Real-time Simulation of Transformer Differential Protection based on Clarke-Wavelet Transform

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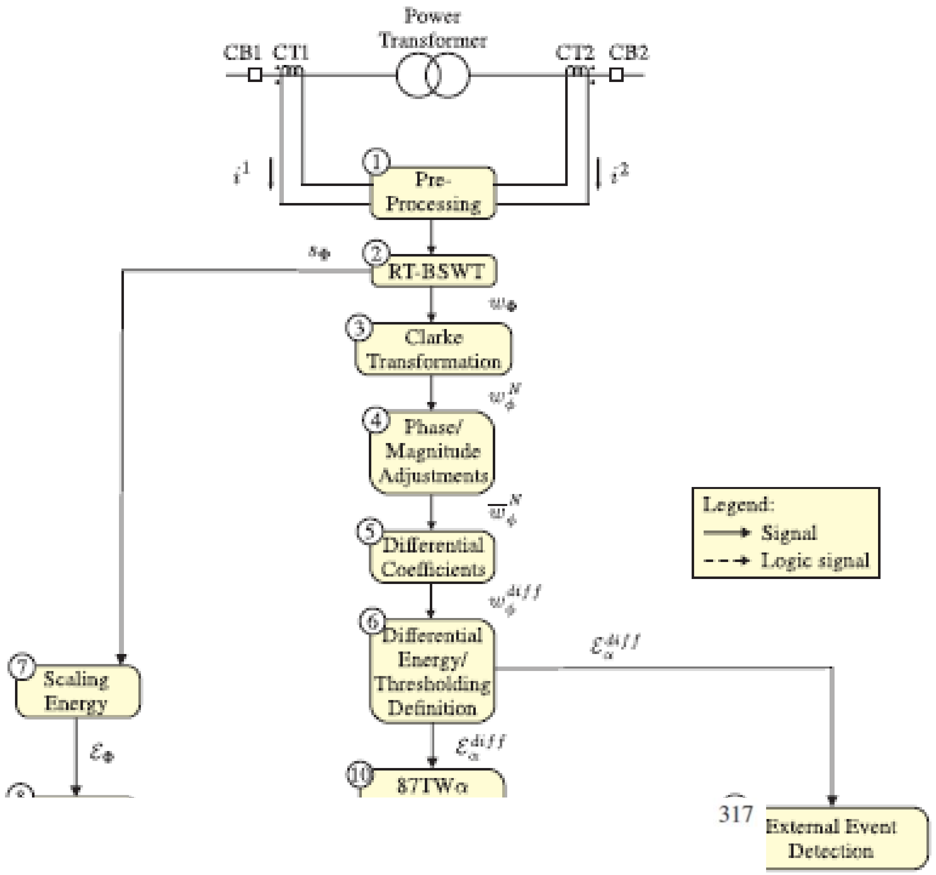
This presentation

- Introduction
- Problem statement
- Developing and results
- Conclusions



IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 37, NO. 1, FEBRUARY 2022 317

A Clarke-Wavelet-Based Time-Domain Power Transformer Differential Protection

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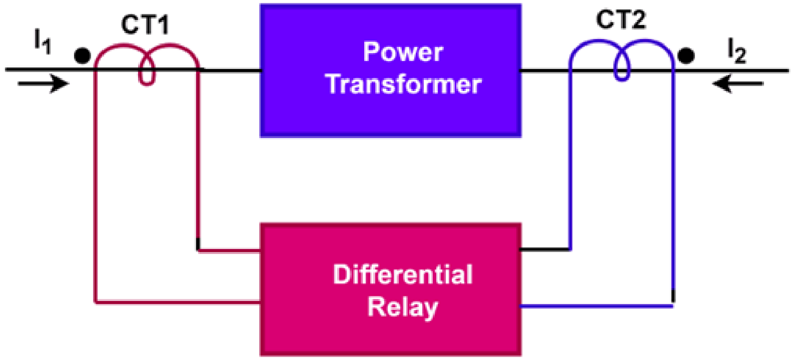
Trip

Introduction

- Power transformers are essential in power systems for several key reasons:
  - **Voltage scaling up/down**: step-up or step-down voltage levels
  - **Voltage control**: regulates the voltage with the tap changer
  - **Load Balancing:** enables load distribution by connecting different parts of the electrical grid
  - **Flexibility in power supply:** allows integration of different types of energy sources, such as renewable energy (solar, wind) and traditional power plants
  - **Safety:** steps down high transmission voltages to safer levels for end users

Problem statement

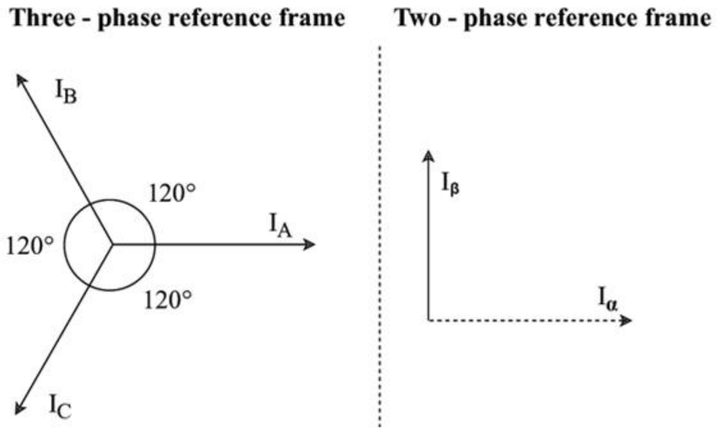
- A fast isolation during fault is imperative to protect the system and the transformer itself
- Commonly, because of its characteristics, **DIFFERENTIAL PROTECTION** is normally used as a primary transformer protection
  - While effective, it must account for diverse situations such as transformer tap changers, CT saturation, overexcitation, and inrush currents
  - Normally, blocking methods enhance the security of the differential protection but may delay internal fault detection and can fail during inrush conditions
  - AI, digital signal processing, and probability theory have been explored to improve protection schemes. Even though they are useful, they increase the computational burden

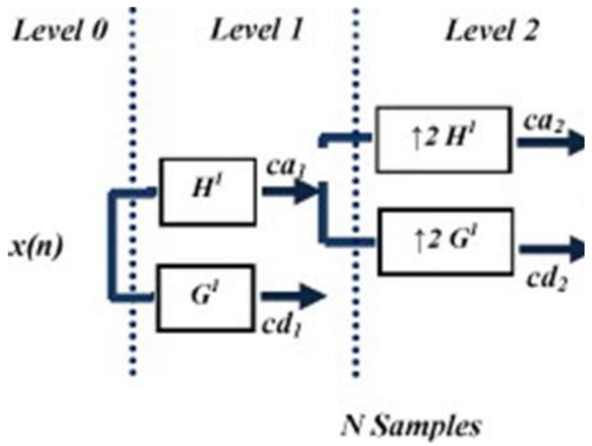


Differential Protection Scheme

Proposed method

- The Proposed method is based partly on Clarke transform
  - Simple transform, low computational burden
  - it is sensitive and facilitates internal fault detection
  - deals with specific fault types and CT saturation.
- and partly on Wavelet transform,
  - improves detection speed
  - improves accuracy by analyzing high-frequency components





