



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

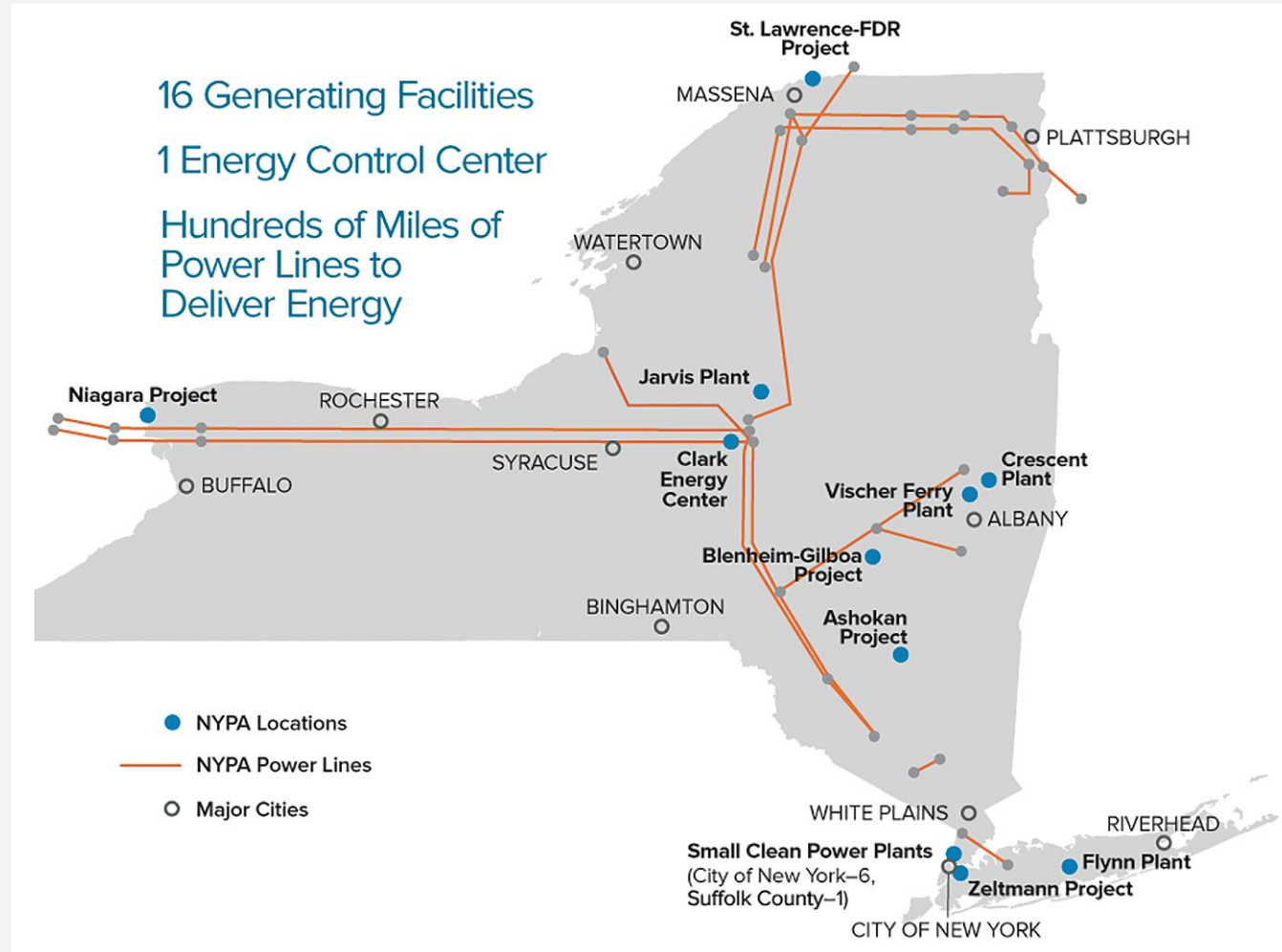
USER SPOTLIGHT SERIES BY  RTDS
Technologies



NY Power
Authority

NYPA OVERVIEW

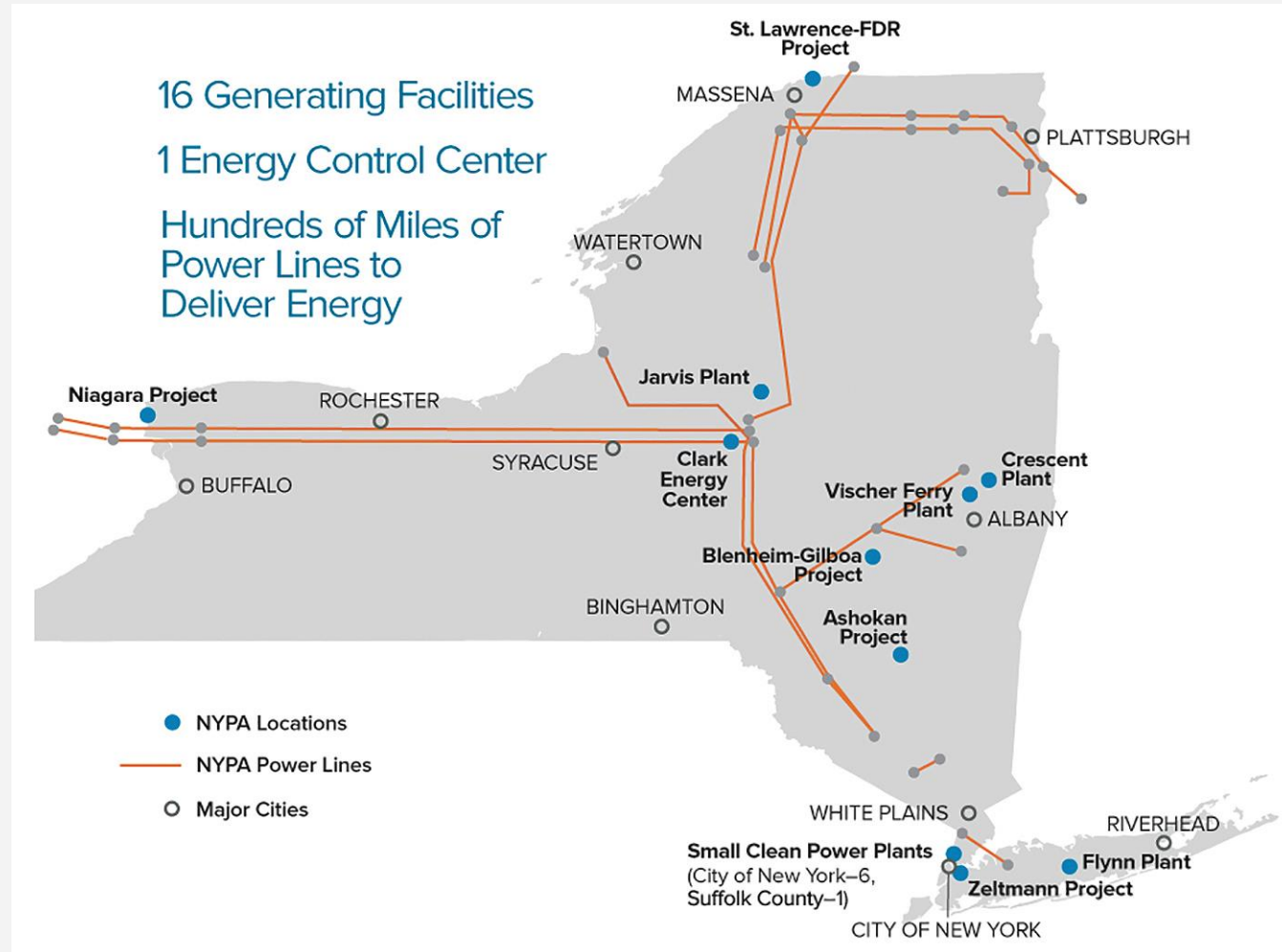
- Largest state electric utility in the United States [1]
- Provides about 25% of New York State's (N.Y.S.) electricity [1]
- Hydro and natural gas generation
- 1,400+ circuit miles [1]



