Assessment of a misoperation on a distance protection relay by means of line impedance measurement and system-based testing

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10 March 2021

Content

> Impact on zero-sequence compensation factor on SLG faults

> Impedance measurements on different line topologies

> Measuring double circuit lines with the parallel circuit in operation

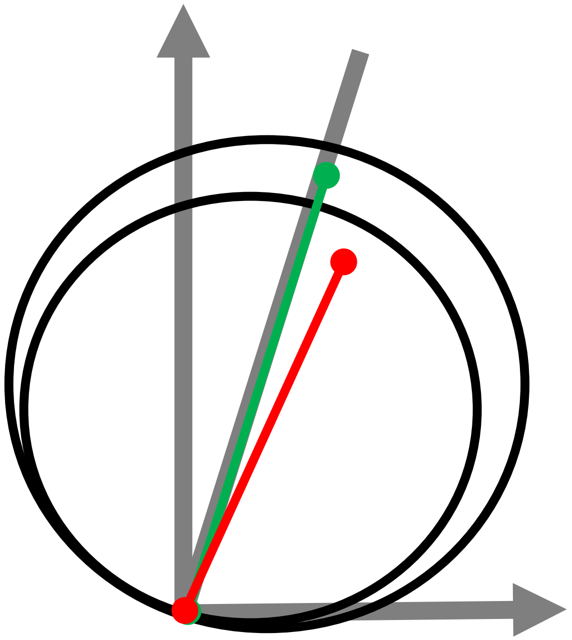
> Case study: Misoperation on a double-circuit line

Impedance Determination of a SLG fault

> AG fault, Location: m, RF = 0Ω

> $\frac{\overline{V}_a}{\overline{I}_a + \overline{k}_0 \overline{I}_r} = m\overline{Z}_{1L}$ where $\overline{k}_0 = \frac{(\overline{Z}_{0L} - \overline{Z}_{1L})}{3\overline{Z}_{1L}}$

> Assumption:
> - Z1L is correct
> - Z0L is too high
> - Ex.: AB and AG Fault at m = 100%



k0 for double circuit lines

- $\overline{k}_0 = \frac{(\overline{Z}_{0L} - \overline{Z}_{1L})}{3\overline{Z}_{1L}}$ only applies to single circuit lines

- In case of mutual coupling following factors also need to be considered:
  - Mutual coupling Impedance Z0M
  - Line Topology
    - Lines terminate at same buses
    - Lines terminate at different buses
  - Infeeds and source impedances
  - Switching state

Measurement of Z1, Z0 (and Z0M), Part 1

> No specific considerations necessary for
  - > positive-sequence impedance Z1
  - > single circuit lines

> All mutually coupled circuits shut down at a time (possible only before commissioning):
  - > Z0 and Z0M can be determined by measurement

