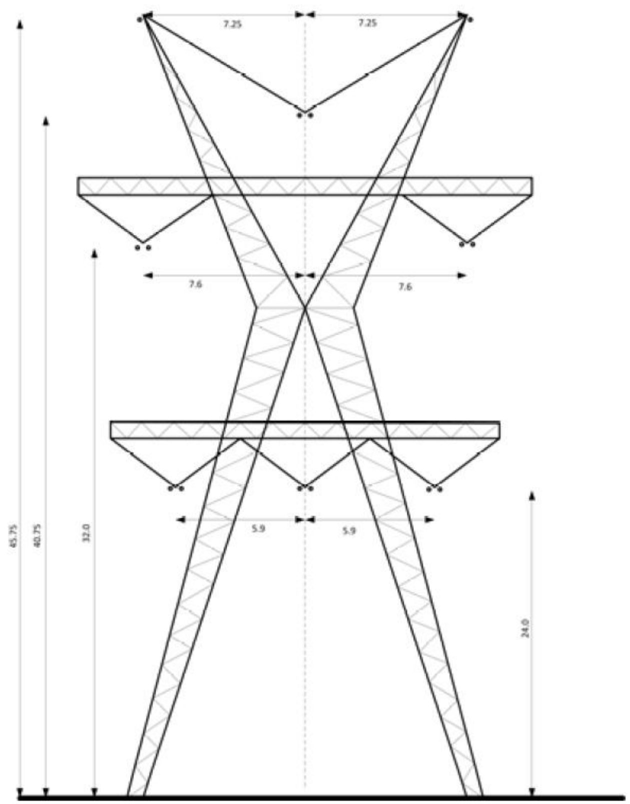
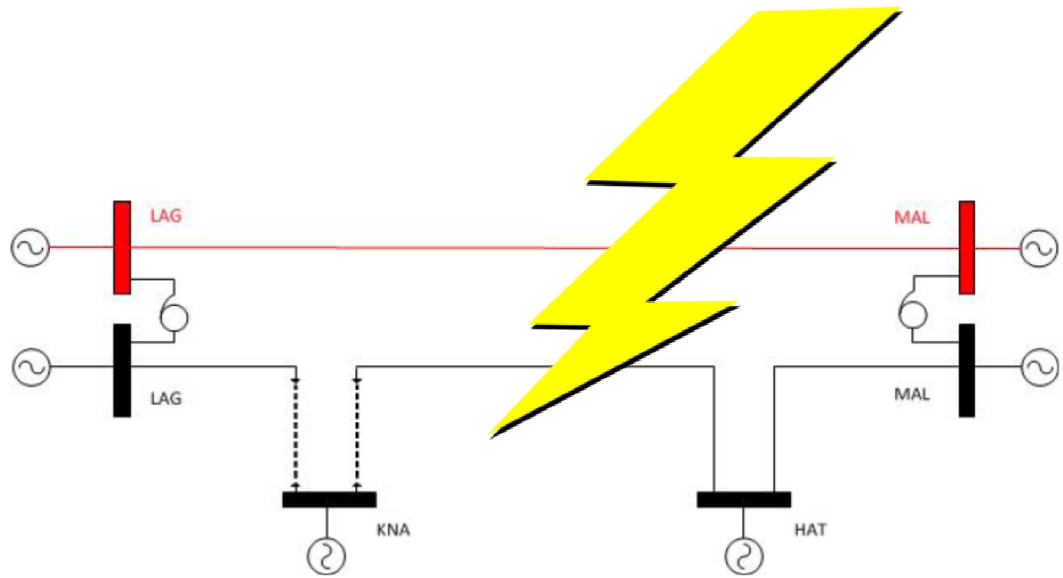
Inter-circuit faults (AC-AC)





By professor Claus Leth Bak
Department of Energy Technology
Aalborg University

Inter-circuit faults (AC-AC)

HISTORY

This research project came up on the basis of a real case from TSO Energinet.dk which related to a number of 400-150 kV inter-faults in the winter of 2013.

Distance protection did not operate fully as would be expected.

Ragnar Sigurbjörnsson, a former Masters student took this challenge for his masters thesis work and did a fine job ☺

His results were published in the DPSP 2016.

Following this Filipe da Silva and I continued working on the topic establishing a thorough analytical modeling and detailed case study in order to have a generally applicable protection setting philosophy for combined OHL's.

Inter-circuit faults (AC-AC)

RESEARCH PUBLICATIONS

- Combined fault of 400 and 150 kV overhead lines, a masters thesis by Ragnar Sigurbjörnsson, 2015.
- Distance Protection Impedance Measurement for Inhomogeneous Multiple-Circuit 400/150 kV Transmission Lines with Shared Towers, C. Leth Bak,R. Sigurbjörnsson, B. S. Bukh, R. Post, DPSP 2016.
- Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.
- Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.
- Distance protection of multiple-circuit shared tower transmission lines with different voltages and underground cable sections, F. Faria da Silva, C. Leth Bak and Bjarne Bukh, Cigré GM 2018 (submitted synopsis).

Inter-circuit faults (AC-AC)

The transmission network in Europe is undergoing major changes in order to be able to accomodate the increase in renewable sources. Right-of-way and public acceptance plays an important role in being able to reinforce/restructurize the power grid. One way to utilize transmission corridors more efficiently is to have several three-phase systems in the same tower. This can be multiple AC and DC circuits or AC circuits with different system voltages.

