Synchro-Waveform Analytics for Incipient Fault Detection and Identification

Jhi-Young Joo, Ph.D.
Grid Data Analytics Area Lead
Lawrence Livermore National Laboratory

2024 IEEE PES General Meeting
Panel *Synchro-Waveforms Data Analytics and Data-Driven Applications*

LLNL-PRES-867157
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

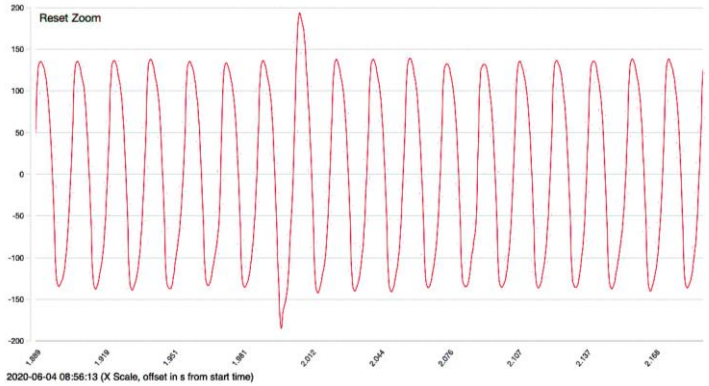
Background

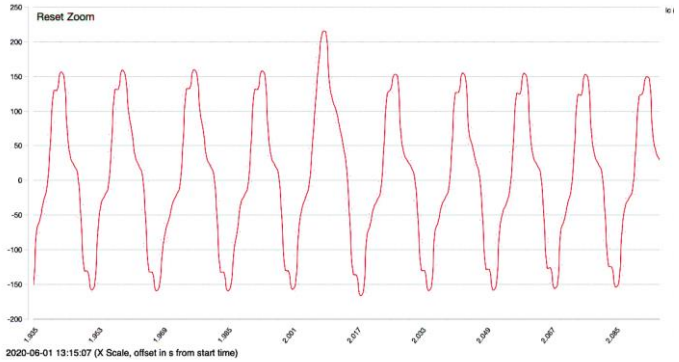
- Aging/failing electric equipment causes power quality issues, outages, and potentially fires
- Why is it difficult to detect arcing equipment?
  - What is arcing?
- Traditional protection schemes are inadequate to detect incipient failure arcing signatures
  - What are the characteristics of arcing in measurements?

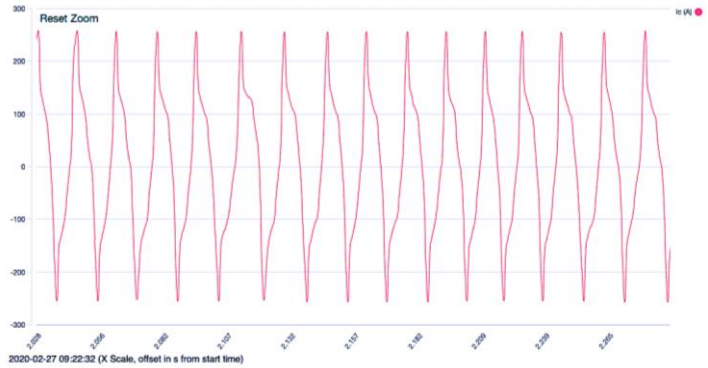
- Jun Ma, Jack CP Cheng, Feifeng Jiang, et al. “Real-time detection of wildfire risk caused by powerline vegetation faults using advanced machine learning techniques”. In: Advanced Engineering Informatics 44 (2020), p. 101070.
- Mead, John and Schoenman, Eric. New Tools in the Fight to Reduce Wildfire Ignition. T&D World, Aug 2021.

