# Dynamic Testing of Distance Protection according to IEC 60255-121 Standard

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# Presentation Summary

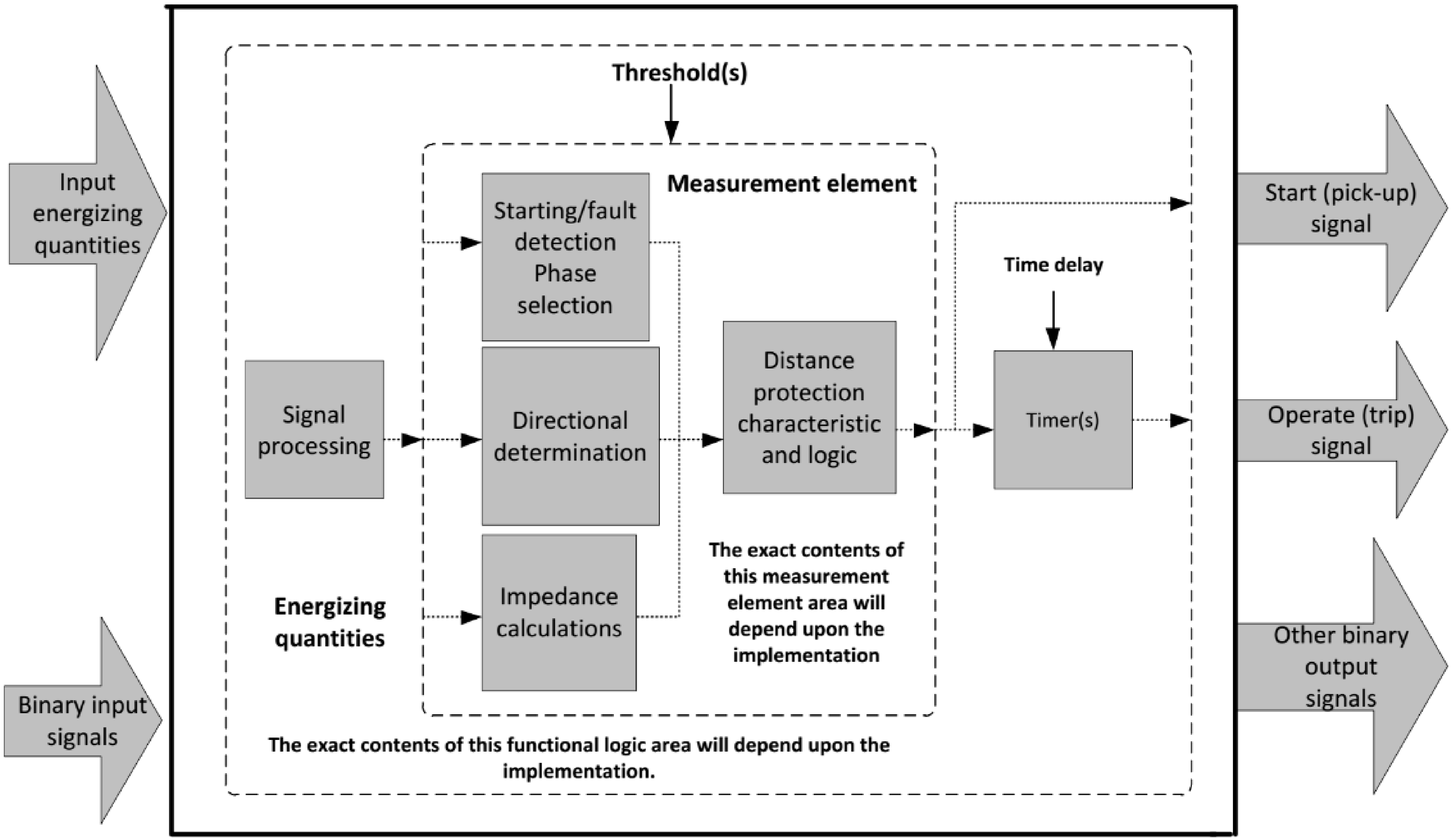
- Research Objectives
- Dynamic Performance of Distance Protection
- Test Methodology
- Results and Analysis
- Conclusions

# Research Objective

- To develop distance protection test modules according to IEC 60255-121:2014 using ATP/EMTP and OMICRON Control Center

- To analyze the distance protection relay performance against dynamic conditions

# Dynamic Performance of Distance Protection




Simplified distance protection function block
(IEC 60255-121)

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- The dynamic performance is the response of distance protection function to various power system conditions (such as faults)
- It provides a complete assessment of all distance relay functions:
  - Signal processing block
  - Starting/fault detection algorithm
  - Directional determination algorithm
  - Impedance calculation algorithm
  - Protection characteristic and logic
- Dynamic performance is defined in terms of **operating time** and **reach accuracy**
  - Operating time is the time interval between the instant when fault occurs and the instant when relay operates (trip)
  - Reach accuracy means no overreach or underreach operation under all dynamic condition

# Dynamic performance test according to IEC 60255-121:2014

- The standard includes methods to test and verify the **operating time** and **reach accuracy** of Zone-1 under dynamic conditions

- It requires proper transient simulation tools, and testing equipment in order to executed the test cases

- Dynamic conditions covered in this research:
  - + Effects of Capacitive Voltage Transformer (CVT) transient
  - + Performance with harmonics
  - + Performance with frequency deviation
  - + Performance under fault with resistance and pre-fault load
  - + Performance under dynamic fault (evolving faults and current reversal condition)

