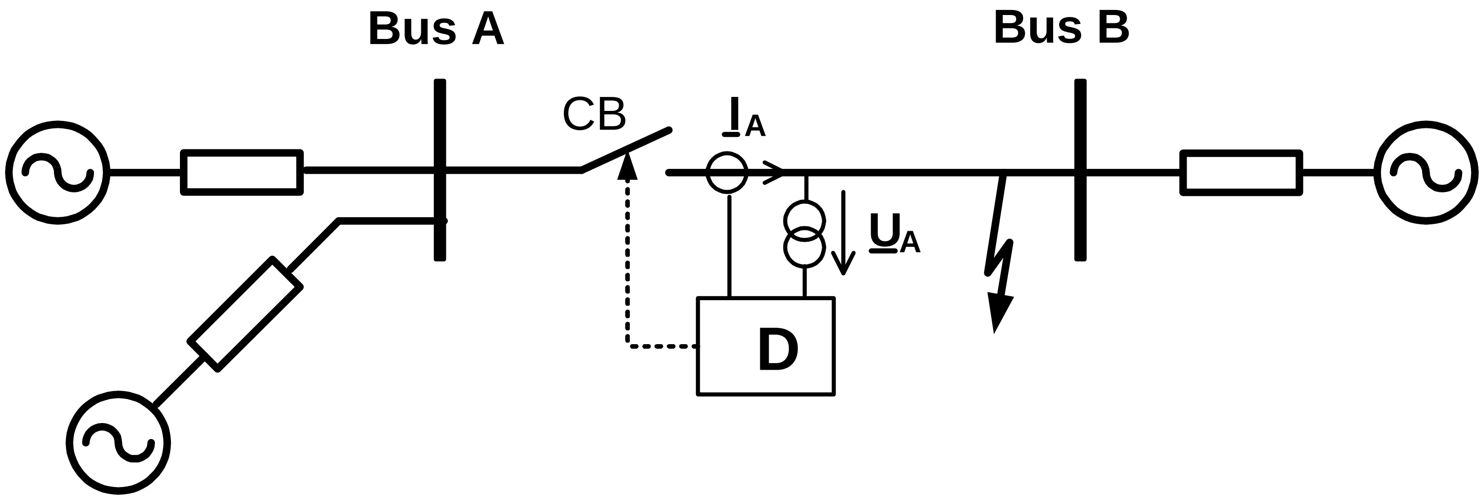
Compensation of impedance measurement error due to arcing

Content

Basic principle of distance protection and fault location



$$\underline{Z}_F = \frac{\underline{U}_A}{\underline{I}_A}$$

$$\underline{Z}_F = (m \cdot \underline{Z}_L + R_F) + \frac{\underline{I}_B}{\underline{I}_A} R_F$$

- The fault impedance is often calculated based on phasors of voltages and currents
- The reactance, the imaginary part of the fault impedance is proportional to the fault location
- The fault resistance R_F is normally seen as a pure resistive component

Phasor estimation for distance protection and fault location

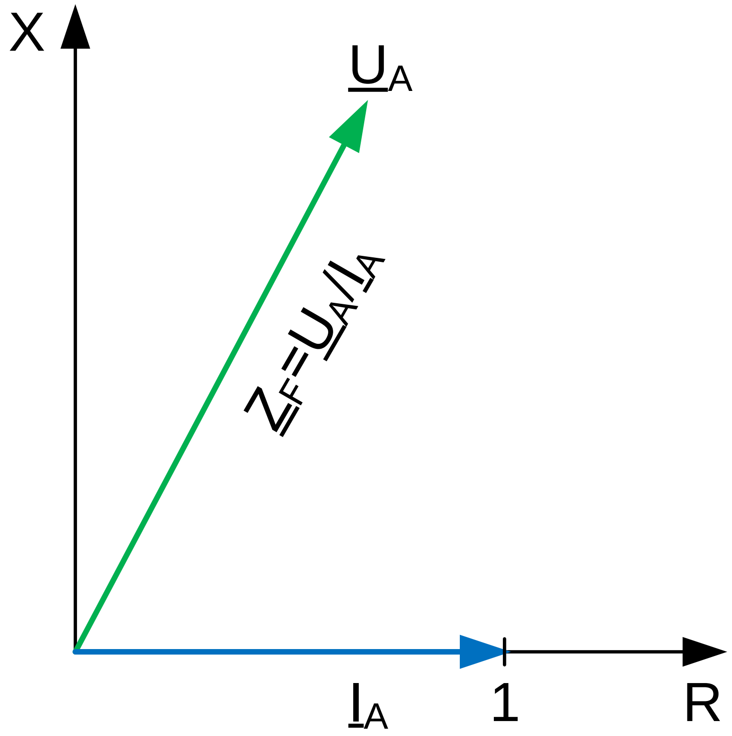
$$\underline{Z}_F = \frac{\underline{U}_A}{\underline{I}_A}$$

$$Re(\underline{U}_k) = \sum_{n=0}^{N-1} (u_{k-n} \cdot cos(2\pi \cdot f_r \cdot n \cdot T_A))$$

$$Im(\underline{U}_k) = \sum_{n=0}^{N-1} (u_{k-n} \cdot \sin(2\pi \cdot f_r \cdot n \cdot T_A))$$

- impedance often calculated based on phasors of voltages and currents
- DFT, FFT or similar methods are used to estimate these phasors
- voltage phasor $\underline{U}$k represents the fundamental component because voltage samples are filtered using a cosinus and sinus function of the rated frequency
- **voltage phasor should represent driving voltage of the system at relay location**
- filtering is used to attenuate noise and other disturbance in the voltage signal

