A CASE STUDY ON COMPARATIVE ANALYSIS OF TRAVELING WAVE BASED PROTECTION METHODS USING RTDS SUB-STEP ENVIRONMENT

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NEW YORK POWER AUTHORITY

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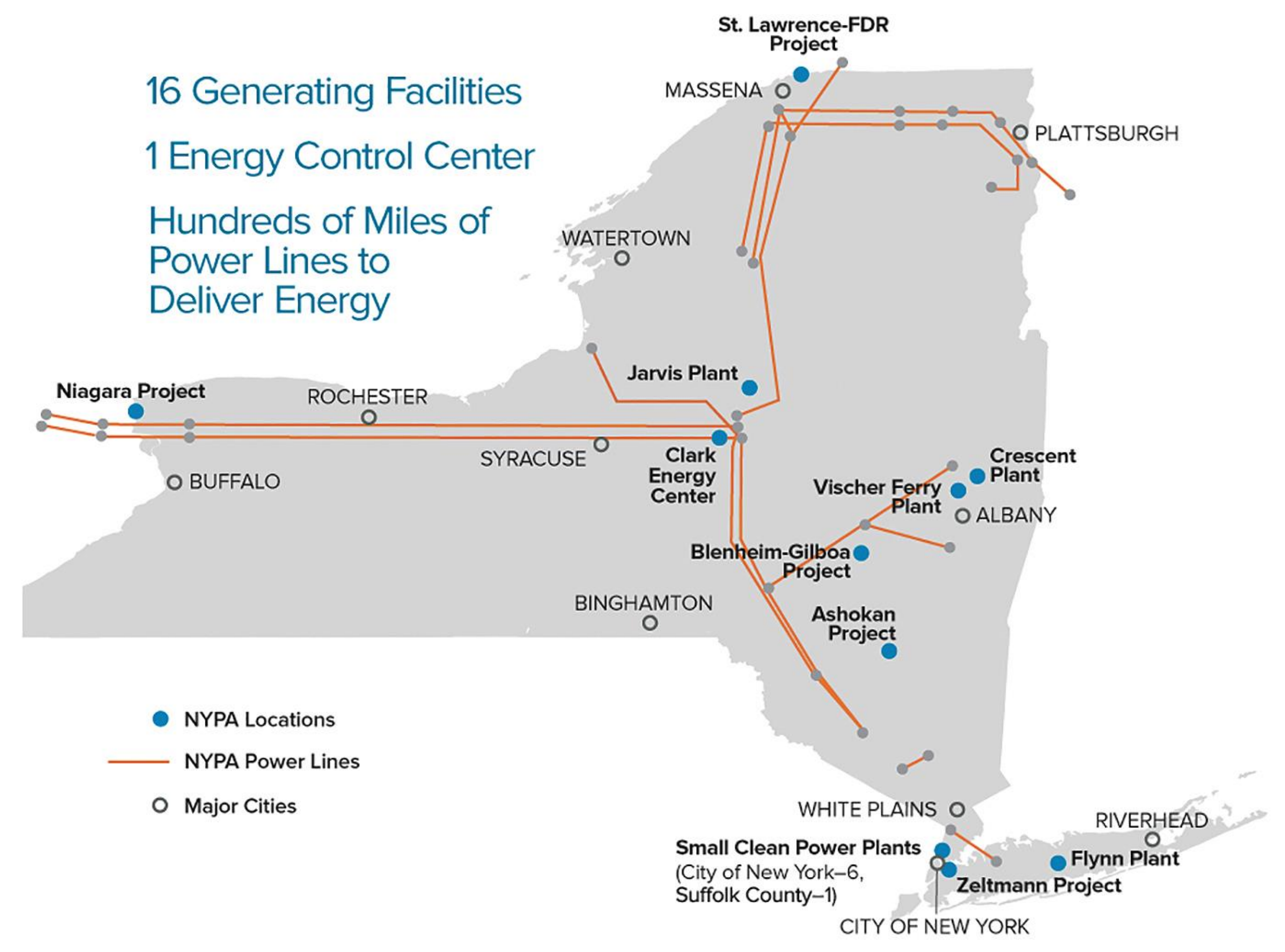
NYPA OVERVIEW

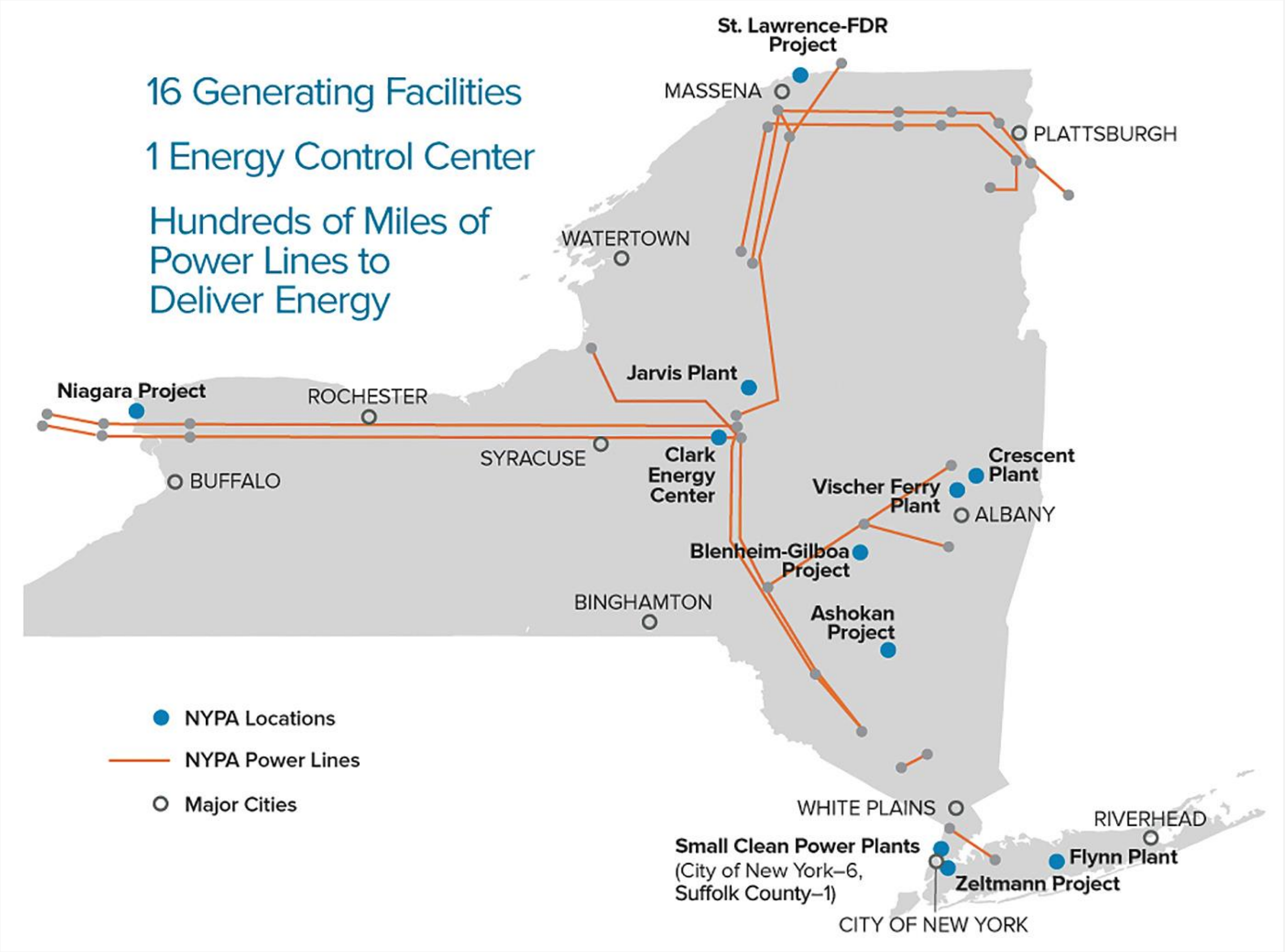
- Largest state electric utility in the United States [1]
- Provides about 25% of New York State's (N.Y.S.) electricity [1]
- Hydro and natural gas generation
- 1,400+ circuit miles [1]



