Protection

Sector Energy PTI NC

Theodor Connor

Content

Task of network protection

Protection of persons against the effects of short-circuits

Protection of operational equipment from destruction and damages

Maintaining the power system operation in case of failures

Owner of high voltage networks

- Public utility companies
  - Interconnected system, National network, Regional system, Urban network
- Industrial companies
  - Steel, Cement, Chemistry, Automobile . . .
- Power plants
- Railways
- Special systems
  - Airports, Hospitals, Testing stations, Ships . . .

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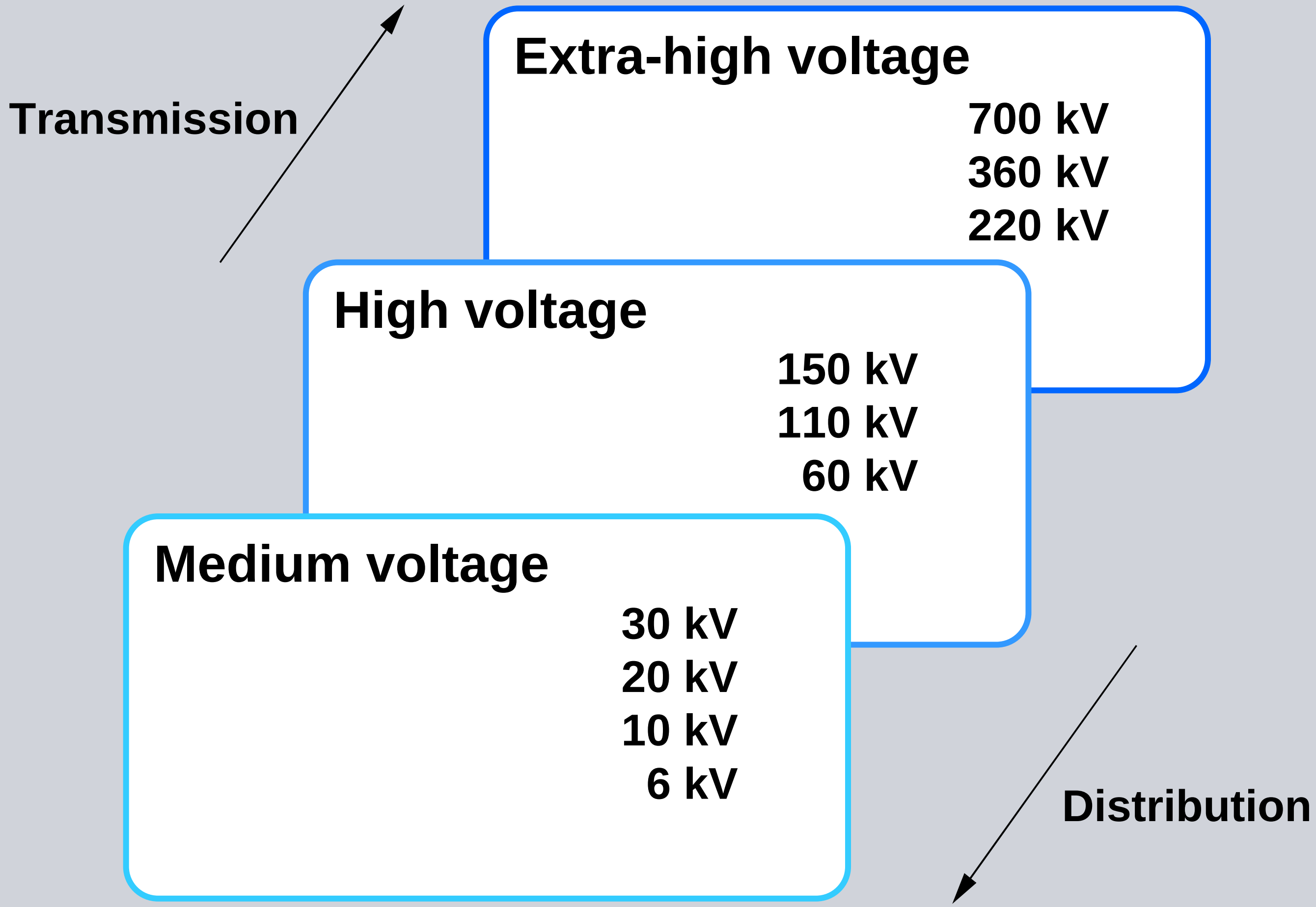
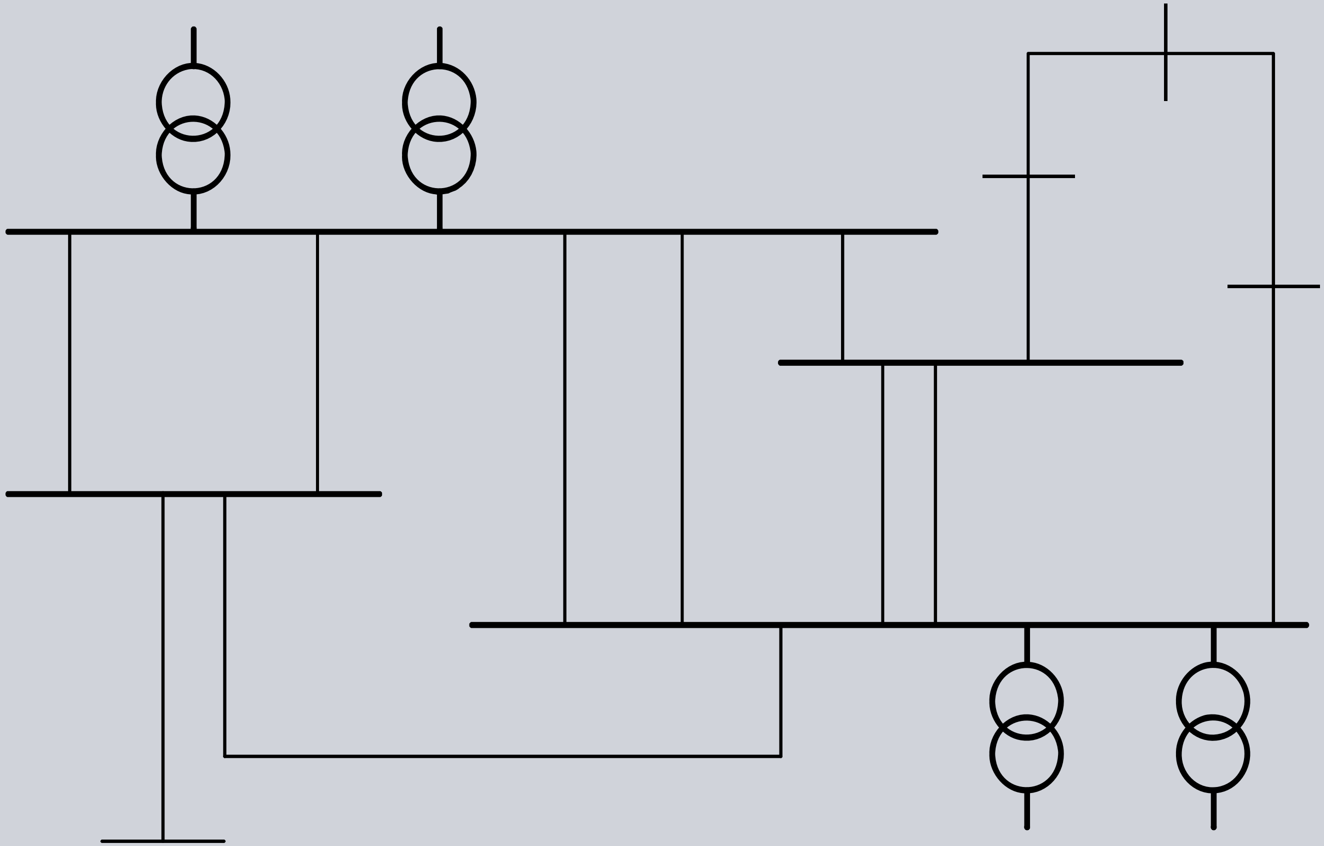
Voltage levels