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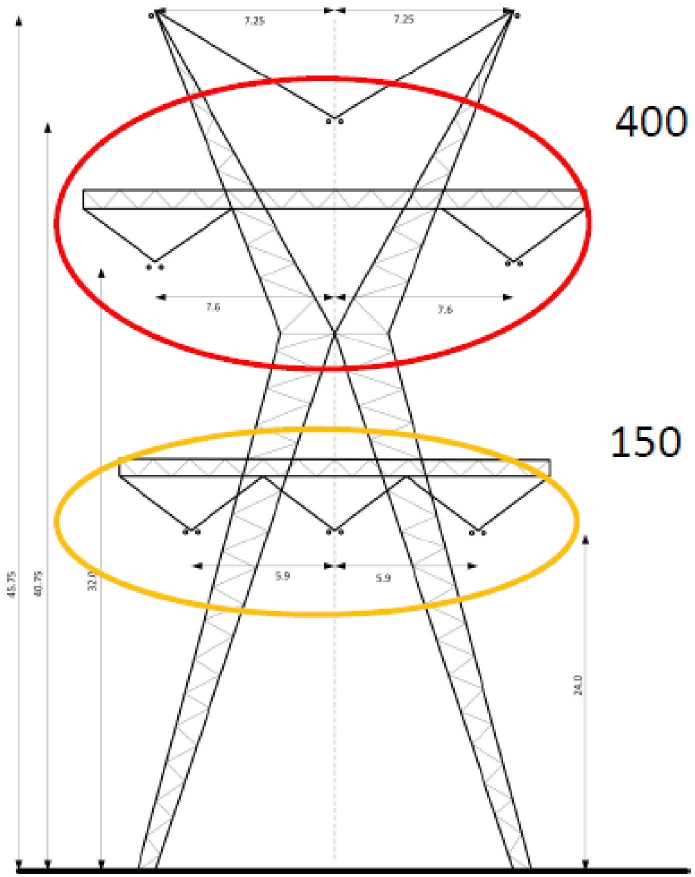
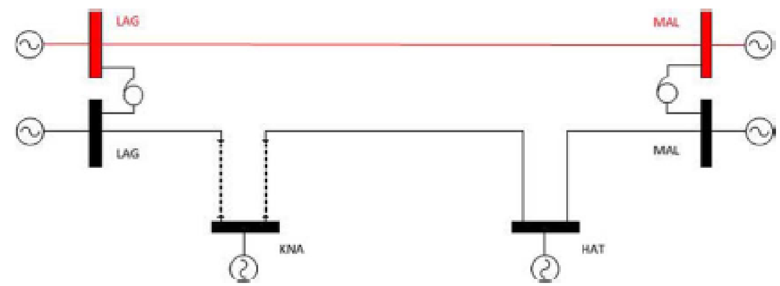
Inter-circuit faults (AC-AC)

400/150 kV OHL Landerupgaard-Malling LAG-MAL



400 kV

150 kV

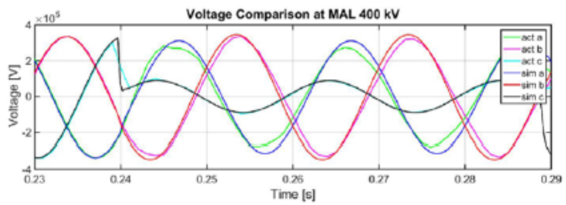


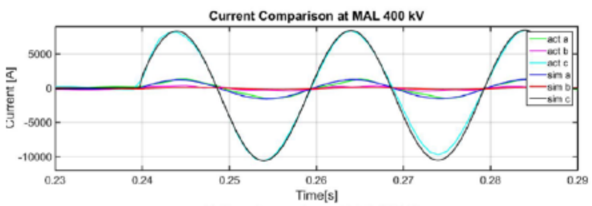
Line length of 400 kV (red) is 78,21 km
and the line lengths of the 150 kV (black) are:

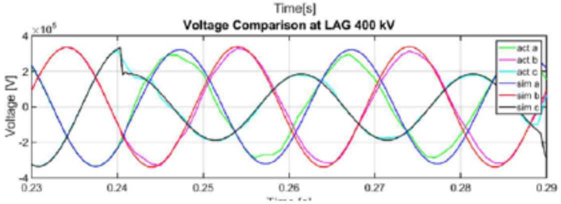
1. LAG to KNA 20.16 km overhead line and a 1.1 km cable section
2. KNA to HAT 1.23 km cable section and a 24.21 km overhead line
3. HAT to MAL 33.84 km overhead line

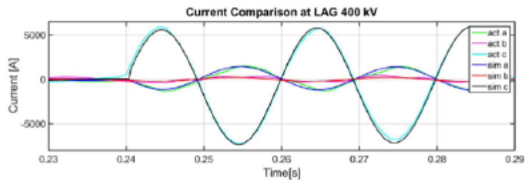
Inter-circuit faults (AC-AC)

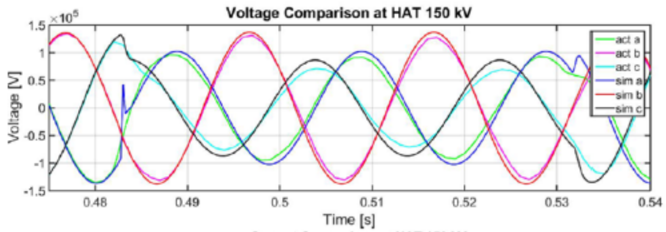
A detailed PSCAD model of the combined LAG-MAL 400/150 kV line including autotransformers in LAG and MAL and short circuit power infeed in six locations (LAG and MAL 400 kV and LAG, KNA, HAT and MAL 150 kV) is constructed.

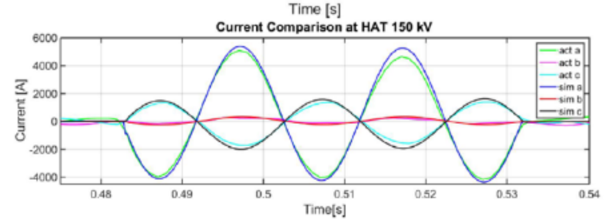












It is noted the complexity of the fault current distribution and the fact that a fault between c-phase in 400 kV and a-phase in 150 kV gives rise to changes in currents and voltages in all phases. This in hand leads to an expectation that both phase-phase as well as phase-earth fault loops will measure varying impedances during faults which are not easily interpreted by the relays with regards to faulted phase and/or impedance location in the impedance plane (zone settings).