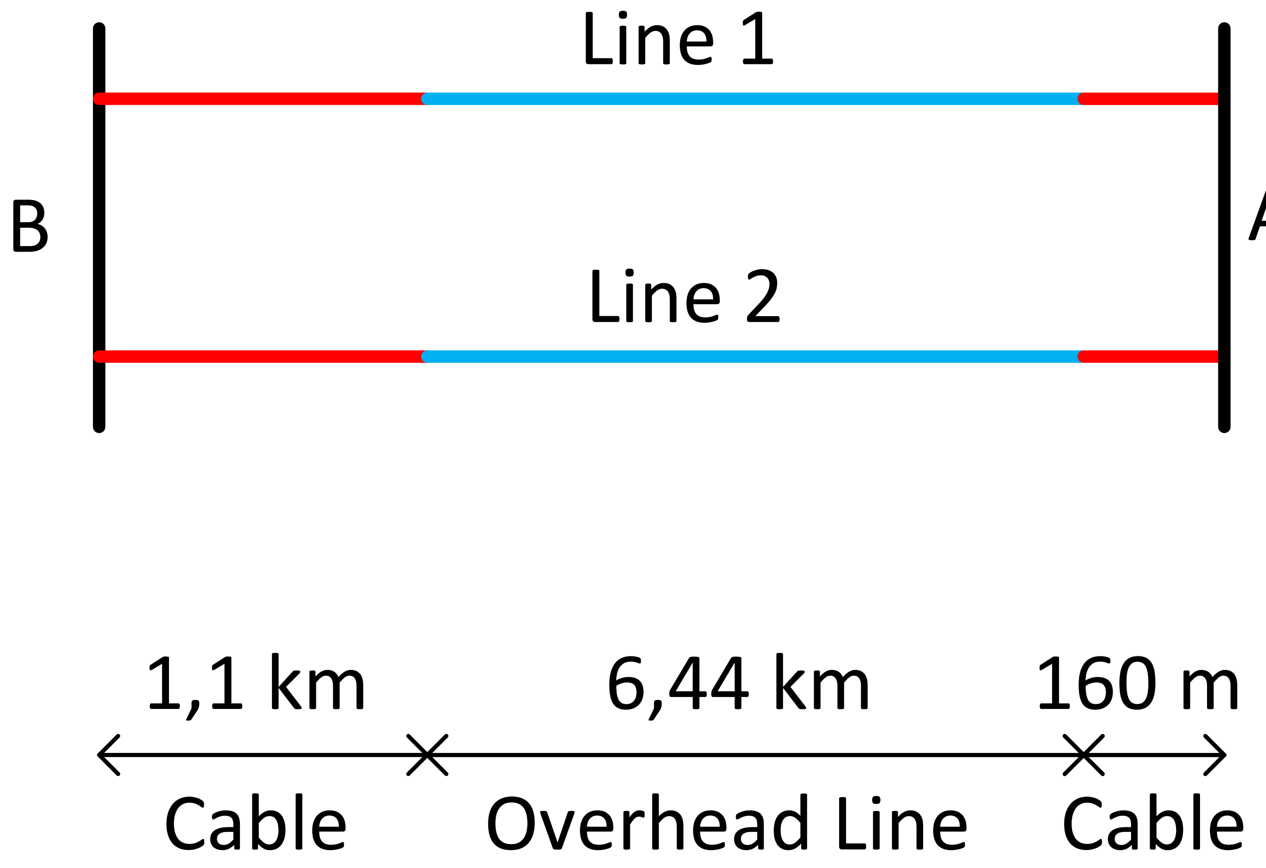
Measurement of Z1, Z0 (and Z0M), Part 2

> Only one circuit out of service at a time:

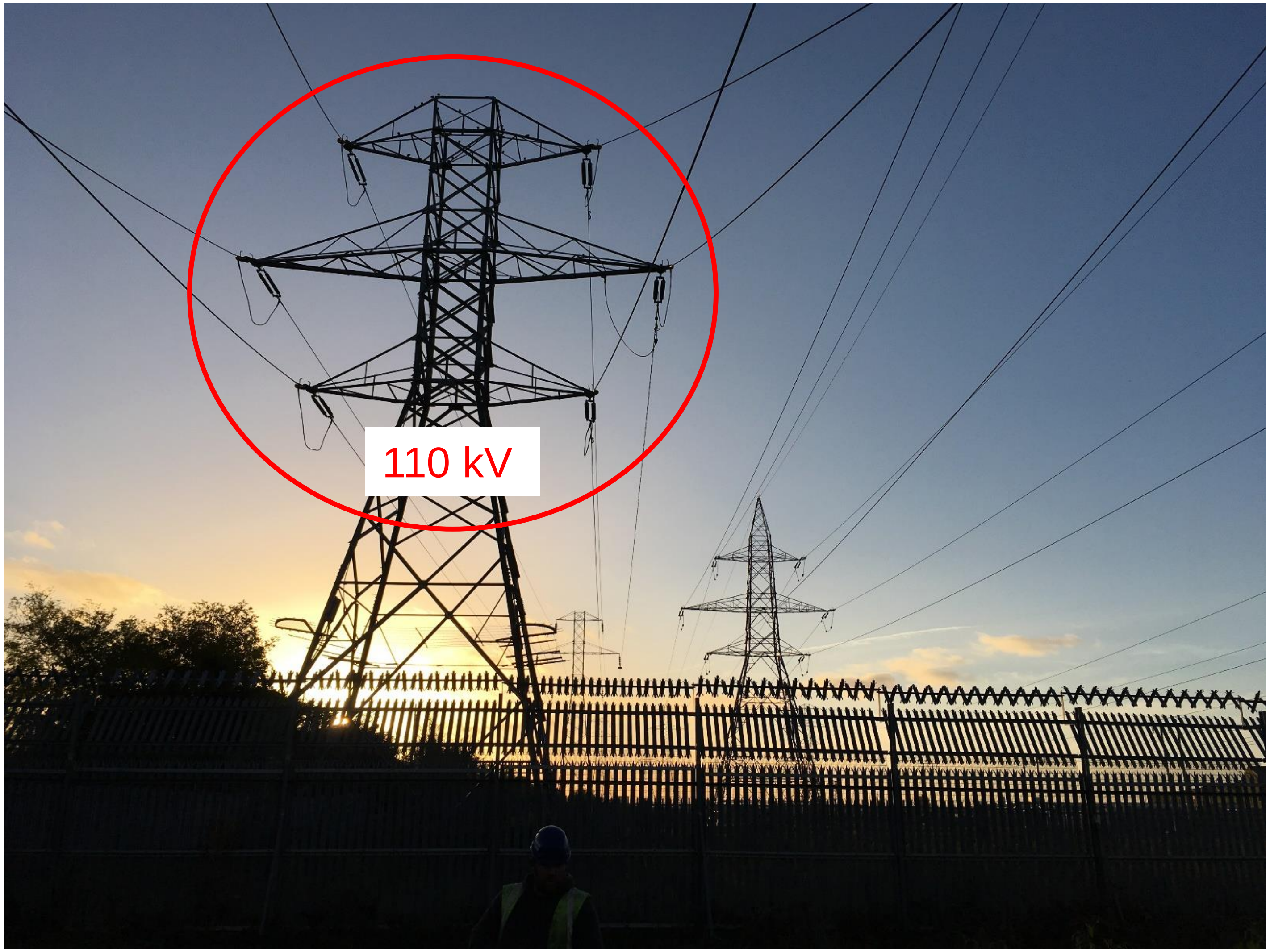
> Z0 can be affected by parallel live circuits
>
> > Correction is possible by means of:
> > Measure current in parallel live circuit
> > Determine auxiliary impedance Zaux from geometry of 6 phase conductors
> > Zaux therefore has the same accuracy as Z1, calculated from geometry