System structure: meshed network



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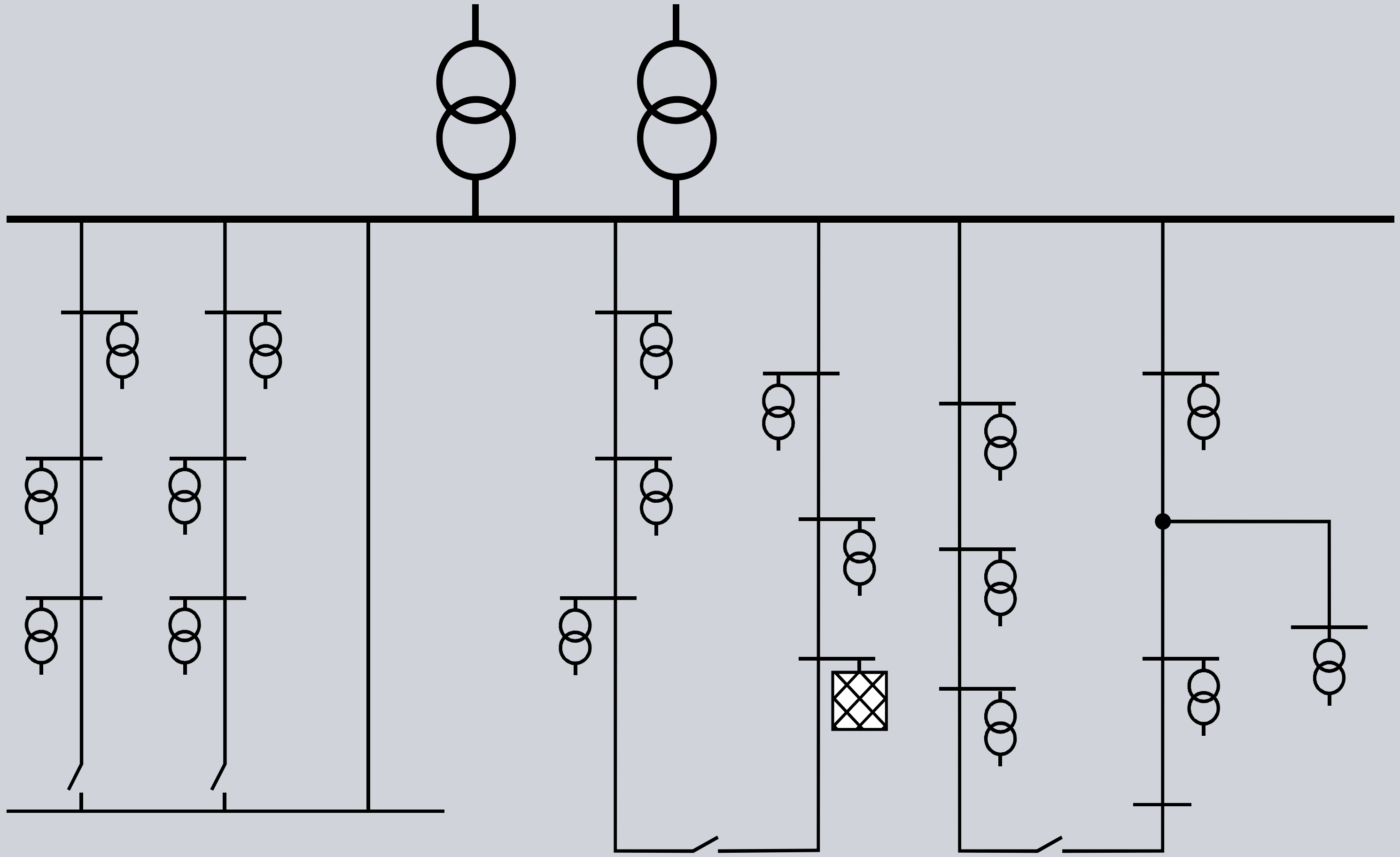
System structure: radial network for public supply



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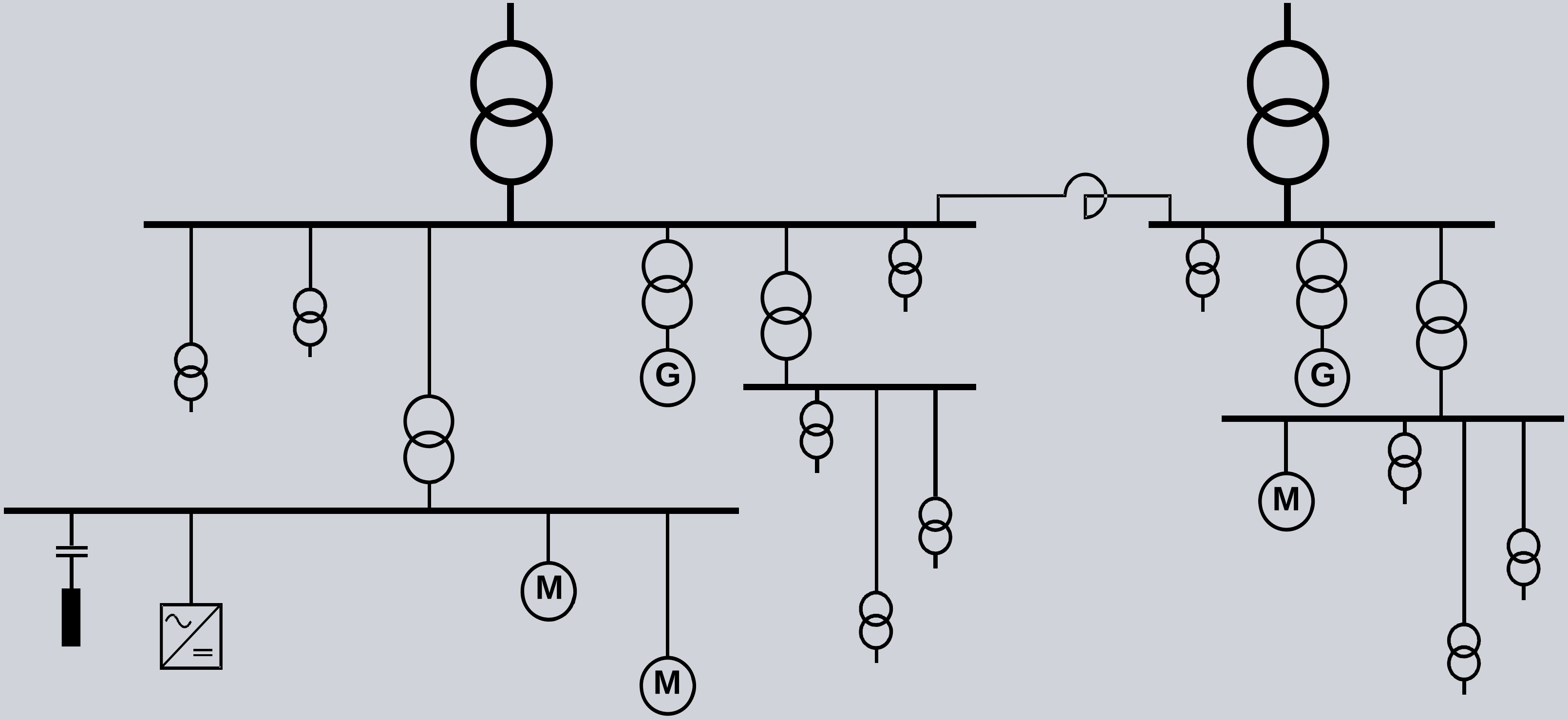
System structure: radial network in the industry



