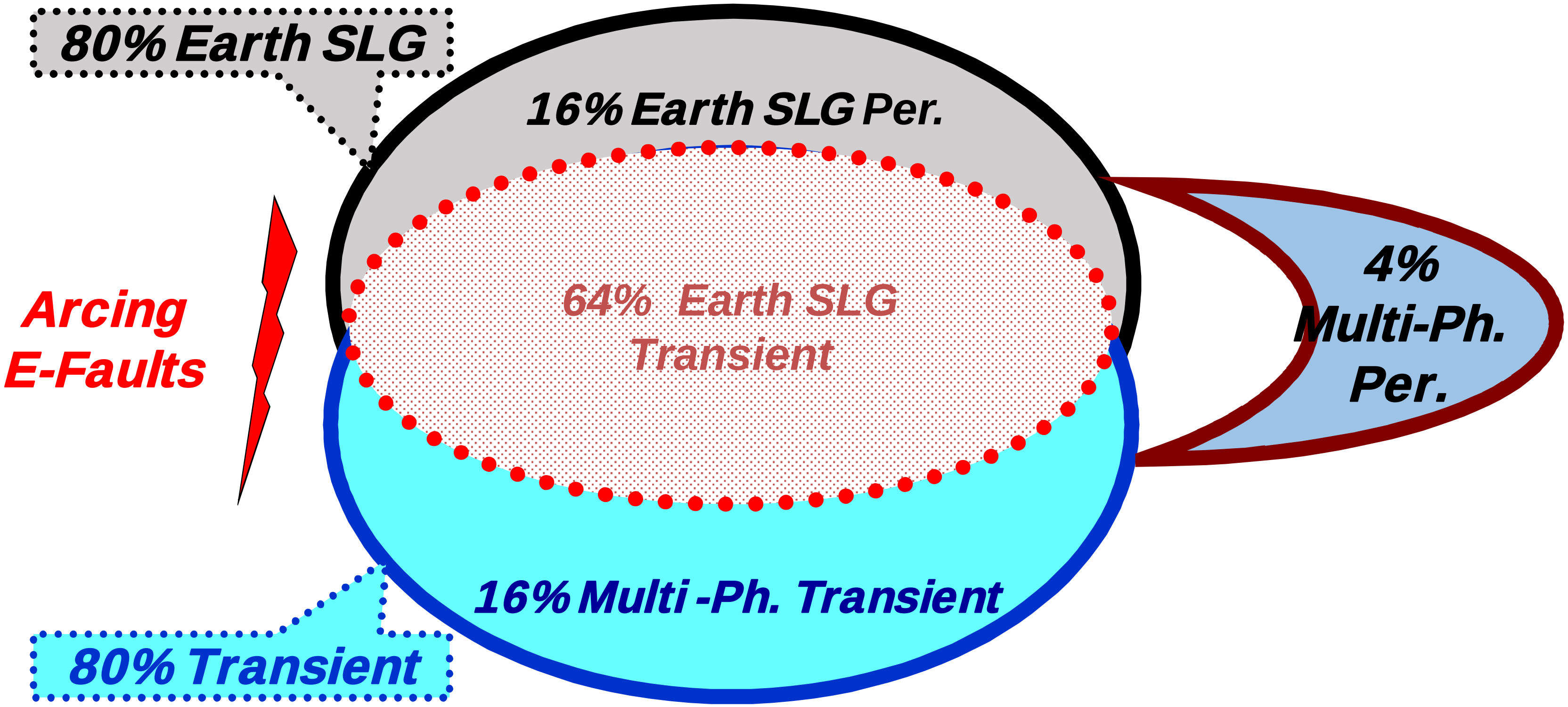
Nordic Workshop in Relay Protection and Control
NTNU, Trondheim, Norway May 25, 2016