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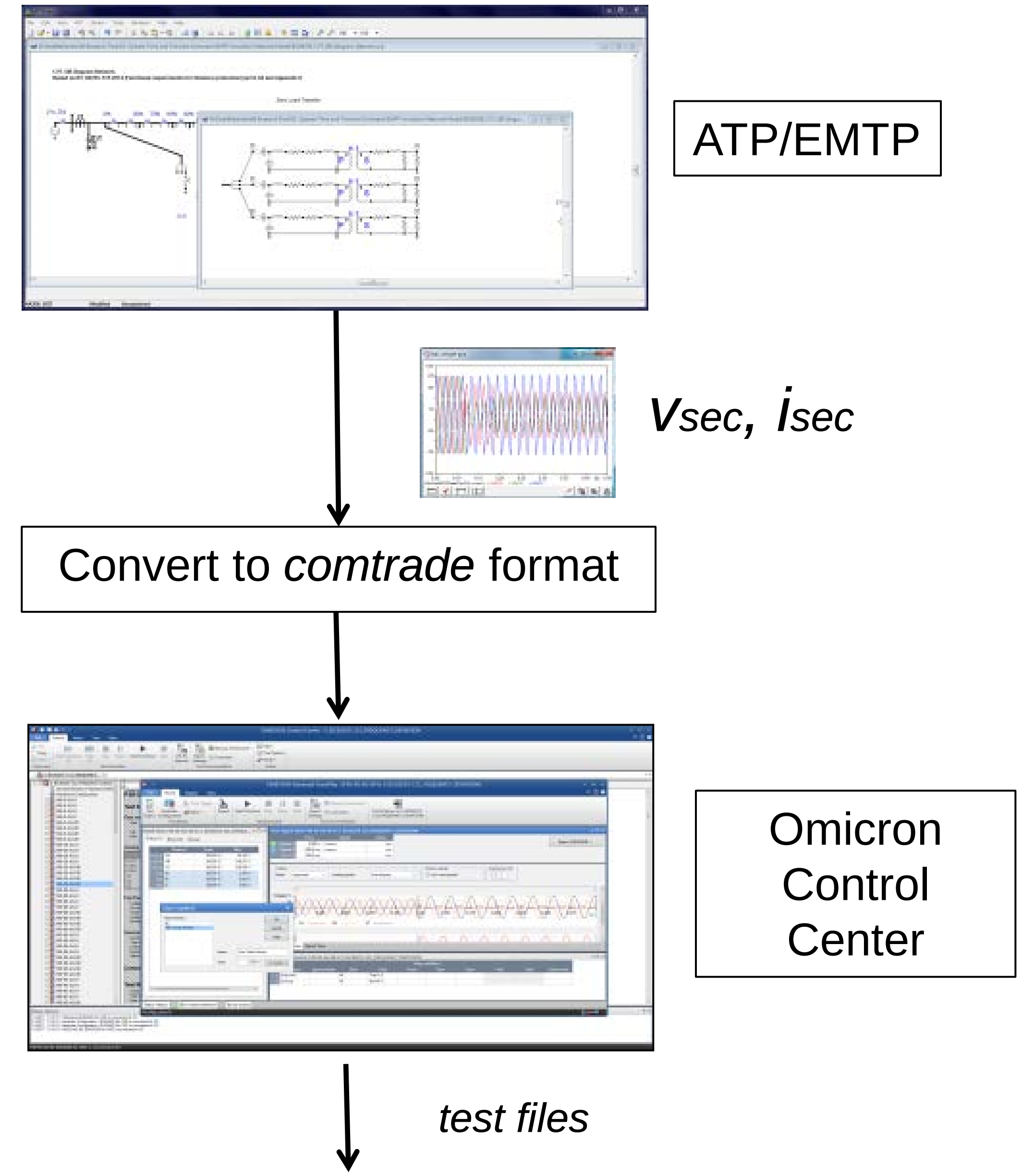
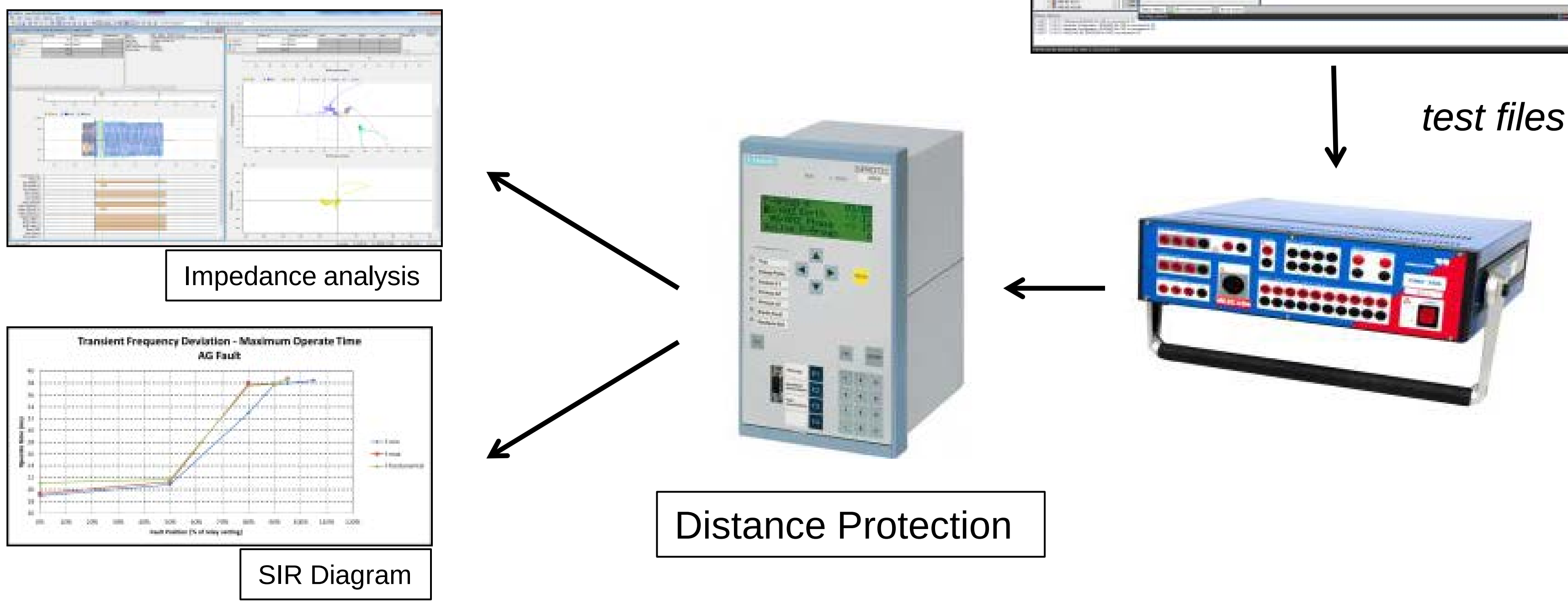
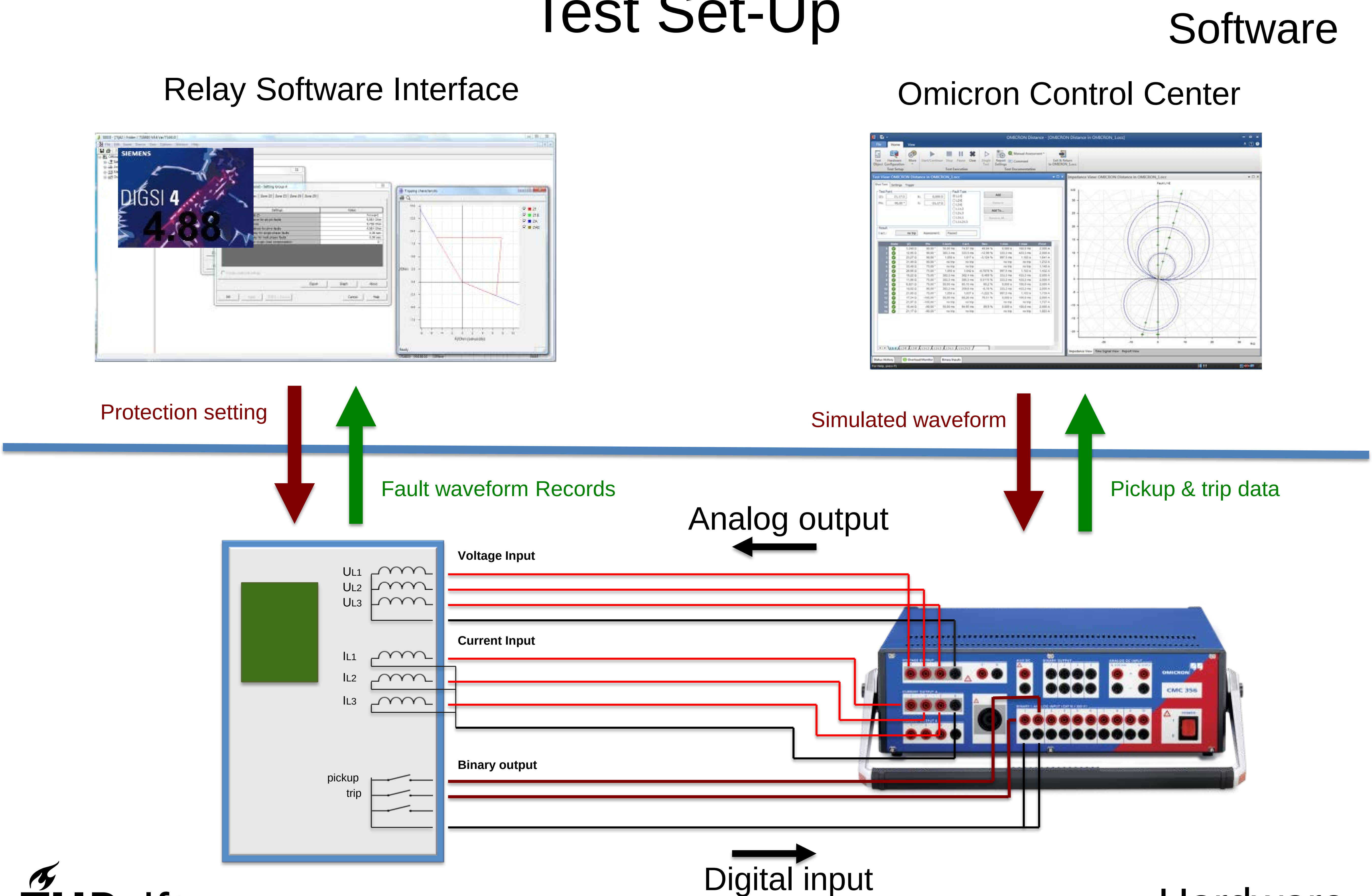
# Test Methodology

- Transient Simulation using ATP/EMTP
  + Network & Components Modelling
  + Fault Test Cases Simulation
  + Recording of Transient Waveform
- Test set-up
  + Omicron CMC 356
  + Numerical Distance Protection
    + Relay M
    + Relay N
- Result analysis