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

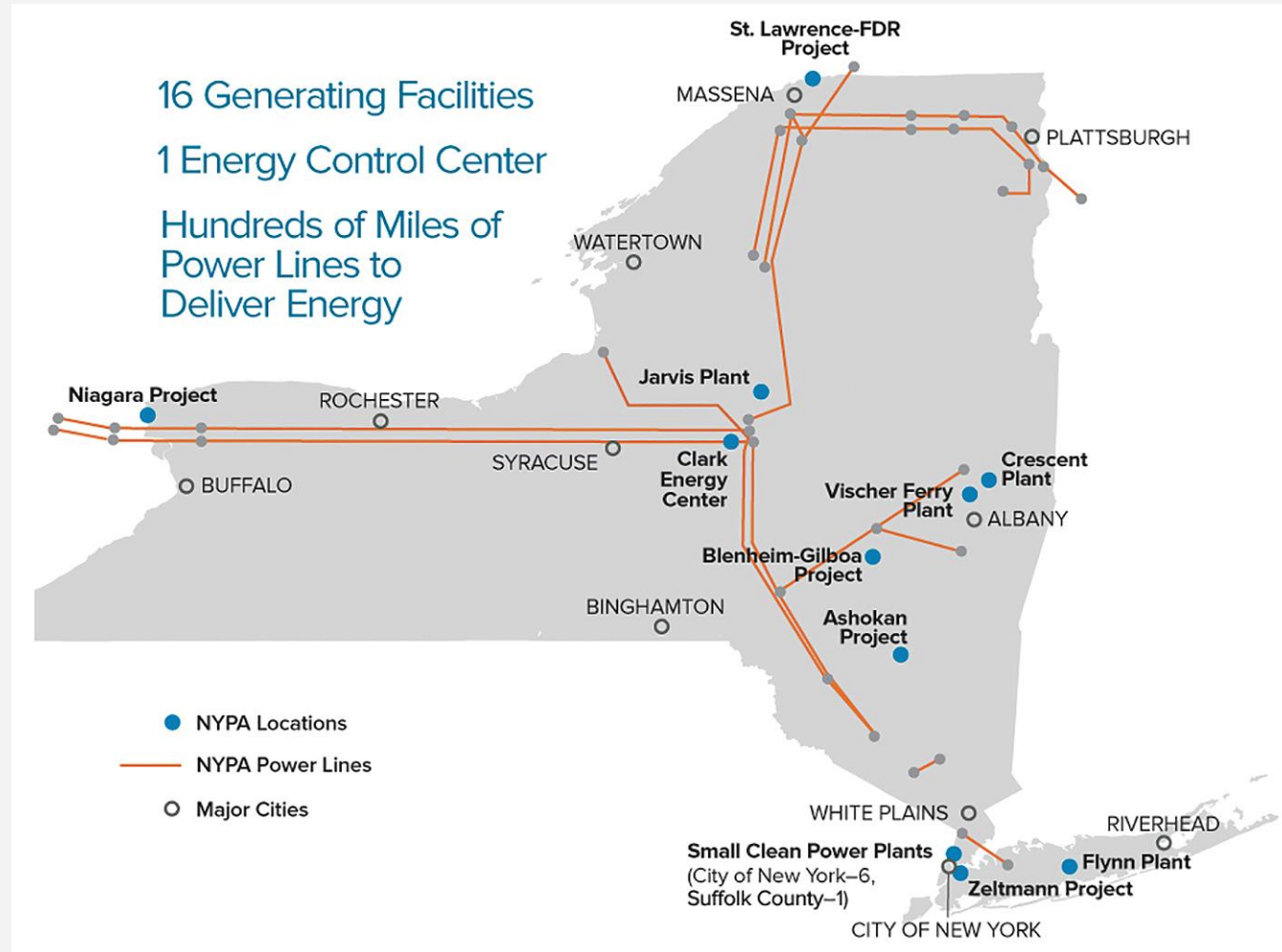
FAULT LOCATION MOTIVATION

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



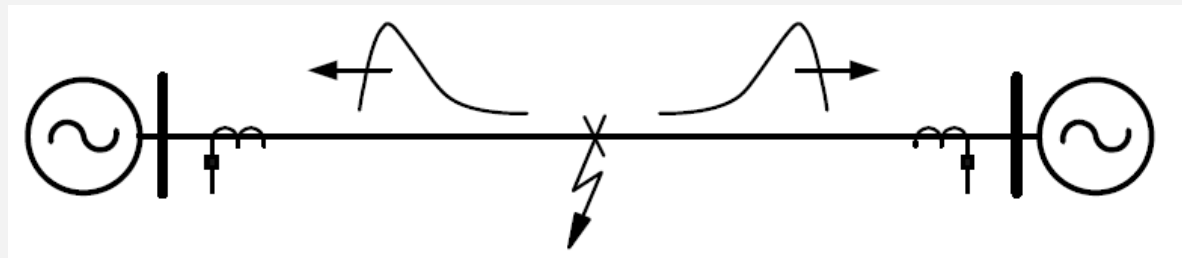
PROJECT OBJECTIVE

- 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

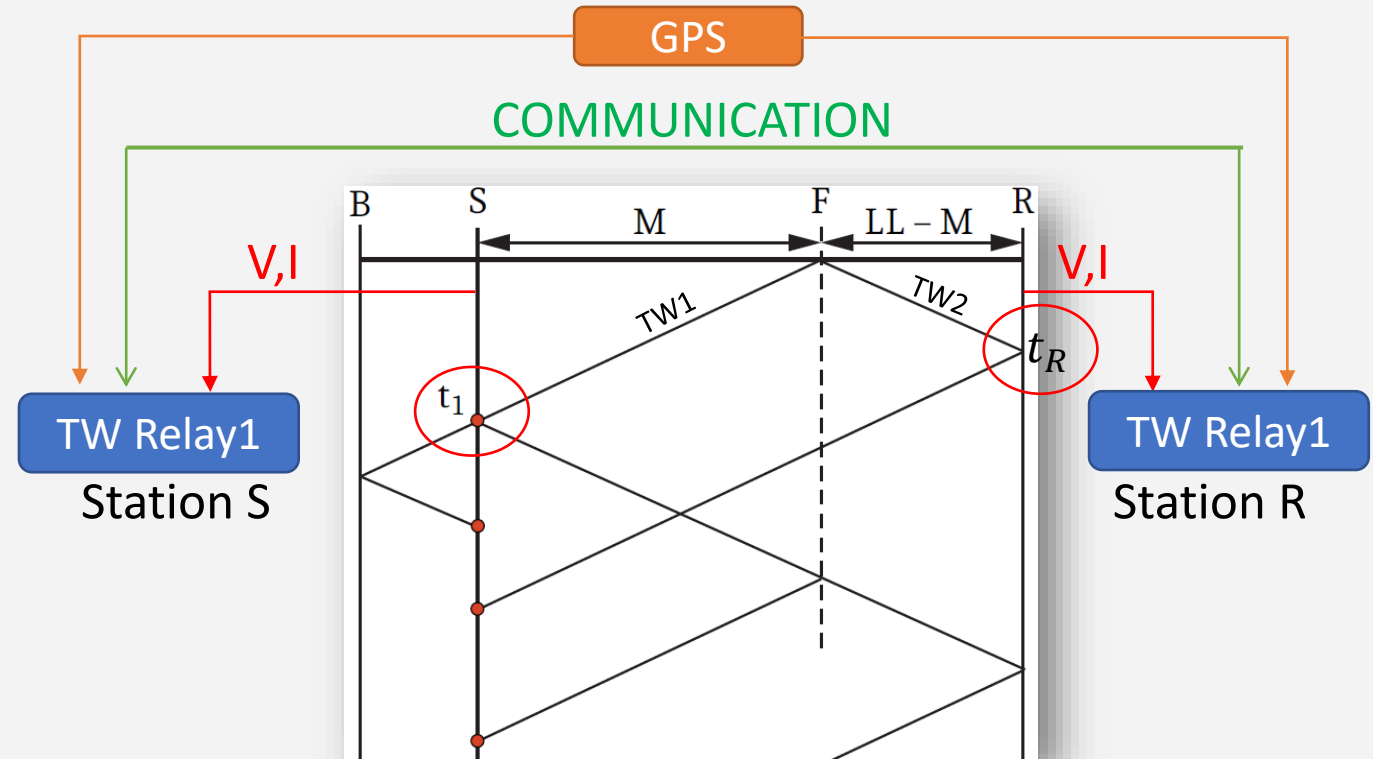
F: Fault Point

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

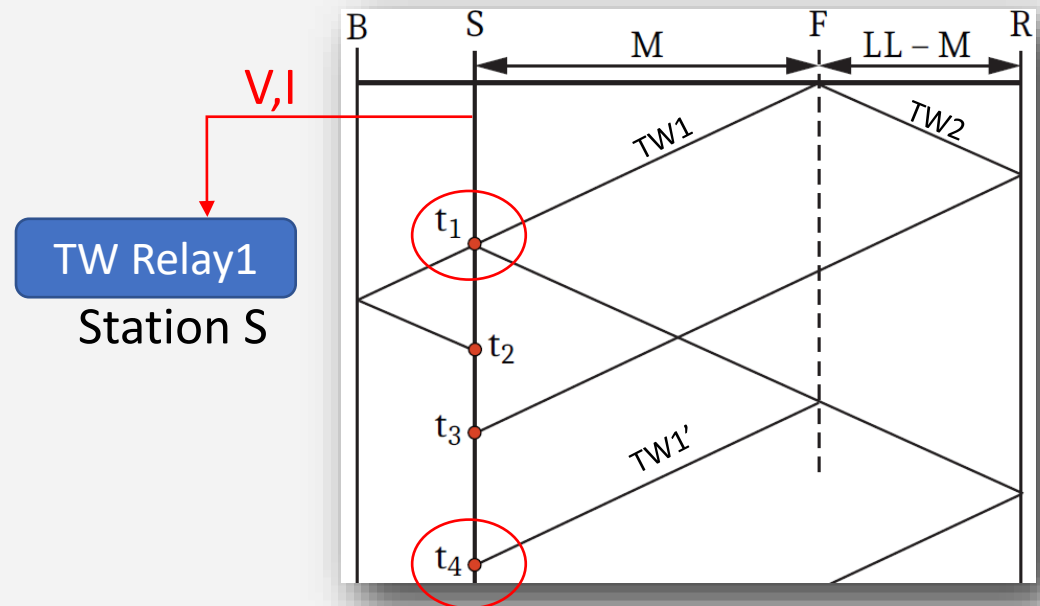
F: Fault Point

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 ($\sim 1\text{MHz}$) 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

