Part 2

Distance Protection Special Cases

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SIEMENS

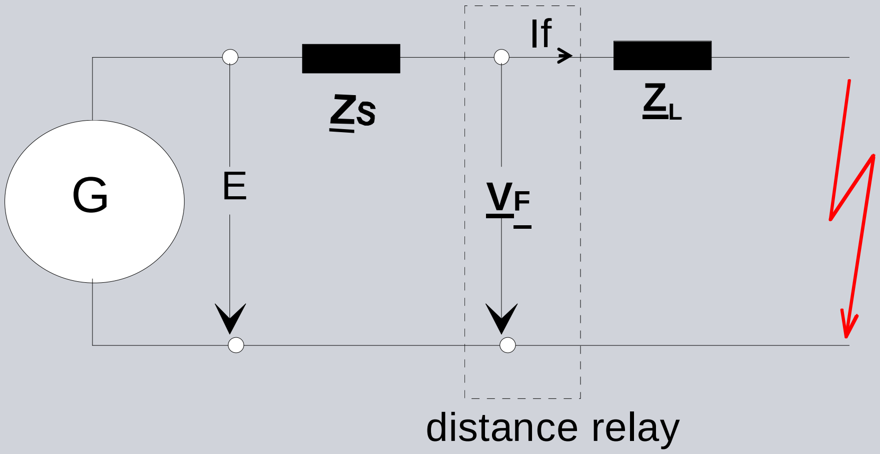
For the application of distance protection

Special Conditions:

1. Short lines/cables
2. Parallel lines
3. Fault resistance

Short Lines: SIR - Definition

SIR (**S**ource **I**mpedance **R**atio) describes the ratio between the source impedance and the line impedance!



$$SIR = \frac{|\underline{Z}_S|}{|\underline{Z}_L|}$$

$$\underline{V}_f = \frac{E}{1 + SIR}$$

High SIR = Small loop voltage $\underline{V}_F$
in case of a fault at the end of the line

Note: SIR trip time curves are mostly related to zone 1, i.e. ZL = Z1

SIR - Considerations about line length and infeed

The SIR gives some information about the power of infeed and the line length!

SIR > 4	short line*
SIR < 4 and >0.5	medium line*
SIR < 0.5	long line*

For a distance relay the short line (large SIR) is more critical than on a long line (small SIR)!

*Classification according IEEE-Guide

Short Lines: Definition of the shortest zone 1 setting

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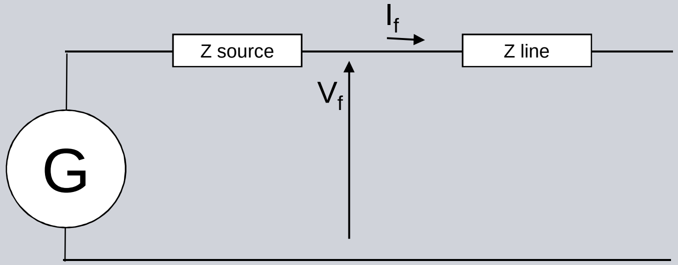
The smallest reach setting of the underreaching Zone 1 will be determined with the minimum voltage measured for a fault at this zone boundary!



$$SIR = \frac{|Z_S|}{|Z_L|}$$

$$\underline{V}_f = \frac{E}{1 + SIR}$$

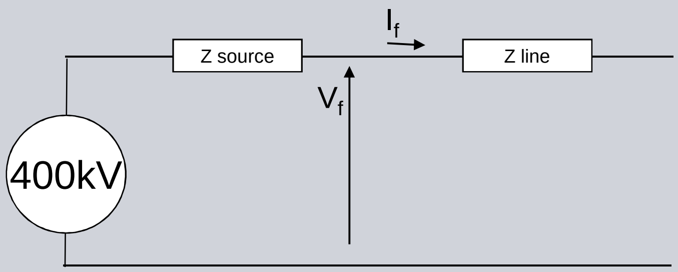
To ensure sufficient measuring accuracy a minimum voltage must be available for a fault at the boundary of the zone 1 setting. By definition of the loop impedances a 3ph fault will result in the smallest voltage:

V_{min}=minimum voltage for measured accuracy in stated tolerance (e.g. 5%)

The shortest line length (zone 1 setting) is therefore defined by V_{min} and the SIR.