> Z0M is calculated from Z0 and Zaux

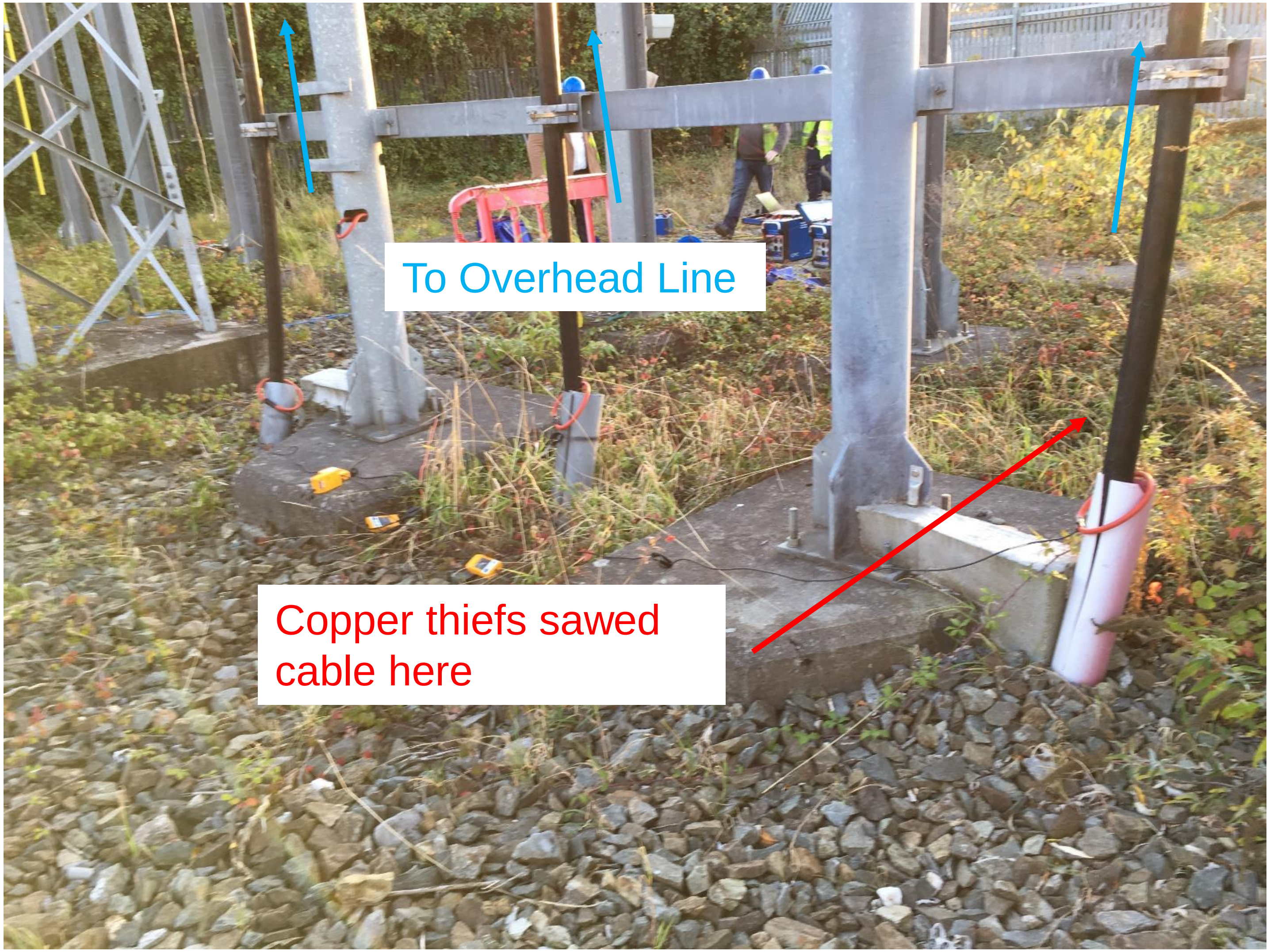
Topology of Double Circuit Line



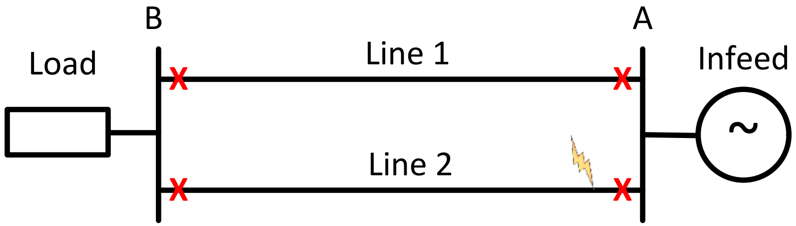
Overhead Line Section on same tower structure

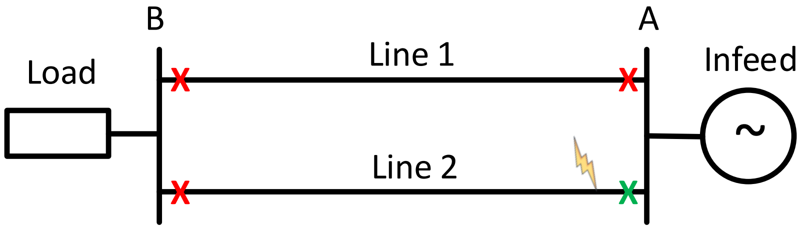