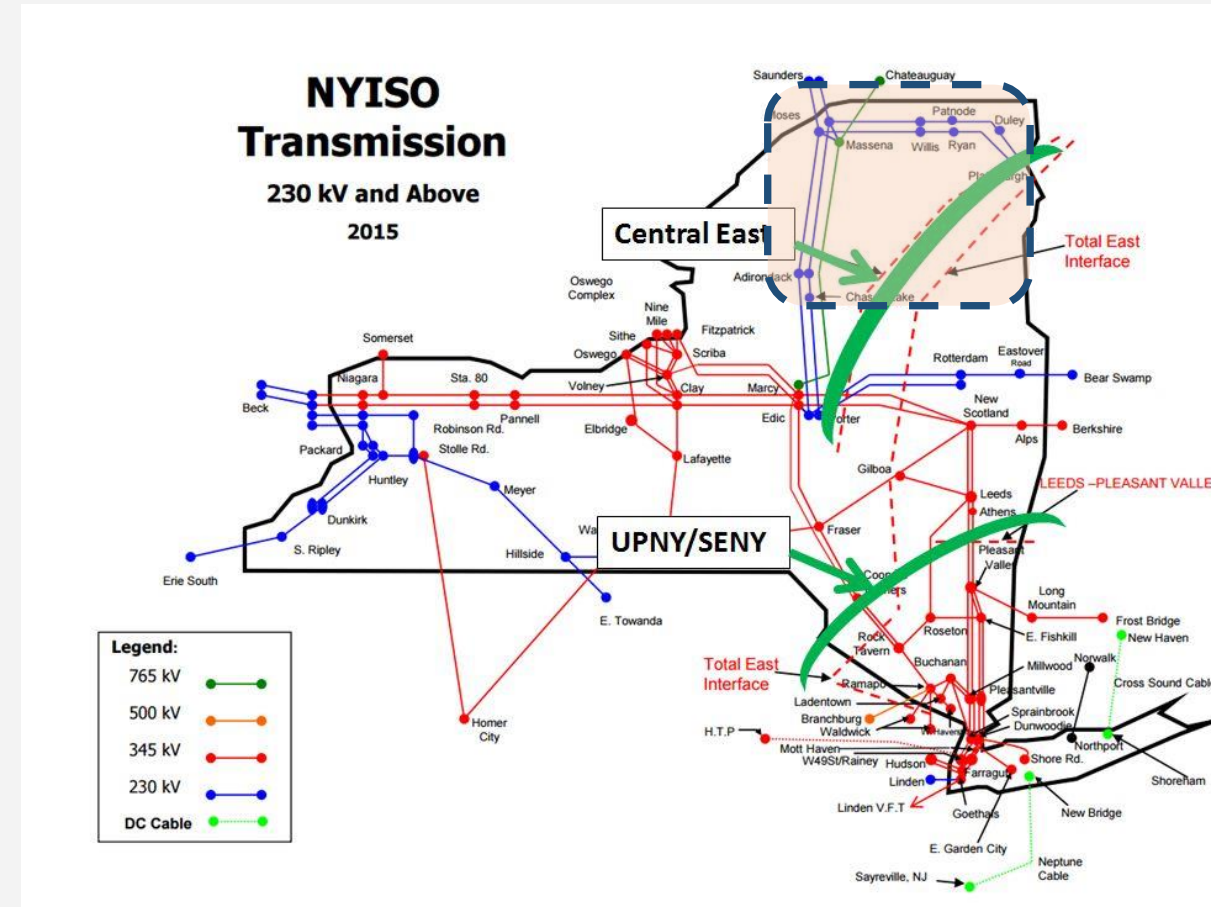
- Current N.Y.S real-time model runs at 50 μ s in Main-Step used as base reference model [6]
- Develop FDPD based lines in the North and Central N.Y.S. Corridor for Sub-Step simulation



[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.

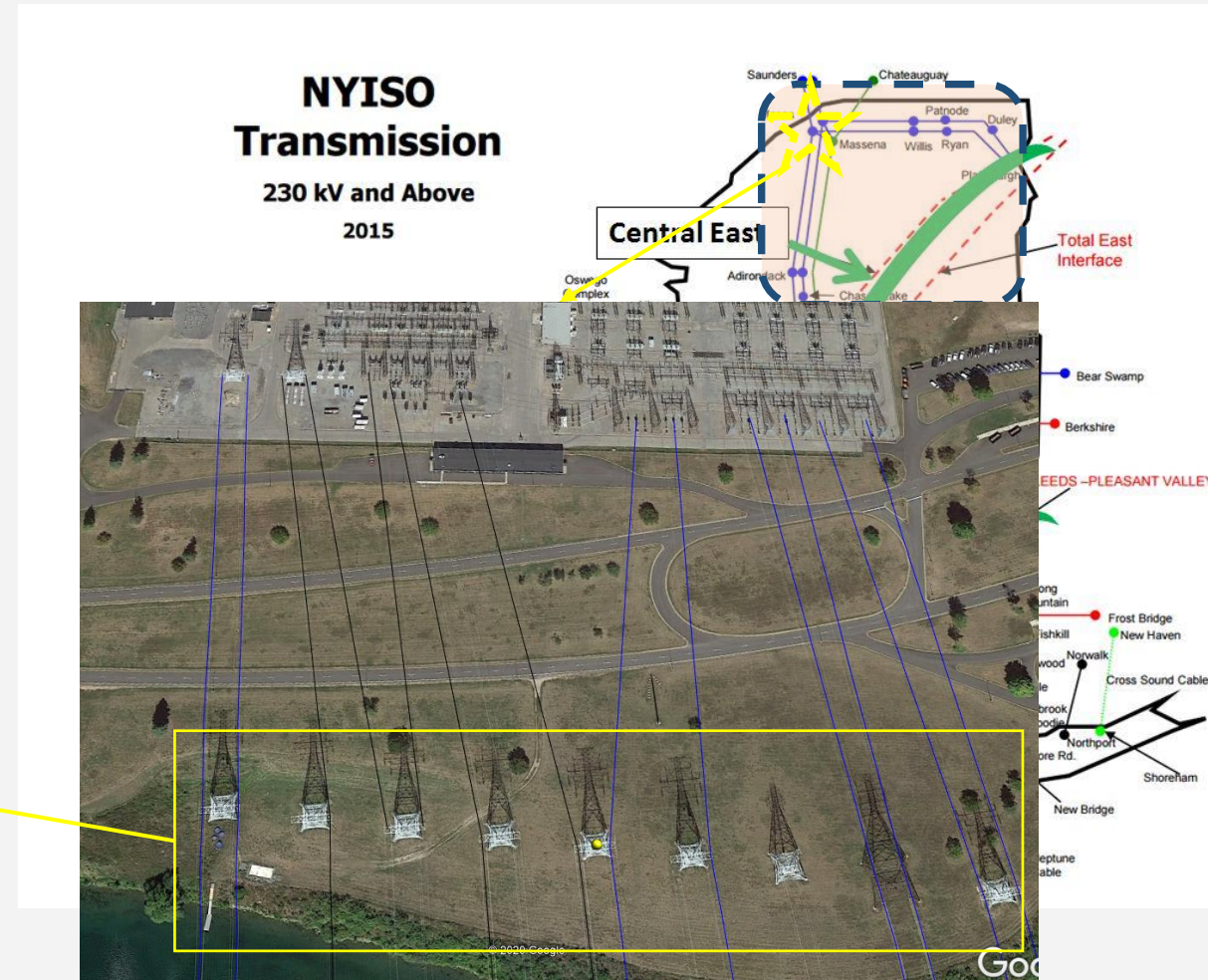
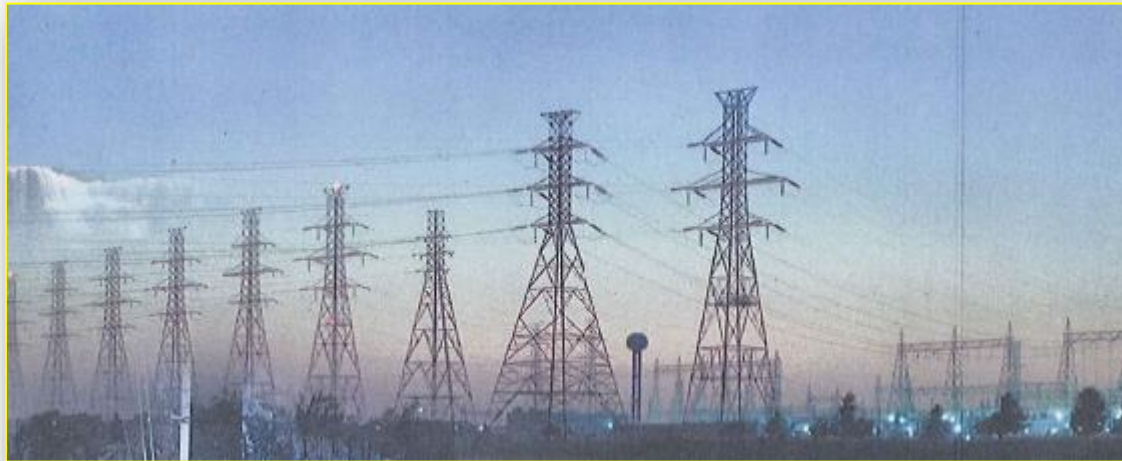


