

# Protection

Sector Energy PTI NC

Theodor Connor



# Content

**Protection principle**

**Network details**

**Network calculation**

## 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 . . .

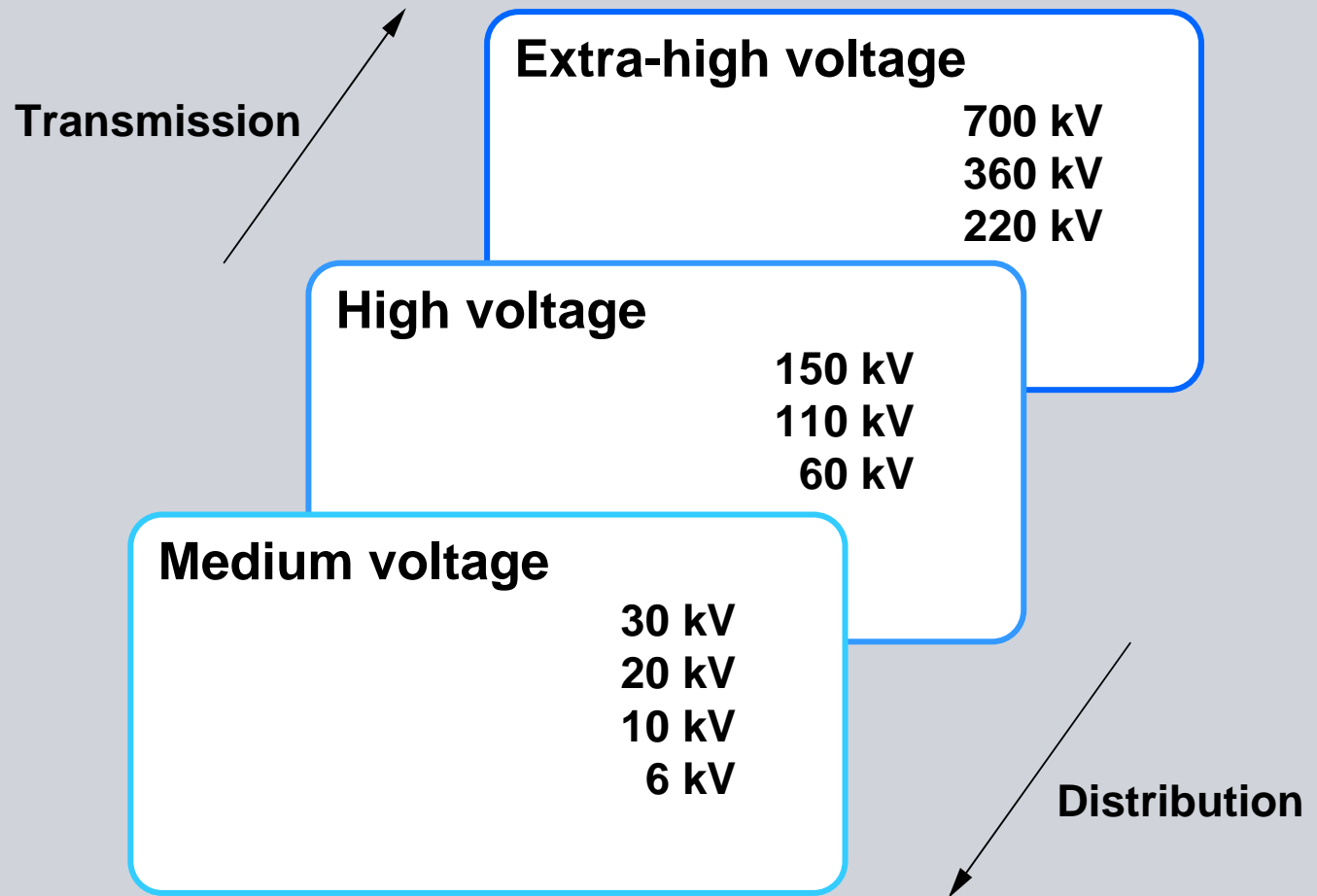
### Power plants

### Railways

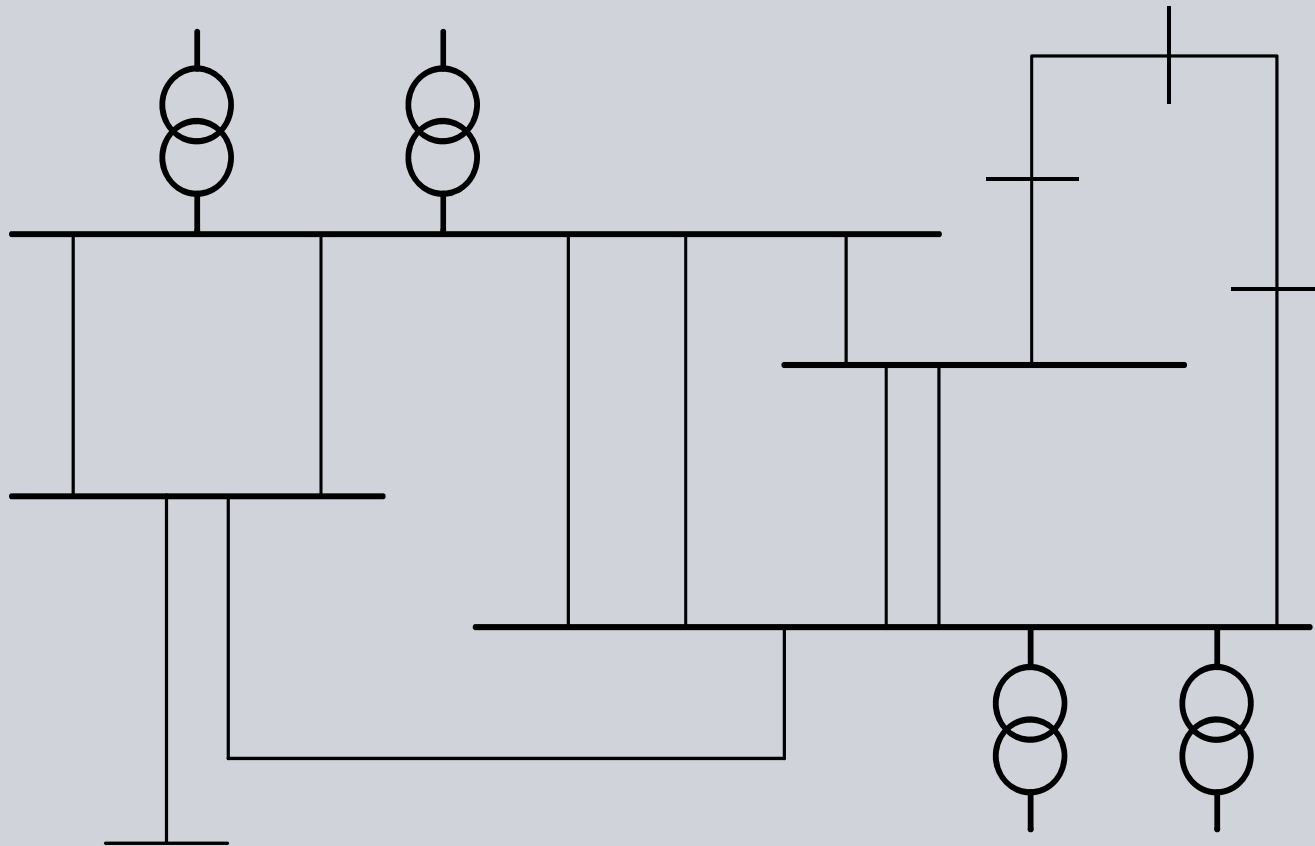
### Special systems

Airports, Hospitals, Testing stations, Ships . . .