Clark-Wavelet differential protection

Preprocessing

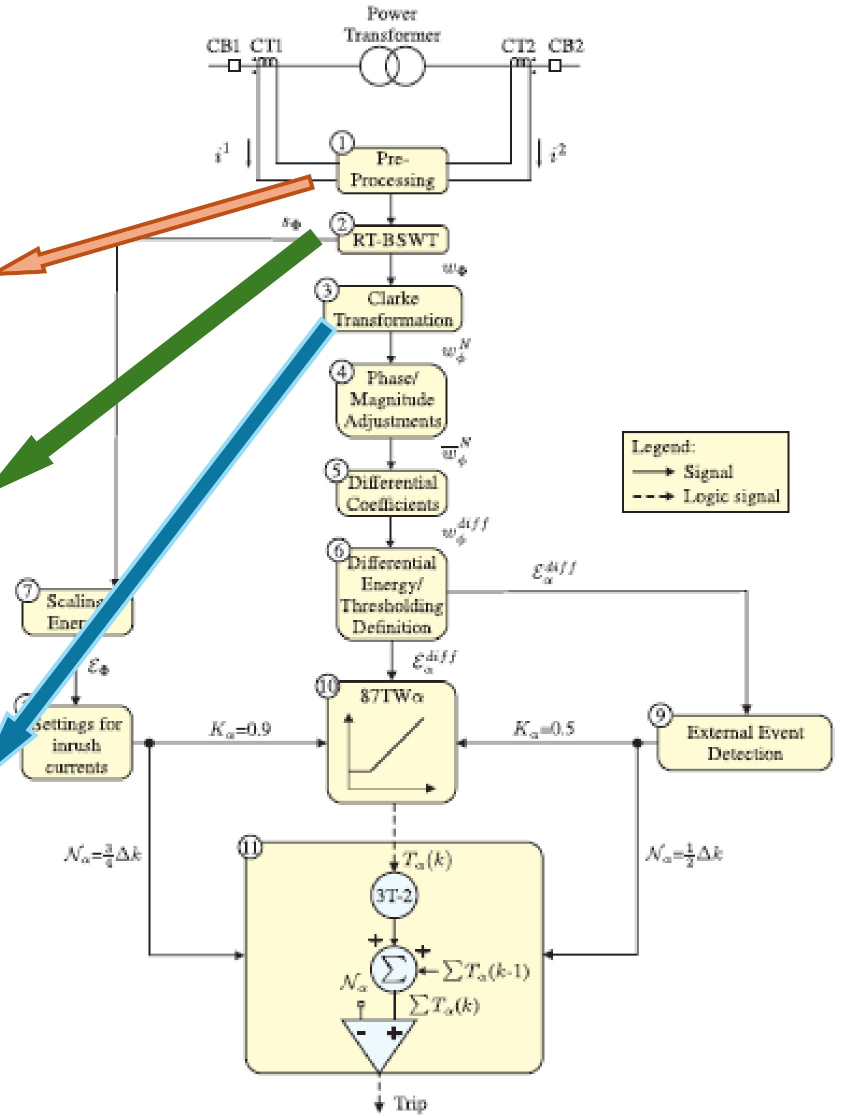
- Acquisition of three-phase CT secondary currents processed by anti-aliasing filters and converter from analogic to digital signal

Real-time boundary stationary wavelet transform RT-BSWT

- Scaling and wavelet coefficient
- $s_{\Phi}(l,k) = \frac{1}{\sqrt{2}} \sum_{n=0}^{L-1} h_{\varphi}(n) i_{\Phi}(k - L + n + 1 + l)$
- $w_{\Phi}(l,k) = \frac{1}{\sqrt{2}} \sum_{n=0}^{L-1} h_{\psi}(n) i_{\Phi}(k - L + n + 1 + l)$

Clark transform

- $\begin{bmatrix} w_{\alpha A}^{N}(k) \\ w_{\alpha B}^{N}(k) \\ w_{\alpha C}^{N}(k) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ -1/2 & 1 & -1/2 \\ -1/2 & -1/2 & 1 \end{bmatrix} \begin{bmatrix} w_{A}^{N}(k) \\ w_{B}^{N}(k) \\ w_{C}^{N}(k) \end{bmatrix}$



Clark-Wavelet Differential protection

Phase/Magnitude Adjustments

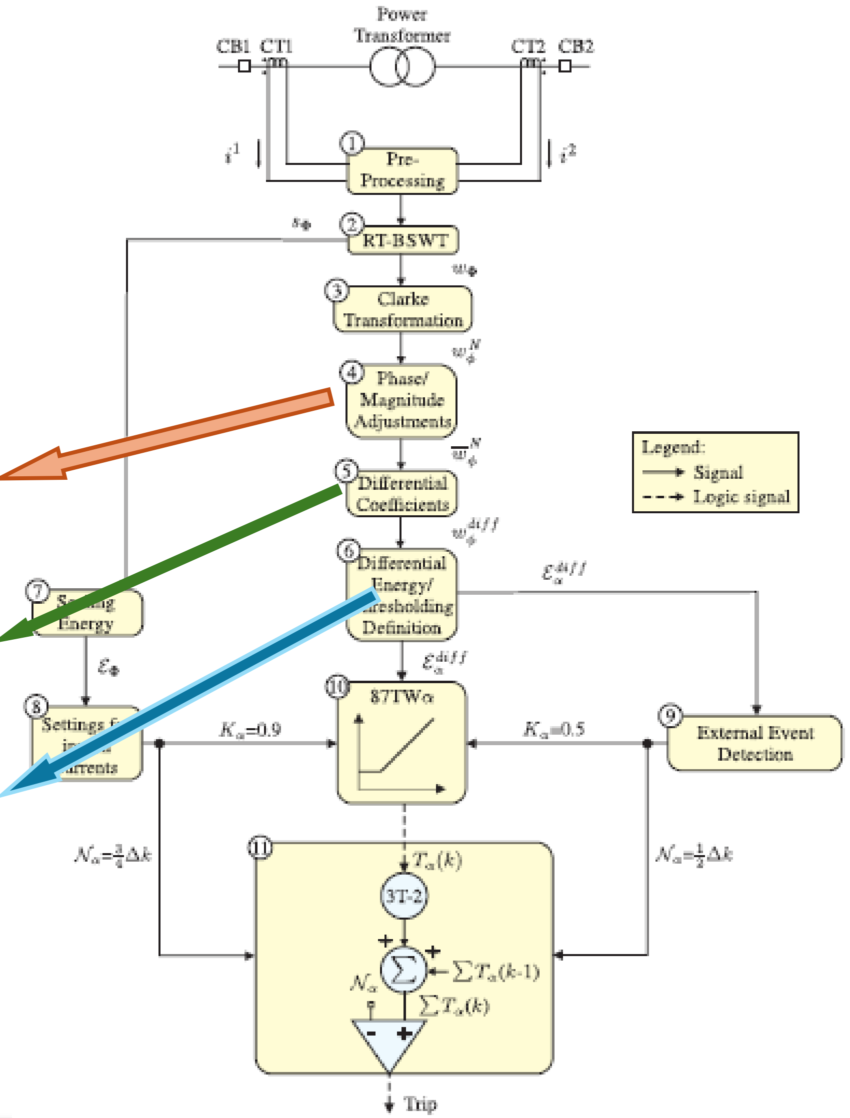
- $\begin{bmatrix} \bar{\bar{w}}_{\alpha A}^{N} \\ \bar{\bar{w}}_{\alpha B}^{N} \\ \bar{\bar{w}}_{\alpha C}^{N} \end{bmatrix} = \frac{1}{TAP_N} M_N \begin{bmatrix} w_{\alpha A}^{N} \\ w_{\alpha B}^{N} \\ w_{\alpha C}^{N} \end{bmatrix}$

Differential Wavelet Coefficients

- $w_{\phi}^{op}(l,k) = \sum_{m=1}^{N} \bar{\bar{w}}_{\phi}^{m}(l,k)$

Differential Energy and Automatic Threshold Definition

- $E_{\alpha}^{diff} = \frac{P}{k_2 - k_1 + 1} \sum_{n=k_1}^{k_2} \varepsilon_{\alpha}^{diff}(n)$