[1] https://www.nypa.gov/power/transmission/transmission-overview

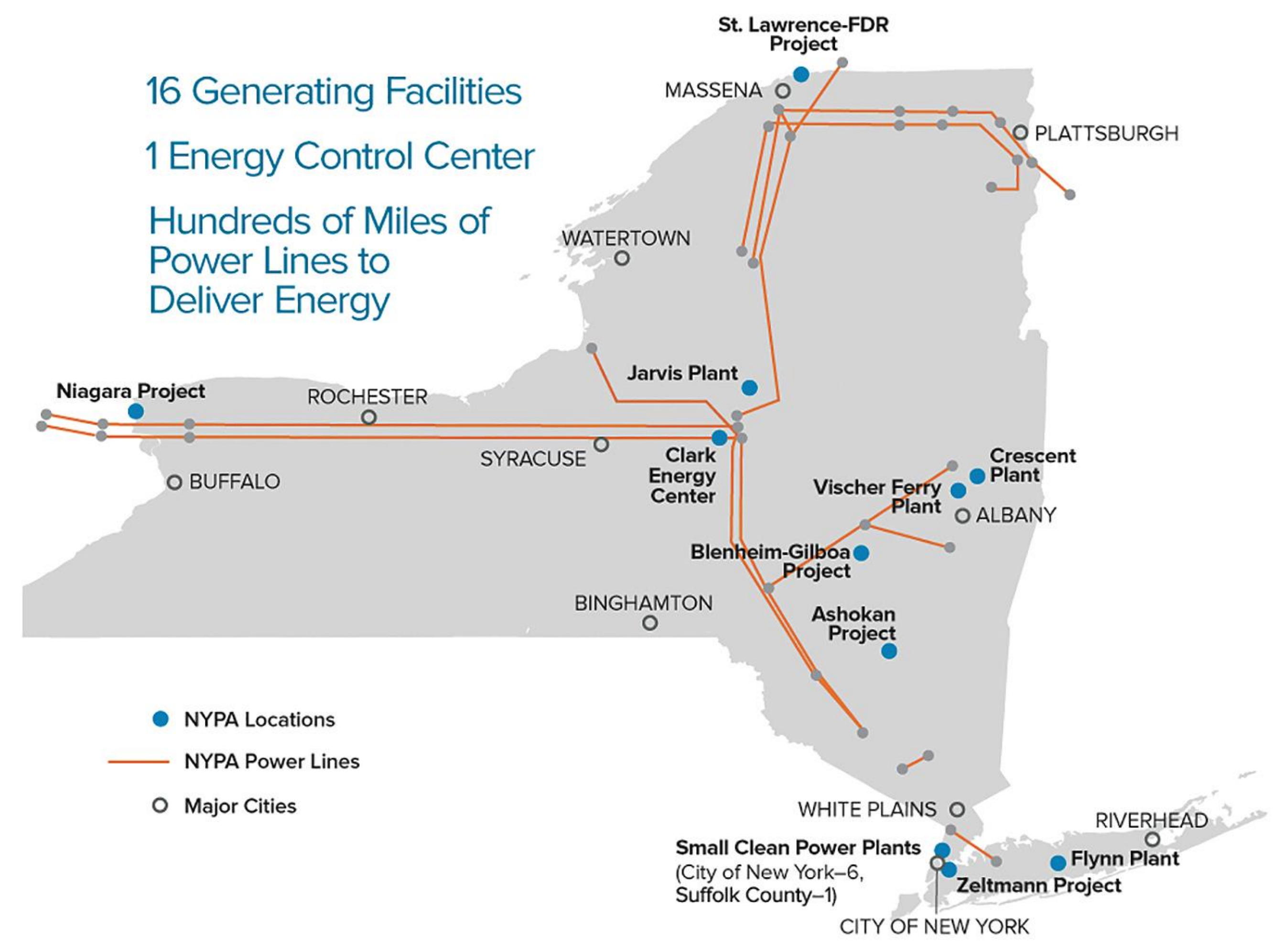
FAULT LOCATION MOTIVATION

- High speed and accurate fault location (FL) can help engineers quickly identify the faulty equipment and speed up restoration
- Increase system reliability



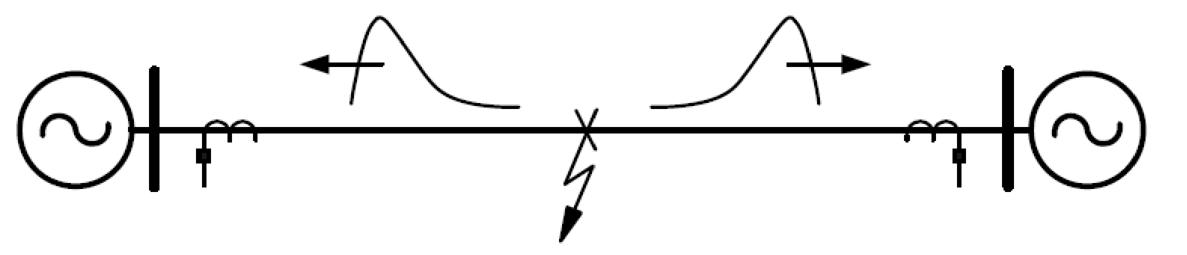
PROJECT OBJECTIVE

- Assess the latest advances in FL smarts for transmission line faults
- Evaluate FL smarts using real-time simulations for their performance evaluation



FL METHODS

- Impedance- (Z) & Traveling Wave (TW)-based methods used for FL [2, 3]
- FL accuracy affected by non-homogenous transmission line, line impedance data errors, mutual coupling, series compensation [2]
- Accuracy of impedance-based FL methods estimated in the order of 0.5 to 2% [2]



TWs propagate to both ends of the line[6]

[2] E. O. Schweitzer, A. Guzmán, M. V. Mynam, V. Skendzic, B. Kasztenny and S. Marx, "Locating faults by the traveling waves they launch," *2014 67th Annual Conference for Protective Relay Engineers*, College Station, TX, 2014, pp. 95-110, doi: 10.1109/CPRE.2014.6798997.
[3] Marx, Stephen, et al. "Traveling wave fault location in protective relays: Design, testing, and results." proceedings of the 16th Annual Georgia Tech Fault and Disturbance Analysis Conference, Atlanta, GA. 2013.

TRAVELING WAVE BASED FAULT LOCATION

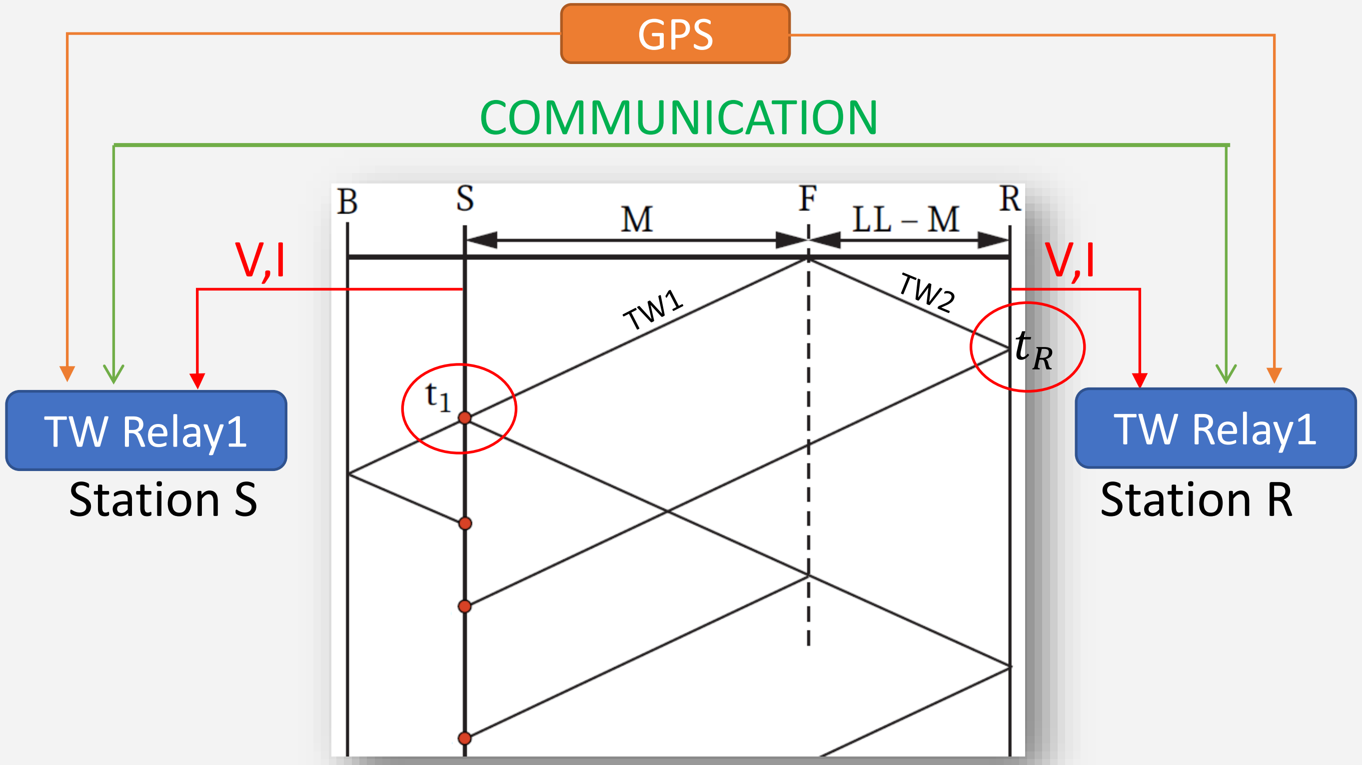
- TW-based fault location methods (TW) [4]:
  - Double Ended (DETW): collects TW information from both line terminals via communications and using a common time references to estimate the FL
  - Single Ended (SETW): collects TW information from one end of the line without the use of communications and precise time reference to estimate the FL

[4] A. Guzmán, B. Kasztenny, Y. Tong and M. V. Mynam, "Accurate and economical traveling-wave fault locating without communications," *2018 71st Annual Conference for Protective Relay Engineers (CPRE)*, College Station, TX, 2018, pp. 1-18, doi: 10.1109/CPRE.2018.8349768.