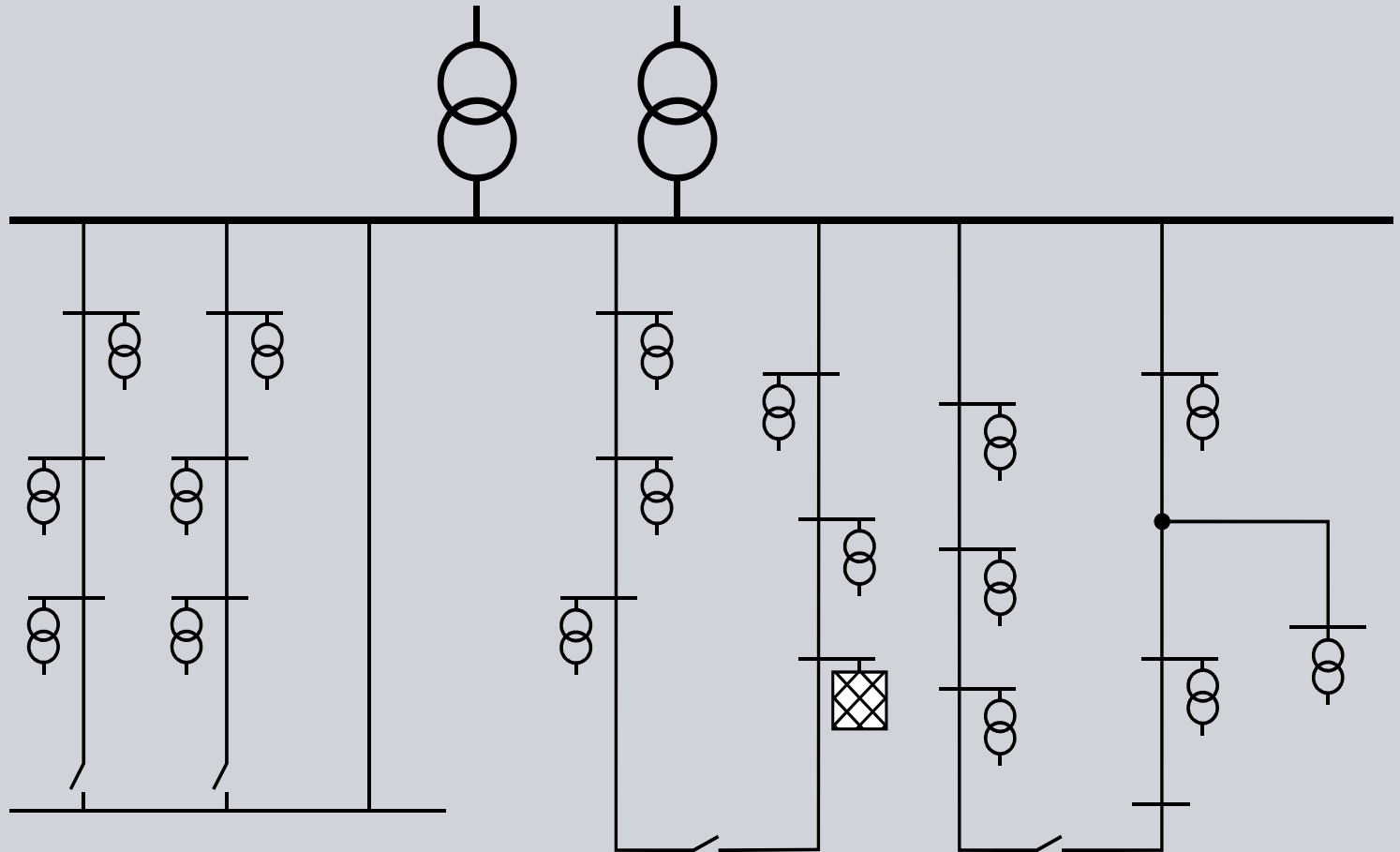
## Voltage levels



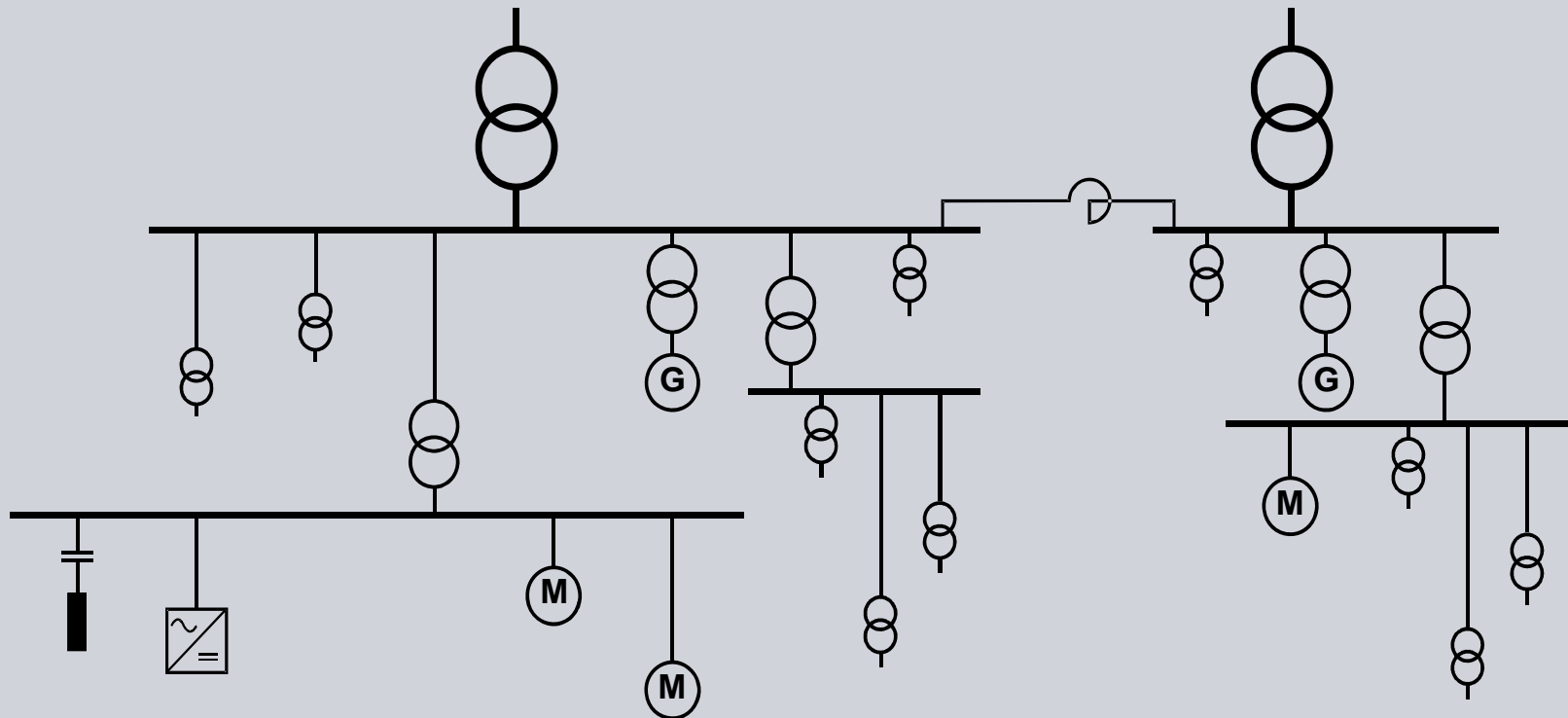