Distance Protection Impedance Measurement for Inhomogeneous Multiple-Circuit 400/150 kV Transmission Lines with Shared Towers, C. Leth Bak,R. Sigurbjörnsson, B. S. Bukh, R. Post, DPSP 2016

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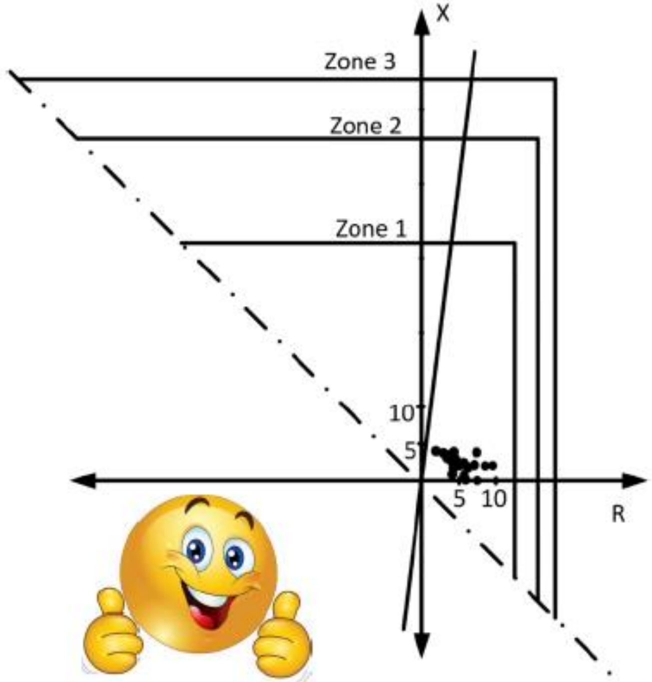
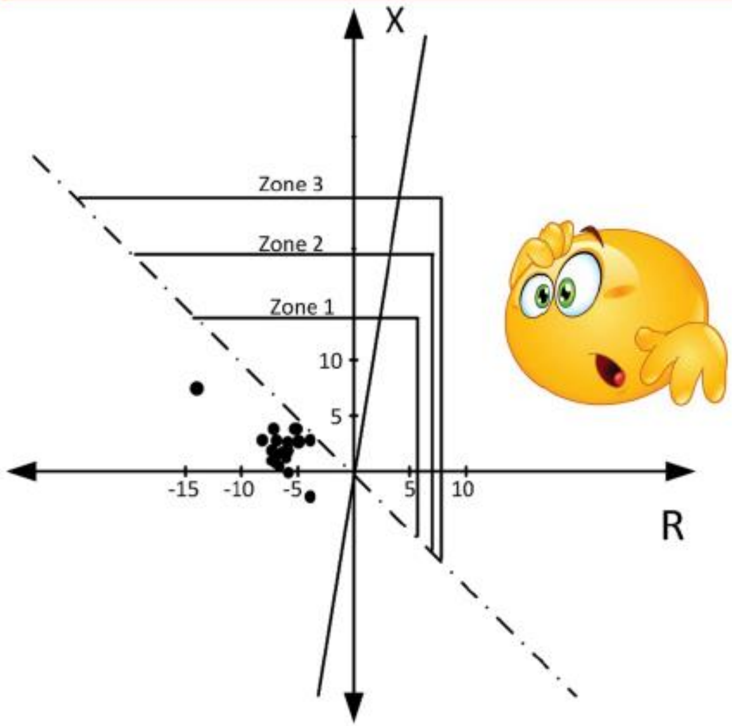
Inter-circuit faults (AC-AC)

Measured fault loop impedance (L-E) in MAL system I (400 kV) when varying parameters



Measured fault loop impedance (L-E) in HAT system II (150 kV) when varying parameters



Distance Protection Impedance Measurement for Inhomogeneous Multiple-Circuit 400/150 kV Transmission Lines with Shared Towers, C. Leth Bak,R. Sigurbjörnsson, B. S. Bukh, R. Post, DPSP 2016

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Inter-circuit faults (AC-AC)

The DPSP paper and Ragnars work was for one SPECIFIC case!

It showed that distance protection setting for combined lines are not straightforward. How to assure equally good performance of distance protection as compared to usual only-one voltage level cases?

How about a generic Inhomogeneous Multiple-Circuit 400/150 kV Transmission Line with Shared Towers?

Is it possible to put up some kind of generally applicable setting guidelines for such transmission lines?

And can such settings be an integral part of the normal settings?

A thorough analytical analysis is needed to reply to this.

