Fast Traveling-Wave Detection and Identification Method for Power Distribution Systems Using the Discrete Wavelet Transform

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Introduction & Background

Increase of Distributed Generation (DG) on distributed systems requires faster protection schemes. However, there are no commercial Traveling Wave (TW) relays for distribution systems.

Commercially-available TW relays for transmission level use a 1MHz sampling frequency, and an effective frequency band of 400 kHz. They require at least 0.1 ms just to start processing the data. Furthermore, ultra-fast protection may be wrongly engaged in non-fault transients, such as capacitor bank switching, transformer de-/energization, etc.

Contribution of this work:

- Designing a simple but sensitive TW detection method for distribution systems based on the Discrete Wavelet Transform (DWT).
- Using the features generated by the DWT to train a Random Forest model that is able to identify the type of event as a fault/not-a-fault.

Methodology

All fault events are simulated on the IEEE 34 nodes system using a variety of fault inception angles, fault types, and fault impedance values from 0.01 to 10 Ω. Other events: Transformer de-/energization on line 832-888, load switching on nodes 818 and 860, and capacitor bank switching on Nodes 844 and 848. All signals include SNR = 60 dB.

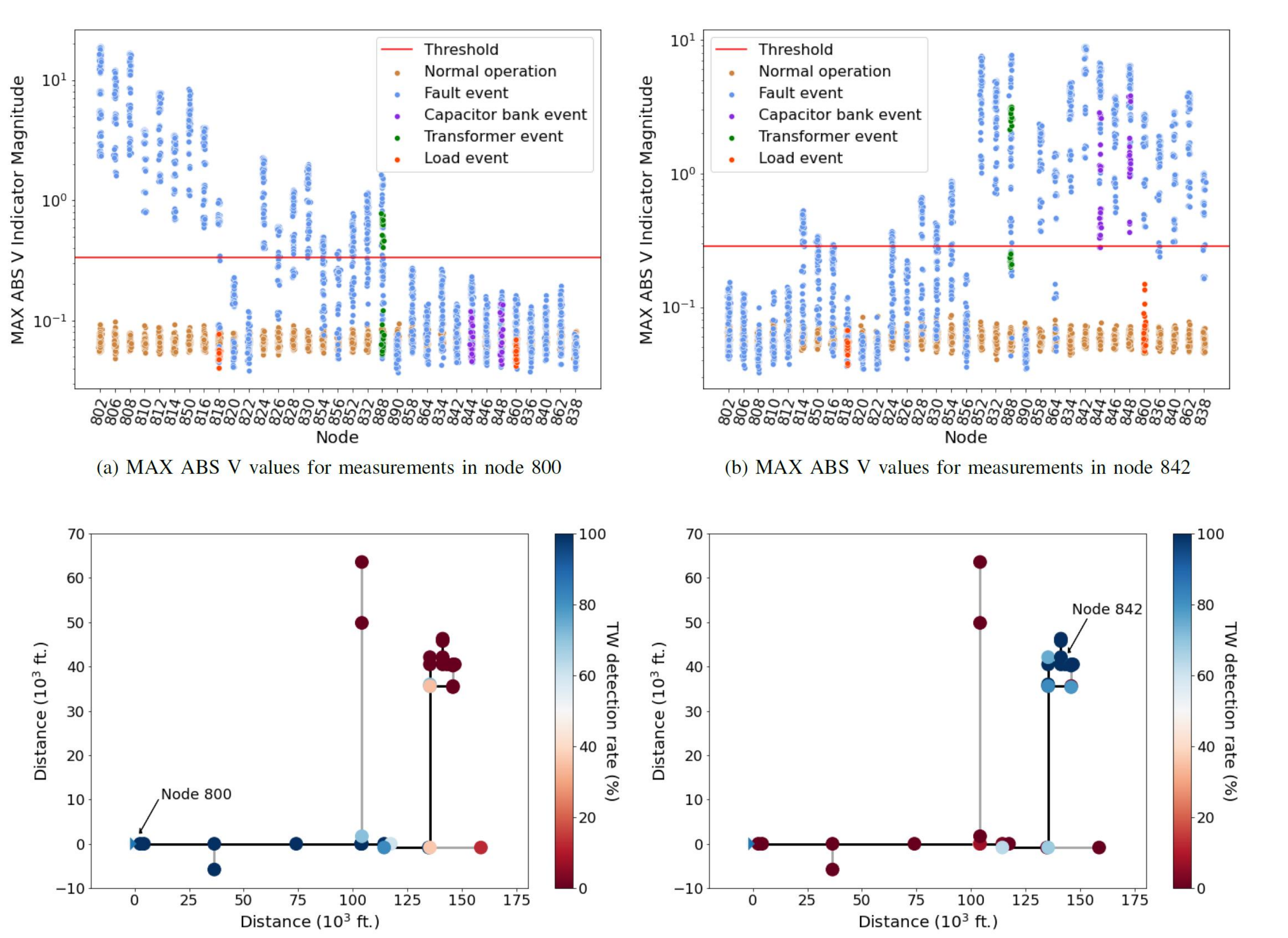
Characteristics of the method:

- Per-phase basis execution. Suitable for both 3-phase and 1-phase signals.
- The mother wavelet Daubechies 4 (db4) is employed.
- Input: Batches of 128 samples at 1 MHz sampling frequency using voltage measurements.
- TW detection is achieved by monitoring the first-level detail coefficients. The maximum absolute value of such coefficients (MAX ABS V indicator) is compared to a pre-defined threshold.

The threshold for each node is determined by 99th percentile of MAX ABS V during normal operation x 4 (Safety Factor). Detected transients are classified as fault/non-fault events by node-specific Random Forest (RF) models. As the dataset is heavily imbalanced, the minority class is augmented using SMOTE.

(Below) Threshold determination and effective detection range for Nodes 800 and 842. Note that other fault events have enough energy to be detected by the proposed method.

(Right) Effective fault TW detection range and exposure to capacitor banks, transformer, and load switching events.



(a) MAX ABS V values for measurements in node 800

(b) MAX ABS V values for measurements in node 842

(c) Fault TW correct detection rate from node 800

(d) Fault TW correct detection rate from node 842

TW Detection

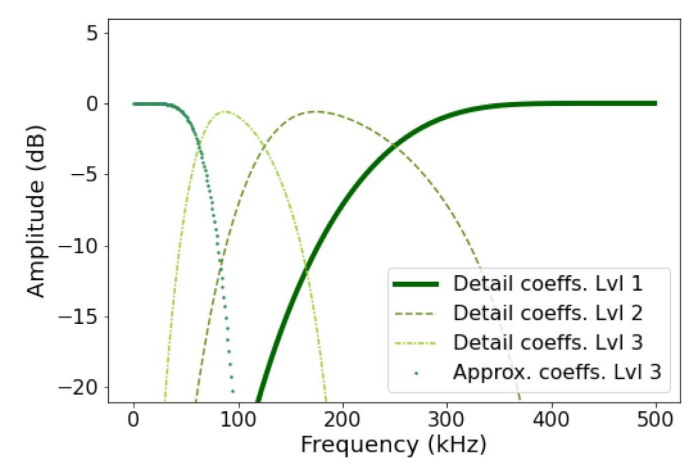
Input: Batches of 128 voltage 1-phase samples @ 1MHz

1. DWT 1st level decomposition → DWT detail coefficients

Is MAX(ABS(Detail coeffs.)) > Safety threshold ?

- No → Wait to next run
- Yes → 2. Find 1st coeff. > Threshold (Get TW arrival time)