N.Y.S. Transmission Network [6]

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

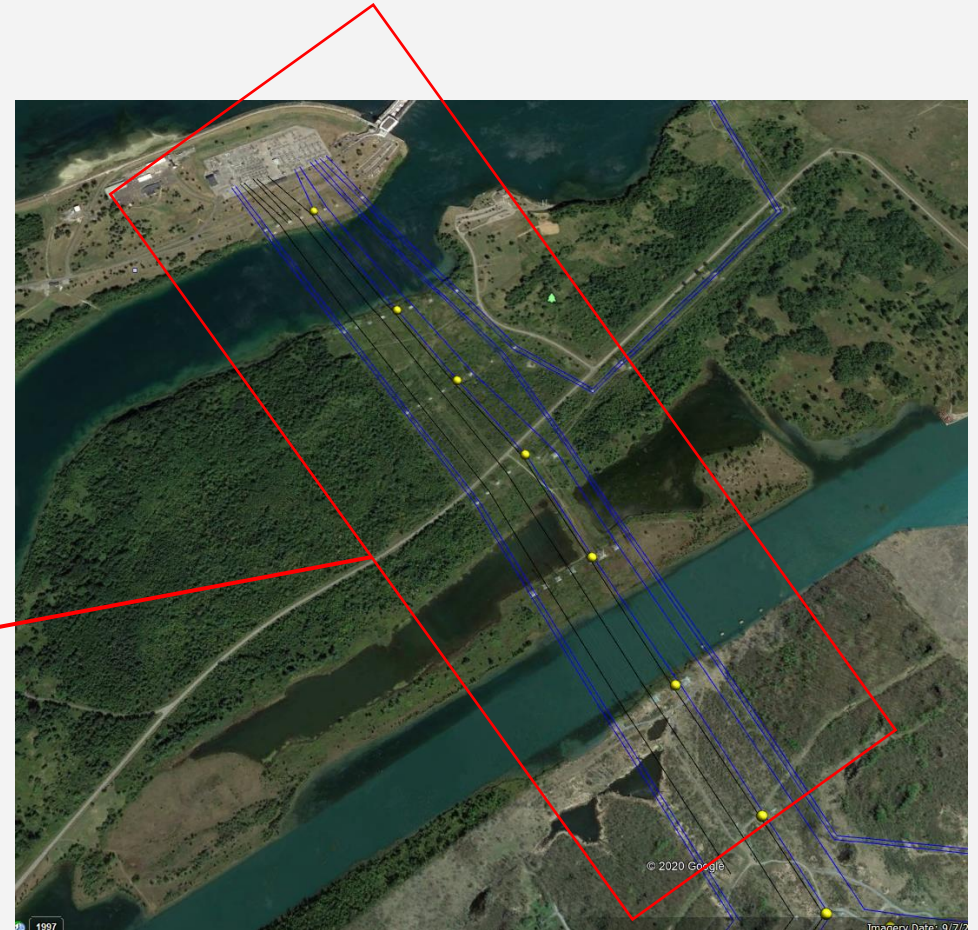
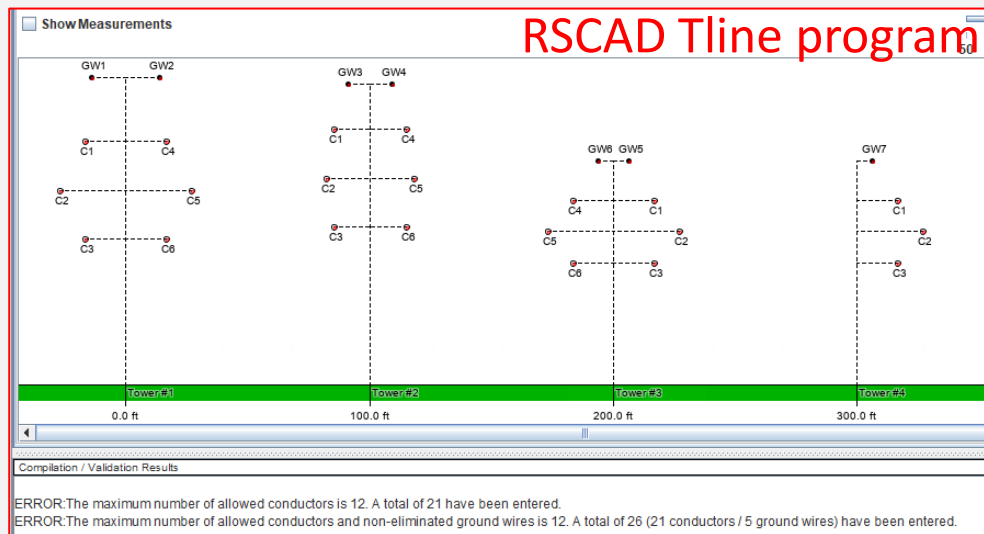
TW-BASED SUB-STEP MODEL DEVELOPMENT

- 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



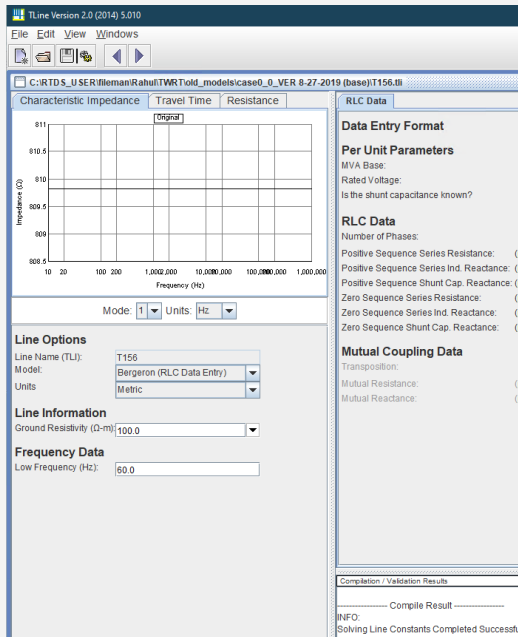
TW-BASED SUB-STEP MODEL DEVELOPMENT

- Modeling Challenges:
 - In sub-step, for e.g., a time-step of $3\mu\text{s}$ 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

