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Protection of Medium and Low Voltage DistributionSystems

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- Typical Calculation procedures
- Protection Principles and Co-ordination:
  - Overcurrent Protection (relay, MCB, fuses)
  - Distance Protection

Urban network structure

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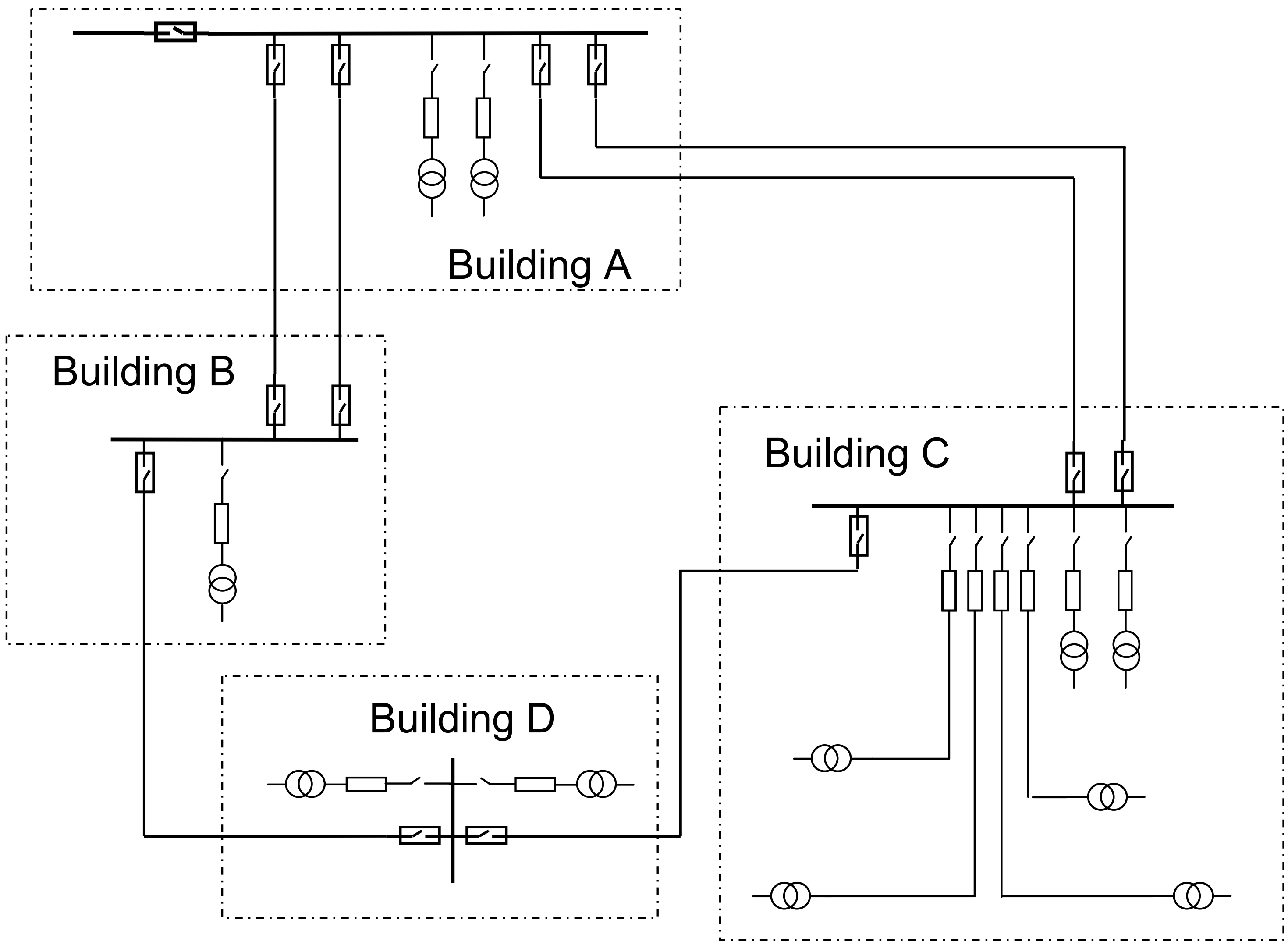

Industrial network structures

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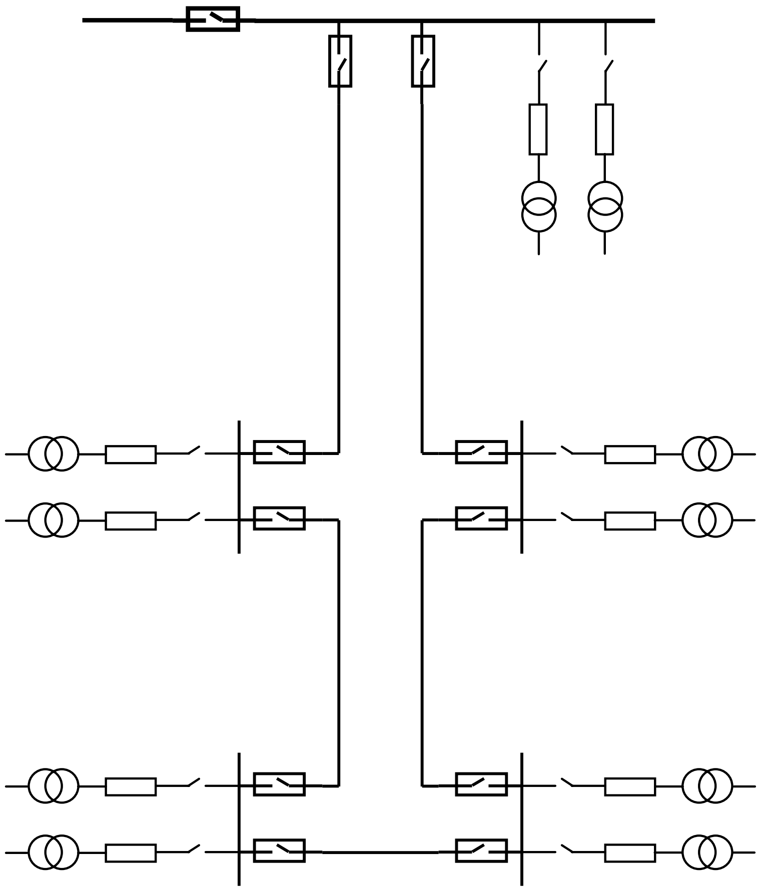
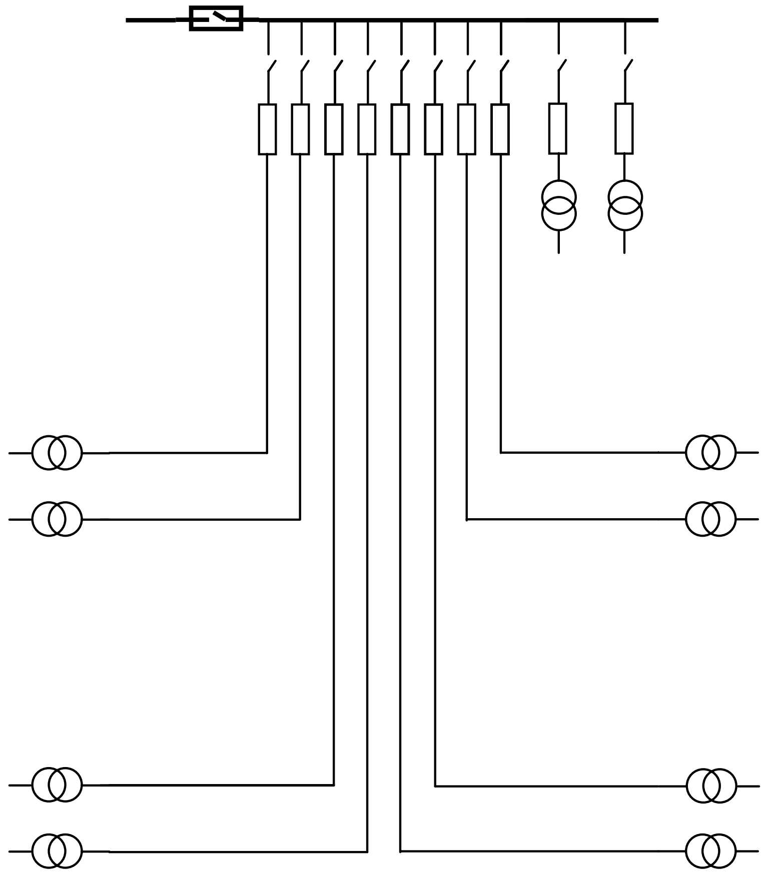
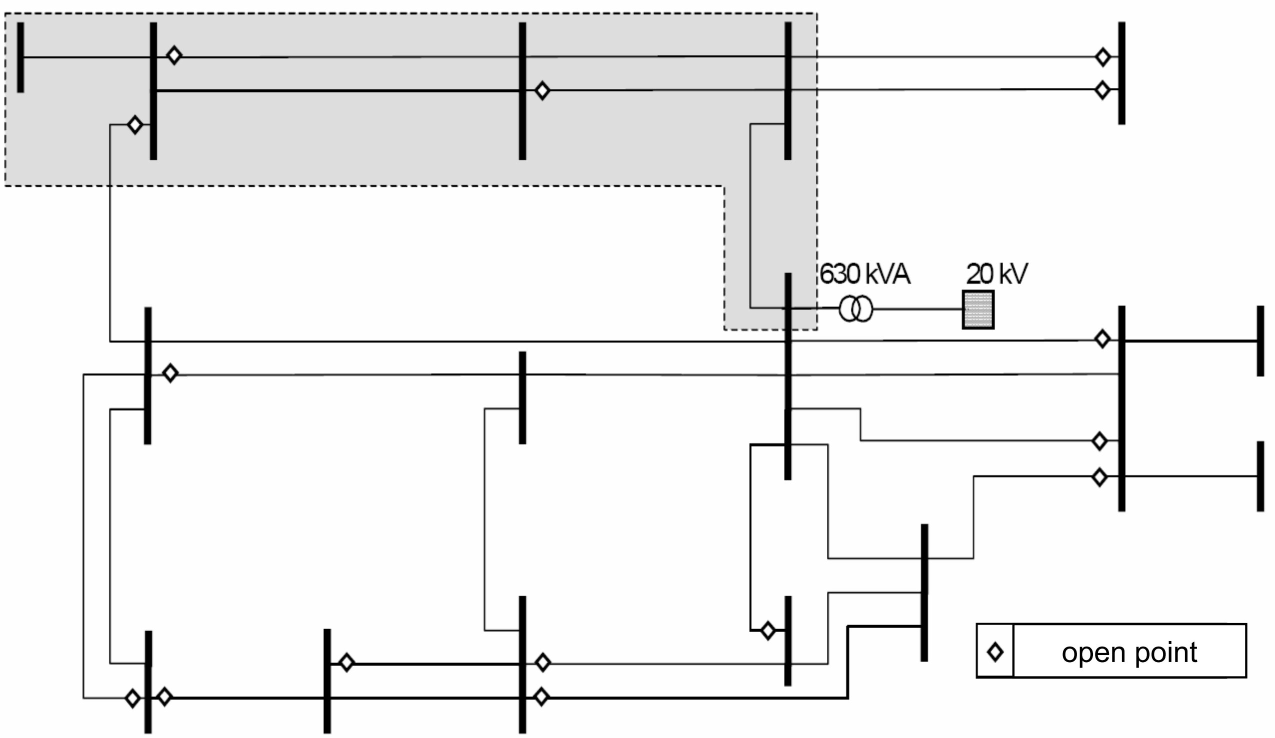
Ring network



Central substation



Urban low voltage network



400 V three phases

Meshed systems – radial systems

Typical Calculation Procedures

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Short-circuit current calculations

$U_0 = U_n/\sqrt{3}$

$$I_{k\,3p.} = \frac{U_0}{Z_1}$$

$$I_{k\,2p.} = \frac{\sqrt{3}\;U_0}{Z_1 + Z_2} = \frac{\sqrt{3}\;U_0}{2\;Z_1} = \frac{\sqrt{3}}{2}\frac{U_0}{Z_1} = \frac{\sqrt{3}}{2}\,I_{k\,3p.}$$

$$(Z_1 = Z_2)$$

$$I_{k\,1p.} = \frac{3\;U_0}{Z_1 + Z_2 + Z_0} = \frac{3\;U_0}{6\;Z_1} = \frac{1}{2}\frac{U_0}{Z_1} = \frac{1}{2}\,I_{k\,3p.}$$

$$(Z_0 = 4\,Z_1)$$

Simple Short - Circuit Calculation

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Netz / network $$Z_n = \frac{c\,U_n^2}{S_k''}$$

Trafo / transformer $$Z_t = \frac{u_k\;U_n^2}{100\;S_{nt}}$$

Strom / current $$I_{k3p.} = \frac{S_k''}{U_n\sqrt{3}}$$

Daten / data

$S_k'' = 300$ MVA

c = 1 LV

c = 1.1 MV

20 / 0.4 kV, 630 kVA, 6 %

Berechnung / calculation

$$Z_n = \frac{c\,U_n^2}{S_k''} = \frac{1\quad 0.4^2}{300} = \frac{0.16}{300} = 0.00053 \text{ (OHM)}$$

$$Z_t = \frac{u_k\;U_n^2}{100\;S_{nt}} = \frac{6\quad 0.4^2}{100\quad 0.63} = \frac{6\;\;0.16}{63} = 0.01524 \text{ (OHM)}$$

$$Z_{SUM.}\quad 0.01577 \text{ (OHM)}$$

$$S_k'' = \frac{c\,U_n^2}{Z_{sum}} = \frac{1\quad 0.4^2}{0.01577} = 10.14585 \text{ (MVA)}$$

$$I_{k3p.} = \frac{S_k''}{U_n\sqrt{3}} = \frac{10.14785}{0.4\;\sqrt{3}} = 14.64 \text{ (kA)}$$

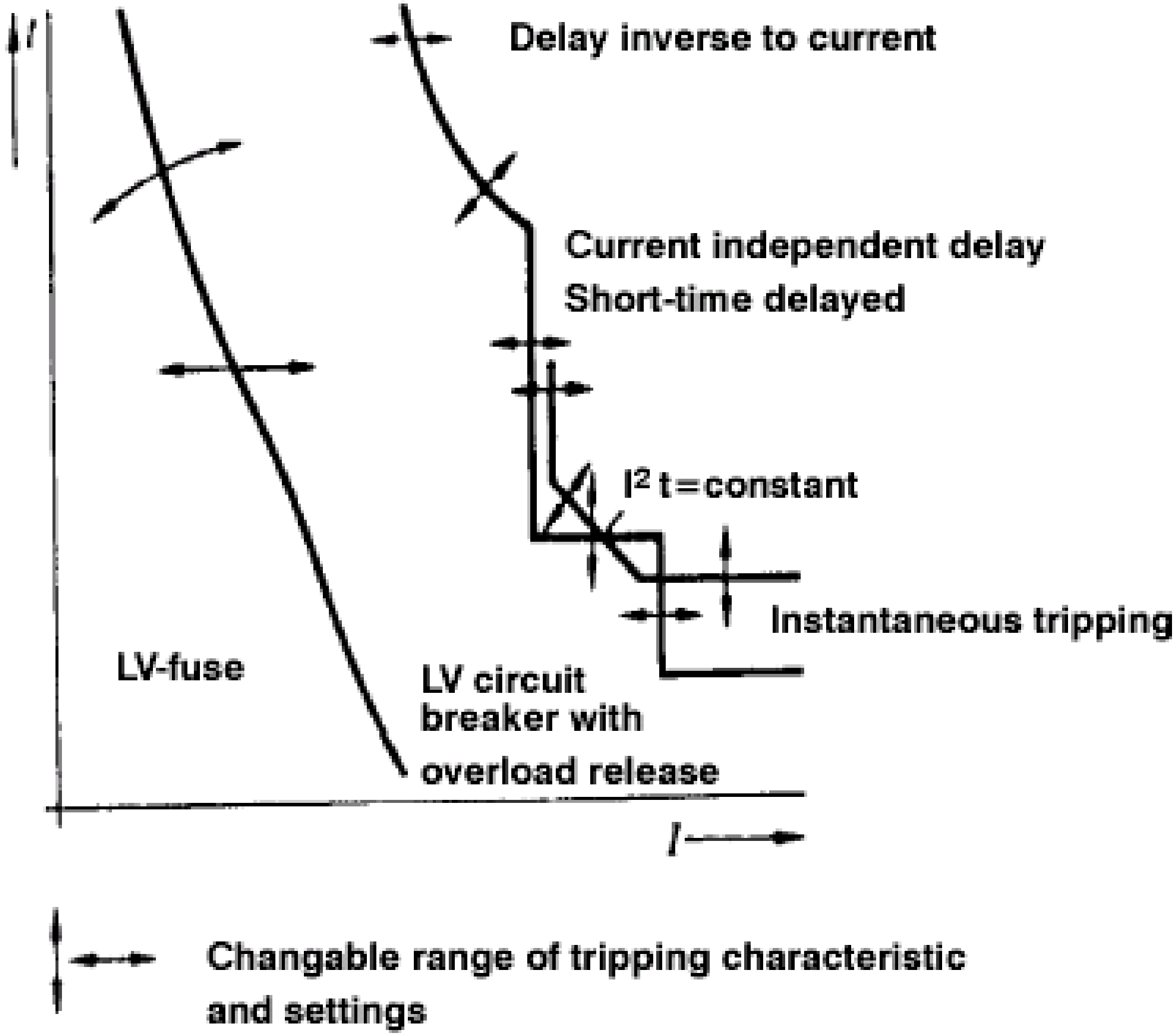
--> 20 kV

$$14.64\text{ (kA)}\;\frac{0.4\text{ (kV)}}{20\text{ (kV)}} = 0.2928 \text{ (kA)}$$

Protection Principles and Co-ordination:

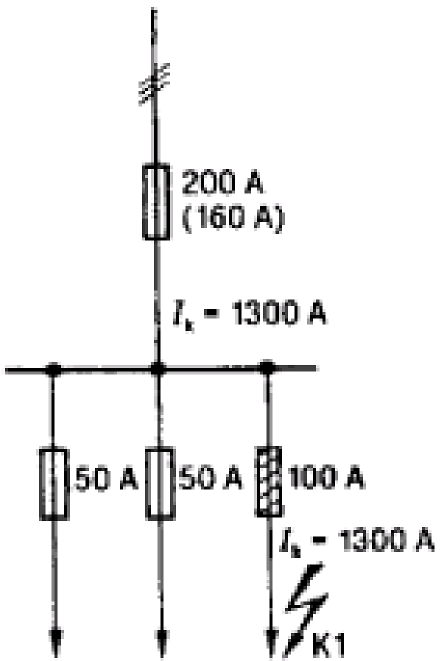
Overcurrent Protection (Relays, MCBs, fuses)

Typical fuse and LC circuit breaker tripping characteristics

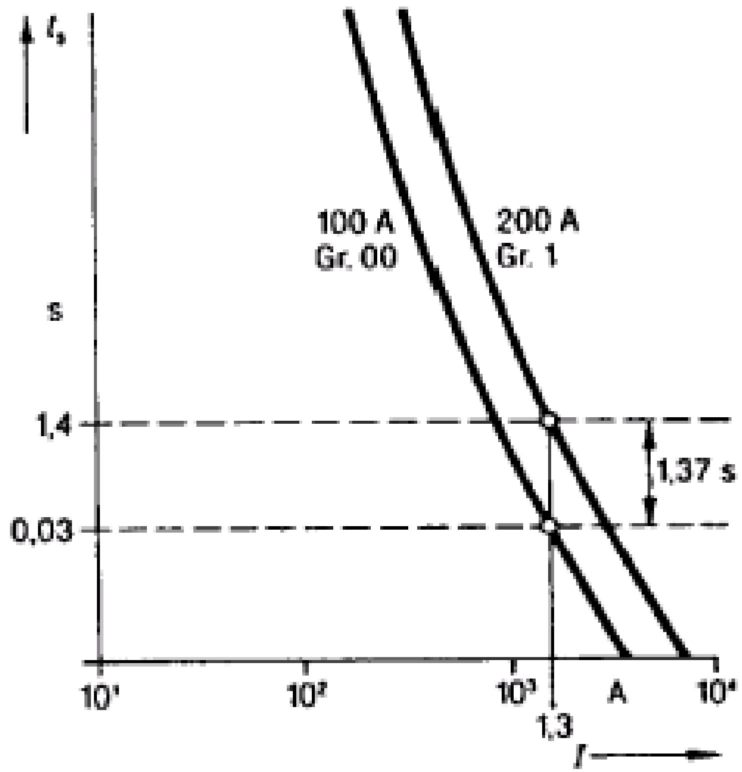


Selectivity of Low Voltage Fuses

t_s : Melting time



a) Selective tripping of fault in K_1



b) Melting time in I_k = 1300A

Current factor for selective tripping: 1:1,6

Selective tripping of fuses in meshed networks

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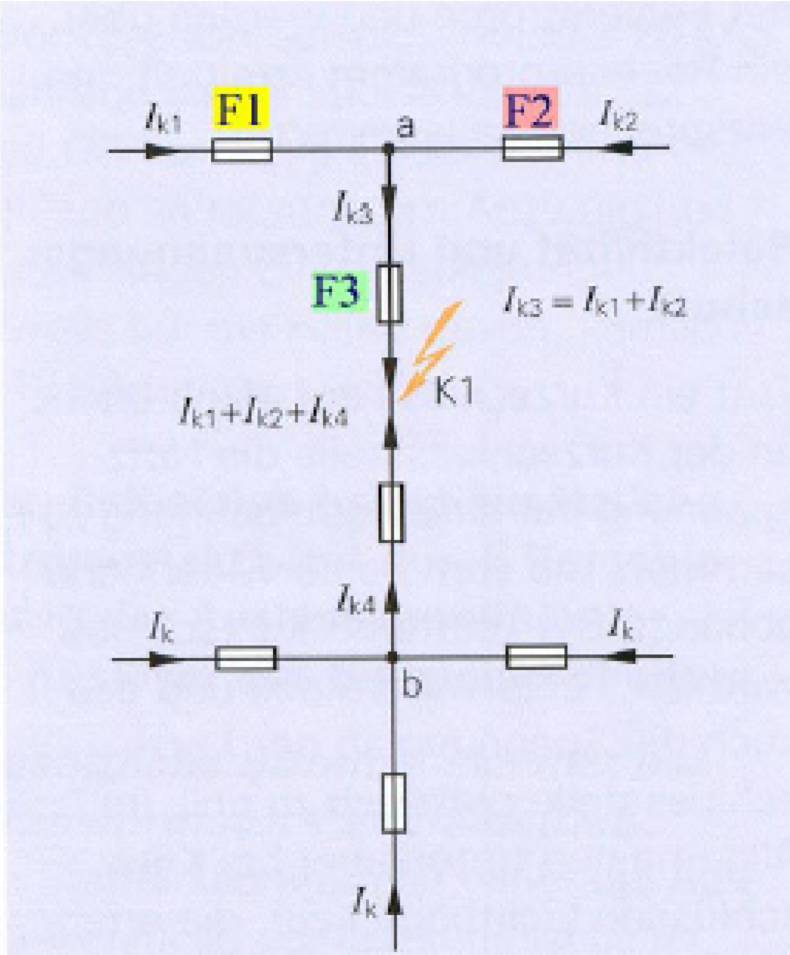
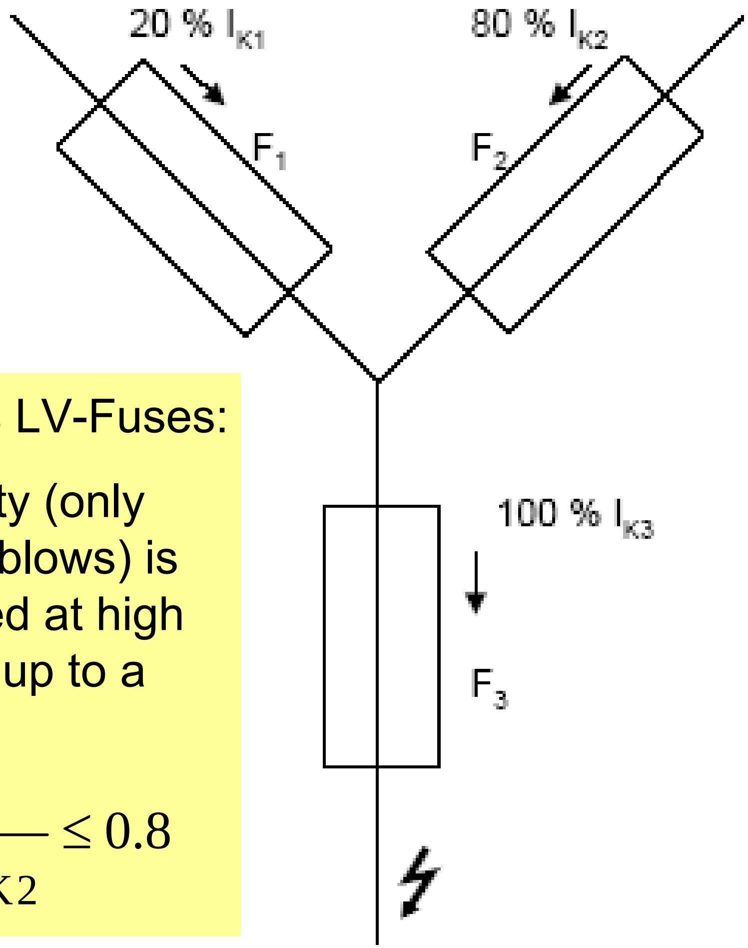


- Cable of same cross-section
- Same LV fuses

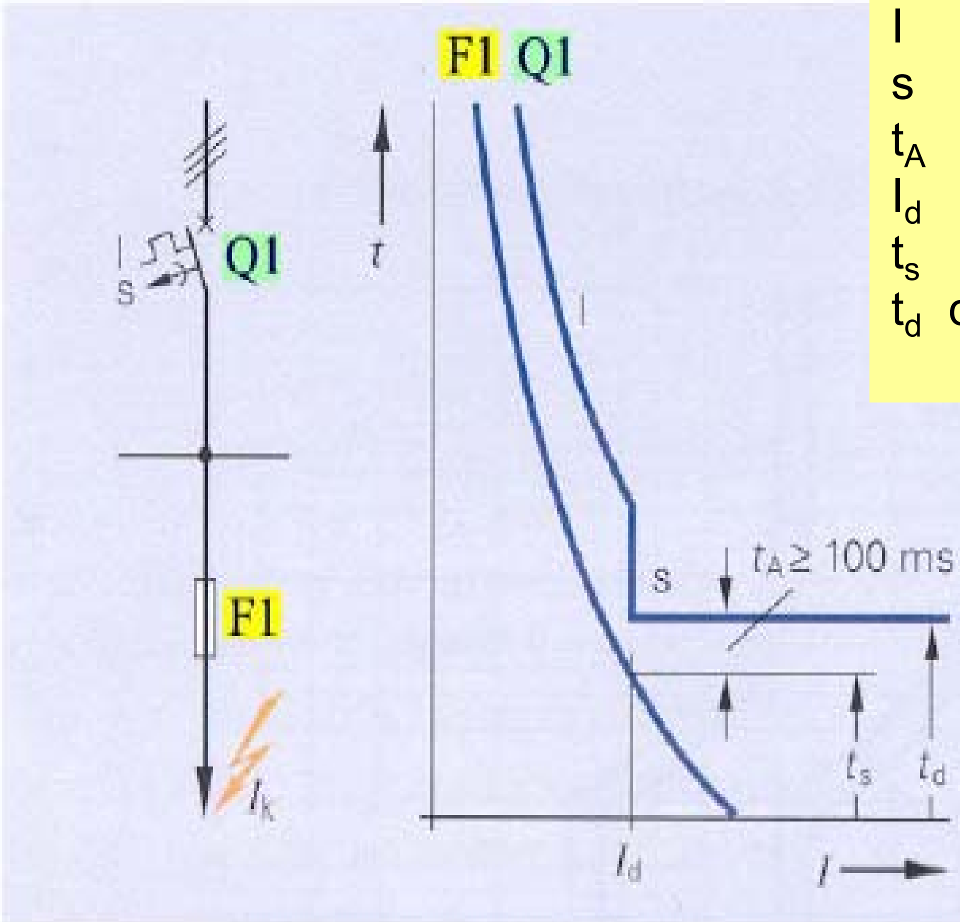
Siemens LV-Fuses:

Selectivity (only Fuse F_3 blows) is guranteed at high currents up to a ratio of :

$$\frac{I_{K1}}{I_{K1} + I_{K2}} \leq 0.8$$



Selectivity: Circuit Breaker → Downstream Fuse



- I current dependent delayed overload trip
- s short time delayed overcurrent trip
- t_A safety margin
- I_d pick-up current of the s-release
- t_s melting time of the fuse
- t_d delay time of the s-release

