# Transmission Lines Protection using Digital Morphologic Filter of Fault-generated High-frequency Transient Signals

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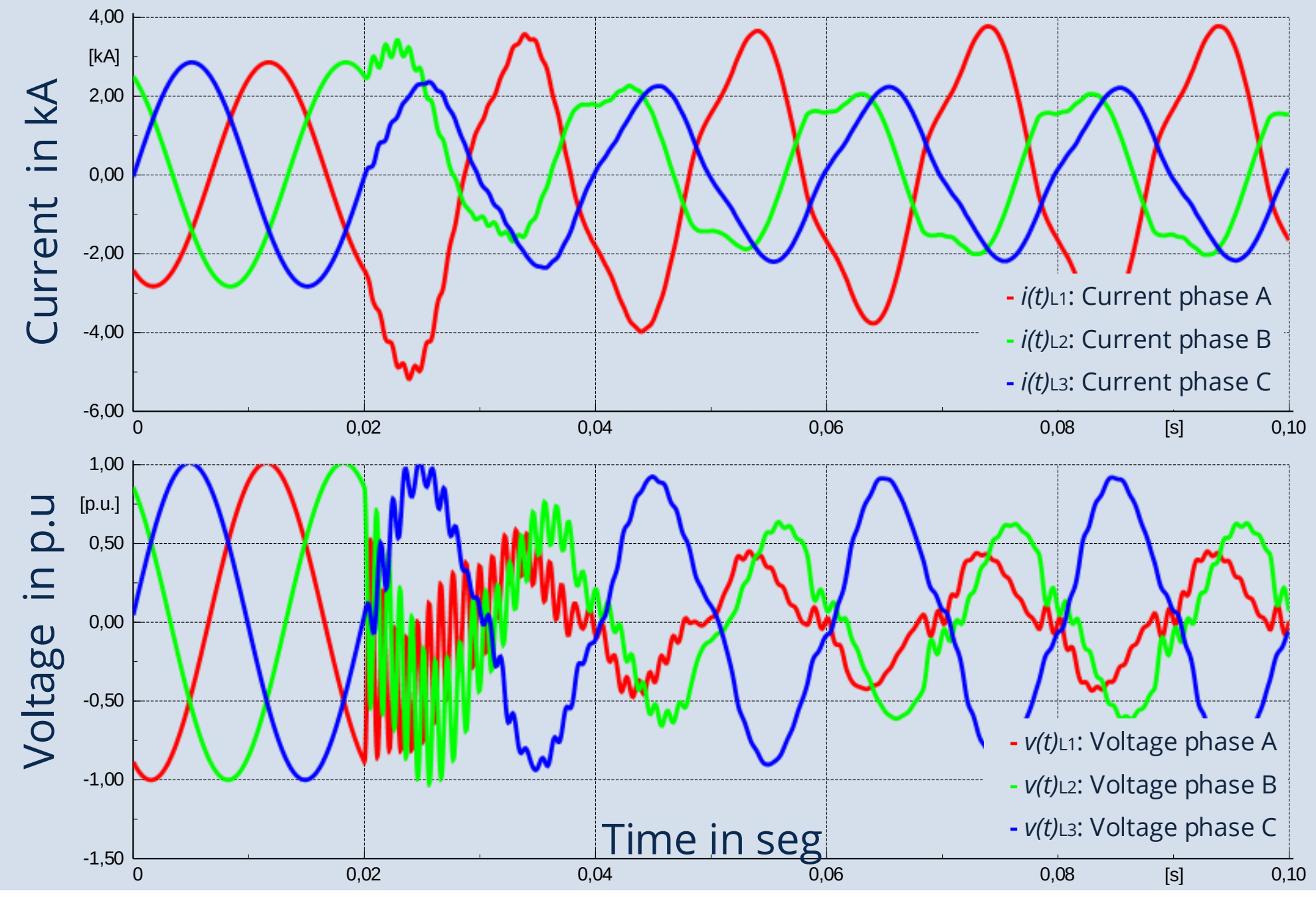
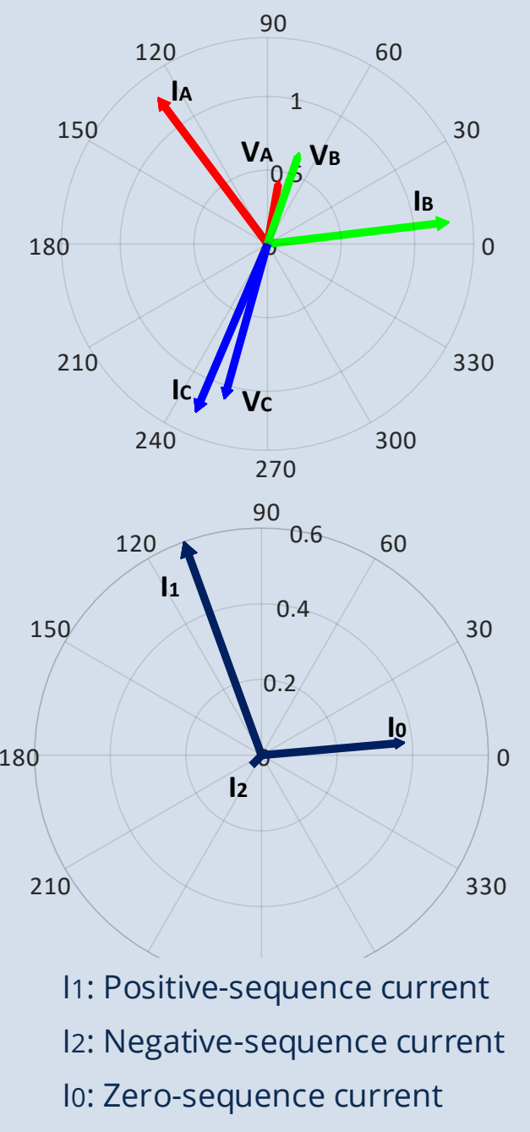
## Motivation