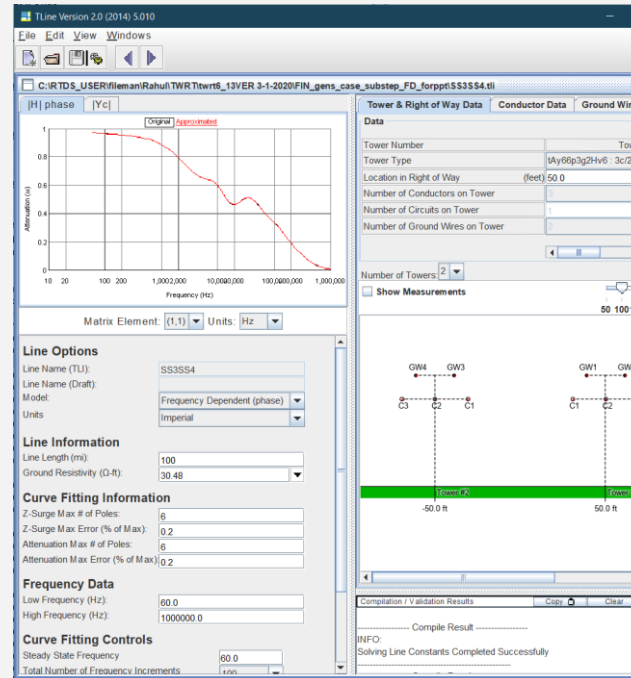


TW-BASED SUB-STEP MODEL DEVELOPMENT

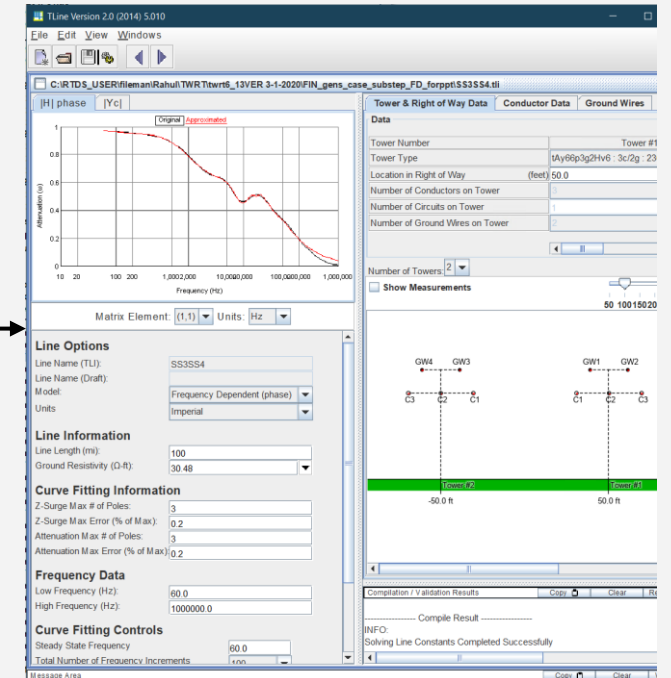
- FDPD lines development (Higher poles increases computational burden)



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

Simple Line Constants Viewer for RSCAD/EMTP-RV - v 0.1.11

Select	Input filename	Output filename	Line Length	Model Type	Modified	Path
<input type="checkbox"/>	Scircuits.tlii	Scircuits.out	62.137 miles	Freq. Dep. model [RTDS]	03/30/2020 13:48	C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\Scirc...
<input type="checkbox"/>	100mile.tlii	100mile.out	100.000 miles	Freq. Dep. model [RTDS]	03/29/2020 16:15	C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\100m...
<input type="checkbox"/>	T1p6g2.tlii	T1p6g2.out	62.137 miles	Bergeron Physical Data...	03/30/2020 11:18	C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T1p6g...
<input checked="" type="checkbox"/>	T2p9g3.tlii	T2p9g3.out	62.137 miles	Bergeron Physical Data...	03/30/2020 11:18	C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T2p9g...
<input type="checkbox"/>	T3p4g5.tlii	T3p4g5.out	62.137 miles	Bergeron Physical Data...	03/30/2020 11:18	C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T3p4g...
<input type="checkbox"/>	T4p4g6.tlii	T4p4g6.out	62.137 miles	Bergeron Physical Data...	03/30/2020 11:18	C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T4p4g...

Sequence MATRIX Result:

Circuit [n]	R1 (ohm/m)	X1 (ohm/m)	B1 (mhos/m)	R0 (ohm/m)	X0 (ohm/m)	B0 (mhos/m)	Ckt[n]-Ckt
Ckt[1] -> 230kV	1.82373614e-05	0.000339262882	4.87833775e-09	0.00036891175	0.00119633292	2.86394675e-09	0.00035802
Ckt[2] -> 230kV	1.82584528e-05	0.000339266304	4.87863489e-09	0.000383821828	0.0011811919	2.89465898e-09	xx
Ckt[3] -> 230kV	1.80911961e-05	0.000336674724	4.96182358e-09	0.000415929111	0.00116433329	3.39026499e-09	xx

Per Unit Results:

Circuit [n]	R1 (p.u.)	X1 (p.u.)	B1 (p.u.)	R0 (p.u.)	X0 (ohm/m)	B0 (p.u.)	Ckt[n]-Ckt
Ckt[1] -> 230kV	0.0034475011491517807	0.06413258748930342	0.2580629304092362	0.0097372637502591	0.2261488943498211	0.15150211582644277	0.06767981
Ckt[2] -> 230kV	0.0034514881637282	0.06413323436736179	0.25807864904600786	0.07255579160149436	0.2232867103581539	0.15312678563804047	xx
Ckt[3] -> 230kV	0.0034198707793486804	0.06364333482366362	0.2624793113655256	0.07862519454915111	0.22009984159609153	0.17934422809967185	xx

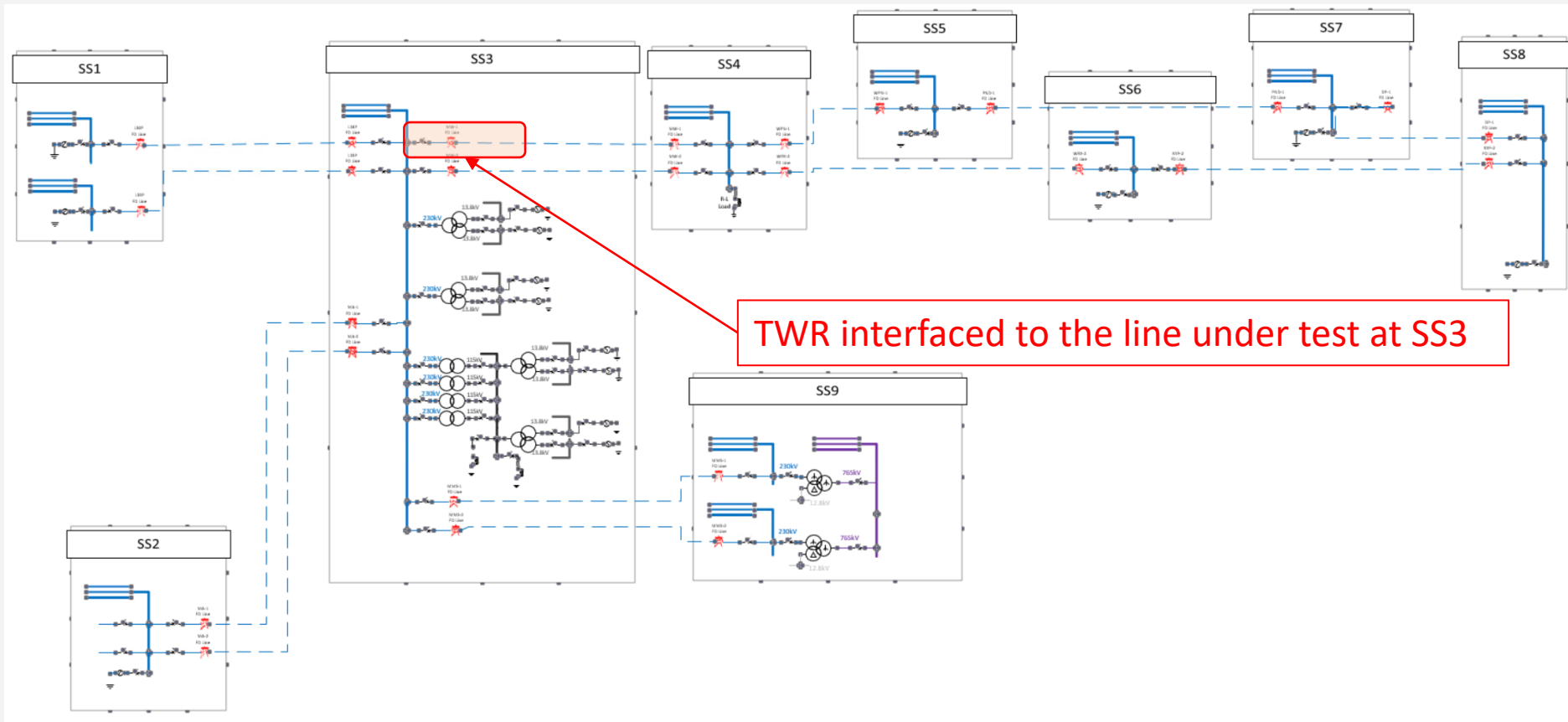
Comparison Results:

Console:

```
05/26/2020 00:39:39 - Default Tline definitions found in C:\Program Files\RTDS\RSCAD_5.010
05/26/2020 00:39:39 - User defined Tline definitions found in C:\RTDS_USER\TLINE_CONS\USER_TLINES
05/26/2020 00:40:00 - C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T1p6g2.tlii: Found 1 voltage bases for 2 circuits from tD123p6g2V.def [RTDS]
05/26/2020 00:40:00 - C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T1p6g2.out: Successfully extracted 2 circuits.
05/26/2020 00:40:03 - C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T2p9g3.tlii: Found 2 voltage bases for 3 circuits from tD123p6g2V.def tAy66p3g2Hv5.def [RTDS]
05/26/2020 00:40:03 - C:\Users\NE096712\PycharmProjects\agile\TWRT calc\sample\T2p9g3.out: Successfully extracted 3 circuits.
```