Selectivity: Fuse → Downstream Circuit Breaker

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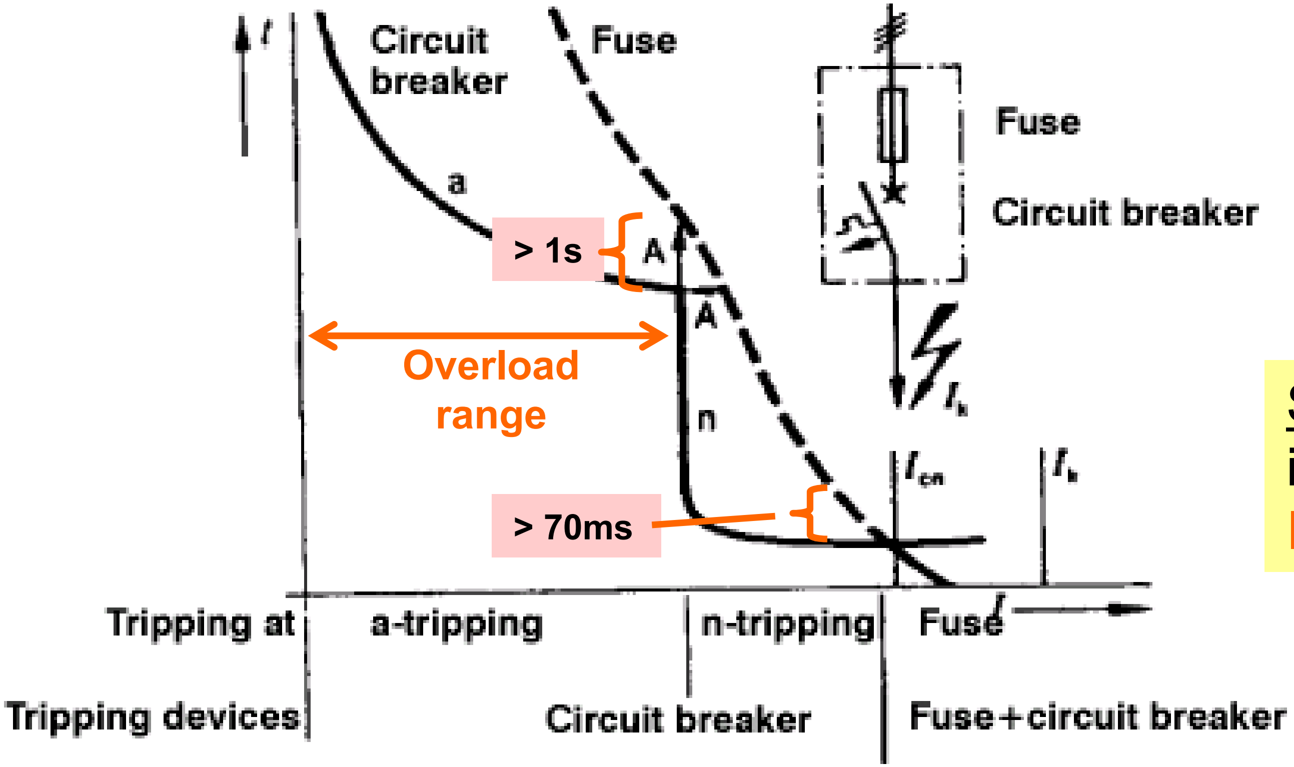

a Current dependent delayed overload release

n Instantaneous overcurrent release

Icn Rated switching capacity of circuit breaker

Ik Steady-stage short circuit current

A Safety margin

<u>Selectivity check</u>
in the short-circuit range by I^2t - comparison

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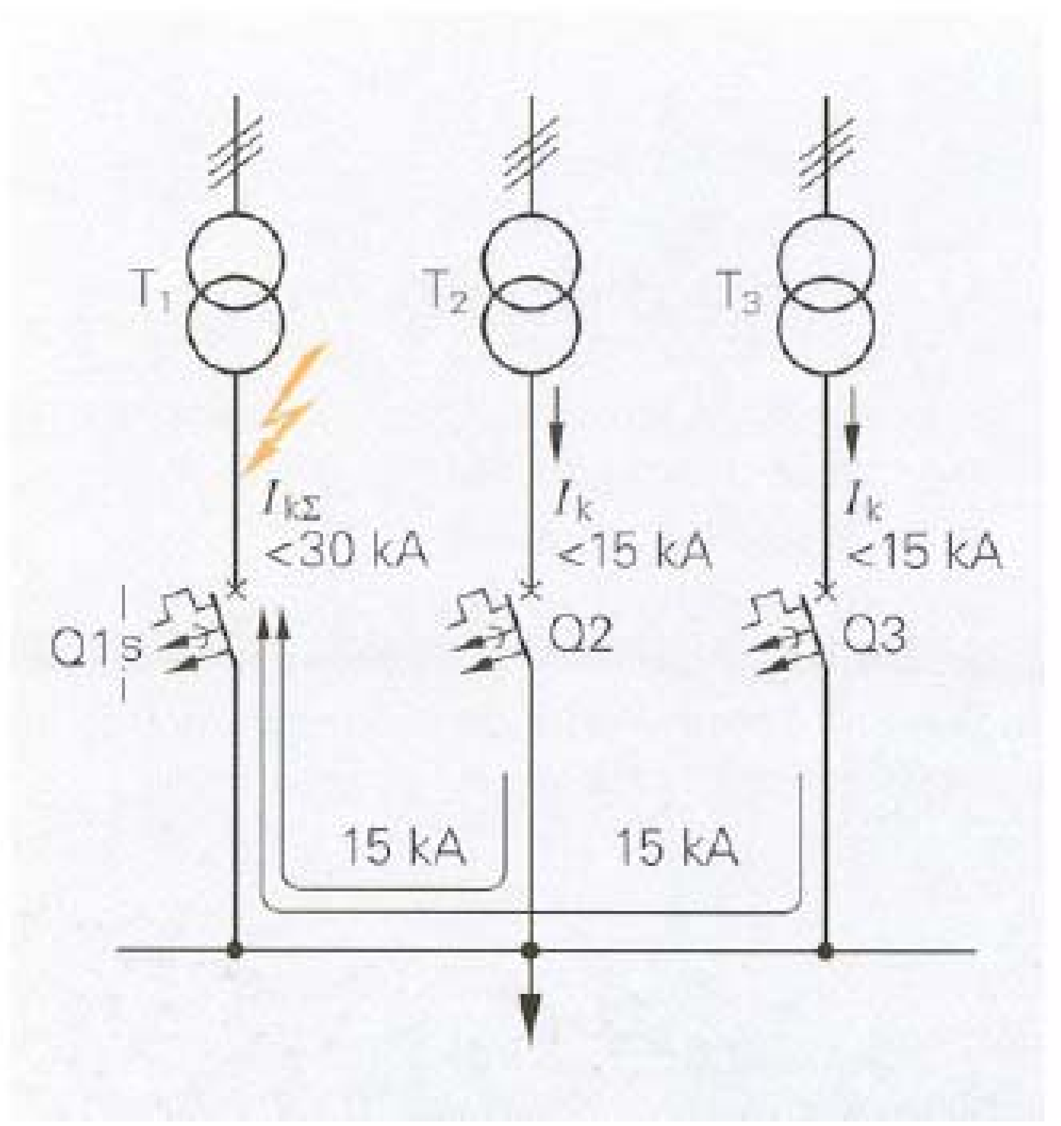
Selectivity: Three similar infeeding transformators



Necessary CB protection functions:

1. Inverse time Overload element a
2. Short time delayed I>>-element z

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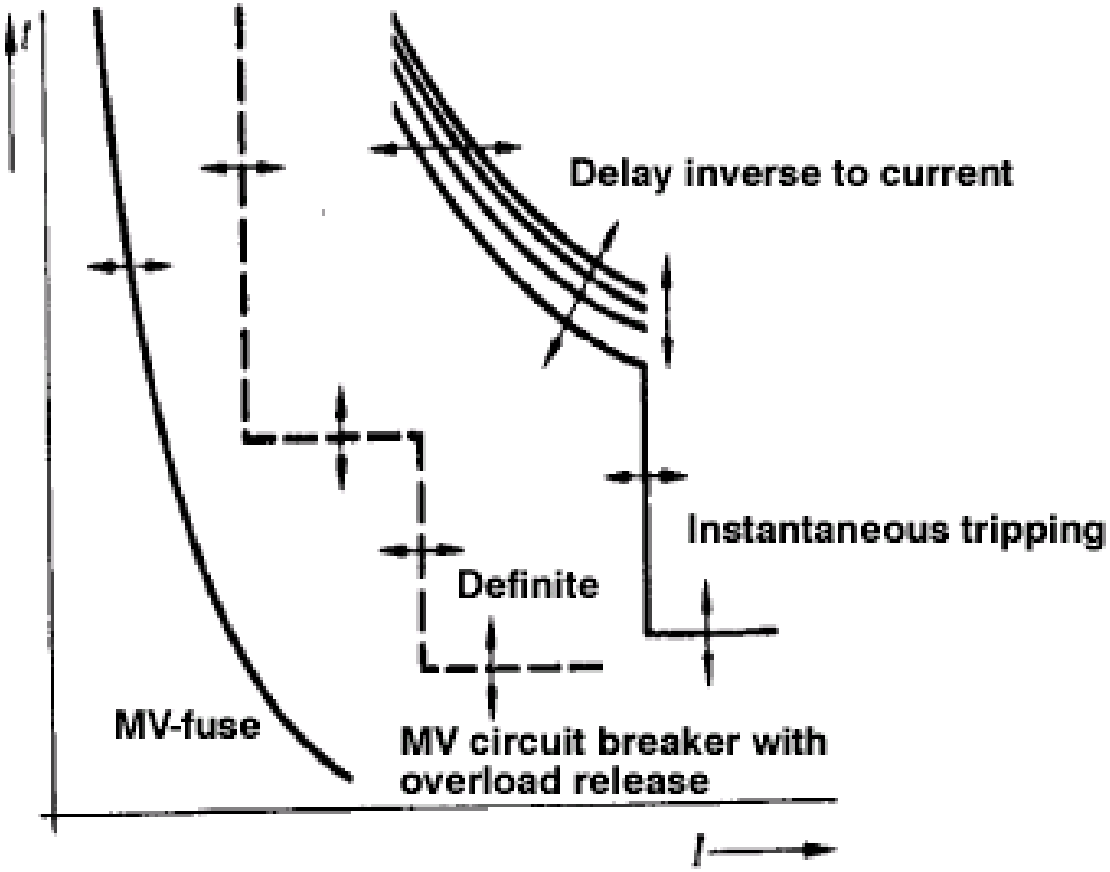
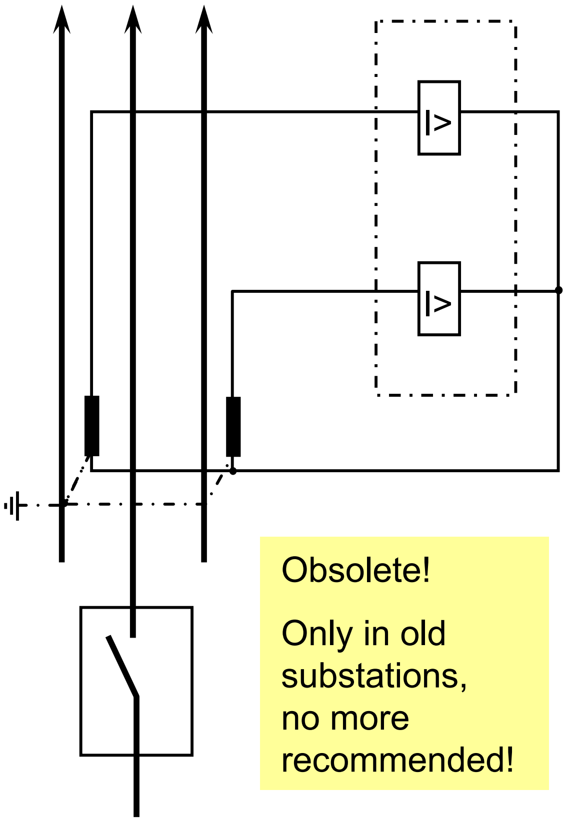
Tripping Characteristic in Medium- and High-Voltage Network

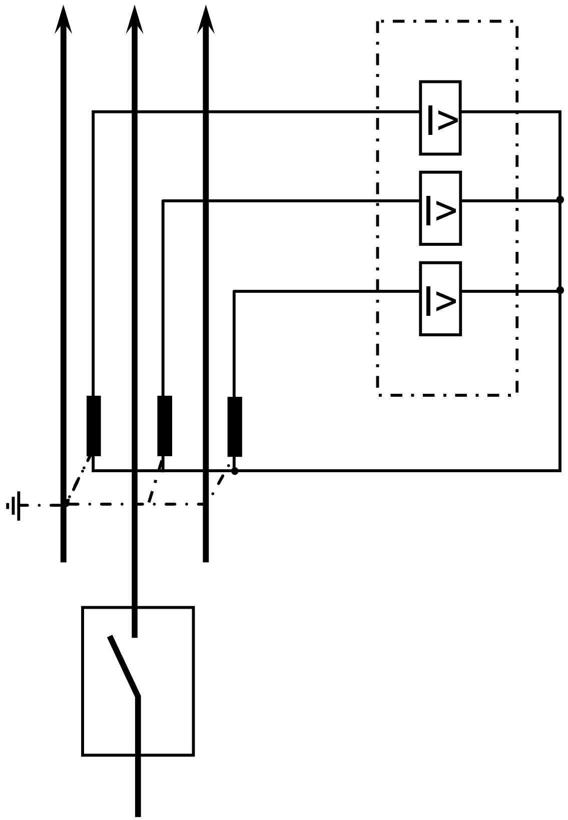


Changable range of tripping characteristic and settings

CT-connections dependent on neutral-earthing

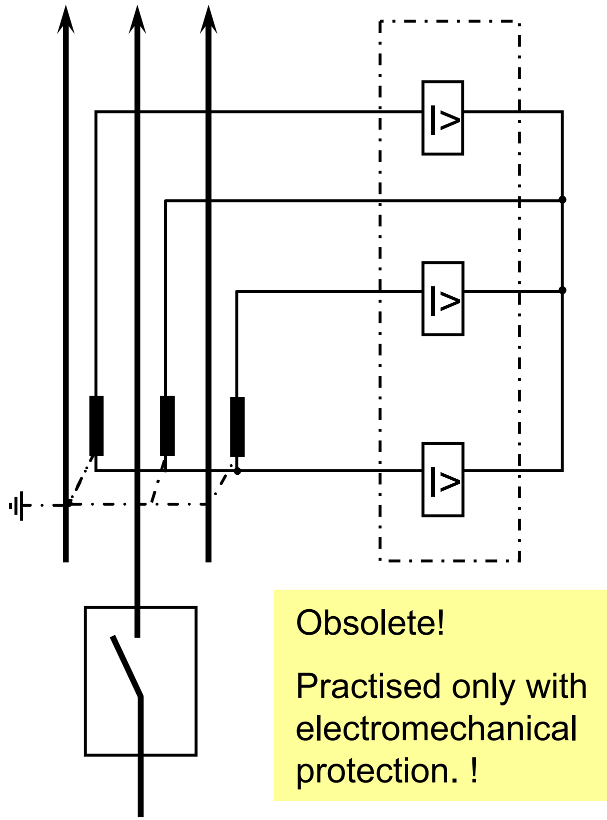


2- phase connection for isolated networks



3- phase connection for earthed networks

Now generally applied, independent of neutral-earthing



2- phase + earth connection for an increased earth fault sensitivity

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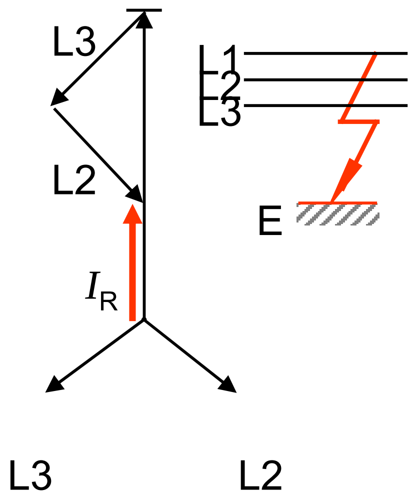
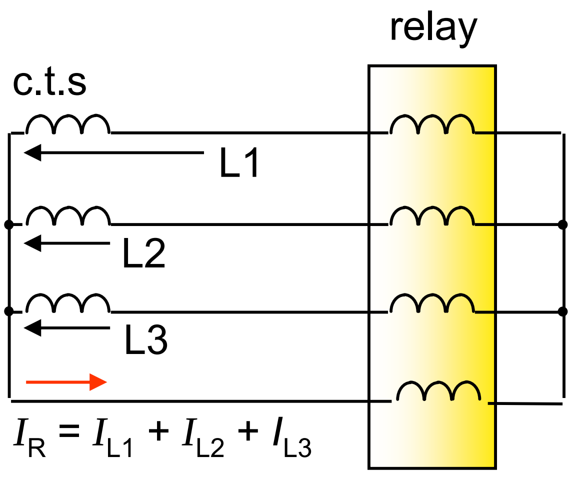
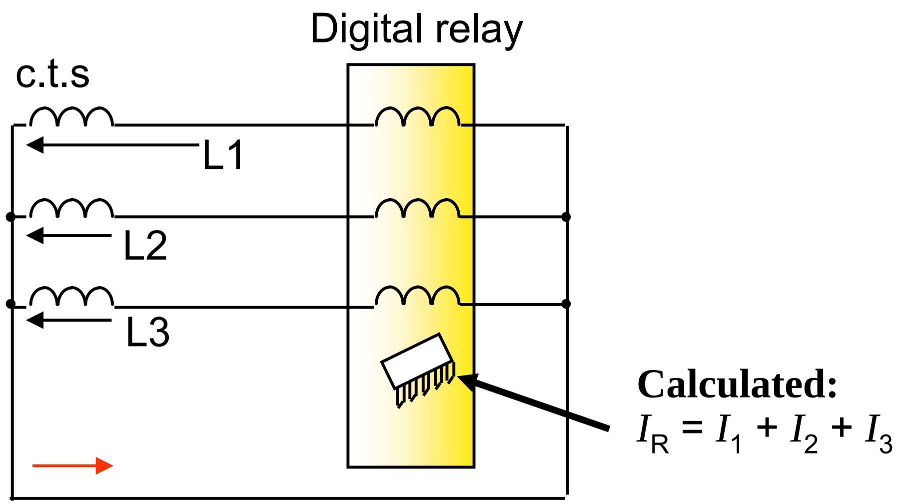
Measurement (analog) and digital calculation of earth current





„Holmgreen“ connection



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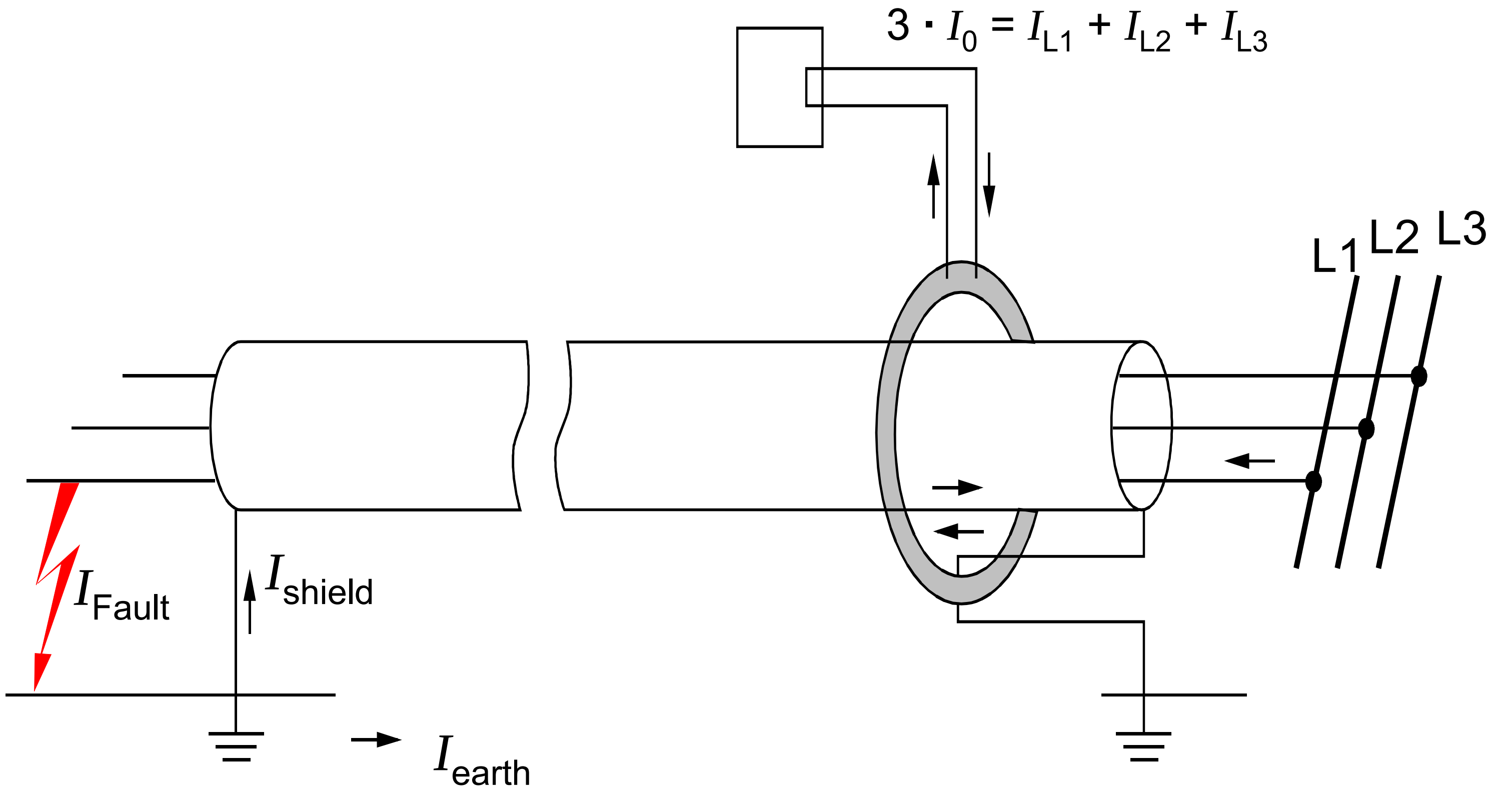
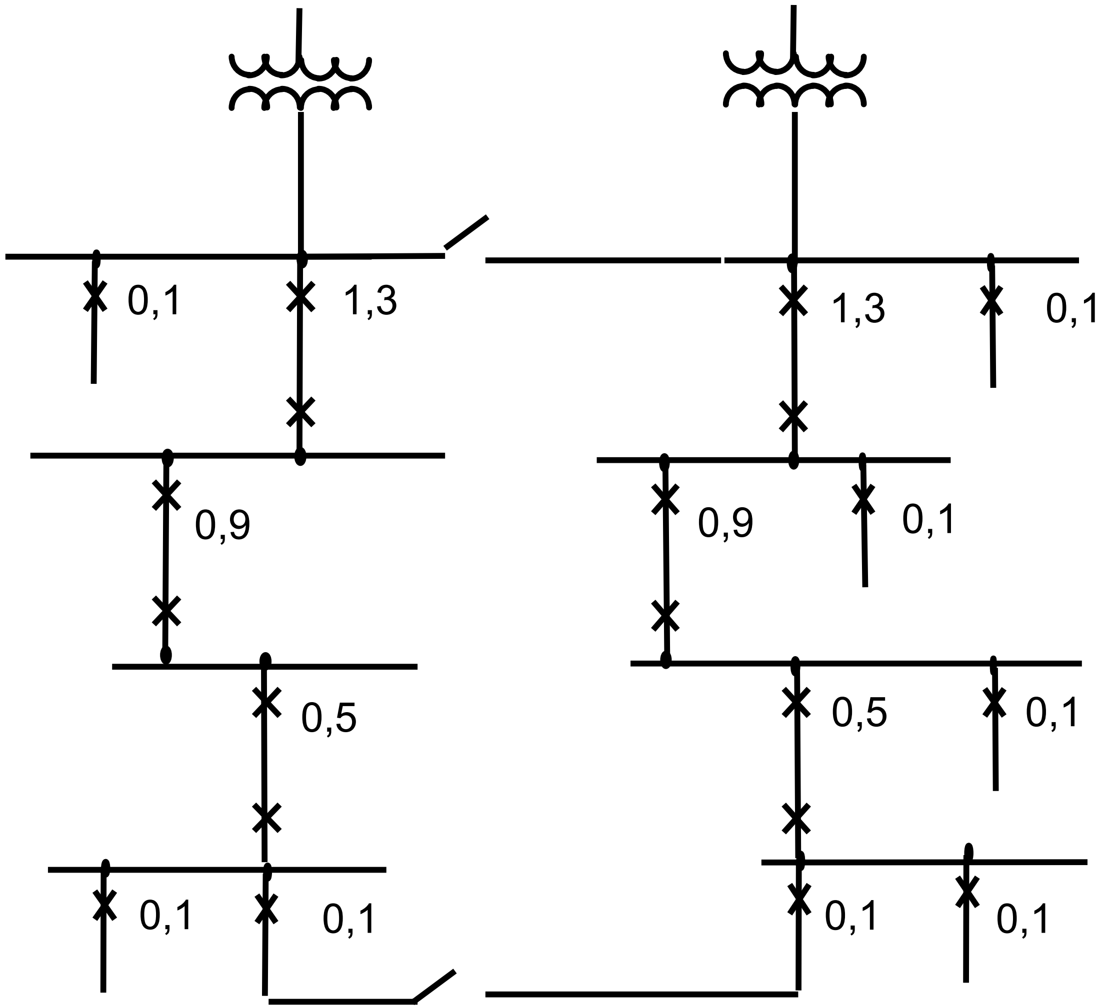
High sensitive earth fault relaying using a window-type CT



Coordination of overcurrent relays: time grading



Starting from the furthest downstream located relay, the operating time is step by step increased in direction of the infeed.

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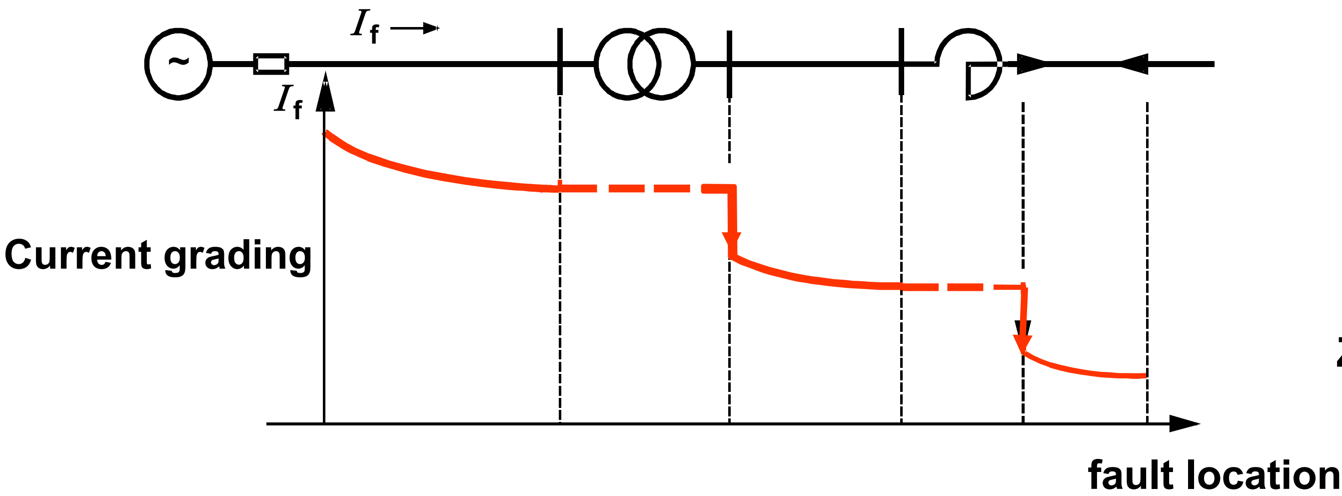
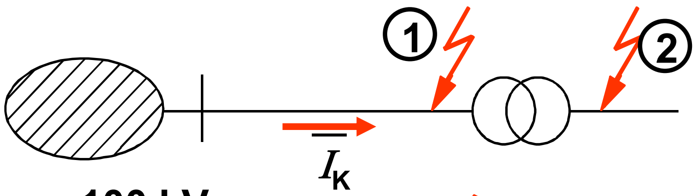
Coordination of overcurrent relays: Current grading



$$Z_N = \frac{U_N^2\,\{kV\}}{S'_K\,\{MVA\}}\,\{\Omega\}$$

$$Z_{Tr} = \frac{U_K\,\{\%\}}{100}\,\frac{U_N^2\,\{kV\}}{S_N\,\{MVA\}}\,\Omega$$

Example: I>> for faults at HV-side



U_N = 100 kV
S_K = 5 GVA
Z_N = 2,4 Ω
S_N = 20 MVA
u_K = 10%
Z_{Tr} = 60,5 Ω

in (1) $$I_K = \frac{110\,kV}{\sqrt{3}\cdot 2{,}4\,\Omega} = 26{,}5\,kA$$

in (2) $$I_K = \frac{110\,kV}{\sqrt{3}\cdot 62{,}9\,\Omega} = 2{,}4\,kA$$

line impedance neglected!