Characteristics of incipient failures in POW measurements

- Low and instantaneous fault current
  - "invisible" until it progresses and causes outages
  - Can last only a few cycles
- Varying manifestation
  - It can have different footprints on voltage/current measurements
- Threshold-based detection and phasor measurements inadequate
  → need for **waveform (point-on-wave)** measurements







Data source: DOE Grid Event Signature Library
https://gesl.ornl.gov

Overall analytics approach

Arcing detection from system measurements

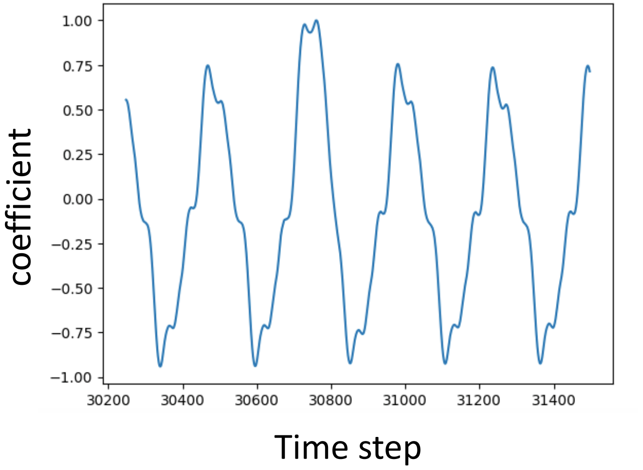
For details on seconds-level feature extraction using spectral correlation functions, refer to
Alaca, Ozgur, et al. "Detection of grid-signal distortions using the spectral correlation function." *IEEE Transactions on Smart Grid* (2023).

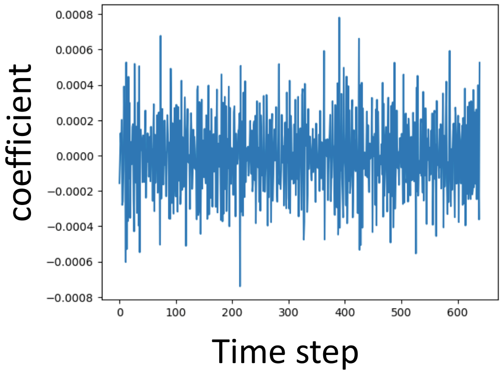
Feature extraction at milliseconds* level

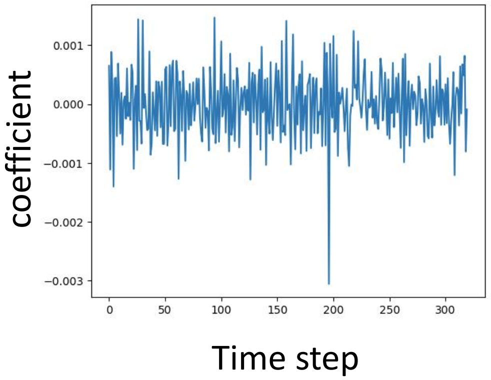
Discrete wavelet transform

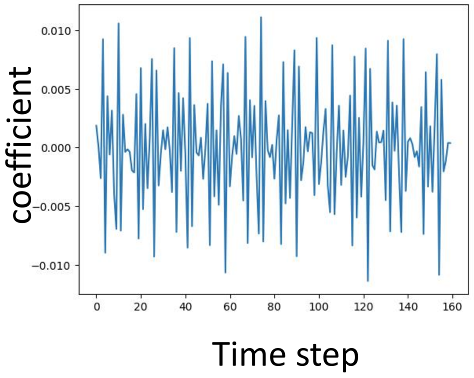
*5 cycles = 83 milliseconds

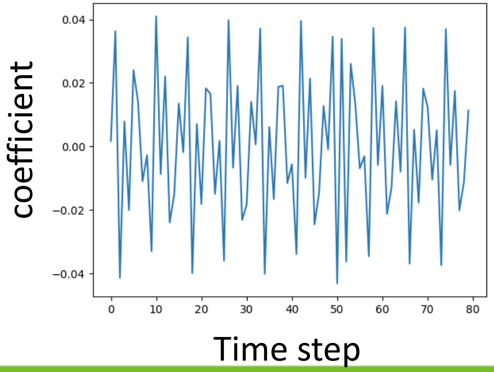
- Arcing signature decomposition results (6 levels with Daubechies wavelet)
  - 15,360 Hz (256 samples/cycle) resolution