Proposed Clark-Wavelet Differential

Scaling Coefficient Energy

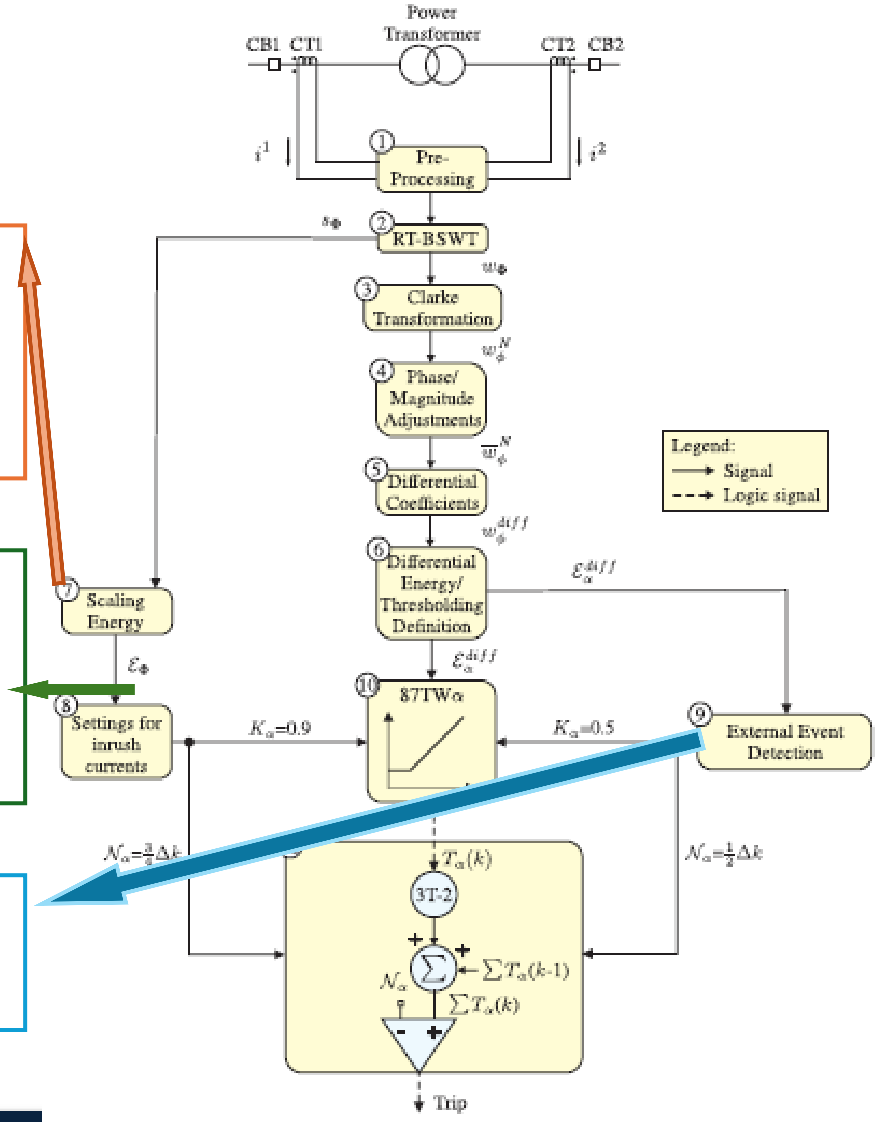
- scaling coefficient energy of the currents are directly proportional to low-frequency components, which is ideal to identify null-currents before transformer energization

Settings for Inrush Currents

- transformer can be identified as opened when currents are lower than the pickup values, accomplished in the wavelet domain as follows $\varepsilon_{\Phi}(k) < E_{\Phi}$

Inception Time Detection of External Events

- Based on energy $\varepsilon_{\alpha}^{op}(k) < K_{\alpha}\varepsilon_{\alpha}^{res}(k)$