Selectivity by current grading

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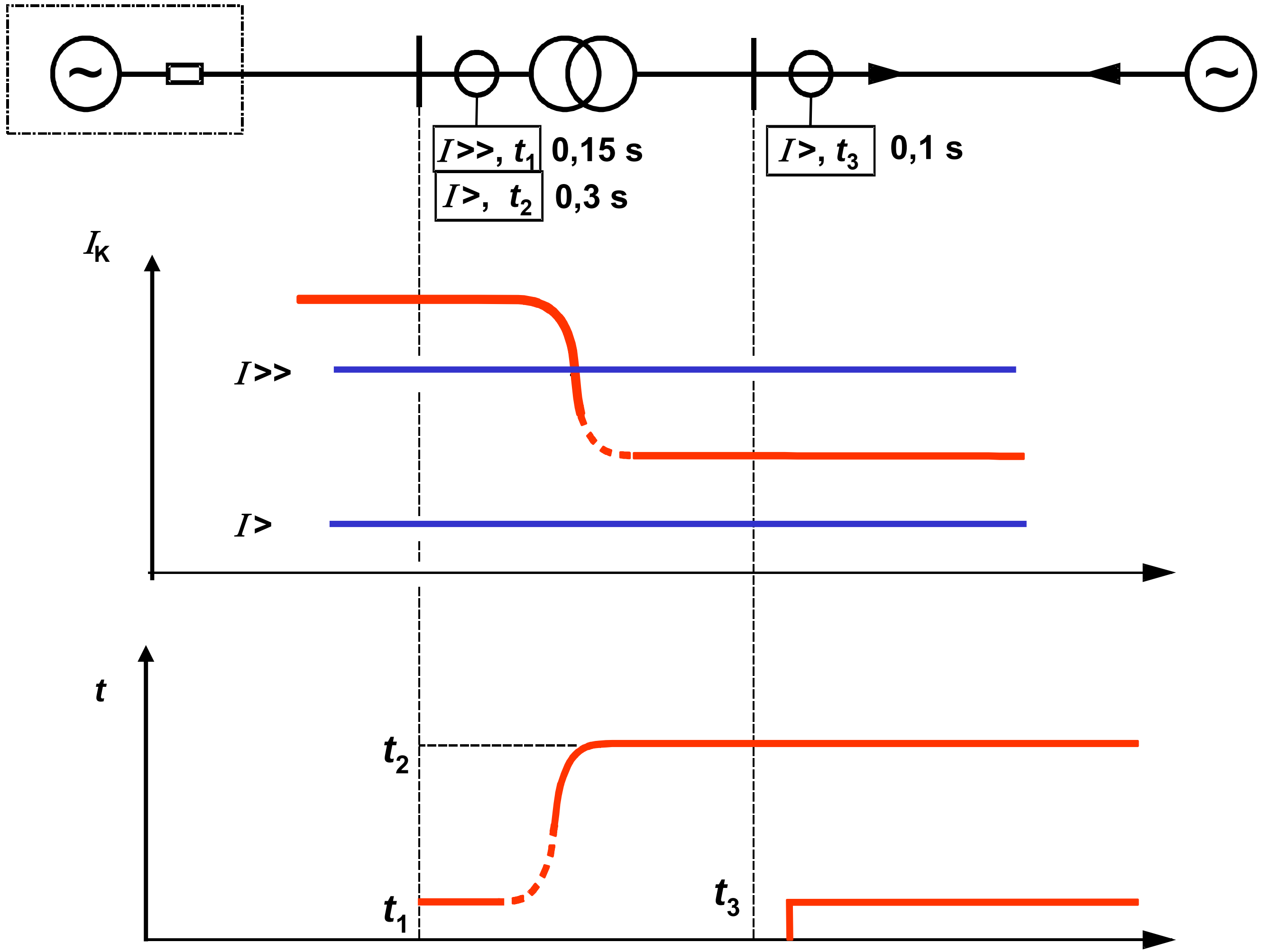
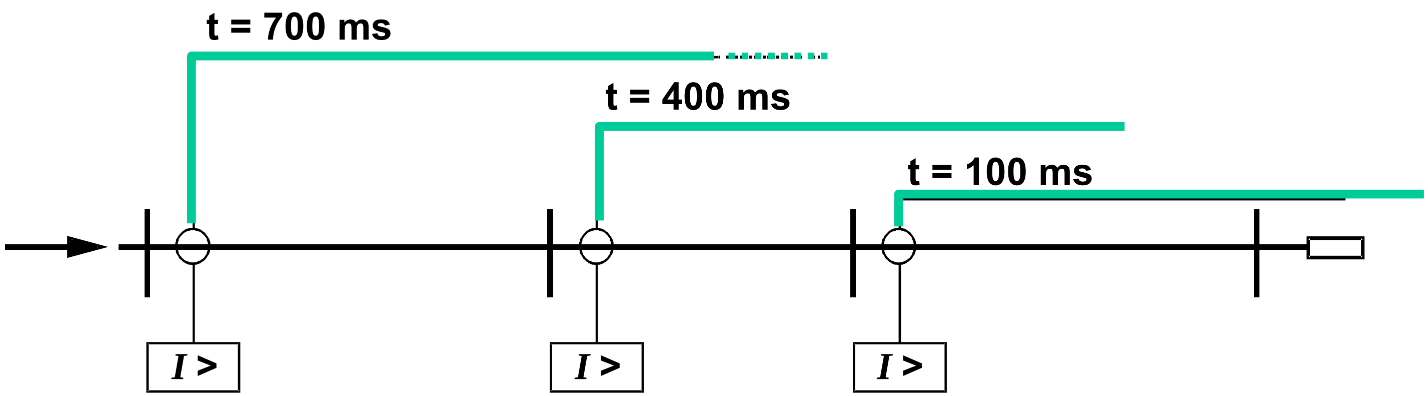
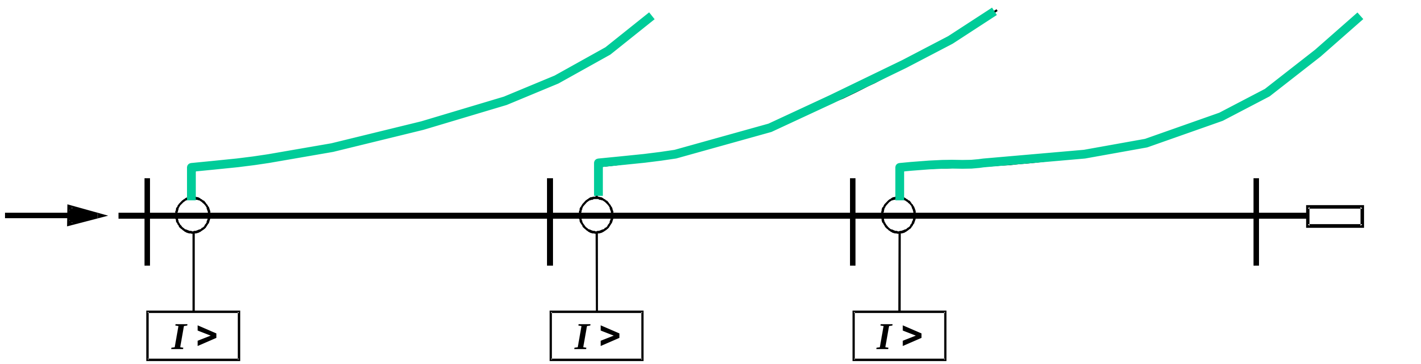


Definite and inverse overcurrent relay characteristics





Inverse time characteristics acc. To IEC 60255

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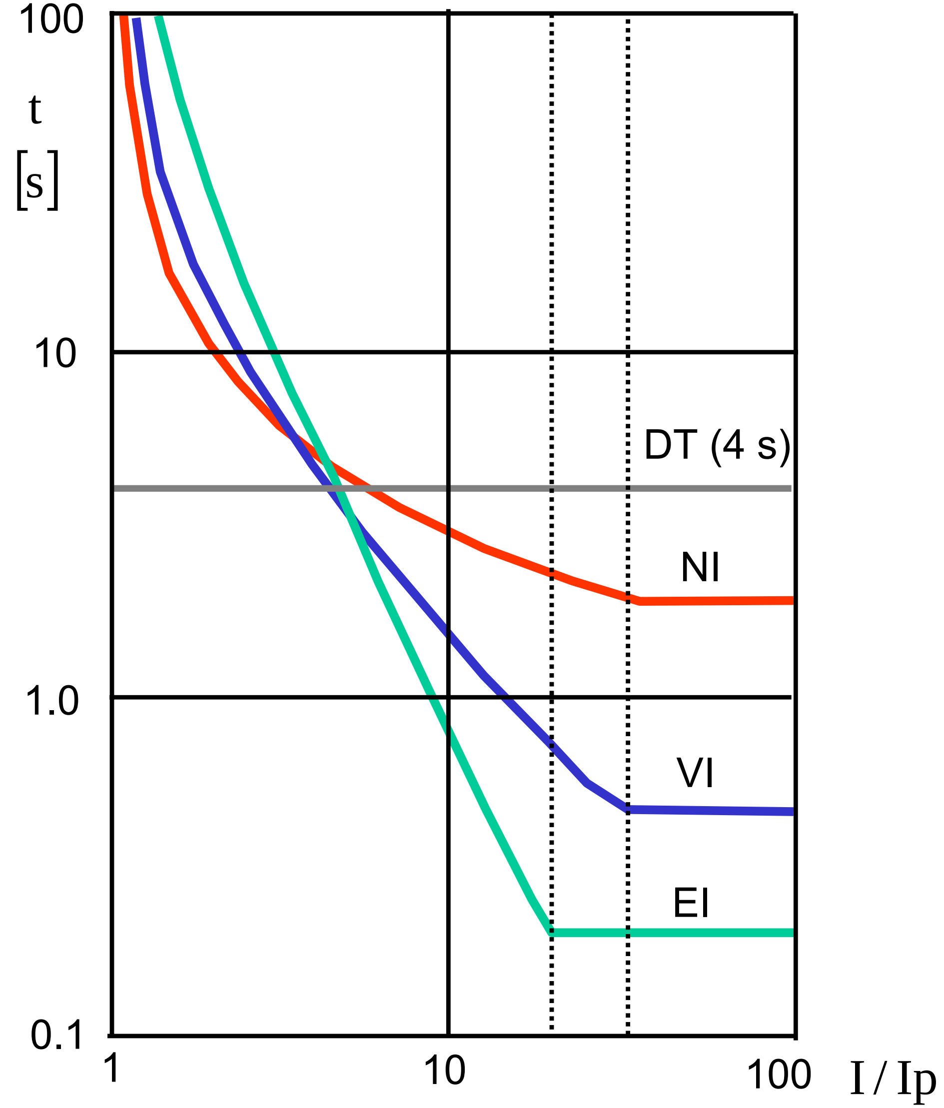

Normal inverse:

$$t = \frac{0.14}{\left(\frac{I}{Ip}\right)^{0.02} - 1} \text{ x } Tp$$

Very inverse:

$$t = \frac{13.5}{\left(\frac{I}{Ip}\right)^{1} - 1} \text{ x } Tp$$

Extremely inverse:

$$t = \frac{80}{\left(\frac{I}{Ip}\right)^{2} - 1} \text{ x } Tp$$

Normal inverse setting characteristic

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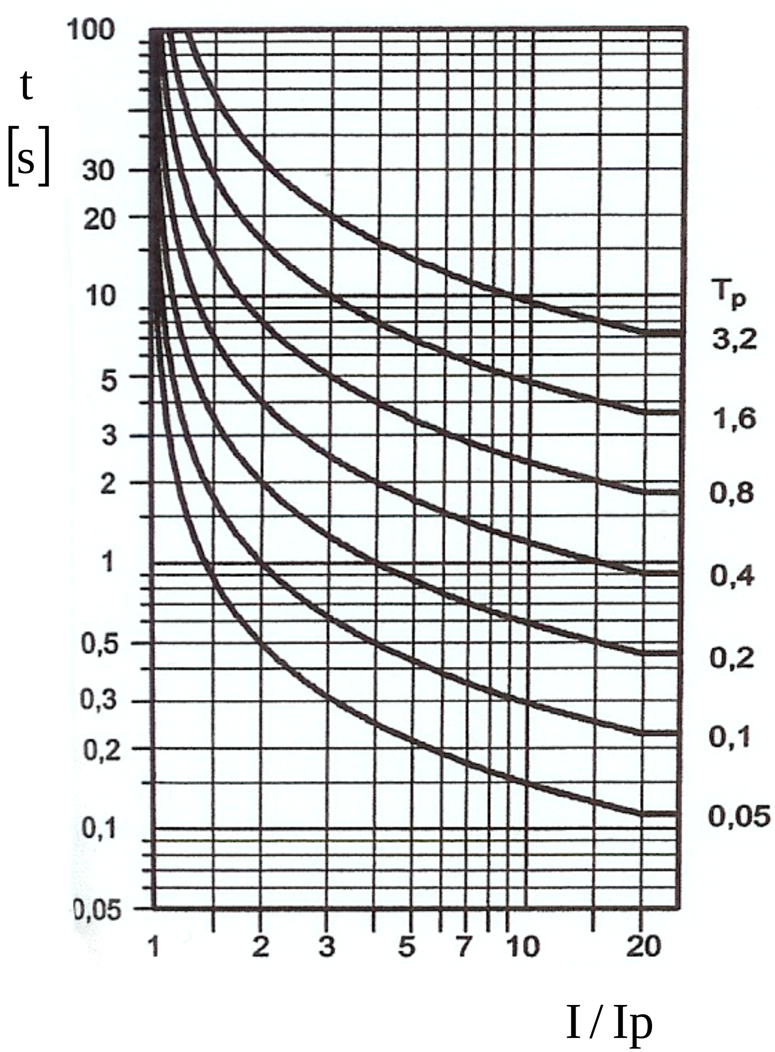

Normal inverse:

$$t = \frac{0.14}{\left(\frac{I}{Ip}\right)^{0.02} - 1} \text{ x } Tp$$

NI setting characterisic of the relay 7SJ6 (Siemens)

Application of different O/C characteristics

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Definite time (DT)

Easy to coordinate
Constant tripping time independent of infeed variation and fault location

Normal inverse (NI)

Relativey small change in time per unit of change of current.
Most frequenly used in utility and industrial circuits.
Especially applicable where the fault magnitude is nmainly dependent on the system generating capacity at the time of fault.

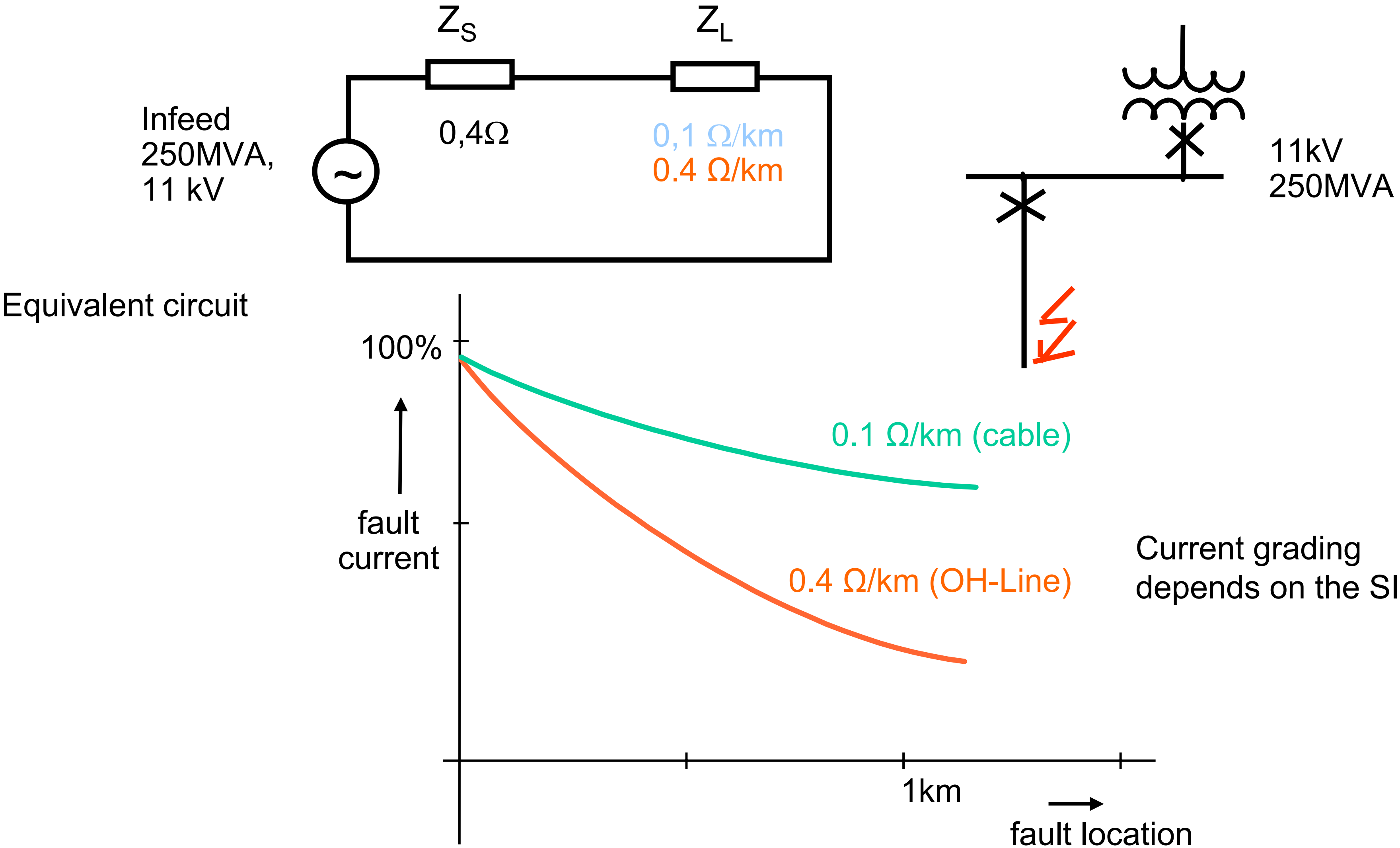
Very inverse (VI)

Suitable if there is a substantial reduction of fault current as the fault distance from the power source increases.

Extemely inverse (EI)

Suitable for protection of distribution feeders with peak currents on switching in (refrigerators, pumps, water heaters and so on).
Particular suitable for grading with fuses.

Fault current dependent on the fault location



Current grading depends on the SIR ratio!

Time grading: definite and inverse time characteristics

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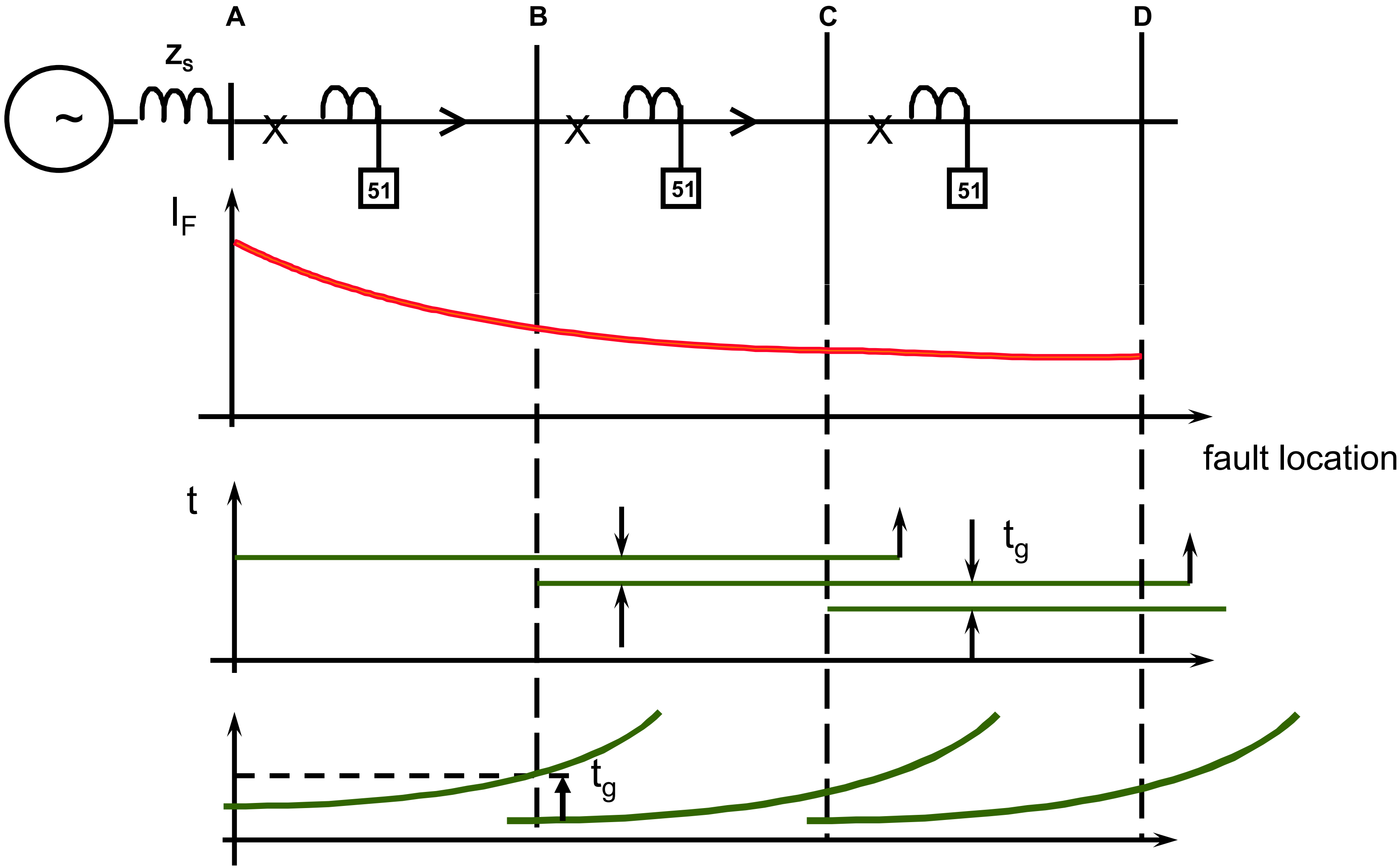
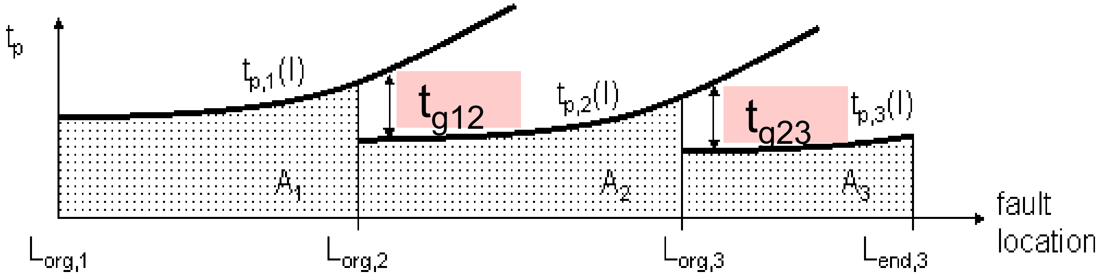


Time grading of normal inverse time characteristics

Grading requirement:

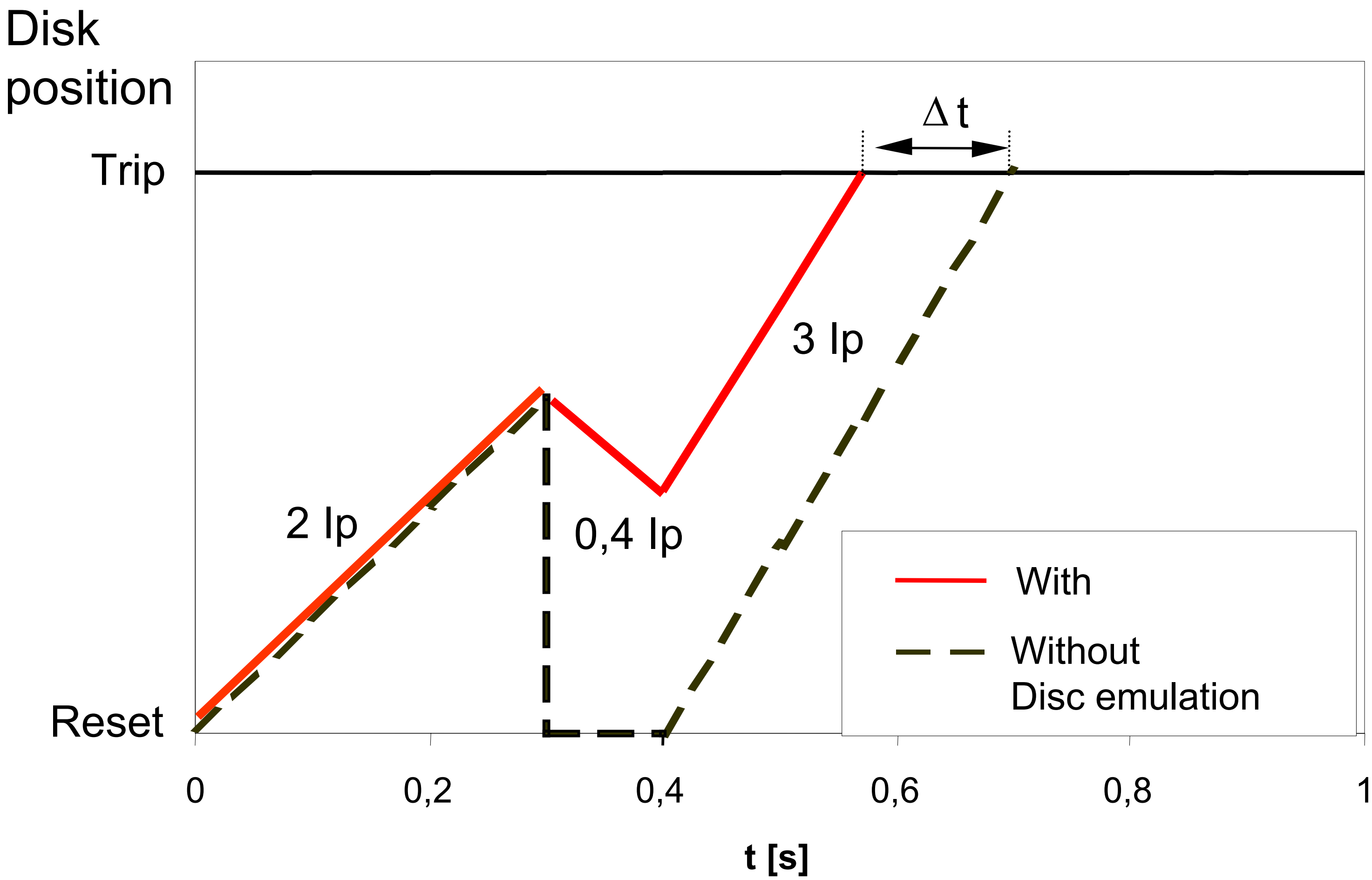
$$t_{g_{12}} = t_{g_{23}} = 200 - 400\text{ms}$$



$$\Rightarrow \frac{0.14 \cdot T_{p,n}}{\left(\frac{I_{sc}}{I_p}\right)^{0.02} - 1} = 200 - 400\text{ms} + \frac{0.14 \cdot T_{p,n+1}}{\left(\frac{I_{sc}}{I_p}\right)^{0.02} - 1} \Rightarrow T_{p,n} = T_{p,n+1} + \frac{200 - 400\text{ms}}{0.14} \cdot \left[\left(\frac{I_{sc}}{I_p}\right)^{0.02} - 1\right]$$

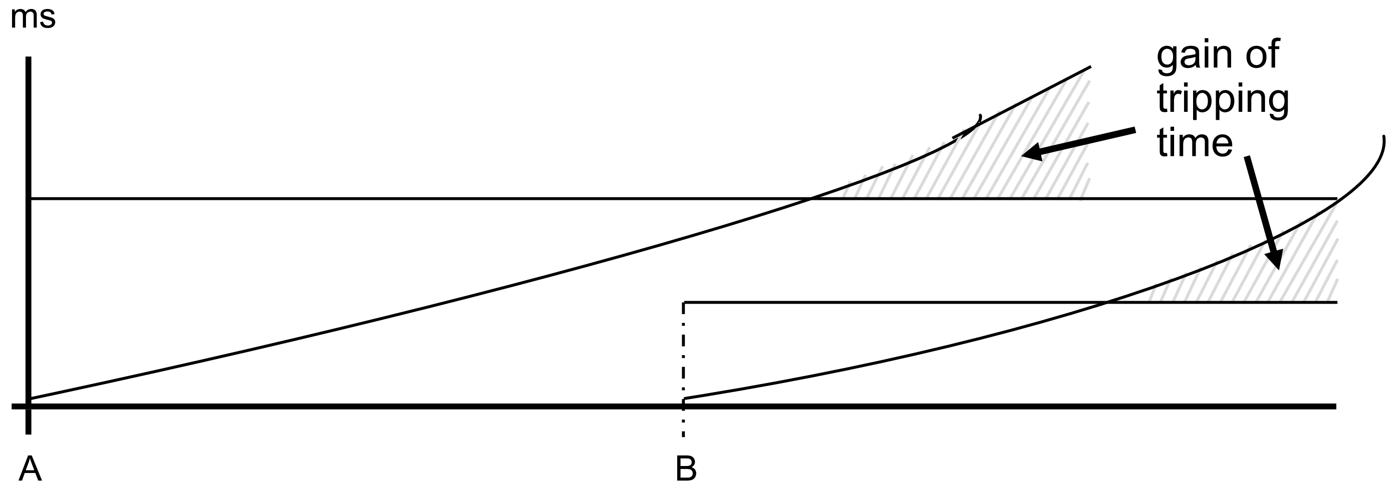
Conventional grading principle: I_{sc} = maximum SC-current in the network

Disk emulation: Simulatin of the induction disc



Combined use of inverse and definit time characteristics

The back-up tripping time can be reduced by
Combining inverse and definite time characteristics



