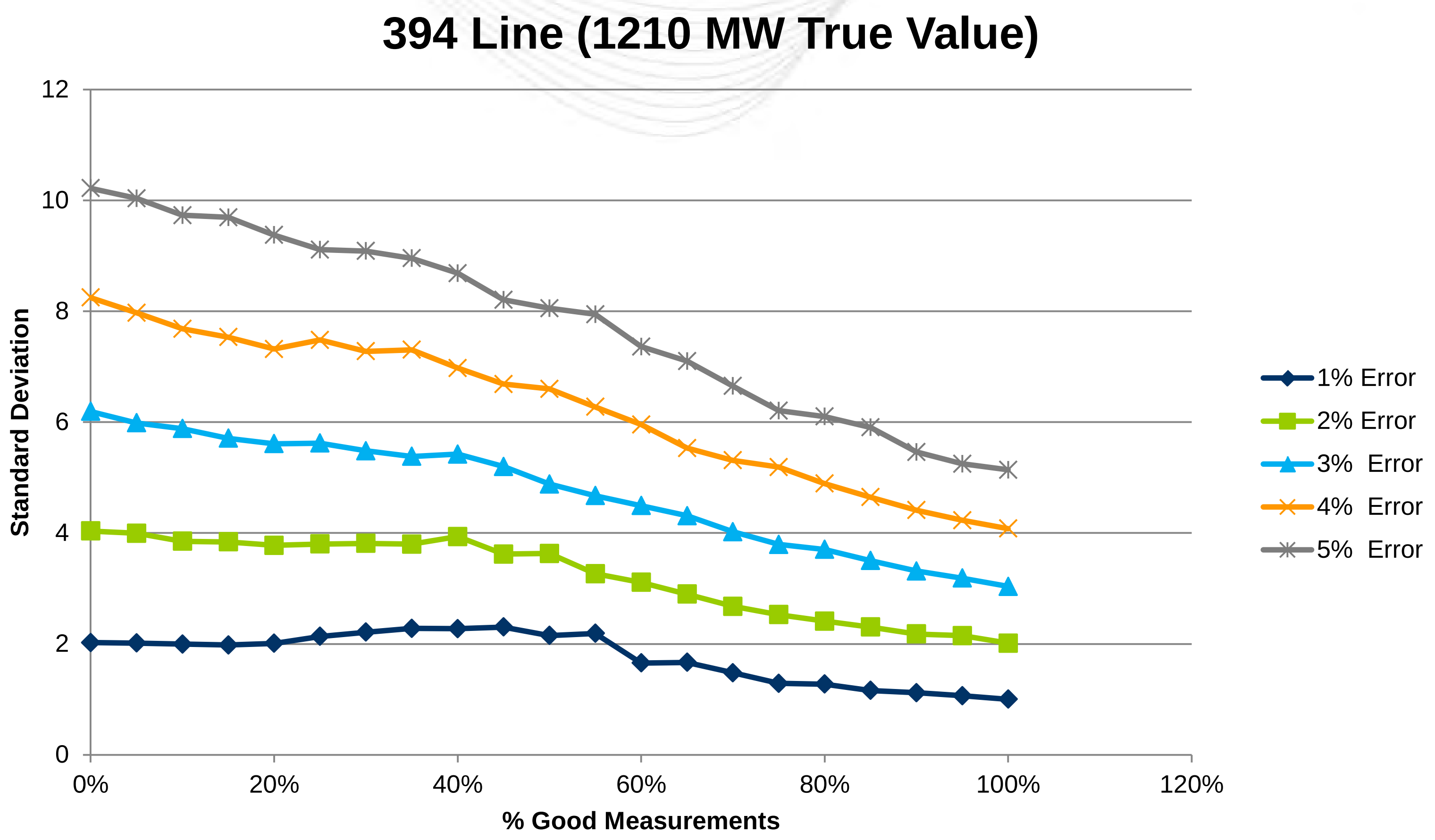



Conclusion:

- In either case, SE computational and convergence performance is not significantly altered.