Transient-Based Protection for Distribution Networks

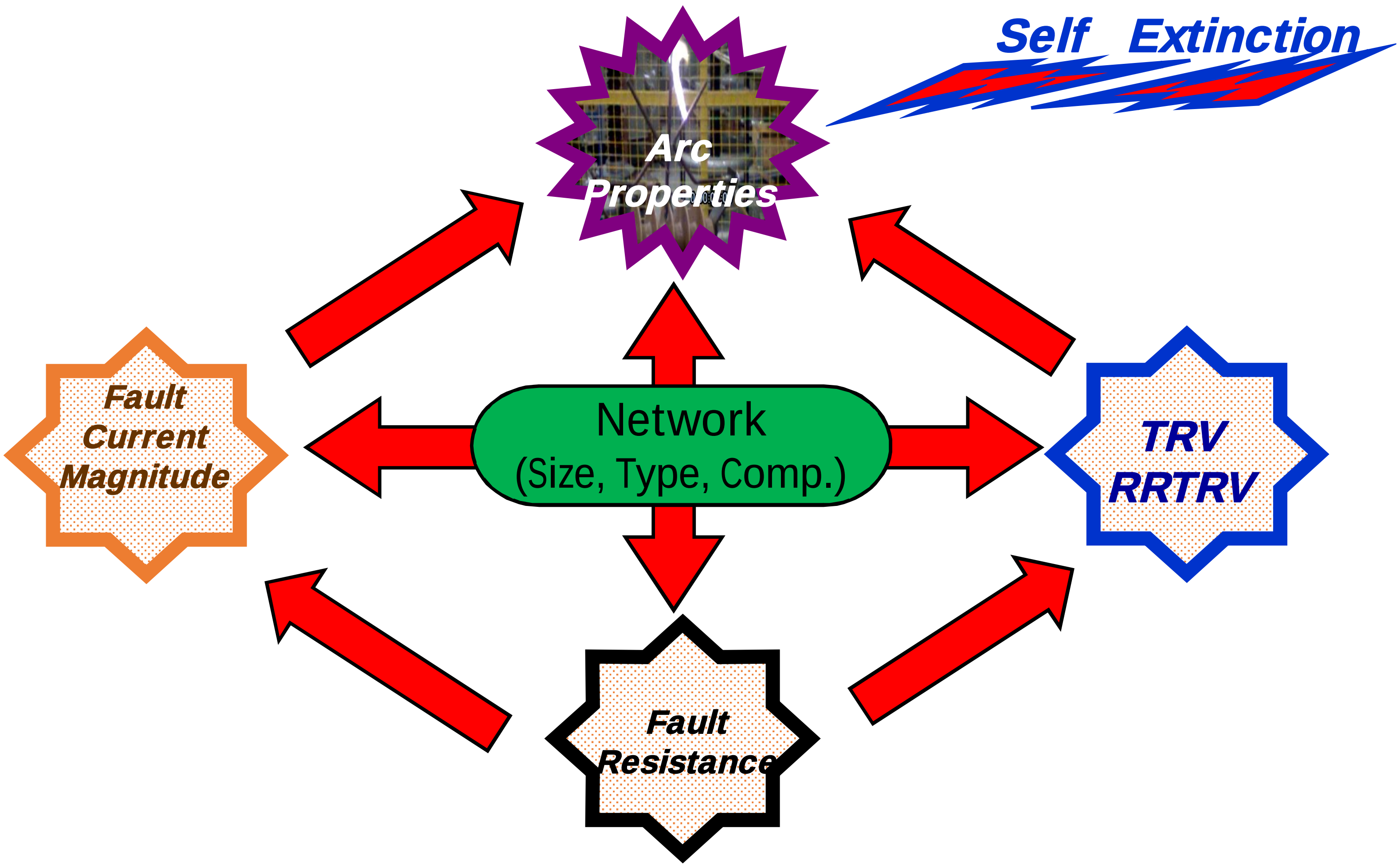
Mohamed Abdel-Fattah
Ass. Professor, Electrical Power Engineering

School of Science and Engineering
Reykjavik University
ICELAND

Earth Faults (%) in Distribution Networks



Earth Faults in Distribution Networks



Protection Philosophy for Active Networks

- A series of efficient sensors and intelligent switches with two-way wireless communication capability.

  ➔ IEDs/smart-meters!

- **Efficient/Fast protection systems** for the detection, diagnoses and location of any fault/interruption within the network.

  ➔ Early (pre-fault) detection possibility!

- Taking appropriate automatic/control actions to isolate the fault as quick as possible.

  ➔ Few seconds!

Protection Philosophy for Active Networks

- Restores power to the greatest number of customers.

  ➔ Self-healing reconfiguration!

- Notifying repair crews of the type and geographic location of the fault/interruption.

  ➔ Minimimizing repair time!

- Minimum number of Interruptions with/or minimum duration/time for minimum number of customers.

  ➔ High reliability!

Protection Philosophy for Active Networks

Possibility of the "sustained-operation" of the network under earth-fault condition ➔ Reliability!

- Limitation of the earth fault currents levels.
- Mitigation of the generated over-voltage, during fault conditions.

➔ Network compensation of the unearthed-neutral network, by compensation (Peterson) coils

➔ Replacing the overhead lines by underground cables (going underground).

Transient-Based Protection

Smart-Grids GENERATE more Transients

- Interactive Dynamic Network (more state-changes)
- Intermittent DG/Electric Vehicles/Energy Storages
- Renewables Integration & Controllable Loads
- Fast Autonomous Corrective Actions:
  - Quick Recovery Time; few millisecond, High Reliability
  - Fast Diagnoses of Interruptions (=> *Transients-Based*)
  - More Switching Operations

Transient-Based Protection

- Utilize the **transient component** in the fault signals.
- Detect the faults **very quickly**
- **Less** dependent on:

    Network configuration

    Power frequency

    Fault levels/parameters (fault resistance)

Advantages

- Efficient for transient/temporary faults

  ➔ very short duration; usually less than one cycle

  Conventional algorithms usually require about two steady-state cycles, which require transient filtering, for phasor analysis at power frequency.

- Supervising any abnormal short duration activities;

  ➔ for early prediction of faut development possibility,

  ➔ e.g. by utilizing partial discharge (PD) activities

Transient-Based Protection

Advantages

- Efficient for low-current faults detection, that present a challenge to conventional protection systems

➔ High-Resistance Faults

(low fault current and random behavior)

➔ Earth-Faults in Compensated-Neutral Networks

(very low fault currents)

➔ Self-Clearing Faults:

Developing Faults =>Long period PD =>Transient Faults

Self-Extinguishing Arcing Faults (Self-extinction)