System structure: meshed network



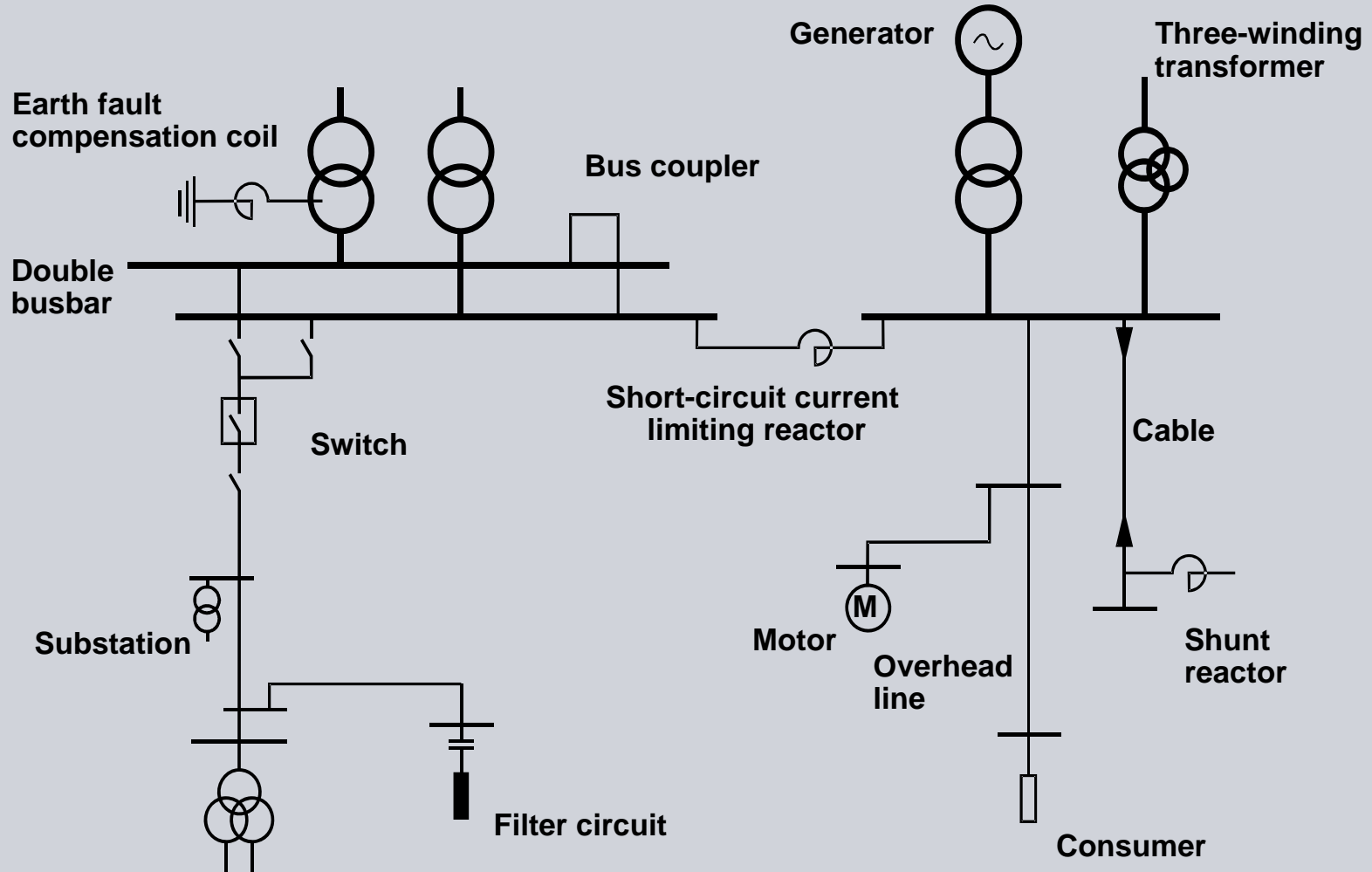
## System structure: radial network for public supply