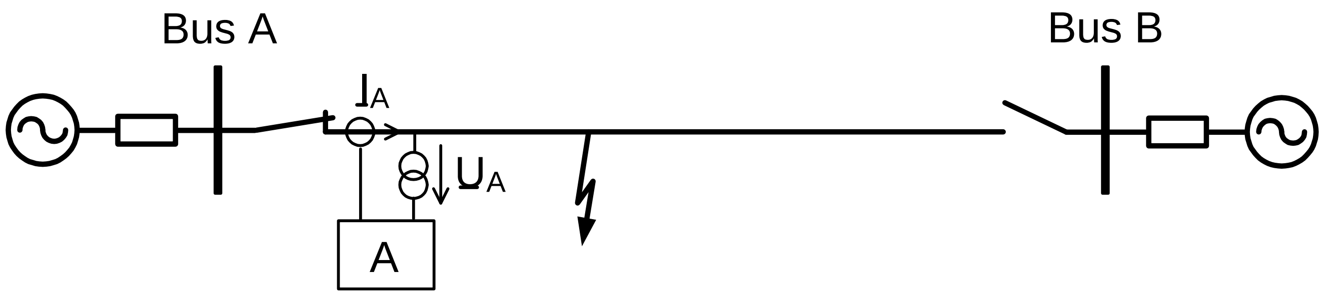
Phasor estimation for distance protection and fault location



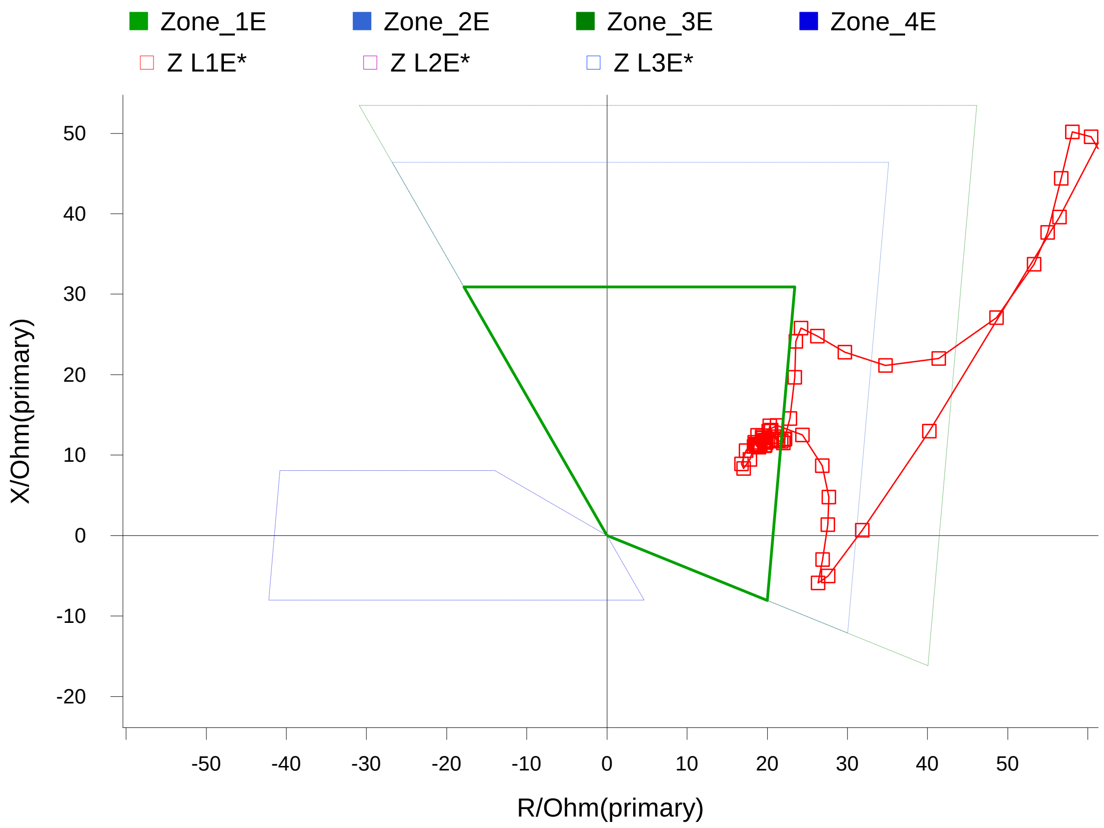
$$\underline{Z}_F = \frac{\underline{U}_A}{\underline{I}_A}$$

- The fault impedance $\underline{Z}_F$ is proportional to the measured voltage $\underline{U}_A$
- Phase or magnitude errors related to $\underline{U}_A$ directly impact the fault impedance $\underline{Z}_F$