Short Lines: Example - shortest zone 1 setting

With minimum short circuit level on the busbar = 4 GVA, what is the smallest possible zone 1 setting is V_{min} = 0.5V secondary?



$$SIR = \frac{|Z_S|}{|Z_L|}$$

$$V_f = \frac{E}{1+SIR}$$

$$Z_{source} = \frac{U_N^{\ 2}}{S_{3ph}} = \frac{400^2}{4000} = 40\Omega$$

$$V_{min\_prim} = \frac{0.5}{100} \cdot 400kV = 2kV$$

$$SIR_{max} = \frac{E}{V_{min}} - 1 = \frac{400}{\sqrt{3} \cdot 2} - 1 = 114$$

$$Z1_{min} = \frac{Z_{source}}{SIR_{max}} = \frac{40}{114} = 0.35\Omega$$

The shortest line length (zone 1 setting) is 0.35 Ohm primary. For a typical line reactance of 0.3 Ohm/km this corresponds to a line length of just over 1km.

Parallel lines: Influence on distance measurement

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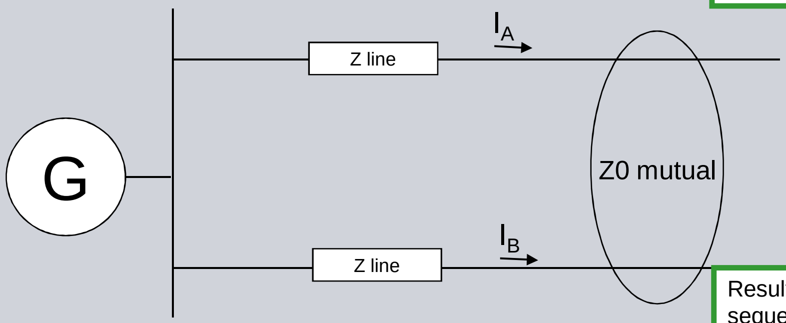
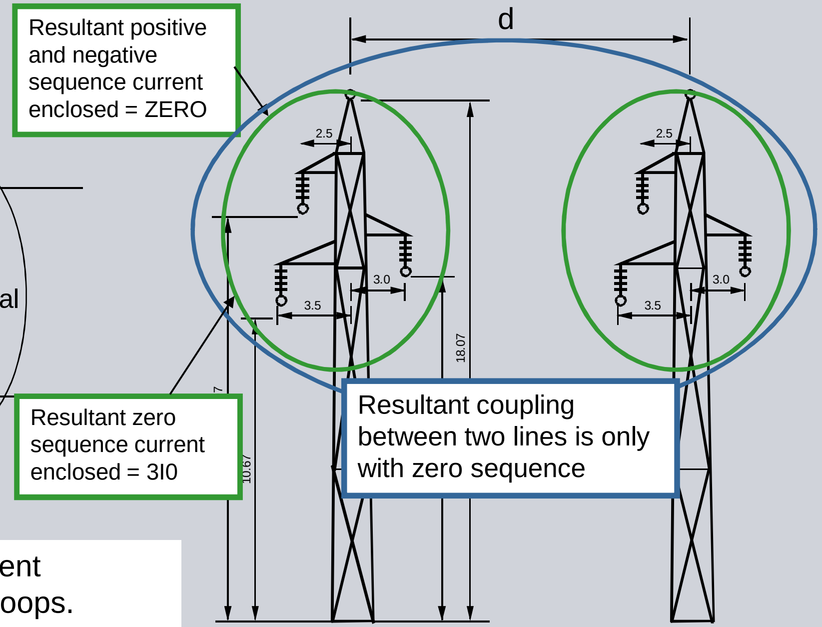
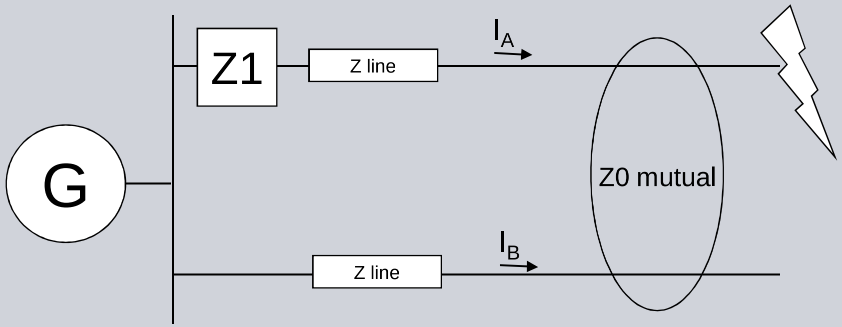
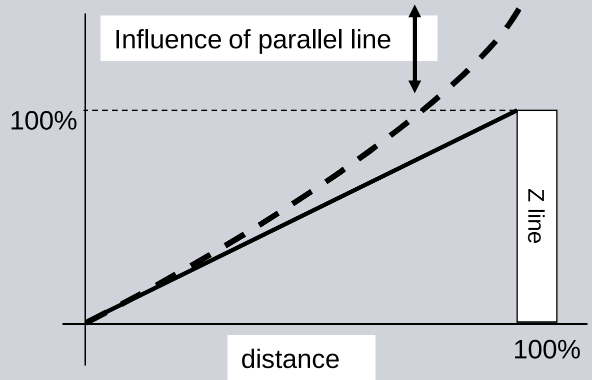




Coupling of the parallel feeders for zero sequence current influences the measured fault impedance with ground loops.