Overcurrent protection co-ordination

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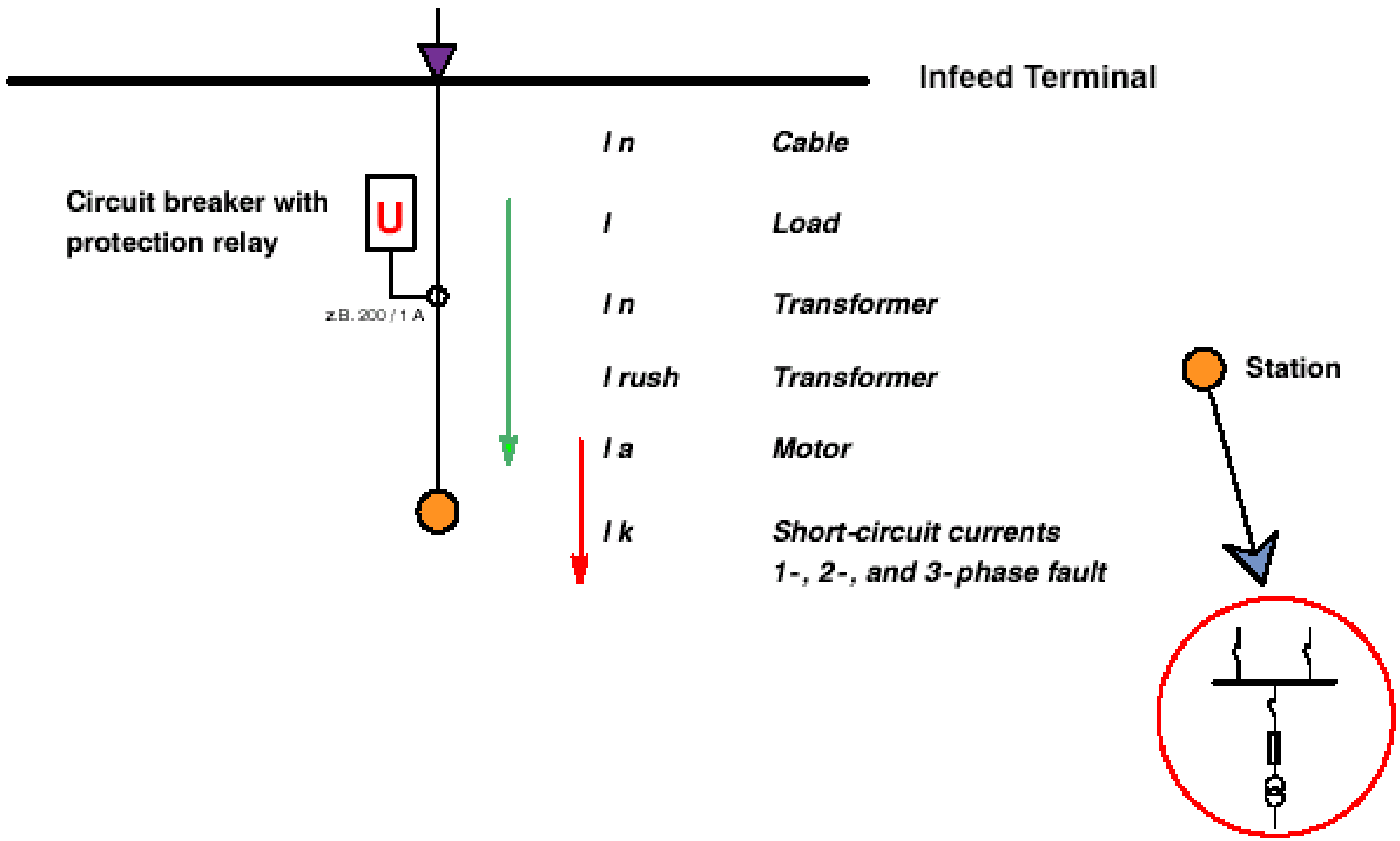
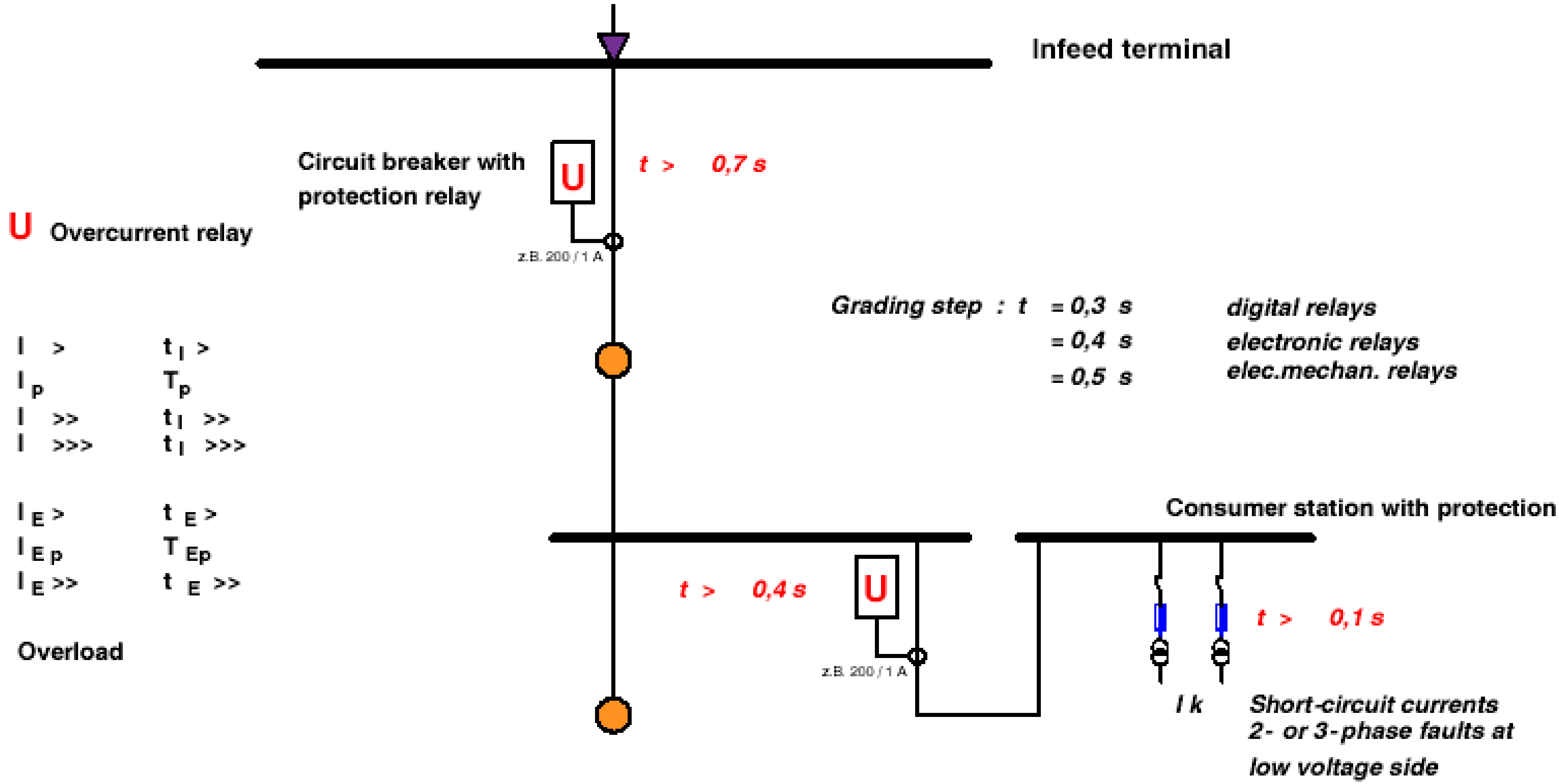
U Overcurrent relay

$I>$	$t_{I}>$
I_{p}	T_{p}
$I>>$	$t_{I}>>$
$I>>>$	$t_{I}>>>$
$I_{E}>$	$t_{E}>$
I_{Ep}	T_{Ep}
$I_{E}>>$	$t_{E}>>$

Overload



Two definite overcurrent relays in series



Protection scheme acceleration

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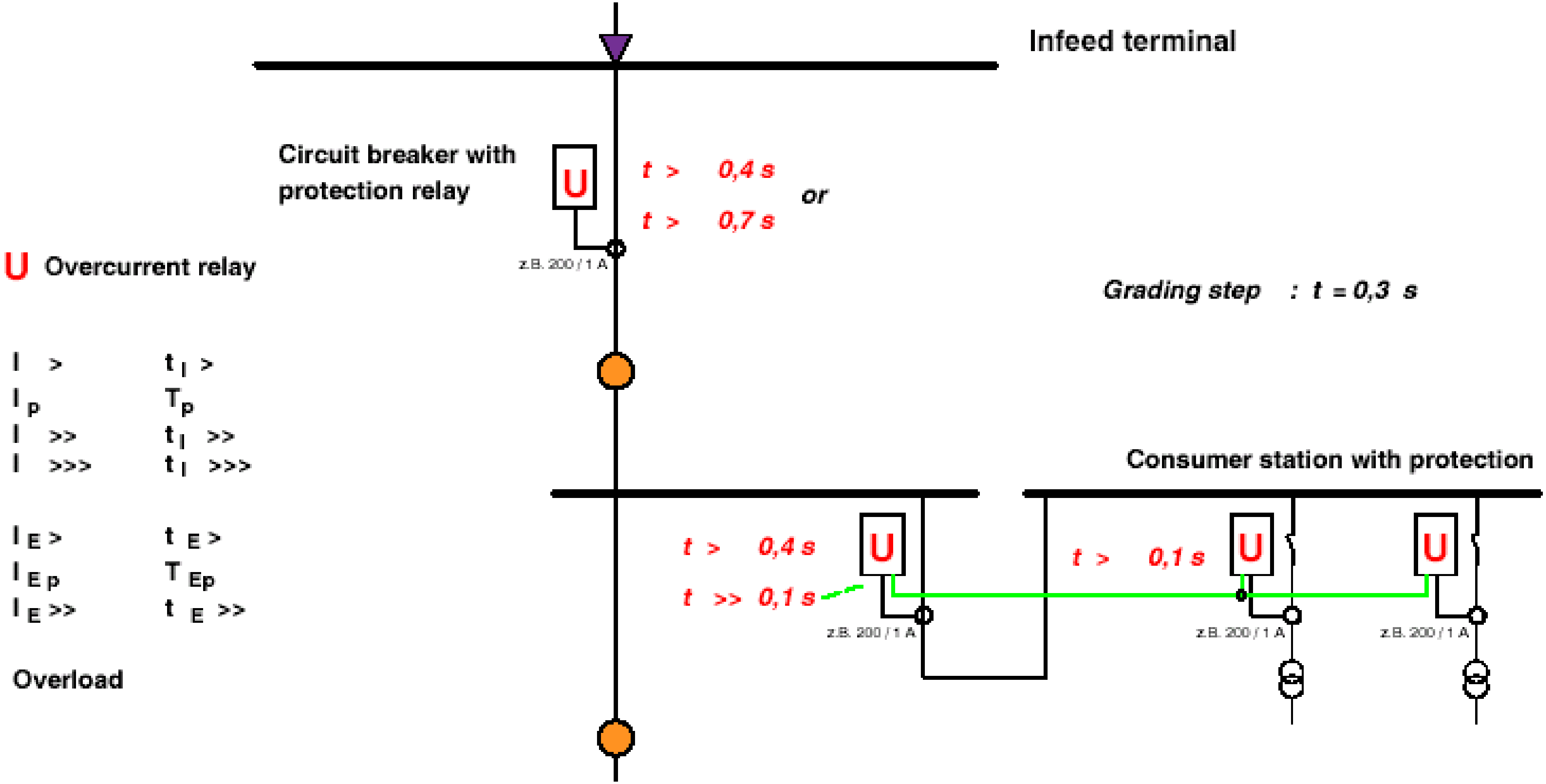

Definite overcurrent protection in cable ring

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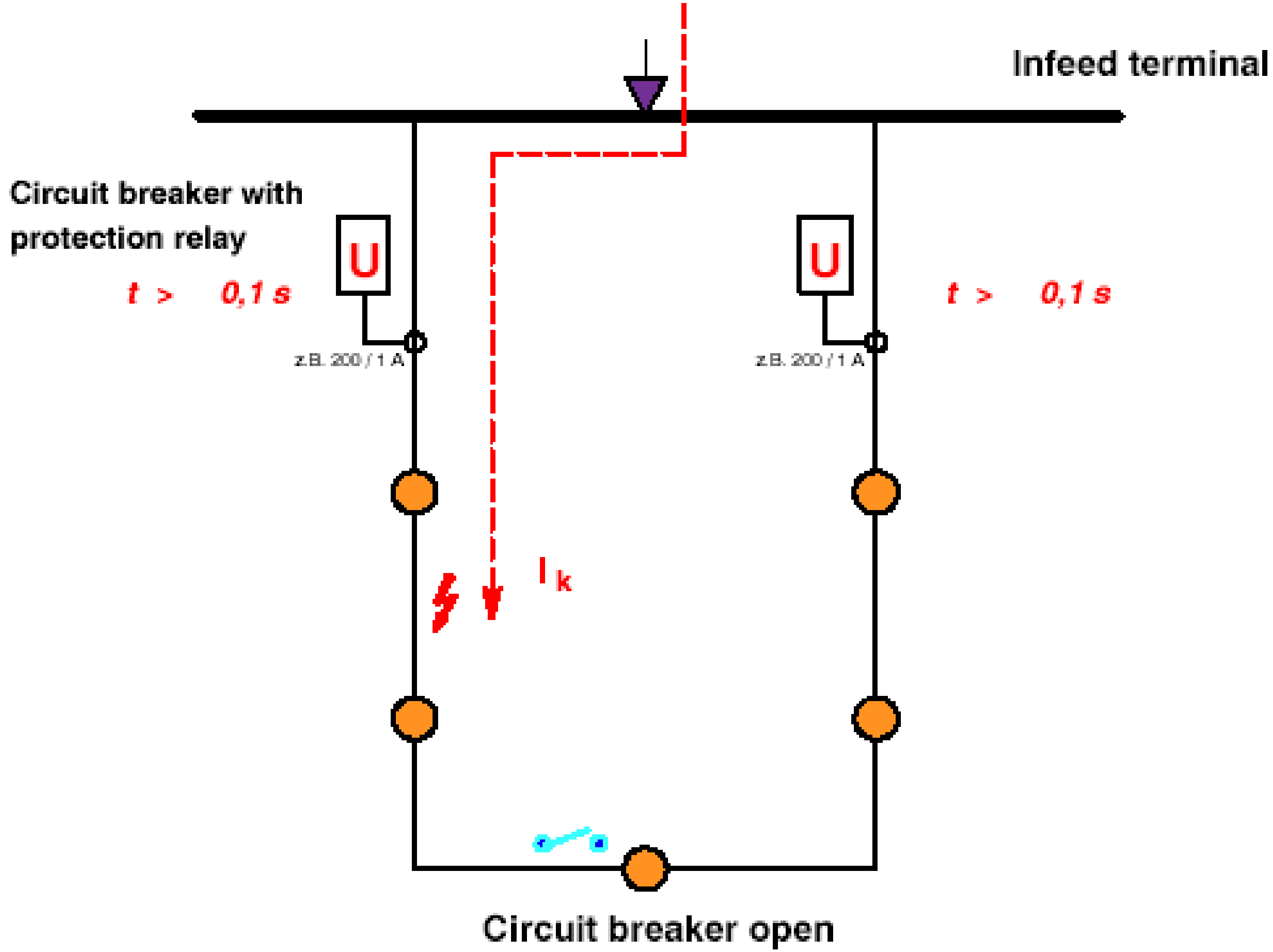

U Overcurrent relay

$I >$	$t_I >$
I_p	T_p
$I >>$	$t_I >>$
$I >>>$	$t_I >>>$
$I_E >$	$t_E >$
I_{Ep}	T_{Ep}
$I_E >>$	$t_E >>$

Overload

Protection in closed cable ring

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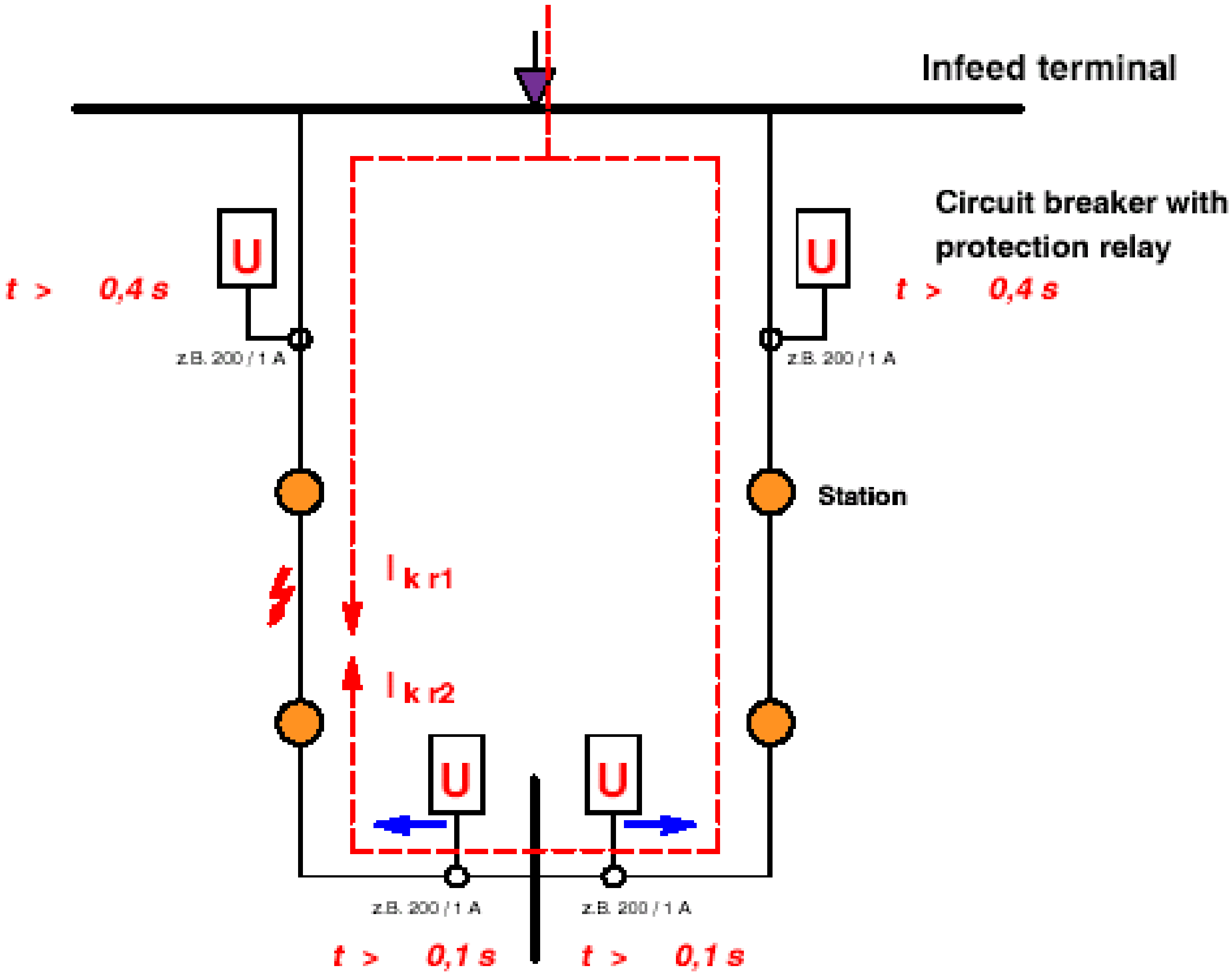
U — Overcurrent relay wth direction

U — Overcurrent relay

$I >$	$t_{I} >$
I_{p}	T_{p}
$I >>$	$t_{I} >>$
$I >>>$	$t_{I} >>>$
$I_{E} >$	$t_{E} >$
I_{Ep}	T_{Ep}
$I_{E} >>$	$t_{E} >>$

Overload



Cable ring with advanced protection

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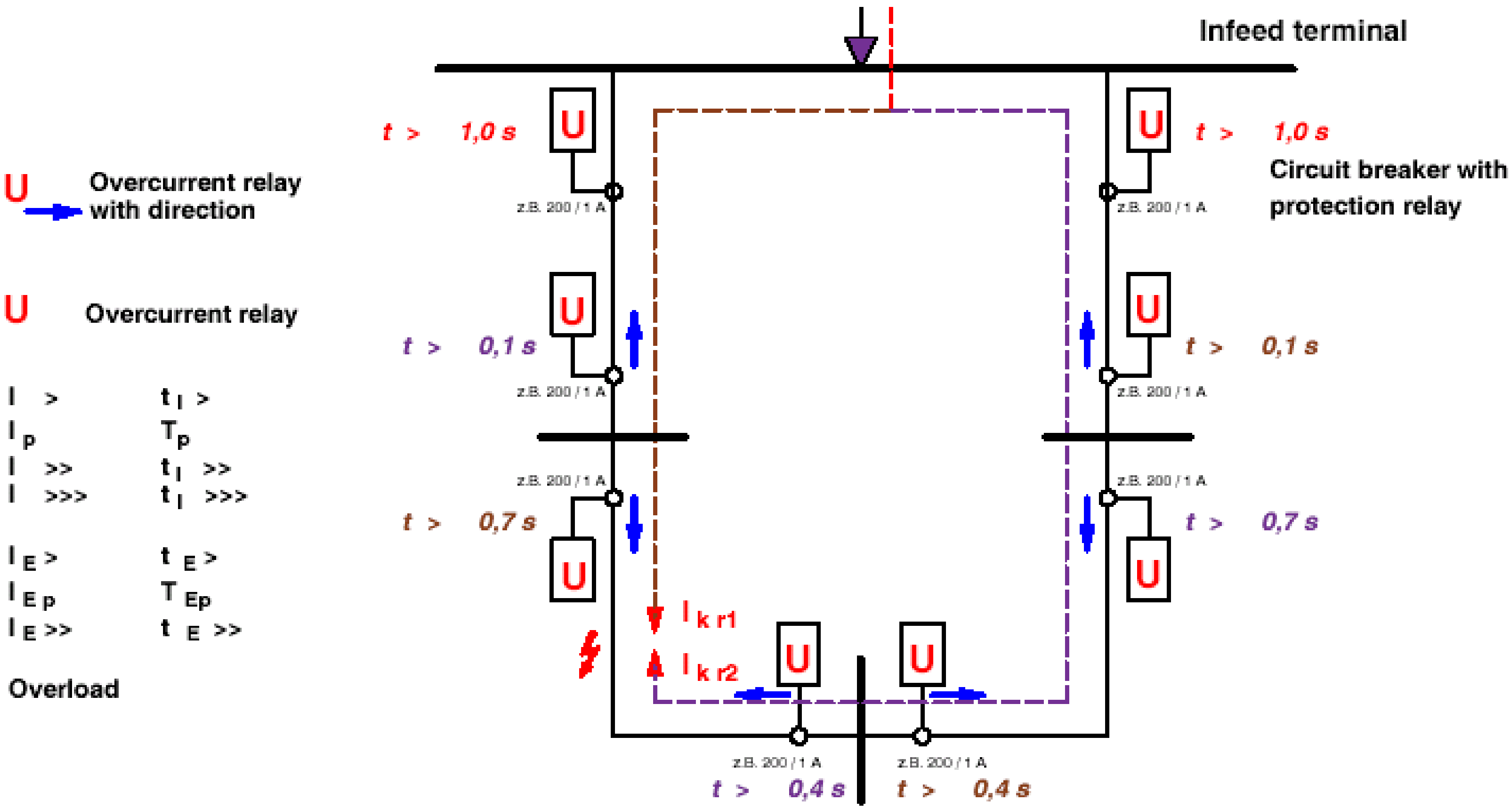

Co-ordination of distance protection at infeeding cables and overcurrent protection at downstream feeder cables

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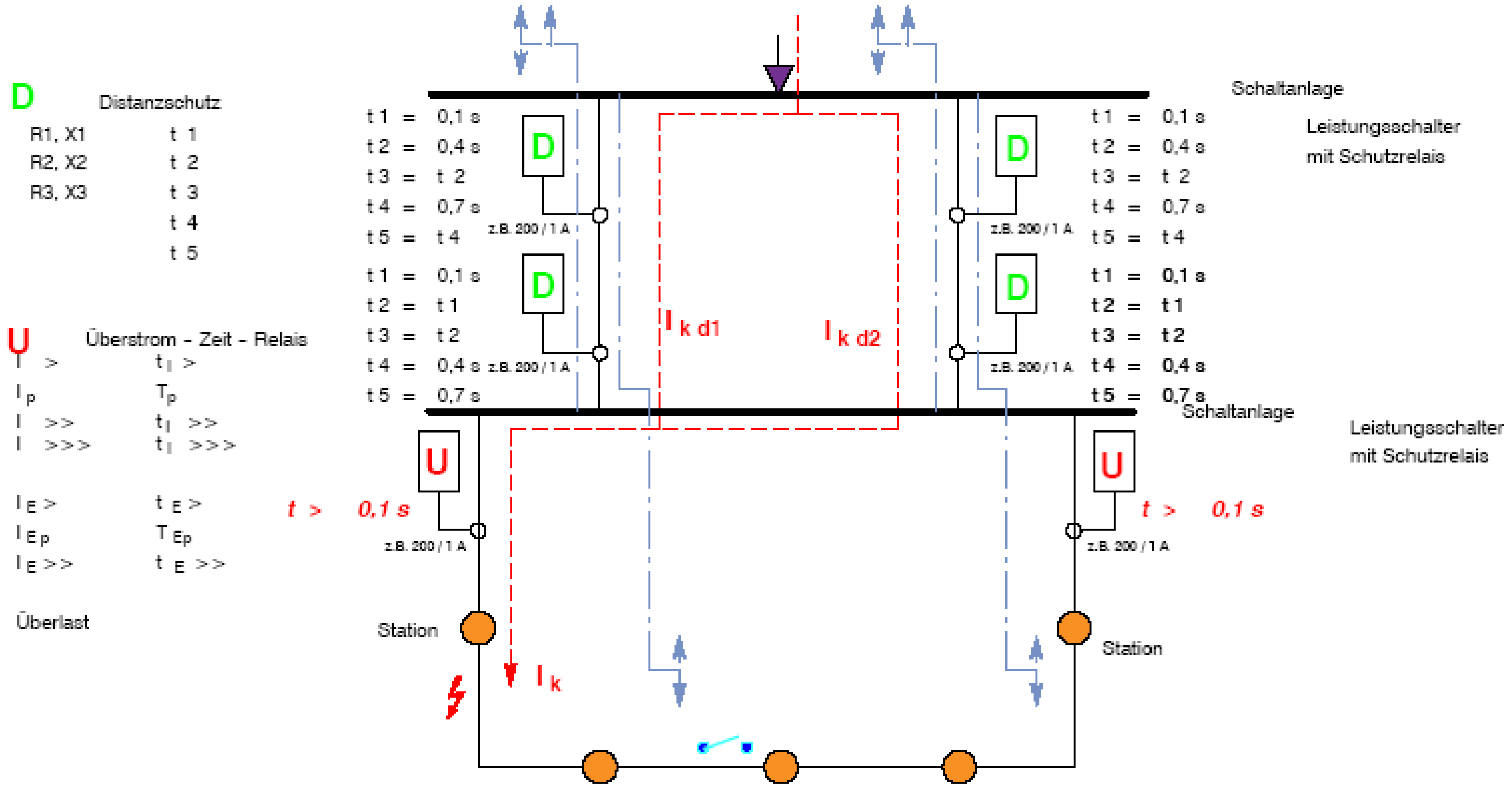

Advanced overcurrent protection
Reverse interlocking principle

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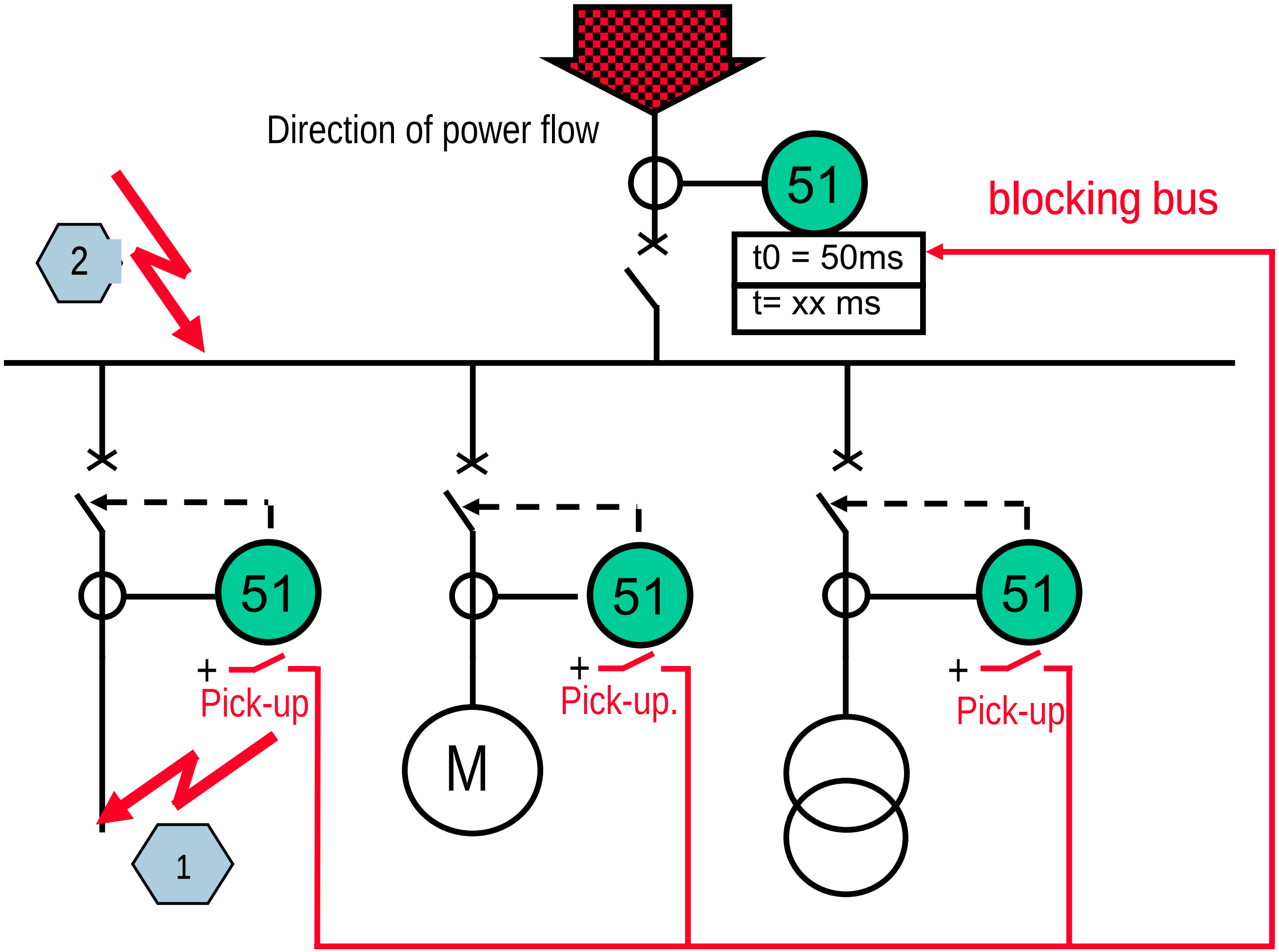


1

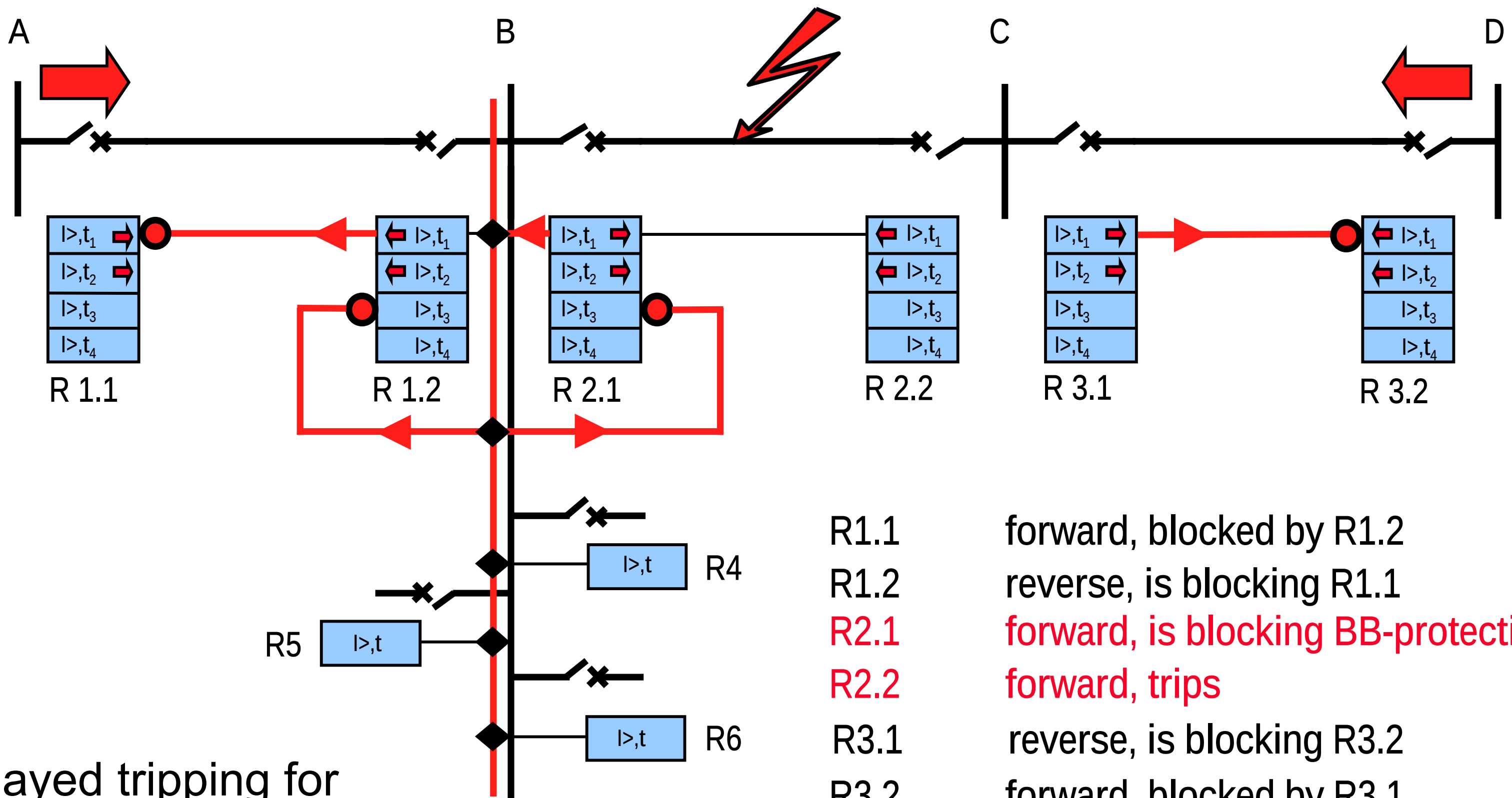
feeder protection blockins the the fast 50ms-stage at the infeeding relay via blocking bus and is only tripping its own CB

2

Infeeding relay trips within 50ms, as blocking bus is not activated

Directional comparison + reverse interlocking

Fault between station B – C



R1.1	forward, blocked by R1.2
R1.2	reverse, is blocking R1.1
R2.1	forward, is blocking BB-protection and trips
R2.2	forward, trips
R3.1	reverse, is blocking R3.2
R3.2	forward, blocked by R3.1
R4	no action
R5	no action
R6	no action

Undelayed tripping for busbar faults (t_3 ca. 50ms) and cable faults using only one relay per feeder!!