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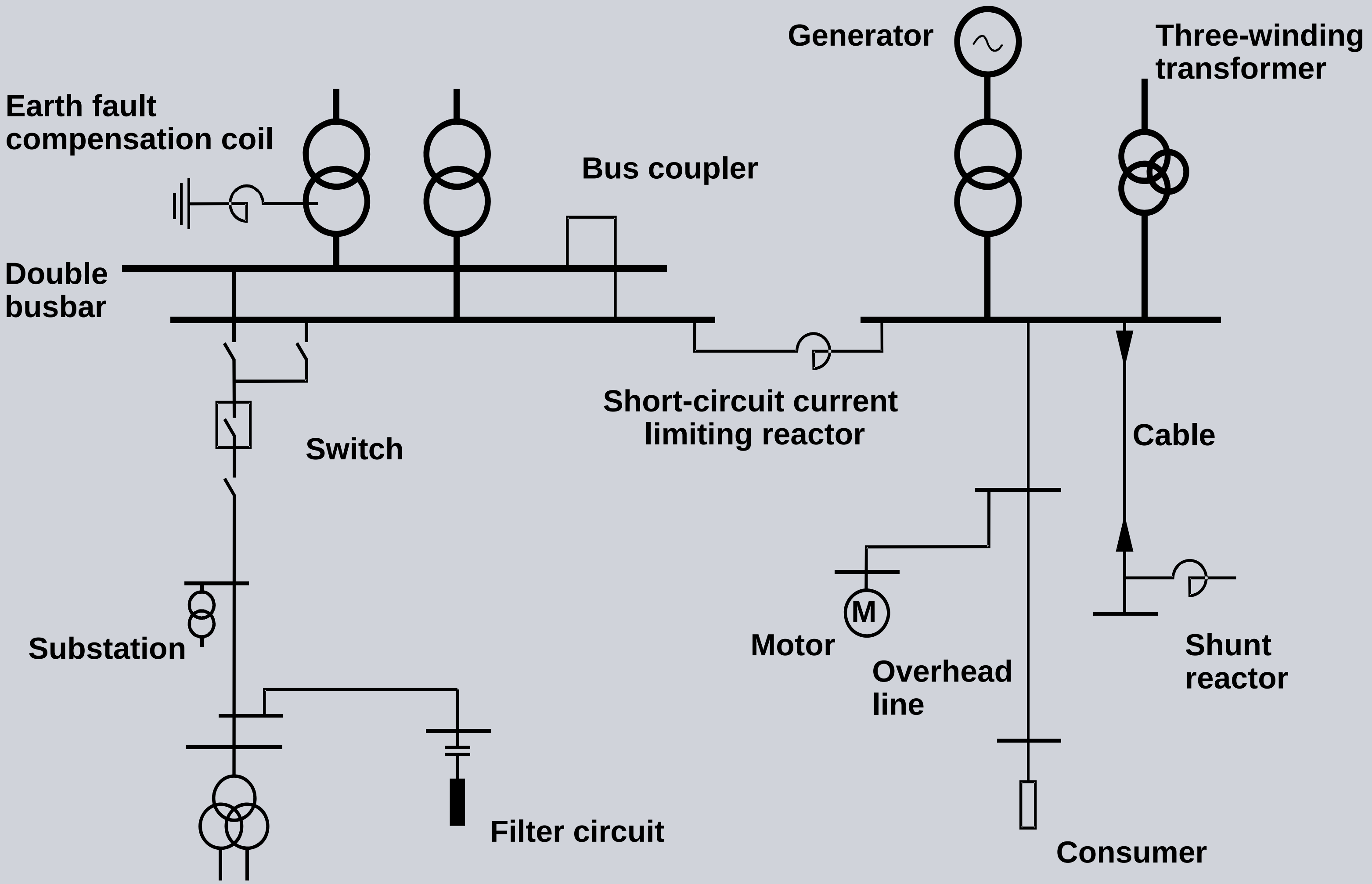
Main components of electrical networks



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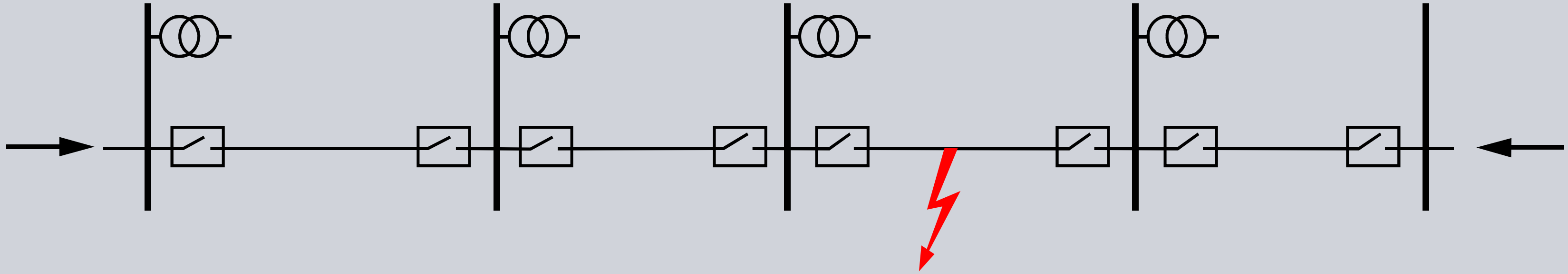
Protection target

Selective

Fast



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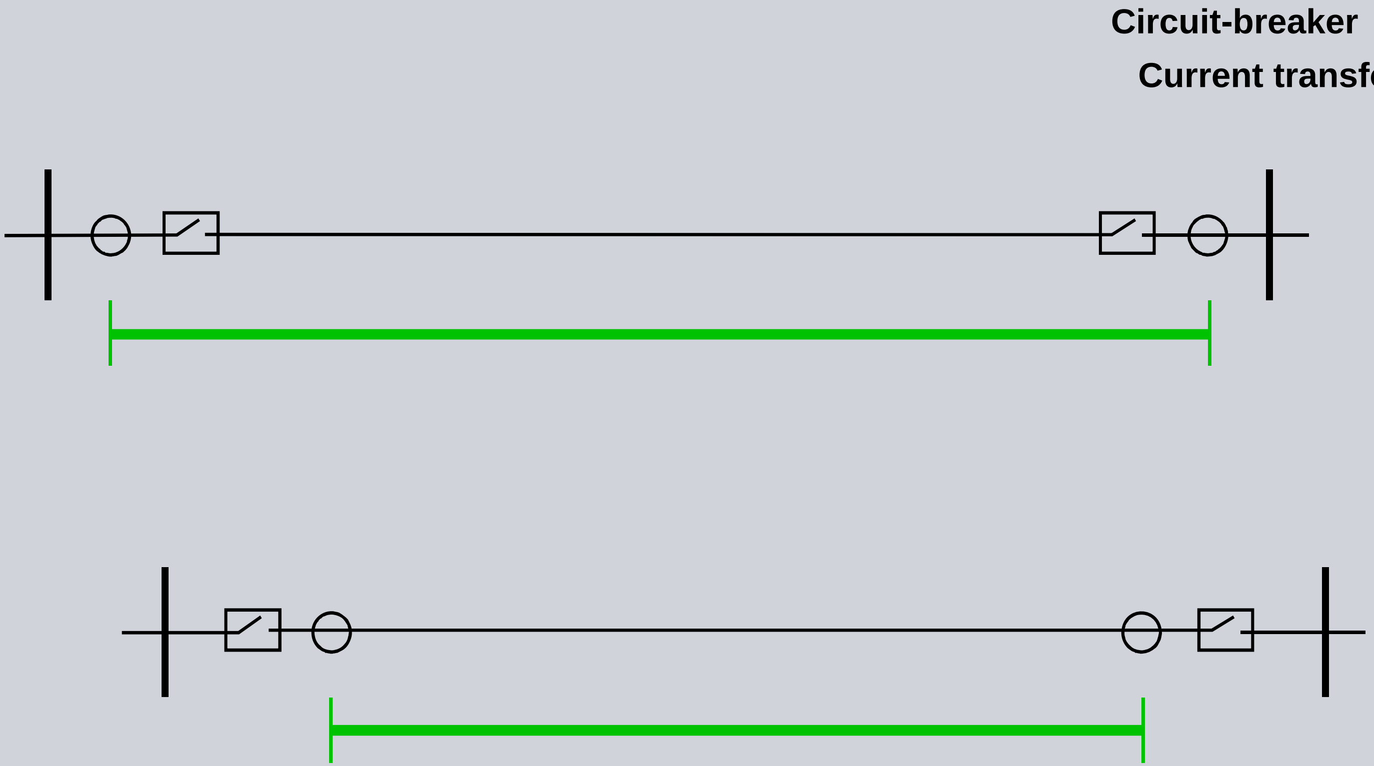
Protected zone