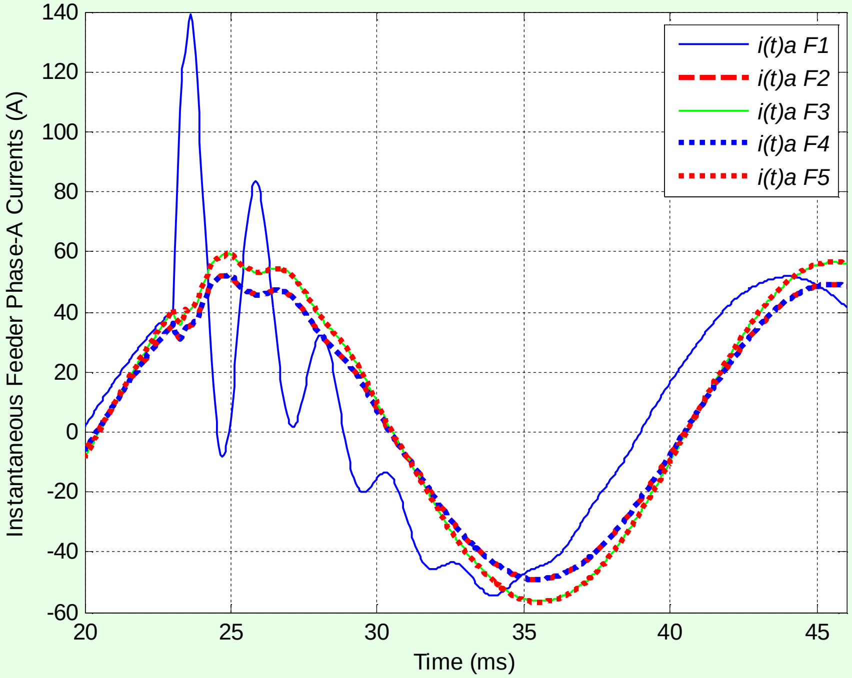
Transient Superimposed Components

- Superimposed currents/voltages are the fault generated currents/voltages changes due to fault incidence.
- They are of zero values in any steady state; including the pre-fault and post-fault steady states
- They can be determined by storing the pre-fault values, for one power frequency period, and subtracting it from the current values during the fault
- They are very sensitive for fault incidence and less dependent on network parameters

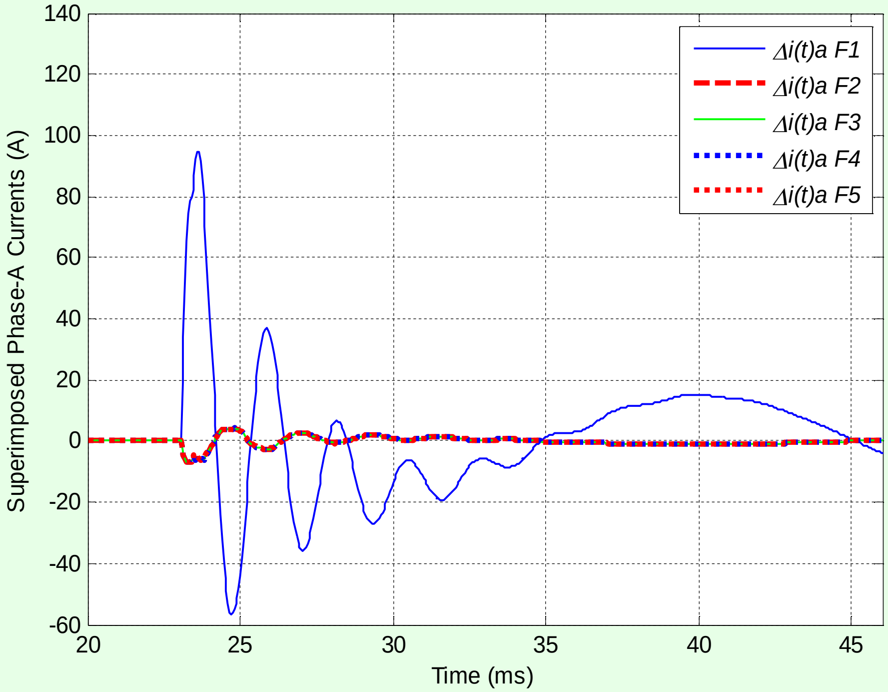
➔ **Recommended for transient-based fault detection.**

