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Towards Online Change Point Algorithms on-the-edge for Real-Time Fault Detection in Power Converters

Zhymir Thompson[1, 2], Cameron Ball[3], Austin R.J. Downey[2, 4], Kerry Sado[3], Enrico Santi[3], Jason D. Bakos[1]

University of South Carolina, [1]Department of Computer Science and Engineering; [2]Department of Mechanical Engineering; [3] Department of Electrical Engineering; [4]Department of Civil and Environmental Engineering

Background

- Power systems are susceptible to cascading damage
- Online change point detection can detect abnormal grid behavior
- Alerted systems can respond appropriately and minimize damage cascade

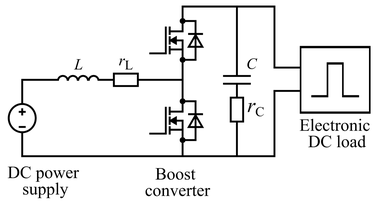

Fig 1. Electrical schematic of the simulated DC-DC boost converter, including source, switching stage, capacitor, and load

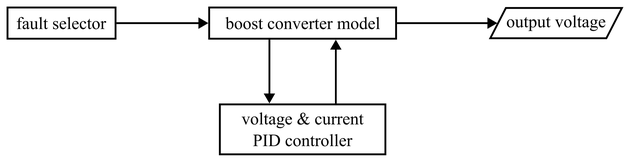

Fig 2. Block-level simulation architecture showing the fault selector, boost-converter model, PID control loop, and measured output voltage used by the detector.

- Online change point detection algorithms used:
  - Bayesian online change point detection (BOCPD)
  - Expectation-Maximization (EM)
  - Cumulative Summation (CUSUM)

Key Points

- Online change point algorithms can mitigate damage cascade by alerting appropriate systems quickly
- More flexible than manually setting threshold
- Currently implemented algorithms:
  - Sub-millisecond response speed
  - Max detection delay of 5 ms
- Tested on simulated DC-DC boost converter
- Work best when observations come from approximately normal distribution that is stable over time
- Swappable models via defined interface

Methods

- Observations are sent to the model(s) for processing
- Each model will then:
  1. Update parameters based on given observation
  2. Make a prediction on whether the observation is normal
- Model output is sent elsewhere to be used

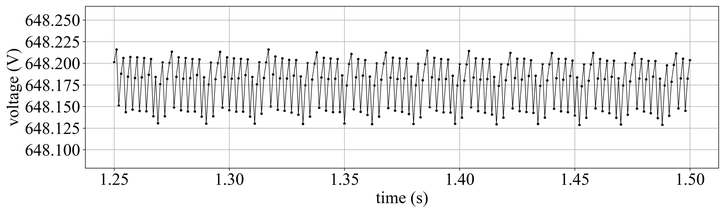

Fig 3. Output-voltage waveform under fault-free operation, sampled every 1 ms from the boost-converter simulation. The waveform exhibits periodic ripple about a nominal steady-state level.

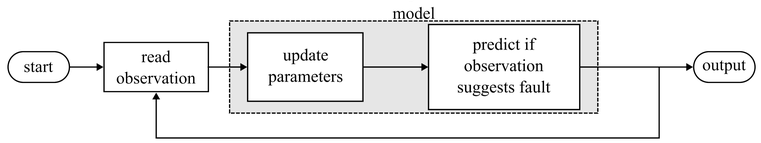

Fig 4. Diagram illustrating how an observation is transformed into a prediction of fault.

- The interface is an abstraction that decouples the model selection from the data source and target destination
- The model behaves the same regardless of where the data comes from (TCP, UDP, sensor, etc.)
- Output of model is sent without concern of how the prediction reaches its destination
- Any model that implements the interface can be substituted in

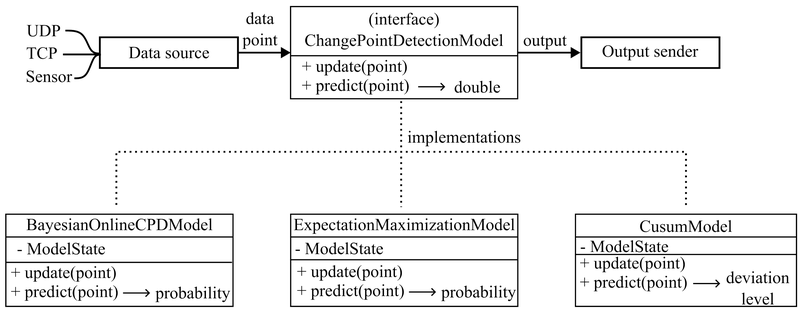

Fig 5. An interface description for the change point detection models. It comprises an update method and predict method.

Results

- Change point detection algorithms were run on a sequence of output voltage measurements
- Regions of signal were shaded by model prediction of normal or abnormal measurement

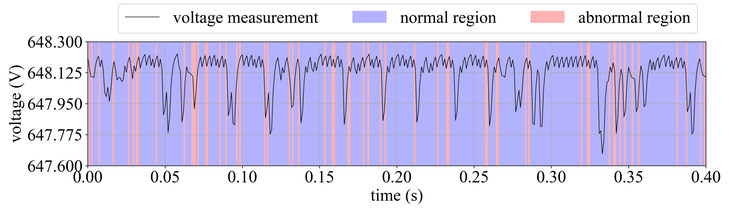

Fig 6. Normal and abnormal regions detected by Bayesian Online Change Point Detection (BOCPD) algorithm run on input short.

- Network simulation
- Algorithms were wrapped into objects
- Objects were sent data at regular interval of 1 ms
- Recorded time received at increments of 0.1 ms

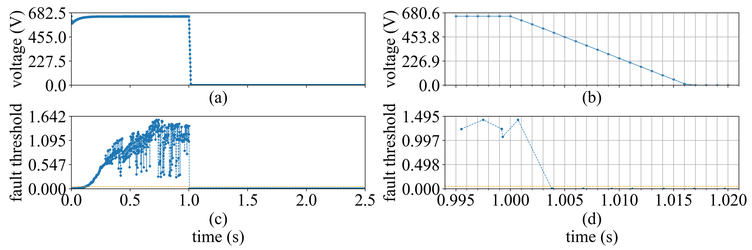

Fig 7. Detection for Bayesian Online Change Point Detection (BOCPD) algorithm on input short. Top left (a) shows voltage measurements. Top right (b) shows zoomed in view of voltage measurements around fault. Bottom left (c) shows model output and a horizontal bar representing threshold. Bottom right (d) shows zoomed in view of model response around threshold for zoomed in section.

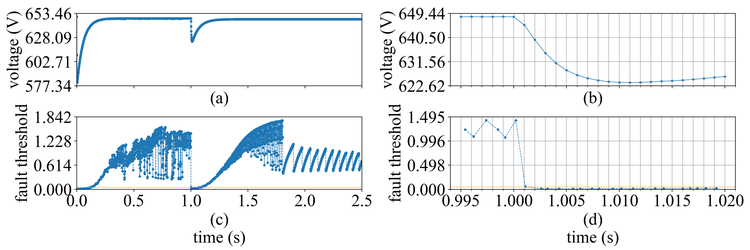

Fig 8. Detection for Bayesian Online Change Point Detection algorithm on input fault.

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