TRAVELING WAVE BASED FAULT LOCATION

- DETW FL method [4]
  - Most accurate FL

S: Local Bus
R: Remote Bus
B: Bus behind *S*
LL: Line Length
F: Fault Point
M: Fault location w.r.t to *S*
t_1: Time for TW1 arrived at *S*
t_R: Time for TW2 arrived at *R*
TWLPT: Wave Propagation Time



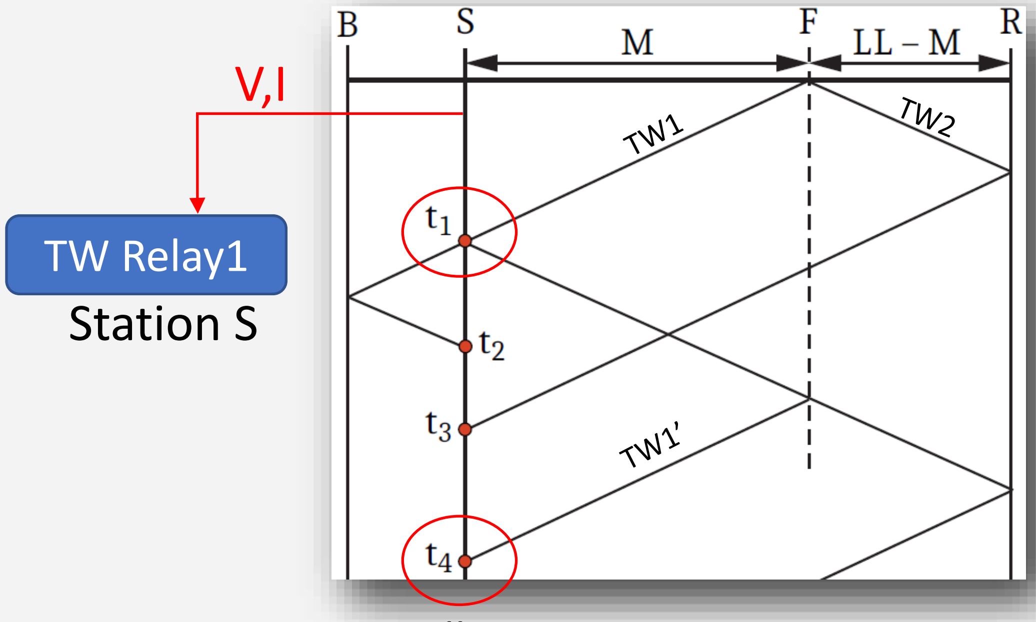
Travelling waves in AC power system

$$M = \frac{LL}{2}\left(1 + \frac{t_1 - t_R}{TWLPT}\right)$$

TRAVELING WAVE BASED FAULT LOCATION

- SETW FL method [4]
  - No comm. required

S: Local Bus
R: Remote Bus
B: Bus behind *S*
LL: Line Length
F: Fault Point
M: Fault location w.r.t to *S*
t_1: Time for TW1 arrived at *S*
t_4: Time for TW1 reflected to *S* via *F*
TWLPT: Wave Propagation Time



Travelling waves in AC power system

$$M = \frac{LL}{2}\left(\frac{t_4 - t_1}{TWLPT}\right)$$

TW-BASED FL TESTING MODELING

- TW based relays (TWR) employs a high sampling rate (~1MHz) to extract high frequency TW components [5]
- Hardware-in-the-loop (HIL) interface for TW based methods require time-steps in the small μs range for correct emulation of the fault waveforms => Realized using Sub-Step [5]
- Freq. Dependent Phase-Domain (FDPD) based line models required to capture the high frequency TW components [5]

[5] https://knowledge.rtds.com/hc/en-us/articles/360042650713-Real-Time-Closed-Loop-Traveling-Wave-Relay-Testing-TWRT-in-the-Environment-of-Multi-Machine-AC-Power-Systems

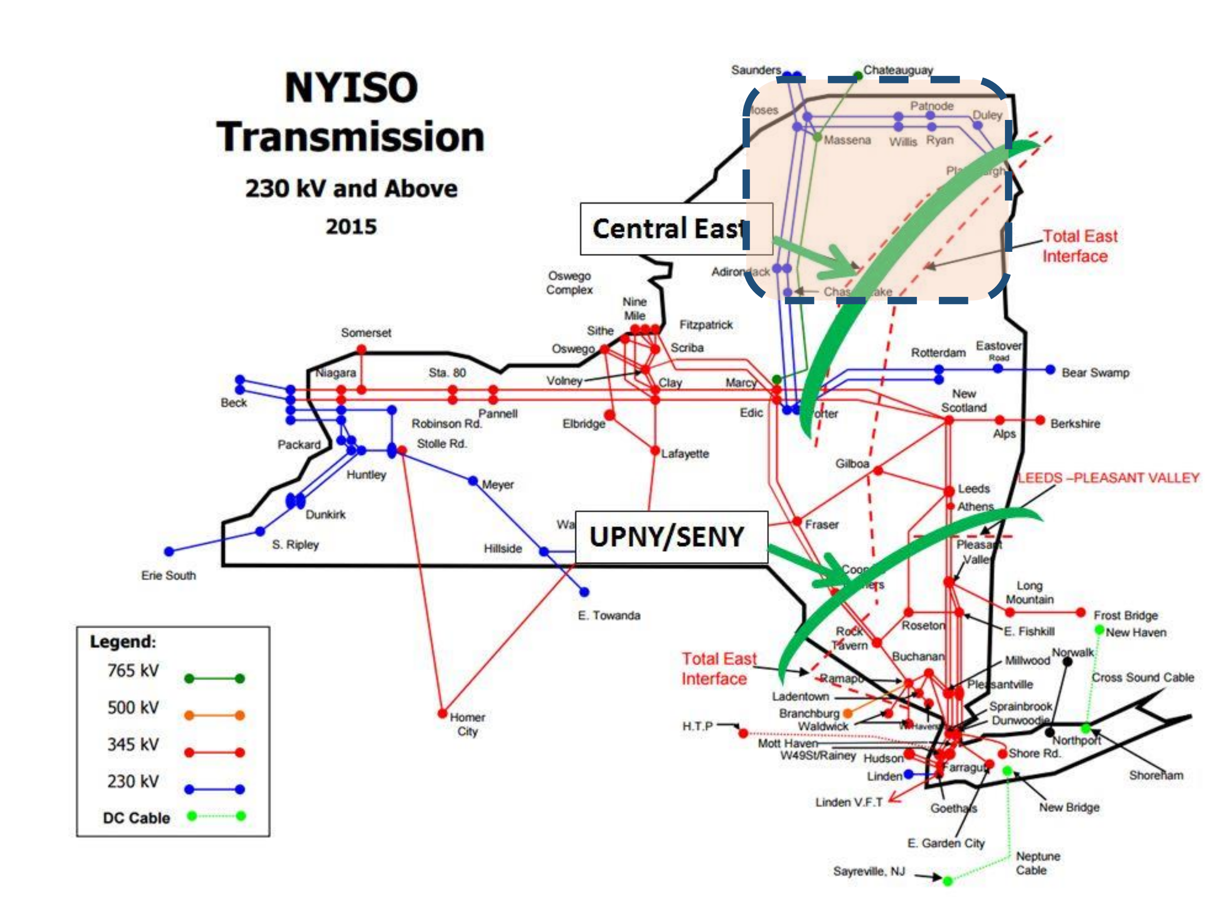
TW-BASED SUB-STEP MODEL DEVELOPMENT

- Current N.Y.S real-time model runs at 50 μs in Main-Step used as base reference model [6]
- Develop FDPD based lines in the North and Central N.Y.S. Corridor for Sub-Step simulation

[6] https://www.tdworld.com/grid-innovations/smart-grid/article/21133342/nypas-agile-lab-speeds-up-smart-grid-innovation

TW-BASED FL TESTING MODEL DEVELOPMENT

- North and Central N.Y.S. Transmission Corridor
  - NYPA Facility in Upstate N.Y. – 16 Hydro Units
  - 10 transmission lines in the ROW
  - 16 multi-circuit lines in the corridor at 230kV and above
  - TWR testing for FL at Upstate N.Y.