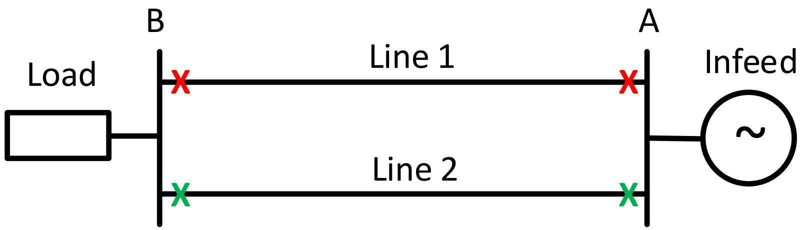
Location of the fault (End of Overhead Line in substation A

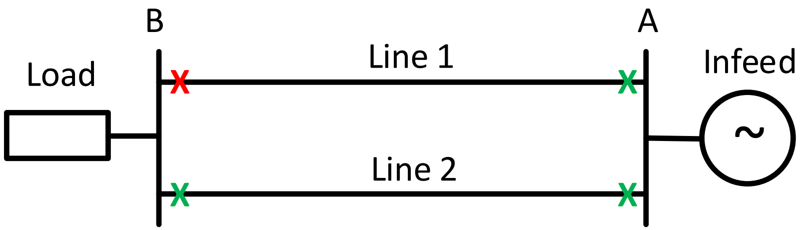


Sequence of CB tripping









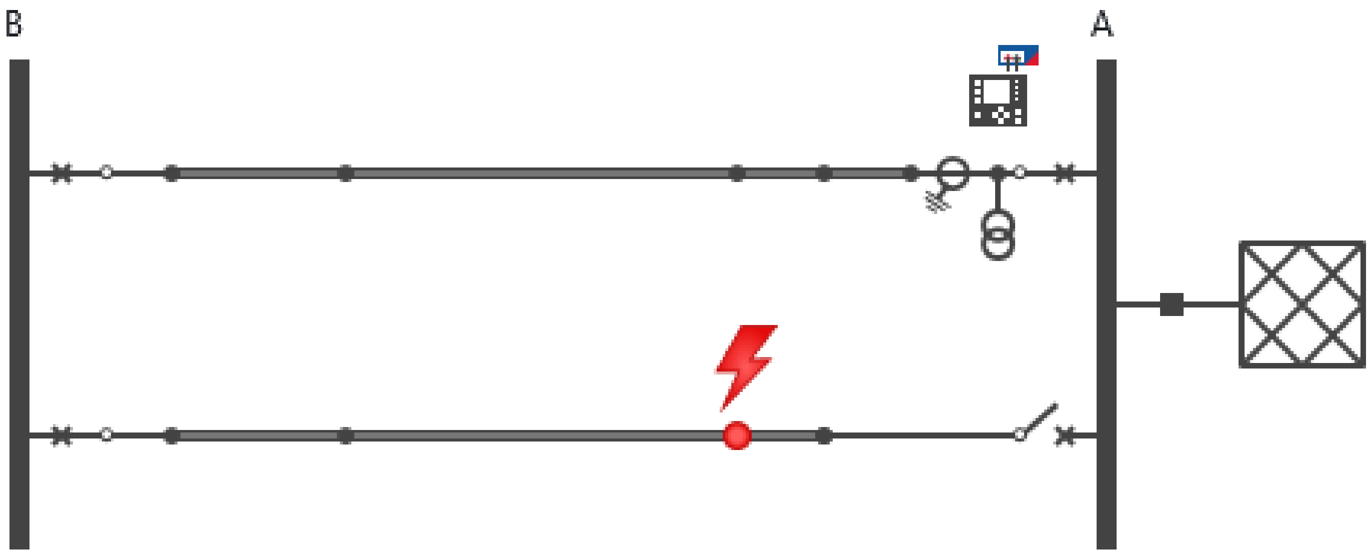
Distance Relay Overreach!