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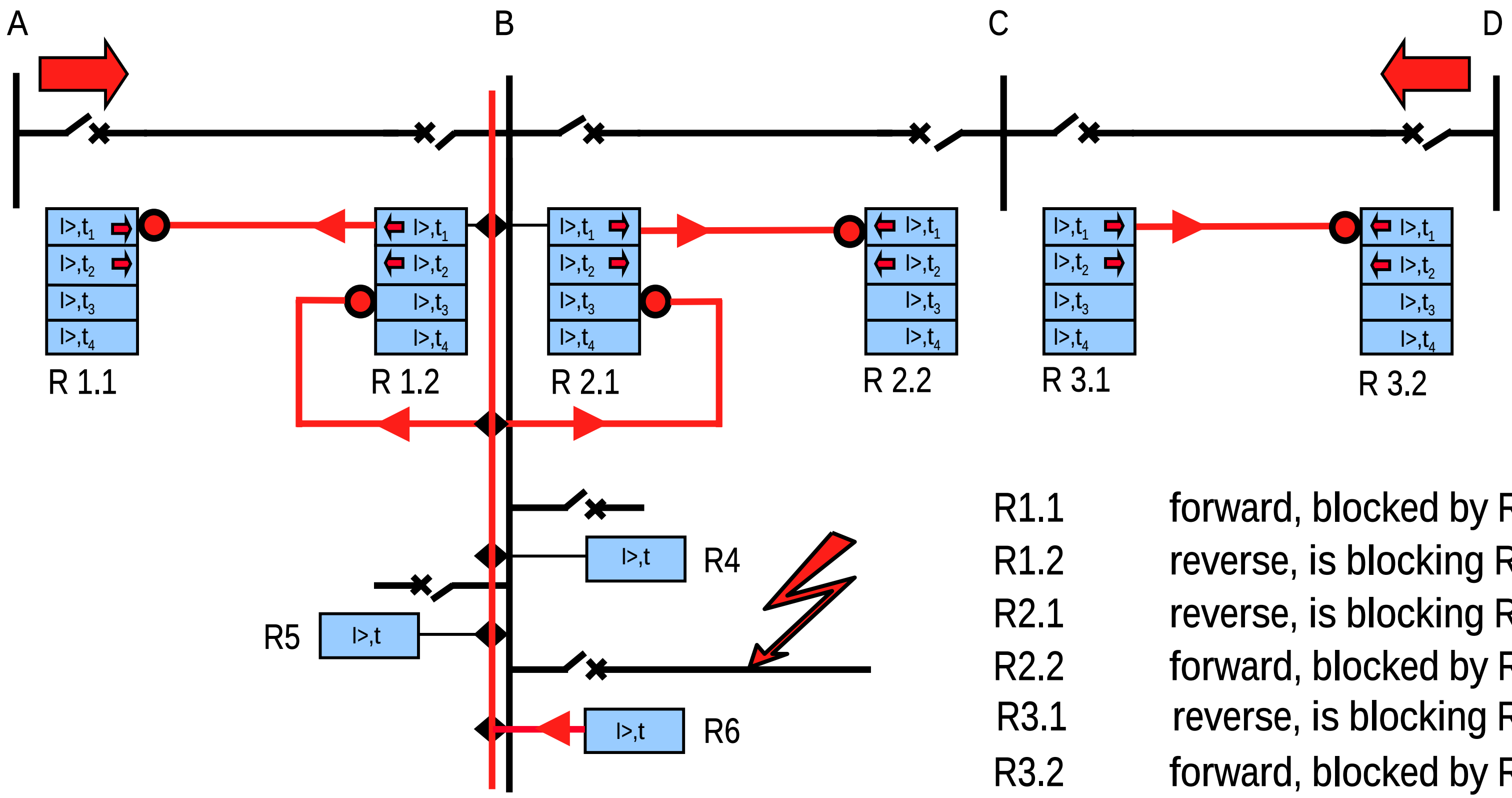
Directional comparison + reverse interlocking

Fault at outgoing feeder



R1.1	forward, blocked by R1.2
R1.2	reverse, is blocking R1.1
R2.1	reverse, is blocking R2.2
R2.2	forward, blocked by R2.1
R3.1	reverse, is blocking R3.2
R3.2	forward, blocked by R3.1
R4	no action
R5	no action
R6	is blocking BB-protection and trips

Directional comparison + reverse interlocking

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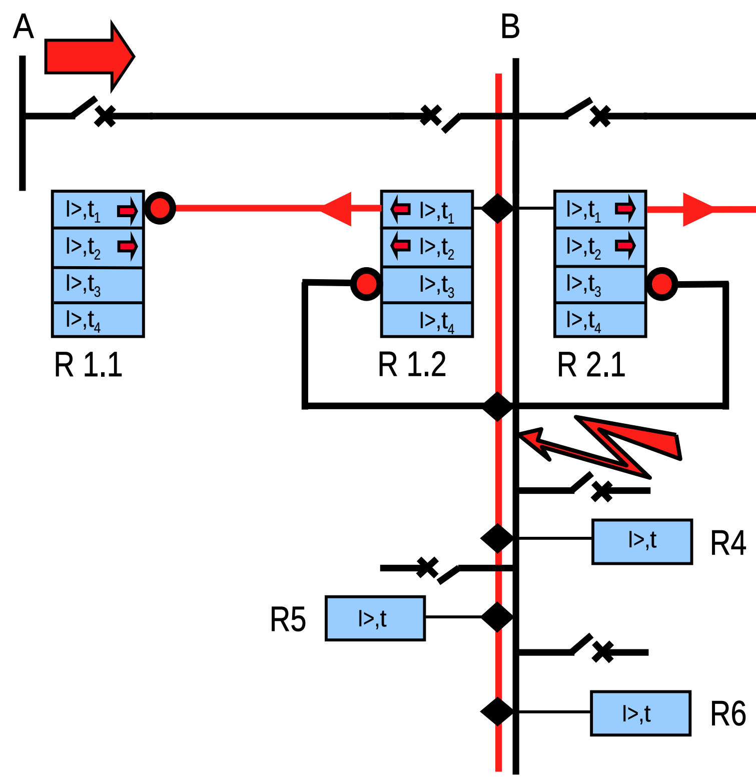
Fault at busbar B



R1.1	forward, blocked by R1.2
R1.2	reverse, is blocking R1.1 and trips BB-protection
R2.1	reverse, is blocking R2.2 and trips BB-protection
R2.2	forward, is blocked by R2.1
R3.1	reverse, is blocking R3.2
R3.2	forward, blocked by R3.1
R4	no action
R5	no action
R6	no action

Protection Principles and Co-ordination:

- Distance Protection

Basic principle of distance protection

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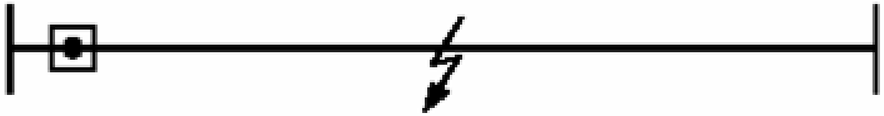
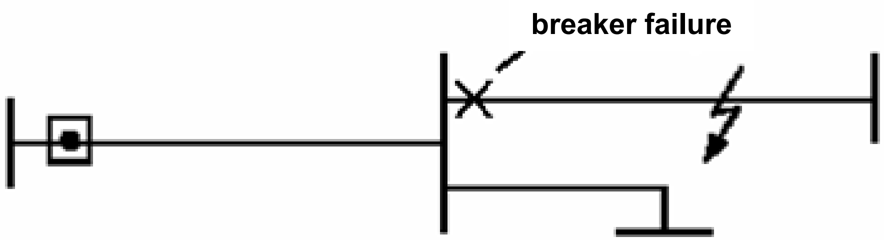
- 

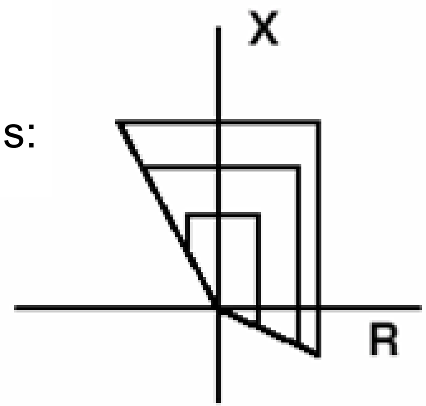
  Undelayed trip in first zone

- 

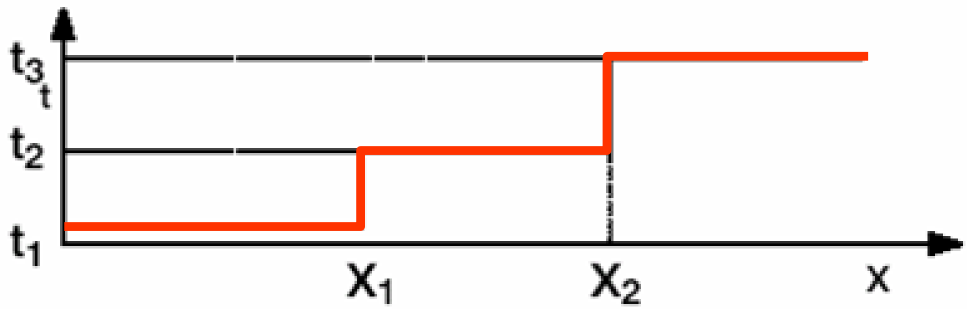
  Trip in second (back-up) zone delayed with second zone time e.g. in case of breaker failure

etc.

- Graphical representations:



Tripping zones in the impedance plane



grading chart

Zone 1 - Setting guidelines

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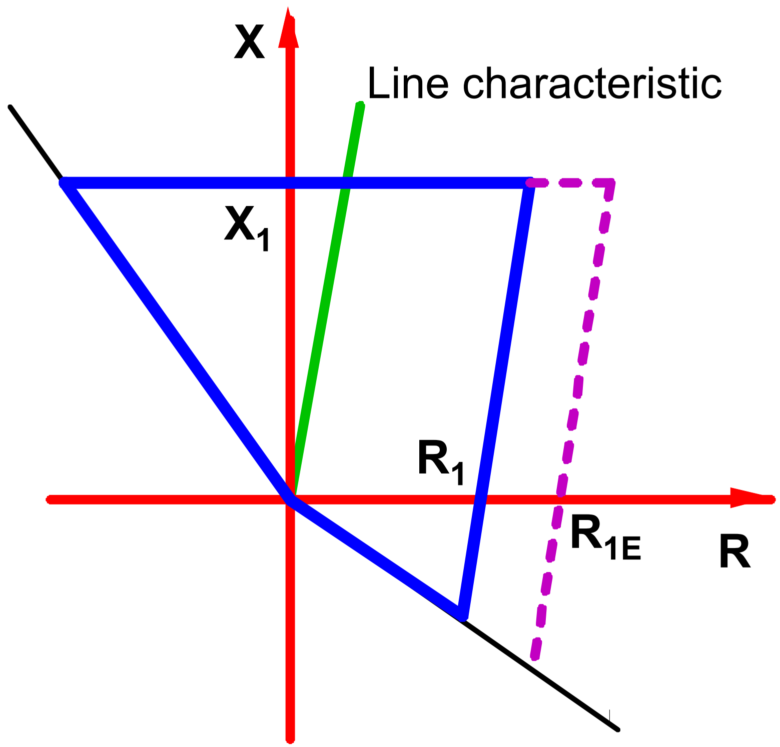


Recommendation for Zone 1 settings:

X_1 ≈ 80...90% of line reactance

R_1 ≈ 100% of arc resistance

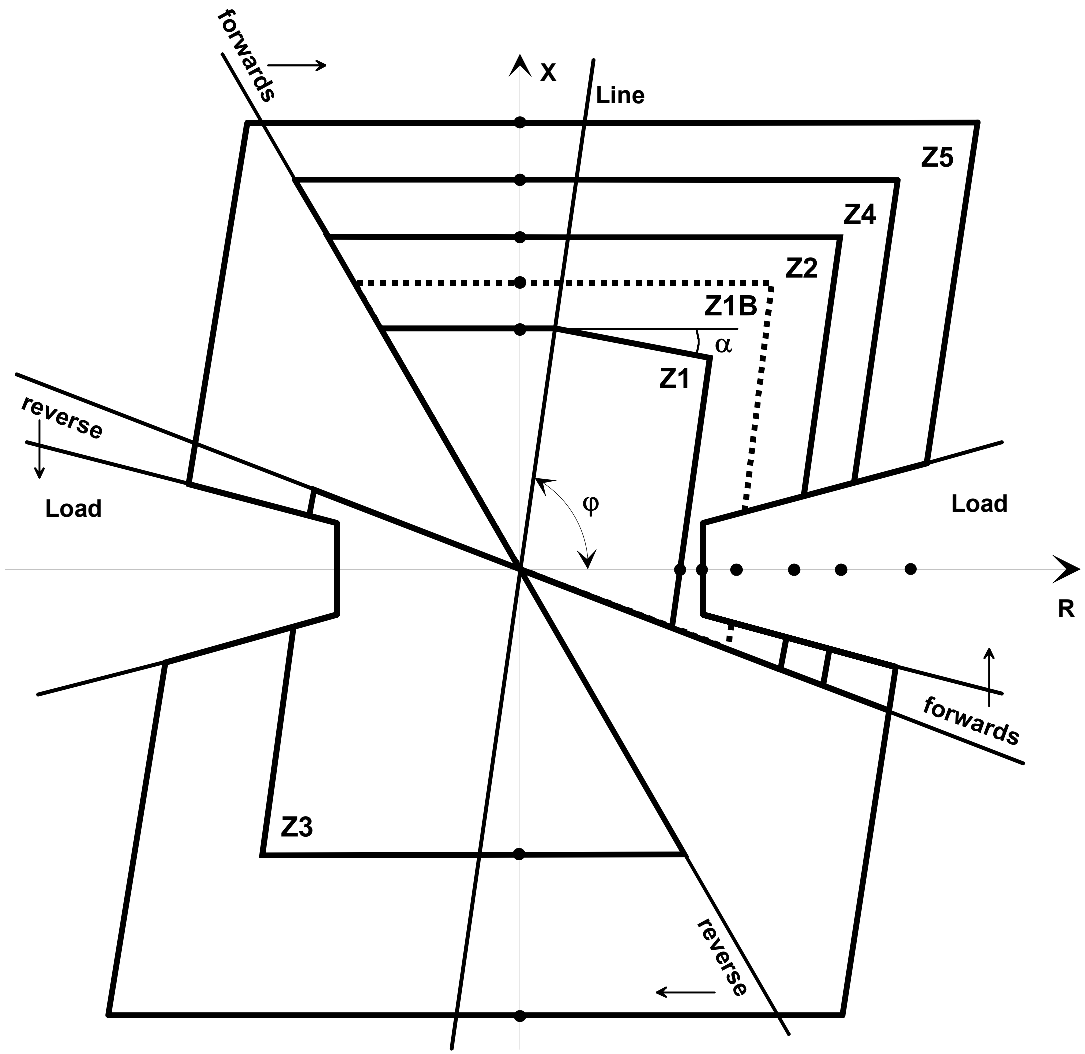
R_{1E} ≈ 100% of arc resistance

t_1 = 0 ms

If the measured impedance is within the set characteristic and the set time has expired, a TRIP command is issued

Distance protection: Zone characteristics

SIEMENS



- **Distance zones**
  - Inclined with line angle φ
  - Angle α prevents overreach of Z1 on faults with fault resistance that are fed from both line ends

- **Fault detection** (7SA6)
  - no fault detection polygon: the largest zone determines the fault detection characteristic
  - simple setting of load encroachment area with R_{min} and φ_{Load}

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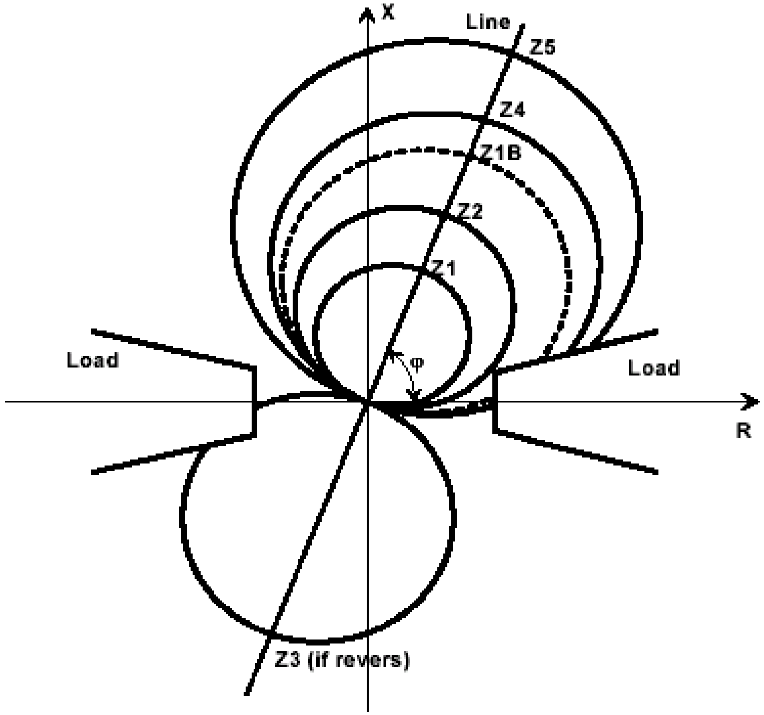
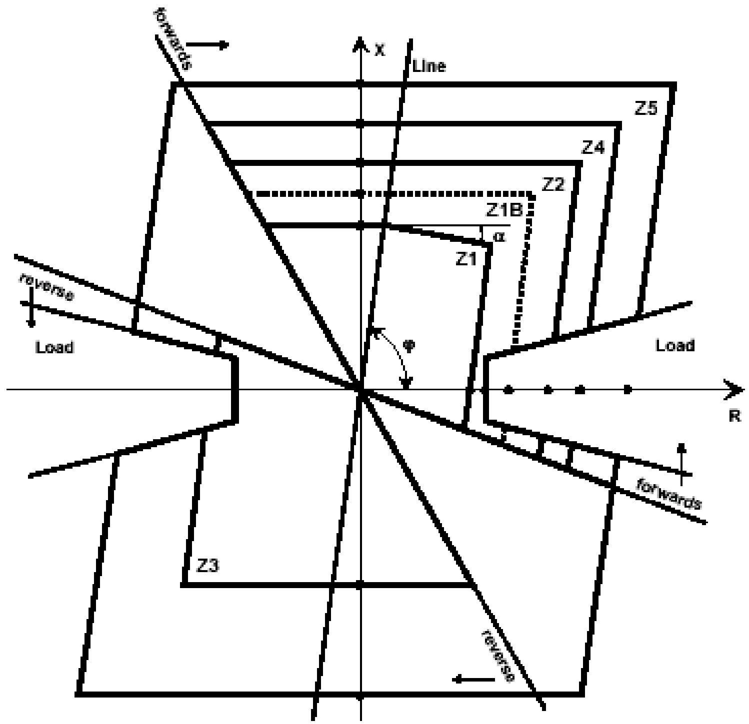
Comparison of zone characteristics: MHO versus polygonal





Grading of the zones - radial network

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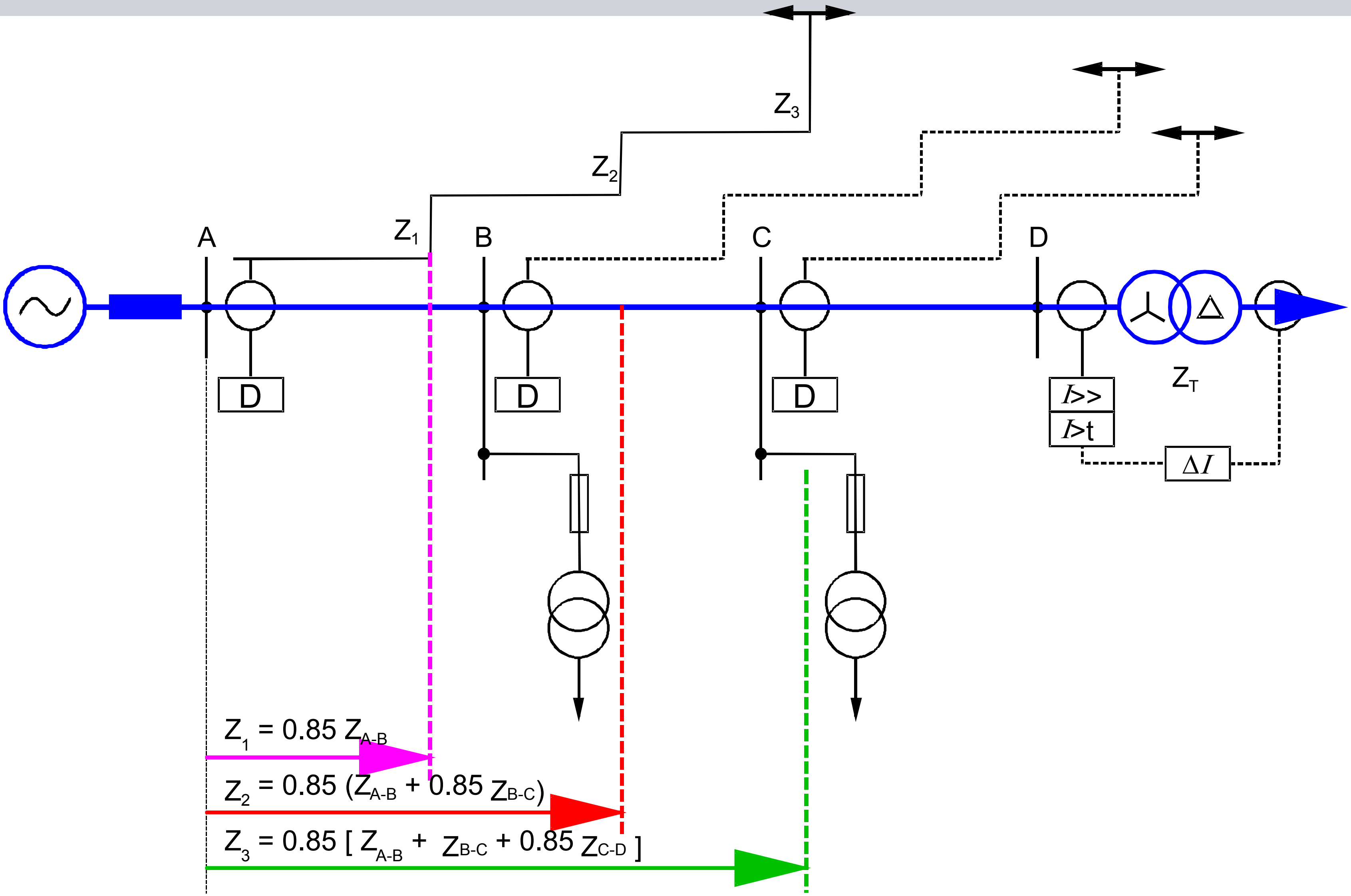
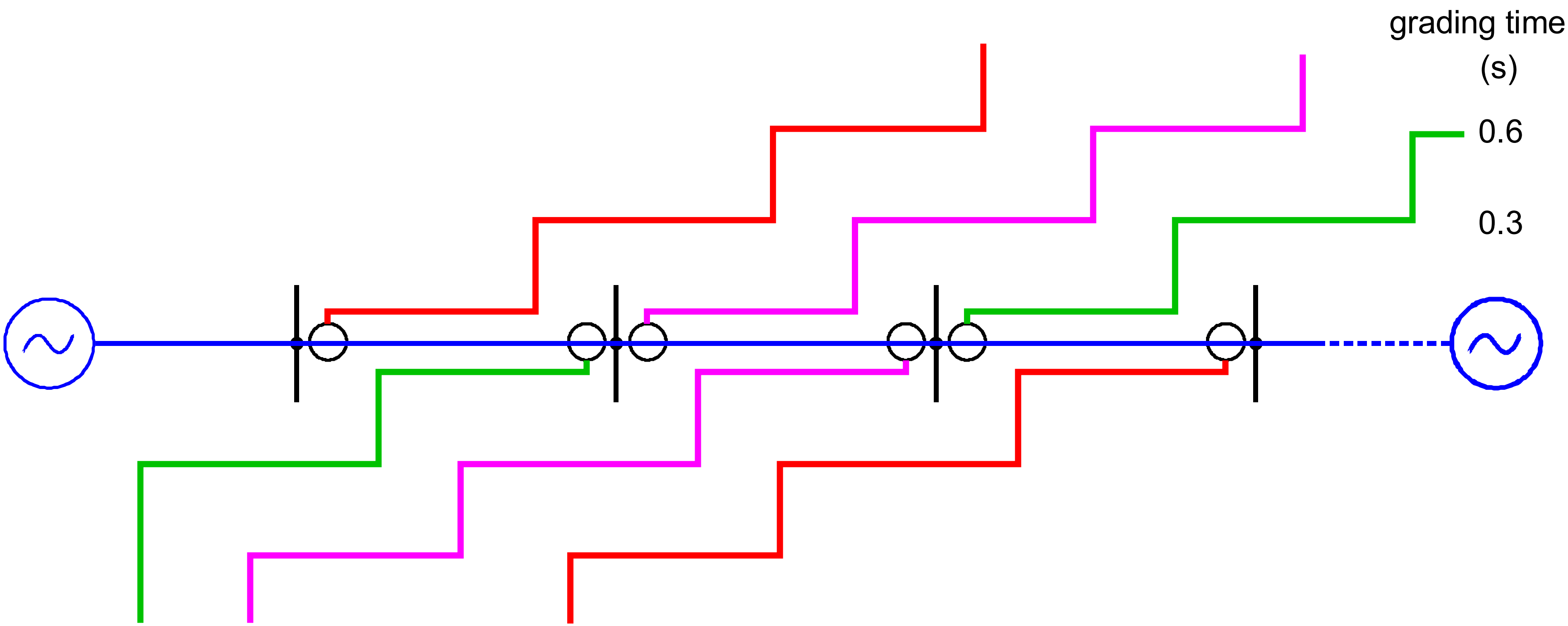


Grading of the zones - infeed at both ends

SIEMENS



Ring with grading towards opposite line end

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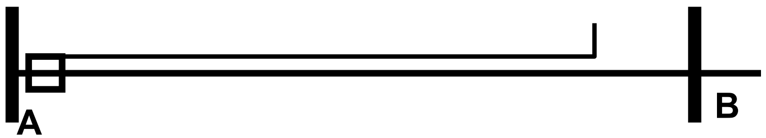
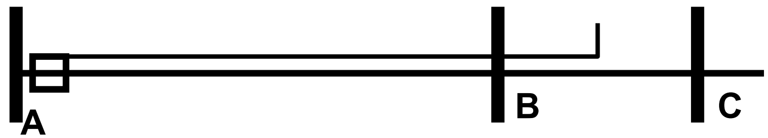
1st Zone Settings