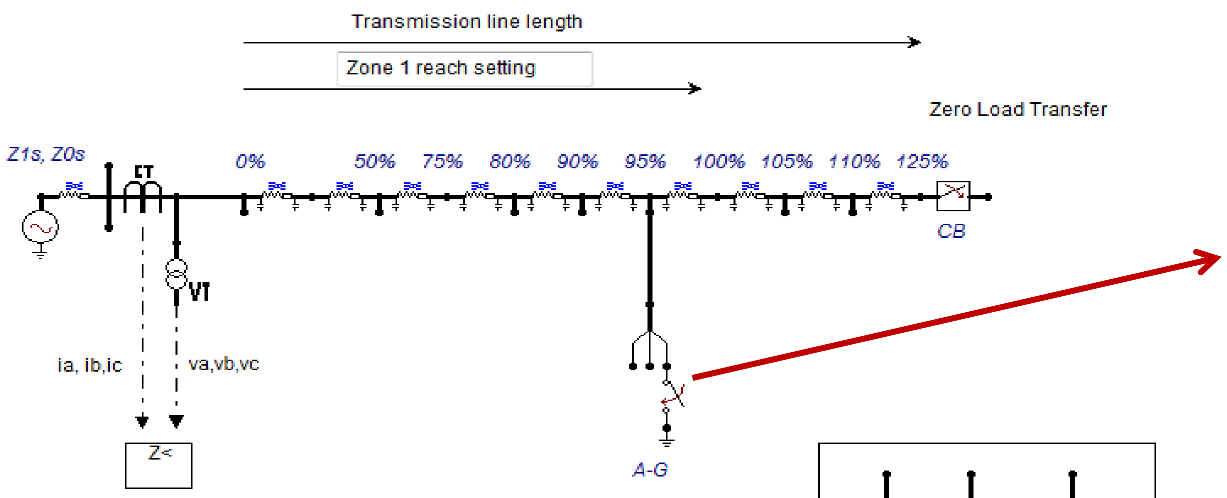



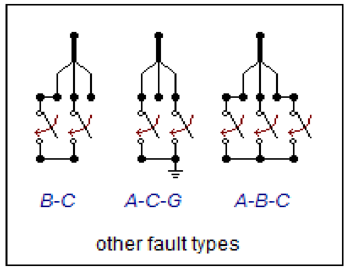
# Test Set-Up


Software
Relay Software Interface
SIEMENS
DIGSI 4
4.88
Omicron Control Center
Protection setting
Fault waveform Records
Simulated waveform
Pickup & trip data
Analog output
Voltage Input
UL1
UL2
UL3
Current Input
IL1
IL2
IL3
Binary output
pickup
trip
OMICRON
CMC 356
Digital input
Hardware

# Distance protection performance with different dc-offset, faulted phases, and source impedance ratio (SIR)

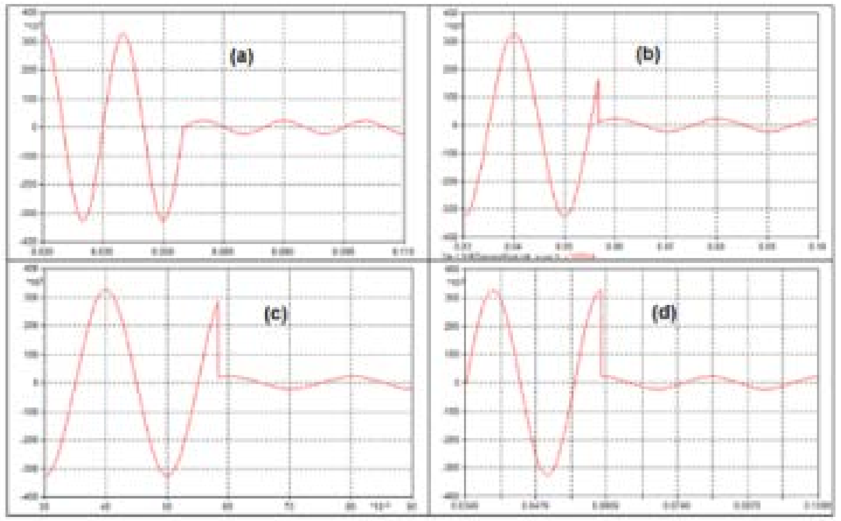
- Network model




System voltage: 400 kV
VT: 400kV/100V
CT: 1200/1 A
Zone 1 setting: 80% transmission length

Fault inception angle: the angle between the inception of the fault and the nearest preceding zero crossing of voltage signal with a positive derivative




Fault inception angle for L-N fault (a) 0°, (b) 30°, (c) 60°, and (d) 90°

- Test cases (total 448 test cases and 1792 test shots)

| Line model | Source impedance ratio (SIR) | Fault position (% of Zone 1 setting) | Fault type | Fault inception angle (°) |
|---|---|---|---|---|
| Short transmission line (20 km) | 5 and 50 | 0, 50, 80, 90, 95, 105, and 110 | A-G, B-C, B-C-G, and A-B-C | 0, 30, 60, 90 |
| Long transmission line (100 km) | 0.2 and 10 | 0, 50, 80, 90, 95, 105, and 110 | B-G, A-C, A-C-G, and A-B-C | 0, 30, 60, 90 |

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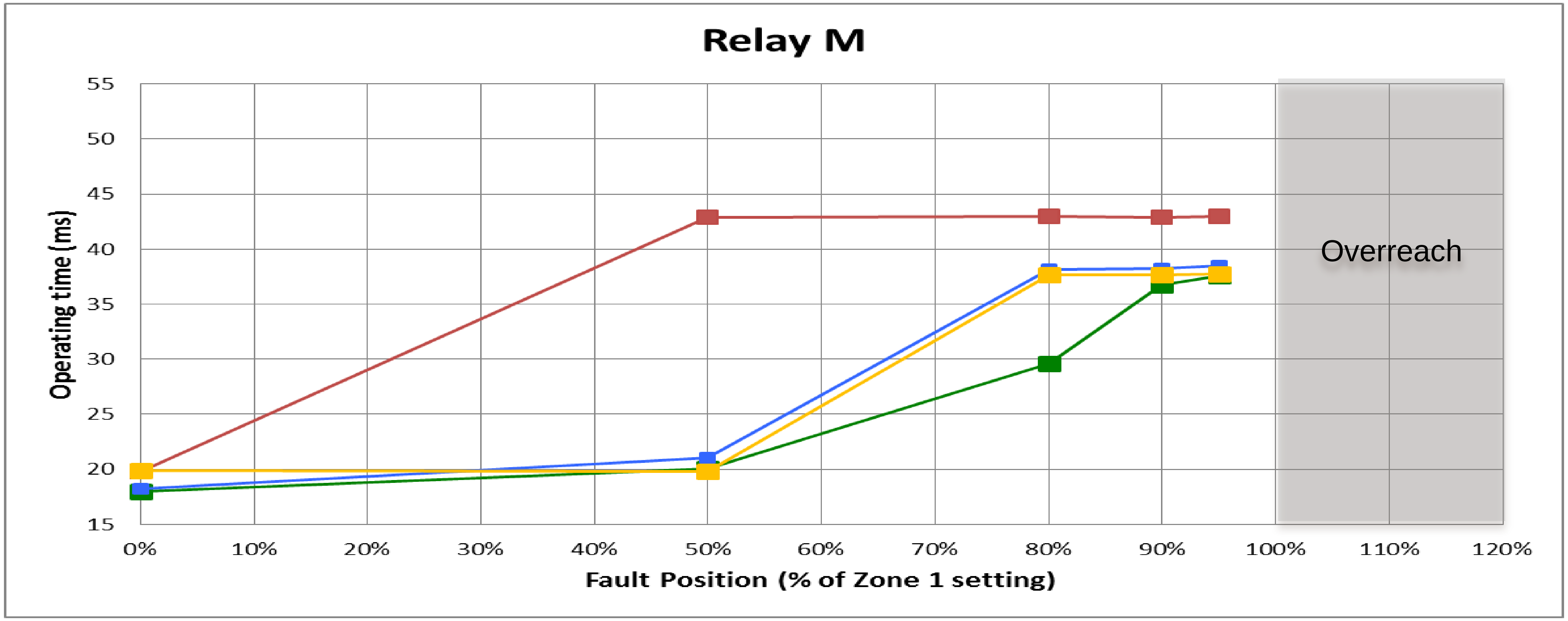
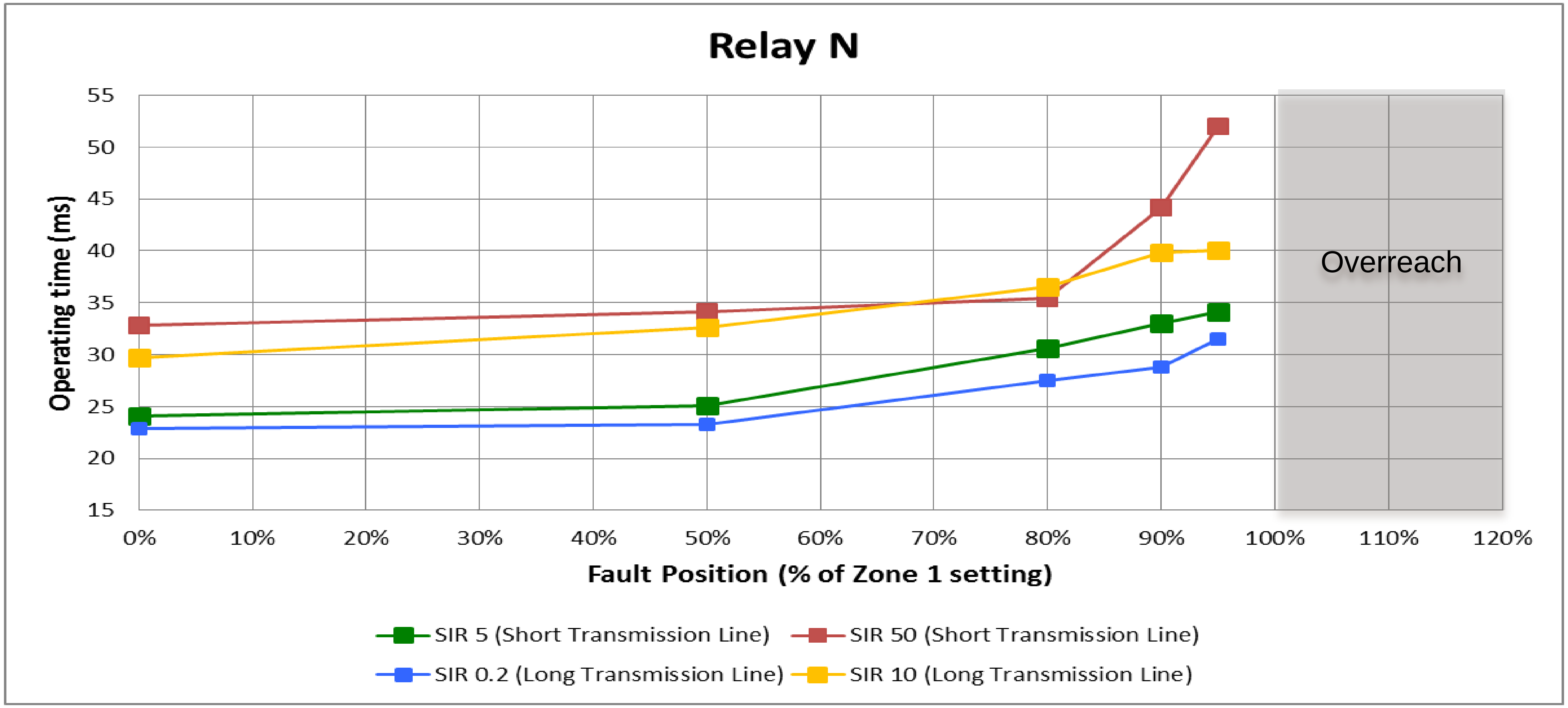
# Average operating time for L-N fault