- The increase of renewable energy sources (RES) involves the dependence of power electronics in electrical networks.
- The RES fault behavior is quite varied as it depends on their structural design features and control system settings.
- Traditional protection devices are experiencing challenges due to the increase of RES.
- Therefore, it is necessary to study new protection algortihms to avoid this effect.
- A new scheme is proposed through the use of fault-generated high-frequency transient signals based on mathematical morphology.

## Protection relays challenges



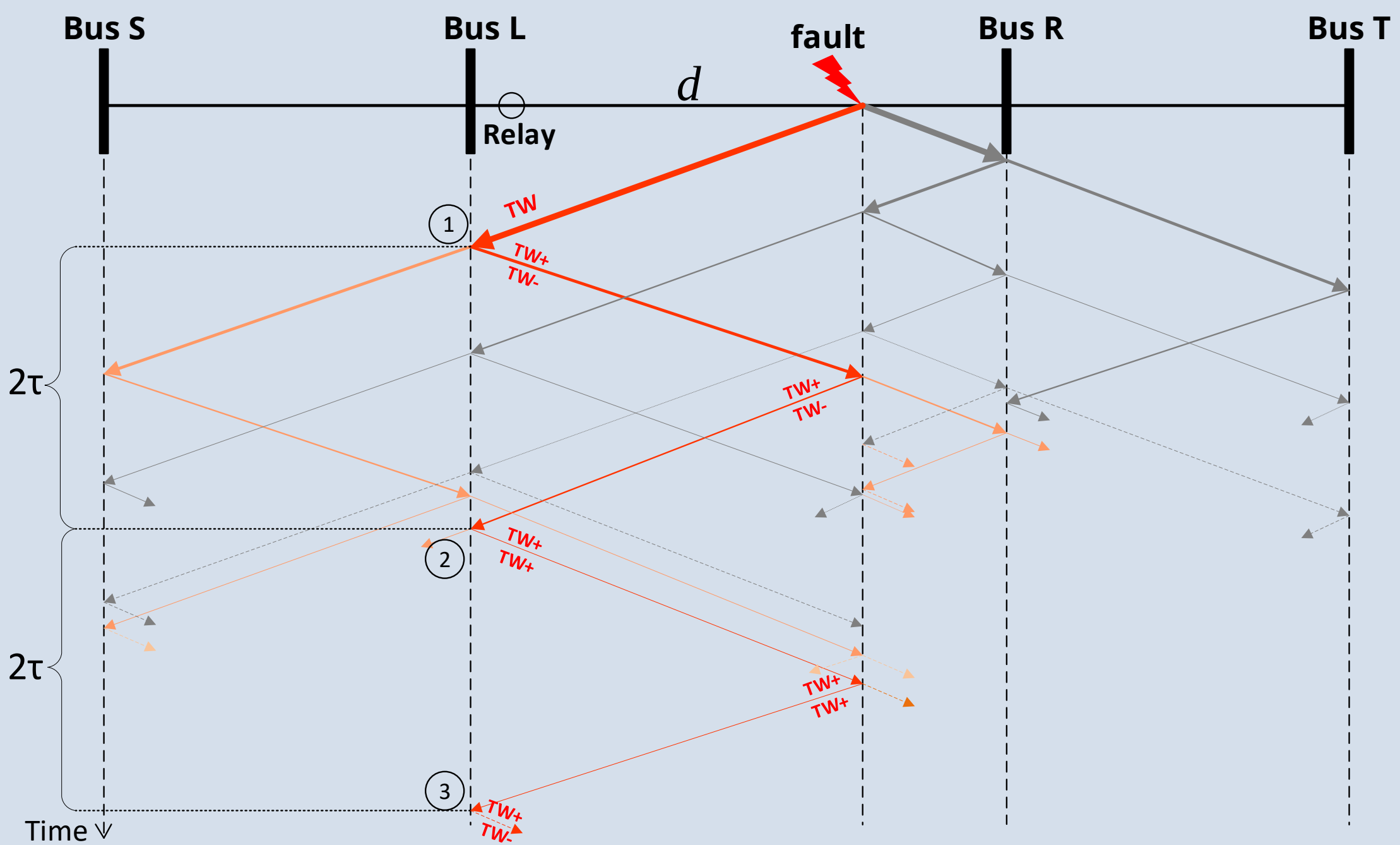