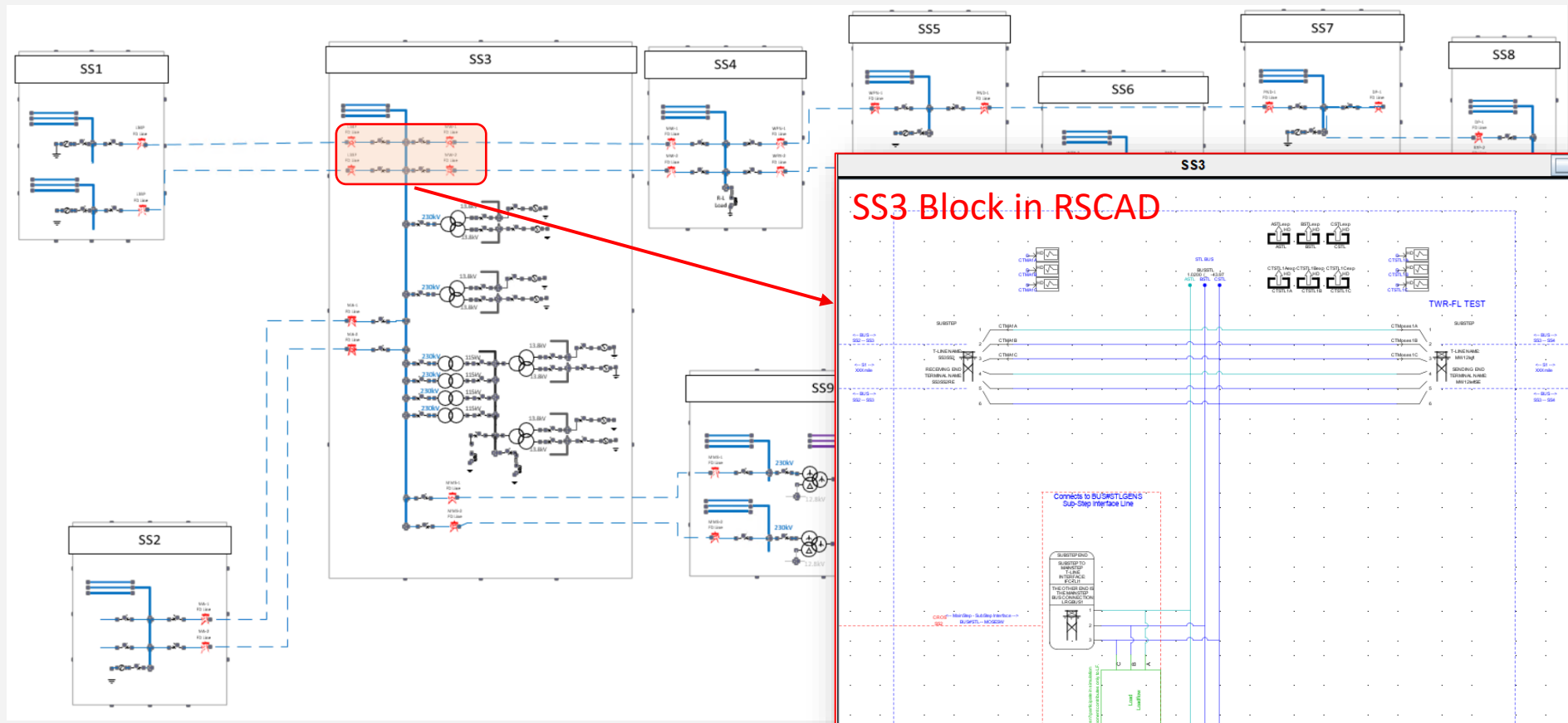
TW-BASED SUB-STEP MODEL DEVELOPMENT

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



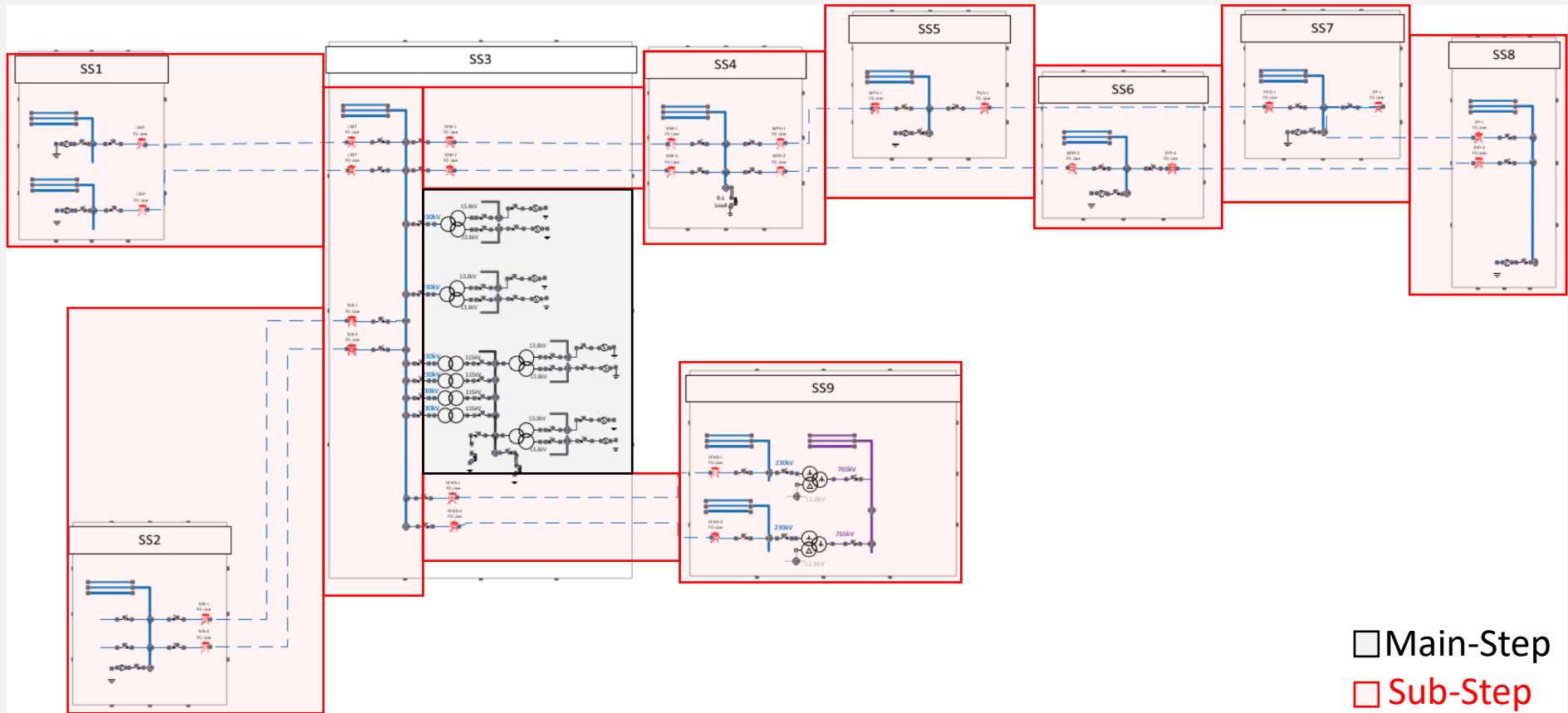
TW-BASED SUB-STEP MODEL DEVELOPMENT

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



TW-BASED FL TESTING MODEL DEVELOPMENT

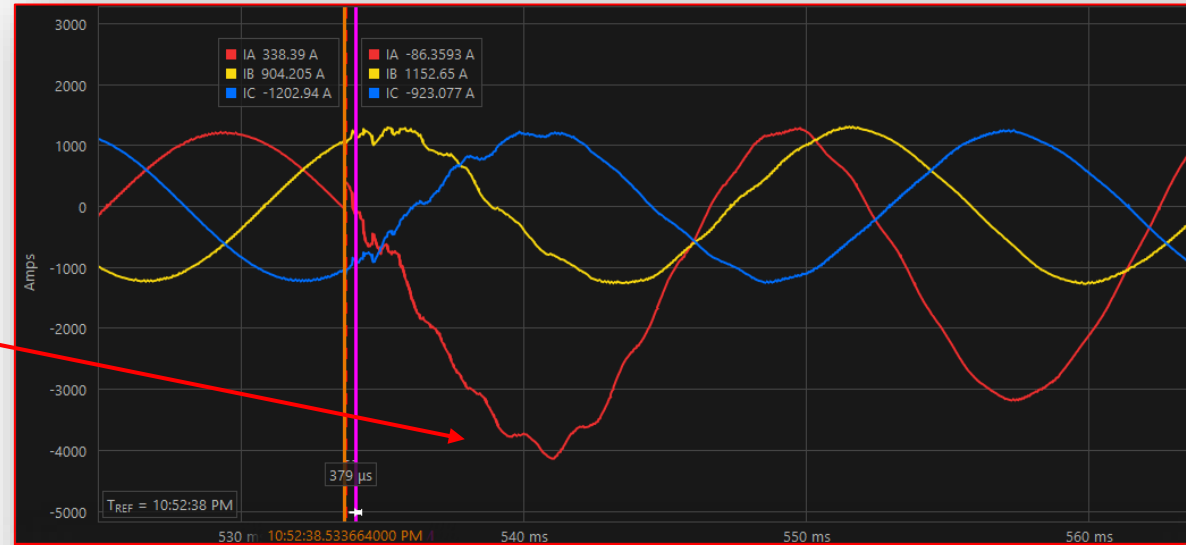
- Main-Step + Sub-Step model of the North and Central N.Y.S. Transmission Corridor