Superimposed Components

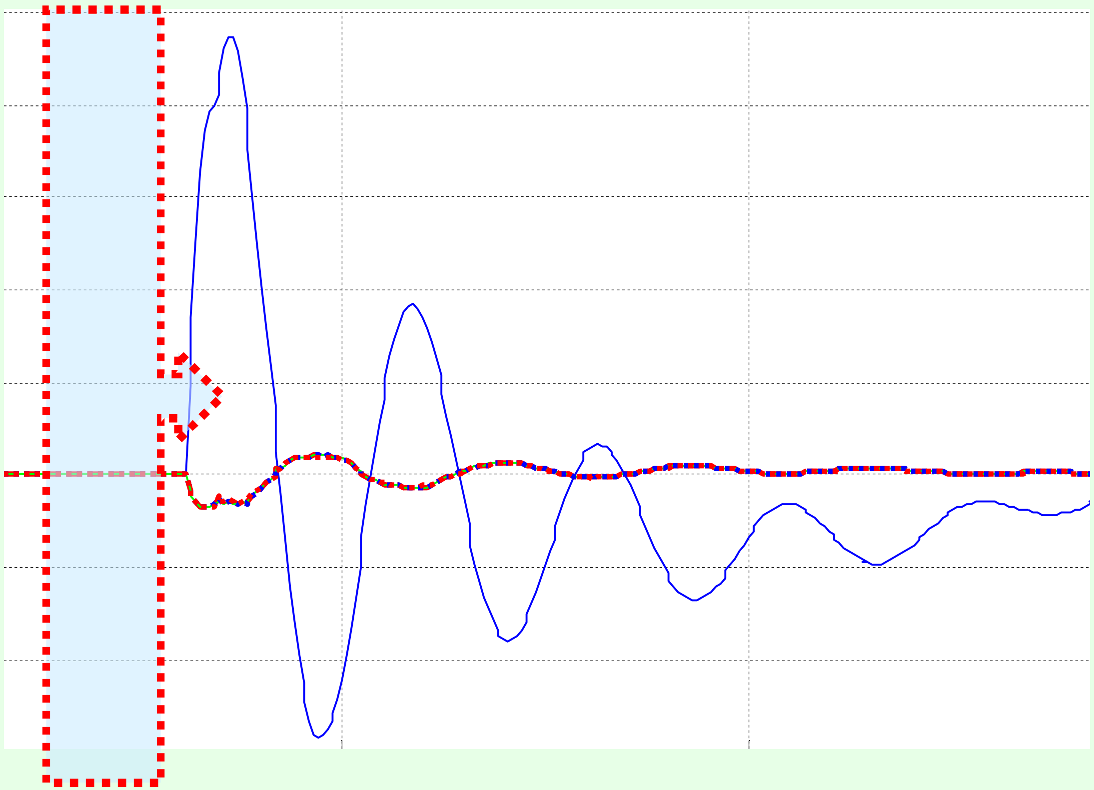
$$i_a(t)$$



$$\Delta i_a(t) = i_a(t) - i_a(t-T)$$



Sub-Cycle Moving Window (2-3 ms)

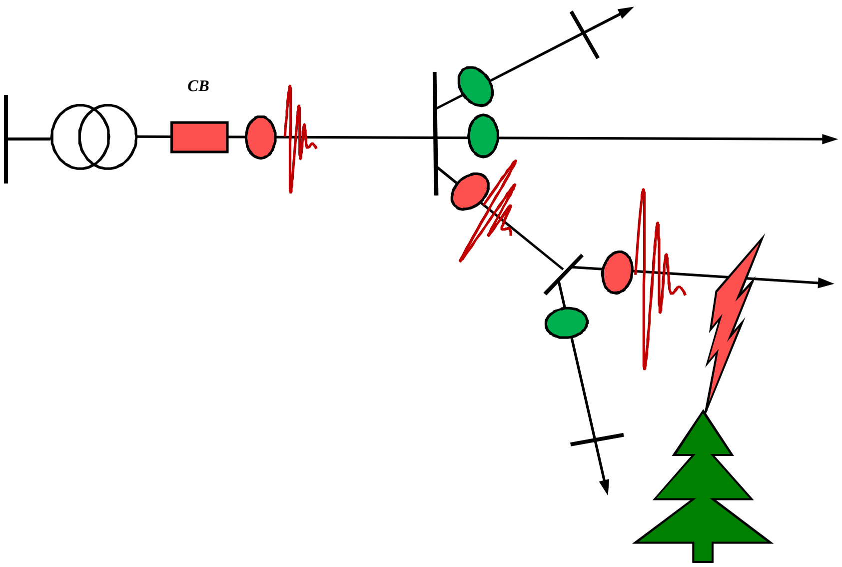


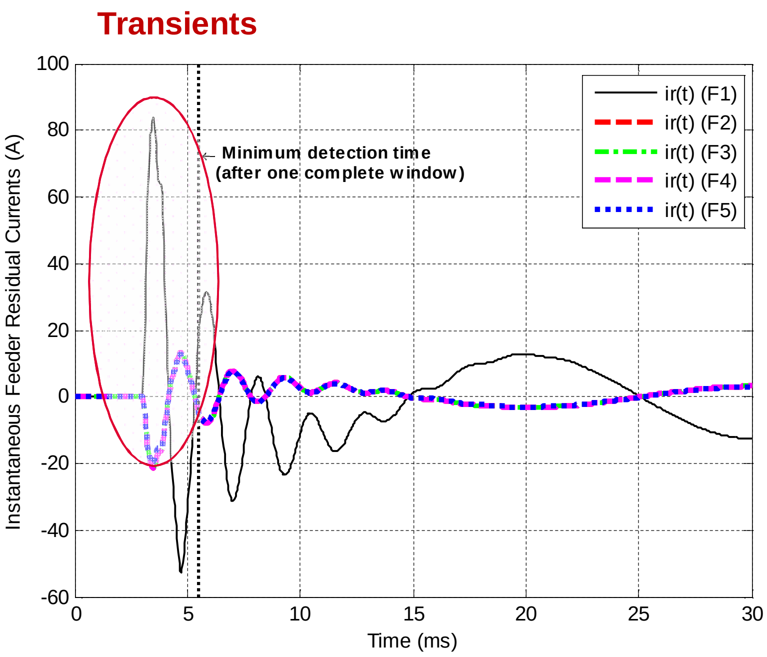
Transient-Based Techniques

Transient Components

Using generated transient components during fault condition.

