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





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]





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 realtime 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

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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

USER SPOTLIGHT SERIES BY



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 timesteps 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



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



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/

Modeling Challenges

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- 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





- 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



RROR. The maximum number of allowed conductors is 12. A total of 21 maye been entered. RROR: The maximum number of allowed conductors and non-eliminated ground wires is 12. A total of 26 (21 conductors / 5 ground wires) have been entered





• FDPD lines development (Higher poles increases computational burden)



Bergeron RLC line model

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Technologies



FDPD line with 6 poles for sub-step model



FDPD line with 3 poles for sub-step model

- 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

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





• 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 atStation S retrieved fromCOMTRADE 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 atStation S retrieved fromCOMTRADE Events

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

USER SPOTLIGHT SERIES BY WRT

Technologies



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_i*) • $j = 5, 20, ..., 360^{\circ}$ BUBSTER Results 3 -- SS4ROW1 CK 3342ROV 1.0202 /_ -36.7 HINE NAME THINE NAME 883884rlot • $SE_TW1_{i,j}$: FL from SETW in TWR events ECEIVING END SENDING EN MINAL NAME: TERMINAL 'NA/ <-- BUS --> • $SE_{Z_{i,i}}$: FL from Z-based in TWR events 553 -- SS4ROW1 CKT2 • SE1_err: $SE_TW1_{i,i} - LL_{i,i}$ • SEZ_err: $SE_{I,i} - LL_{i,i}$ SS3-SS4 CKT 1 AND CKT 2

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 <u>all *LL_i* and</u> <u>*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?