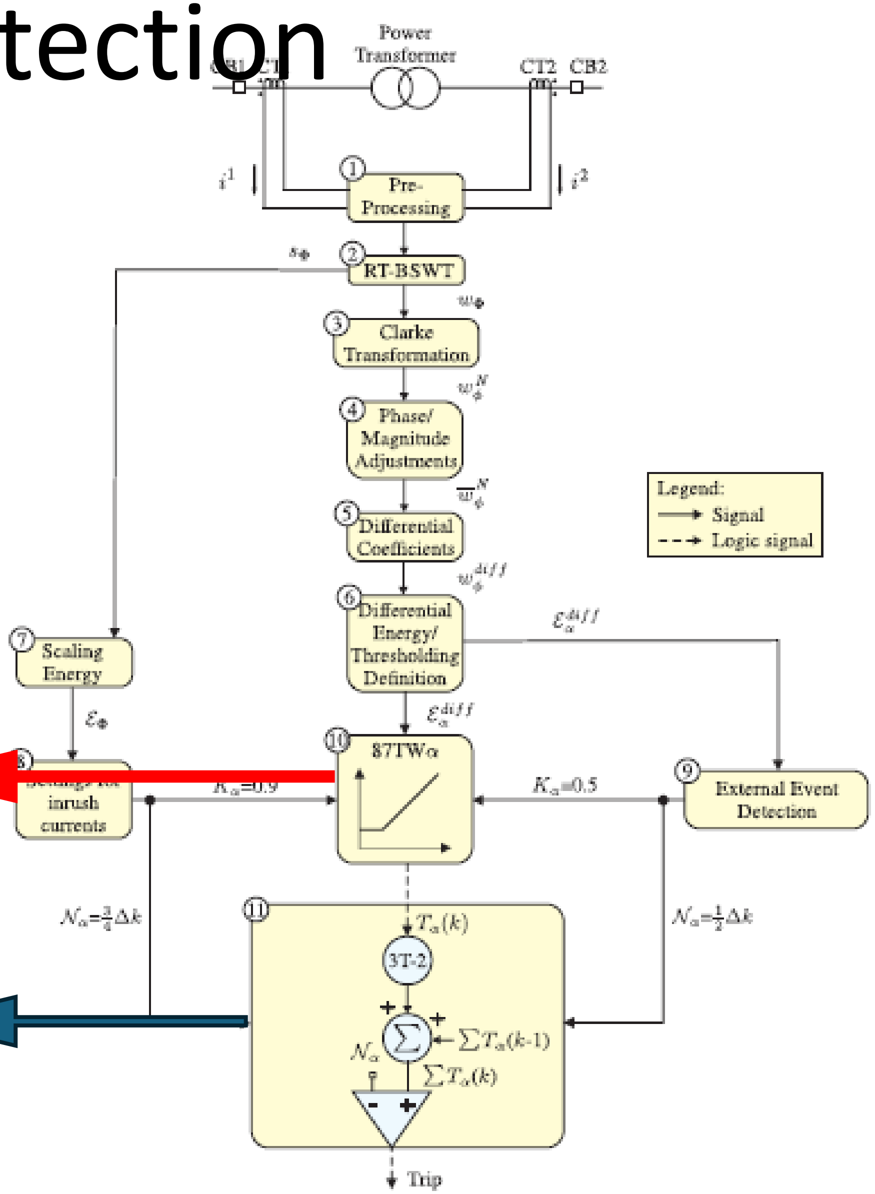


Clark-Wavelet Differential protection

Differential protection unit

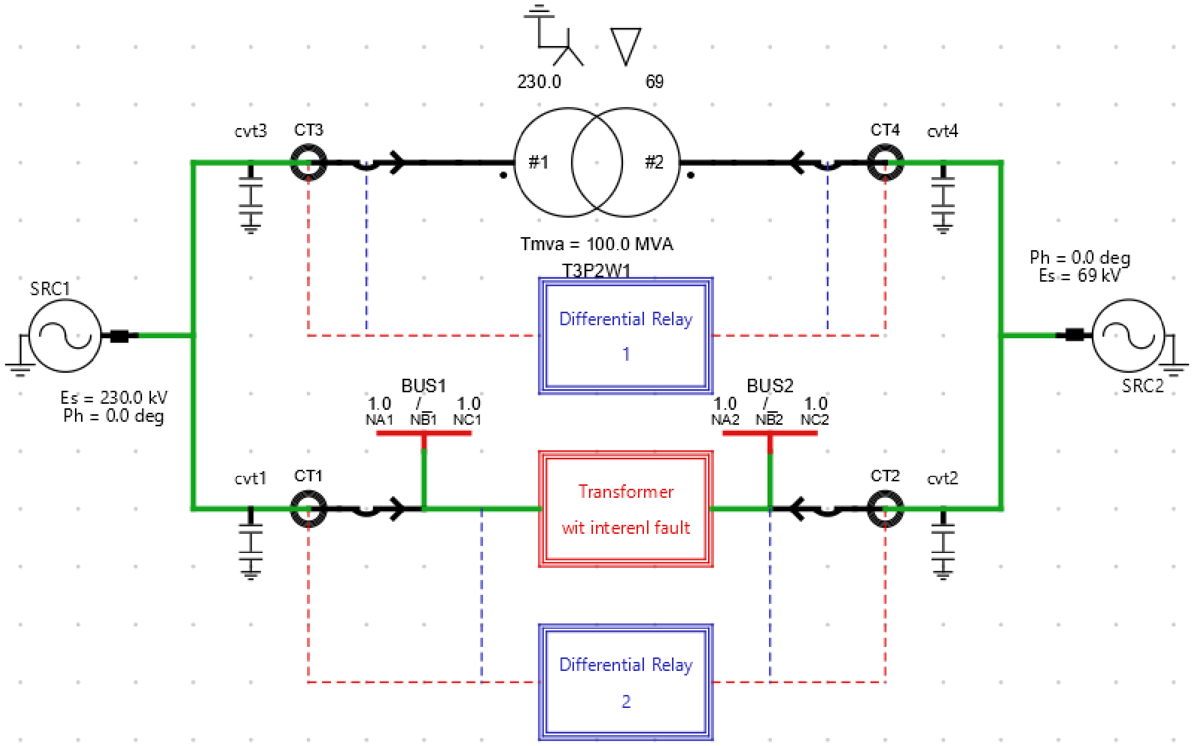
- Internal fault if
- $\begin{cases} \varepsilon_\alpha^{op}(k) > K_\alpha \varepsilon_\alpha^{res}(k) \\ \varepsilon_\alpha^{op}(k) > E_\alpha^{op} \end{cases} and \begin{cases} \varepsilon_\alpha^{op}(k-1) < E_\alpha^{op} \\ \varepsilon_\alpha^{res}(k-1) < E_\alpha^{res} \end{cases}$

Trip Management

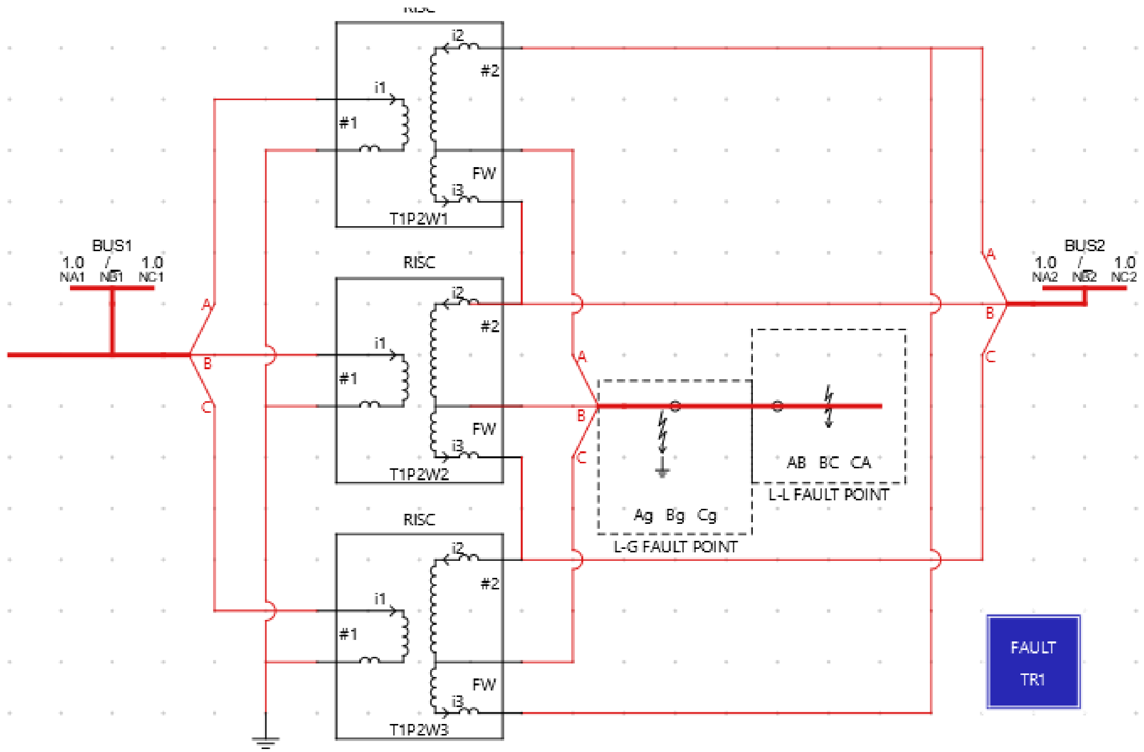


RTDS implementation

- Study case RSCAD Draft

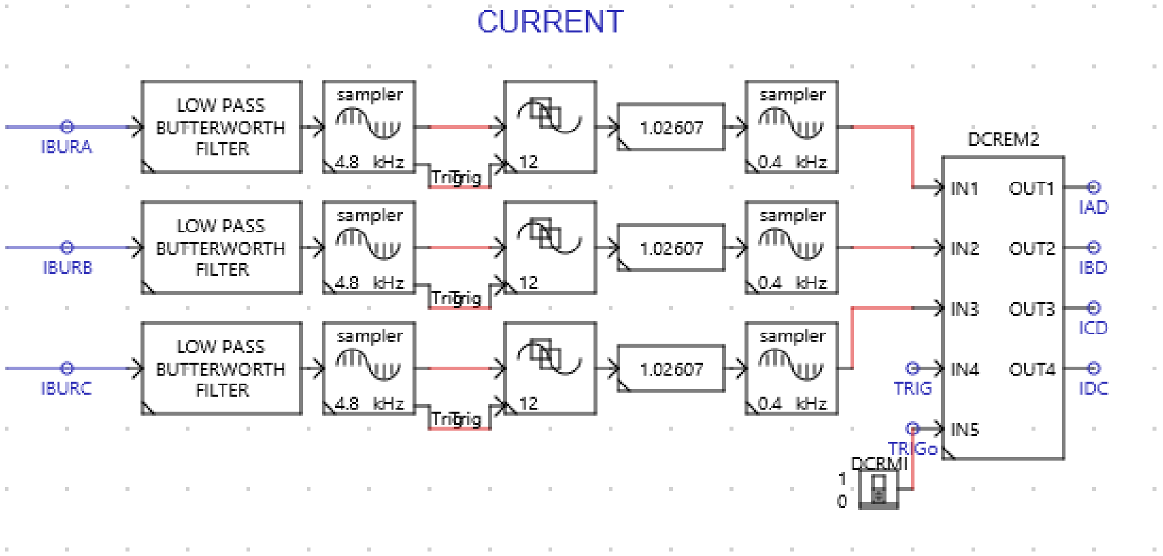


- YgD transformer internal fault

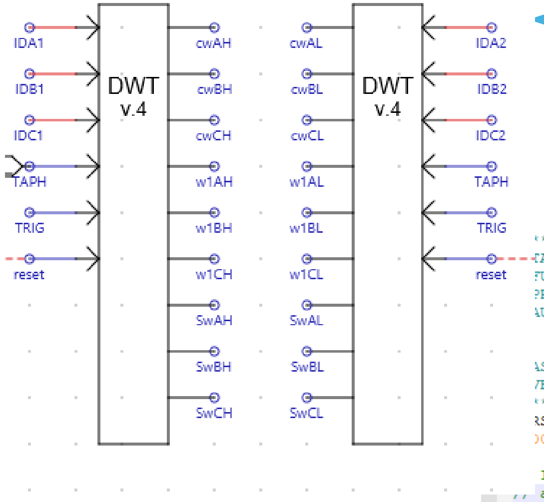


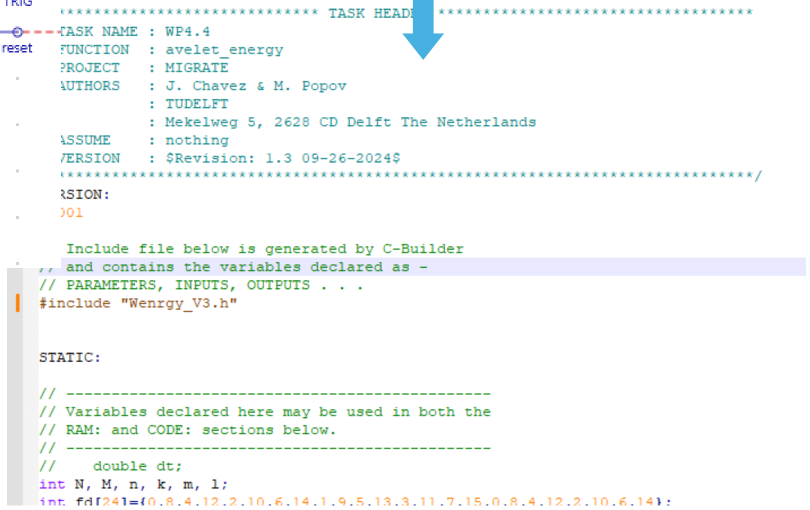
RTDS implementation (1)