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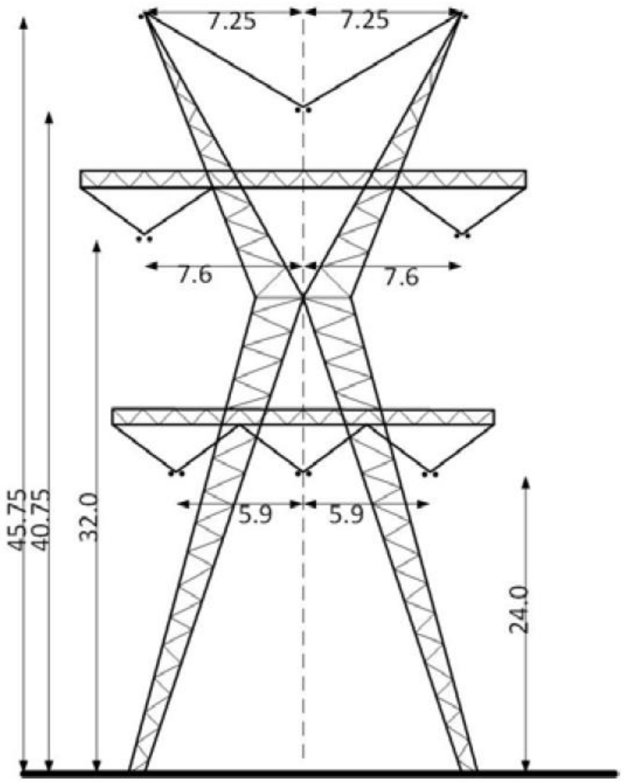
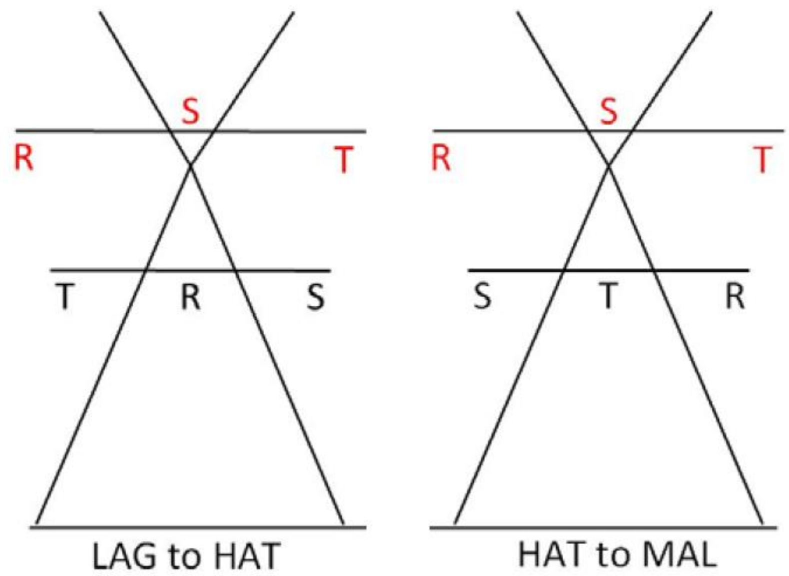
Inter-circuit faults (AC-AC)

We need an analytical model of this based on sequence components

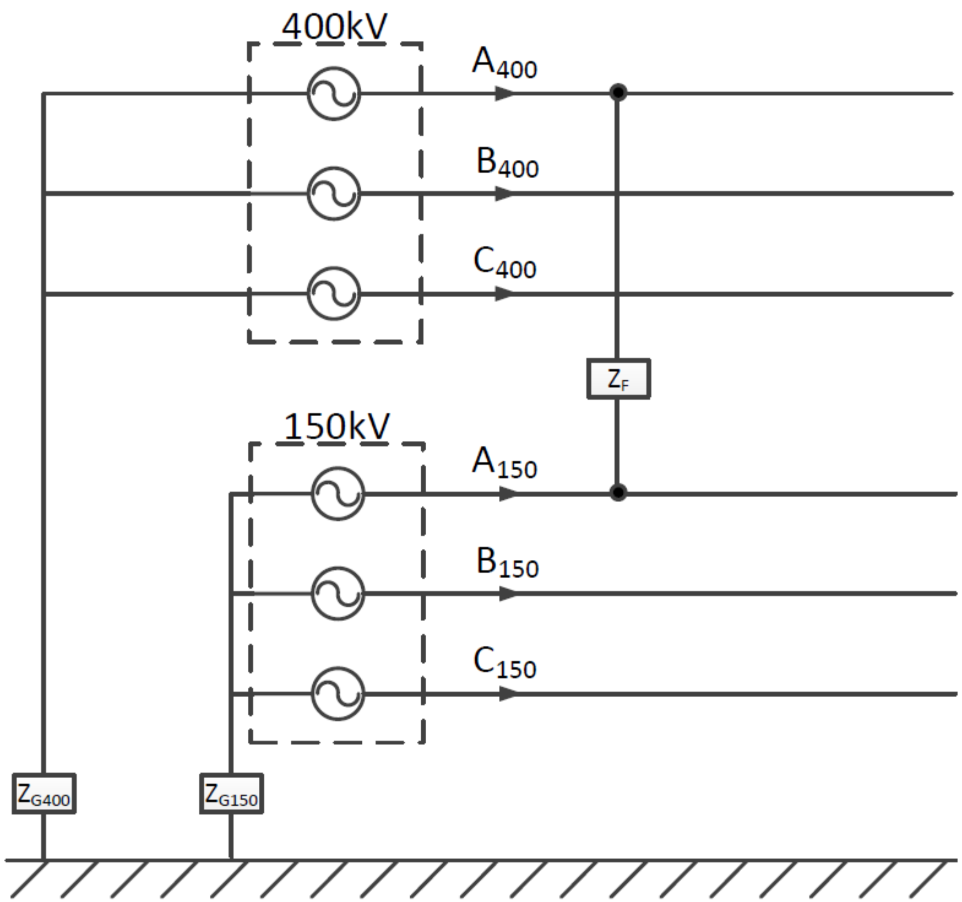




Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)