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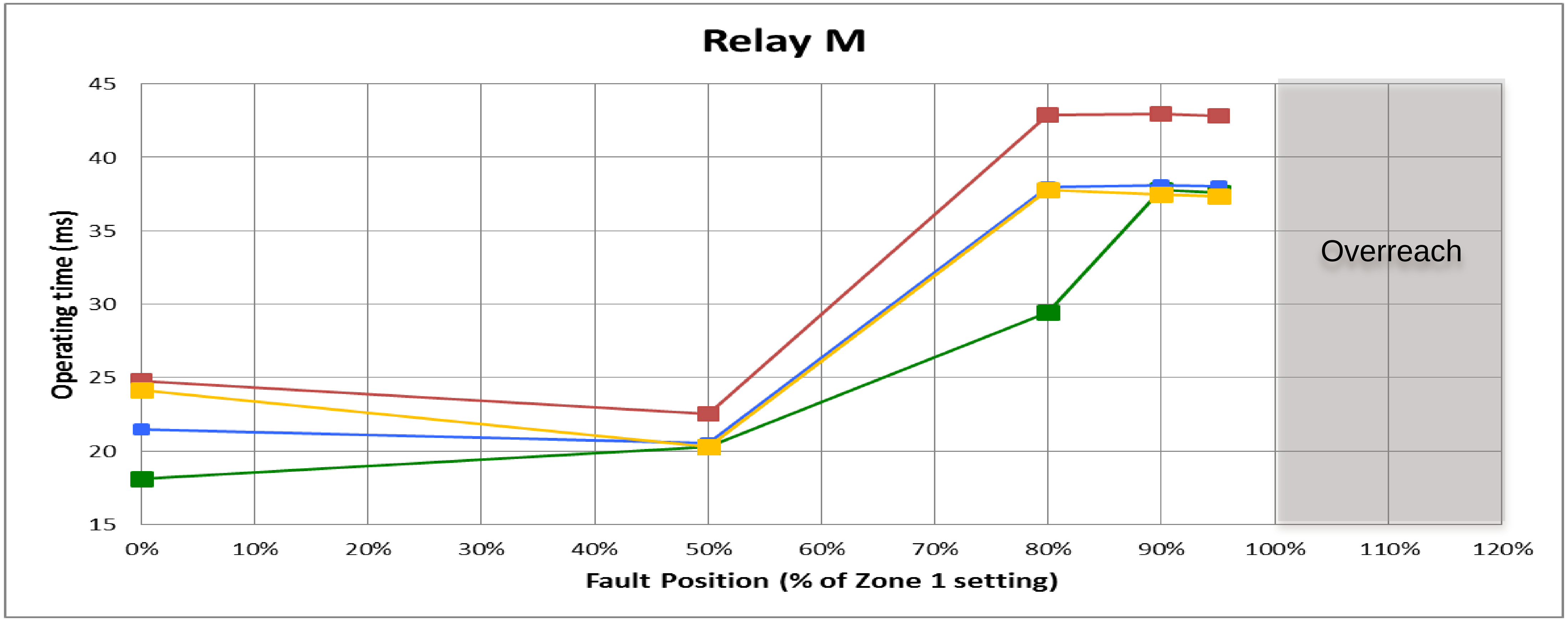
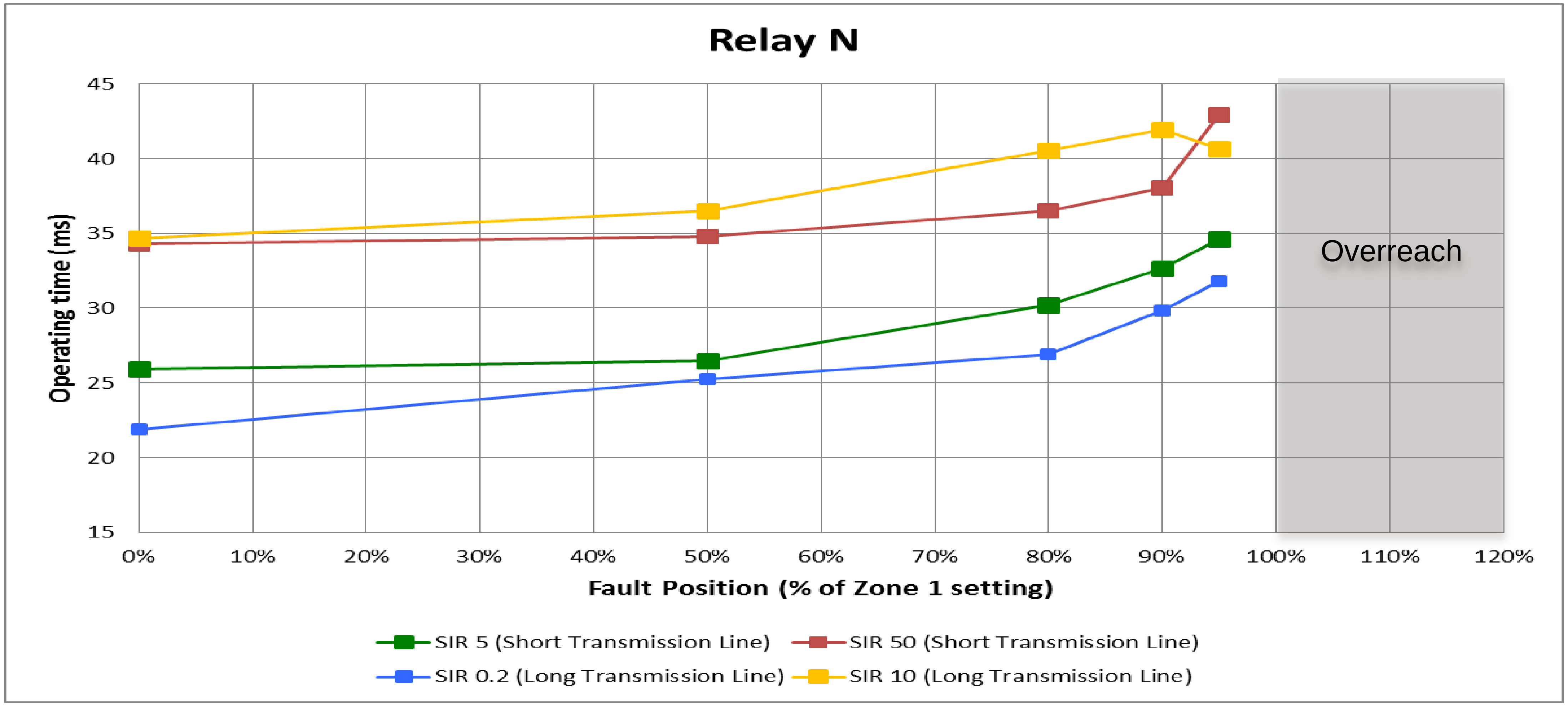
# Average operating time for L-L fault