- 1st Analog to digital



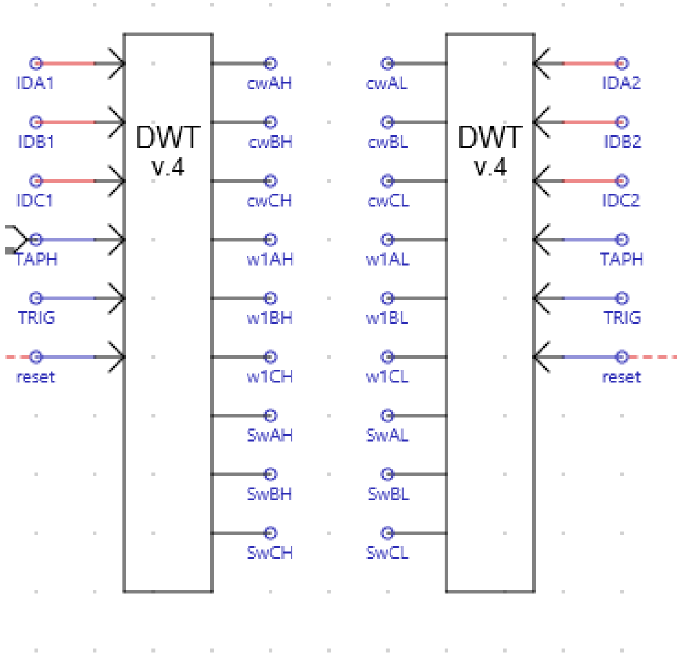
- 2nd Real time boundary stationary wavelet
  - Cbuilder 2.0
  - Code



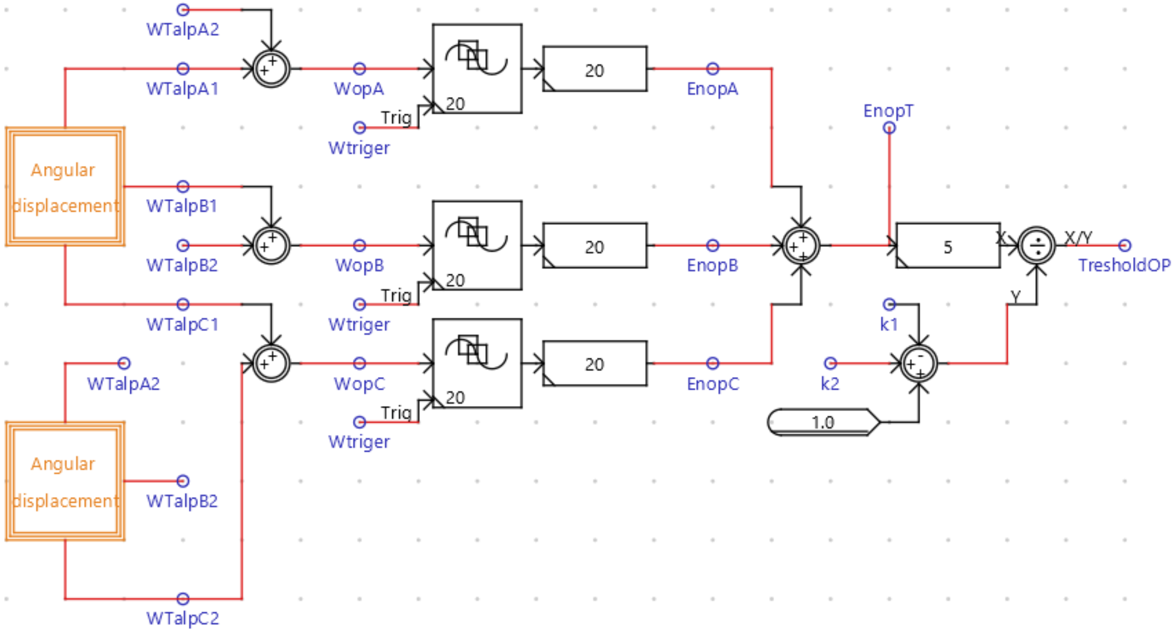


RTDS implementation (2)

- 3th & 4th Clark transform and Real-time boundary stationary wavelet and phase adjustment

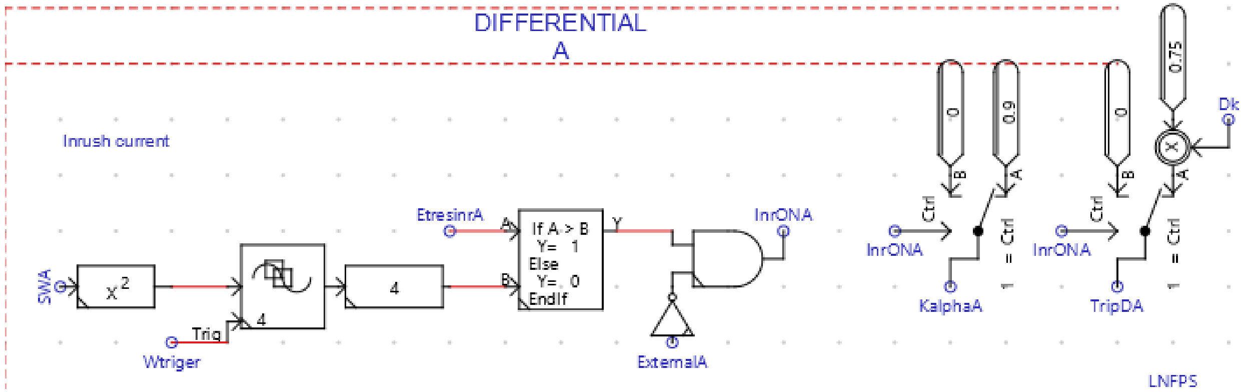


- 6 Differential energy and threshold calculation

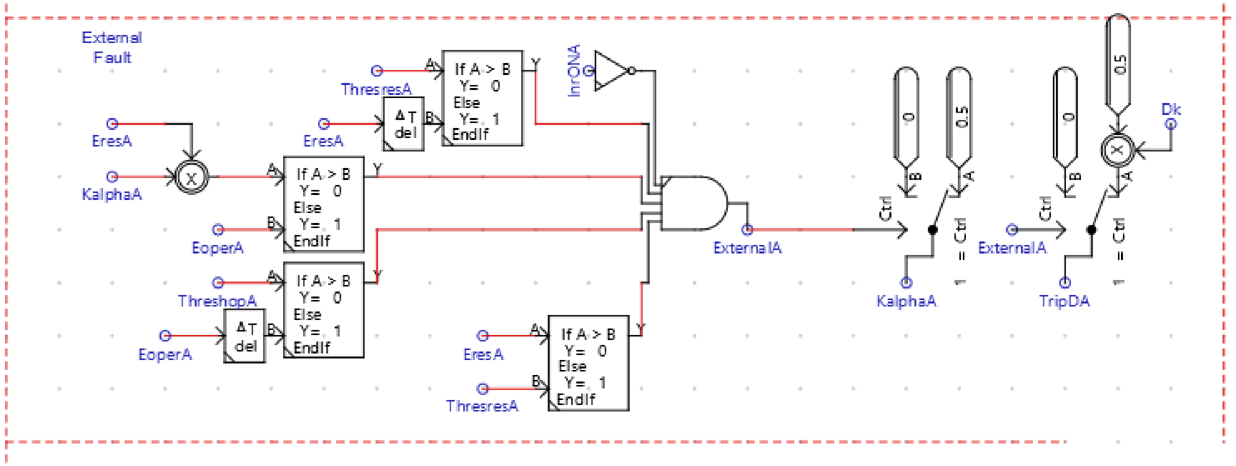


RTDS implementation (3)