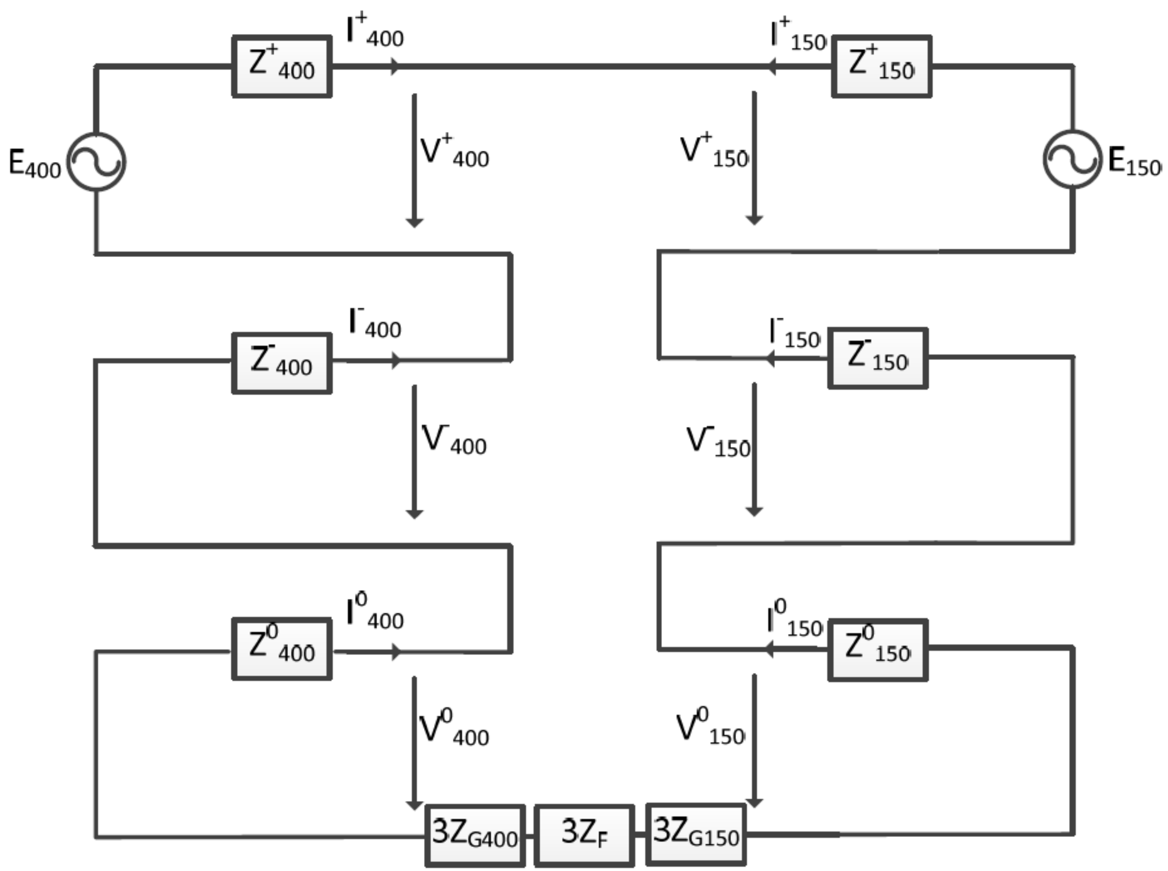
Equivalent scheme for combined fault – transformer neglected



Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)

Model in sequence components



Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

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Inter-circuit faults (AC-AC)

1. Neglecting the mutual coupling

$$I_{400}^{+} = I_{400}^{-} = I_{400}^{0} = \frac{E_{400} - E_{150}}{Z_{400}^{+} + Z_{150}^{+} + Z_{400}^{-} + Z_{150}^{-} + Z_{400}^{0} + Z_{150}^{0} + 3\left(Z_F + Z_{G400} + Z_{G150}\right)}$$

2. Including mutual coupling

$$I_{400}^{+} = I_{400}^{-} = I_{400}^{0} = \frac{E_{400} - E_{150}}{Z_{400}^{+} + Z_{150}^{+} + Z_{400}^{-} + Z_{150}^{-} + Z_{400}^{0} + Z_{150}^{0} + 3\left(Z_F + Z_{G400} + Z_{G150}\right) - 2\times\left(3Z_M\right)}$$

Both are shown to give a good agreement as compared to detailed PSCAD studies using a variety of parameter cases.

So we can use these equations to analyze combined faults and hopefully lay down a strategy for distance relay setting.

Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

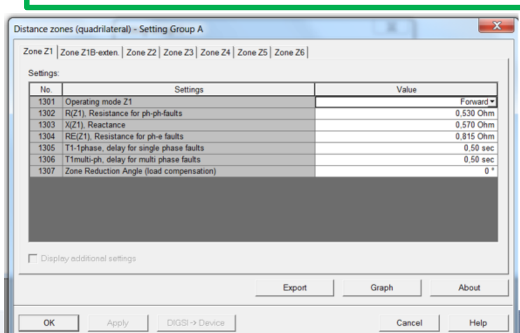
Inter-circuit faults (AC-AC)

Distance relays have phase-phase and phase-earth fault loops.

Hypothesis: Is it possible to use one or both of these and using almost ”normal” settings to achieve coverage for combined faults?

To reply to this we must analyze the equations from a theoretical point of view and compare to Single Phase To Ground SPTG faults.

The result shows that the magnitude of the fault current of a combined fault can be bigger or lower than of a SPTG fault, but it is expected to be larger than for the former if the short-circuit power is not infinite



Distance zones (quadrilateral) - Setting Group A

Zone Z1 | Zone Z1B-exten. | Zone Z2 | Zone Z3 | Zone Z4 | Zone Z5 | Zone Z6

Settings:

No.	Settings	Value
1301	Operating mode Z1	Forward
1302	R(Z1), Resistance for ph-ph-faults	0,530 Ohm
1303	X(Z1), Reactance	0,570 Ohm
1304	RE(Z1), Resistance for ph-e faults	0,815 Ohm
1305	T1-1phase, delay for single phase faults	0,50 sec
1306	T1multi-ph, delay for multi phase faults	0,50 sec
1307	Zone Reduction Angle (load compensation)	0 °

Display additional settings

Export | Graph | About

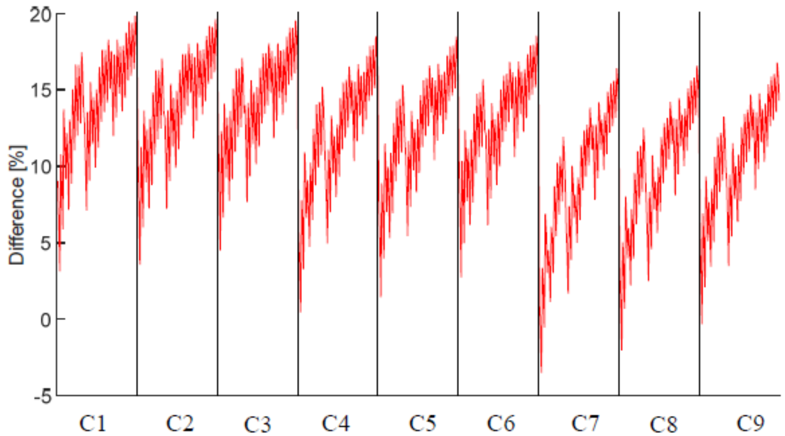
OK | Apply | DIGSI -> Device | Cancel | Help