Case: Two-phase fault

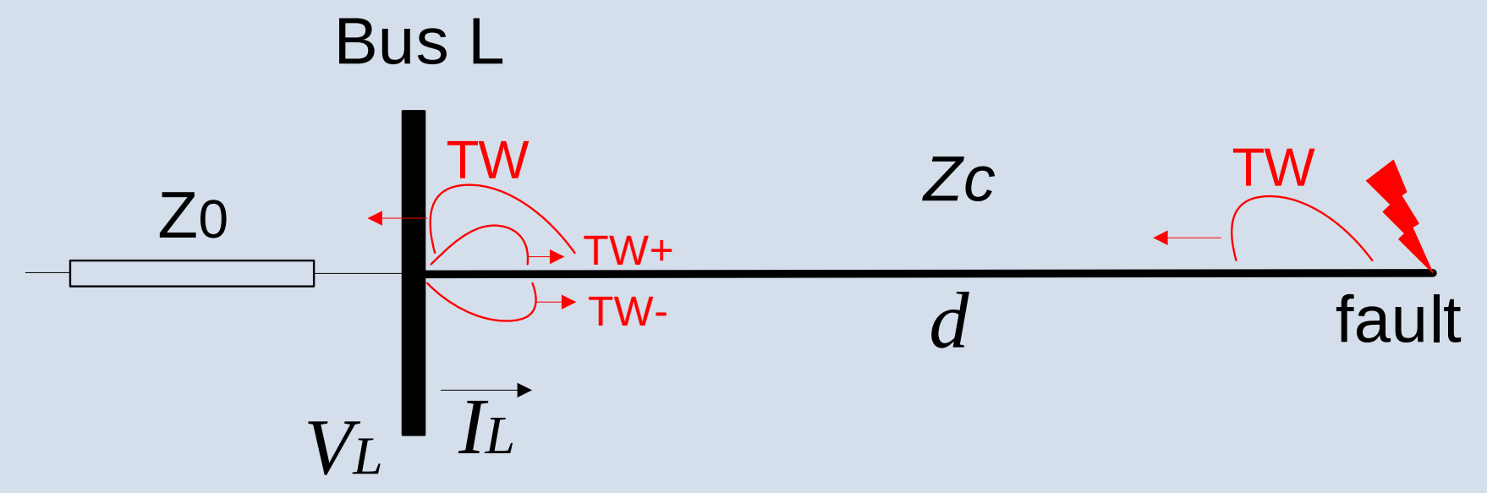
- The control in the phasor quantities, especially in the phase shift of the voltages and currents may cause a confusion in the relay.
- The magnitude of the current negative-sequence of the RES is almost zero, consequently, directional element malfunction may occur.
- The magnitude of the short-circuit current is low (max 1.5 p.u. rated current), this could cause malfunctioning of the overcurrent monitoring algorithms.

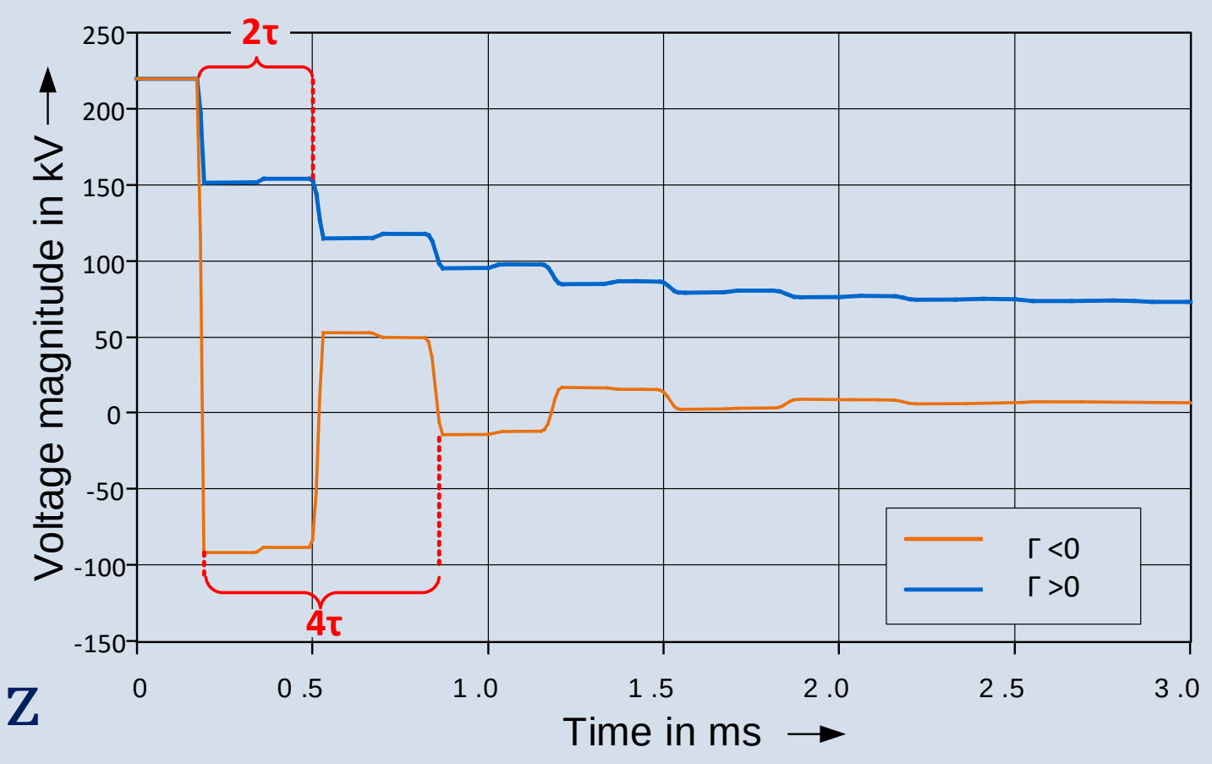
## Fault-generated High-frequency Transient Signals