## System structure: radial network in the industry



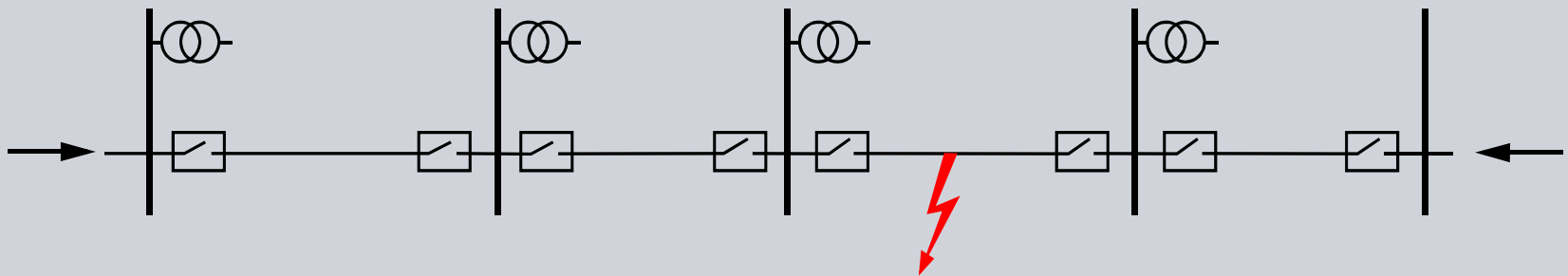
## Main components of electrical networks



## Protection target

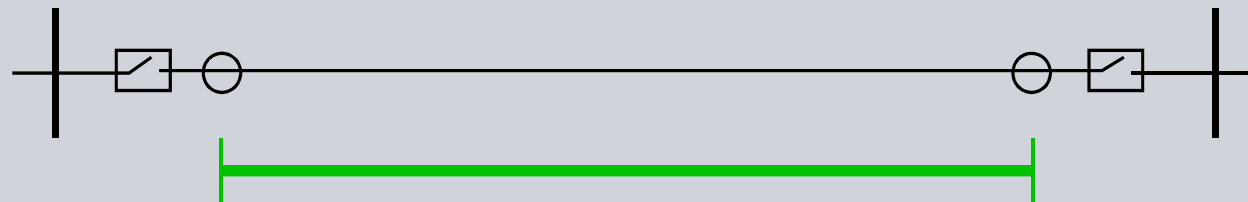
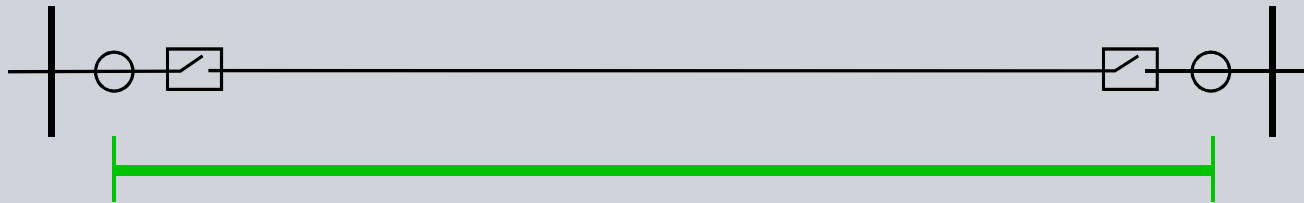
Selective