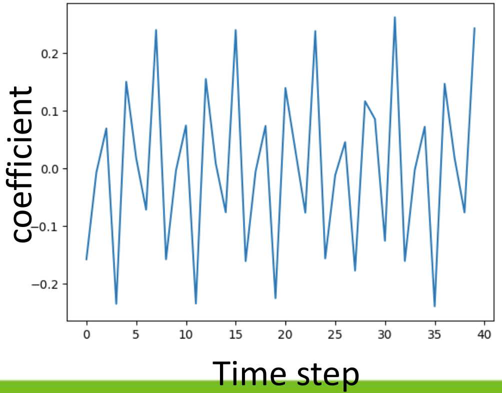


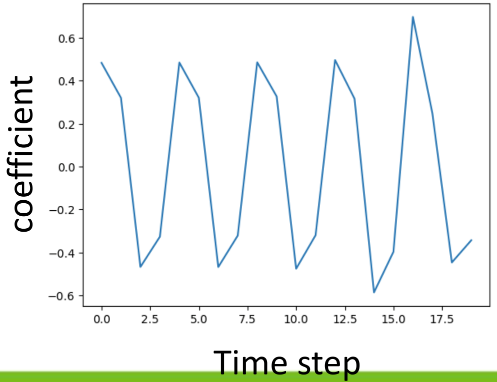










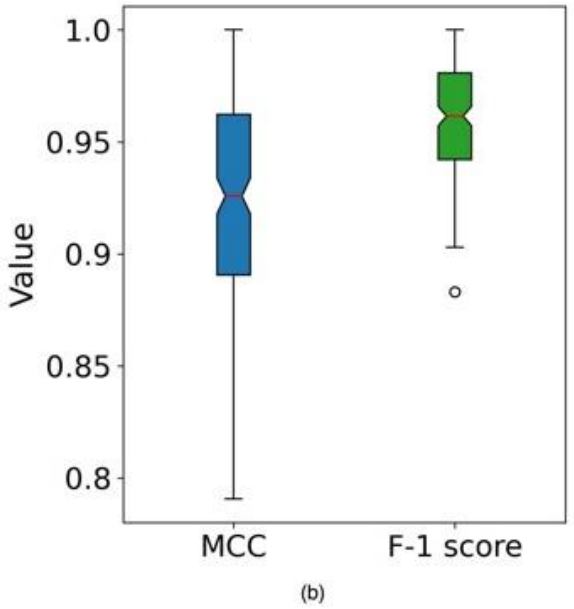


LLNL-PRES-867157

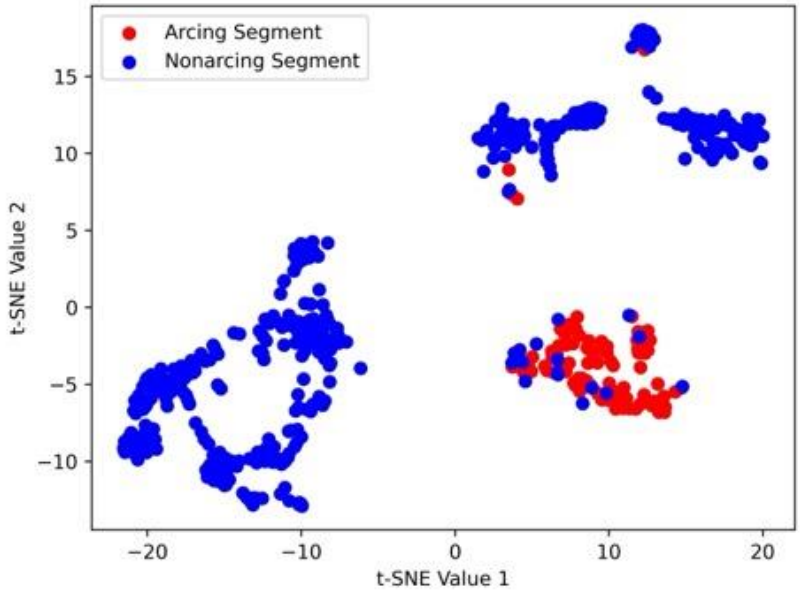
Unsupervised classification

Over 90% accuracy in identifying arcing segments

- Random sampling of testing vs. training datasets (1 to 9 ratio) from GESL arcing signatures
- Prediction based on *k*-nearest neighbors
- 200 iterations yielded highly accurate prediction over 90% on average