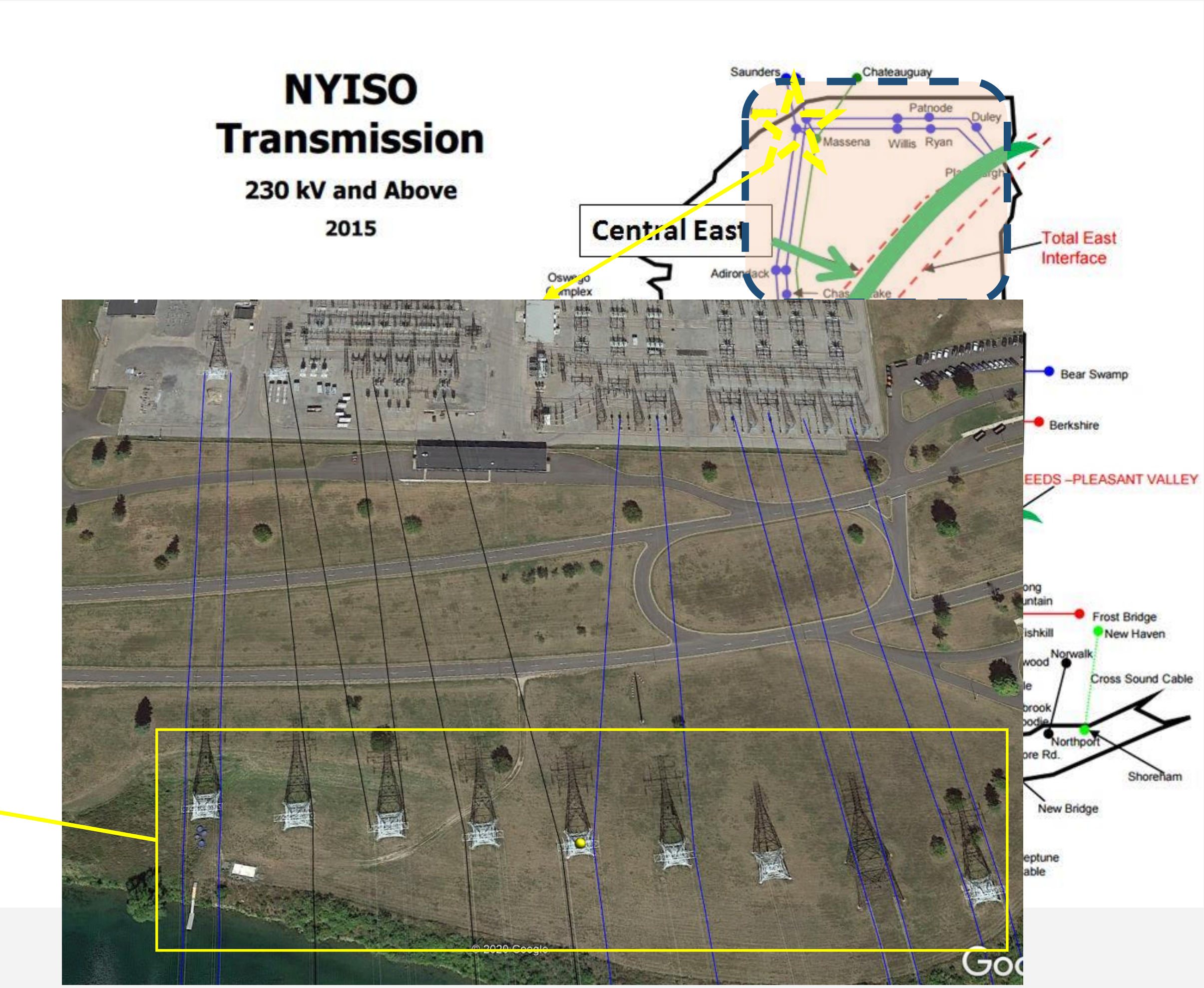


N.Y.S. Transmission Network [6]

[6] https://energywatch-inc.com/1-2bn-of-transmission-upgrades-recommended-to-reduce-costsemissions-in-ny/

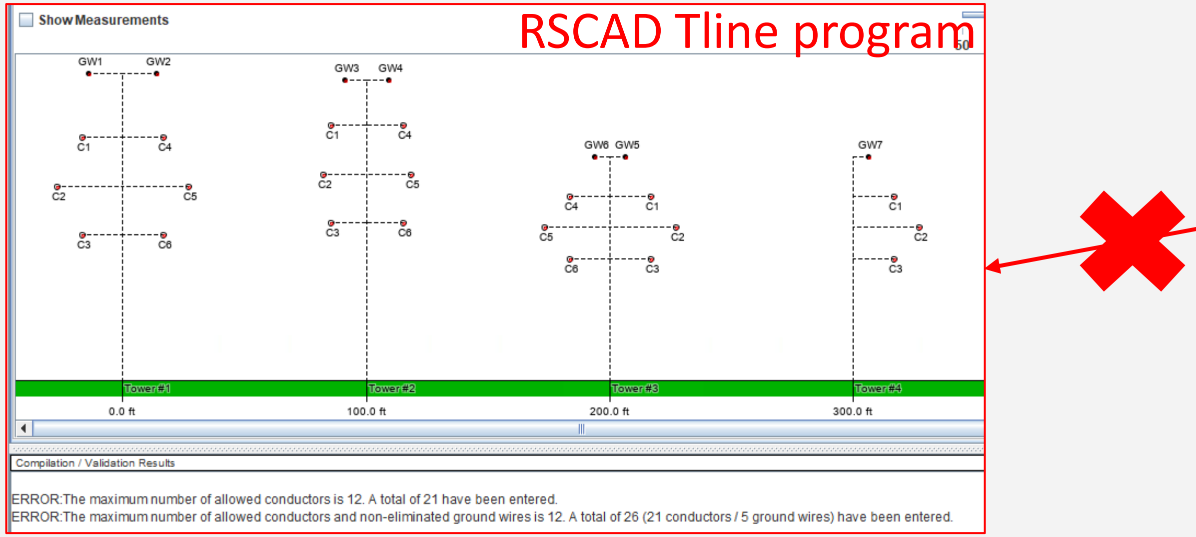
TW-BASED SUB-STEP MODEL DEVELOPMENT

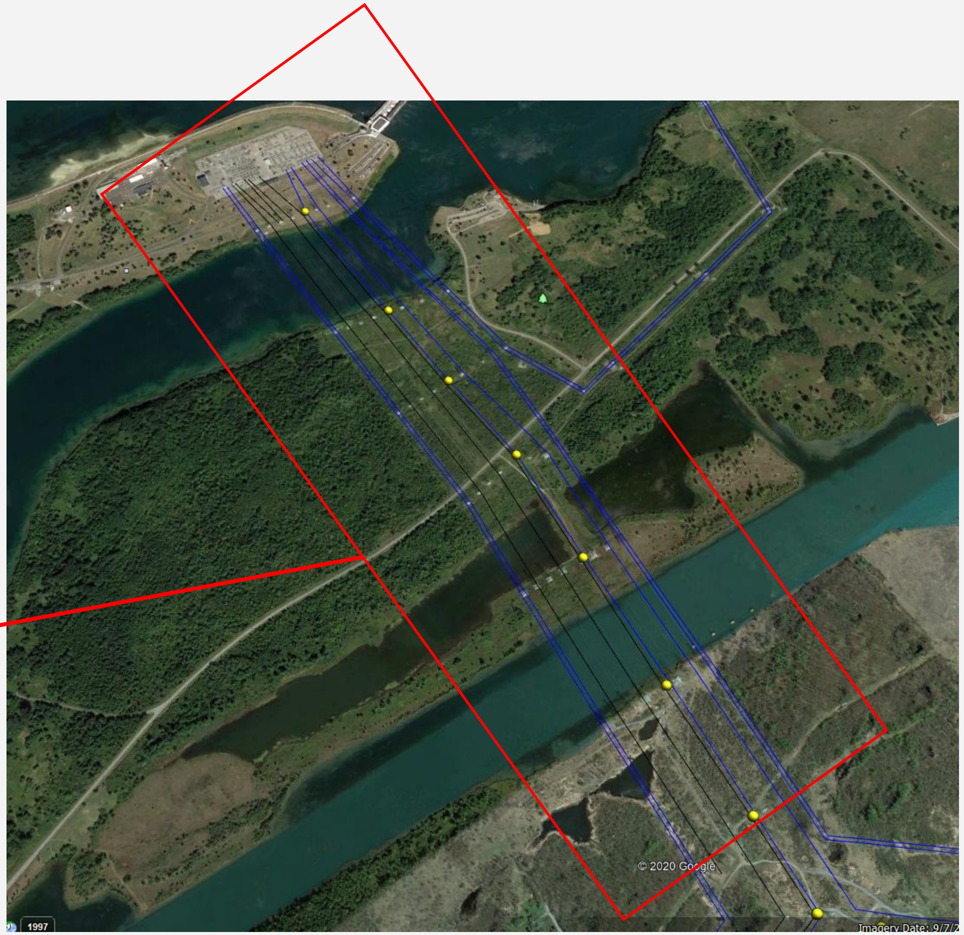
- Modeling Challenges
  - NYPA Facility in Upstate N.Y. – 16 Hydro units
  - 10 transmission lines in the ROW for more than a mile at different voltages
  - Model and validate FDPD line models