Line Impedance Measurement

	Z_1 (R/X)	Z_0 (R/X)	Z_{0M} (R/X)
Measured in Ω	0,849 2,776	2,131 9,132	1,144 5,779
Theoretical in Ω	0,94 2,78	3,07 17,2	Not present
Error in %	10,85 0,13	44,71 **88,29**	**Not present**

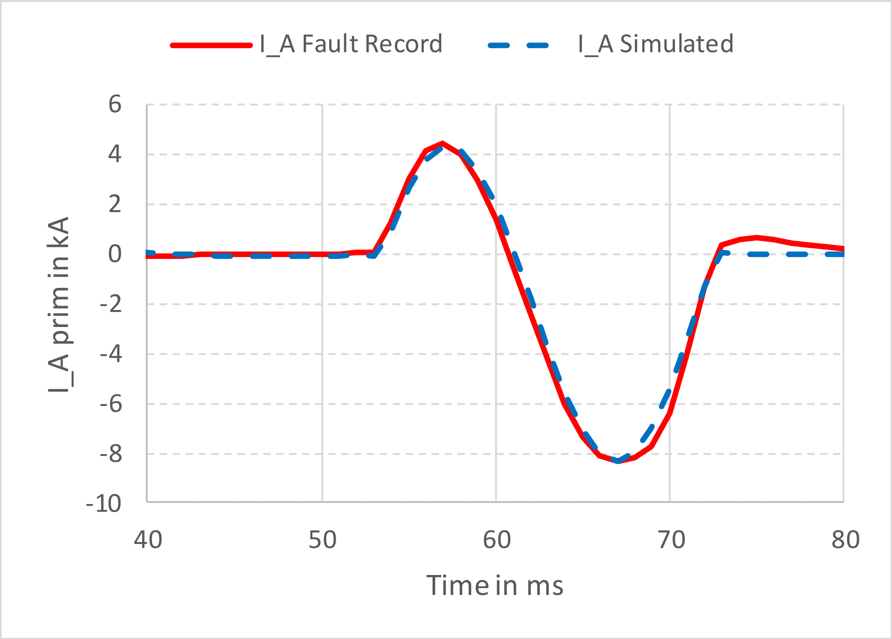
- Error of Z1 is negligibly small, as expected
- Error of Z0 is significant, especially for X value which is relevant for distance relay performance
- Mutual Coupling Impedance hasn‘t been considered at all