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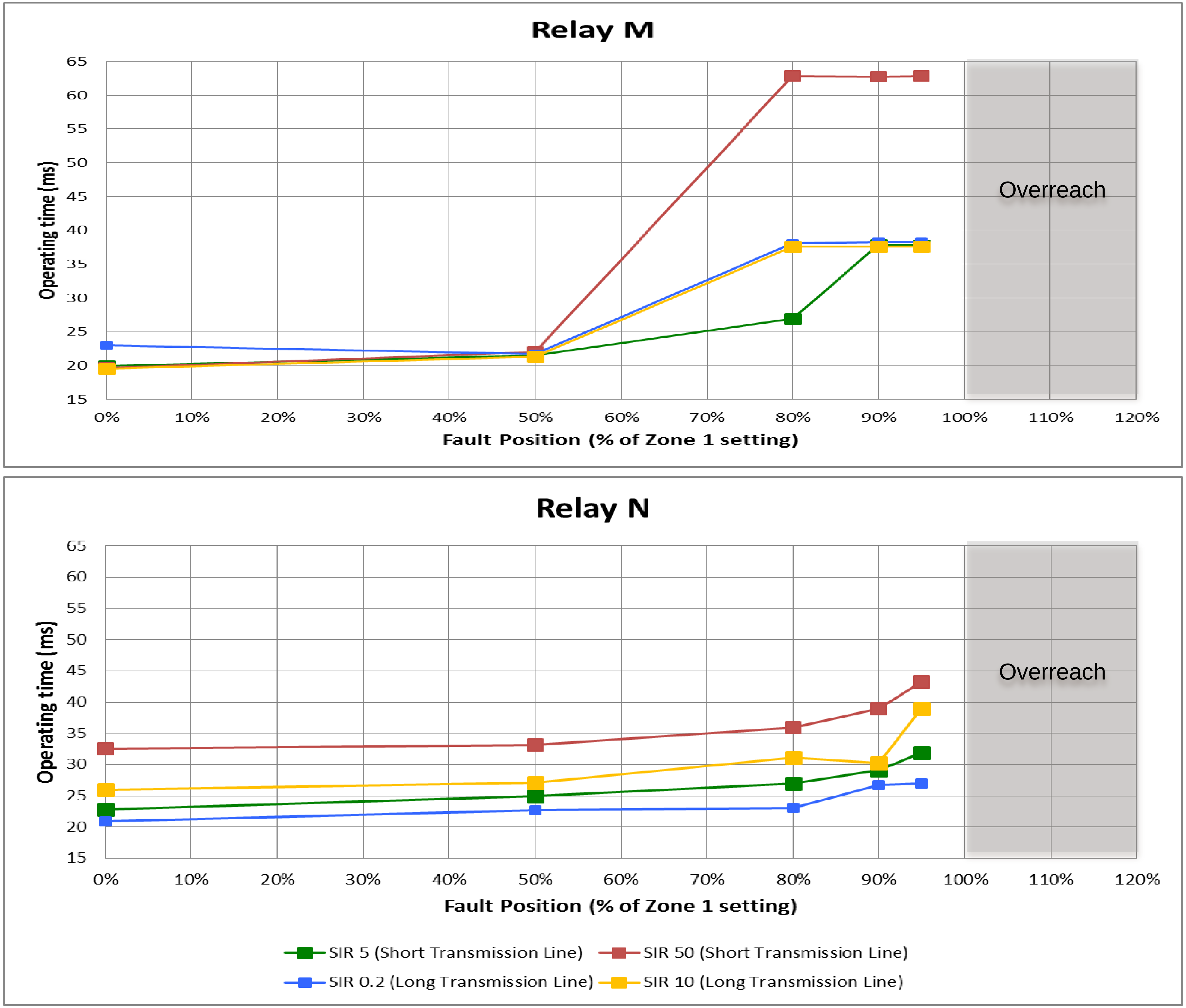
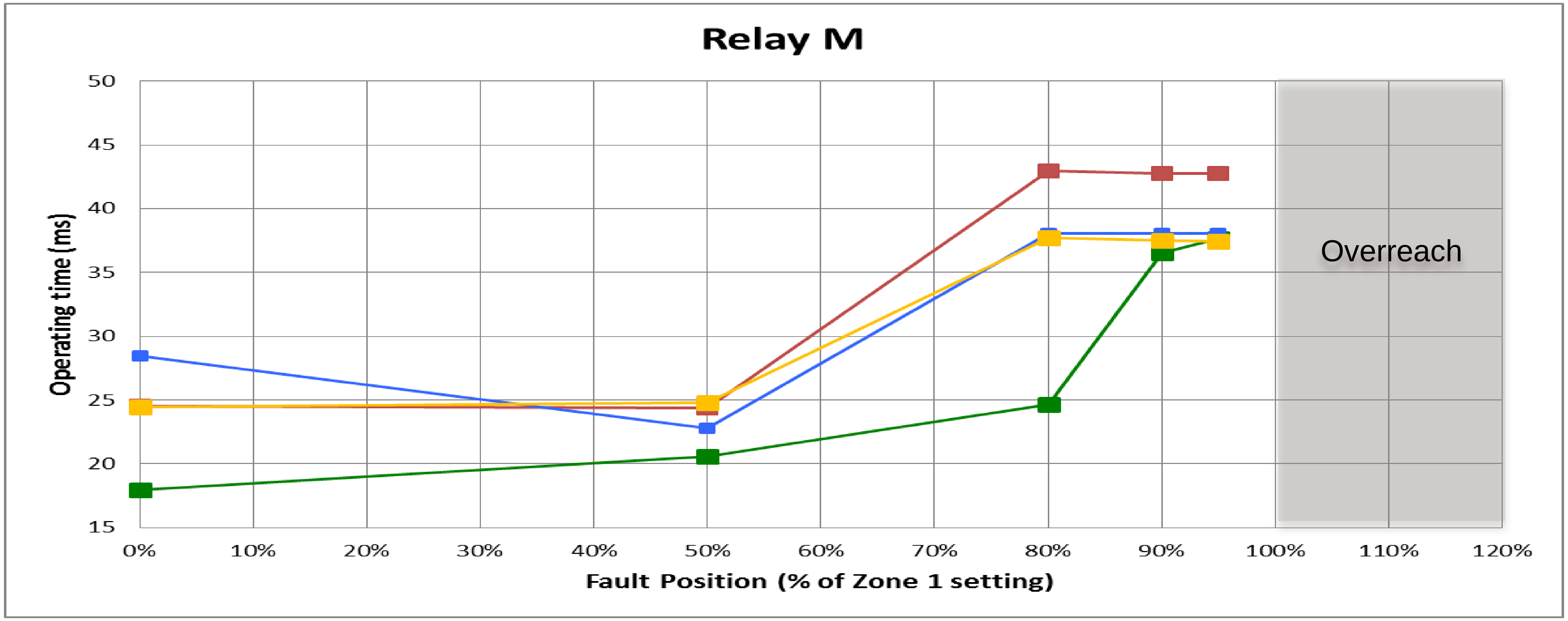
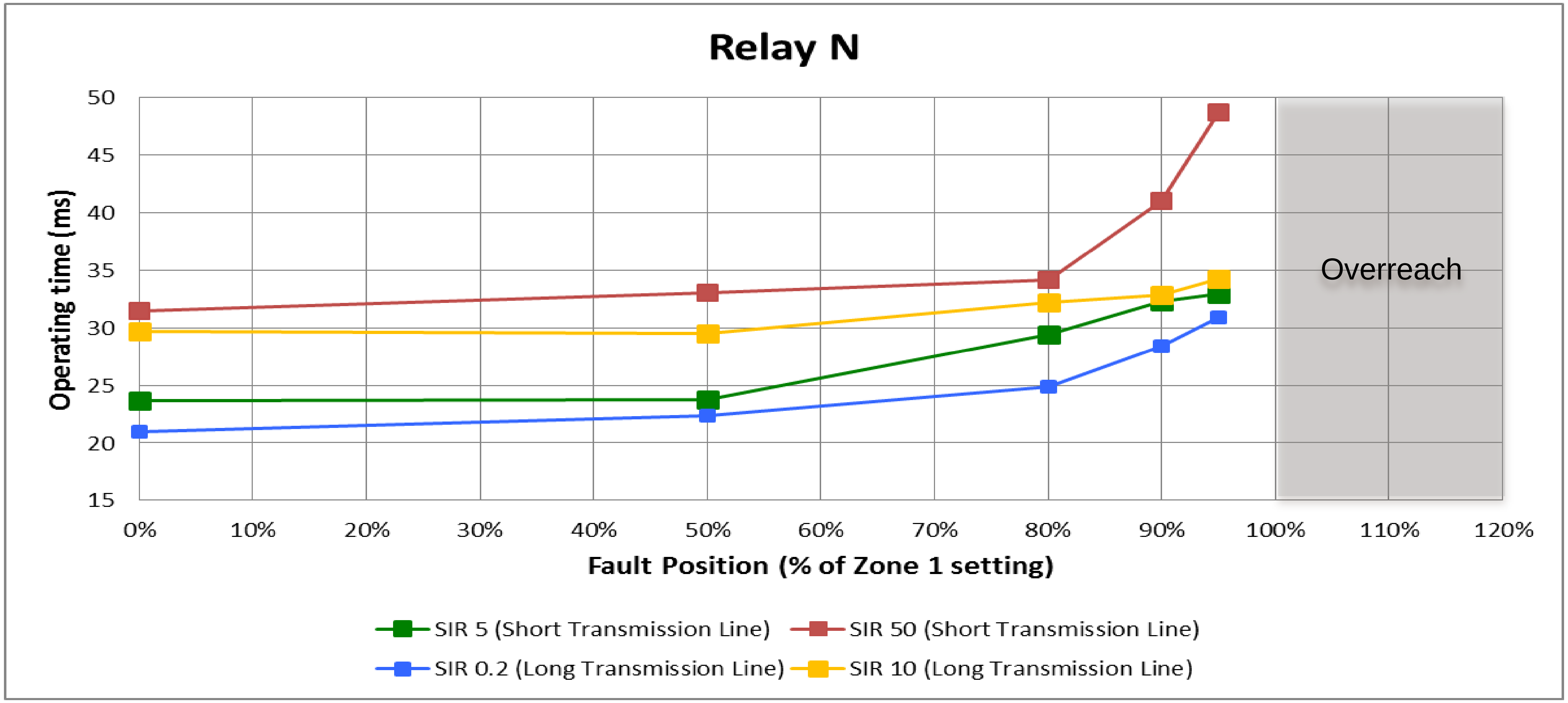
# Average operating time for L-L-N fault