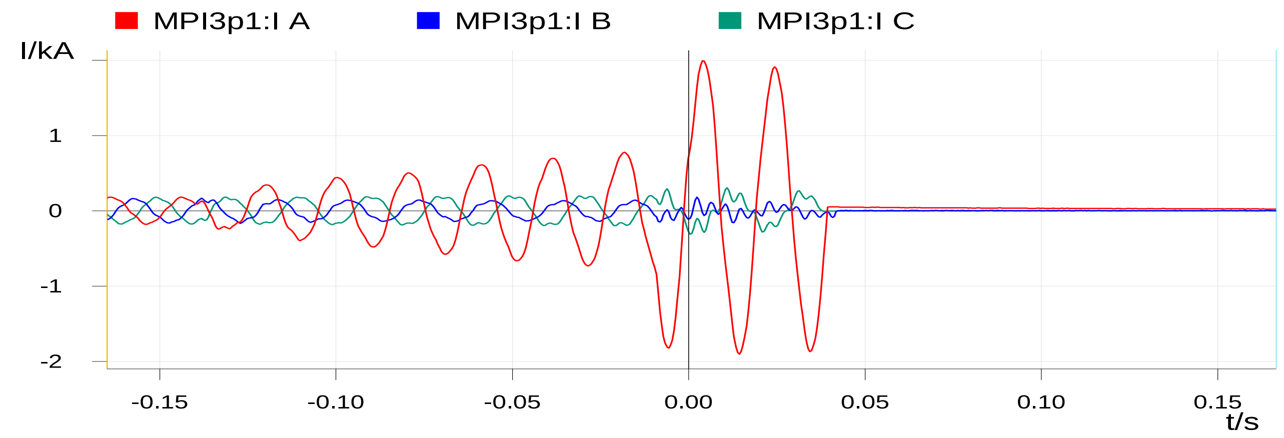
Wrong fault location due to arcing

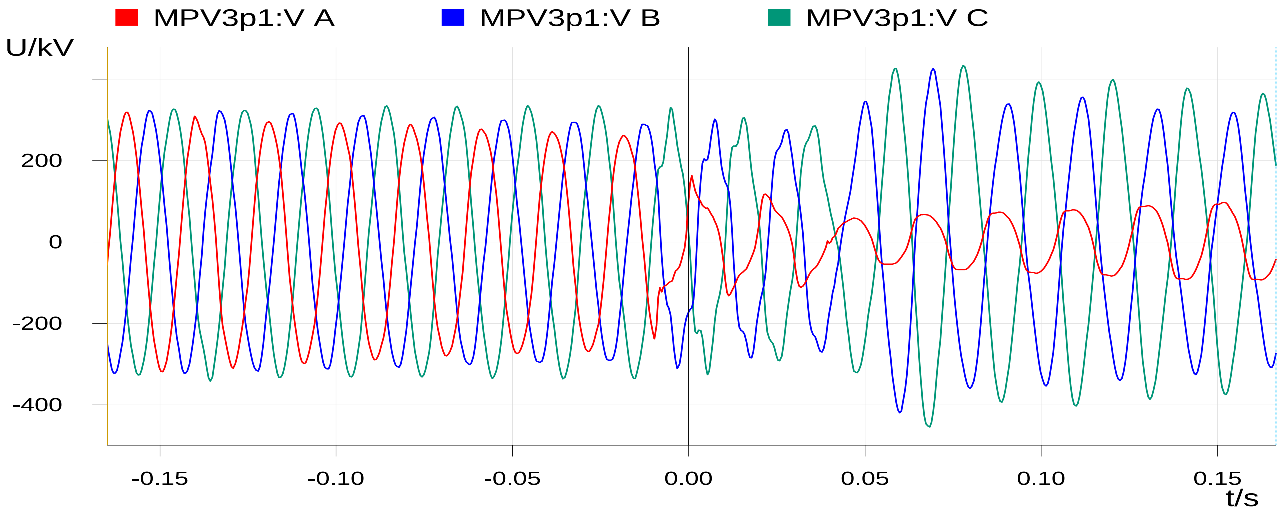


- 400 kV line with remote end open
- single-phase to ground fault in Zone 1
- successful trip of the line
- deviation of fault location given by relay A greater than 100% !



