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An Algorithm for Fast Fault Location and Classification Based on Mathematical Morphology and Machine Learning

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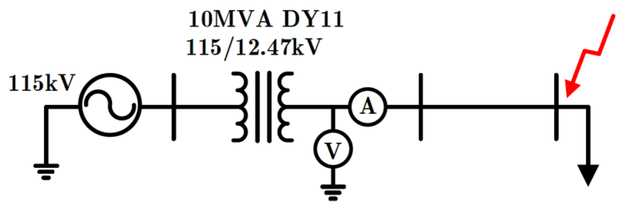
Introduction

- Power system protection is critical to maintain power systems operating reliably.
- Traditional protection methods need to be updated to operate optimally in power systems with increased penetration of inverter -based resources (IBRs). This is particularly important for distribution level systems.
- Protection methods typically use data sampling with low resolution and are based on simple rules sometimes based on the physics of the system
- This work combines a signal processing technique – Mathematical Morphology (MM)- with a classical machine

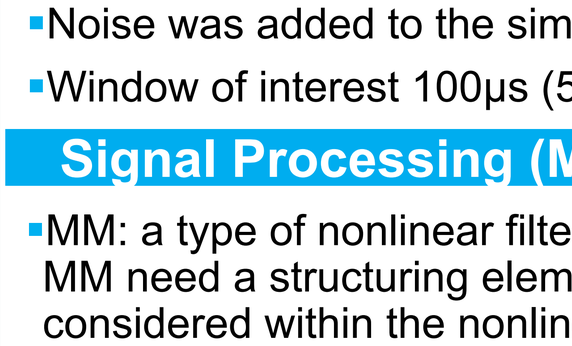
Test Power System

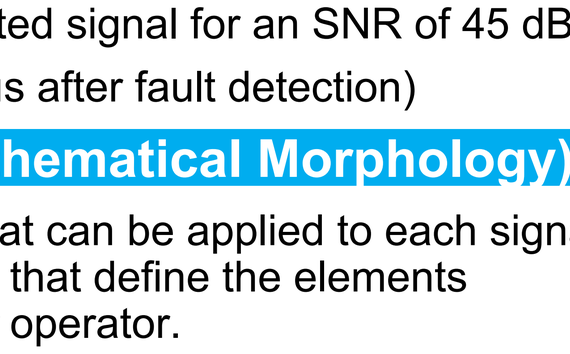


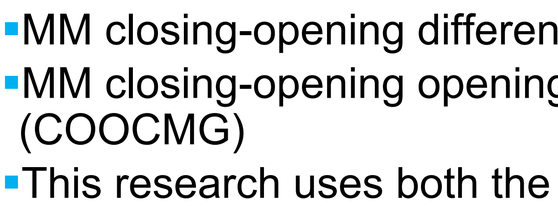
- Faults applied every 25m from 25m to 4000m
- Three different type of faults were considered
  - Single line to ground
  - Line to line
  - Three-phase fault
- The fault was a applied for seven different values of resistances: 0.01, 0.05, 0.1, 0.5, 1.0, 5.0, and 10.0 ohms
- 3360 simulations in total at 10 MHz. The fault is applied at 30ms after the system has reached a steady condition
- Noise was added to the simulated signal for an SNR of 45 dB
- Window of interest 100μs (50 μs after fault detection)

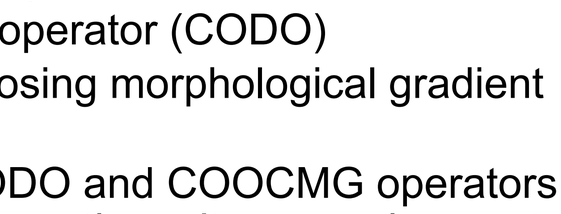
Signal Processing (Mathematical Morphology)

- MM: a type of nonlinear filter that can be applied to each signal. MM need a structuring element that define the elements considered within the nonlinear operator.
- MM closing-opening difference operator (CODO)
- MM closing-opening opening-closing morphological gradient (COOCMG)
- This research uses both the CODO and COOCMG operators with 5 different sizes of SE to parse the voltages and currents of the measurement signals of the system