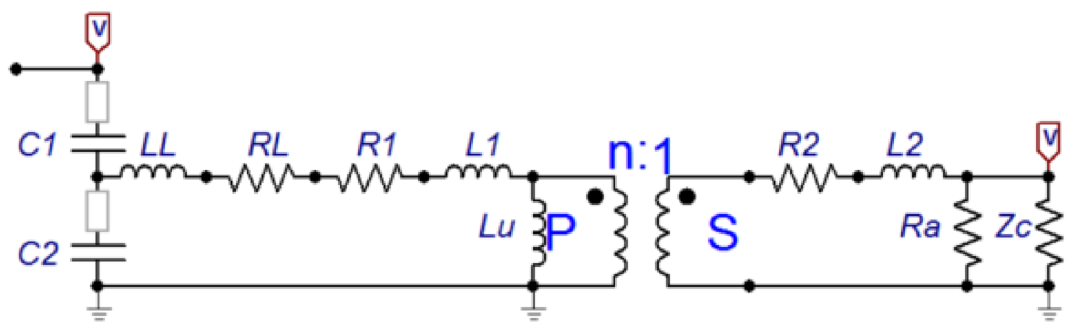
# Average operating time for L-L-L fault



# Distance protection performance with CVT transient

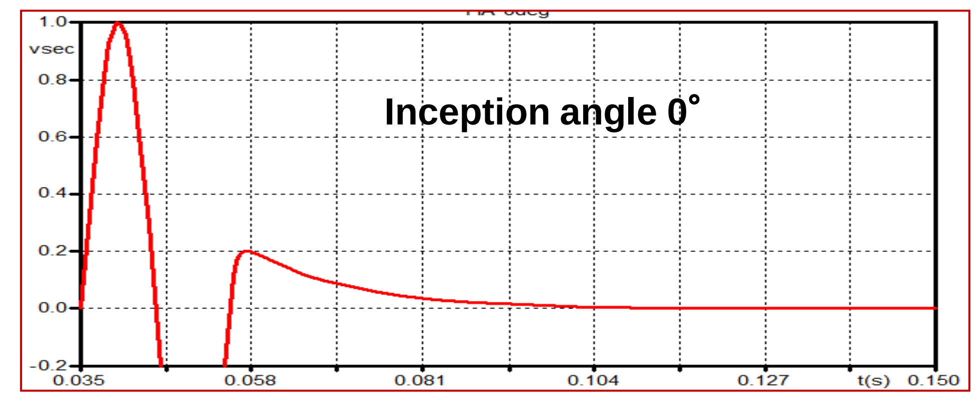
- CVT model

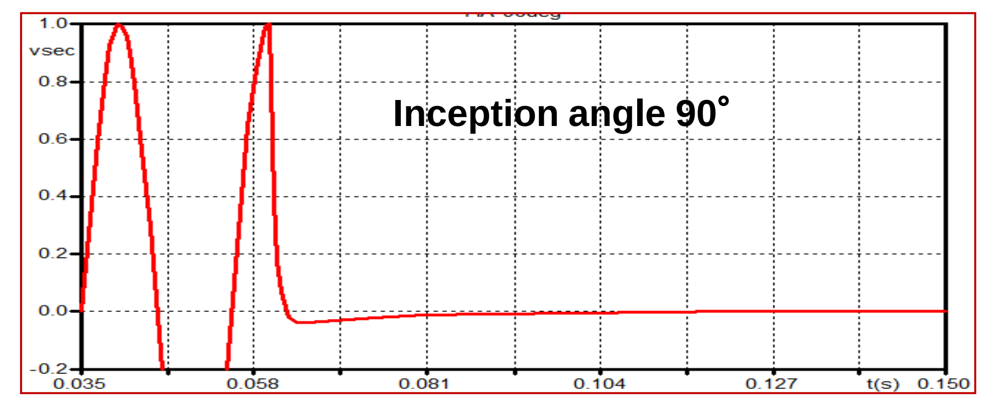



| | | | | | |
|---|---|---|---|---|---|
| **Vpri** | 400000 | V | **Ra** | 177700 | Ω |
| **Vsec** | 100 | V | **LL** | 107 | H |
| **C1** | 4210 | pF | **L1** | 5 | H |
| **C2** | 80000 | pF | **L2** | 8 | H |
| **Ce** | 0 | pF | **Lμ** | 177820 | H |
| **RL** | 650 | Ω | **Zc** | 80/1840 | VA/ kΩ |
| **R1** | 1550 | Ω | **Load PF** | 1 | |
| **R2** | 2700 | Ω | | | |

CVT Parameter (IEC 60255-121)

Transient response of the model




- Test cases (total 224 test cases and 896 test shots)

| Line model | Source impedance ratio (SIR) | Fault position (% of Zone 1 setting) | Fault type | Fault inception angle (°) |
|---|---|---|---|---|
| Short transmission line (20 km) | 5 and 50 | 0, 50, 80, 90, 95, 105, and 110 | A-G, B-C, A-C-G, and A-B-C | 0, 30, 60, 90 |