Fast

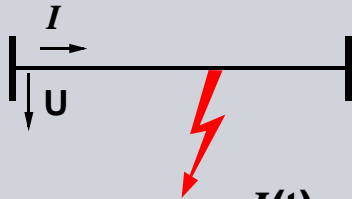


## Protected zone

Circuit-breaker  
Current transformer



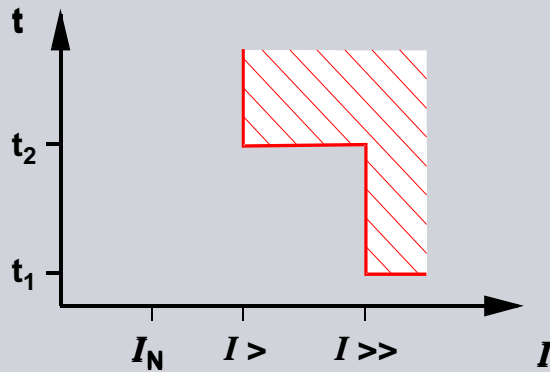
## Criteria indicating fault condition



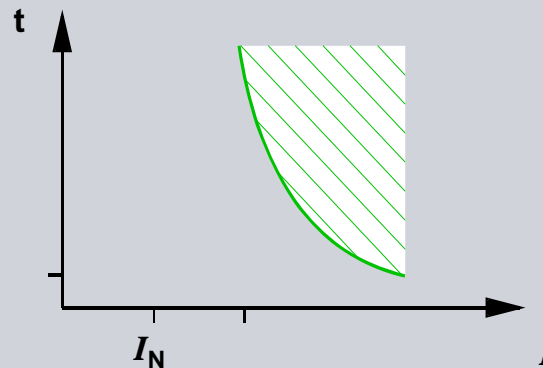
$$I(t) = I \cdot \sin \omega t + e^{-\frac{t}{\tau}}$$

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

## Overcurrent-time protection



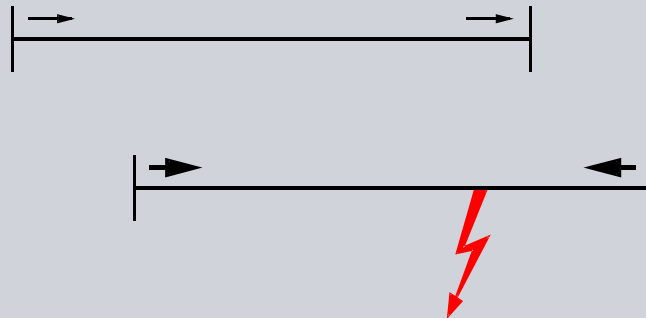
**Definite-time  
overcurrent-  
protection**