Normal Situation



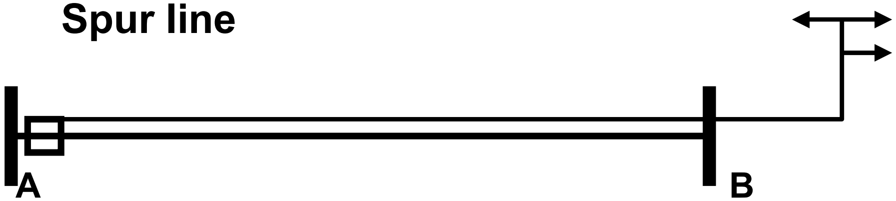
$Z_{1.zone} = 0.85 \times Z_{A,B}$

No relay in the next station



$Z_{2.zone} = 0.85 \times (Z_{A,B} + Z_{B,C})$

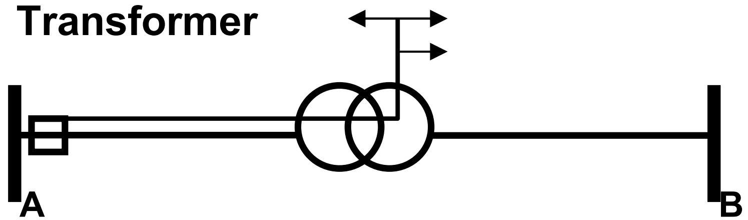
Spur line



$Z_{1.zone} = 1.20 \times Z_{A,B}$

$Z_{1.zone} = Z_{2.zone} = Z_{3zone}$

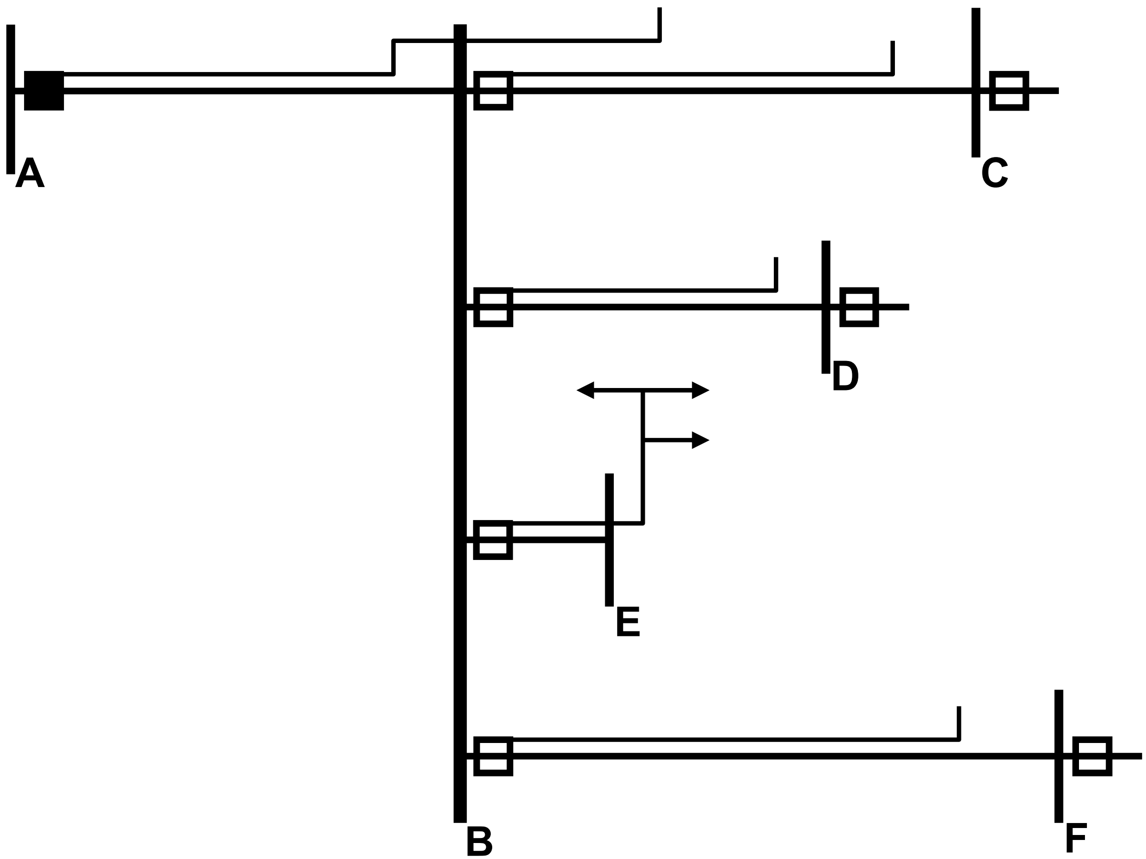
Transformer



$Z_{1.Zone} = 0.85 \times Z_{transf.}$

$Z_{1.zone} = Z_{2.zone} = Z_{3.zone}$

2nd Zone Settings



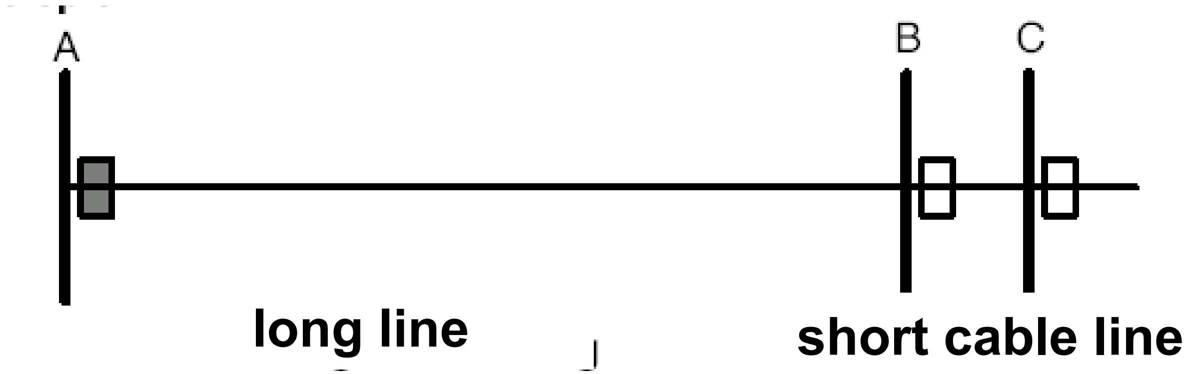
$Z_{2.zone}$ = 0.90 x ($Z_{A,B}$ + 0.85 x min {Z_B…})

2nd zone impedance grading acc. to the shortest 1st zone setting and the next busbar ($Z_{B,D} < Z_{B,C} < Z_{B,F}$), hereby spur lines are neglected ($Z_{B,E}$).

$Z_{2.zone}$ = 0.90 x ($Z_{A,B}$ + 0,85 x $Z_{B,D}$)

2nd Zone Settings in Case of Short and Long Lines in Series

Example



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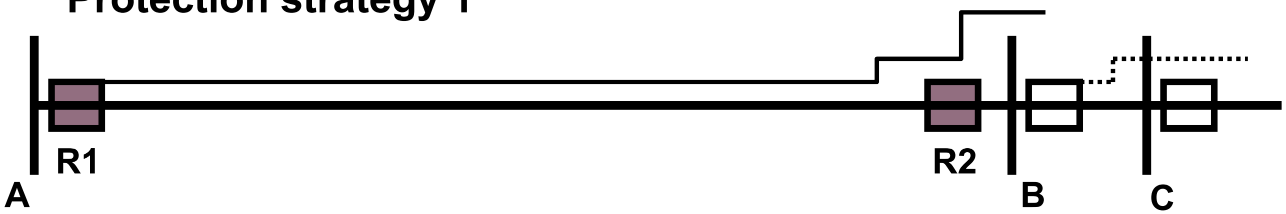
2nd Zone Settings in Case of Short and Long Lines in Series

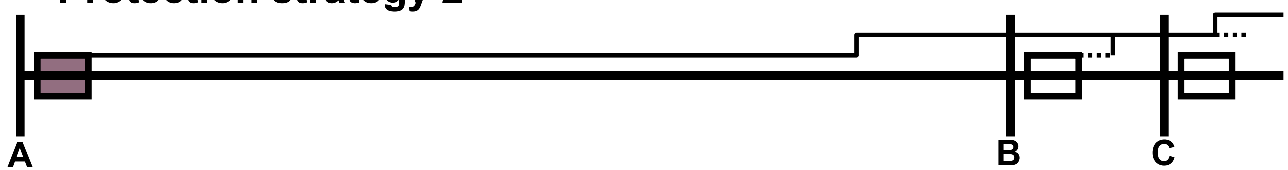
Protection strategy 1



$Z_{2.zone}$ = 0.85 x (Z_{AB} + 0.85 x Z_{AC}) < 1.00 Z_{AB}

Comment: absolutely selective grading schedule, but short-circuit faults on the last part of long line will be tripped in the 3rd zone.

Protection strategy 2



$Z_{2.zone}$ = 1.2 x Z_{AB}

Comment: fast 1st zone and 2nd zone will trip all short-circuit faults on the long line, but no selective tripping in the 2nd and higher zones.

Alternative:
Protection relay R2 at the terminal B can be graded with 2nd zone in reverse direction.

3rd Zone Settings

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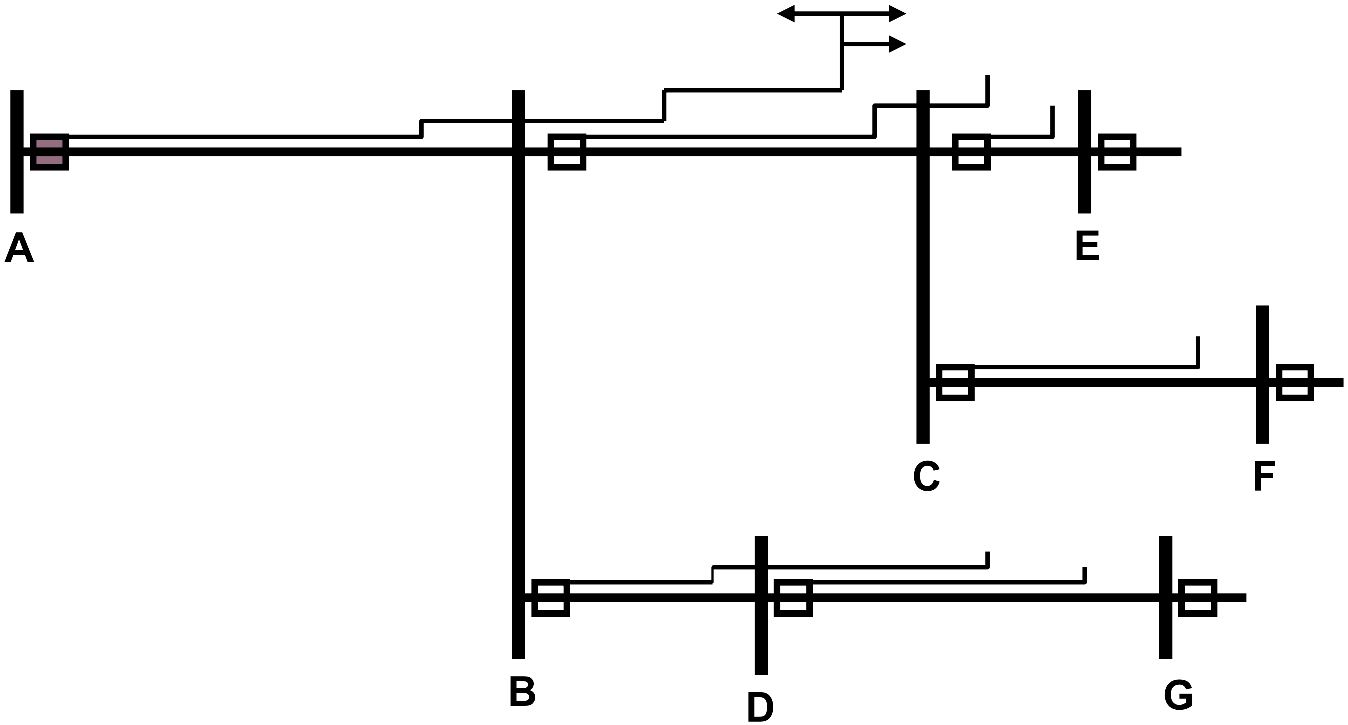

$Z_{3.zone} = 0.85 \times (Z_{A,B} + 0.85 (Z_{B,C} + 0.85 \times Z_{C,E}))$

$Z_{B,C} + 0.85 \times Z_{C,E} < Z_{B,D} + 0.85 \times Z_{D,G}$

Grading according to the shortest 2nd zone of the outgoing lines at the next station . Fault at station C will not be cleared with 3rd zone!

3rd Zone Settings

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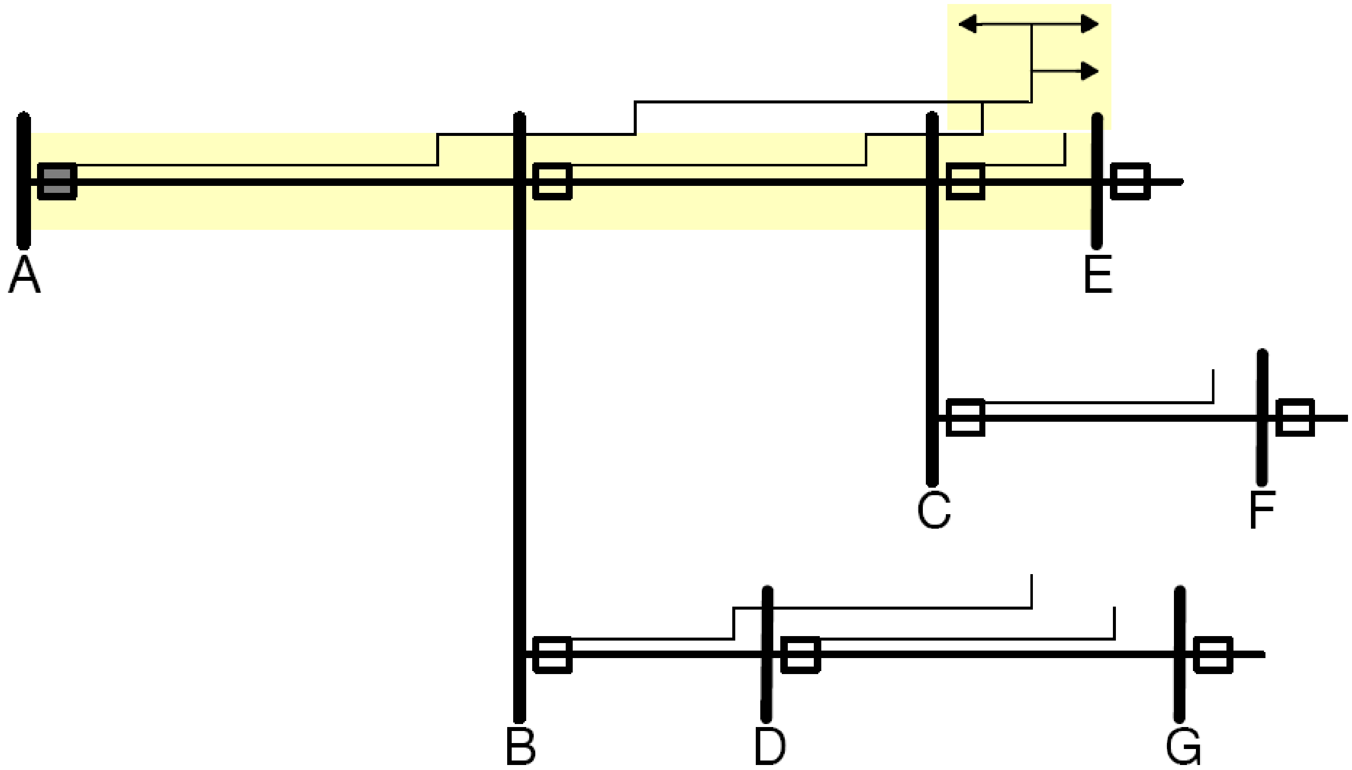
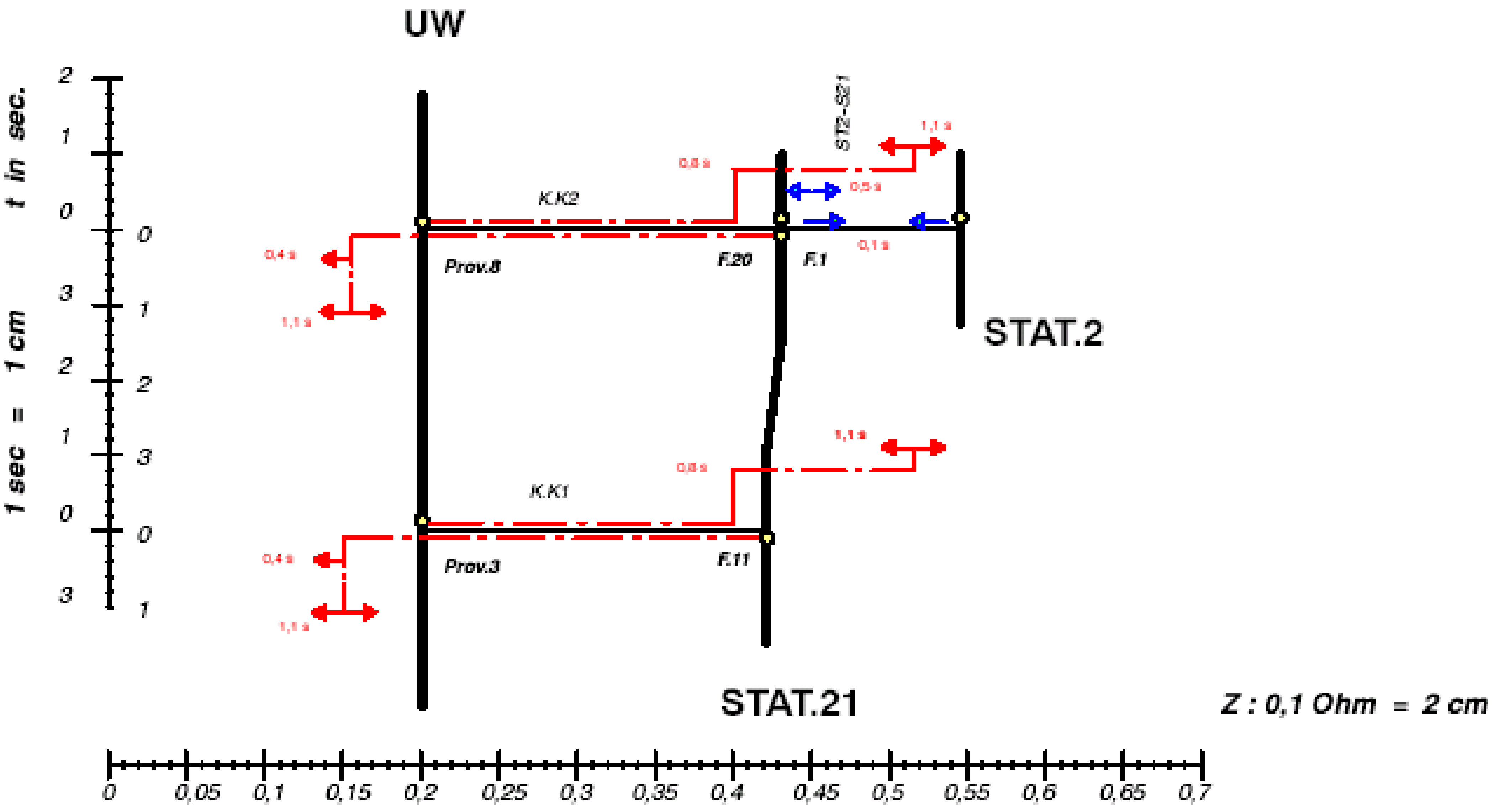


$Z_{3.zone} = 1.20 \cdot (Z_{A,B} + Z_{B,C})$ $Z_{B,C} > Z_{B,D}$

Setting of the 3rd zone that short-circuit faults on the electrically farest next-to-next station will be tripped in the 3rd zone.

This setting leads to unselective 3rd zone tripping.

Infeed Cable with Distance Protection



Impedance Plan with Relay Zone Reach

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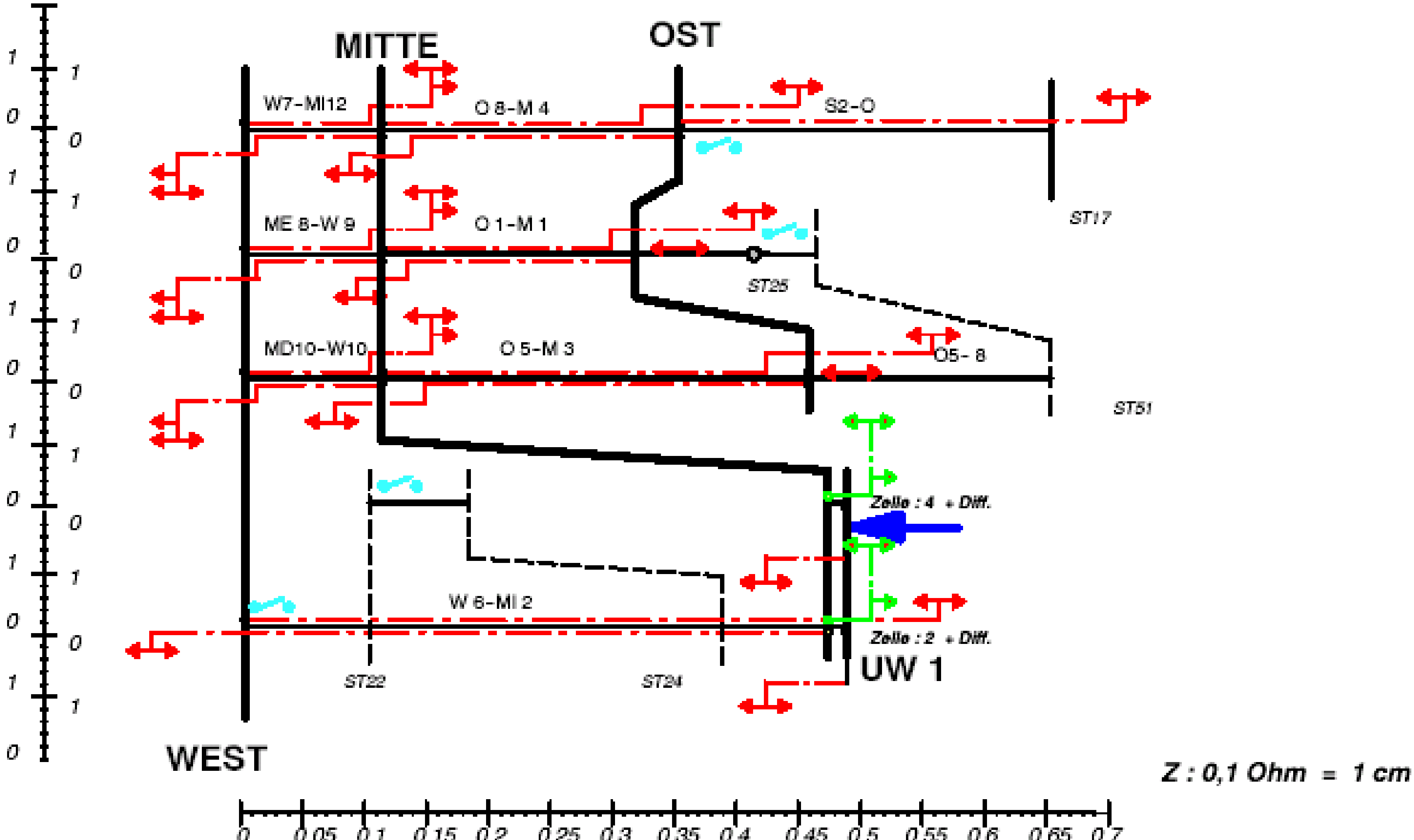

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Coordination of Relays, Fuses and LV-Circuit breakers

Case Study

Inverse time Relay Setting Parameters

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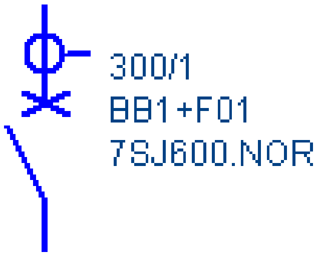
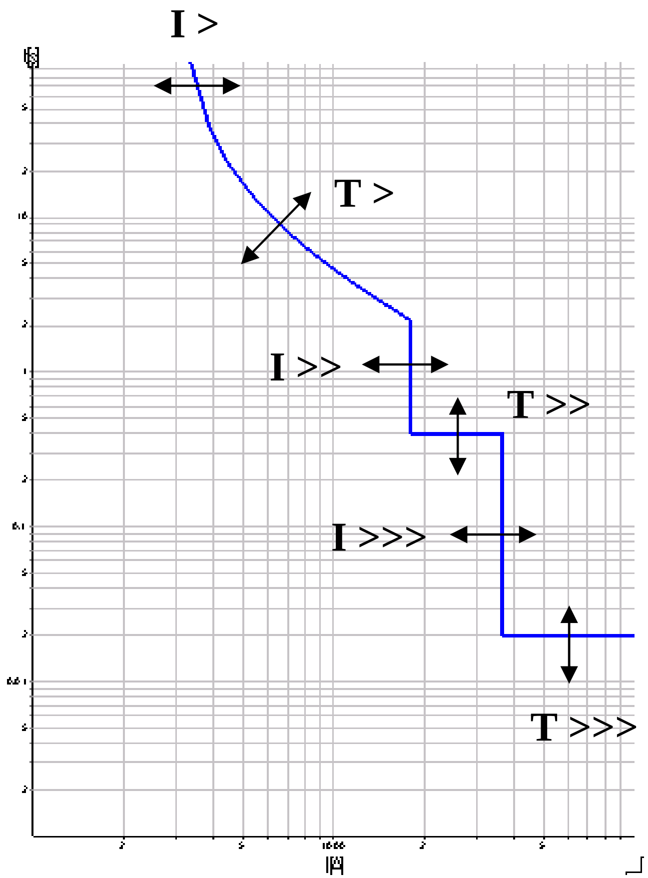


Phase Fault :	**Ip**	**Tp**	*)
	I >	**T >**	
	I >>	**T >>**	
	I >>>	**T >>>**	
Earth Fault :	**I Ep**	**TEp**	*)
	I E>	**T E>**	
	I E>>	**T E>>**	

***) characteristic**



Definite Time Relay SettingCharacteristics

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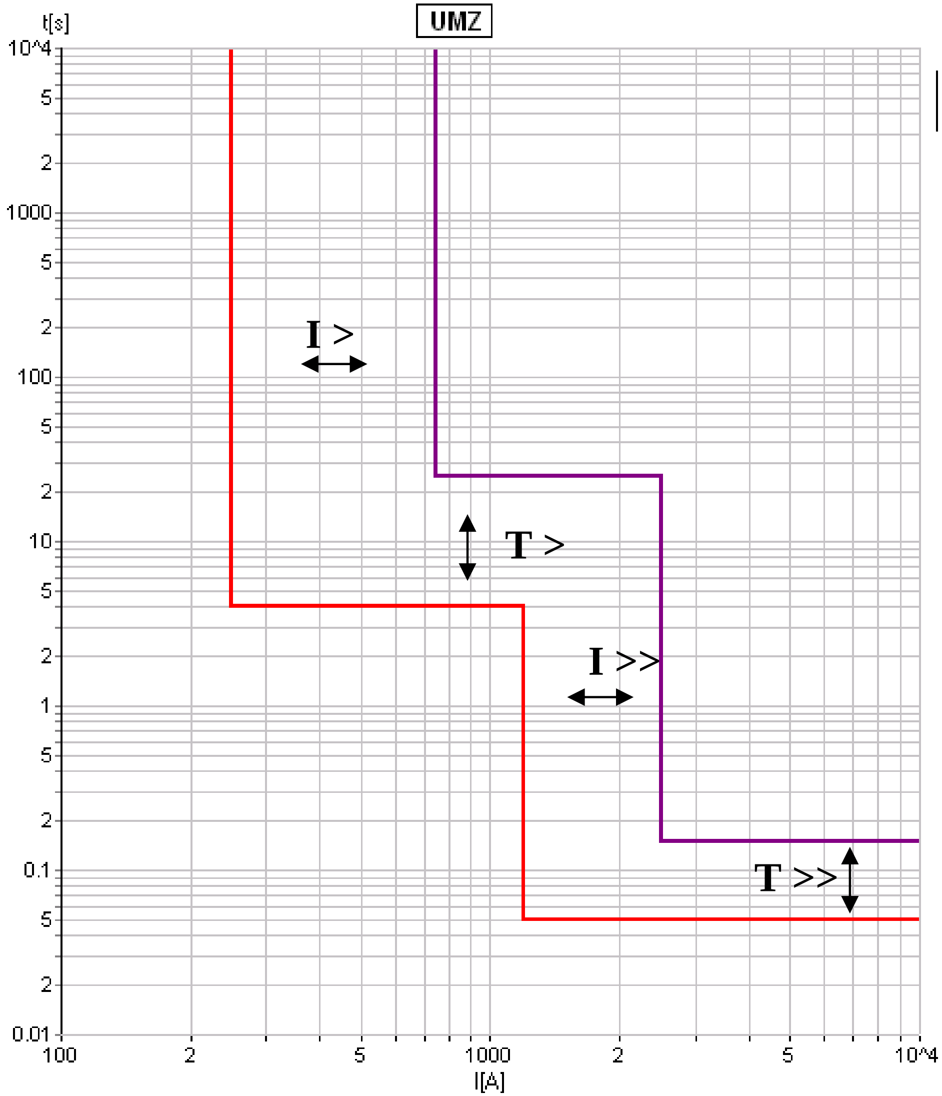
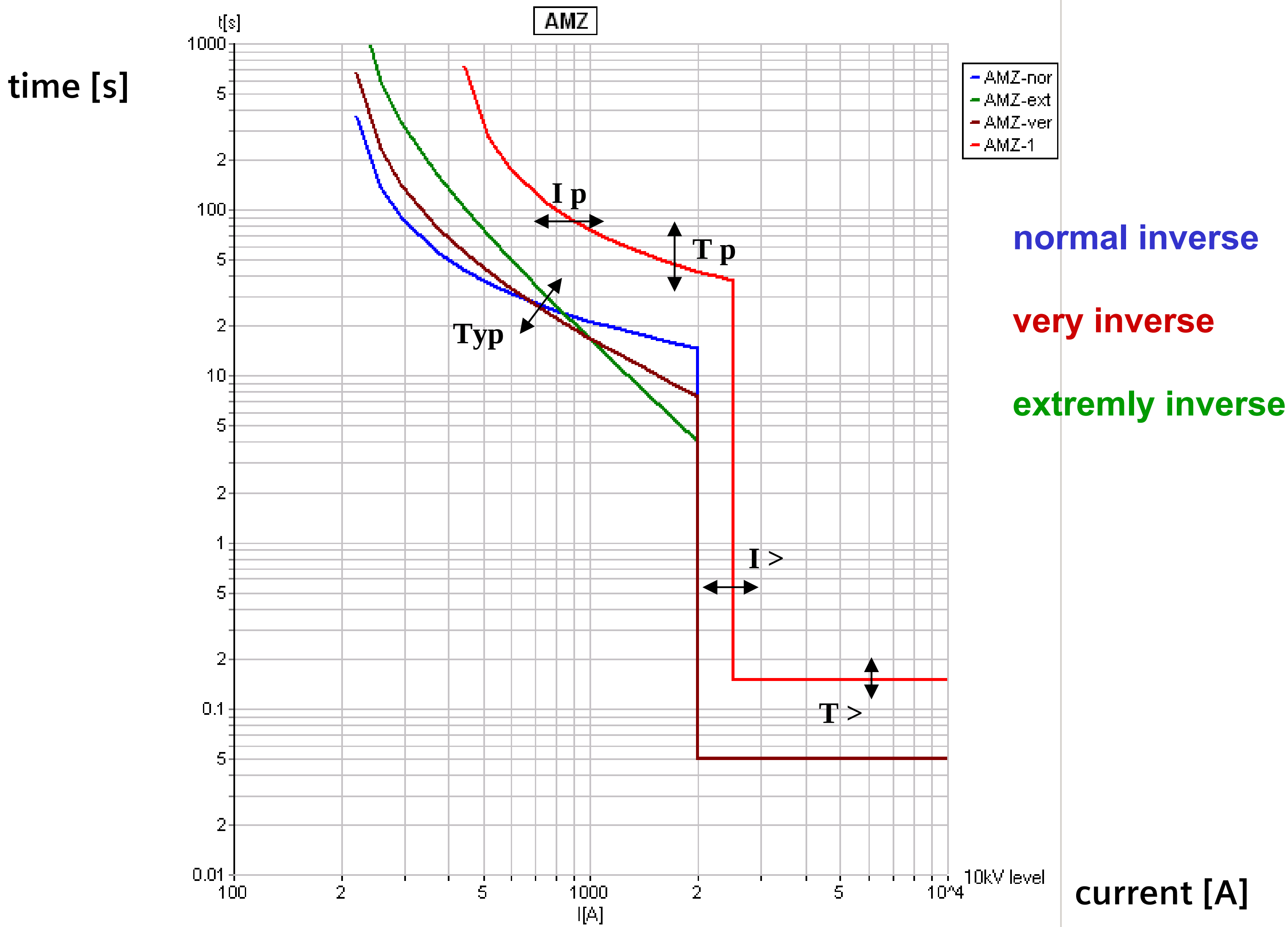
time [s]