Transient ➔ Fast Transients ➔ Travelling Waves



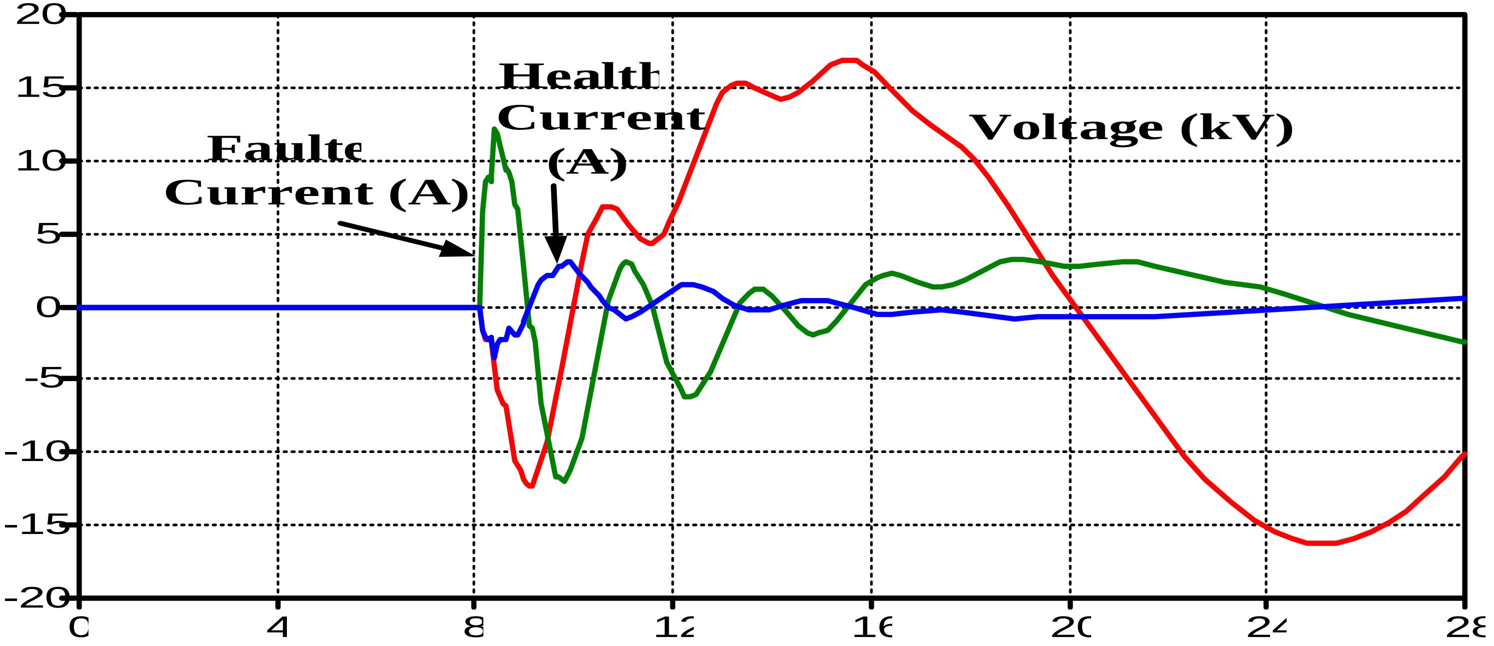


Transient-Based Techniques

- **Transient Components**

  Using generated transient components during fault condition.

Polarity Comparison

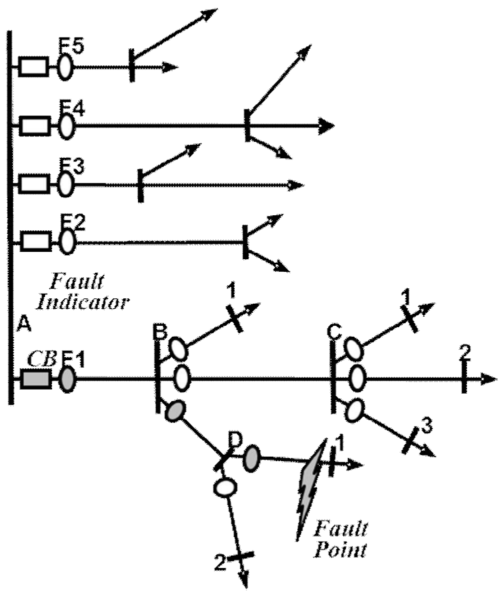


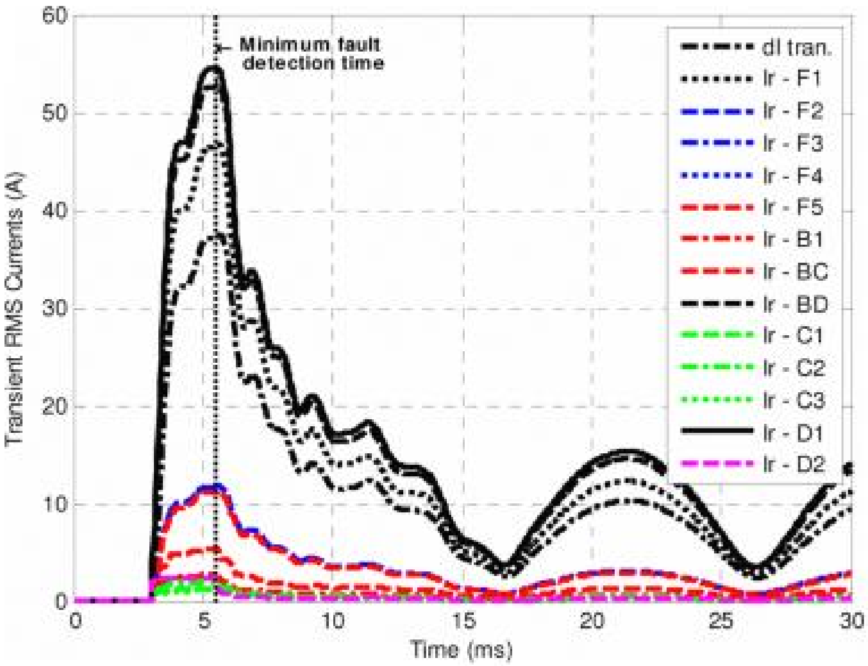
Transient-Based Techniques

➢ Transient Components

Using generated transient components during fault condition.