3. Save TW data (-32/+96 samples since arrival time)



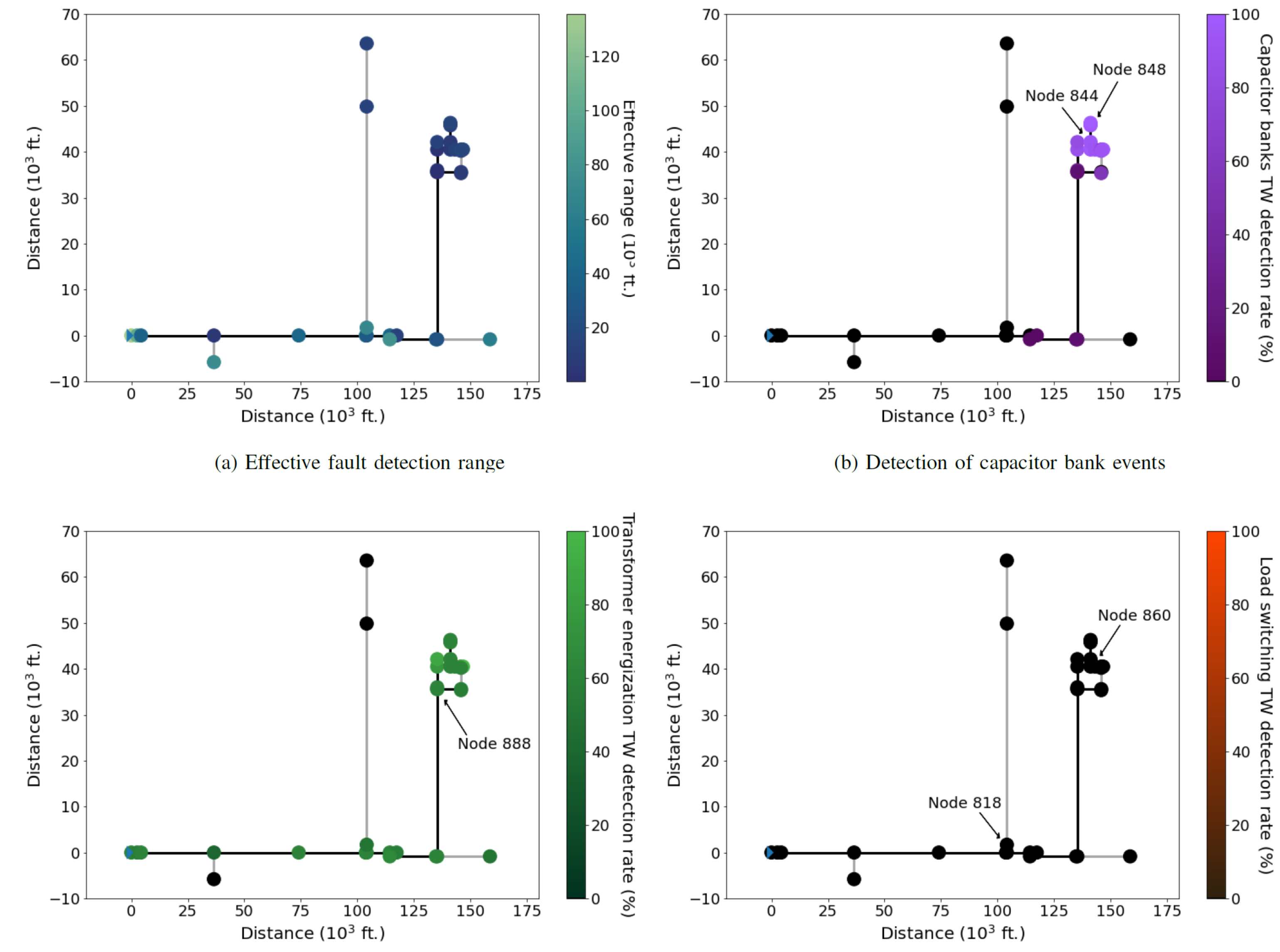
(Above) DWT filters frequency response for decomposition levels 1 to 3 using the mother wavelet db4

Event Identification

4. Karrenbauer Transformation in 3 decoupled modes
5. DWT decomposition into 3 frequency-bands
6. Parseval Energy
7. Classify the TW as fault/non-fault event using Machine Learning (Random Forest)

Output: Event type & Time of Arrival

Results



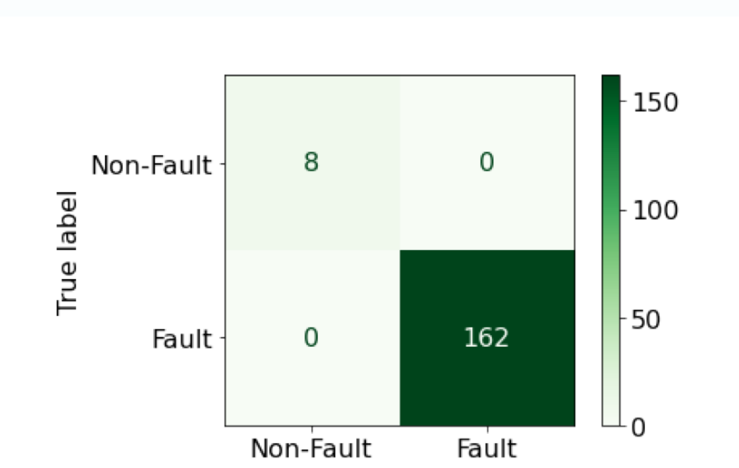
(a) Effective fault detection range

(b) Detection of capacitor bank events

(c) Detection of transformer events

(d) Detection of load events

(Below) Confusion matrix for event identification for Node 842. A total of 1073 faults, 40 capacitor banks, and 16 transformer events are detected. Using SMOTE, additional non-fault event samples are created to equal the number of fault events in the training set. The train/test split is 85%/15%.



Conclusions

The proposed Traveling Wave (TW) detection method using the Discrete Wavelet Transform (DWT) for distribution systems achieves a:

- ✓ Sensitive and accurate detection with as little as **128 microseconds of voltage data**, in a per-phase basis.
- ✓ Low-computational cost (only one DWT decomposition level).
- ✓ **Perfect identification** of the even type **(fault/not-a-fault)** using a Random Forest model and SMOTE for data augmentation.

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