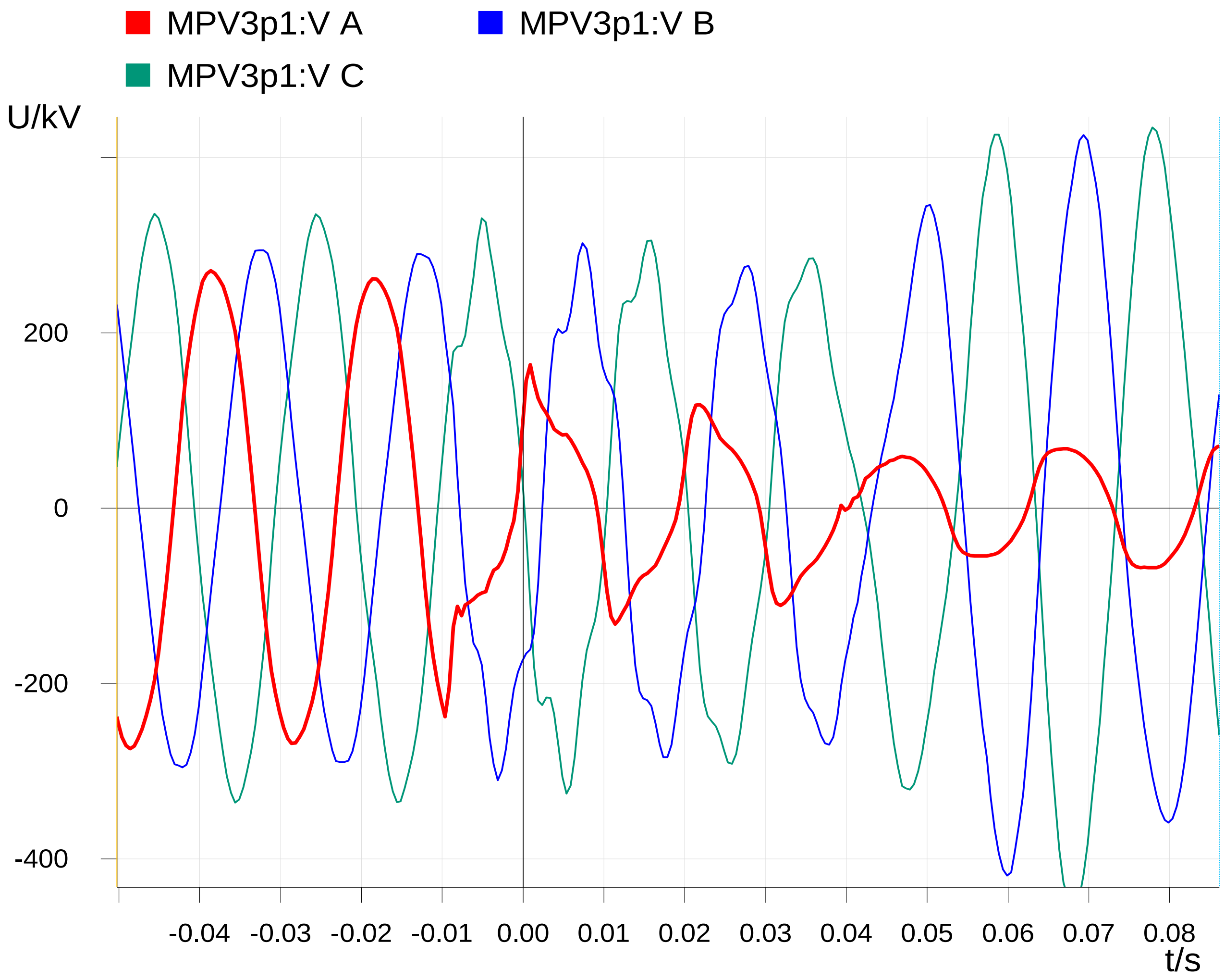
Wrong fault location due to arcing





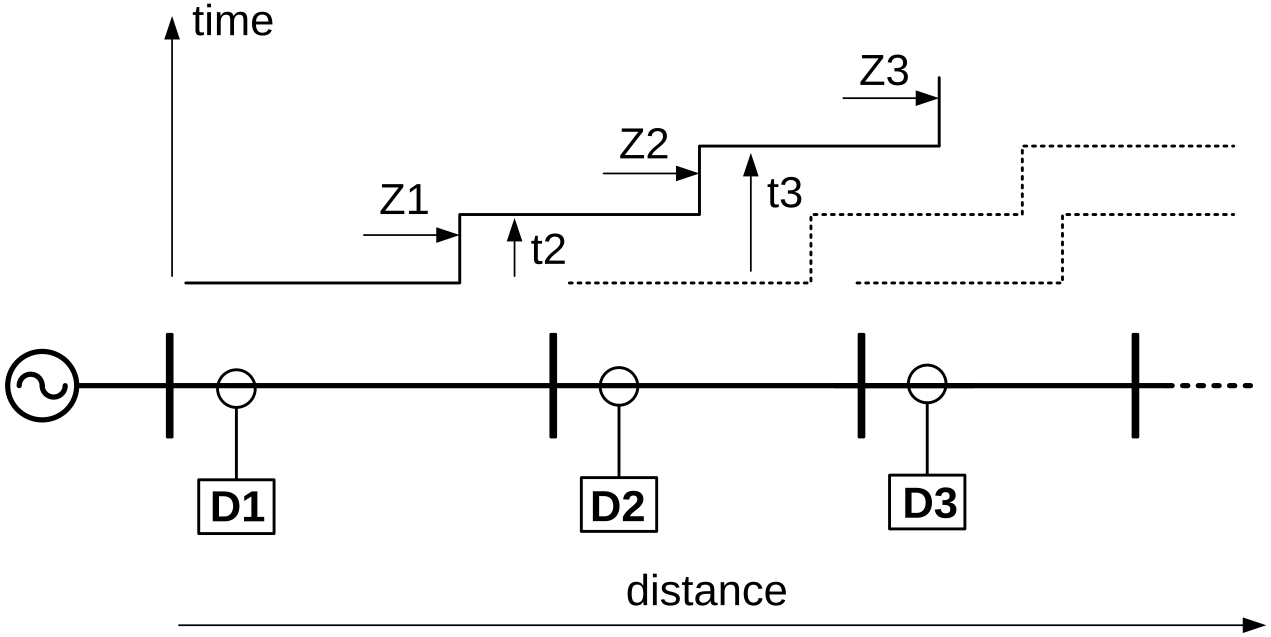
- Fault current quite sinusoidal
- Typical arcing voltage

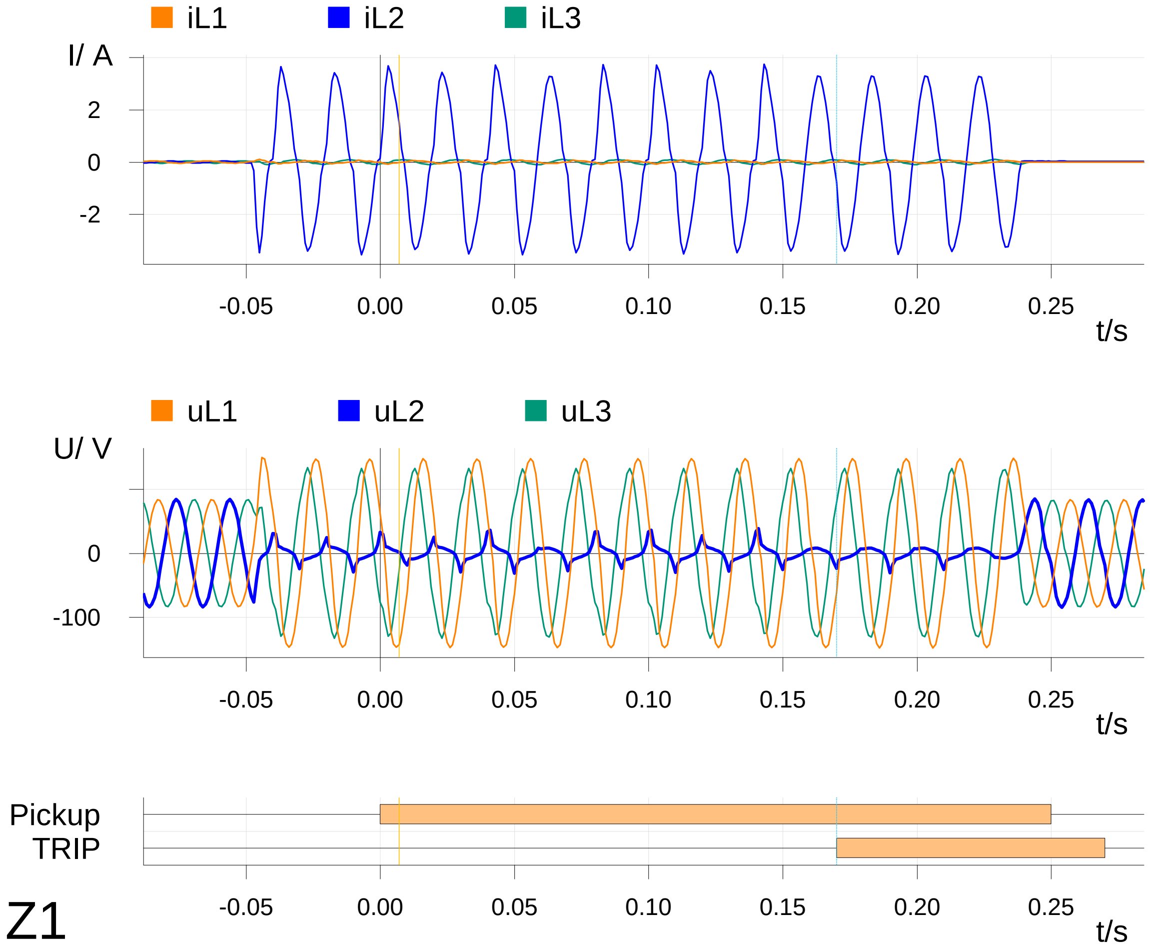
Wrong fault location due to arcing



- After zero crossing the voltage is rising fast
- If the voltage reaches a critical limit, arcing starts and breaks down the voltage
- The second part of each halfwave is quite sinusoidal