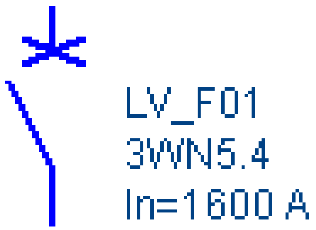


current [A]

Relay inverse Time Characteristics acc. to IEC and BS142

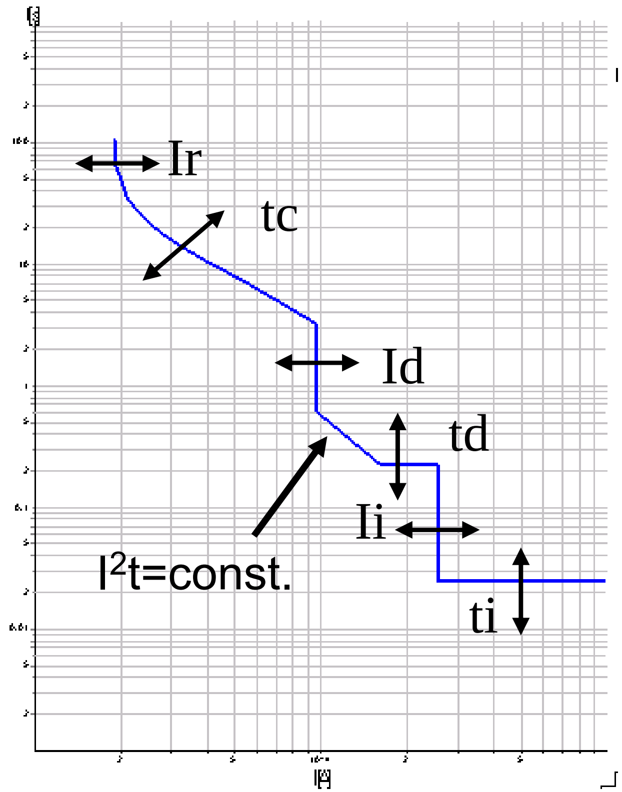


LV Circuit Breaker Setting Parameters

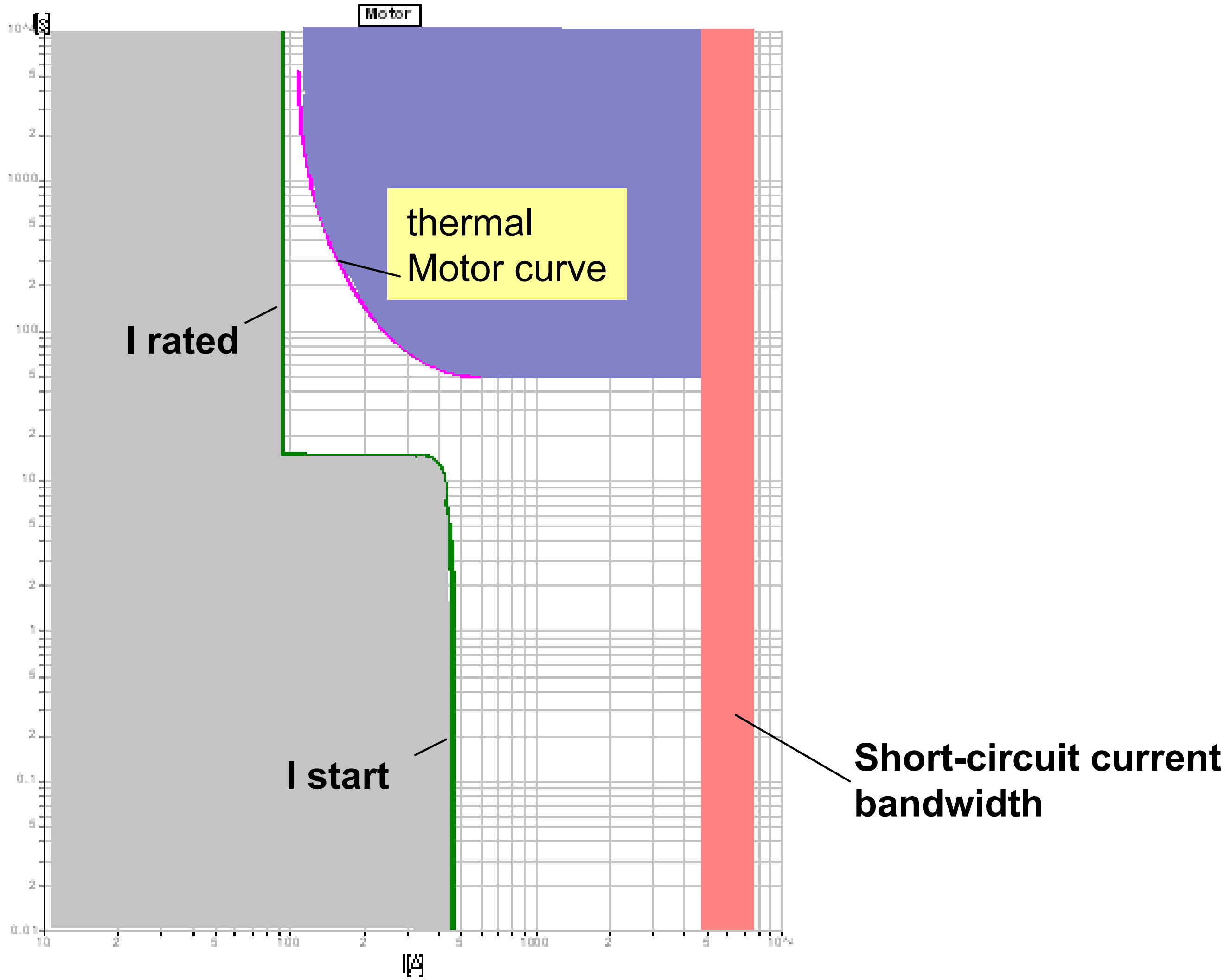


Phase Fault : Ir tc
I d t d
I i t i

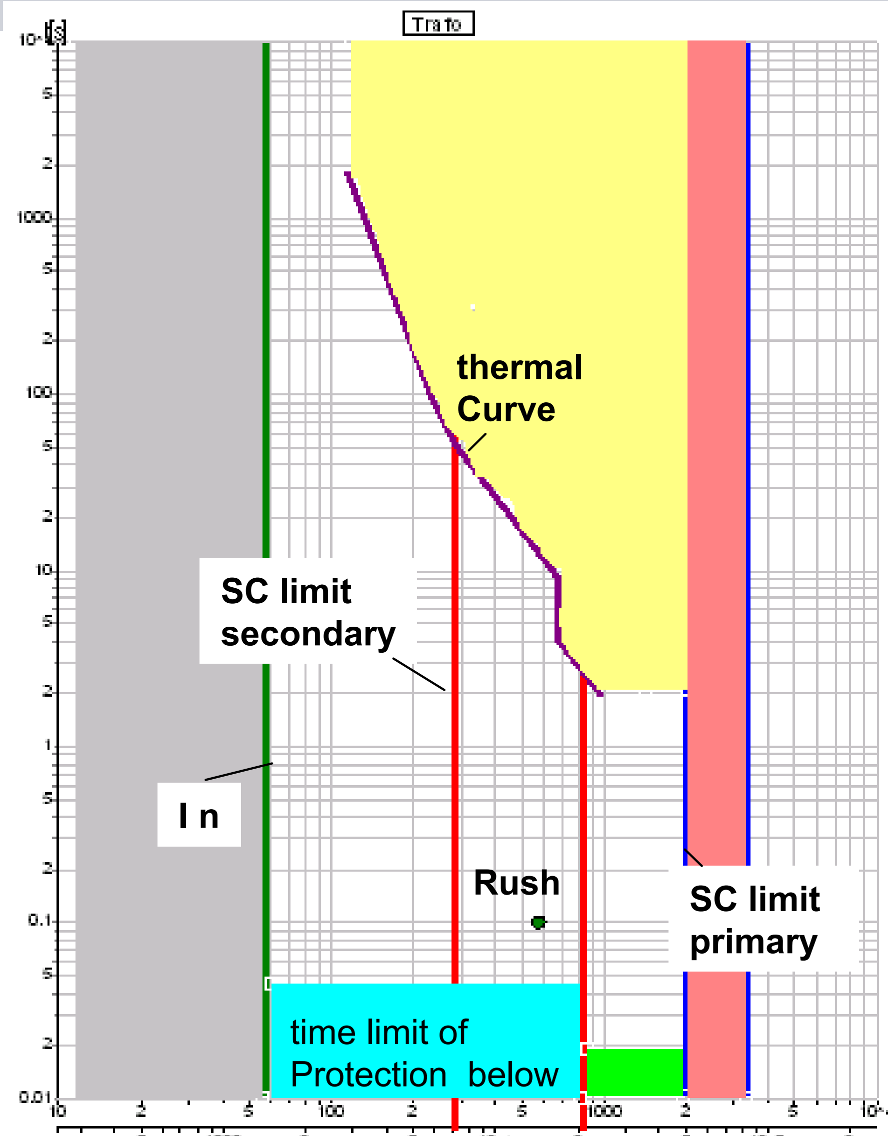
Earth Fault : I g tg



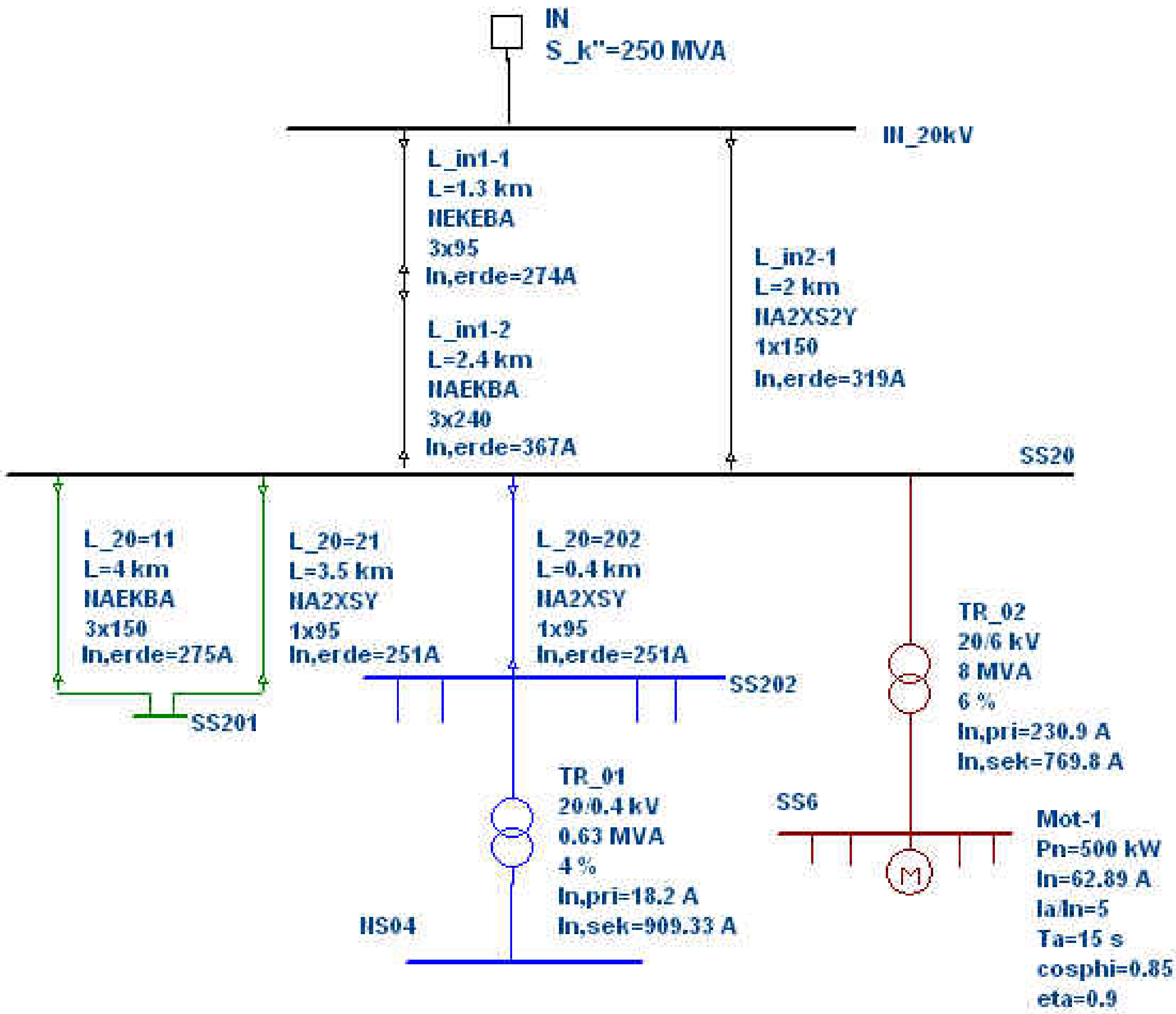
Protection Area - „Motor“



Protection Area - „Transformer“



Example: Network 20/6/0.4 kV



Data base for short circuit calculation

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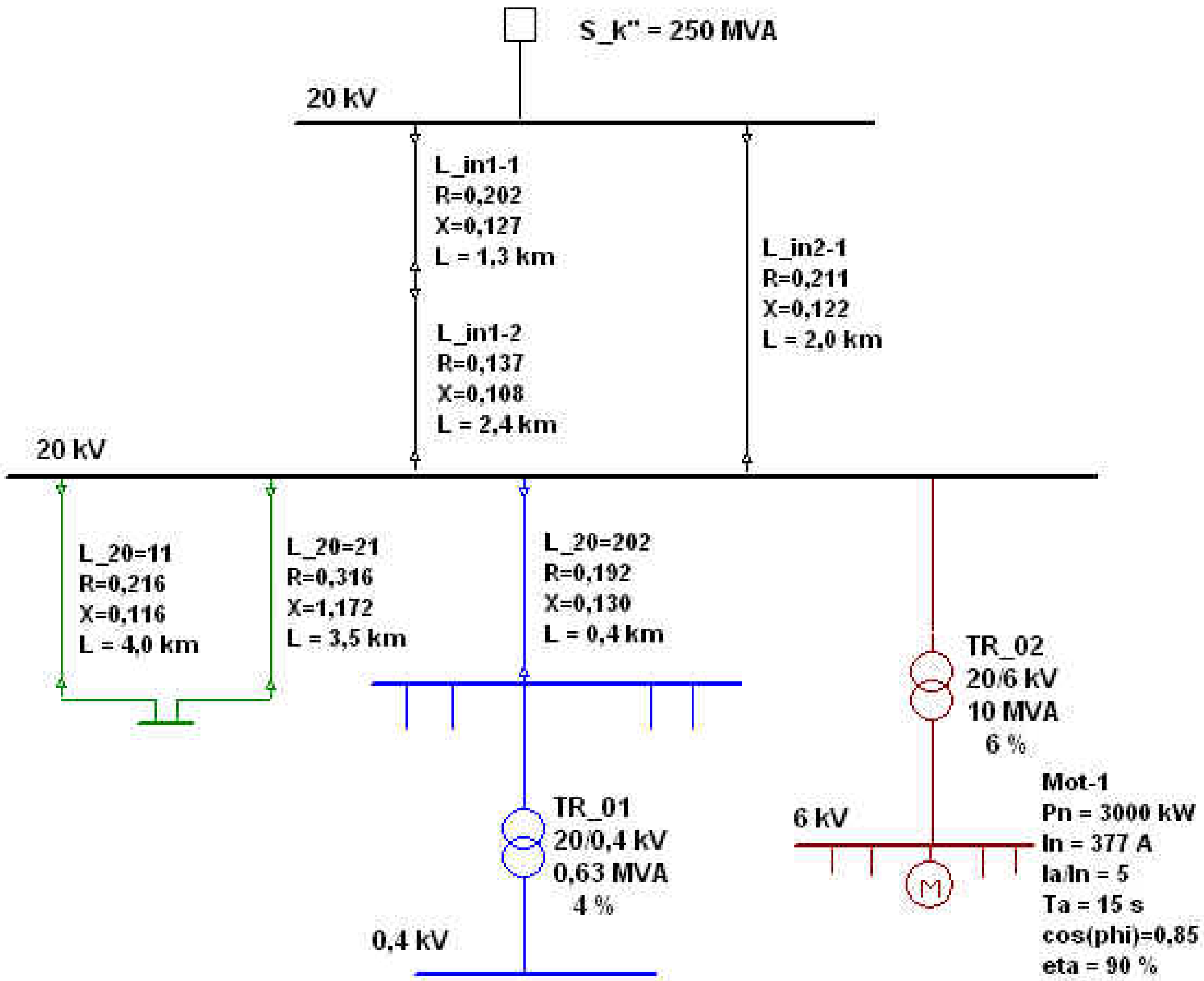
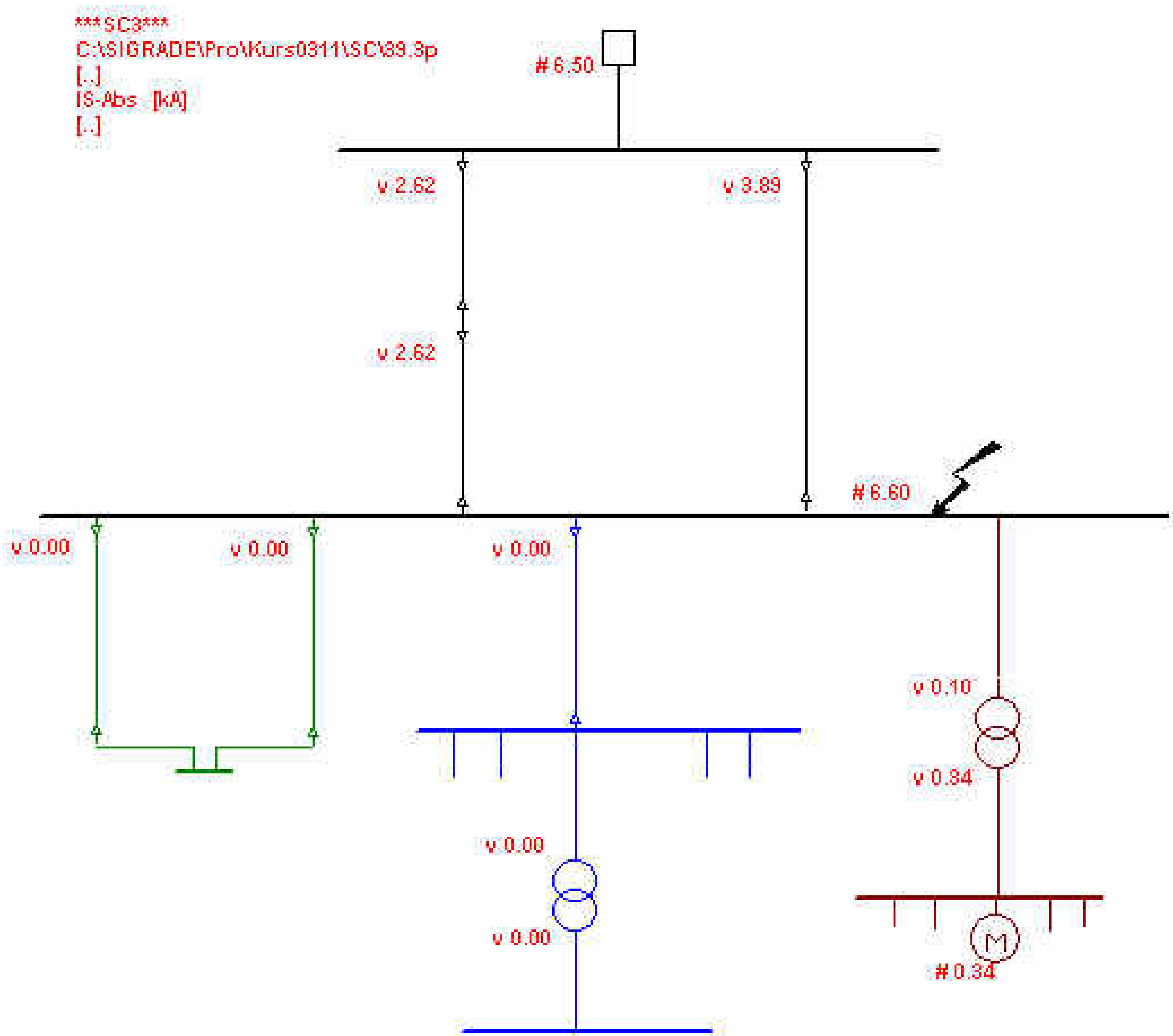
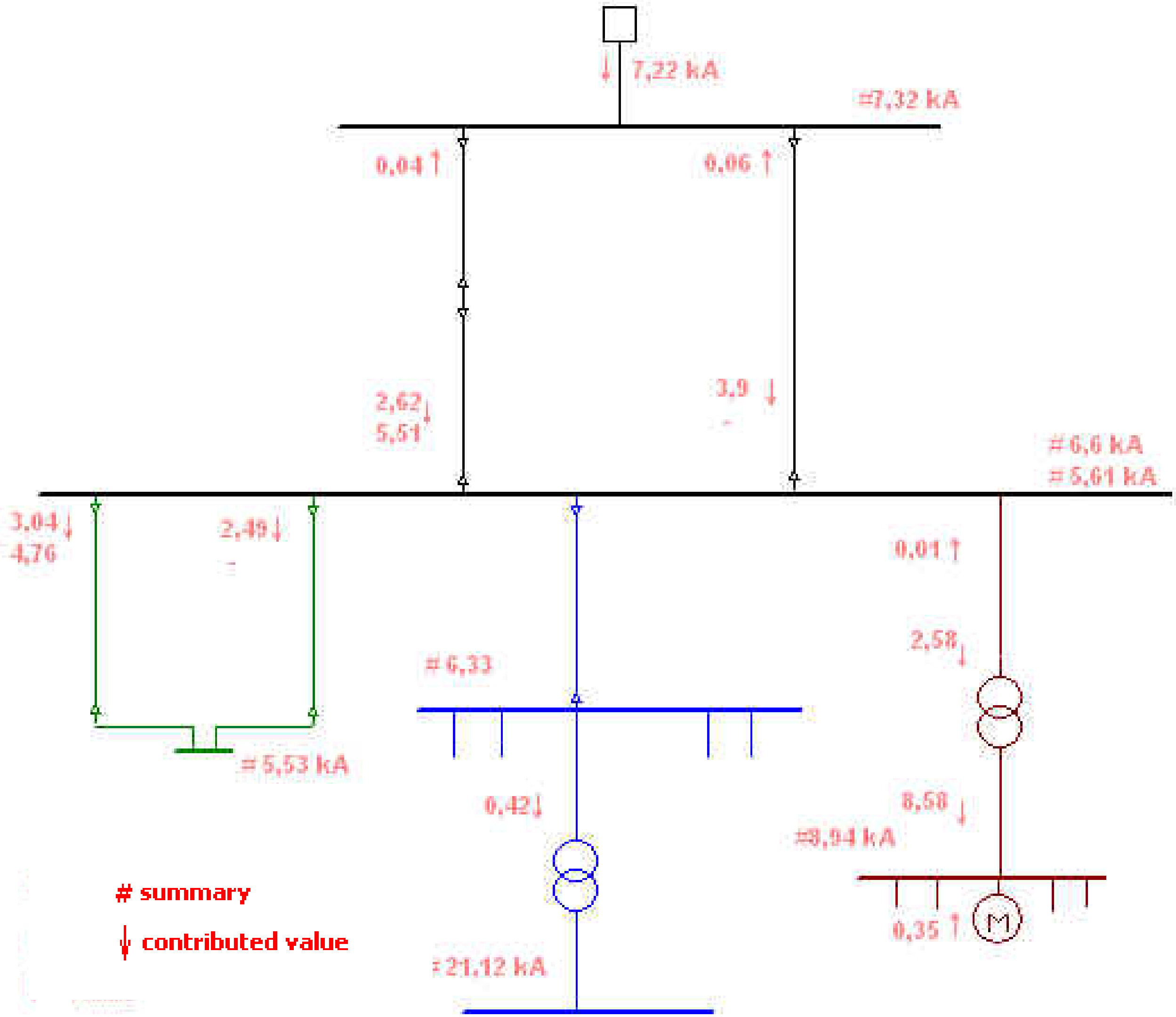