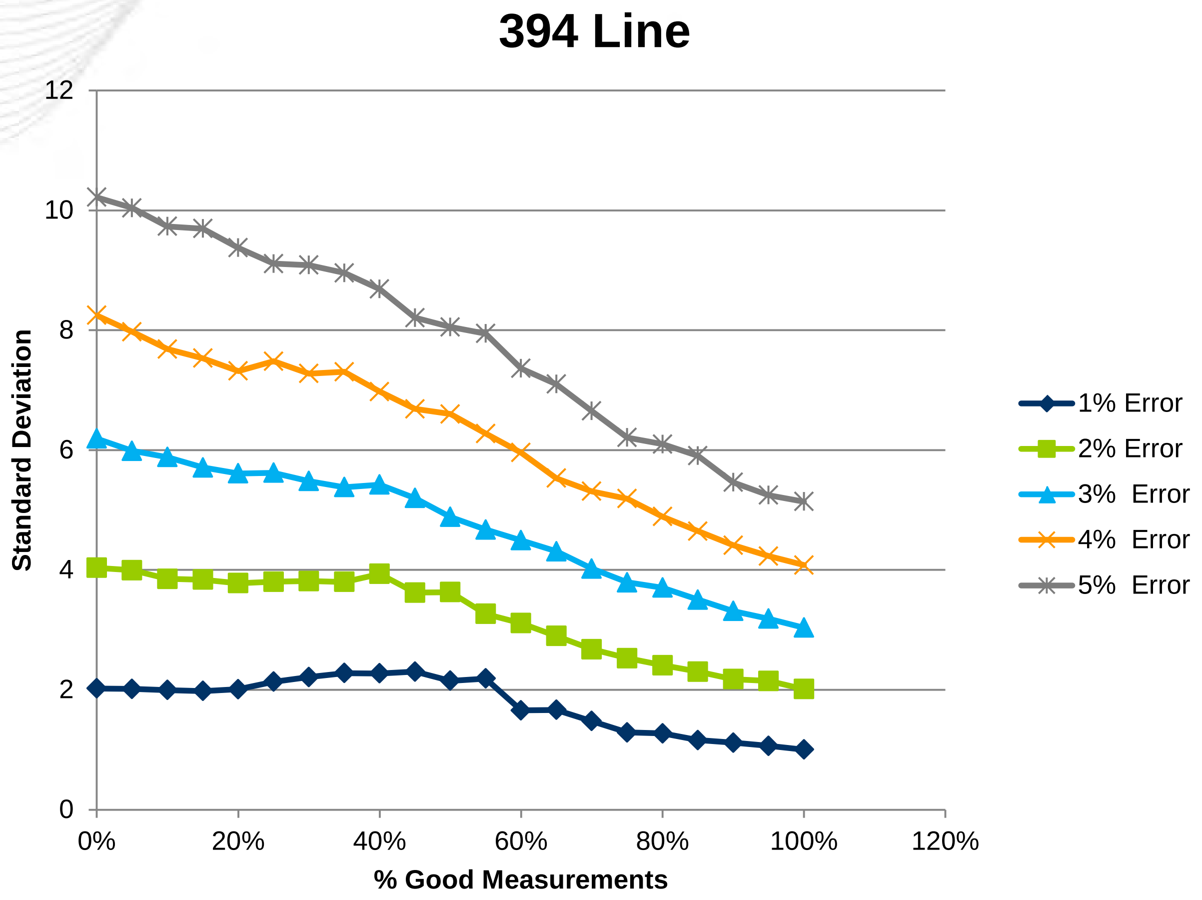


# Results and Conclusions (2nd model)



Conclusion:

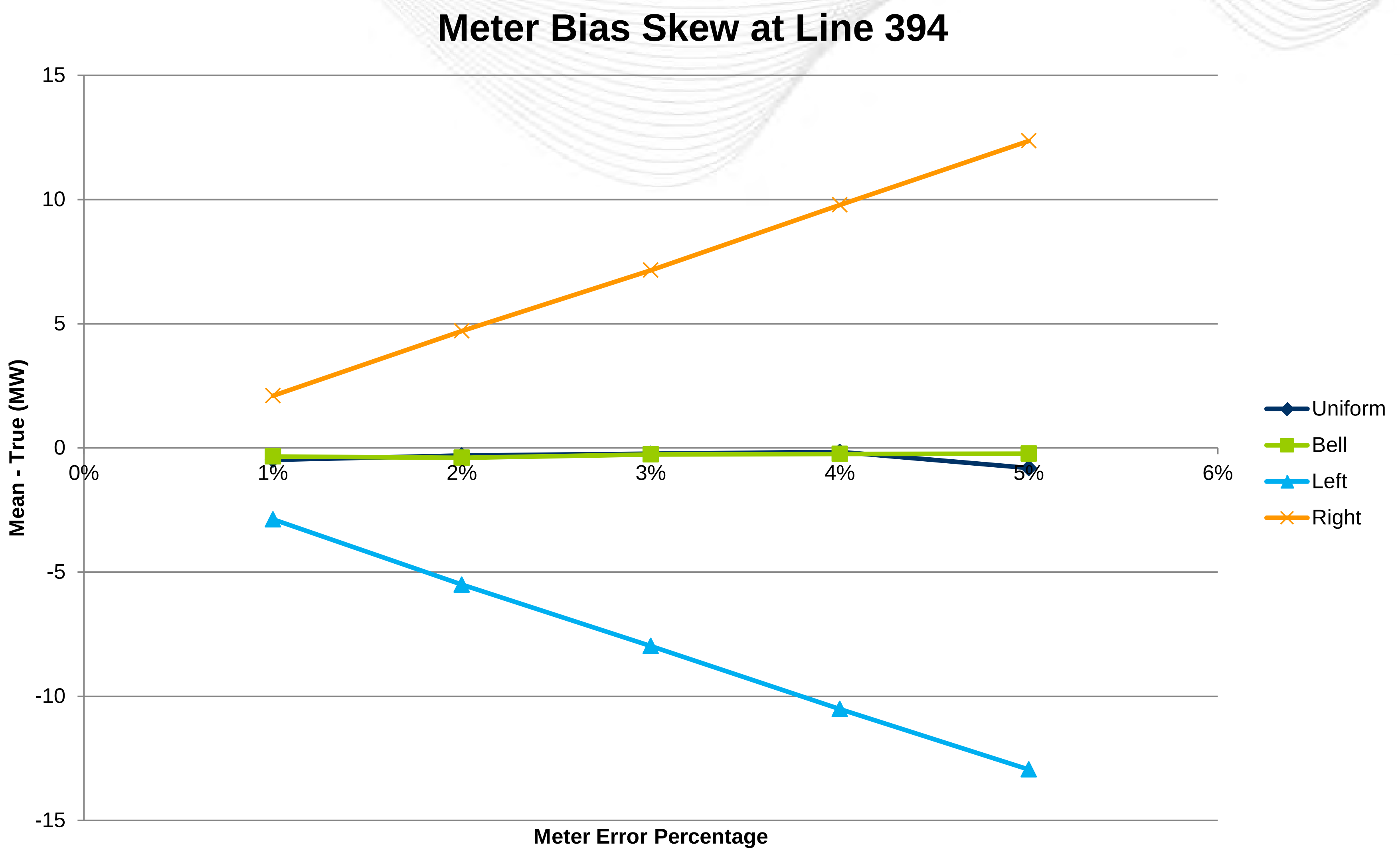
- Standard deviation of line flow decreases significantly with more measurements, especially for lower accuracy metering.
- **20% more metering approx. equivalent to 2% instead of 4% meter error.**



# A note on the density of metering at PJM.

- Out of ~15400 Internal Busses, about 2%, or 300 busses, are unobservable by PJM due to lack of telemetry. This number may be higher including busses where pseudo-loads are in use.
- PJM estimates that out of all possible model measurements, about 16% have telemetered values. This number may be affected by redundant points and non-critical measurements, but still suggests PJM cannot do with less telemetry.