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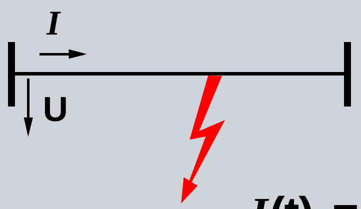
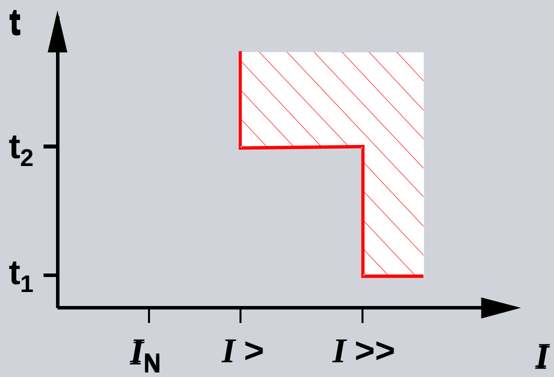
Criteria indicating fault condition



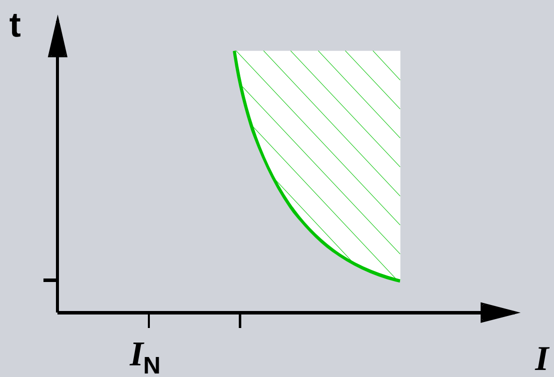
$$I(t) = I \cdot \sin\omega t + e^{-\frac{t}{T}}$$

Current	I	$I>$ $\vec{I}>$ $I>>$ ΔI ΣI $\frac{dI}{dt}$
Voltage	U	$U<$ $U>$
Impedance	Z	$Z<$
Phase angle	φ	$\Delta\varphi$
Power	S	$\vec{P}$ $\vec{Q}$ $S(t)$
Frequency	f	Δf