TW-BASED SUB-STEP MODEL DEVELOPMENT

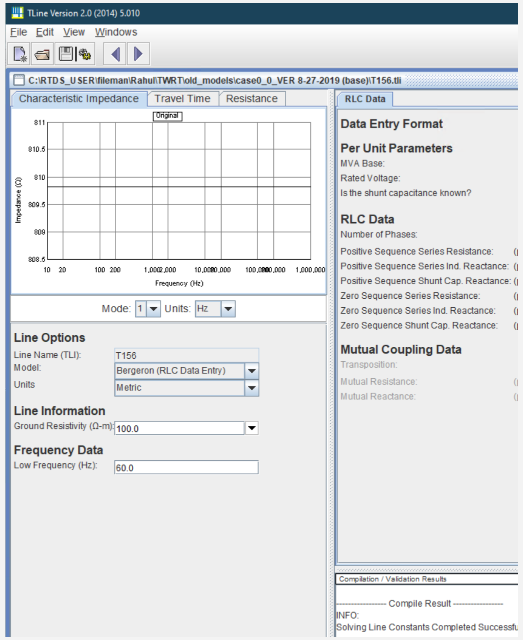
- Modeling Challenges:
  - In sub-step, for e.g., a time-step of 3μs now restricts minimum line length to be ~0.558 miles for a TW based line model
  - Up to 4 coupled three phase circuits limit in RSCAD



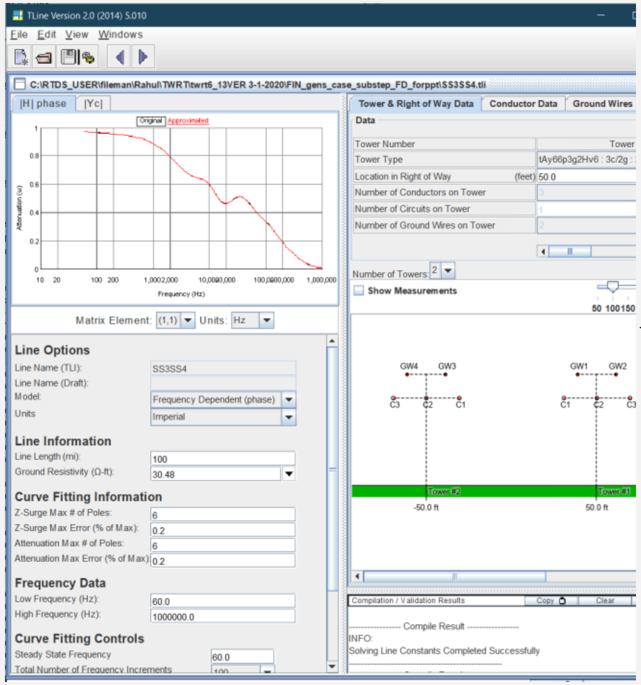


TW-BASED SUB-STEP MODEL DEVELOPMENT

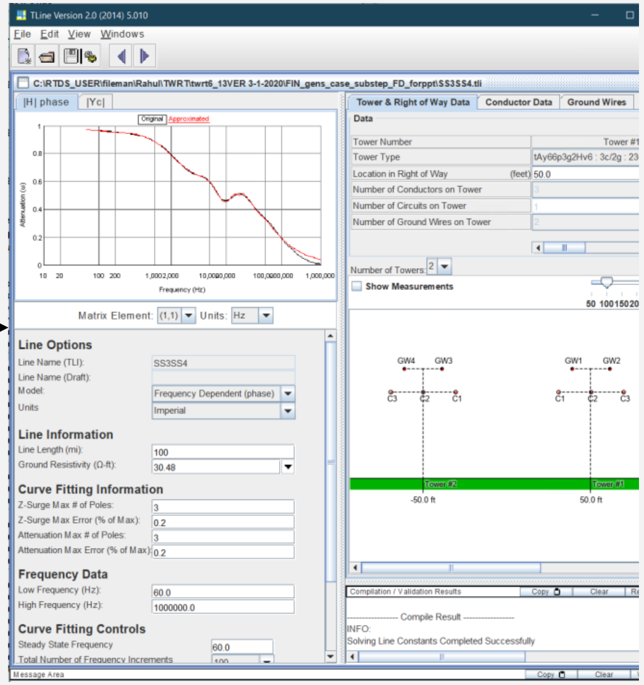
- FDPD lines development (Higher poles increases computational burden)



Bergeron RLC line model



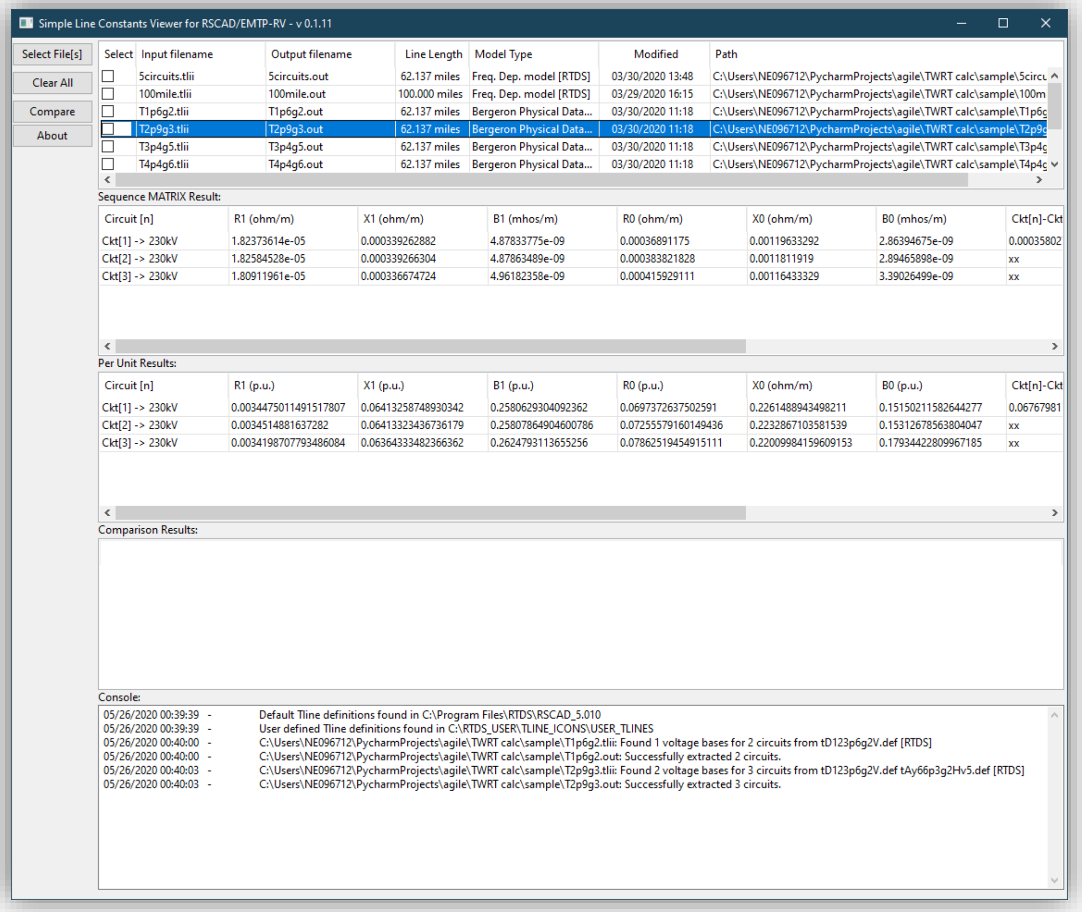
FDPD line with 6 poles for sub-step model