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

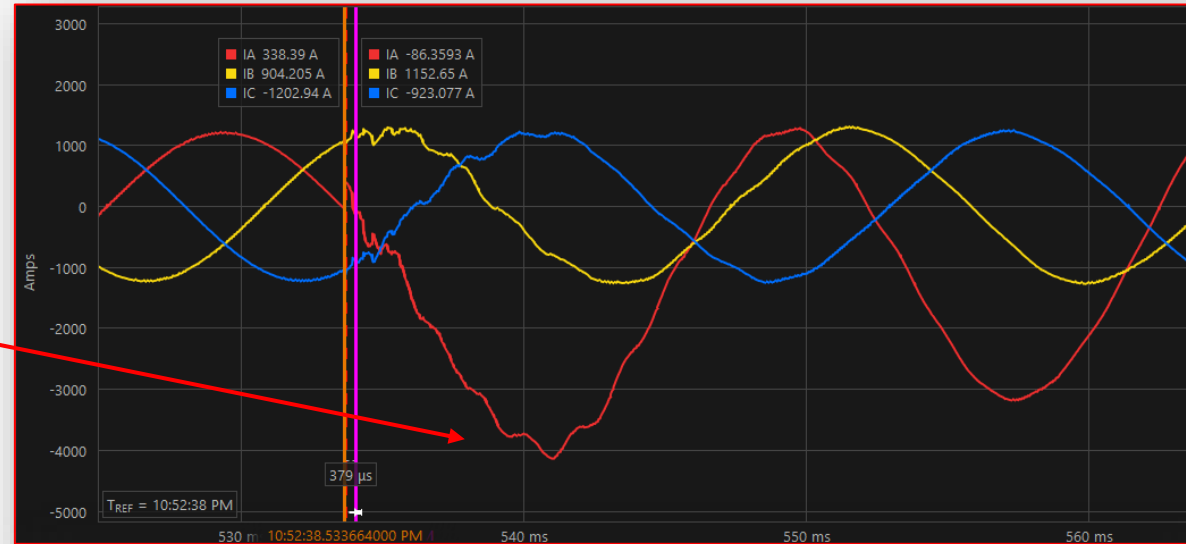
• SETW Test

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

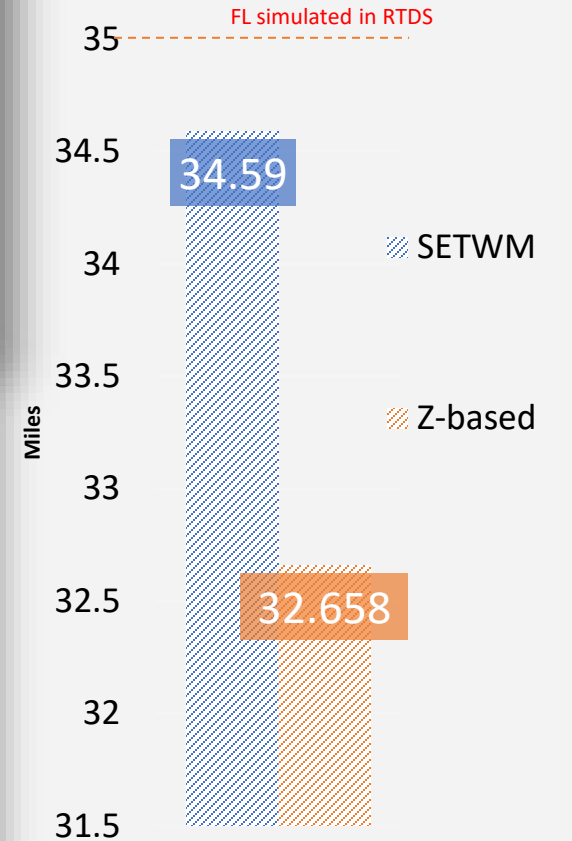
2. TWs received at Station S retrieved from COMTRADE Events