Overcurrent-time protection



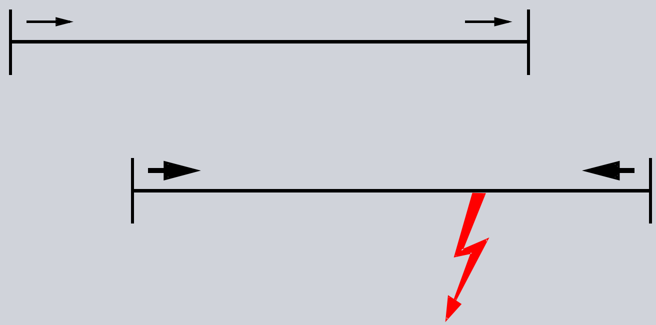
Definite-time overcurrent-protection



Inverse-time overcurrent-protection

Differential protection

Line



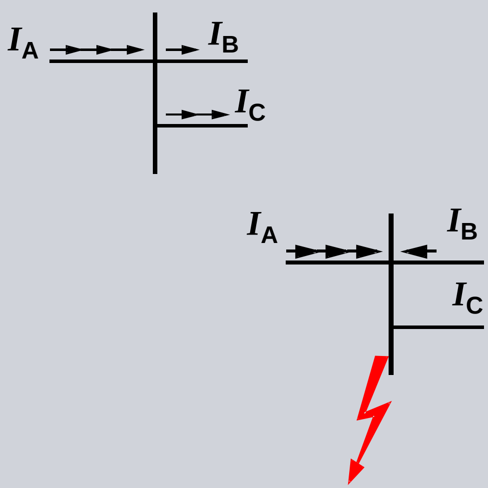
Load condition

$I_{start} - I_{end} = 0 \quad \rightarrow \quad \Delta I = 0$

Fault condition

$I_{start} - I_{end} \neq 0 \quad \rightarrow \quad \Delta I \neq 0$

Busbar



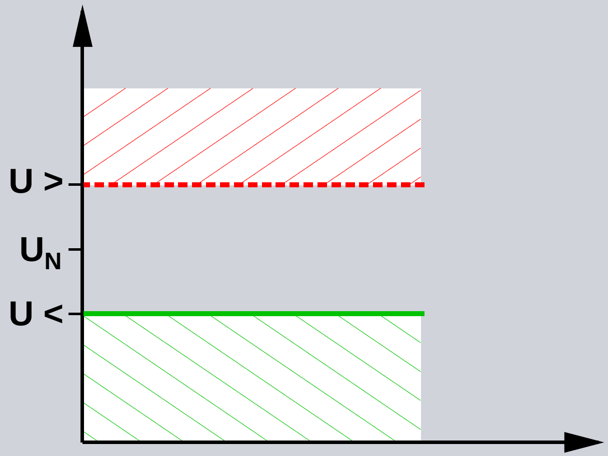
Load condition

$I_A + I_B + I_C = 0 \quad \rightarrow \quad \Sigma I = 0$

Fault condition

$I_A + I_B + I_C \neq 0 \quad \rightarrow \quad \Sigma I \neq 0$

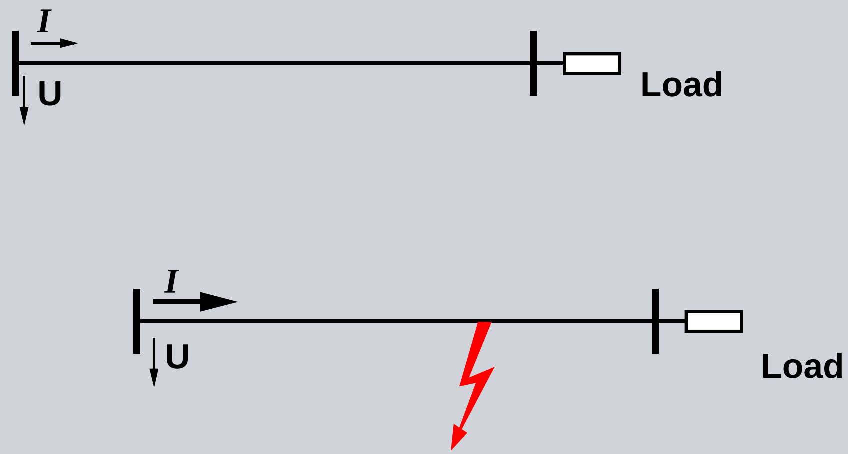
Overvoltage - Undervoltage



Overvoltage

Undervoltage

Impedance protection



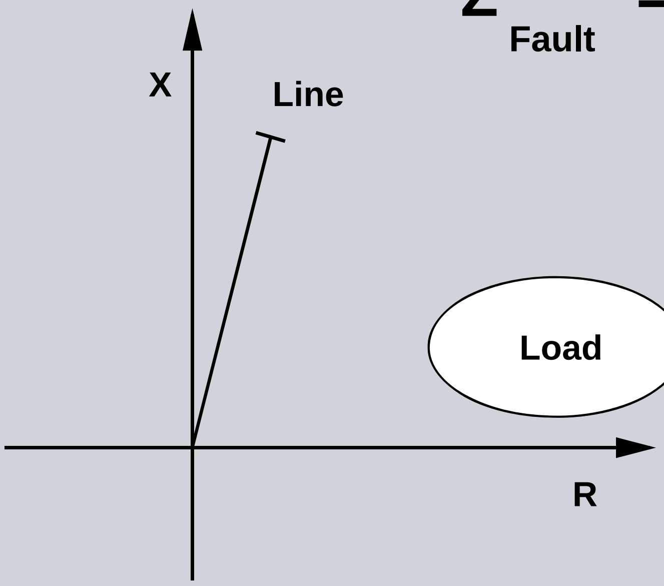
$$\frac{U}{I} = Z_{Load}$$

$$\frac{U}{I} = Z_{Fault}$$

$$Z_{Fault} \ll Z_{Load}$$

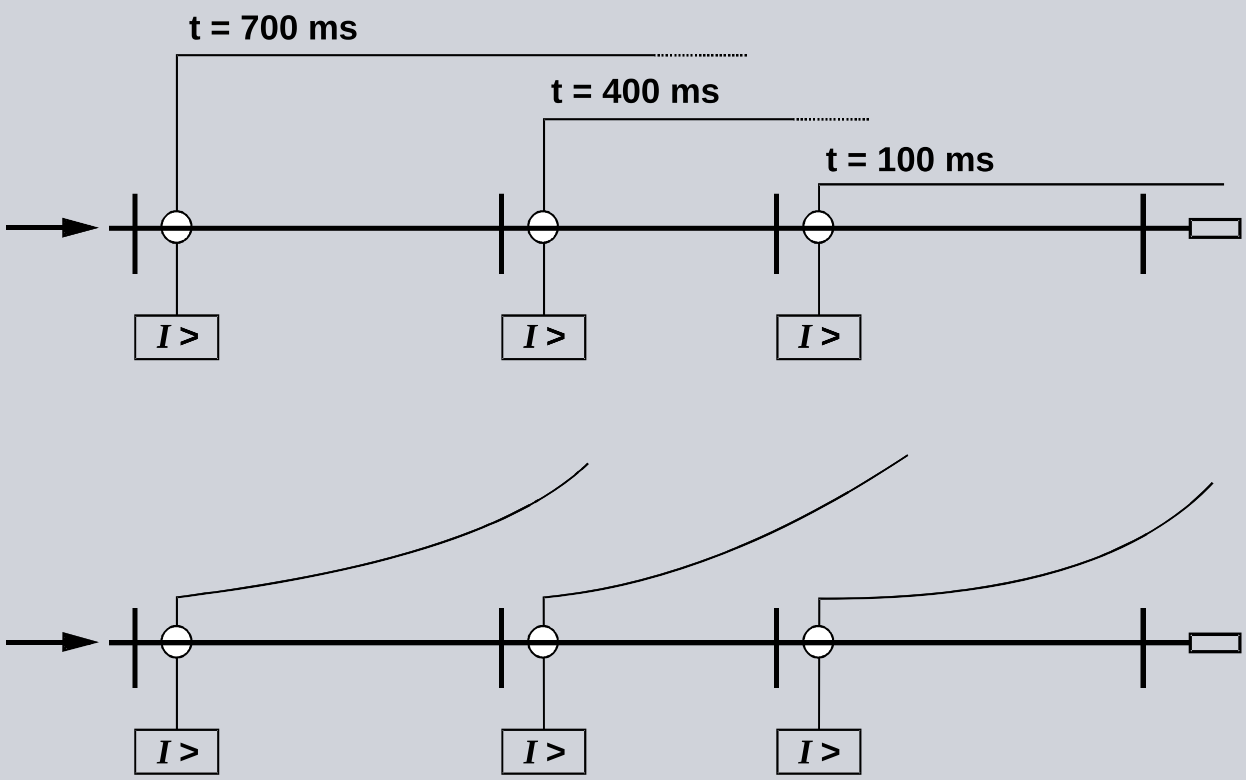
Distance protection

$$Z_{Fault} = l \cdot Z'_{Line}$$

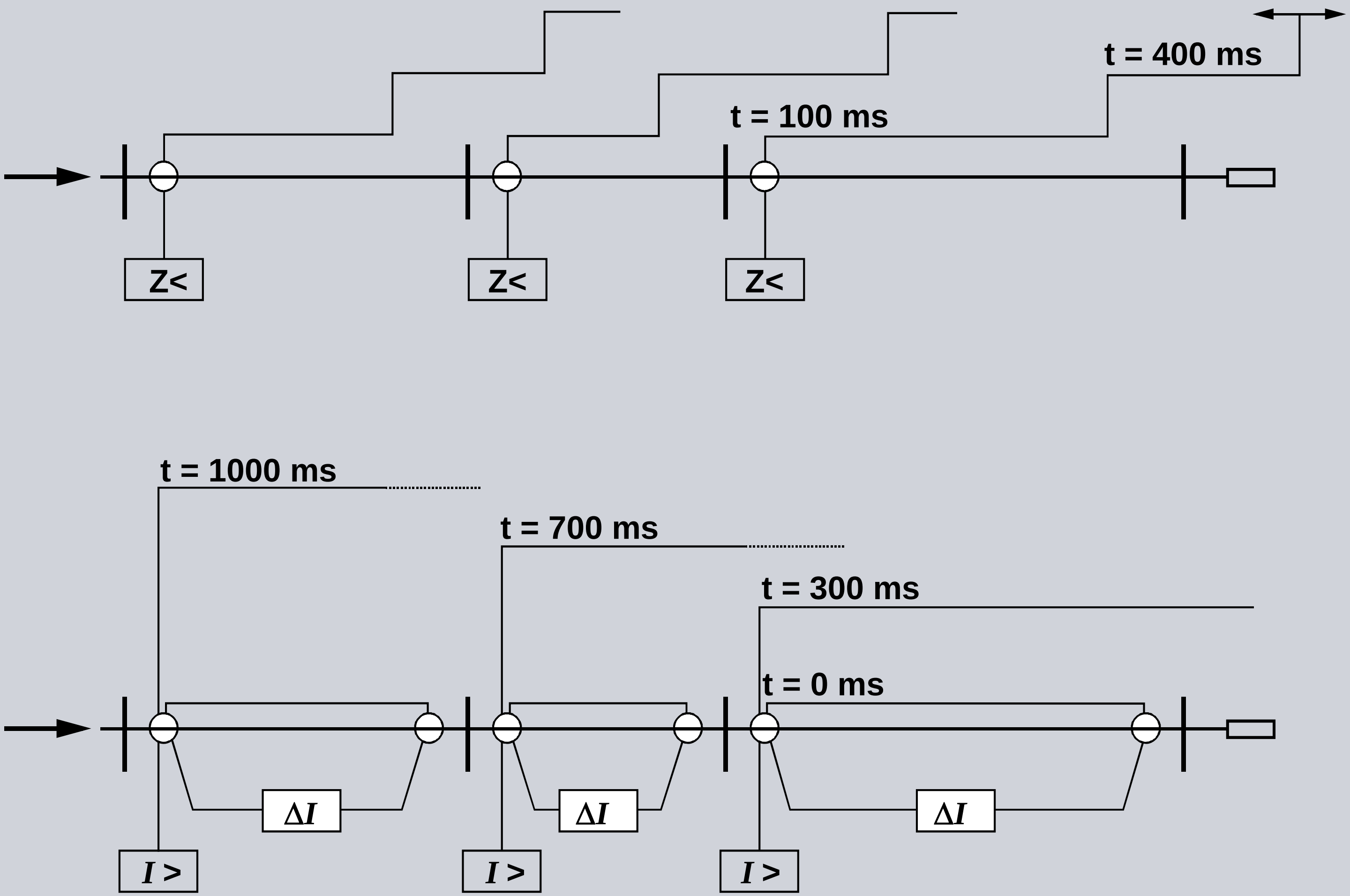


$$Z_{Load} = \frac{U_N^2}{S_{Load}}$$

Back-up protection I



Back-up protection II



Survey Equipment - Type of protection

Line	Time-graded protection Differential protection
Transformer **High voltage - Medium voltage**	Differential protection Time-graded protection
Busbar	Reverse interlock Differential protection
Transformer **Medium voltage - Low voltage**	Fuse Time-graded protection
Motor	Time-graded protection Overload protection