Parallel lines: Influence on distance measurement





The loop voltage measured by Z1 for a single phase to ground fault as shown:

$$U_{L-G} = I_L \cdot Z_{Line} - I_{E\_A} \cdot Z_E - I_{E\_B} \cdot \frac{Z0_M}{3}$$

The measured loop impedance:

$$Z_{L-G} = Z_{Line} - \frac{I_{E\_B} \cdot \frac{Z0_M}{3}}{I_L - K0 \cdot I_{E\_A}}$$

Parallel lines: Compensation with modified XE/XL

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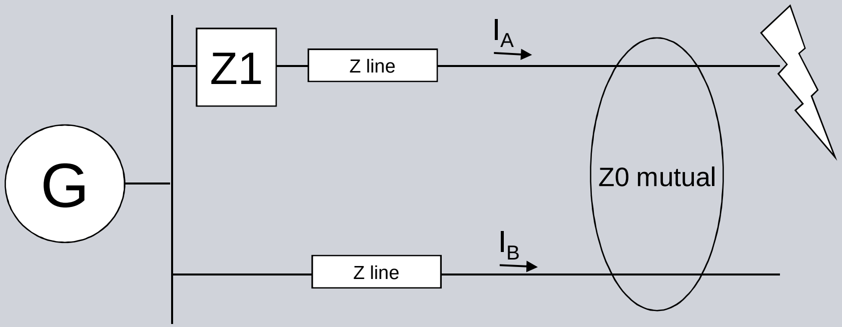

For compensation, influence of the parallel by $X0_M$ is considered:

$$U_{L-G} = I_L \cdot X_L - I_{E\_A} \cdot X_E - I_{E\_B} \cdot \frac{X0_M}{3}$$

$$K_{X0} = \frac{XE}{XL}$$

$$K_{X0M} = \frac{X0_M}{3XL}$$

$$r_{I0} = \frac{I_{E\_B}}{I_{E\_A}}$$

$$K_{X0}' = K_{X0} + K_{X0M} \cdot r_{I0}$$

The measured loop reactance with modified XE/XL=K_{X0}':

$$X_{L-G} = \frac{I_L \cdot X_L - I_{E\_A} \cdot X_E - I_{E\_B} \cdot \frac{X0_M}{3}}{I_L - K0' \cdot I_{E\_A}} = X_{Line}$$

Parallel lines: Compensation with measured IE of parallel line

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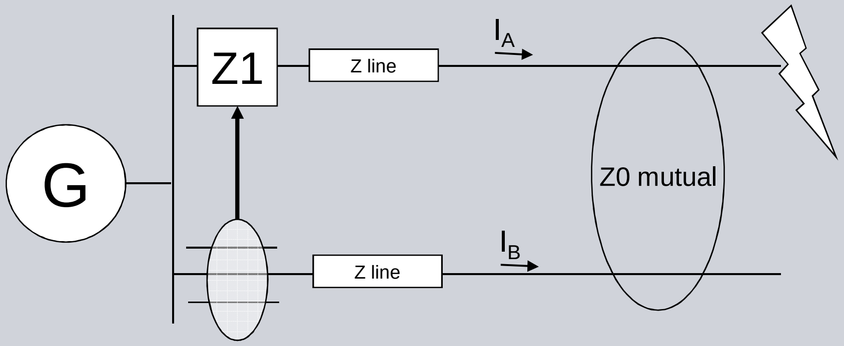

The loop voltage measured by Z1 for a single phase to ground fault as shown:

$$U_{L-G} = I_L \cdot Z_{Line} - I_{E\_A} \cdot Z_E - I_{E\_B} \cdot \frac{Z0_M}{3}$$

The measure loop impedance with modified parallel line compensation:

$$Z_{L-G} = \frac{I_L \cdot Z_{Line} - I_{E\_A} \cdot Z_E - I_{E\_B} \cdot \frac{Z0_M}{3}}{I_L - K0 \cdot I_{E\_A} - K0M \cdot I_{E\_B}} = Z_{Line}$$