Machine Learning

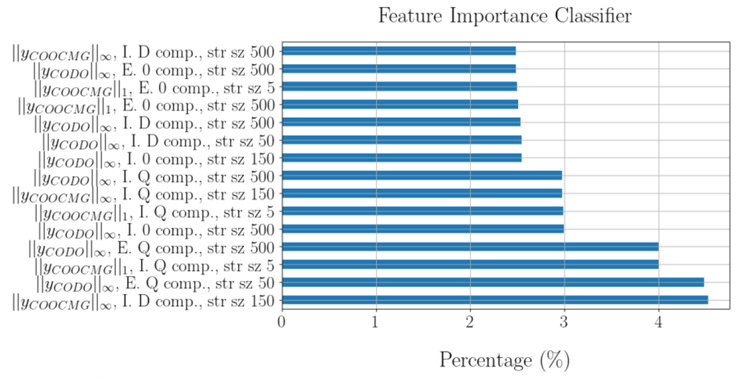
- Features (metrics computed to the MM signals, one and infinity norms of discrete signals)

$$||x||_1 = \sum_{k=1}^{n} |x_k| \qquad ||x||_\infty = \max_{1 \le k \le n} |x_k|$$

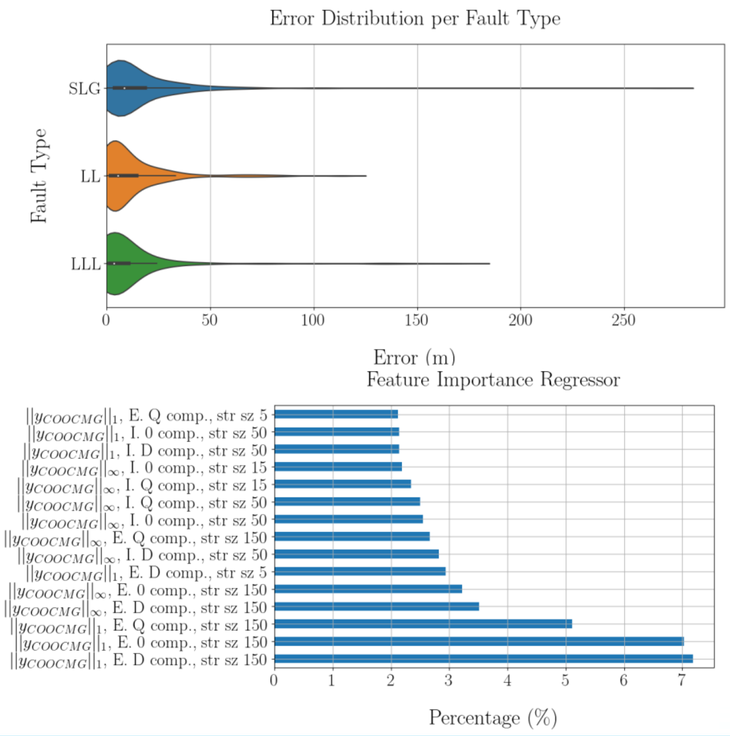
- In total, for each simulation 120 *features* can be computed:
  - Two measurements (voltages and currents)
  - Three transform components (DQ0)
  - Two MM operators (CODO, COOCMG)
  - Five sizes of structuring element
  - Two norms (1 and infinite norm)
- Random Forests (RF) are one of the best machine learning algorithms (not counting neural networks).
- Train a RF for regression and another for classification.

Results

- The RF for classification gets 100% accuracy and precision and recall.



- The regressor has:
  - Mean error of 13.105m.
  - Standard deviation of 21.788m.



Conclusions

- Proposed a protection approach combining mathematical morphology with classical machine learning (random forests)
- Approach performs better than similar approaches using the Wavelet Transform for the signal processing stage
- Proposed method requires only a fraction of the data (100μs) to identify the type of fault and to predict where it occurred
- Prediction error of 13m for signals with 45 dB of SNR

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