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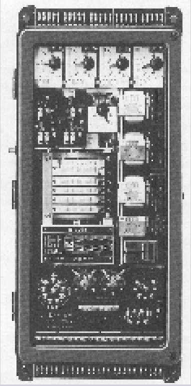
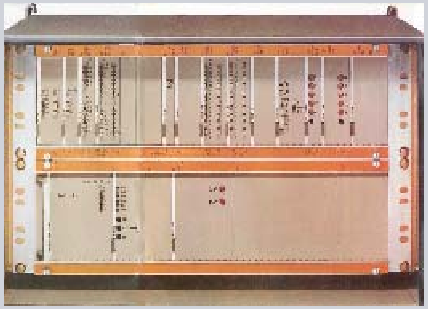
History

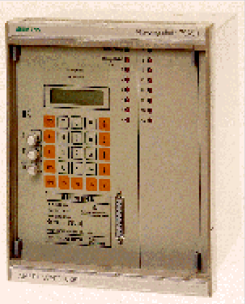
1900
Electromechanical relays



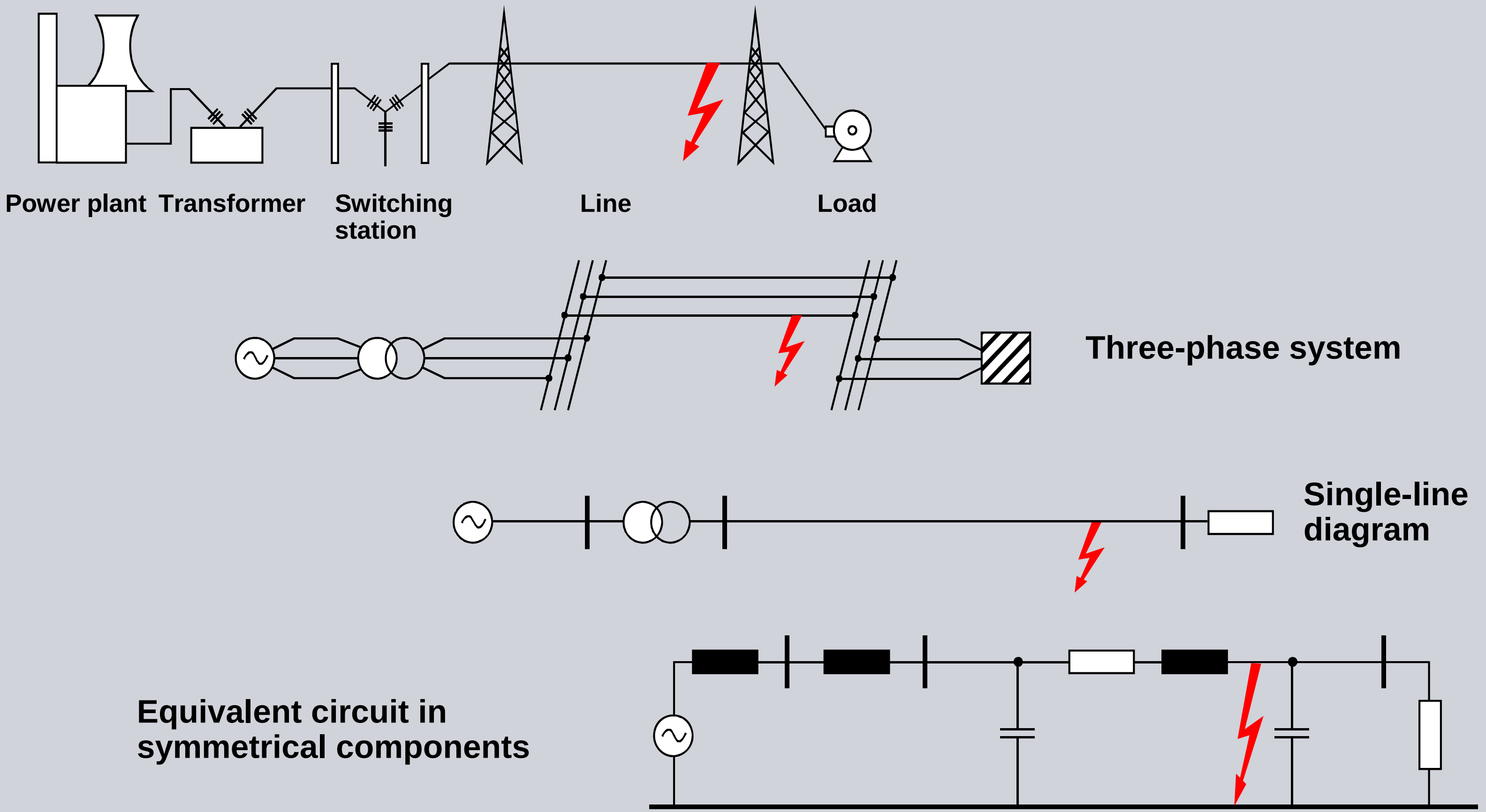
1980
Analog electronical relays



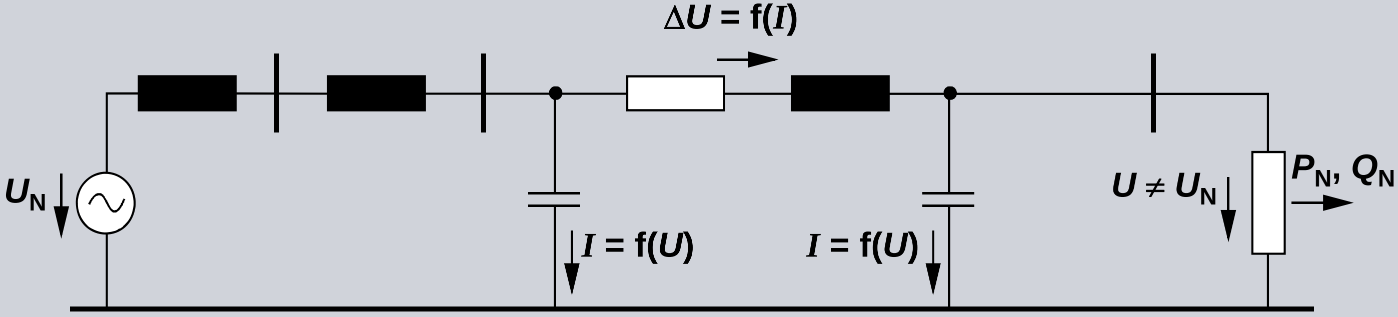
1990
Numerical relays



Network calculation



Load flow
A non-linear task



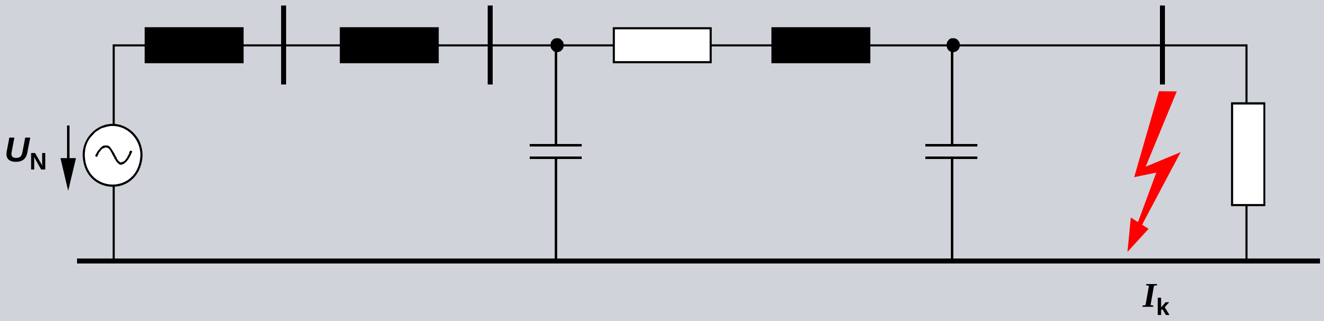
Iteration-process:

Current iteration
Newton - Raphson

$$I_{Load} = \frac{S_N}{\sqrt{3}\,U_N}$$

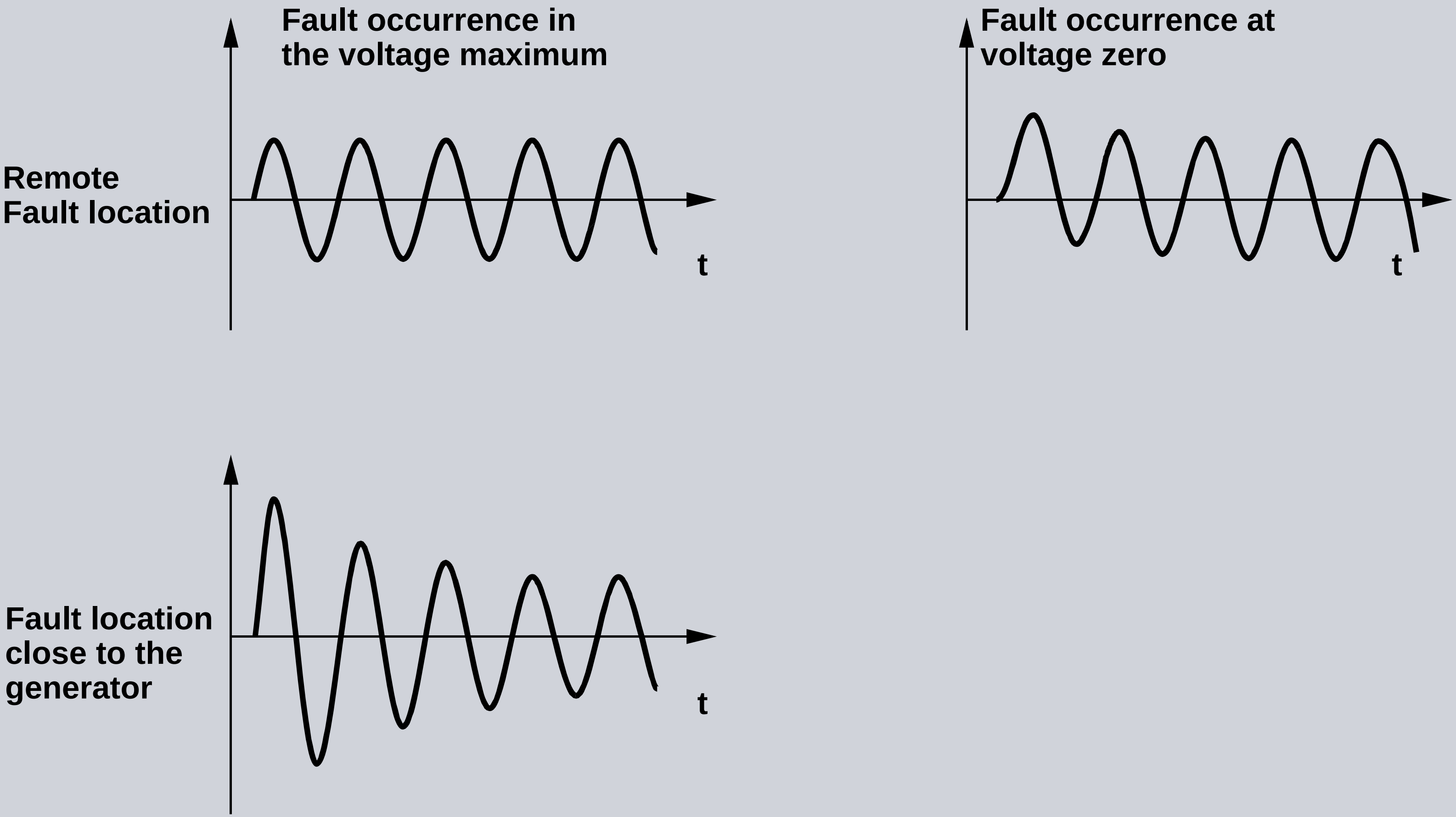
$$Z_{Load} = \frac{U_N^2}{S_N}$$

Short-circuit calculation



Ohms Law: $I = \frac{U}{R}$

Time characterictics of short-circuit currents



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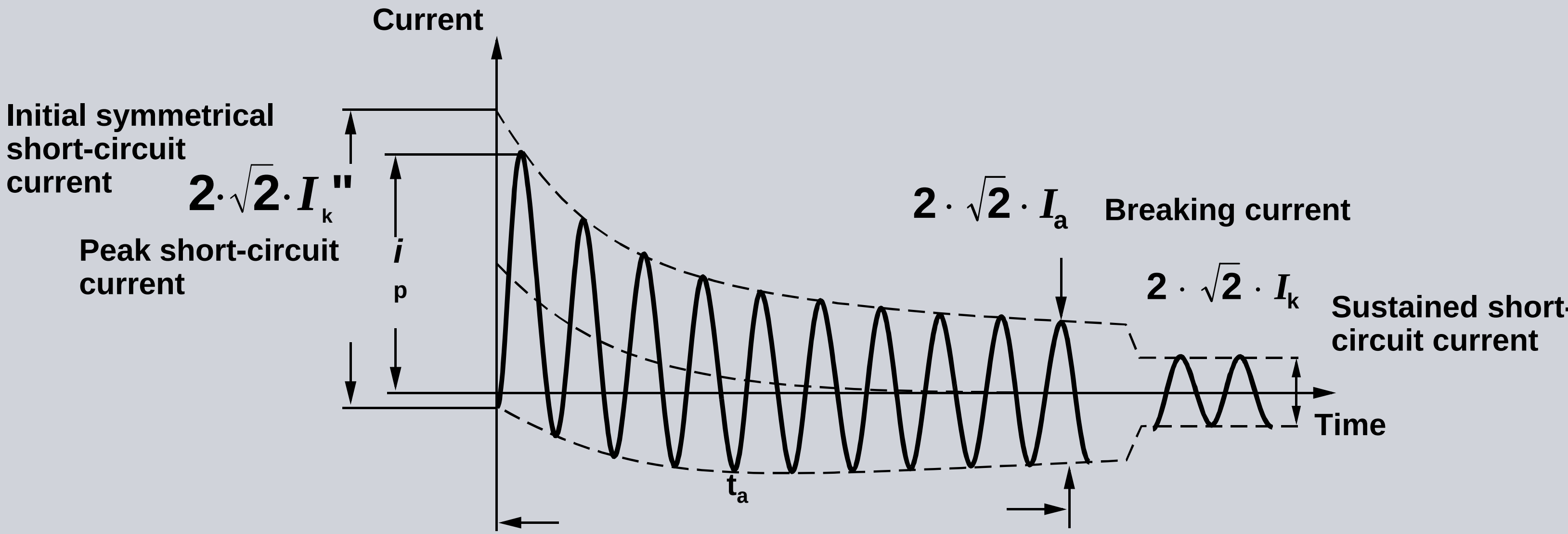
Fault currents