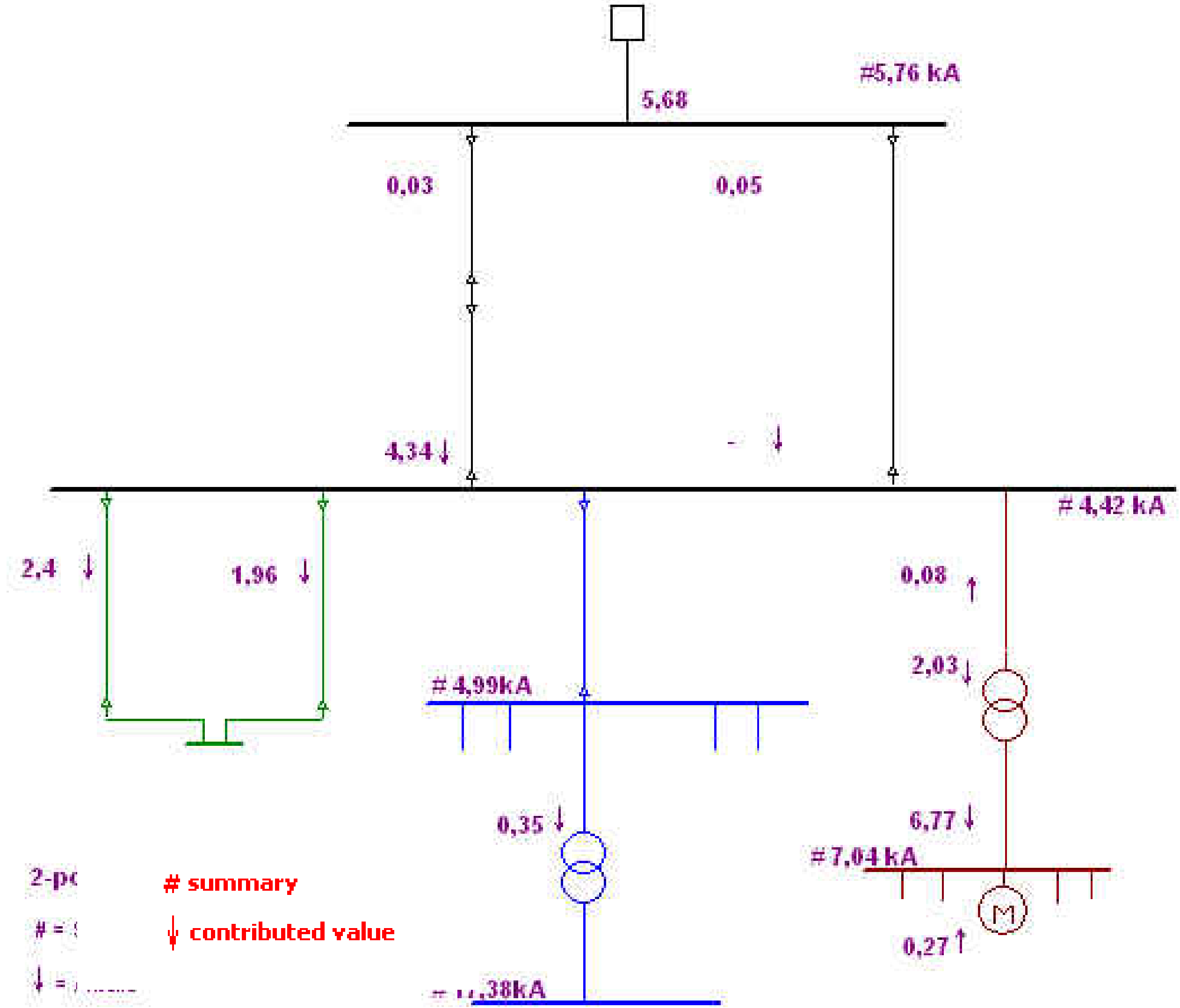
Short circuit calculation results



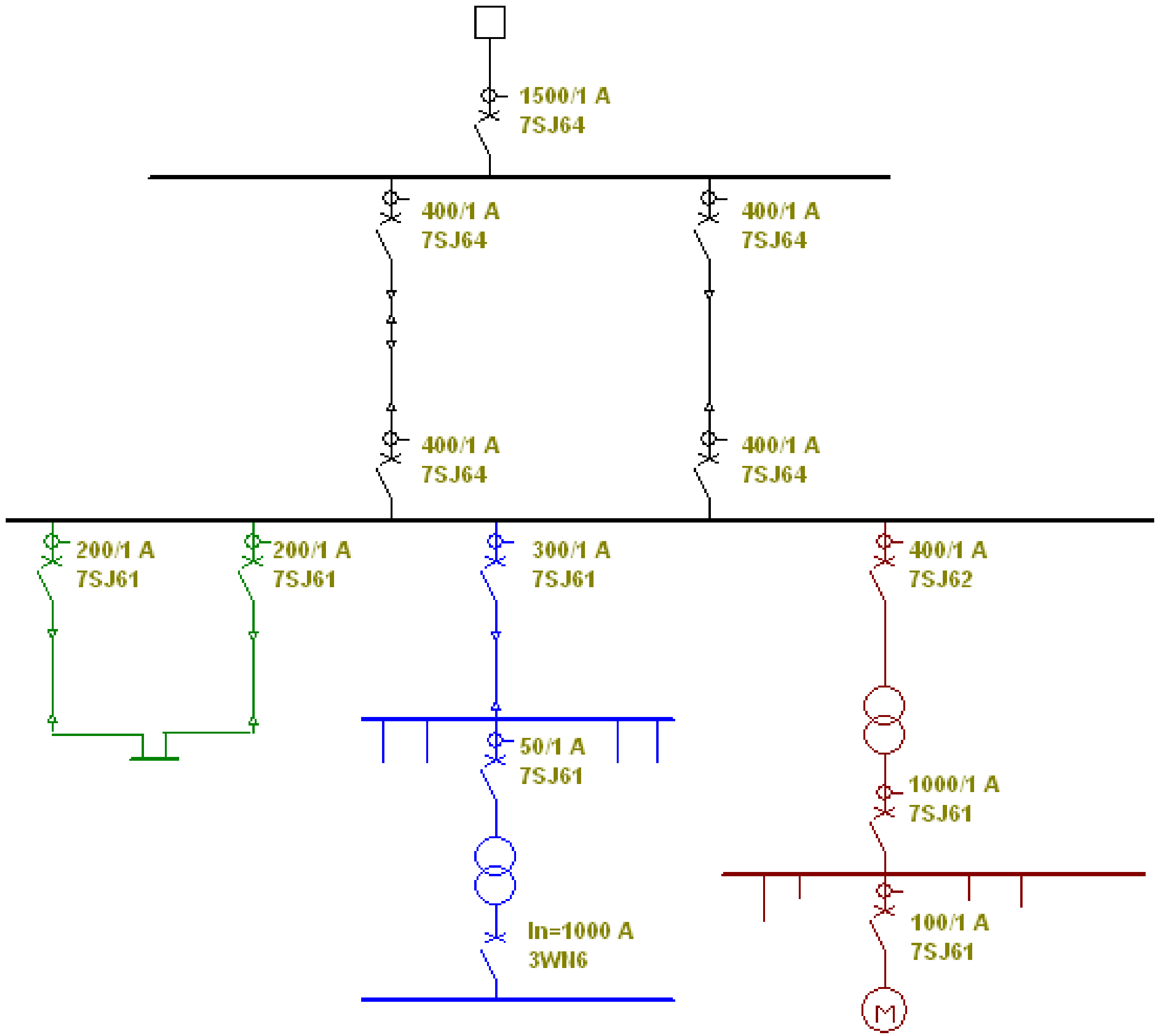
Summary of results - maximum 3-phase short circuit



Summary of results - minimum 2-phase short circuit



CT data and protection devices



Protection Coordination – Motor feeder

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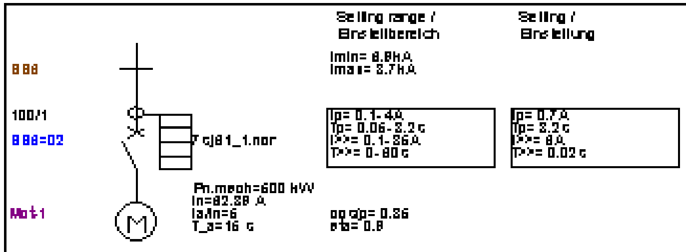
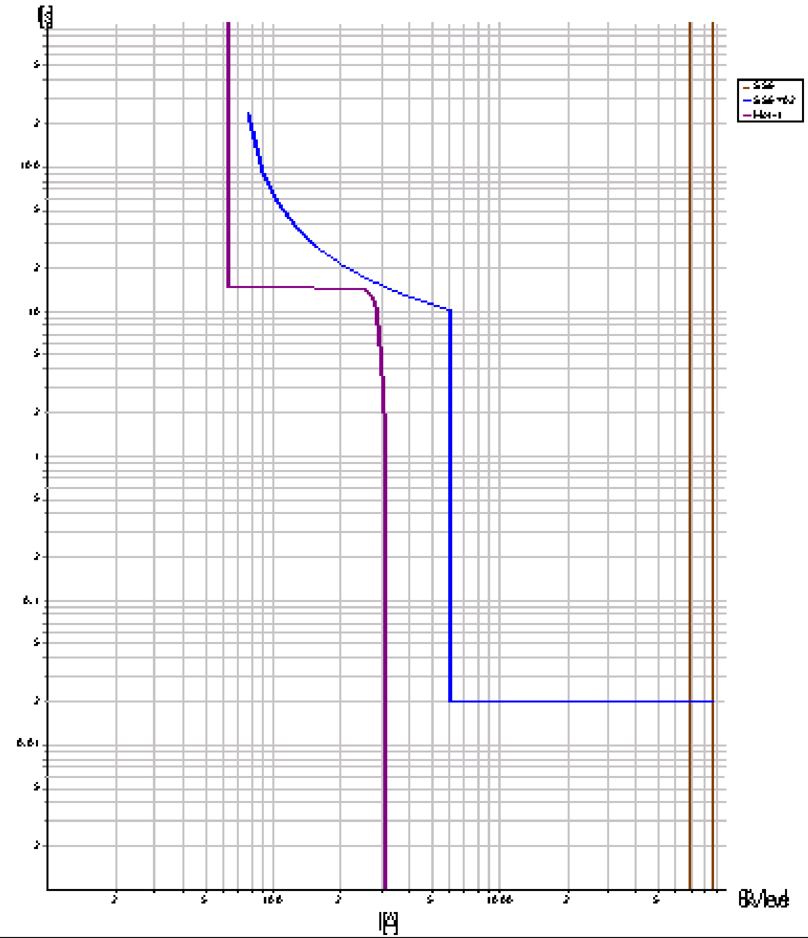




Requirements:

Ip ~ 110 % * In,motor

tmot[Istart,motor] < tcurve

Istart,motor < I>> < Isc,min

Datum 11.11.2005

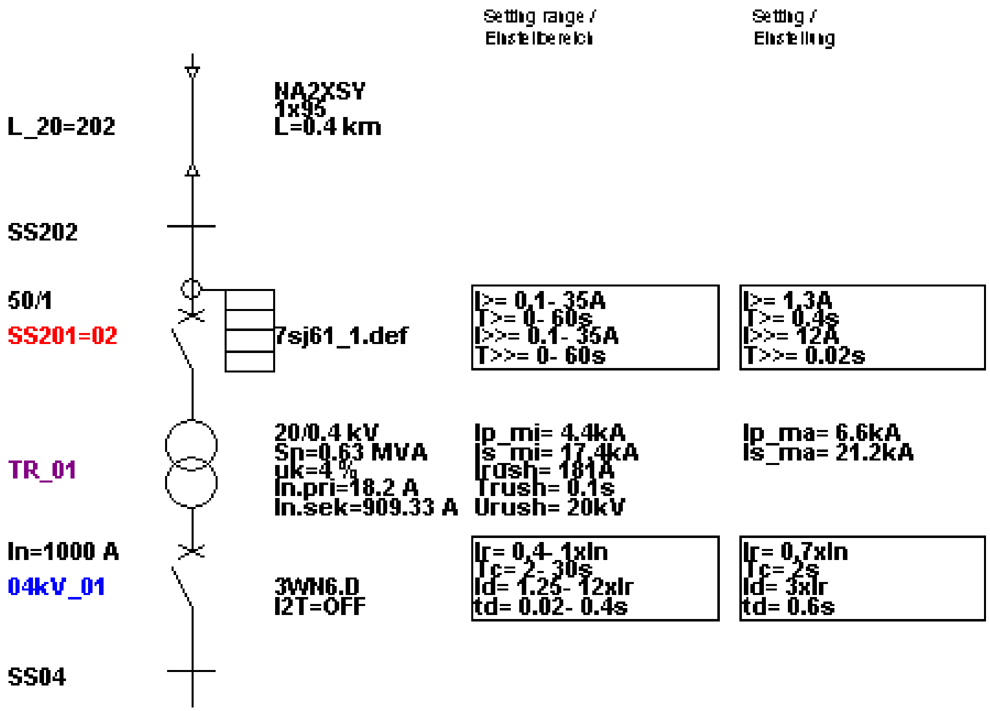
Projekt == TRAINING NEG ==

Motor Feeder

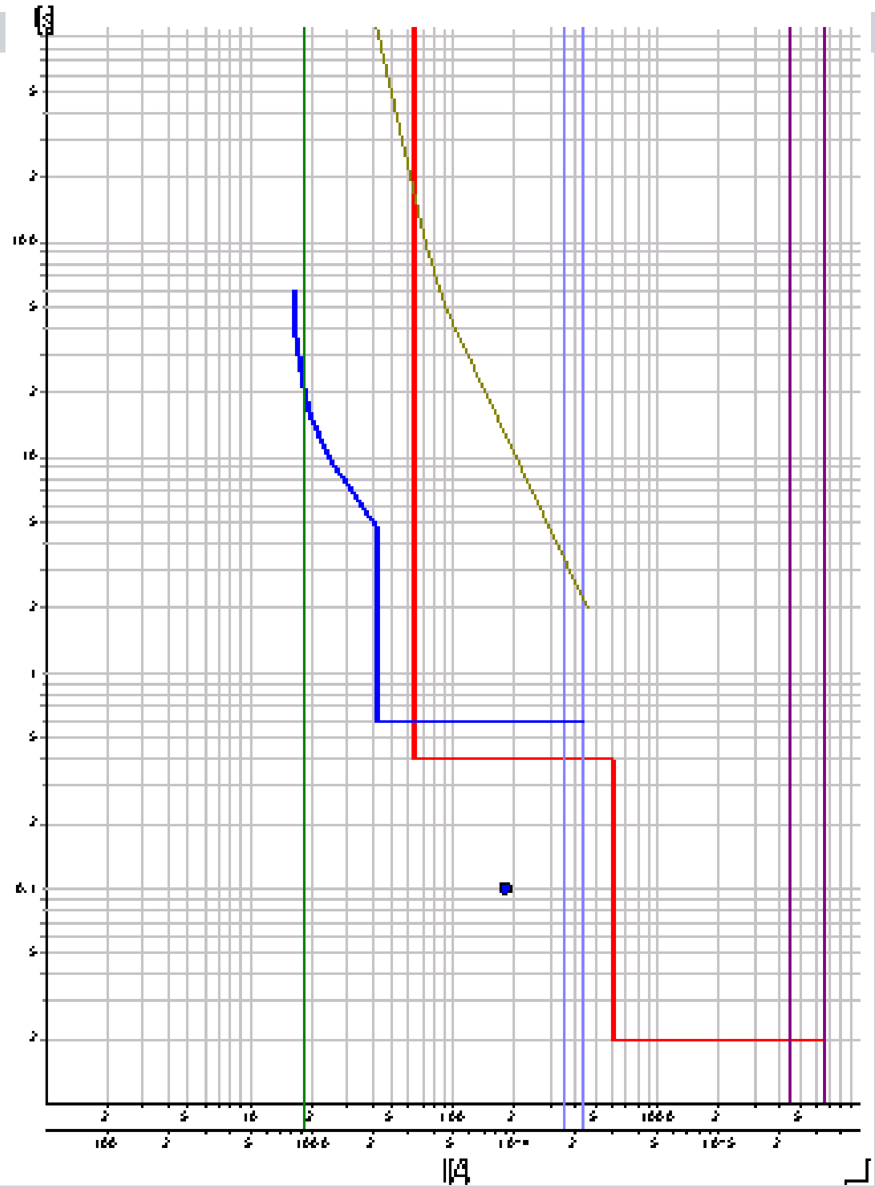
SIEMENS AG

PTD SE NCS

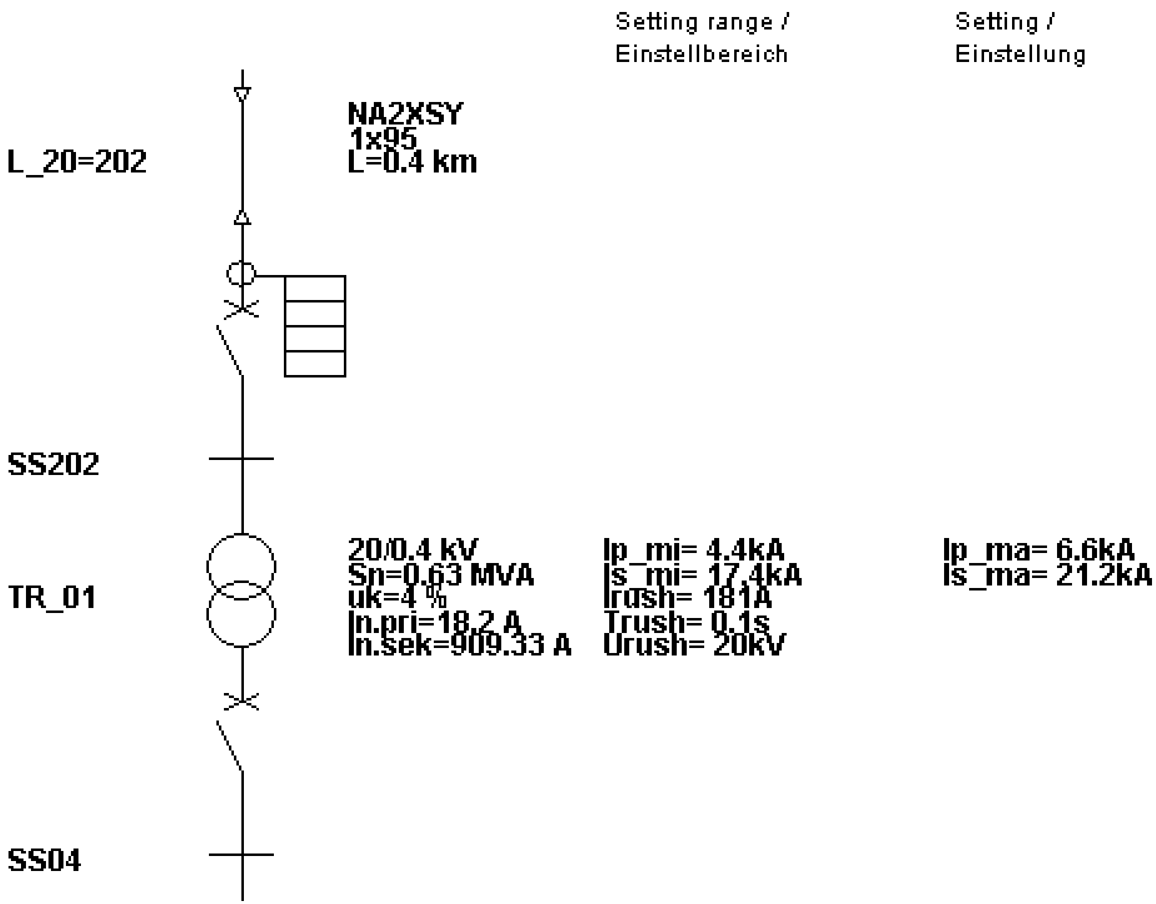
Protection Coordination (1)– Transformer feeder 20/0,4kV



Check settings !!!



Protection Coordination (2)– Transformer feeder 20/0,4kV



Requirements HV side:

I> ~ I>>sec.side
T> = T>>sec side + 1 time step

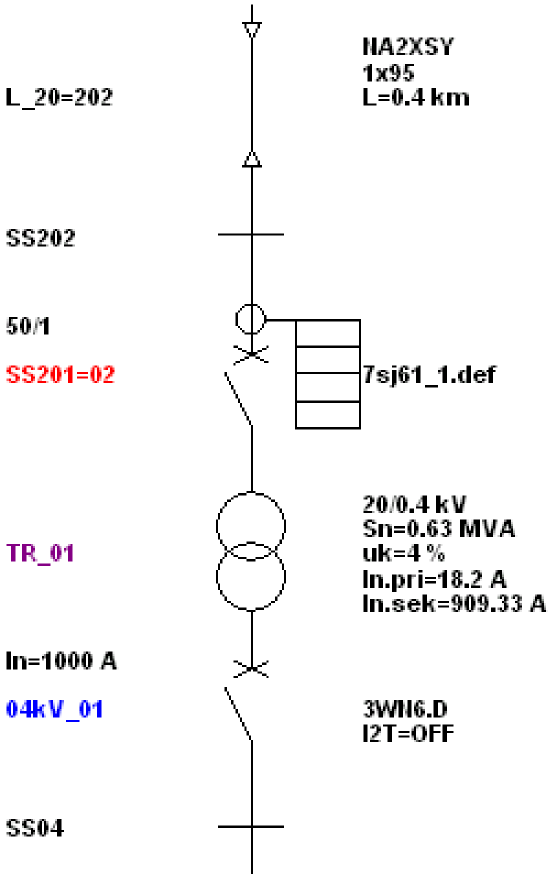
I>> > Isc,max of sec. side
I>> < Isc,min of prim side

Requirements LV side:

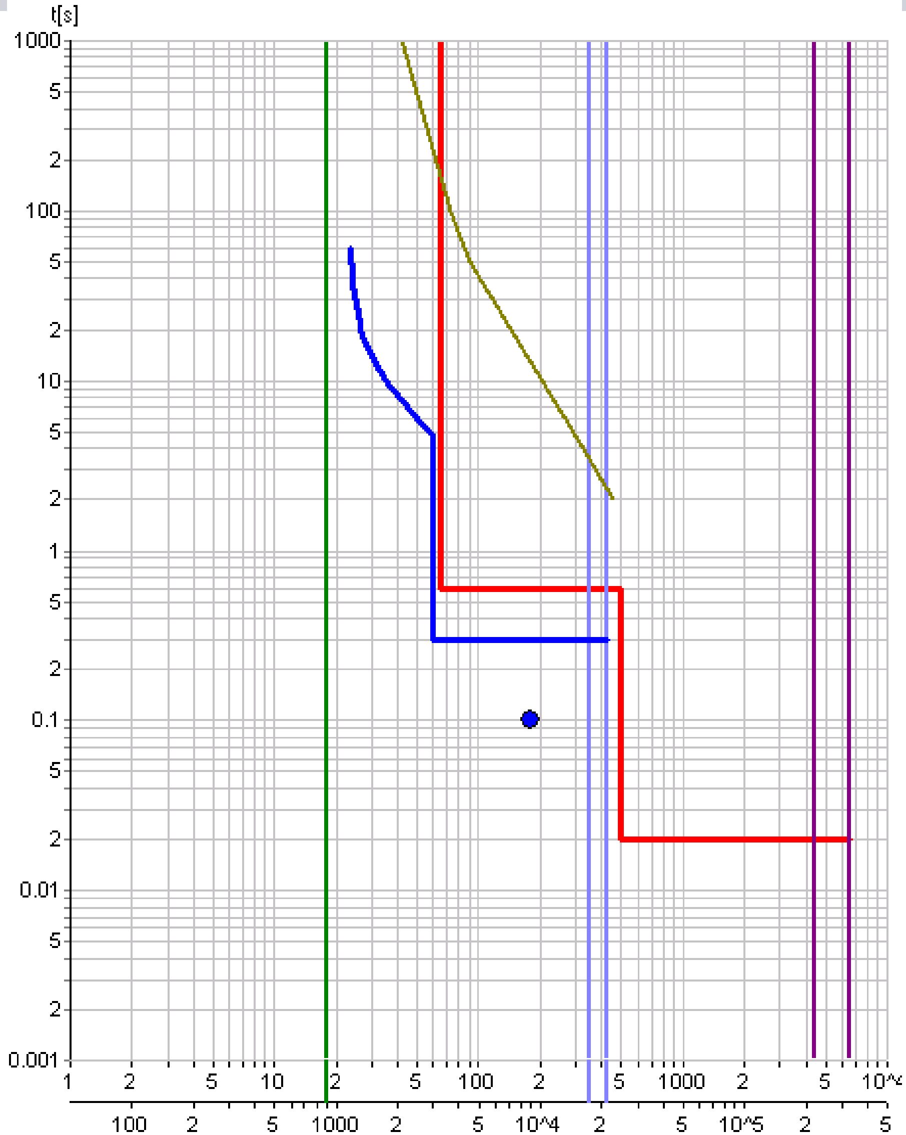
Ip ~ 1.1 * In,tr

I>> ~ 3 – 4 * In,tr
I>> < Isc,min

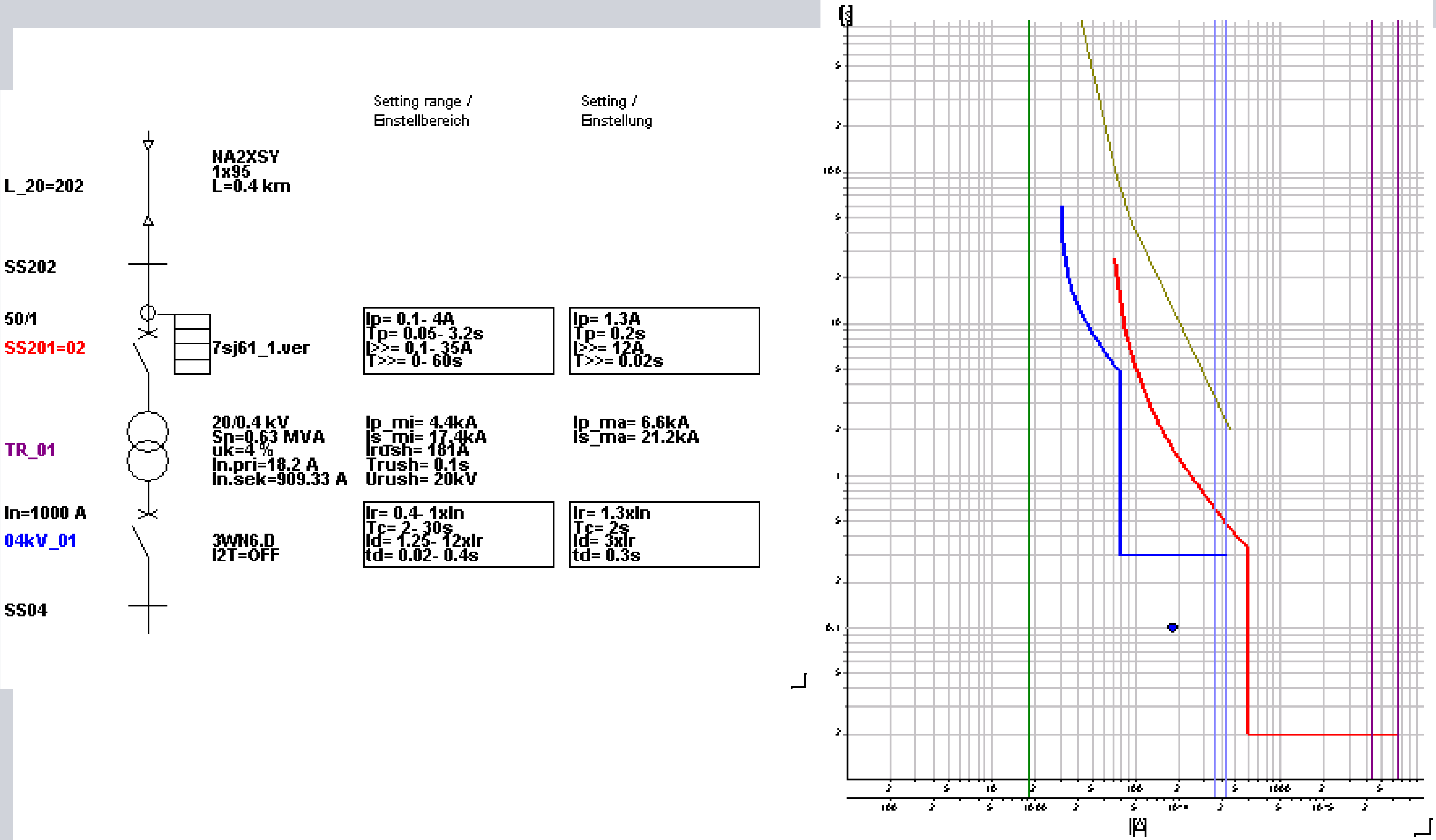
Protection Coordination (3)– Transformer feeder 20/0,4kV



Setting range / Einstellbereich	Setting / Einstellung
Ir= 0.4- 1xIn Tc= 2- 30s Id= 1.25- 12xIr td= 0.02- 0.4s	I>= 1.3A T>= 0.6s I>>= 10A T>>= 0.02s
Ip_mi= 4.4kA Is_mi= 17.4kA Irush= 181A Trush= 0.1s Urush= 20kV	Ip_ma= 6.6kA Is_ma= 21.2kA
Ir= 0.4- 1xIn Tc= 2- 30s Id= 1.25- 12xIr td= 0.02- 0.4s	Ir= 1xIn Tc= 2s Id= 3xIr td= 0.3s



Protection Coordination (4)– Transformer feeder 20/0,4kV



Protection Coordination –Transformer 20/6kV

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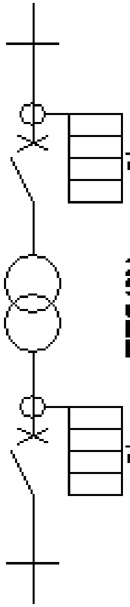
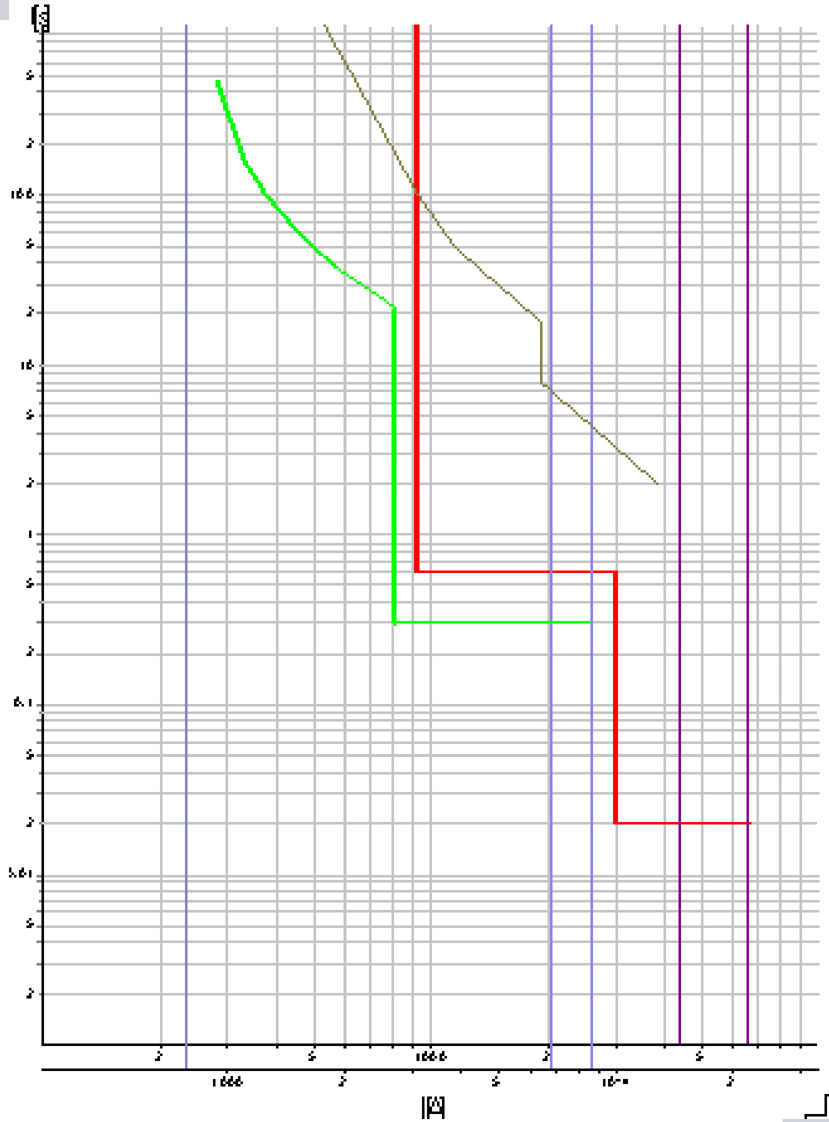
	Setting range / Einstellbereich	Setting / Einstellung
SS20		
400/1, SS20=04, 7SJ62_1.NOR	I>= 0.1- 35A T>= 0- 60s I>>= 0.1- 35A T>>= 0- 60s	I>= 2.3A T>= 0.6s I>>= 7.5A T>>= 0.02s
TR_02: 20/6 kV, Sn=8 MVA, uk=6 %, In.pri=230.9 A, In.sek=769.8 A	Ip_mi= 4.4kA Is_mi= 6.77kA	Ip_ma= 6.6kA Is_ma= 8.58kA
1000/1, SS6=01, 7sj61_1.ver	Ip= 0.1- 4A Tp= 0.05- 3.2s I>>= 0.1- 35A T>>= 0- 60s	Ip= 0.85A Tp= 3.5s I>>= 2.7A T>>= 0.3s
SS6		





Check Protection Coordination – Motor & Transformer