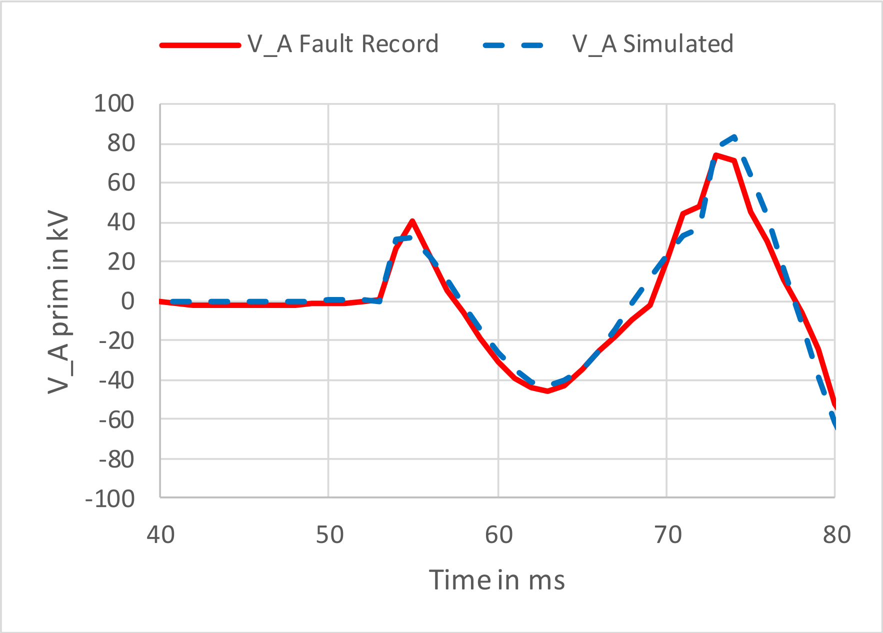
Simulation with Power System Model



- Observed Switching State: CB1 open. This is the state the relay of CB3 tripped off.
- Fault location is 200% from observed relay (CB3).

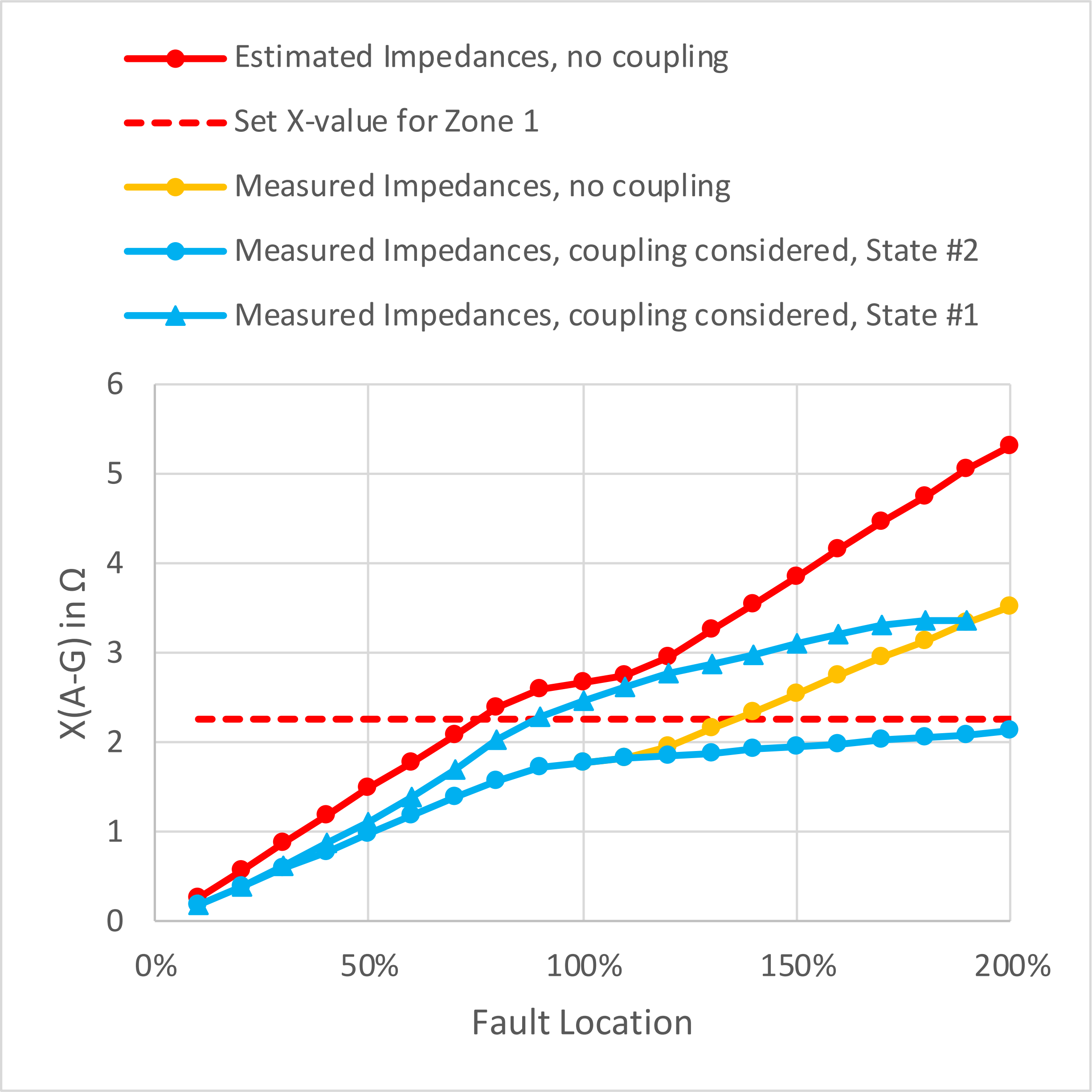
Voltage and Current from Fault Record and Simulation