Distance measurement
Fault loop formulas

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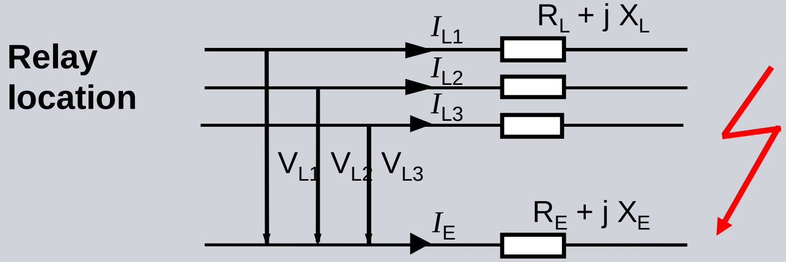

Phase-to-Earth loop:

$$\underline{V}_{L1} = \underline{I}_{L1} \cdot (R_L + jX_L) - \underline{I}_E \cdot (R_E + jX_E)$$

$$\underline{V}_{L1} = (\underline{I}_{L1} \cdot R_L - \underline{I}_E \cdot R_E) + j(\underline{I}_{L1} \cdot X_L - \underline{I}_E \cdot X_E)$$

$$\underline{V}_{L1} = R_L \cdot \left(\underline{I}_{L1} - \frac{R_E}{R_L} \cdot \underline{I}_E \right) + jX_L \left(\underline{I}_{L1} - \frac{X_E}{X_L} \cdot \underline{I}_E \right)$$

Line and earth impedance are measured

Phase-to-Phase loop: $$\underline{V}_{L1-L2} = (R_L + jX_L) \cdot (\underline{I}_{L1} - \underline{I}_{L2})$$

Only the Line impedance is measured

(Ph-E-loop) - influence of fault resistance with setting RE/RL and XE/XL - Siemens method

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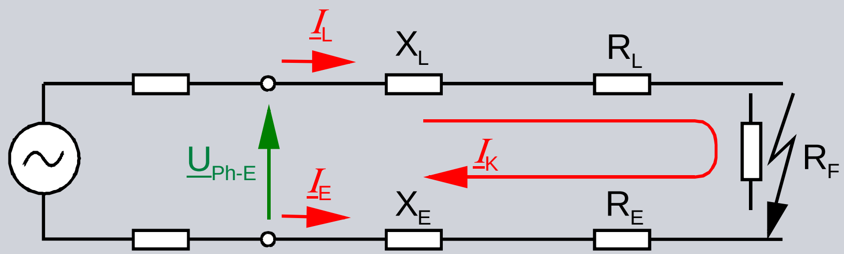

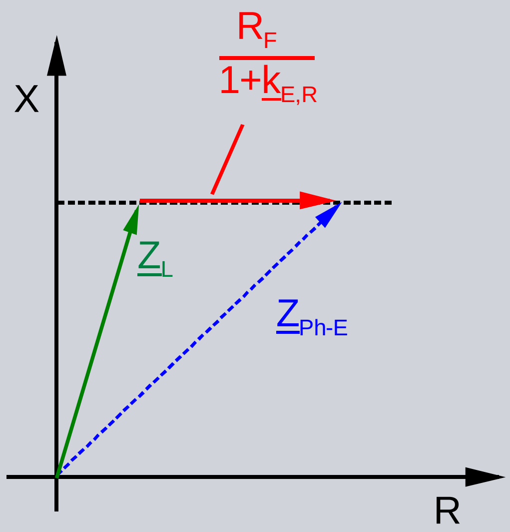

$$\underline{U}_{Ph-E} = \underline{I}_L (\underline{R}_L + j\,\underline{X}_L) - \underline{I}_E (\underline{R}_E + j\,\underline{X}_E) + R_F \cdot \underline{I}_L$$

$$X_{Ph\text{-}E} = \frac{\mathrm{Im}\left[\frac{\underline{U}_{Ph-E}}{\underline{I}_L}\right]}{1 + \frac{X_E}{X_L}} = X_L$$

$$R_{Ph\text{-}E} = \frac{\mathrm{Re}\left[\frac{\underline{U}_{Ph-E}}{\underline{I}_L}\right]}{1 + \frac{R_E}{R_L}} = R_L + \frac{R_F}{1 + k_{E,R}}$$

with $I_E = - I_L$

No measuring error in the X-direction

(Ph-E-loop) - influence of fault resistance with separation of fault and line resistance - Not Siemens method