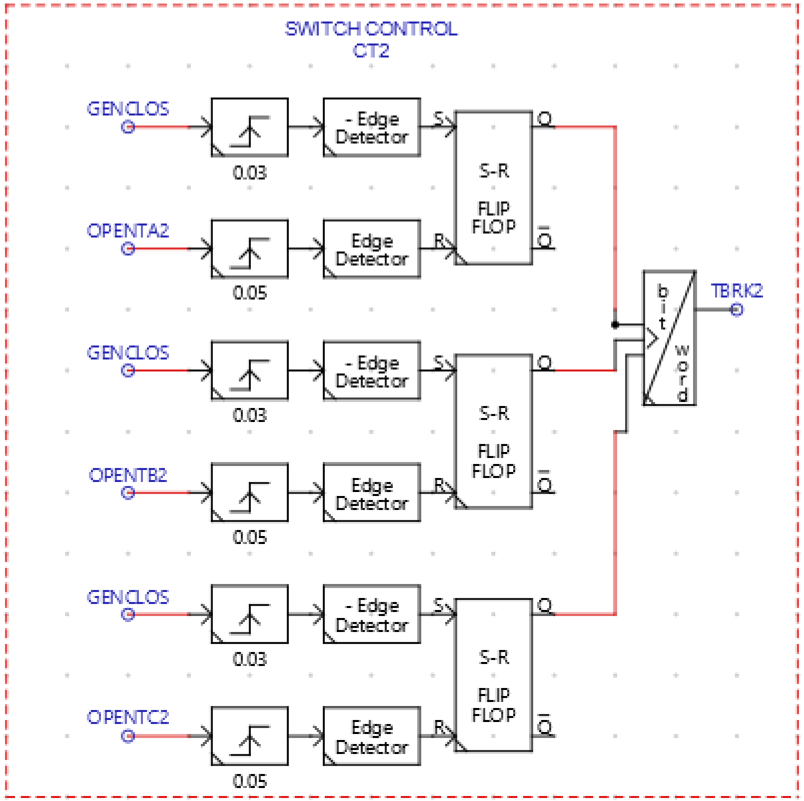
- 7th & 8th Inrush current



- 9th External detection

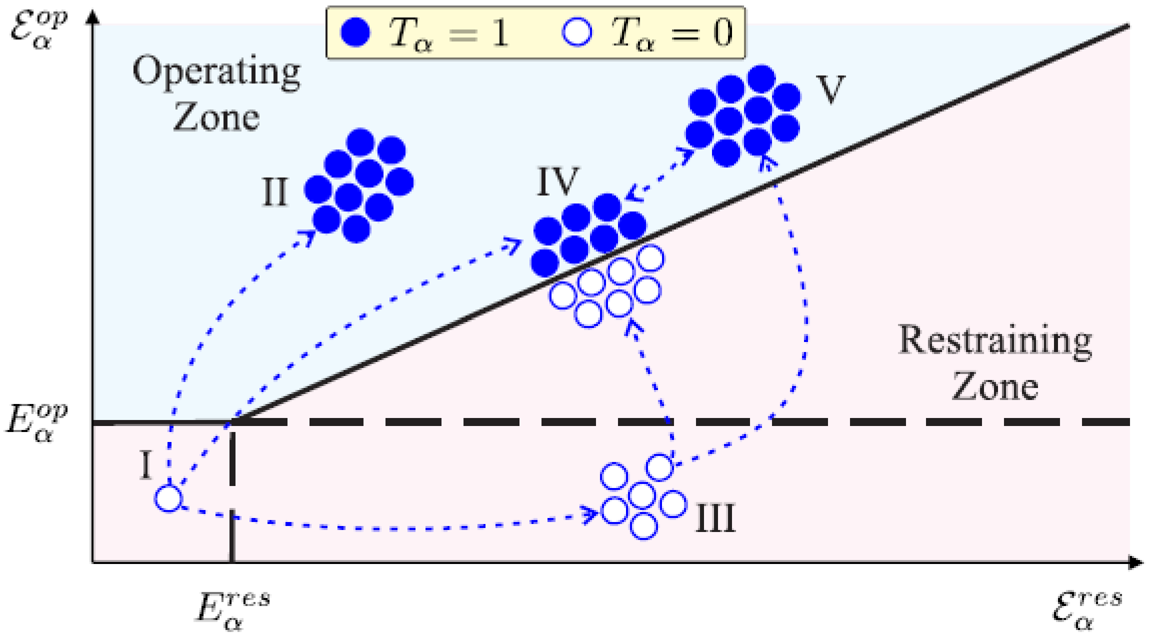


- Breaker control

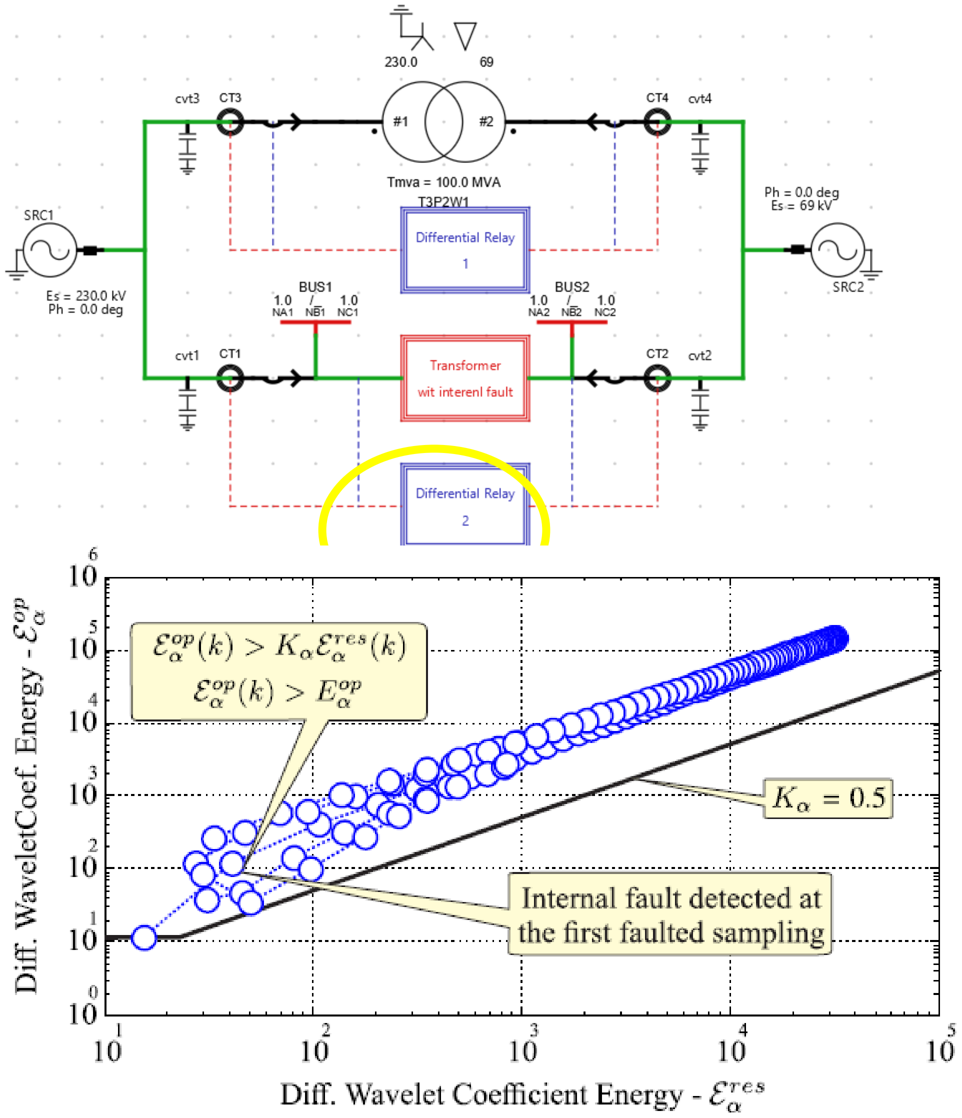


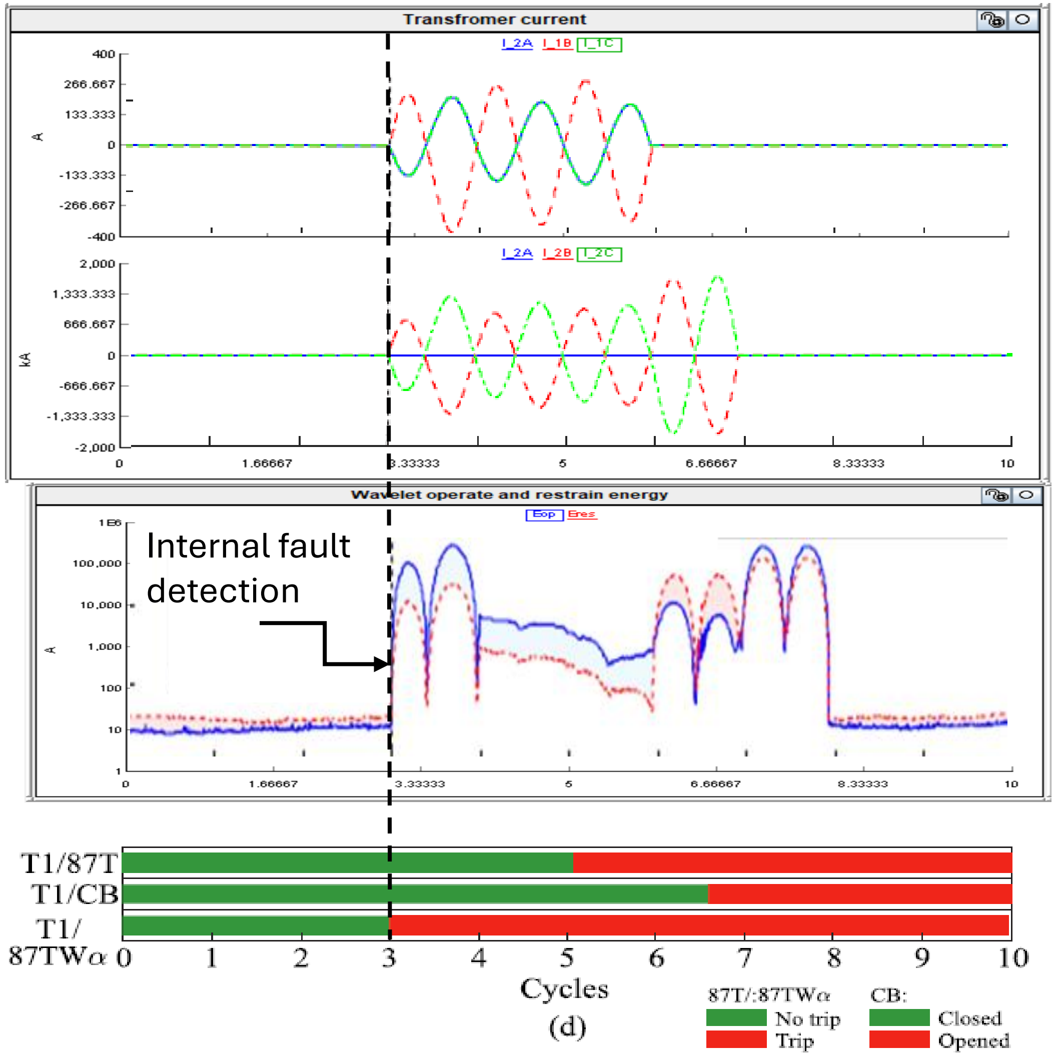
Trajectory of the energy operating points for most of the events

- Steady-state zone I
- Internal fault zone II
- Externals fault zone III
- External fault followed by CT saturation from I to III and then from III to IV (in the restraining region)
- External fault followed by internal fault from I to III and from III to V
- Overexcitation from I to III and then to IV (in the restraining region)
- Inrush current IV (restraining region)
- Inrush current with permanent fault II
- Inrush current followed by permanent fault from I to IV when the internal fault starts it changes to V