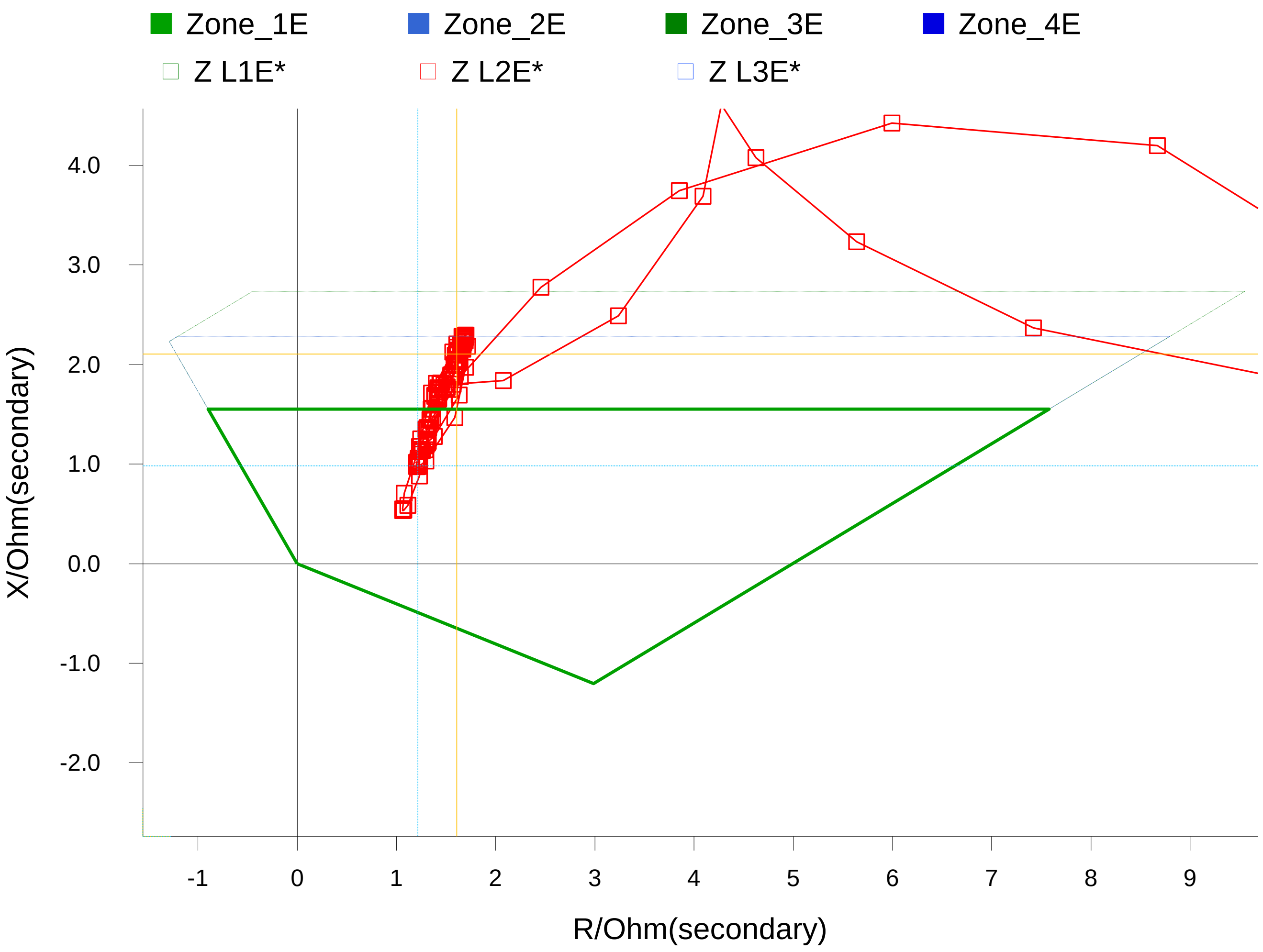
Delayed trip of distance protection due to arcing





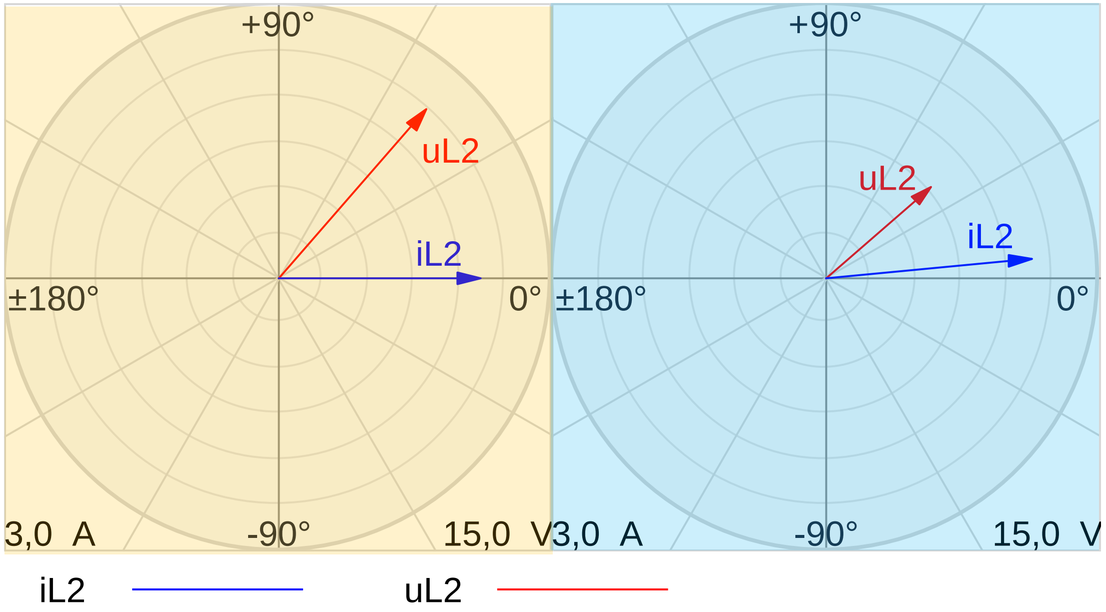
- distance protection applied to a medium voltage cable system
- delayed TRIP of distance protection for a fault in Z1
- TRIP command after typical shape of arcing disappears in positive half wave