Transient RMS $$I_r = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(i_{r,k})^2}$$



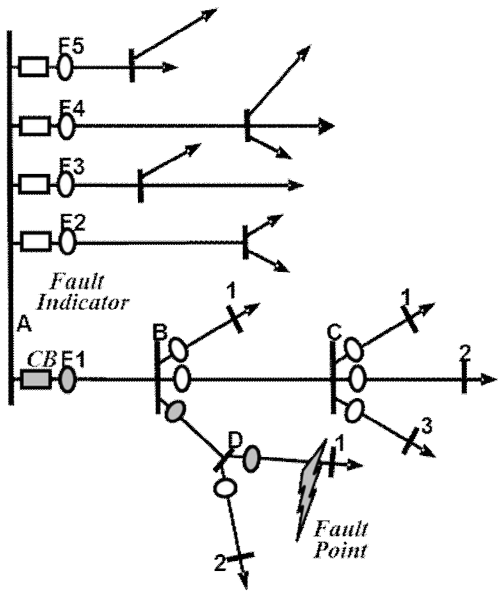


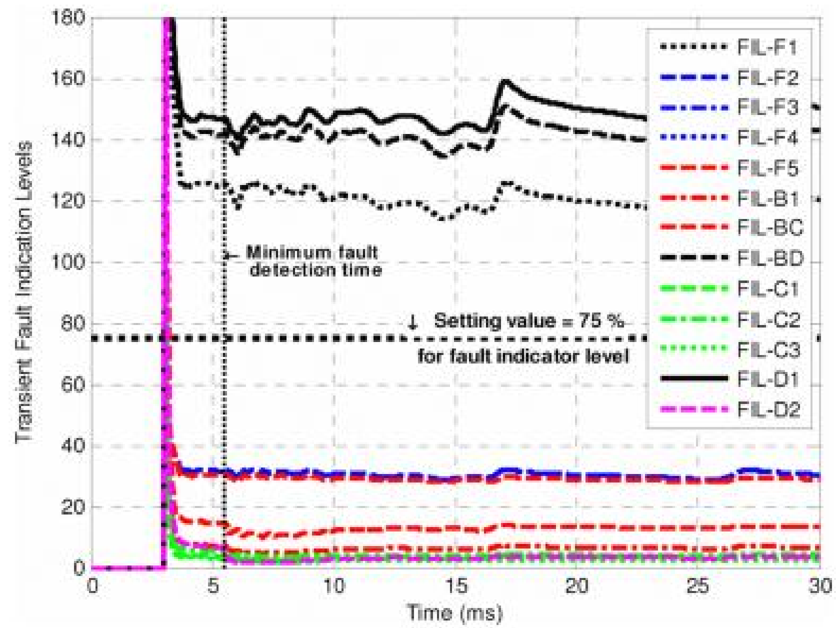
Transient-Based Techniques

➢ **Transient Components**

Using generated transient components during fault condition.

Transient RMS $$I_r = \sqrt{\frac{1}{N}\sum_{k=1}^{N}(i_{r,k})^2}$$



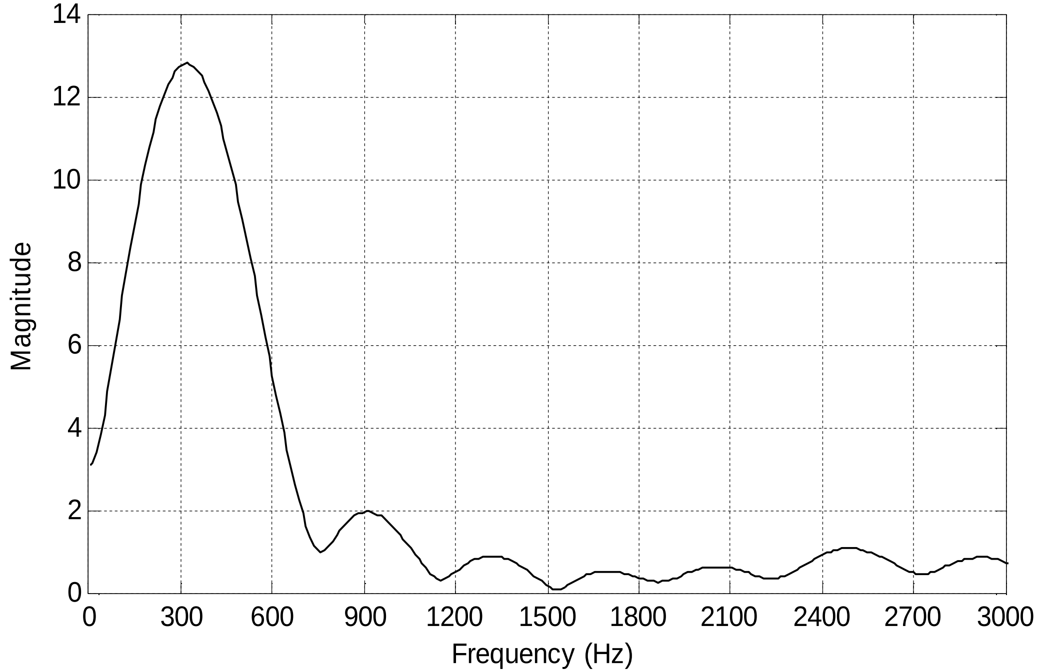


Transient-Based Techniques

➤ Transient Components

Using generated transient components during fault condition.