**Inverse-time  
overcurrent-protection**

## Differential protection

### Line



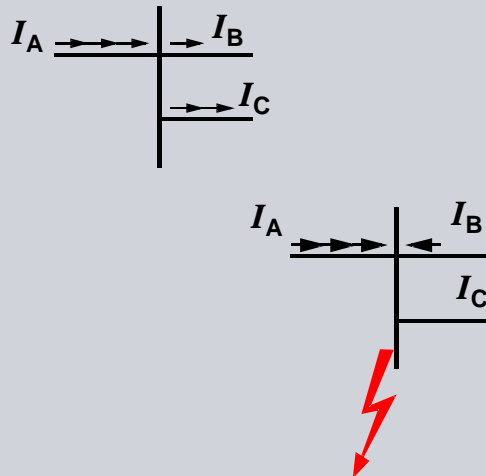
### Load condition

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

### Fault condition

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

### Busbar



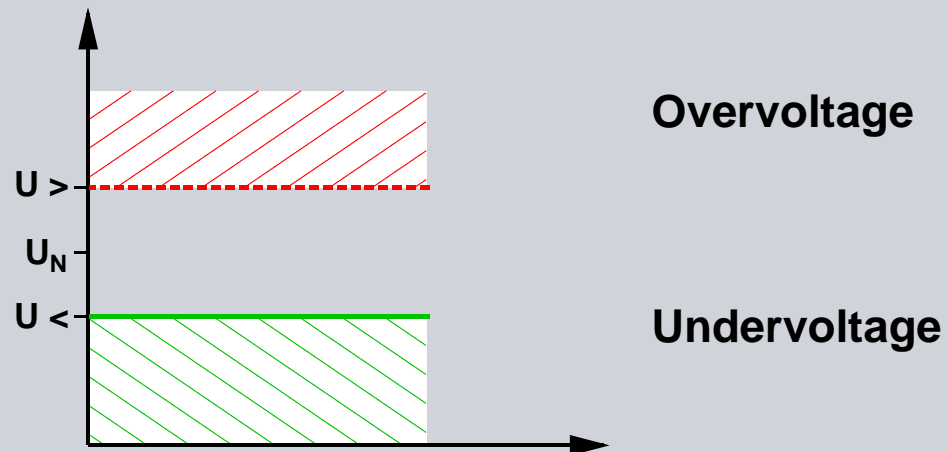
### Load condition

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

### Fault condition

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

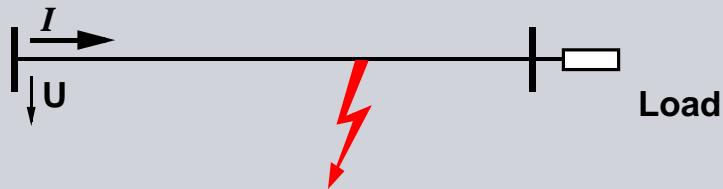
# Overvoltage - Undervoltage



## Impedance protection



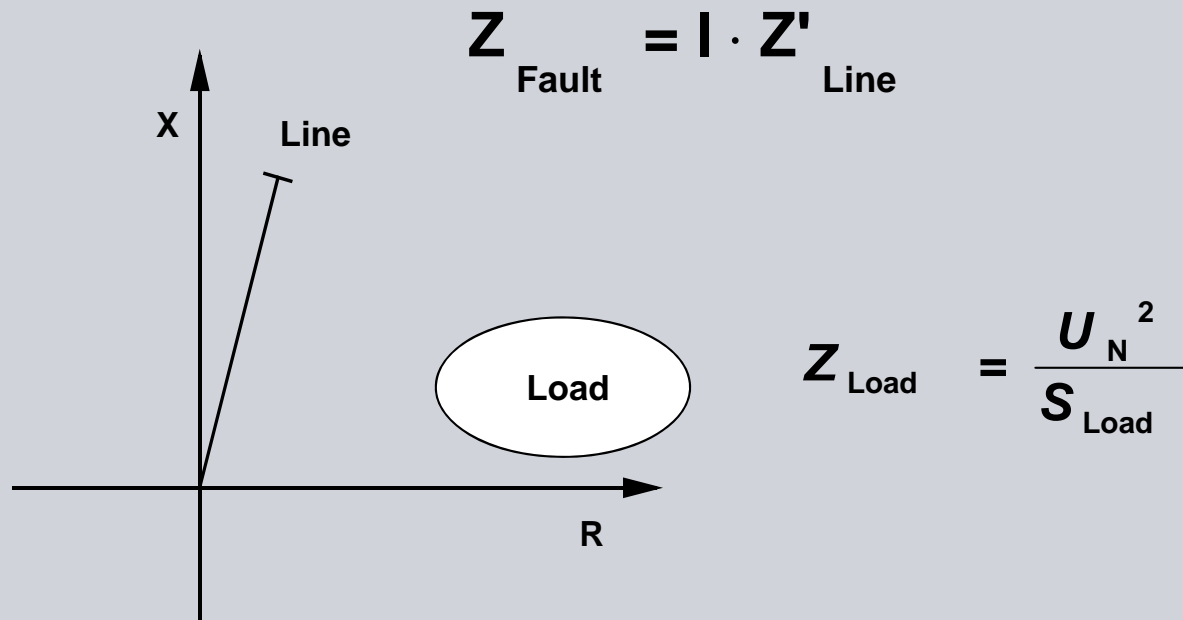
$$\frac{U}{I} = Z_{\text{Load}}$$



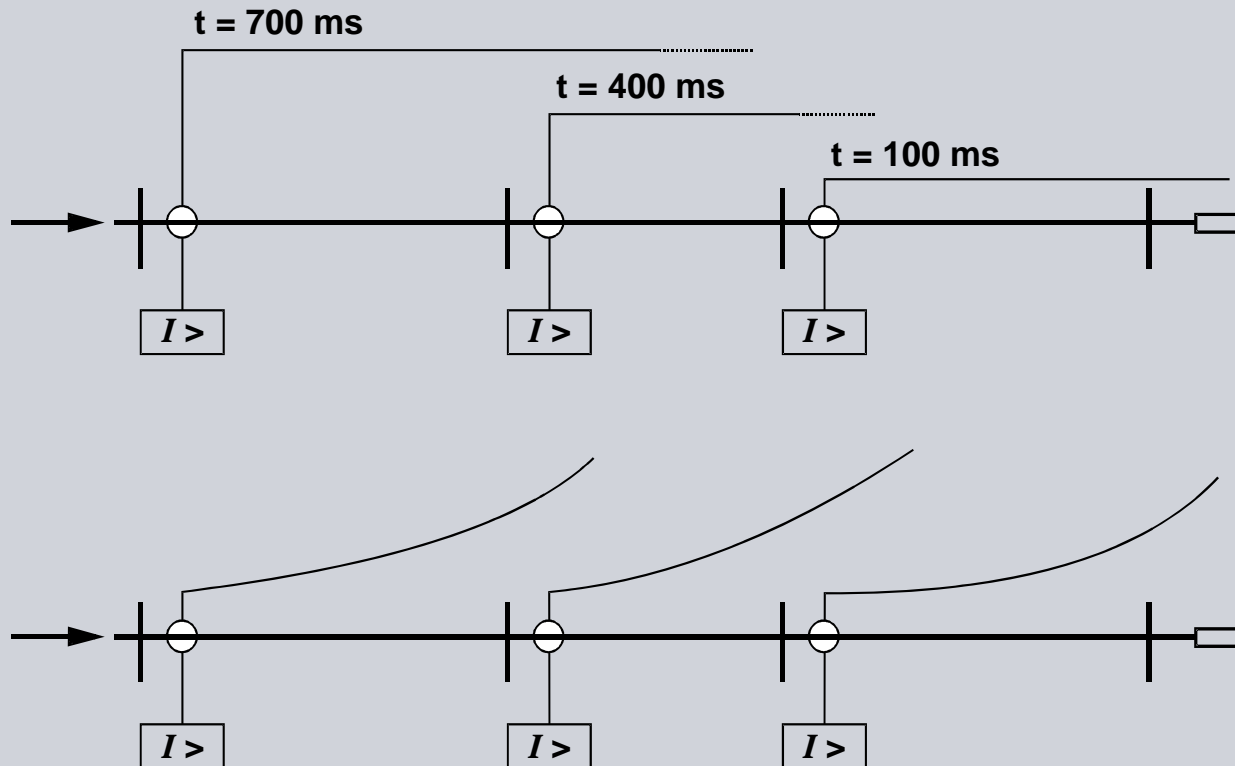