Delayed trip of distance protection due to arcing



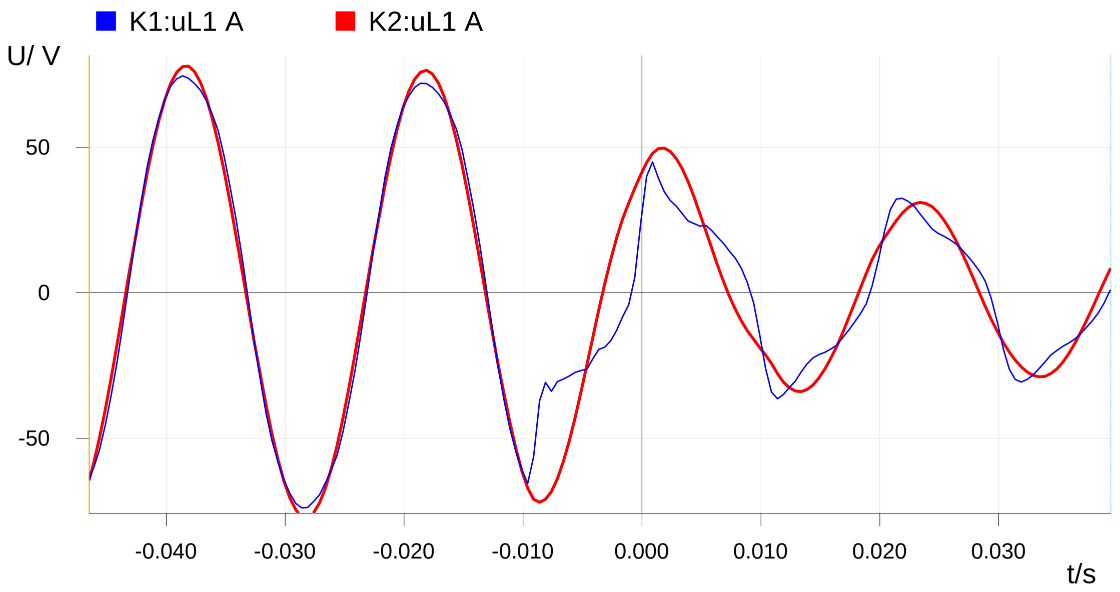
- fault impedance outside zone Z1 at fault inception (yellow cursor)
- fault impedance inside Z1 at tripping (blue cursor)

Delayed trip of distance protection due to arcing



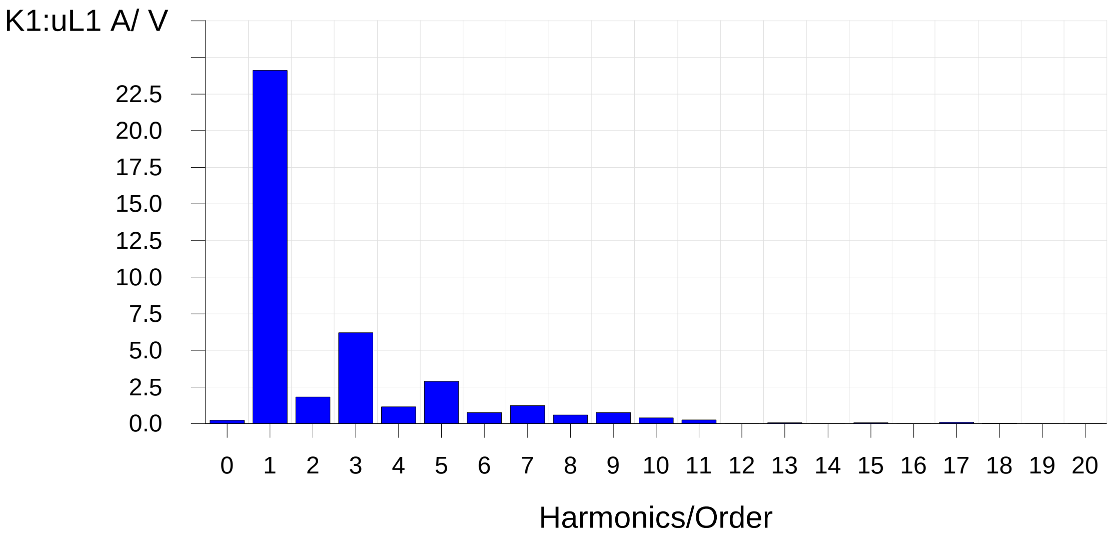
- voltage and current of faulted phase at fault inception (yellow diagram) and tripping (blue diagram)
- voltage is measured too great and leading phase at fault inception