FDPD line with 3 poles for sub-step model

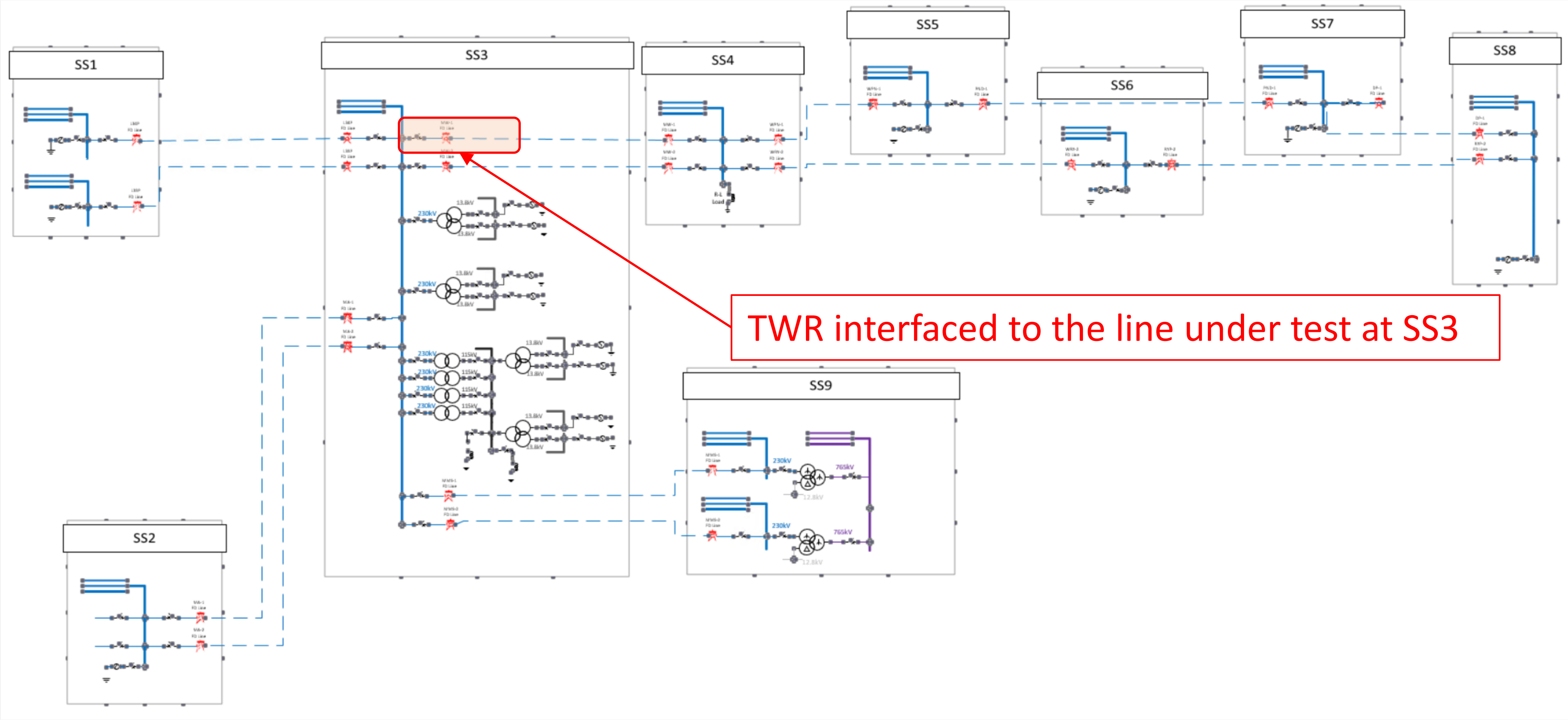
TW-BASED SUB-STEP MODEL DEVELOPMENT

- FDPD line model development
  - Physical parameters such as conductor configuration and tower geometry from reference line data
- Line constant results from FDPD lines close match with the reference
  - Internal tools for relatively easy p.u. calculations and comparison



TW-BASED SUB-STEP MODEL DEVELOPMENT

- North and Central N.Y.S. Transmission Corridor Model in RTDS



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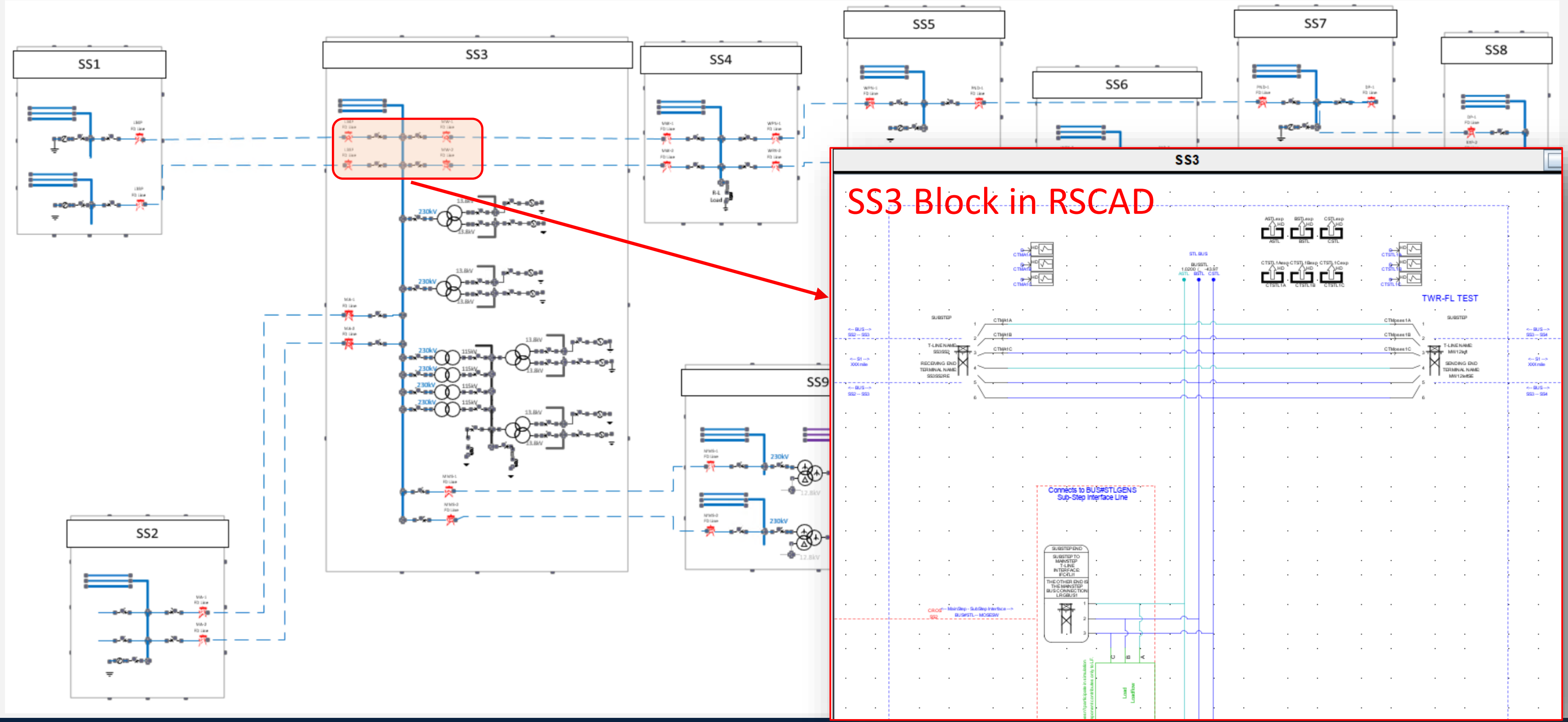
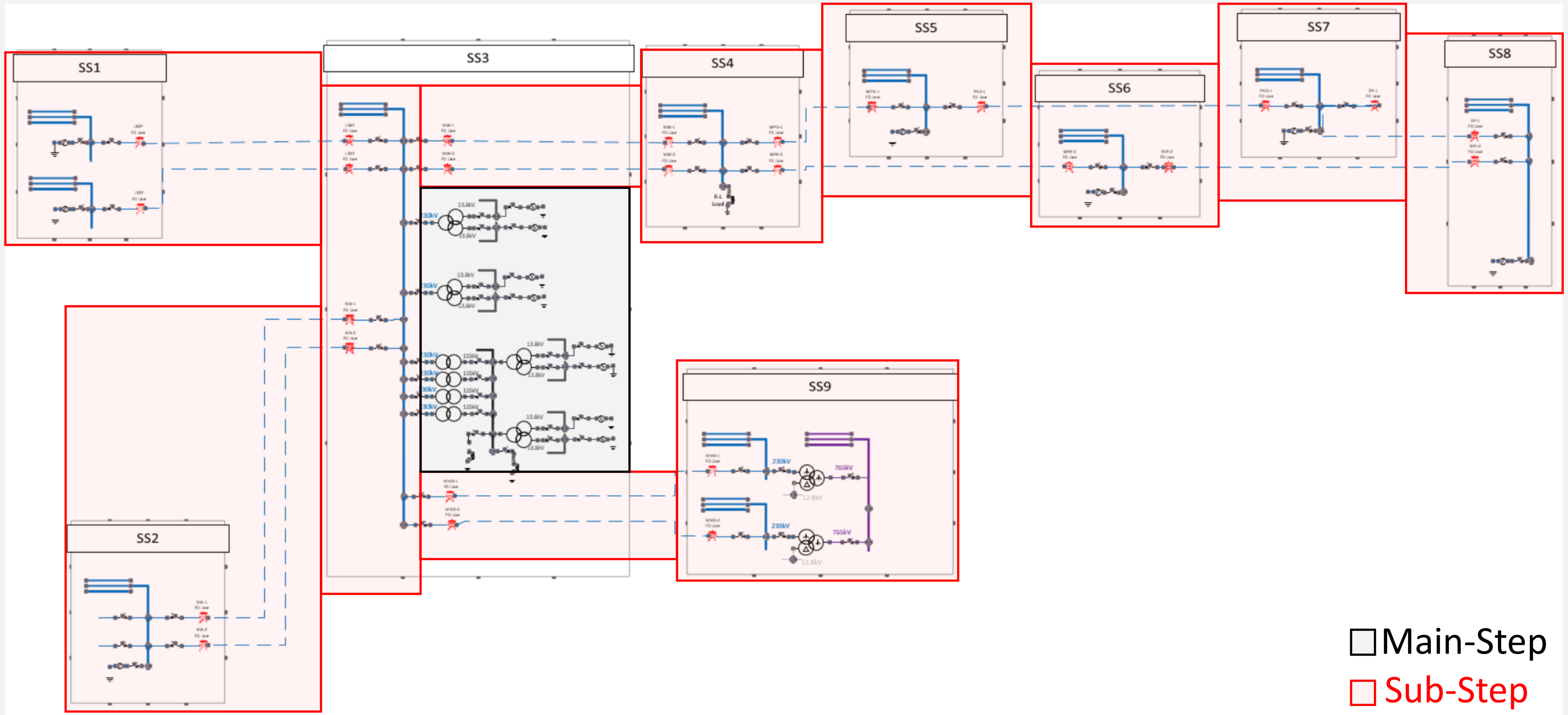