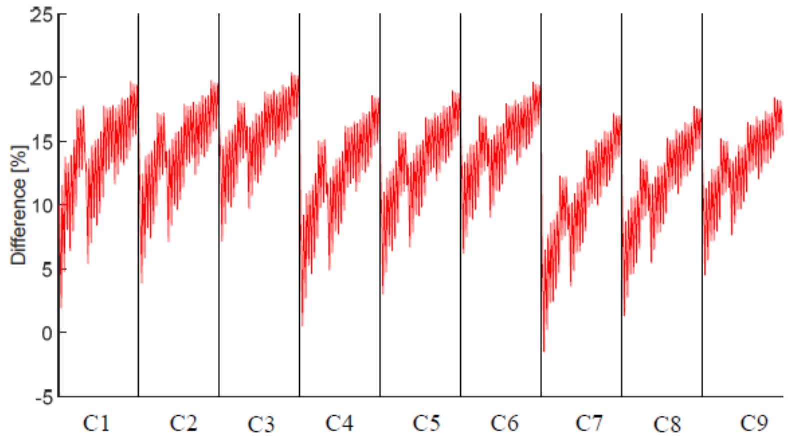
Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)

Sensitivity study – varying the ratios of short circuit powers

	C1	C2	C3	C4	C5	C6	C7	C8	C9
400 kV	500	500	500	2000	2000	2000	6000	6000	6000
150 kV	500	2000	6000	500	2000	6000	500	2000	6000





Graph shows DIFFERENCE between fault current in SPTG fault as compared to an inter-fault between 400 kV and 150 kV. Almost always larger!!

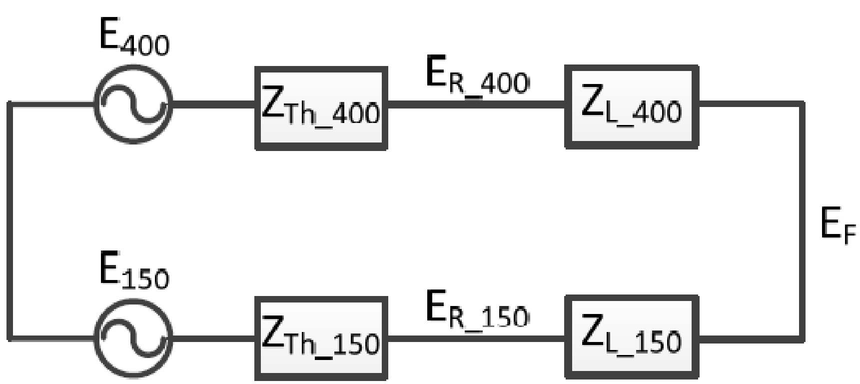
Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part I: Fault current magnitude, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)

Next step is to conduct a theoretical analysis of the expected location of the impedance in the R-X plane for a combined fault, as compared to a SPTG fault.

$$I^{+}_{400\_CF} = \frac{E_{400} - E_{150}}{Z^{+}_{400} + Z^{+}_{150} + Z^{-}_{400} + Z^{-}_{150} + Z^{0}_{400} + Z^{0}_{150} + 3\left(Z_F + Z_{G400} + Z_{G150}\right) - 2\times\left(3Z_M\right)}$$

$$I^{+}_{400\_\mathrm{SPTGF}} = \frac{E_{400}}{Z^{+}_{400} + Z^{-}_{400} + Z^{0}_{400} + 3\left(Z_F + Z_{G400}\right)}$$

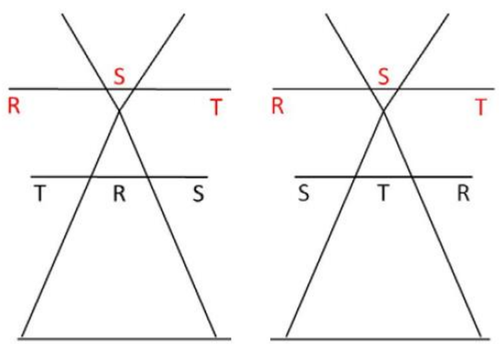


Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

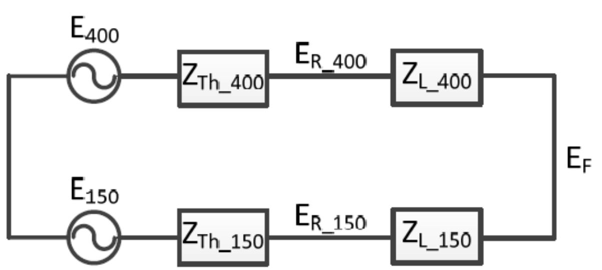
Inter-circuit faults (AC-AC)

Expected behaviour for a combined fault when the faulted phase from the higher voltage level **leads** the faulted phase from the lower voltage level

	Higher voltage leads
Higher voltage level	Sees fault in forward direction
Lower voltage level	Sees fault in reverse direction
Impedance real part (HV relay)	More resistive as short-circuit power decreases
Impedance imaginary part (HV relay)	Inductance decreases and eventually capacitive as short-circuit power decreases