Wrong estimation of voltage phasor due to arcing

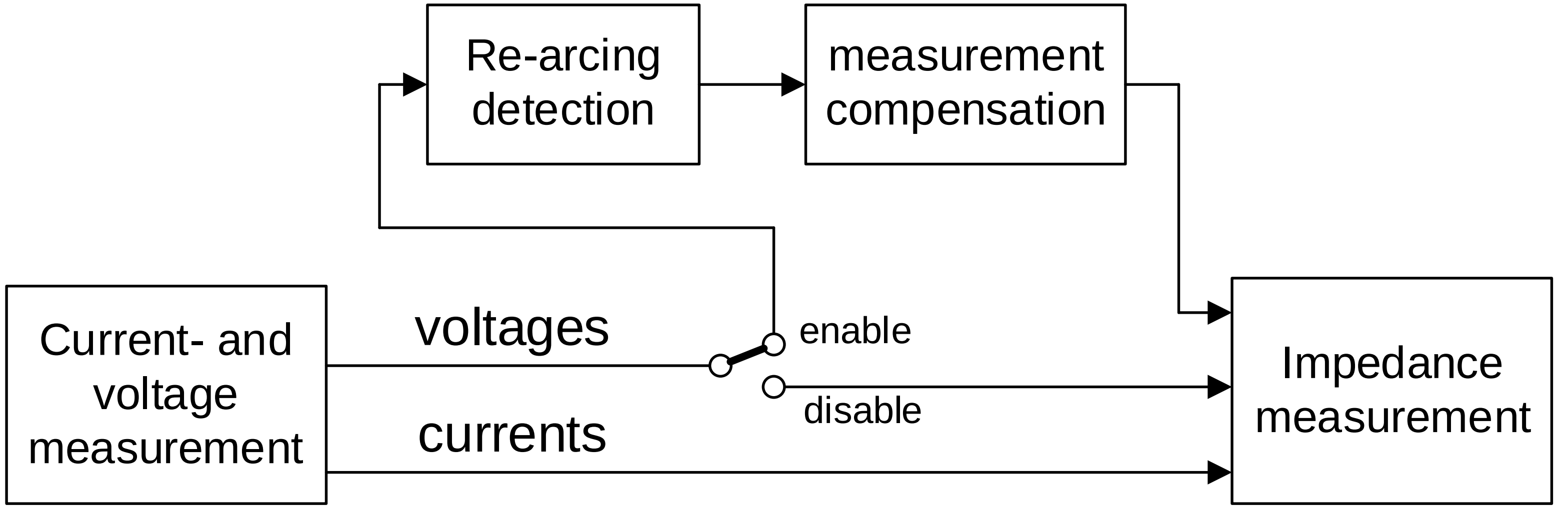


- Blue marked signal “K1: uL1 A” represents the original voltage
- Non-linear behavior of arcing especially in the first part of each half-wave
- Characterized by a great amount of harmonics

- red marked signal “K2: uL1 A” is recalculated from the phasor estimated via FFT from the blue marked original signal “K1: uL1 A”
- great deviation in phase and magnitude!



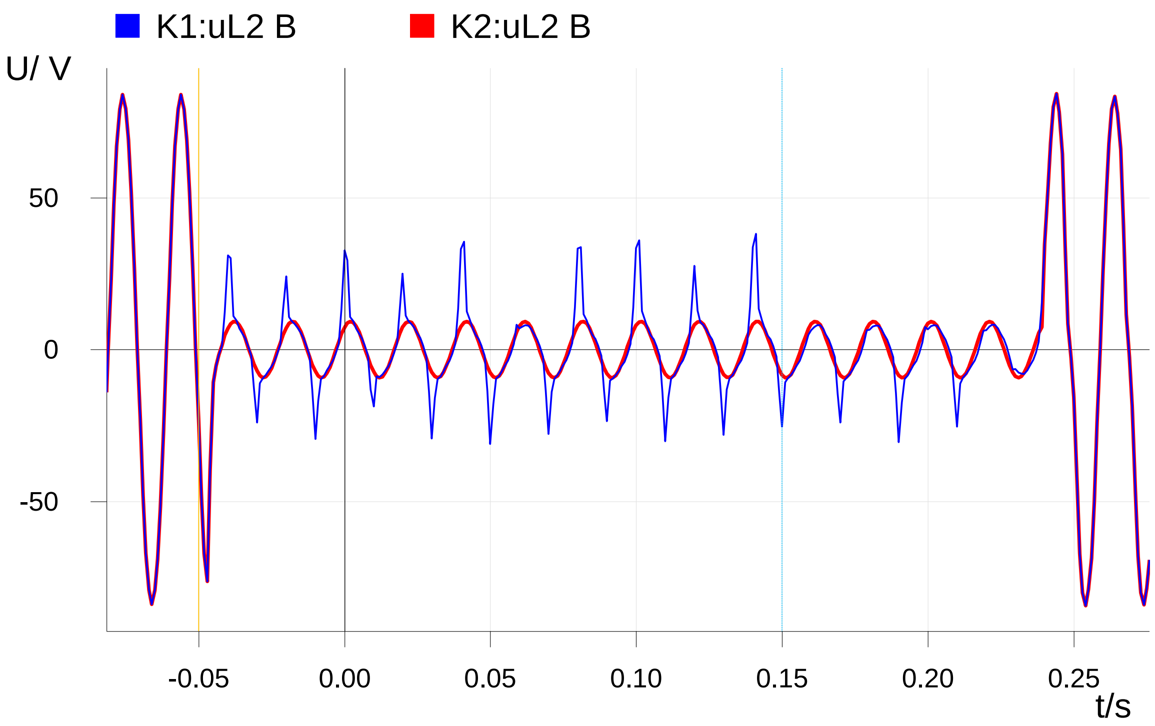
Compensation of impedance measurement error



- voltage signals are analysed for disturbances due to re-arcing
- can be done in time domain (signal shape) or in frequency domain (harmonics)
- correction using the following two main criteria explained in time domain:

1. The corrected voltage signal should have the same zero crossings compared to the original signal
2. The corrected voltage signal should follow the shape of the second half-wave of the original signal as precise as possible