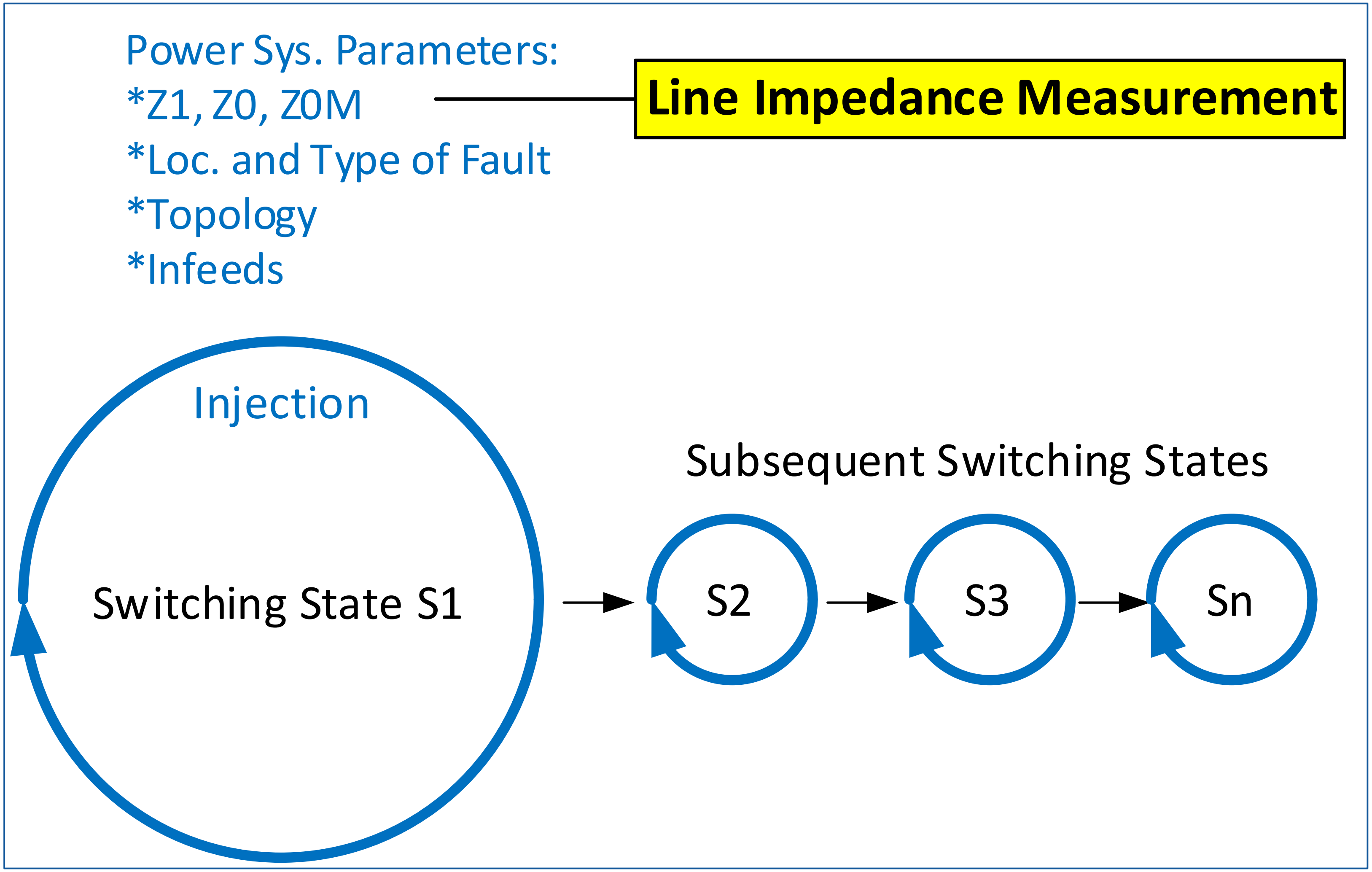


- Tuning Source Impedance to match with current -> Close match is possible
- Match of voltage is also pretty close which proves that simulation is very close to real conditions (real impedances seen from relay)