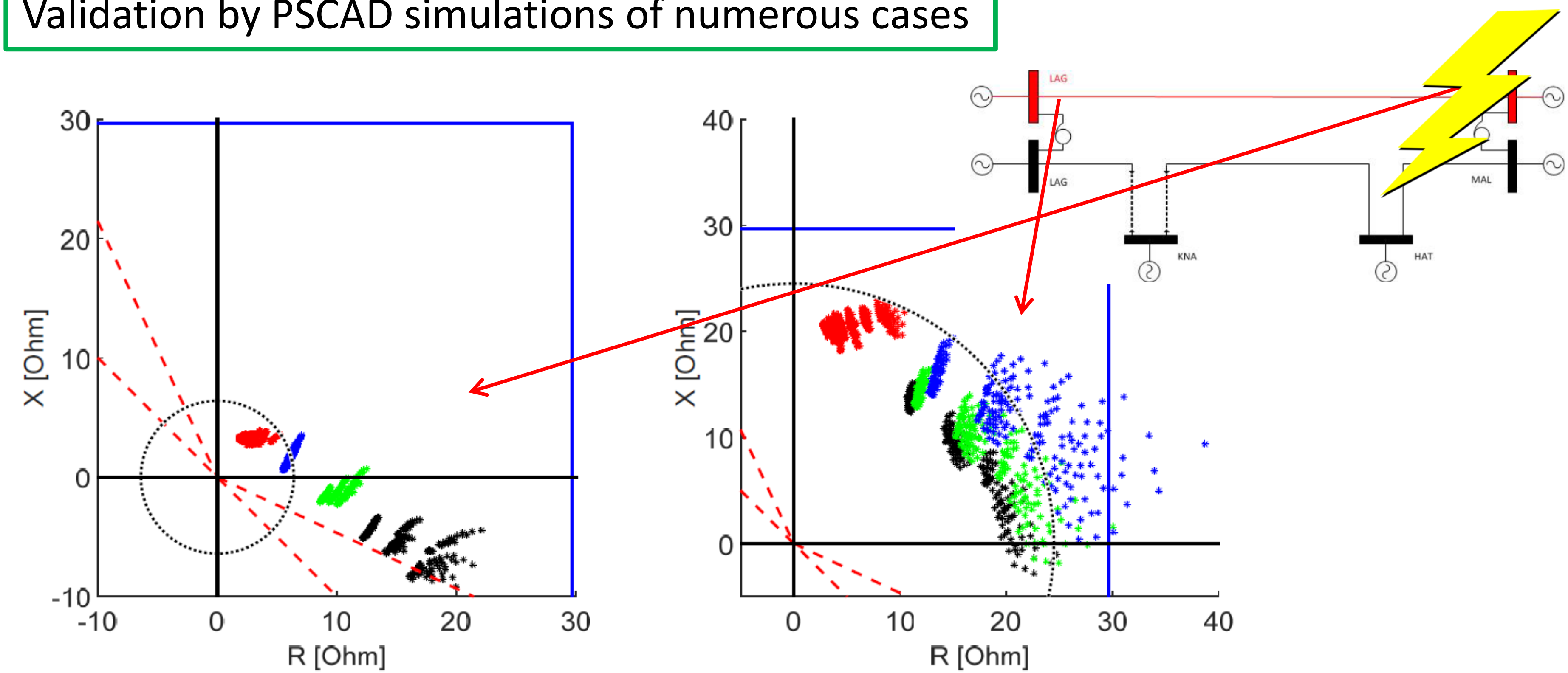
LAG to HAT HAT to MAL



Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)

Validation by PSCAD simulations of numerous cases



Fault loop impedance at MAL (left) and LAG (right) for a SPTG fault (red stars) and a combined fault (remaining colours) at 10km from MAL, with the **higher voltage level leading**. Blue lines: Z1 extended zone for autoreclosure for R/X=1. Circular black dots: Largest impedance of the SPTG fault.

Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

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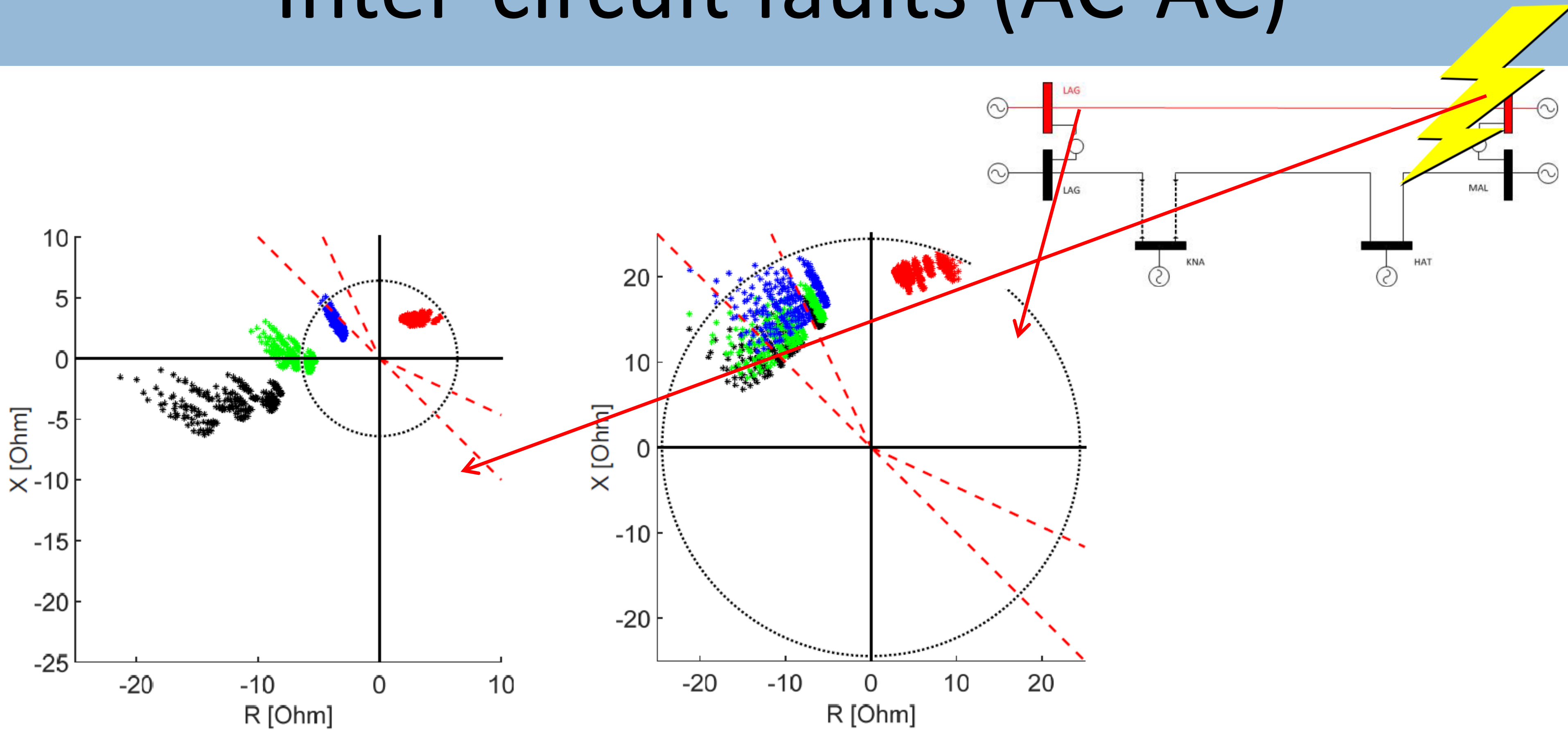
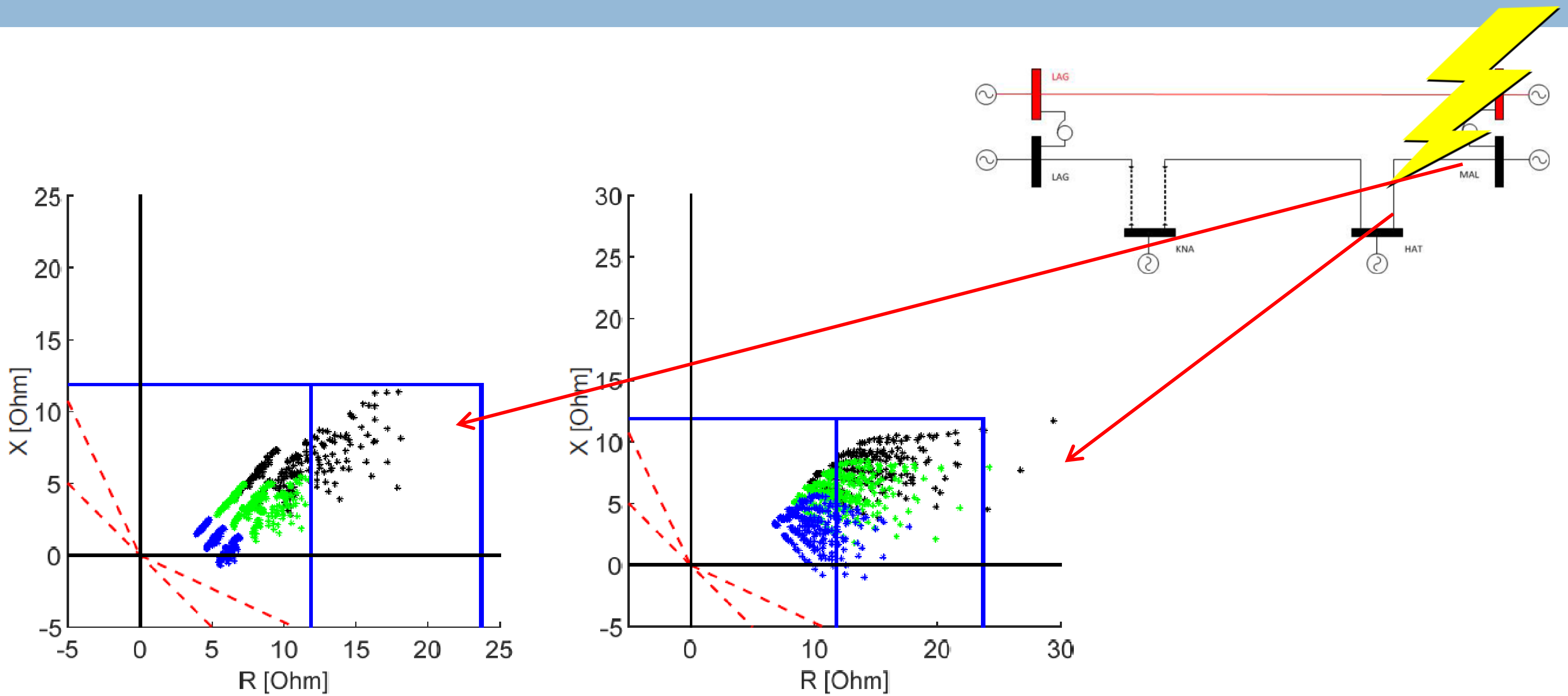
Inter-circuit faults (AC-AC)



Fault loop impedance at MAL (left) and LAG (right) for a SPTG fault (red stars) and a combined fault (remaining colours) at 10km from MAL, with the **higher voltage level lagging.** Blue lines: Z1 extended zone for autoreclosure for R/X=1. Circular black dots: Largest impedance of the SPTG fault

Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)



Fault loop impedance at MAL-150kV (left) and HAT (right) for a combined fault at 10km from MAL, with the higher voltage level lagging. Blue lines: Z1 extended zone for autoreclosure for R/X=1 and R/X=2

Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.

Inter-circuit faults (AC-AC)

Conclusions

Based on the theory and demonstrations previously done it is suggested that the best way to protect against inter-faults in transmission lines with different voltages is to have a preventive attitude when connecting the phases and to assure that any prospective combined faults can only occur with the higher voltage level leading the lower voltage level.

Be careful to select R/X not too small (i.e. 1-2 at least).

The unbalancing of the lines is still minimised and the distance relays at the higher voltage level assure the clearing of the fault by seeing it as a SPTG fault, with a higher level of certainty.

Distance protection of multiple-circuit shared tower transmission lines with different voltages. Part II: Fault loop impedance, F. Faria da Silva and C. Leth Bak, IET GTD journal 2016.