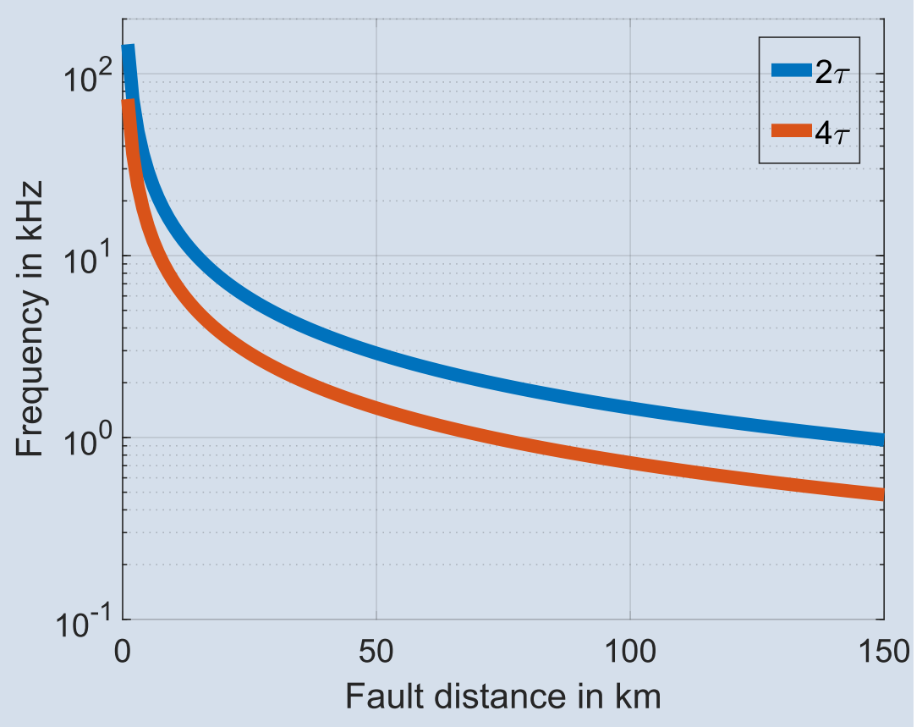
### Traveling waves (TWs) reflection and refraction.



Lattice diagram







$$\Gamma_{TW} = \frac{Z_c - Z_0}{Z_c + Z_0} \begin{cases} \Gamma_{TW-} < 0 \rightarrow Freq_{\text{fault}} = \frac{1}{4\tau}\ \text{Hz} \\ \Gamma_{TW+} > 0 \rightarrow Freq_{\text{fault}} = \frac{1}{2\tau}\ \text{Hz} \end{cases}$$