I_{k3} I_a i_p S_k'' S_a

Fault current contributions **Fault current distribution in the system**

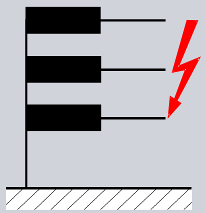
I_{k2} I_{k2E} I_{EE}

I_{k1}

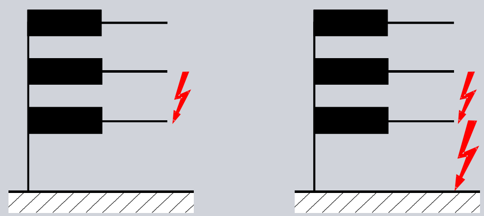
$I_{k\,max}$ $I_{k\,min}$

VDE **Preloaded short-circuit**

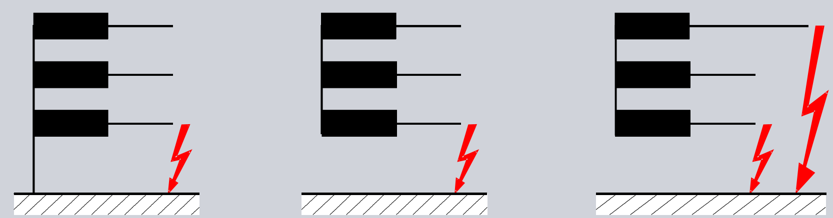
Types of short-circuits in three-phase systems



3-pole

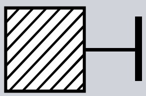


2-pole



1-pole

Typical equipment data Network



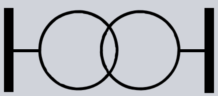
Z_{System}

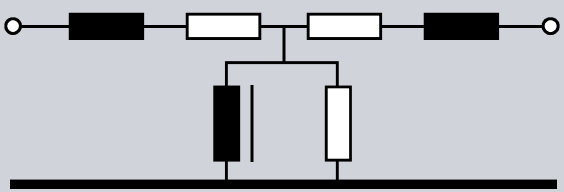
$$S_k'' = \sqrt{3} \cdot U_N \cdot I_K$$

$$Z_{System} = \frac{U_N^2}{S_k''}$$

U_N	S_K''	I_K''	Z_{System}
380 kV	26 GVA	40 kA	5.5 Ω
110 kV	1 GVA	5 kA	12.1 Ω
	5 GVA	26 kA	2.4 Ω
20 kV	350 MVA	10 kA	1.1 Ω
	500 MVA	14 kA	0.8 Ω
10 kV	500 MVA	28 kA	0.2 Ω

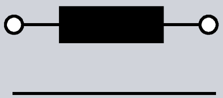
Typical equipment data Transformer





$$Z_{Transf.} = \frac{U_N^{\ 2}}{S_N} \cdot u_K$$

$Z_{transf.}$



U_{N1}/U_{N2}	S_N	u_K	$Z_{Transf.}$ 380 kV	$Z_{Transf.}$ 110 kV	$Z_{Transf.}$ 20 kV
380/110 kV	300 MVA	15 %	72 Ω	6 Ω	0.2 Ω
110/20 kV	40 MVA	15 %		45Ω	1.5 Ω
20/0.4 kV	630 kVA	6 %			37.0 Ω

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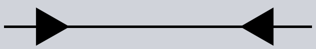
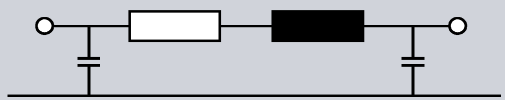
Typical equipment data Line





$$Z_{Line} = l \cdot (R'_1 + j\, X'_1)$$

Z_{Line}

		R'_1	X'_1	Z'_1	C'_1
380 kV					
	Overhead line	0.03	+ j 0.25 Ω/km	0.25 Ω/km	14 nF/km
110 kV					
	Overhead line	0.07	+ j 0.38 Ω/km	0.39 Ω/km	10 nF/km
	Cable	0.04	+ j 0.11 Ω/km	0.12 Ω/km	400 nF/km
20 kV					
	Overhead line	0.31	+ j 0.36 Ω/km	0.48 Ω/km	10 nF/km
	Cable	0.20	+ j 0.13 Ω/km	0.24 Ω/km	300 nF/km

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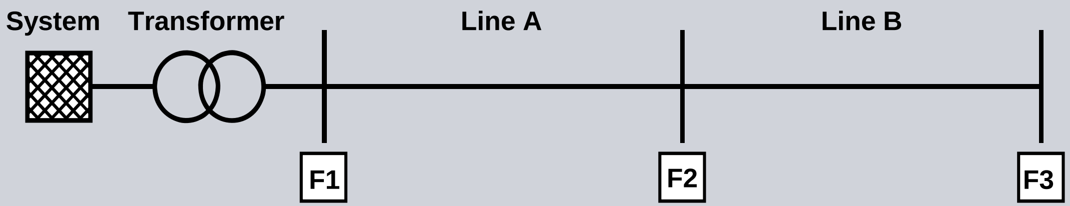
Data for a sample calculation



System	Transformer	Line A	Line B	
3 GVA 110 kV	110/20 kV 40 MVA 15 %	5 km 0.2 Ω/km (0.5 Ω/km)	5 km 0.2 Ω/km (0.5 Ω/km)	Cable (Overhead line)

$$Z_{System} = 1.1 \frac{(110 \cdot 10^3)^2}{3 \cdot 10^9} \cdot \frac{(20 \cdot 10^3)^2}{(110 \cdot 10^3)^2} = 0.15\ \Omega$$

$$Z_{Transformer} = \frac{(20 \cdot 10^3)^2}{40 \cdot 10^6} \cdot \frac{15}{100} = 1.5\ \Omega$$

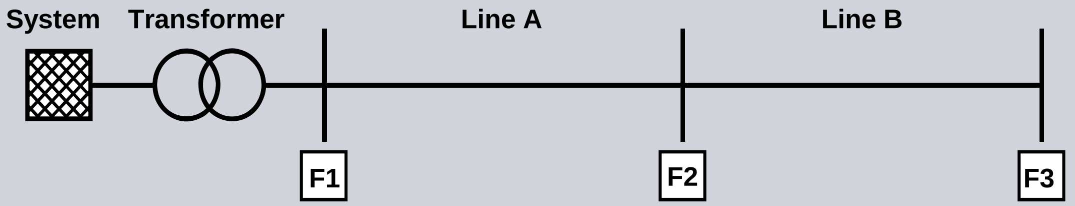
$$Z_{Line\ A} = 5 \cdot 0.2 = 1.0\ \Omega \qquad (2.5\ \Omega)$$

$$Z_{Line\ B} = 5 \cdot 0.2 = 1.0\ \Omega \qquad (2.5\ \Omega)$$

Short-circuit current calculation Results

		Cable	Overhead line
F1	$I_{K3} = \frac{1.1 \cdot 20 \cdot 10^3}{\sqrt{3} \cdot [0.15 + 1.5]} = 7.7\ kA$		(7.7 kA)
F2	$I_{K3} = \frac{1.1 \cdot 20 \cdot 10^3}{\sqrt{3} \cdot [0.15 + 1.5 + 1.0]} = 4.8\ kA$		(3.1 kA)
F3	$I_{K3} = \frac{1.1 \cdot 20 \cdot 10^3}{\sqrt{3} \cdot [0.15 + 1.5 + 1.0 + 1.0]} = 3.5\ kA$		(1.9 kA)

Short-circuit current calculation Results



F1	F2	F3	
7.7 kA	4.8 kA	3.5 kA	Cable
(7.7 kA)	(3.1 kA)	(1.9 kA)	Overhead line