$$\frac{U}{I} = Z_{\text{Fault}}$$

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

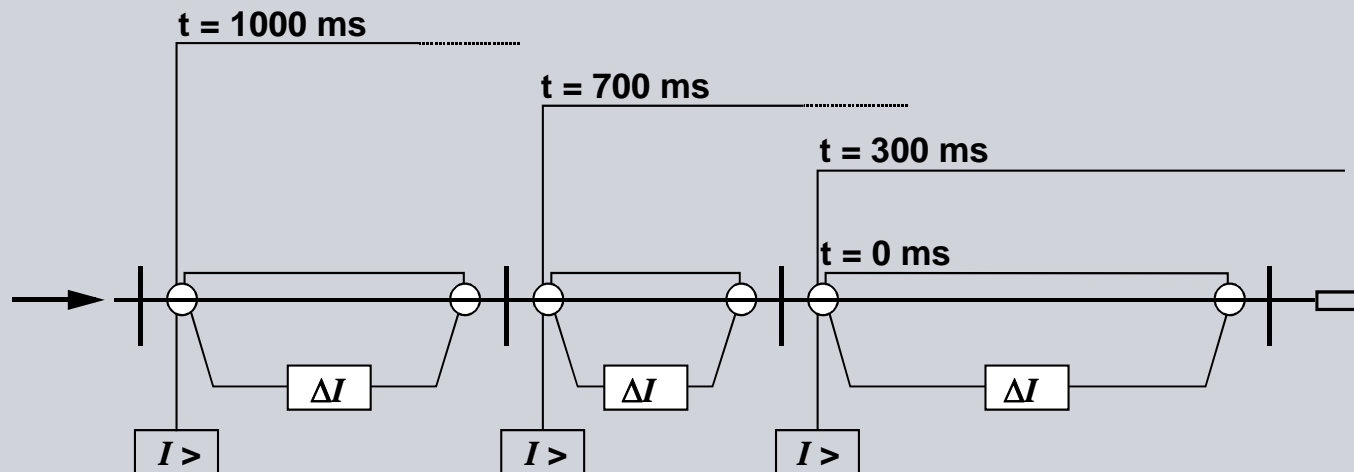
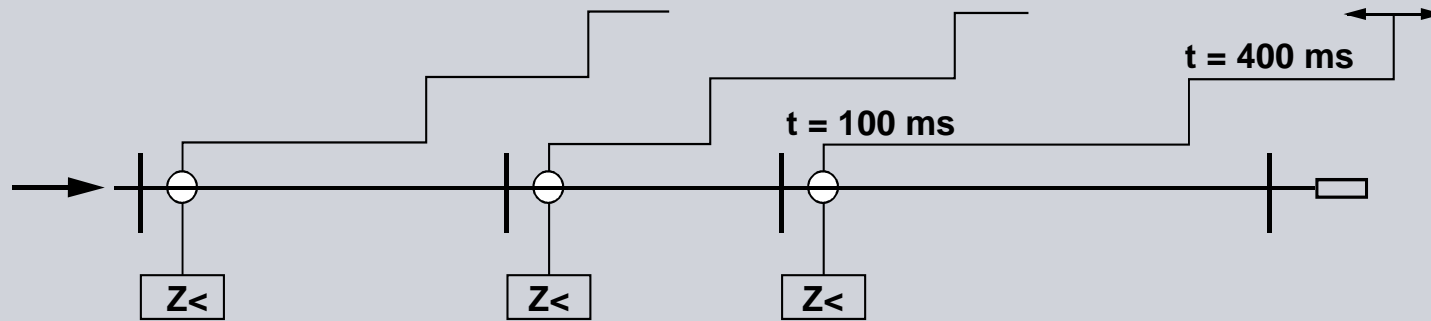
## Distance protection



## 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

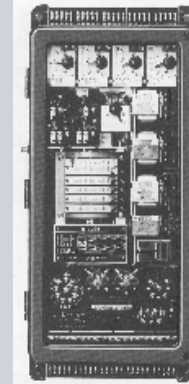
Fuse  
Time-graded protection

**Motor**

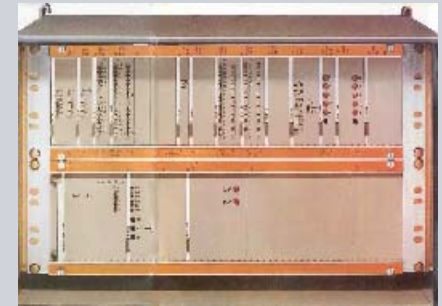
Time-graded protection  
Overload protection

## History

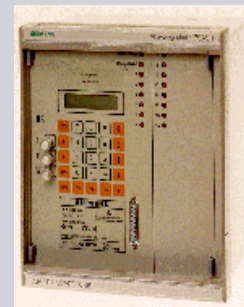
**1900**  
**Electromechanical relays**



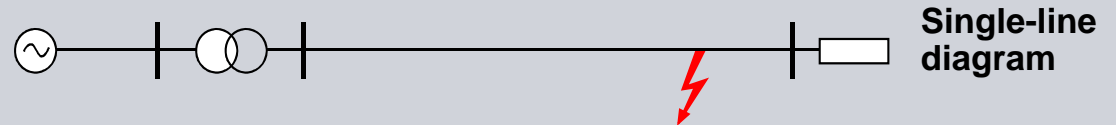
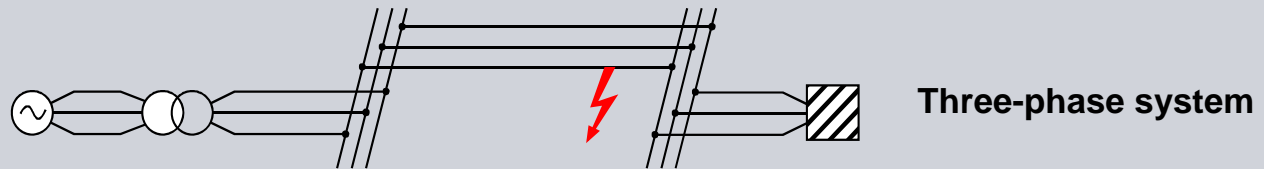
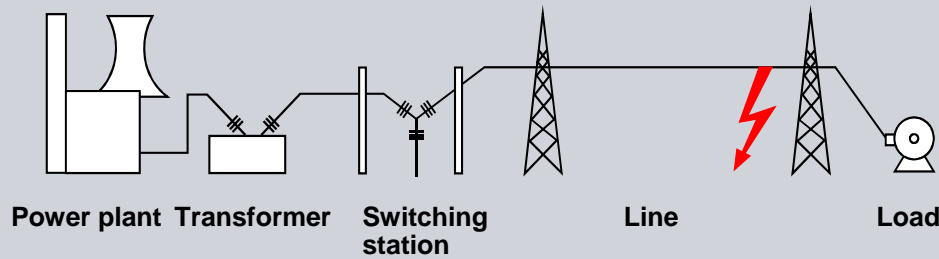
**1980**  
**Analog electrical relays**