Dominant Transient Frequency



Transient-Based Techniques

➢ **Transient Components**

Using generated transient components during fault condition.

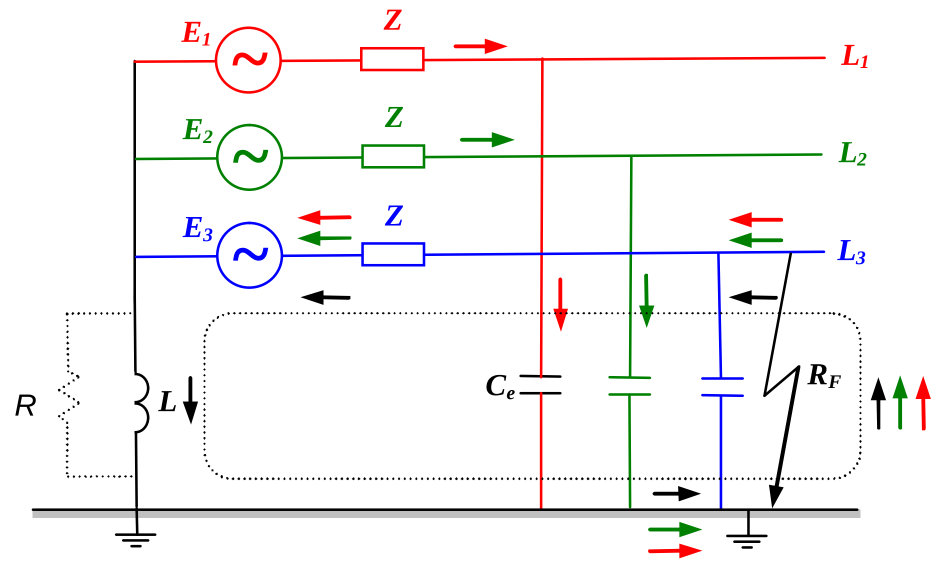
Dominant Transient Frequency

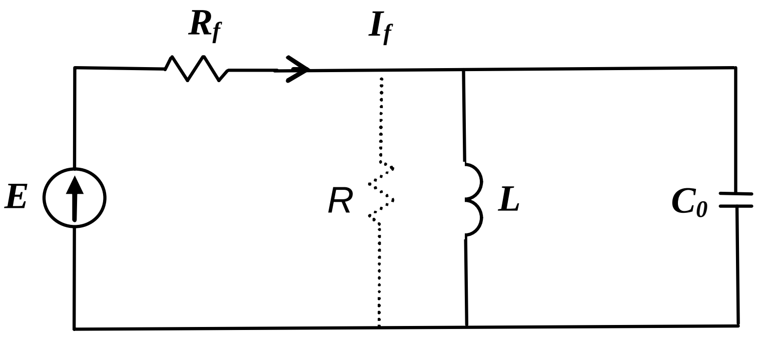
$$I_{Fualt} \propto C_{Back} \qquad C_e = \frac{1}{2\pi \; f_{tr} \; Z_0} \qquad K_c = \frac{C_{e,\,Calculated}}{C_{e,\,Total}}$$

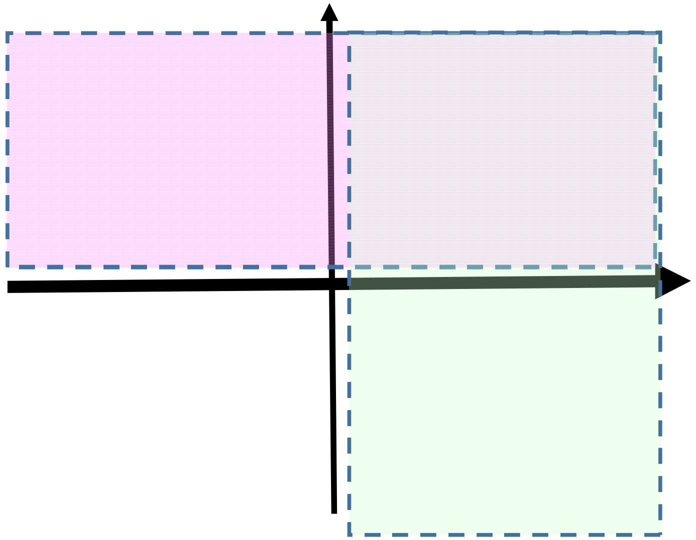
- Transient Impedance: from residual voltage and currents (earth modes) samples, in the window.
- Dominant Transient Frequency: from DFT (Discrete Fourier Transform)
- Earth capacitance ➔ Indicates the faulted feeder
- Earth fault indication:

➔ e.g. 5-feeders: Faulty – 80%, Heathy +20%

Neutral Treatment Effect





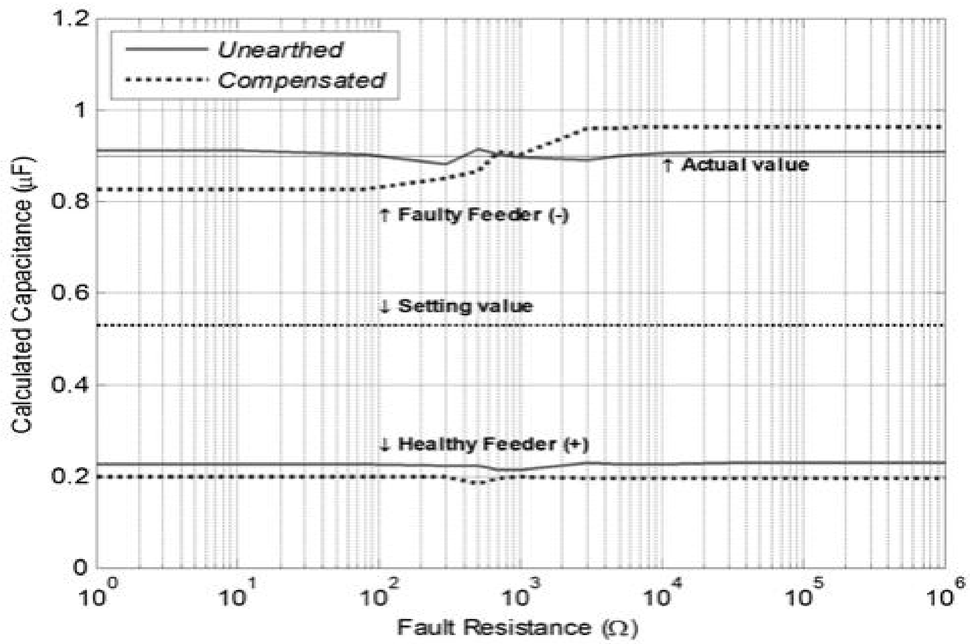


➢ Transient Components

Using generated transient components during fault condition.

Transient-Based Earth Capacitance Estimation [*]

$$C_{0B} = \frac{T_s \sum_{k=1}^{N} i_{0k}}{v_{0N} - v_{01}}$$



[*] M.F. Abdel-Fattah and M. Lehtonen, " Transient algorithm based on earth capacitance estimation for earth-fault detection in medium-voltage networks," IET Gener. Transm. Distrib., 2012, Vol. 6, Iss. 2, pp. 161–166.

Transient-Based Techniques

- **Other Methods**

  Based on:

  ☺ Active Energy
  ☺ Wavelet
  ☺ ANN
  ☺ Probabilistic Analysis
  ☺ Mathematical Morphology

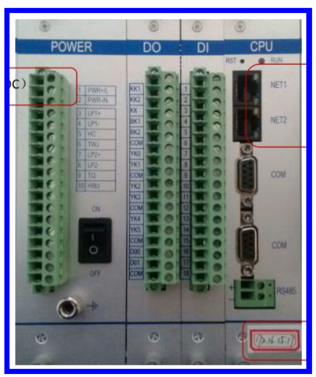
Transient-Based Techniques

➢ Transient Components

Using generated transient components during fault condition.

Correlation Analysis [*]

$$Cor(i1,i2)=\frac{\sum_{k=1}^{N}(i1_k-M_{i1})(i2_k-M_{i2})}{\sqrt{\sum_{k=1}^{N}(i1_k-M_{i1})^2\sum_{k=1}^{N}(i2_k-M_{i2})^2}}$$



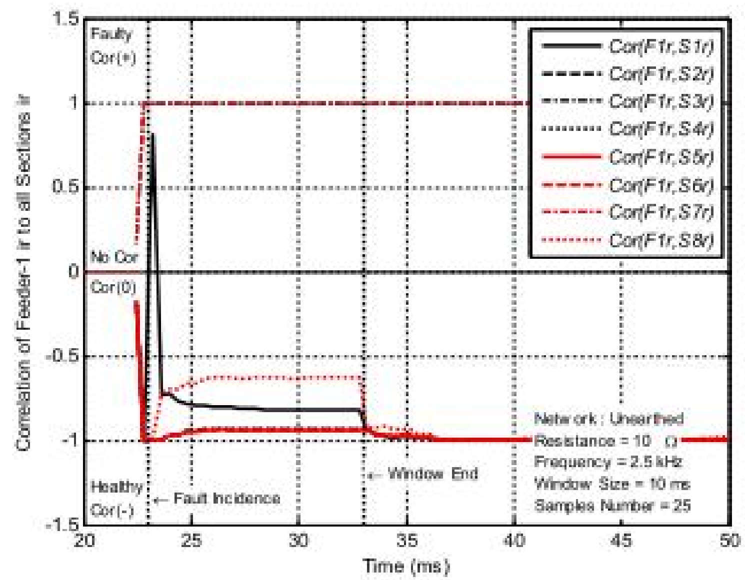


Fig. 5. Correlation of Feeder-1 i_r to all Sections i_r

[*] M. F. Abdel-Fattah, M. Lehtonen and X. Bingyin, "A New Correlation-Based Earth Fault Indication Algorithm Using Only Transient Current Measurements," International Review of Electrical Engineering (IREE) Journal, vol. 9, no. 3, pp. 111-121, May-June 2014.

Relay Functions for Transient Faults

➢ Transient Components

Using generated transient components during fault condition.

E.g. Siemens SIPROTEC 5
Incudes detection of transent ground faults
Frequency could reach 8 kHz with limitations!

Algorithm?

Thanks!

Mohamed Abdel-Fattah

Ass. Professor, Electrical Power Engineering

abdelfattah@ru.is

School of Science and Engineering
Reykjavik University
ICELAND