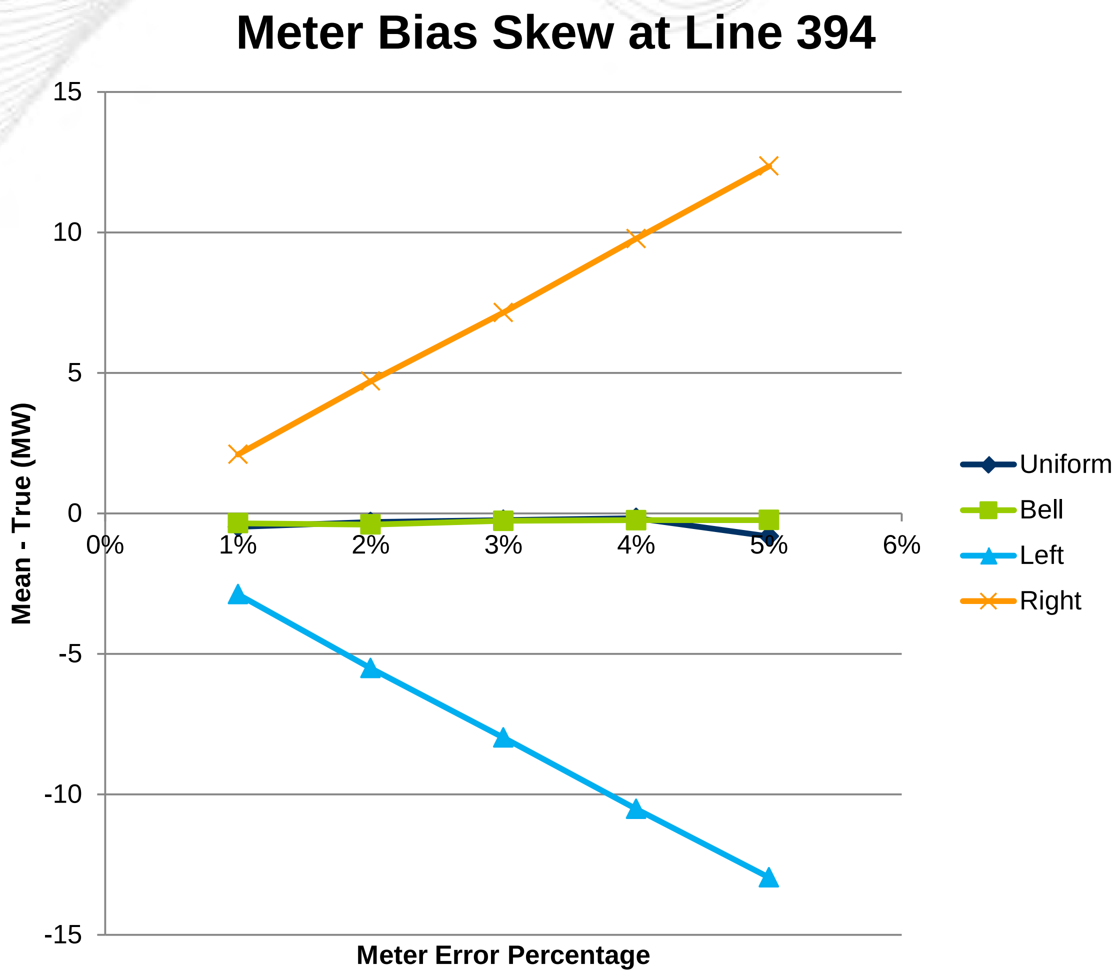
# Results and Conclusions (2nd model)



# Results and Conclusions (2nd model)

Conclusion:

- Similar to 1st model, uniform distributions cancel out high and low measurements, but left or right is probably more realistic since meter bias isn't randomized every scan, so results show how much a line will constantly be off due to meter inaccuracy.



# Overall Conclusions

- Metering accuracy ranging between 1% and 5% has moderate impact on SE solution accuracy, viewed over a model or single piece of equipment.
- Metering inaccuracy that is biased high or low consistently unevenly will lead to likewise consistently high or low SE solutions (settlements problem).
- More metering and telemetry to some degree mitigates the effects of less accurate metering.
- Metering accuracy has only modest effect on other SE performance (iteration and non-convergence count).