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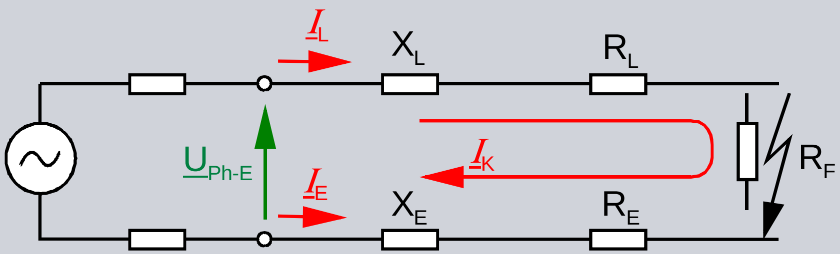


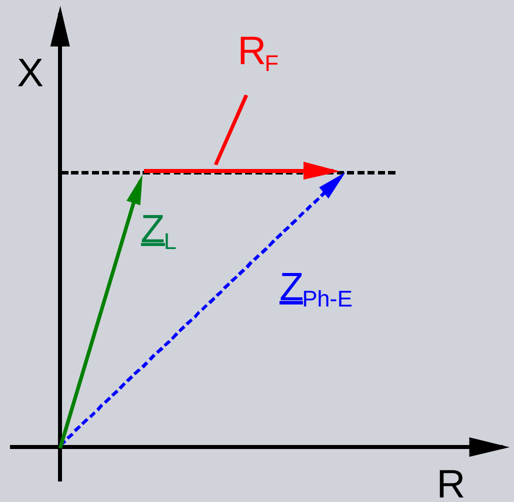
$$\underline{U}_{Ph-E} = \underline{I}_L(\underline{R}_L + j\,\underline{X}_L) - \underline{I}_E(\underline{R}_E + j\,\underline{X}_E) + R_F \cdot \underline{I}_L$$

$$X_{TypeC} = \frac{\mathrm{Im}\{\underline{U}/\underline{I}\}}{1+K_x} = X_L$$

with $I_E = - I_L$

$$R_{TypeC} = \mathrm{Re}\{\underline{U}/\underline{I}\} - X_{TypeC}/\tan(\varphi_L)\cdot K_r$$

$$R_{TypeC} = R_L + R_F$$



Note difference in fault resitance coverage with same zone setting!

(Ph-E-loop) - influence of fault resistance with complex KO setting - Not Siemens method

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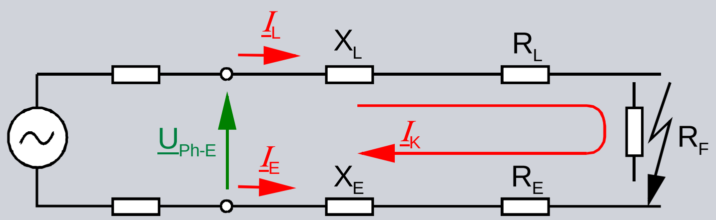
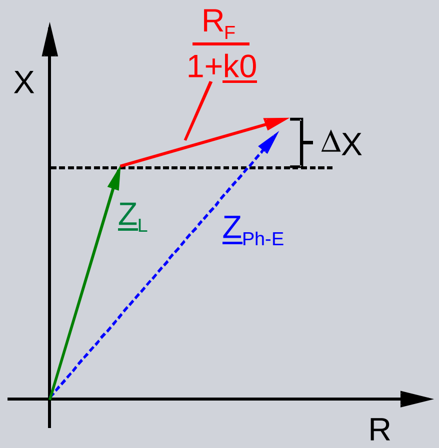


This method is not used by SIEMENS



$$\underline{U}_{Ph-E} = \underline{I}_L\left(\underline{Z}_L + \underline{Z}_E\right) + R_F \cdot \underline{I}_L \quad \text{assume} \quad \underline{I}_L = -\underline{I}_E$$

$$\underline{Z}_{Ph-E} = \frac{\underline{U}_{Ph-E}}{\underline{I}_L - \underline{k0} \cdot \underline{I}_E} = \underline{Z}_L \cdot \frac{1+\frac{\underline{Z}_E}{\underline{Z}_L}}{1+\underline{k0}} + \frac{R_F}{1+\underline{k0}}$$

If $\underline{k0}$ setting adapted to $\frac{\underline{Z}_E}{\underline{Z}_L}$, then $\underline{Z}_{Ph-E} = \underline{Z}_L + \frac{R_F}{1+\frac{\underline{Z}_E}{\underline{Z}_L}} = \underline{Z}_L + \frac{R_F}{1+\left|\frac{\underline{Z}_E}{\underline{Z}_L}\right| \cdot e^{j(\varphi_E-\varphi_L)}}$

➡ Also an additional measuring error in the X-direction