$$\tau = \frac{\text{Fault distance}}{\text{TW speed}} = \frac{d}{v}$$

$$v = \frac{1}{\sqrt{LC}}\ \text{km/s}$$

$$Z_c = \sqrt{\frac{L}{C}}\ \Omega$$

$\Gamma$: Reflection coefficient

$Z$: characteristic impedance

$Freq_{\text{fault}}$: Fault frequency

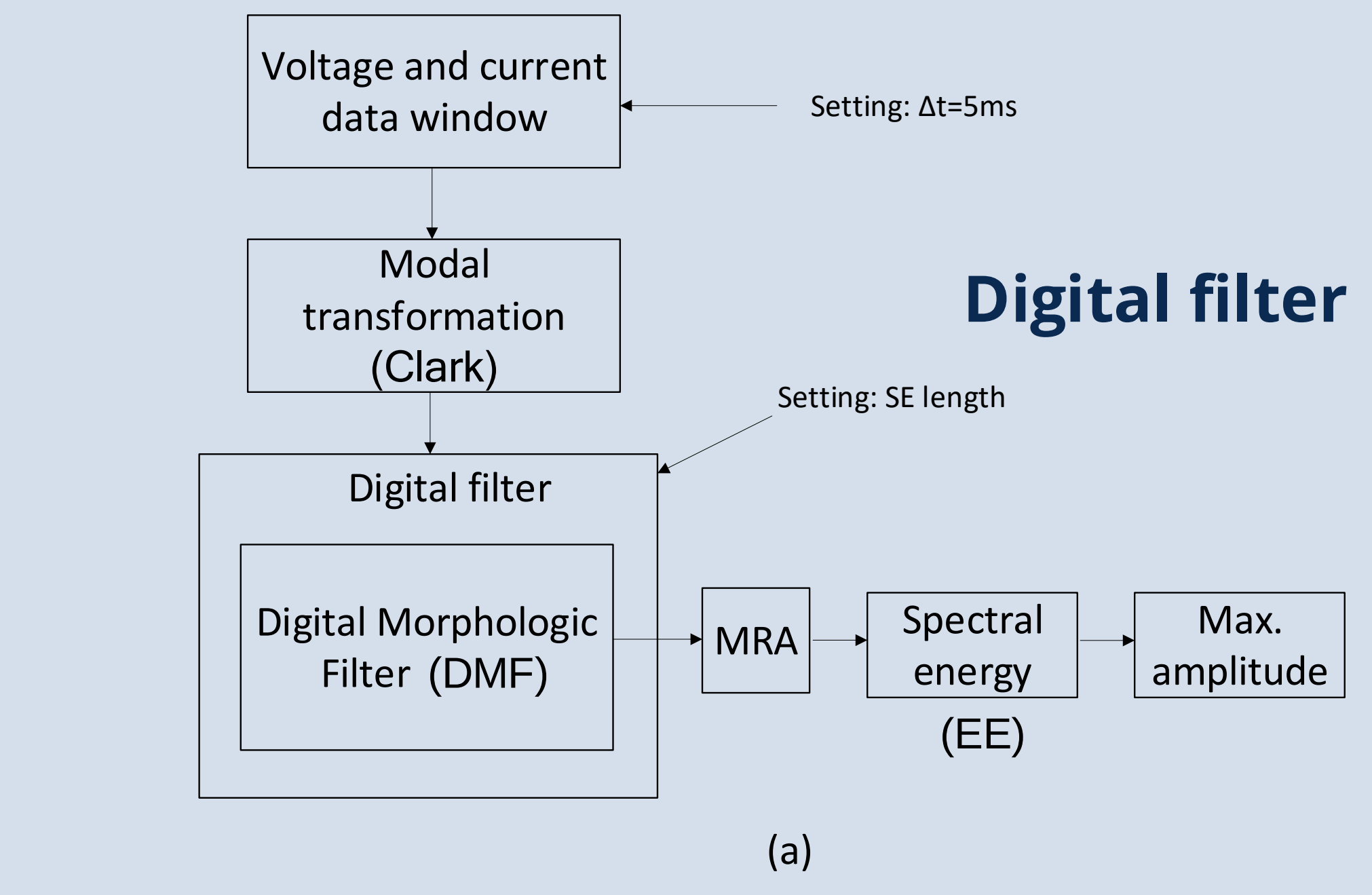
$\tau$: Wave travel time from fault to bus L

$L$: Transmission line impedance

$C$: Transmission line capacitance

## Methodology and results

### Diagram of the protection scheme



Voltage and current data window

Setting: Δt=5ms

Modal transformation (Clark)

**Digital filter**

Setting: SE length

Digital filter

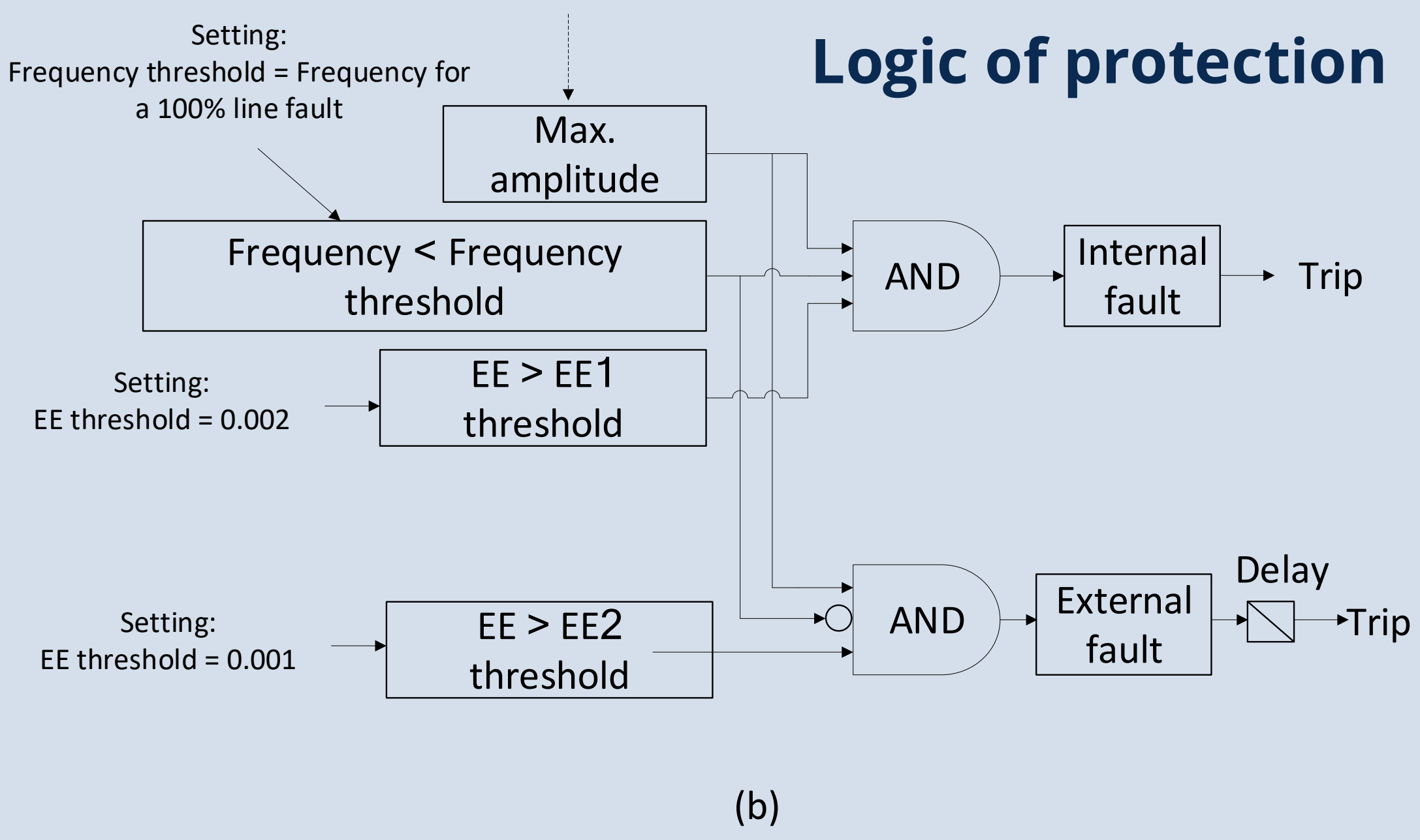
Digital Morphologic Filter (DMF)