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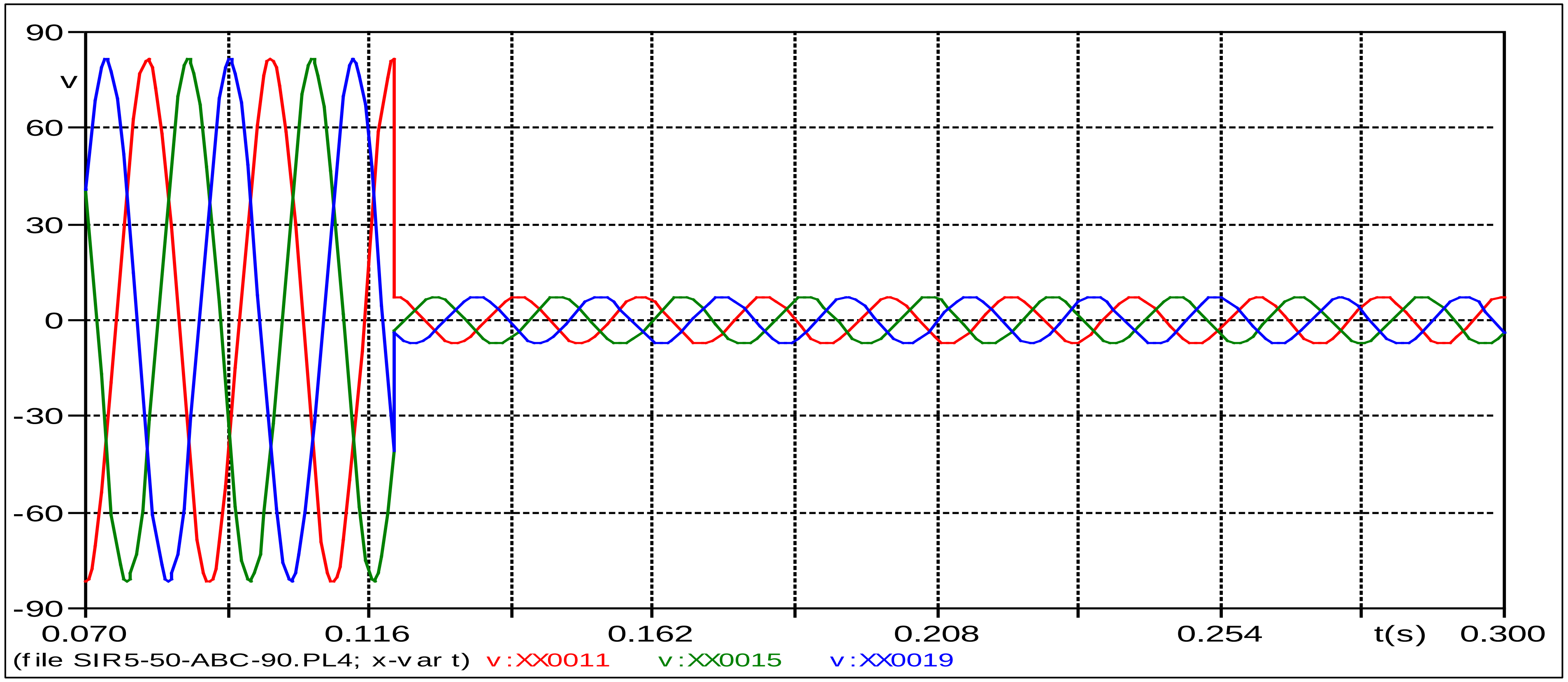
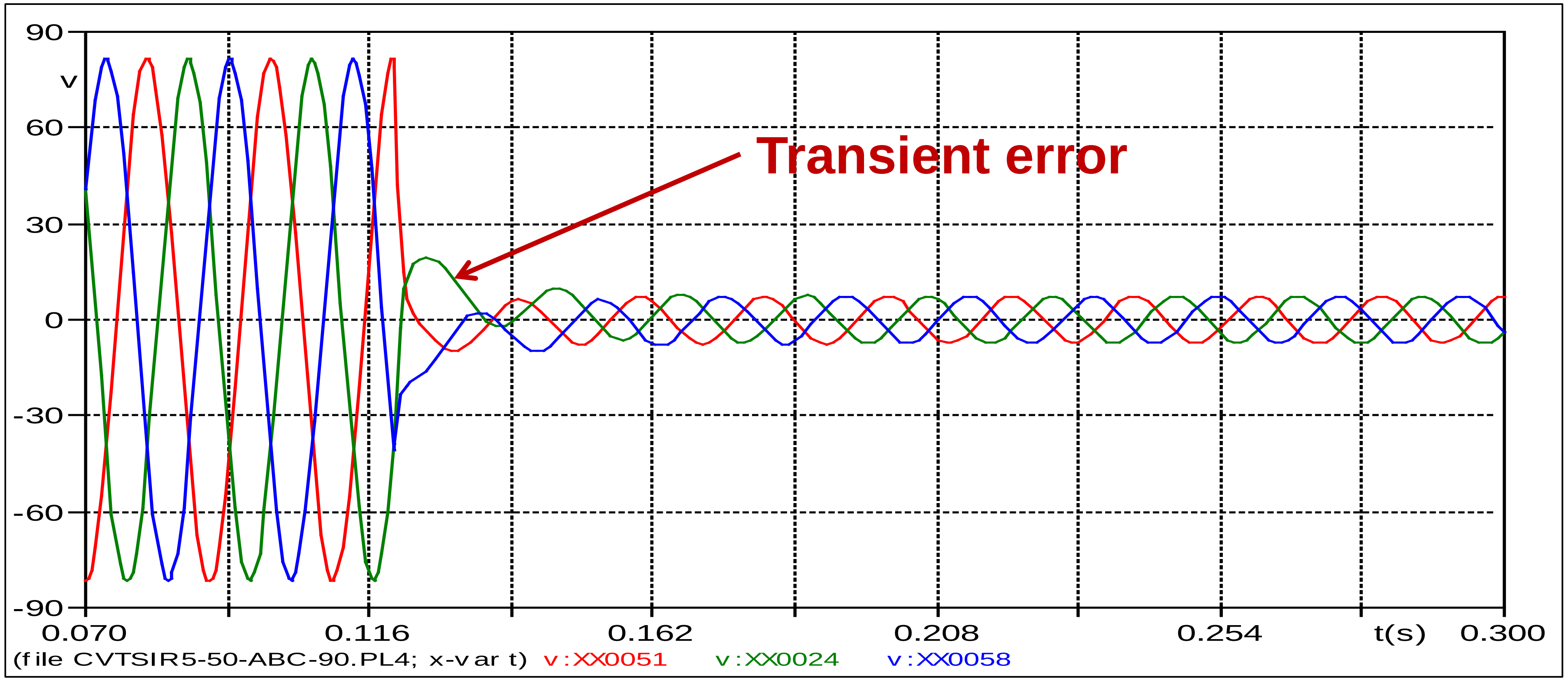