Matthews Correlation Coefficient and F1-score of binary classification



t-SNE plot of the feature vectors (GESL data)

Conclusion

Incipient failure signatures can be captured with waveform measurements

- Cycle-level anomalies makes it inadequate to detect with thresholds or phasor measurements
- Feature extraction of anomalies (vs. “normal” signals) is critical
  - Different signal processing techniques can be effective
- More datasets on both anomalies and normal signals help


THE MNIST DATABASE

of handwritten digits

Yann LeCun, Courant Institute, NYU
Corinna Cortes, Google Labs, New York
Christopher J.C. Burges, Microsoft Research, Redmond

Please refrain from accessing these files from automated scripts with high frequency. Make copies!

The MNIST database of handwritten digits, available from this page, has a training set of 60,000 examples, and a test set of 10,000 examples. It is a subset of a larger set available from NIST. The digits have been size-normalized and centered in a fixed-size image.

It is a good database for people who want to try learning techniques and pattern recognition methods on real-world data while spending minimal efforts on preprocessing and formatting.

The MNIST database of handwritten digits, available from this page, has a training set of 60,000 examples, and a test set of 10,000 examples. It is a subset of a larger set available from NIST. The digits have been size-normalized and centered in a fixed-size image.

It is a good database for people who want to try learning techniques and pattern recognition methods on real-world data while spending minimal efforts on preprocessing and formatting.

http://yann.lecun.com/exdb/mnist/

https://commons.wikimedia.org/wiki/File:MnistExamples.png

Acknowledgment

- Project “Low-Current Arcing Detection for Wildfire Prevention”
  - Sponsor
    - U.S. Department of Energy Office of Electricity
  - Project partners
    - Oak Ridge National Laboratory
    - Southern California Edison
    - Right Analytics
    - Schweitzer Engineering Laboratories (advisory)

References

- Publications and patents
  - J. Joo, C. Annalicia, A. Pochiraju, O. Alaca, A. R. Ekti, M. Balestrieri, H. Valizadeh Haghi, A. Elandaloussi, Detecting Anomalies for Fire Prevention in Distribution Systems, IEEE Power and Energy Magazine Grid Edge Special Issue, *submitted for review*
  - A. Pochiraju, N. Lee, C. Annalicia, J. Joo, Signal Decomposition Methods for Anomaly Detection in Electric Distribution Systems for Wildfire Prevention, Center for Advanced Signal and Image Sciences (CASIS) 27th Annual Workshop, 2023
  - A.R. Ekti, A. Wilson, J. Olatt, J. Holliman II, S. Yarkan, P. Fuhr, “A Simple and Accurate Energy-Detector-Based Transient Waveform Detection for Smart Grids: Real-World Field Data Performance” Energies, 15, 8367
  - Wilson, Aaron J., Ali Riza Ekti, and Yilu Liu. “Power System Event Detection Using the Energy Detector: A Performance Analysis.” 2023 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT). IEEE, 2023
  - O. Alaca, A.R. Ekti, A. Wilson, J. Holliman II, E. Piersall, N. Stenvig, “Detection of Grid-Signal Distortions Using the Spectral Correlation Function” in IEEE Transactions on Smart Grid
  - Technical report (ORNL/TM-2023/3130: Low-Current Arcing Detection and Location for Fire Prevention)
  - 2 patents pending/in progress on arcing detection and classification algorithm

Jhi-Young Joo

joo3@llnl.gov

Lawrence Livermore National Laboratory

LLNL-PRES-867157