MRA

Spectral energy (EE)

Max. amplitude

(a)



Setting: Frequency threshold = Frequency for a 100% line fault

**Logic of protection**

Max. amplitude

Frequency < Frequency threshold

Setting: EE threshold = 0.002

EE > EE1 threshold

AND

Internal fault

Trip

Setting: EE threshold = 0.001

EE > EE2 threshold

AND

External fault

Delay

Trip

(b)

Determination of multiresolution signals by means of a morphology filter:

$$DMF_{OC} f(x) = (f \circ g \cdot g)(x)$$

$$DMF_{CO} f(x) = (f \cdot g \circ g)(x)$$

$$DMF_g f(x) = \frac{DMF_{OC} f(x) + DMF_{CO} f(x)}{2}$$

$$f_n = DMF_{gn} f_{n-1}$$

$$H_n = f_{n-1} - f_n$$

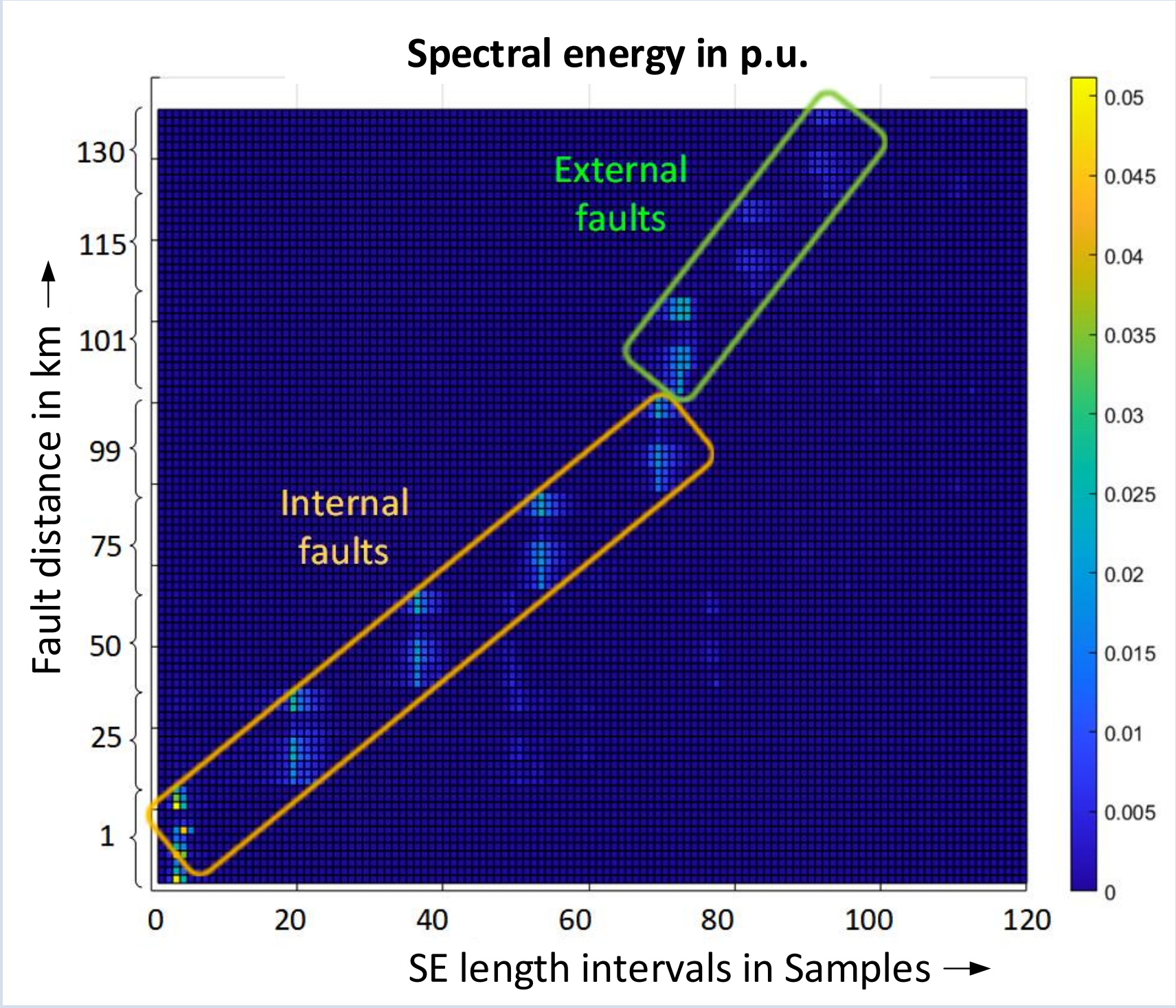
- The SE length defines the frequency of the multiresolution signal.
- The frequency defines the fault location .