TW-BASED FL TESTING MODEL DEVELOPMENT

- Main-Step + Sub-Step model of the North and Central N.Y.S. Transmission Corridor

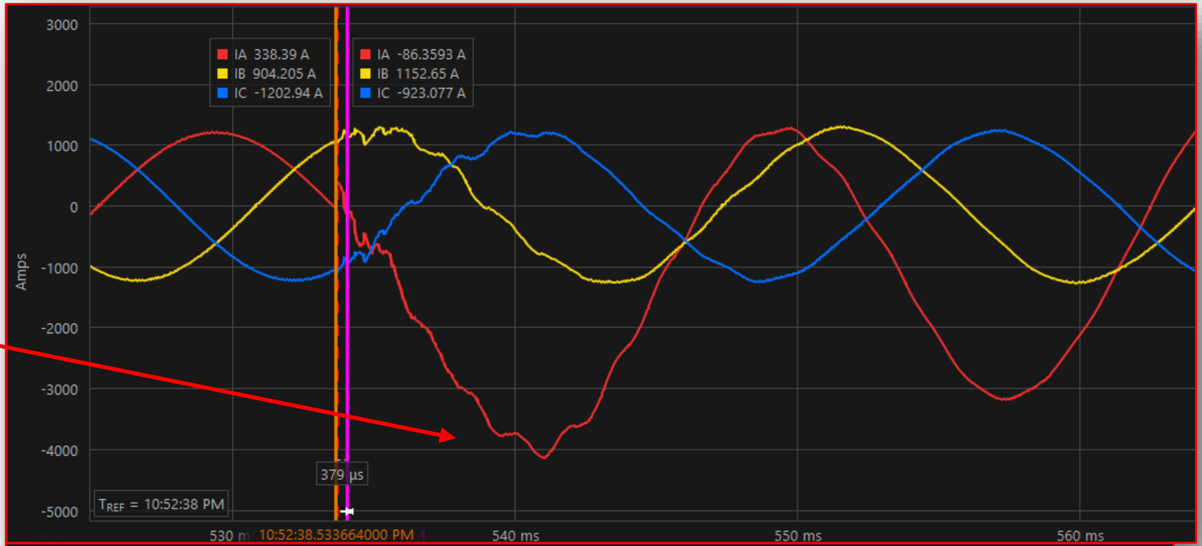


TW-BASED FL TESTING MODEL SIMULATION

- SETW Test

1. A-ph to Ground fault simulated at 35 miles on a 100 mile from Station *S* in the Runtime

2. TWs received at Station *S* retrieved from COMTRADE Events



TW-BASED FL TESTING MODEL SIMULATION

- SETW Test

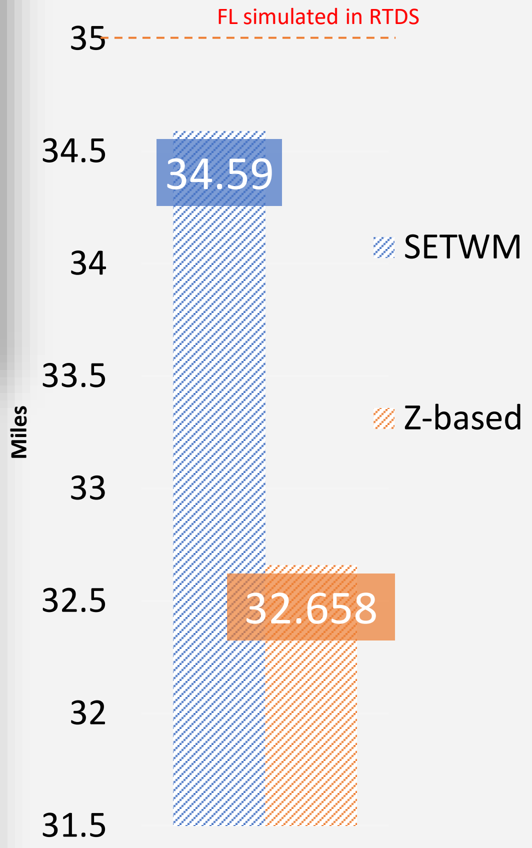
1. A-ph to Ground fault simulated at 35 miles on a 100 mile from Station *S* in the Runtime

2. TWs received at Station *S* retrieved from COMTRADE Events

3. Using SETW:

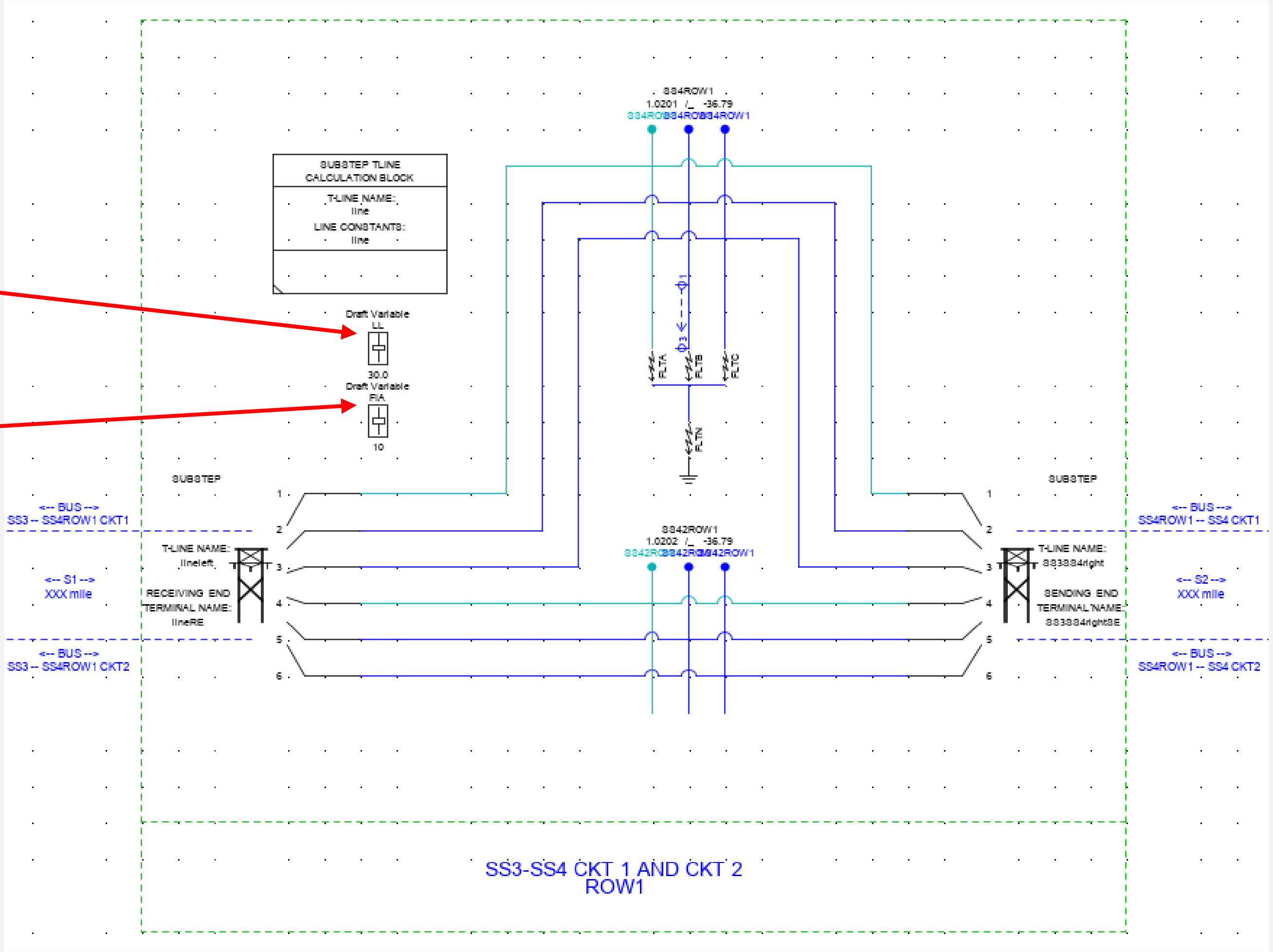
$$M = \frac{100mile}{2}\left(\frac{379\mu S}{547.77\mu S}\right)$$
$$= 34.59 miles\ from\ Stn.S$$