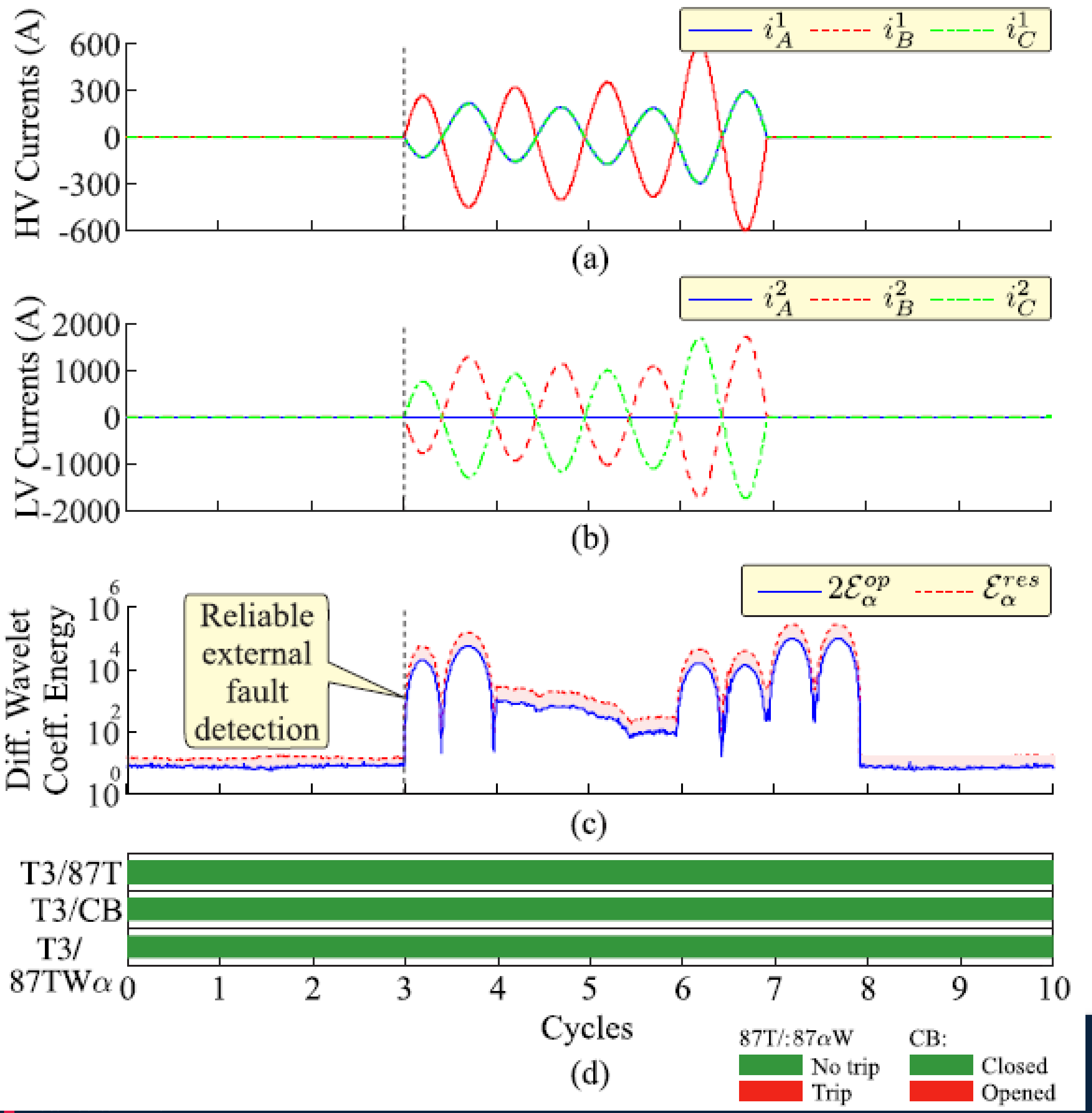


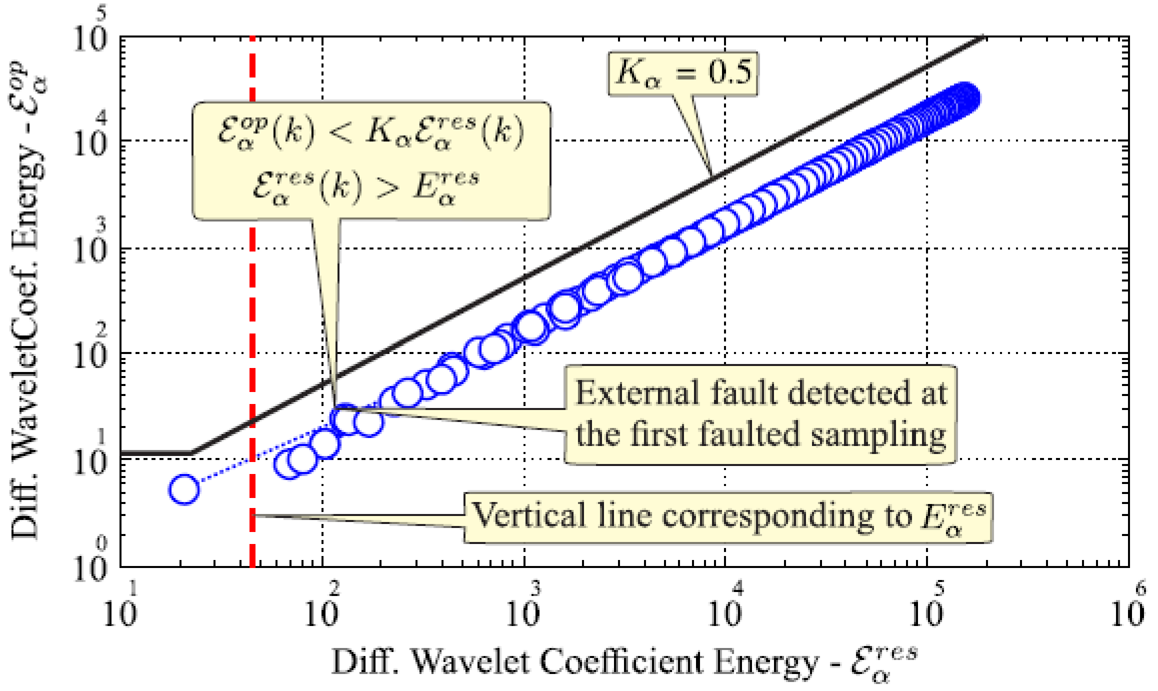
Internal fault A-B



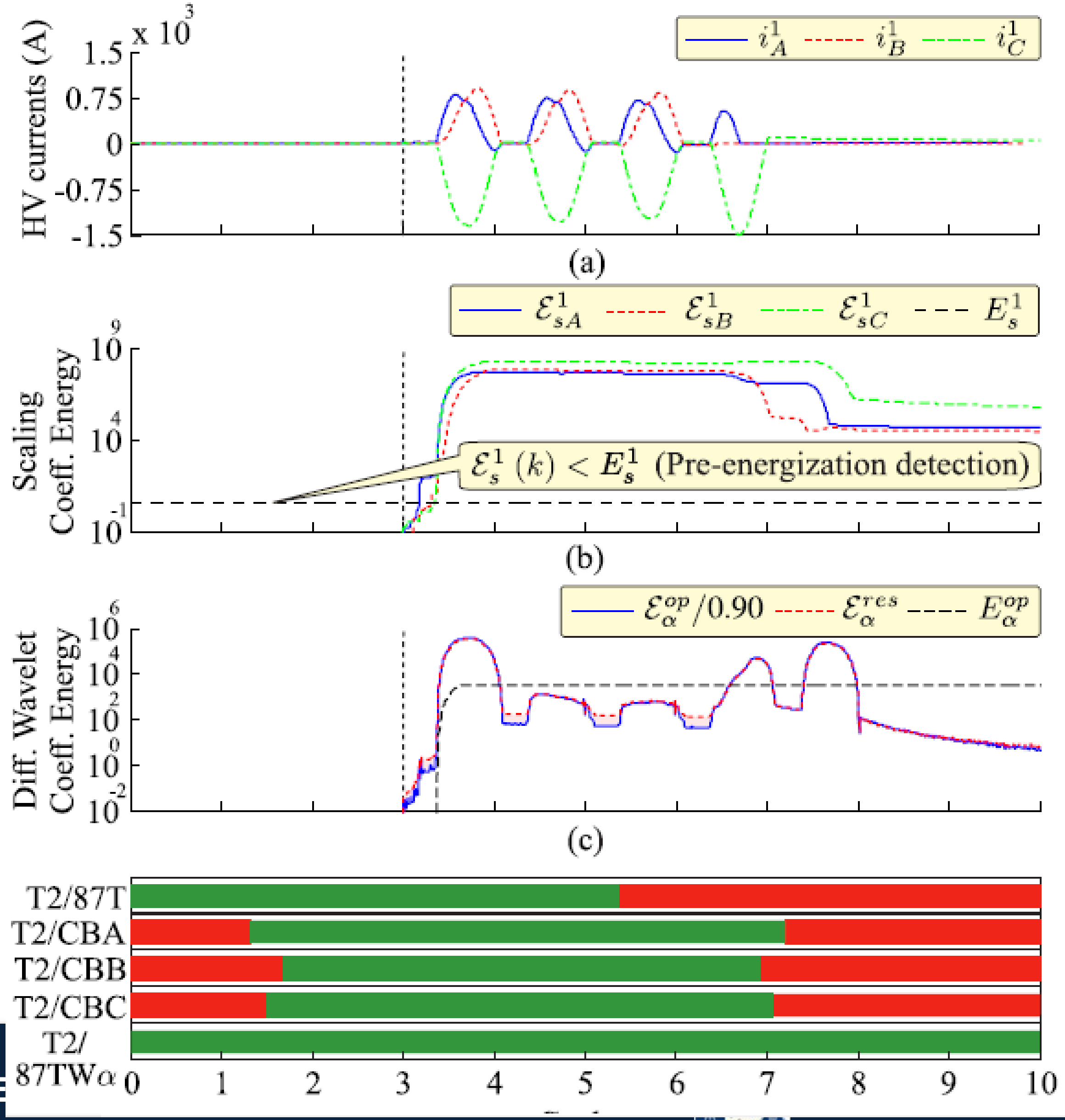


External fault and clearance





Transformer energization



Conclusions

- **Transformer Protection Method:** a time-domain transformer differential protection method using wavelet and Clarke transforms, with a single differential unit (87TWα) that does not require phase segregation or harmonic-based functions.
- **Comparison with Conventional Protection**: The performance of the method was compared to conventional differential protection using both actual and simulated data.
- **Handling Actual Data**:
  - Conventional methods failed during transformer energization due to low harmonic content, resulting in a false trip.
  - The proposed method successfully handled this case in offline analysis.
  - Both methods correctly detected internal faults, but the proposed method was faster, detecting the fault in 65 µs versus two cycles for the conventional method.
- **Efficiency and Simplicity:** The use of Clarke and wavelet transforms ensures computational efficiency and simplicity, with the equations requiring only addition and multiplication, making hardware implementation feasible.