$f(x)$: One-dimensional discrete signal

$g(x)$: Structuring Element (SE)

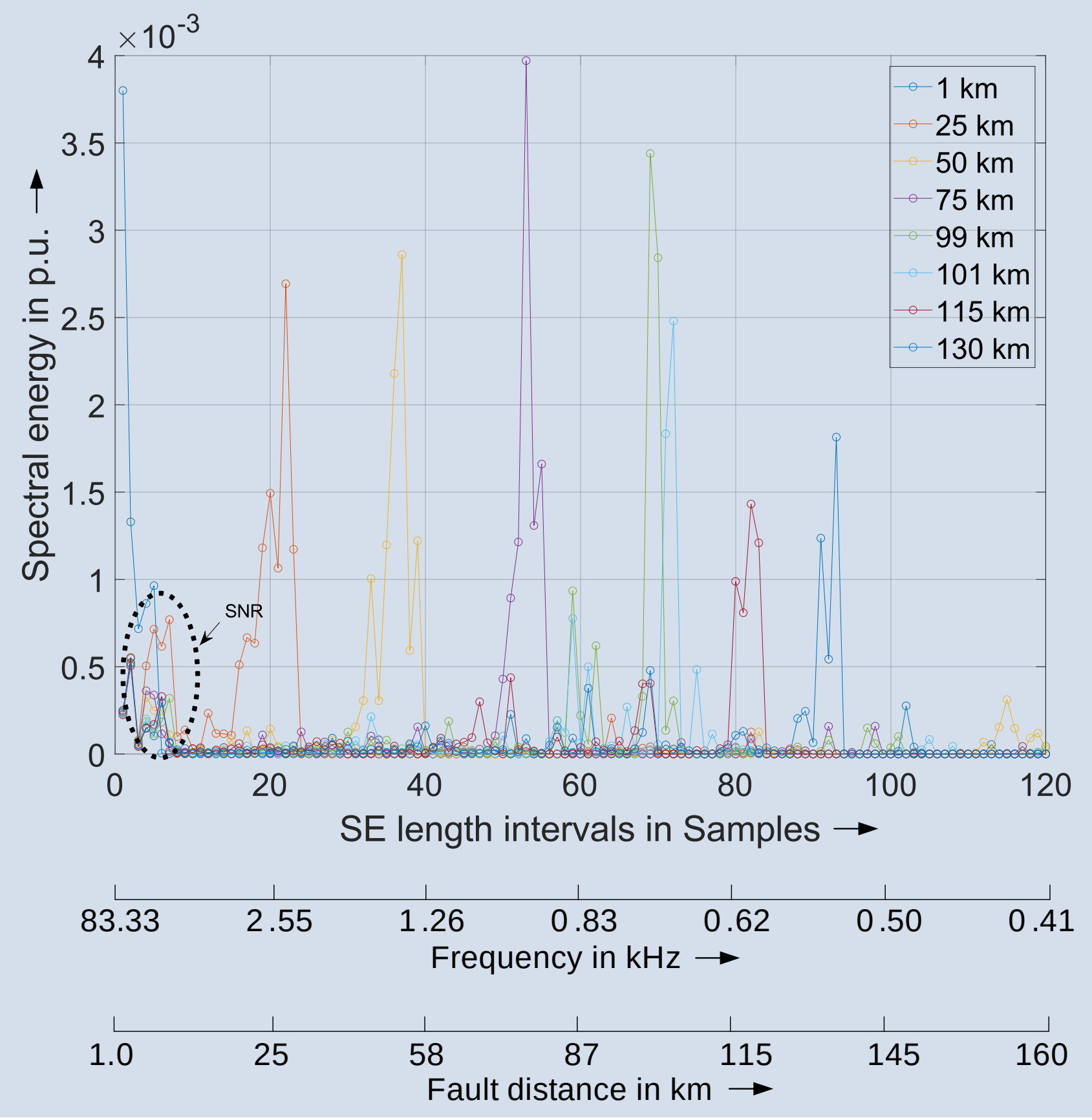
$H_n$: Multiresolution signal

### Multiresolution spectral energy for different fault location

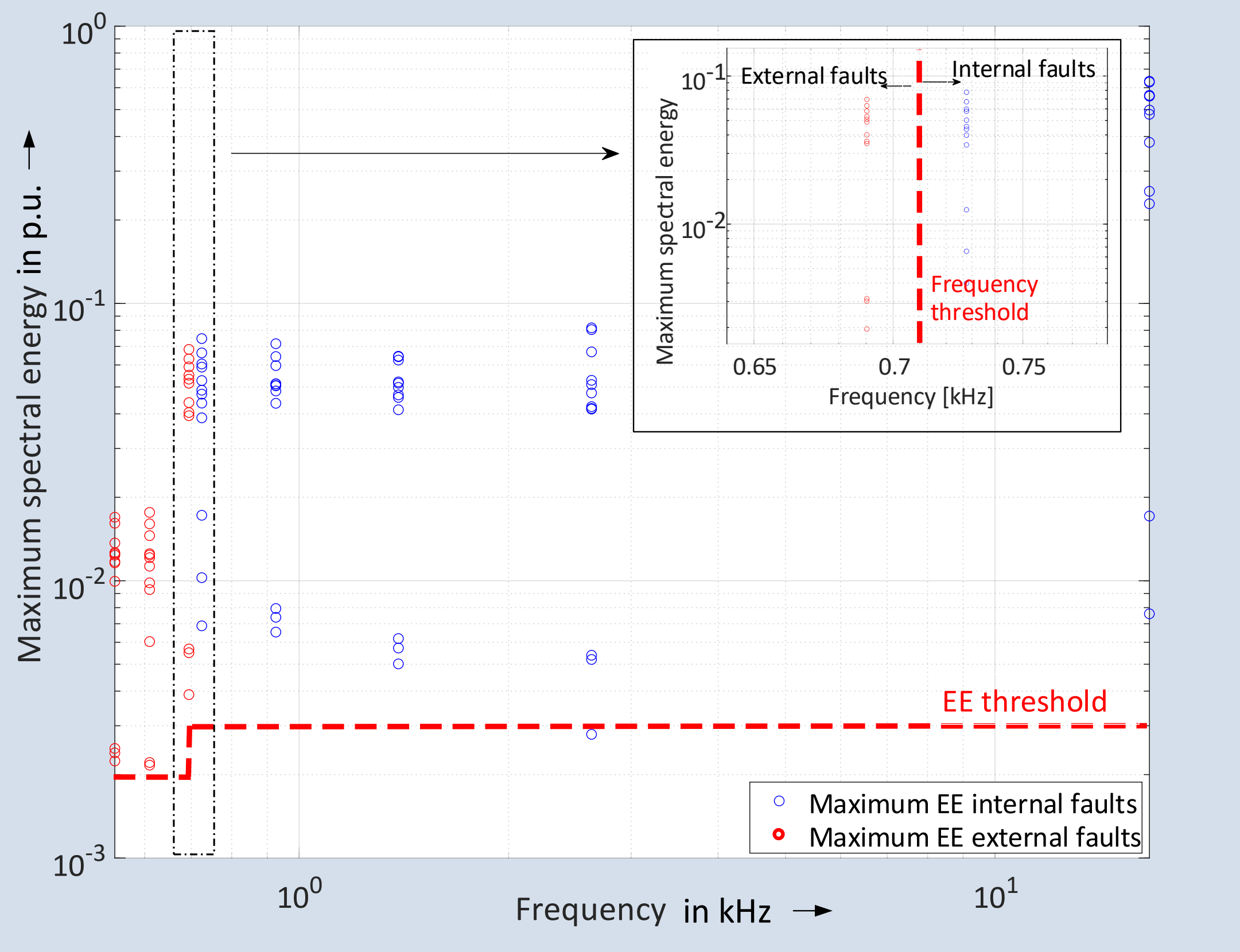


### Spectral energy for worst-case scenarios:

- Faults resistance R=[0-50] Ohm
- Insertion angle near zero crossing
- Gaussian noise with signal-to-noise ratio (SNR) of 30 and 40 dB with 10 kHz frequency.



### Definition of protection thresholds:



## Conclusion

This research proposes a novel distance protection criterion using fault-generated high-frequency transient signals extracted from a digital filter based on mathematical morphology theory. Then, this method can identify internal and external faults of transmission lines.

- Utilize a quarter-cycle time window achieving high-speed, improving system stability and avoiding the effect of inverter's power control system behavior.
- Performs the modal transformation, therefore, it does not need negative-sequence quantities.
- Robust against noise of very-high frequencies (in order of the converter switching frequency) because this method clearly differentiates the noise.
- This method verifies all the factors that influence the fault behavior, such as resistance, insertion angle and location.

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