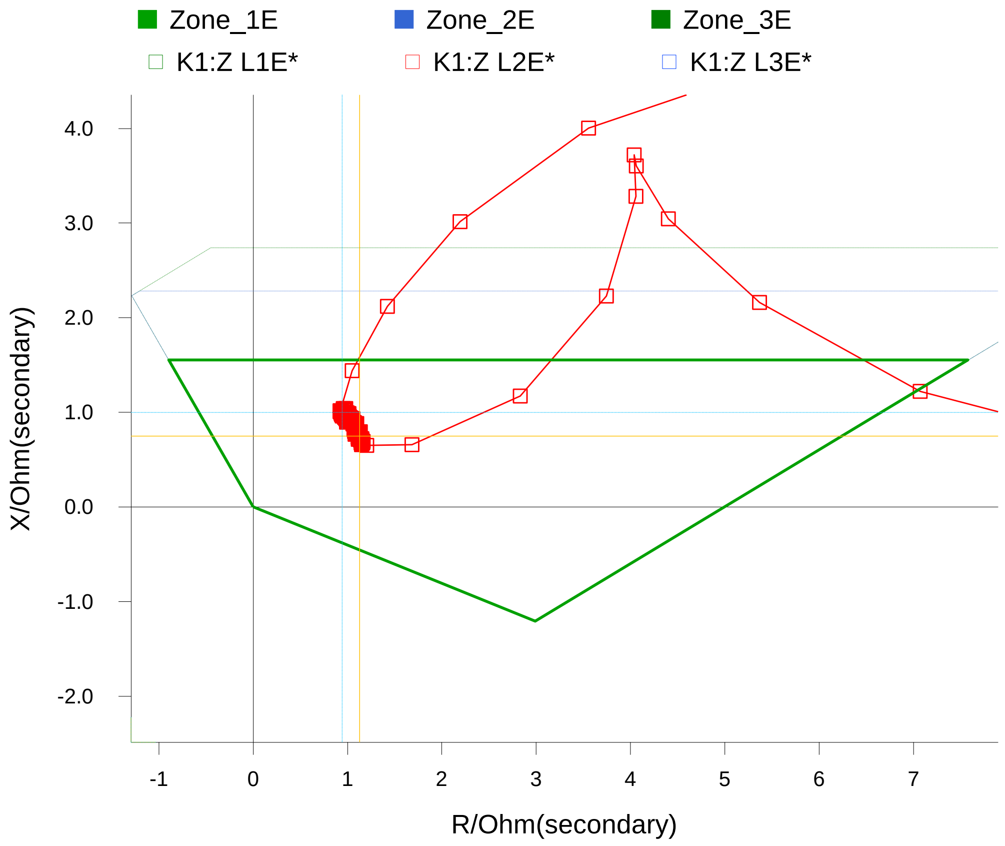
Voltage signal before and after correction

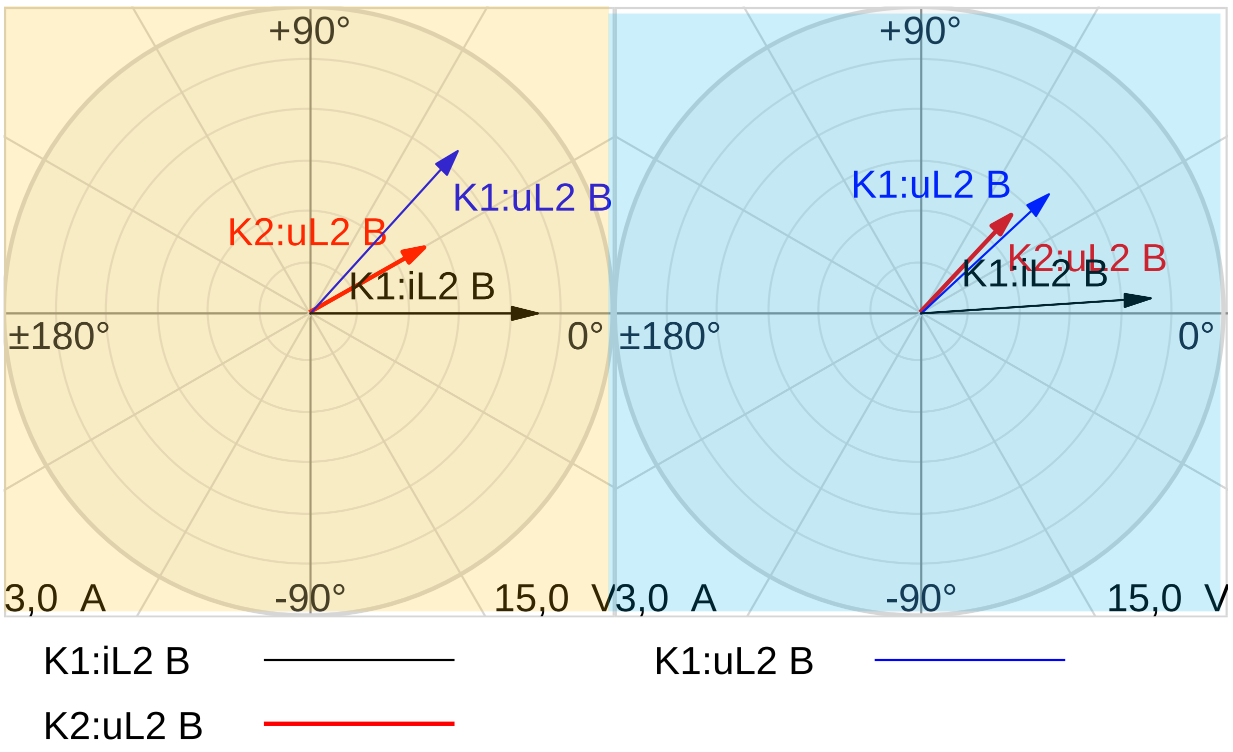


- blue marked “K1: uL2 B” is the original re-arcing voltage
- red marked “K2: uL2 B” is the corrected voltage

- Signals are identical if the original signal follows a pure sinusoidal shape
- Correction algorithm only removes the spikes in the voltage signal which are originating from the re-arcing

Compensated impedance measurement





- impedance based on the compensated voltage is measured to be in zone Z1 just from the beginning of the fault
- the phasor diagrams show the original voltage (blue phasor) and the compensated voltage (red phasor) at fault inception and original tripping

Conclusion

- Using two real world examples it was explained how arcing can impact the impedance measurement of distance protection and fault locator
- A main reason was identified related to phasor estimation algorithm based on DFT
- Based on these results a compensation was suggested which can be applied to correct the huge measurement error

Thank you for your attention

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