VT secondary voltage for A-B-C fault at 95% of zone 1




CVT secondary voltage for A-B-C fault at 95% of zone 1

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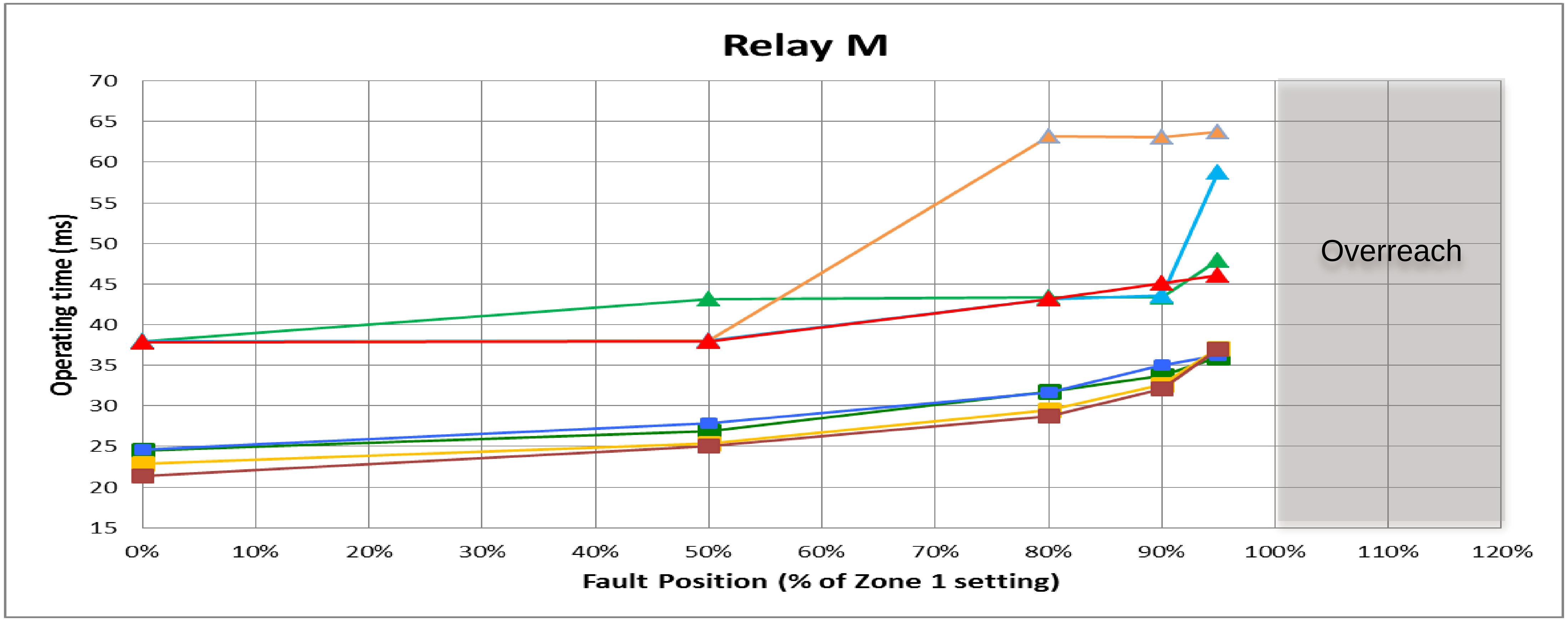
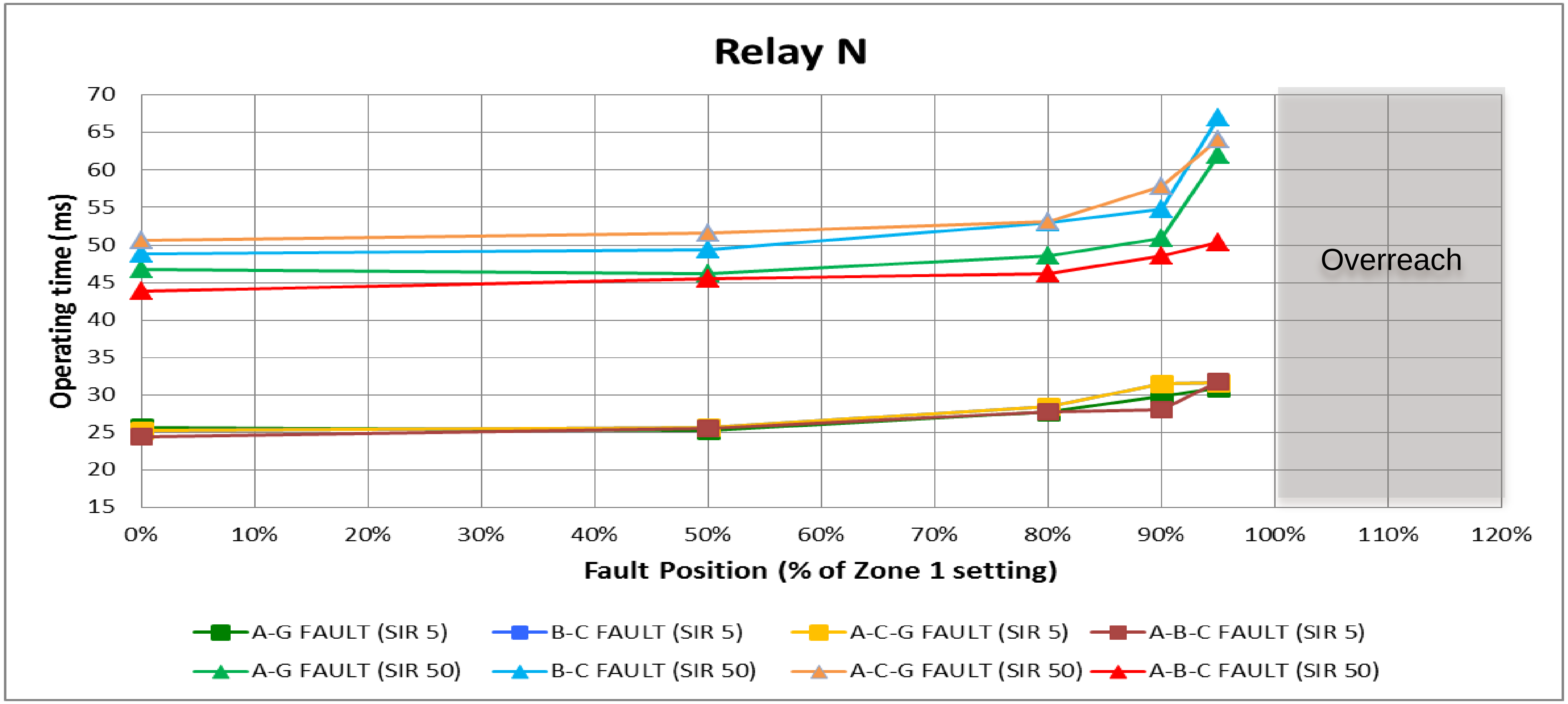
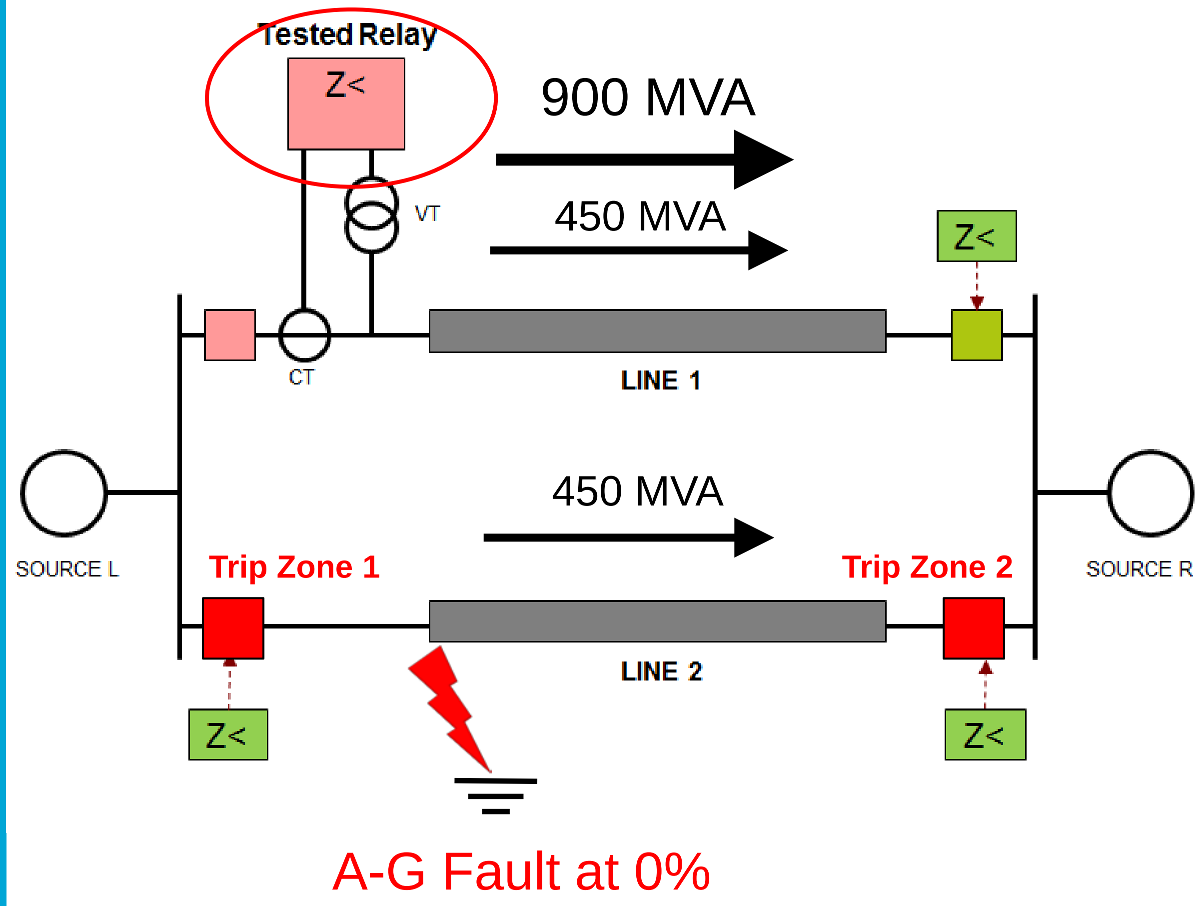
# Average operating time with CVT



# Distance protection performance with current reversal




**Simulation Sequence in ATP/EMTP**

1. **Pre-fault export load 450 MVA for each line**
2. **Fault occurs on line 2, seen in reverse direction by tested relay**
3. **Correct trip of zone 1 after 60 ms**
4. **Correct trip of zone 2 after 300 ms**
5. **Double export load flow 900 MVA on line 1**

**The tested relay is expected NOT to trip in forward direction**

- Test result

| Fault no. | Fault Type | Fault on line | Fault position | Zone 1 Criteria | Operating Time (ms) | |
|---|---|---|---|---|---|---|
| | | | | | RELAY M | RELAY N |
| 89 | A-G | 2 | +0% | No Trip | - | - |

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# Conclusions

- Modules for dynamic testing of distance protection according to IEC 60255-121 have been developed using ATP/EMTP simulation and Omicron tester
- Dynamic performance comparisons of distance relay M and N are as follow:
  - The operating time of relay M is faster than relay N in case of near busbar faults. While for end of zone-1 faults, relay N operate faster than relay M.
    - Close in faults: Relay M: 24.4 ms; Relay N: 31.1 ms
    - End of Zone-1 faults: Relay M: 41.9 ms and Relay N: 36 ms
  - The average tripping delays caused by:
    - High SIR: Relay M: 8.5 ms; Relay N: 6.9 ms
    - CVT transient in high SIR: Relay M: 6.9 ms and Relay N: 14.1 ms
  - Both distance protections seem to have problems to detect faults with resistance. Relay M and relay N fails to trip 17 times and 5 times from the total 88 test cases, respectively. Furthermore, most of the fails-to-trip cases occur on short transmission lines (21 out of 22 cases)

# Conclusions

- Dynamic performance of relay M against harmonics, frequency deviation, and evolving faults can be summarized as follow:
  - Certain harmonics order could cause severe delay in its operating time, in this case $7^{th}$ harmonics caused delay up to 18 ms for AG fault at 95% of zone 1 setting
  - Frequency deviation does not affect its operating time. However, the relay seems to have overreach problems when operating on minimum frequency
  - The Relay shows good selectivity function for evolving faults