3. Using SETW:

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

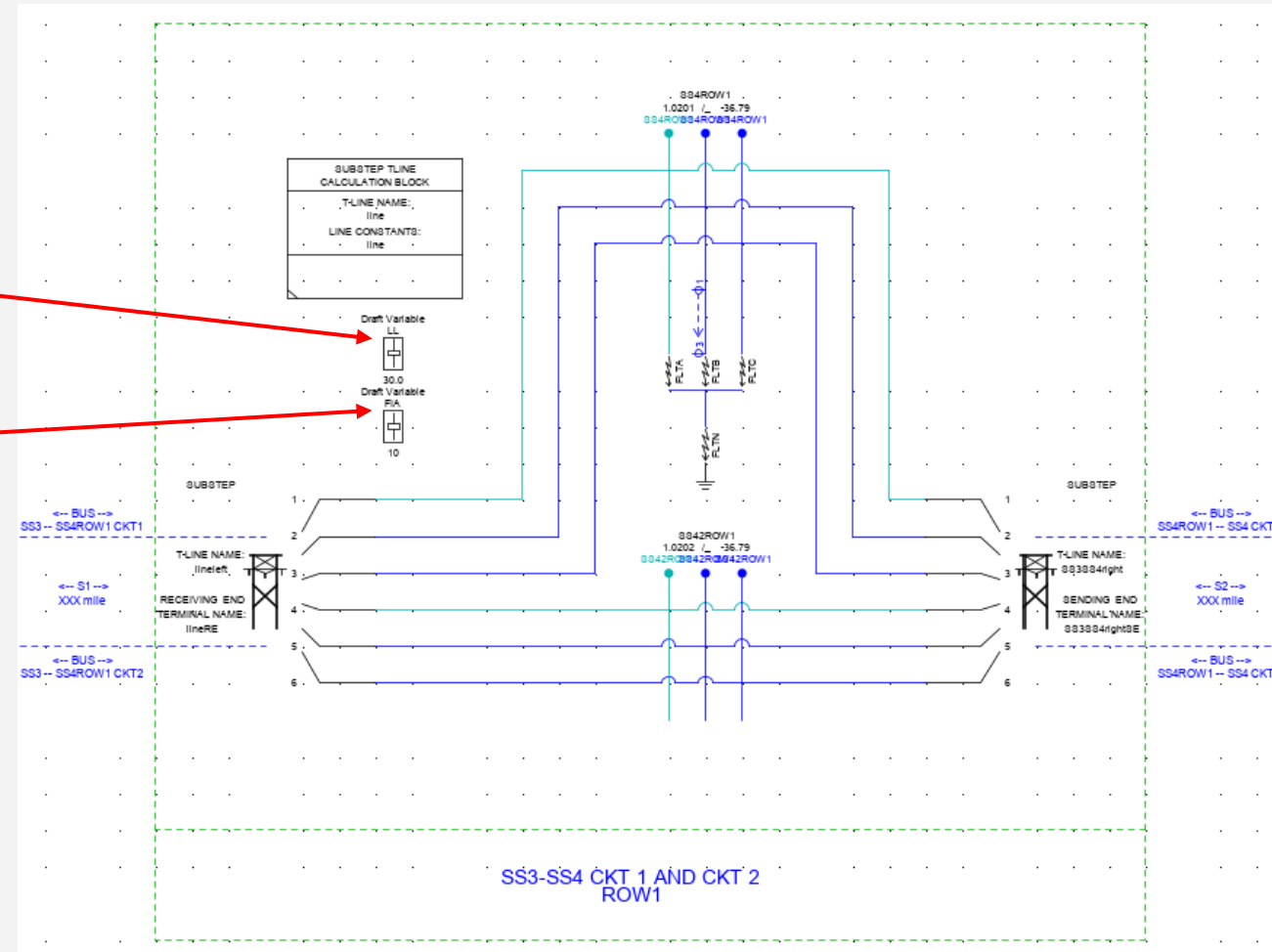


4. COMTRADE EVENT RESULT



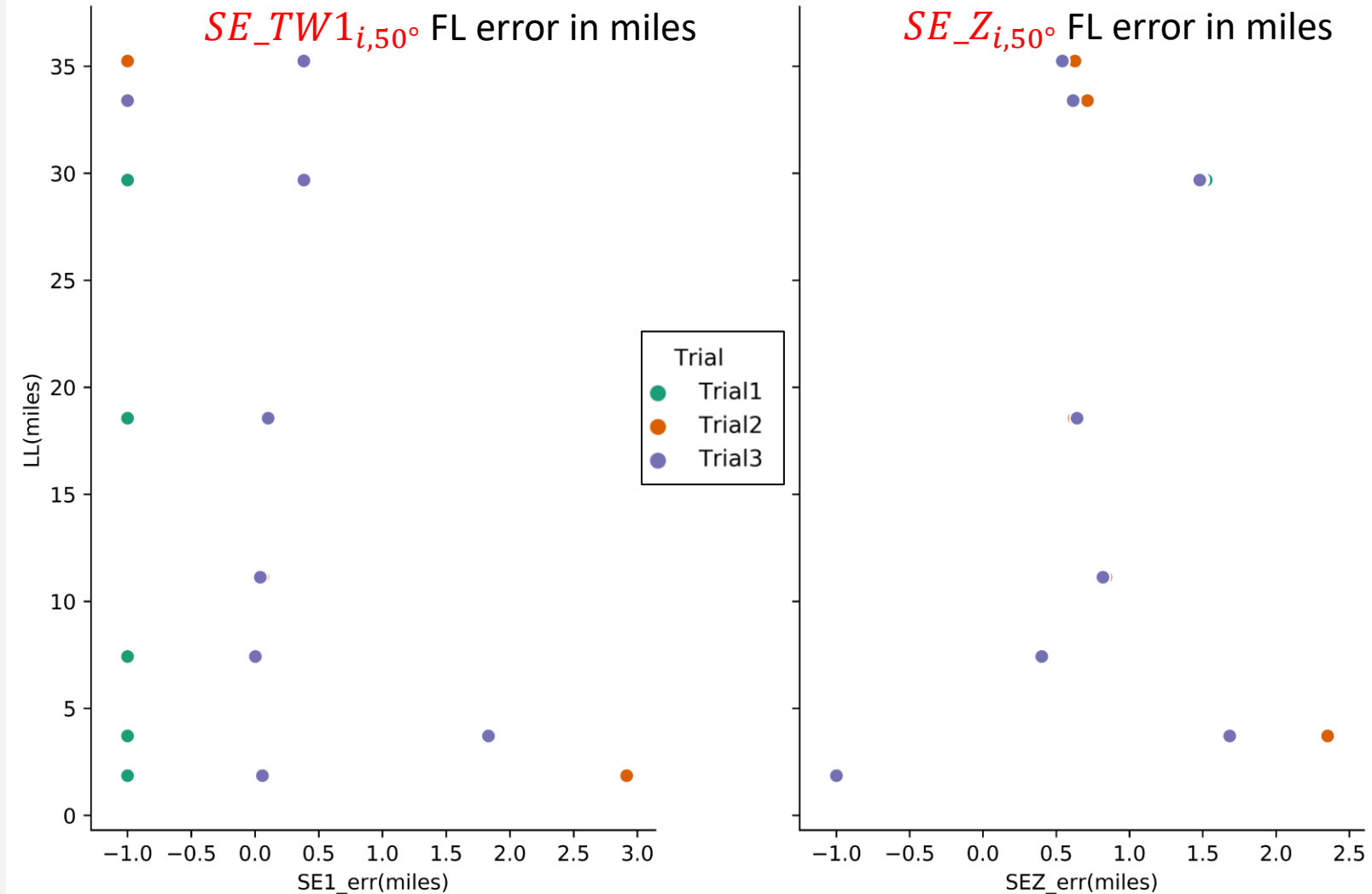
TW-BASED FL TESTING MODEL SIMULATION

- 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)
 - $j = 5, 20, \dots, 360^\circ$
- 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} : $SE_{Z_{i,j}} - LL_{i,j}$



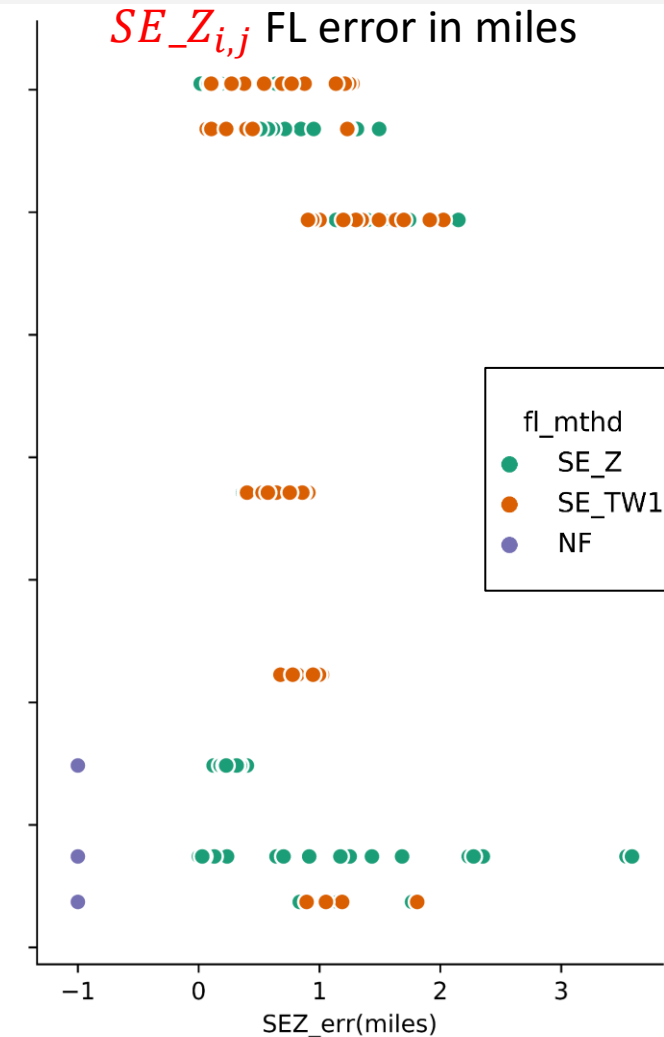
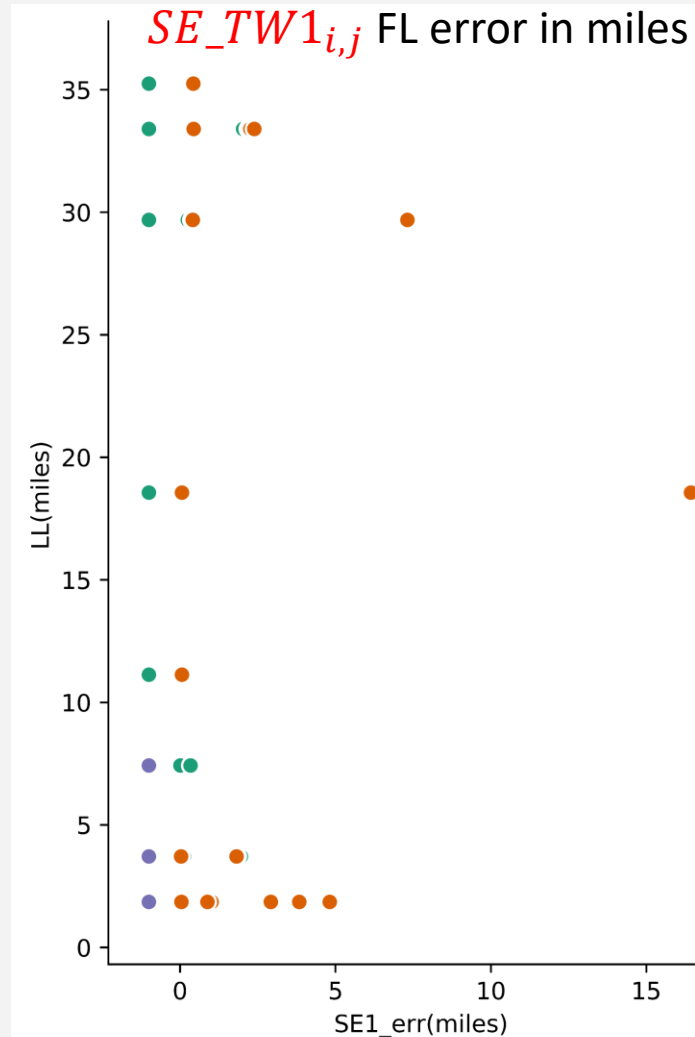
TW-BASED FL TESTING MODEL RESULTS

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



TW-BASED FL TESTING MODEL RESULTS

- FL method selected by TWR for A-Grnd fault for all LL_i and POW_j
 - 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?