Impedance versus Distance of Fault Location

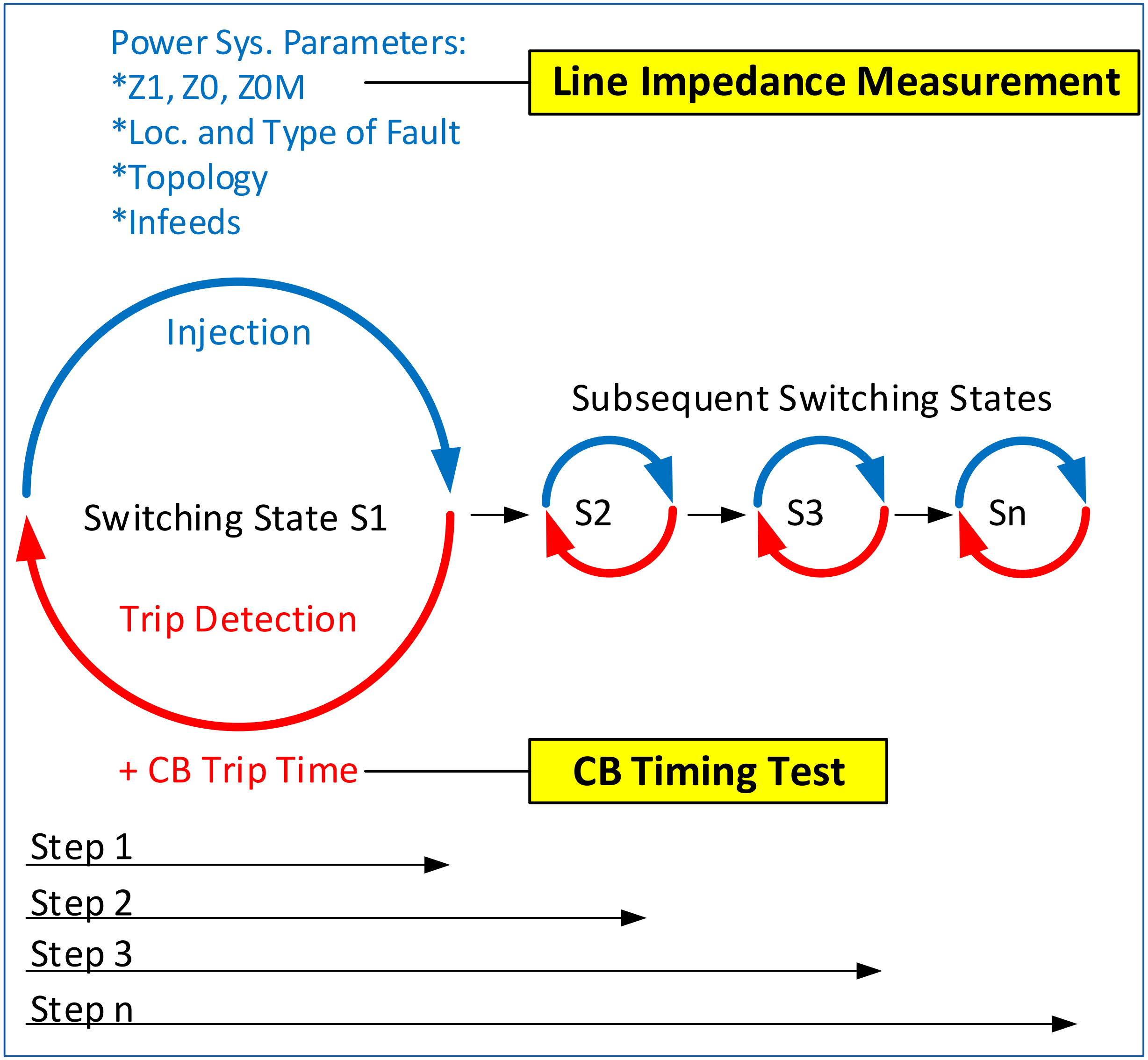


End-to-End Testing with PSS (Approach 1)



- Prerequisite: Sequence of switching states and their durations must be known

End-to-End Testing with PSS (Approach 2)



- Fully automated testing
- Real sequence of switching states is considered

Comparison between alternative and common method

	Z_1 (R/X)	Z_0 (R/X)	Z_{0M} (R/X)
Common (in Ω)	0,849 2,776	2,131 9,132	1,144 5,779
Minimum invasive (in Ω)	0,863 2,776	2,200 8,690	1,25 5,01
Deviation in %	1,65 0	3,24 **-4,84**	9,27 **-13,3**

- Z1 is not affected by parallel live line, therefore no deviation
- Z0 is quite accurate, about 4% off
- Deviation of Z0M is 13%
- However, when simulating relay impedances the deviation is in the range of 4% which is acceptable for the application of distance protection.

Conclusion

> Impedances should be measured...
>> ...and can be measured!
>> Minimally-invasive measurement is a feasible option for double-circuit lines

> Network Simulation Software...
>> ...determines true impedances of SLG faults (Design)
>> ...can be used to test relay with true V and I (Testing)

Thank you!

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