4. COMTRADE EVENT RESULT



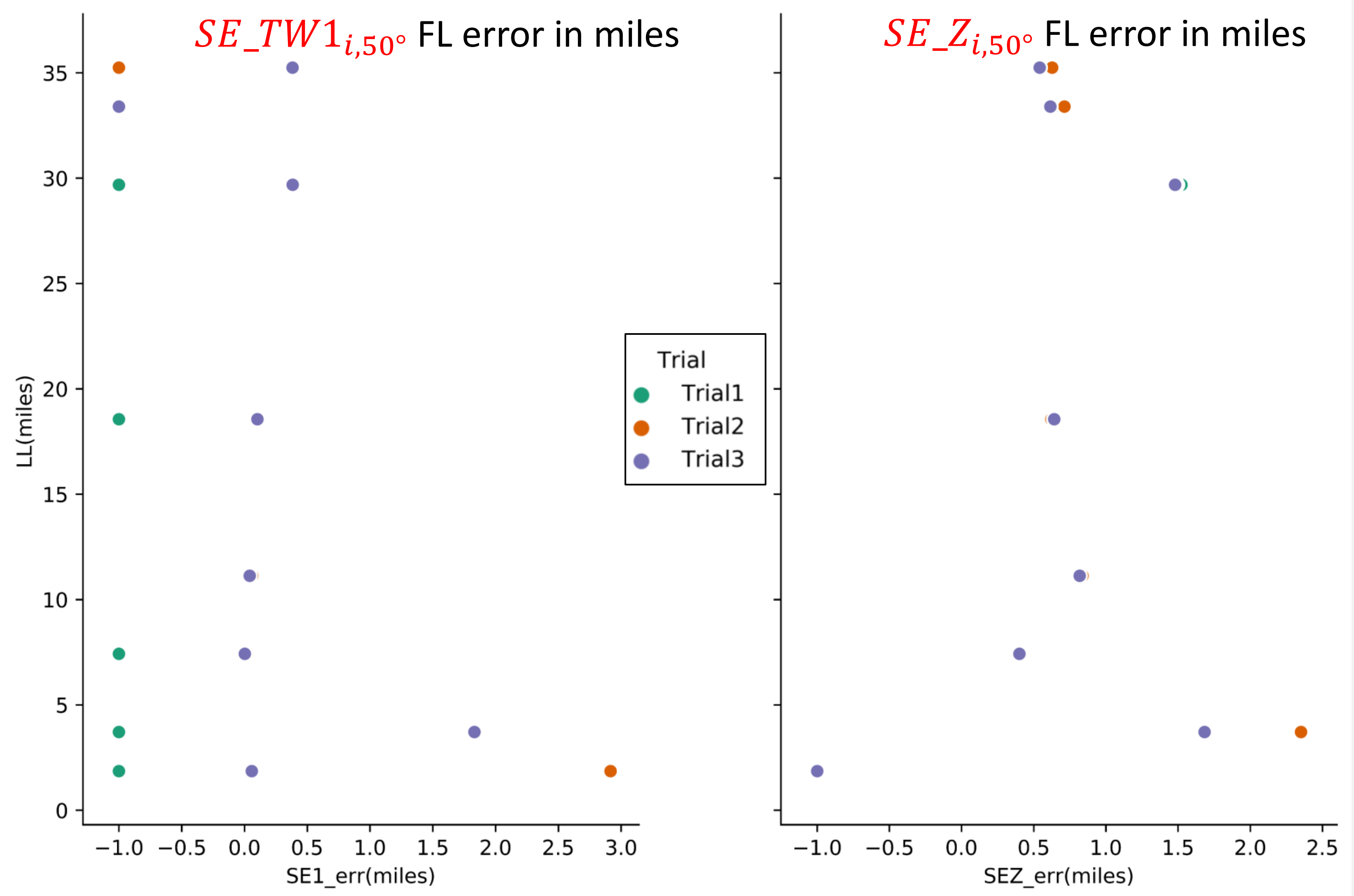
TW-BASED FL TESTING MODEL SIMULATION

- Batch Testing using RunTime Scripts
  - Fault scenario simulated in RTDS
    - Line Length (LL_i)
      - $i = 5, 10, 20, 30, 50, 80, 90, 95\%$
        - Fault Inception Angles (FIA_j)
          - $j = 5, 20, \ldots, 360°$
- Results
  - $SE\_TW1_{i,j}$: FL from SETW in TWR events
  - $SE\_Z_{i,j}$: FL from Z-based in TWR events
  - SE1_err: $SE\_TW1_{i,j} - LL_{i,j}$
  - SEZ_err: $SE\_Z_{i,j} - LL_{i,j}$



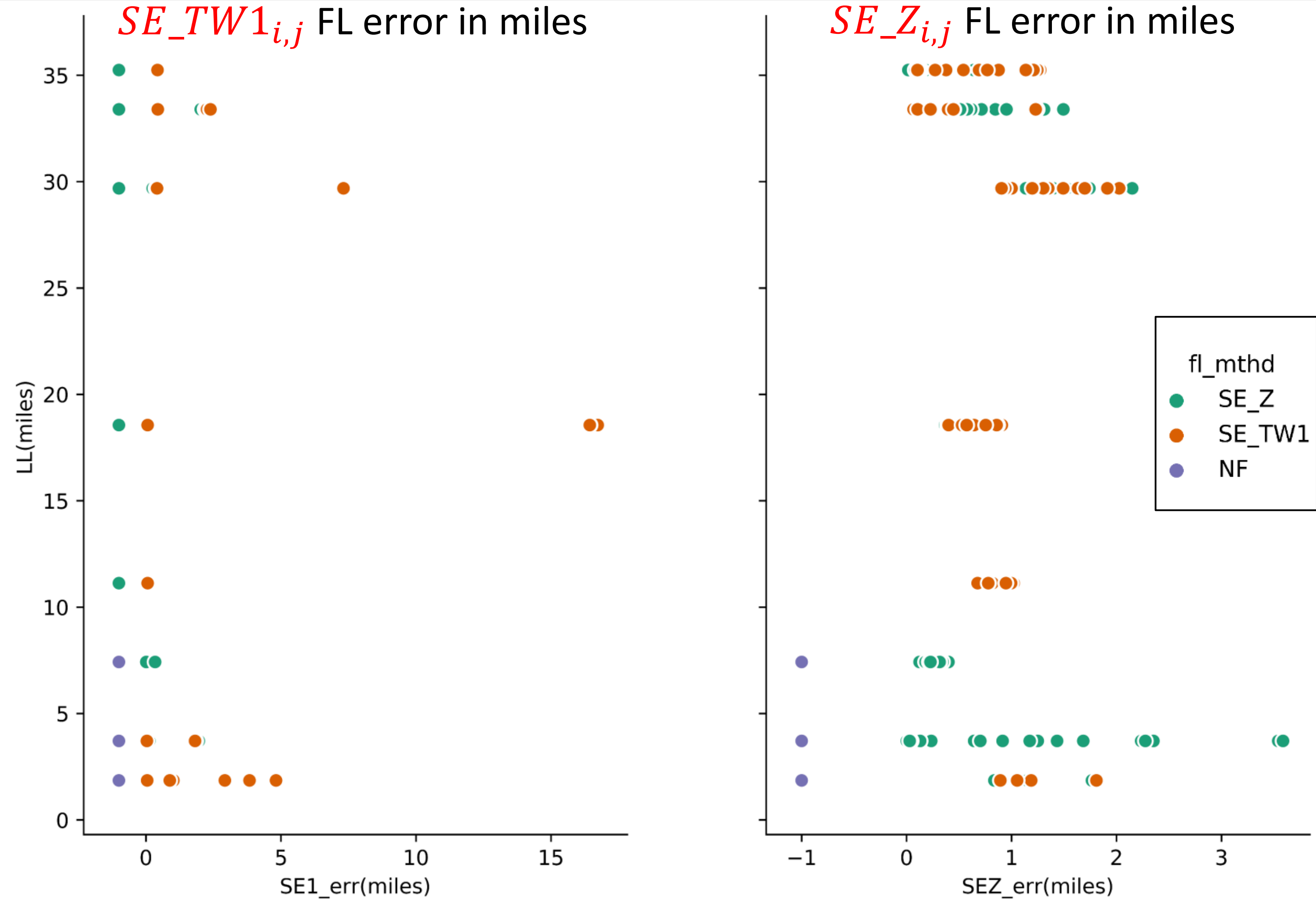
TW-BASED FL TESTING MODEL RESULTS

- FL absolute error comparison between SETW and Z-based methods
  - A-Grnd fault for all LL_i at $\boldsymbol{FIA_{j=50deg}}$
  - -1.0 indicates no FL



TW-BASED FL TESTING MODEL RESULTS

- FL method selected by TWR for A-Grnd fault for <u>all LL_i and POW_j</u>
  - SE_TW1 based FL: 36.3%
  - SE_Z based FL: 58.33%
  - In 6% cases, FL was not estimated (*NF*)



TW-BASED FL TESTING MODEL SUMMARY

- An open loop HIL-based model was developed
- A preliminary performance comparison was performed
- Closed loop HIL simulation as future work

QUESTIONS?