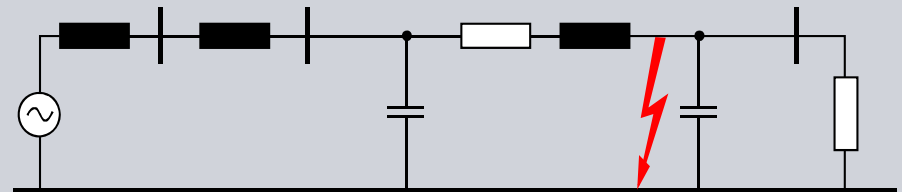
**1990**  
**Numerical relays**



## Network calculation

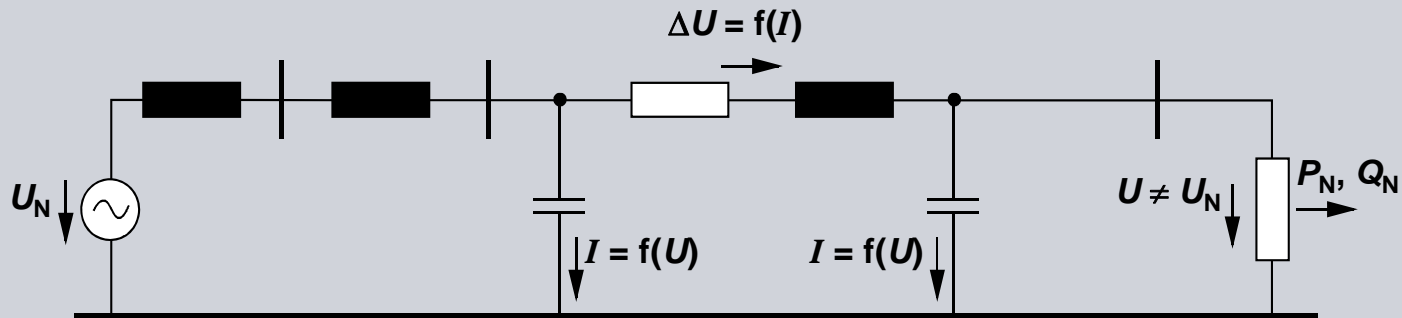


Equivalent circuit in symmetrical components



# Load flow

## A non-linear task



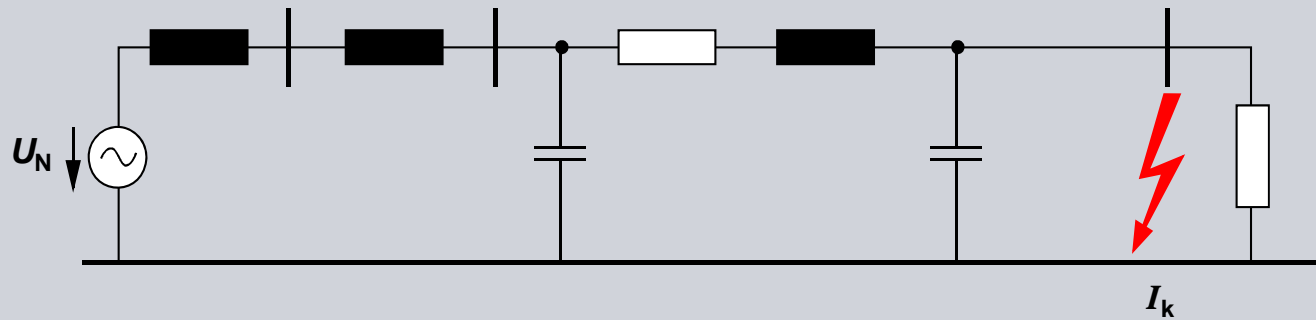
Iteration-process:

Current iteration  
Newton - Raphson

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

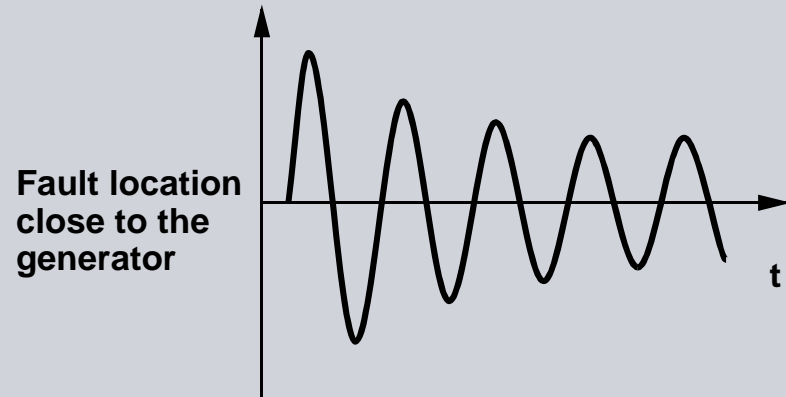
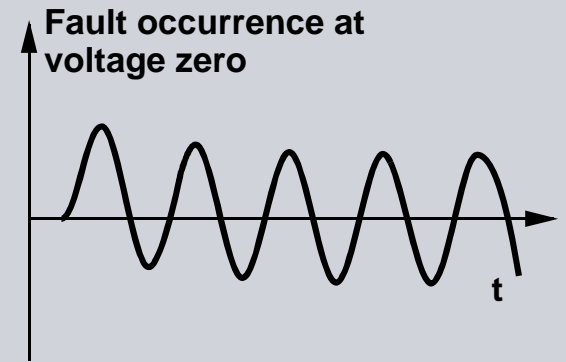
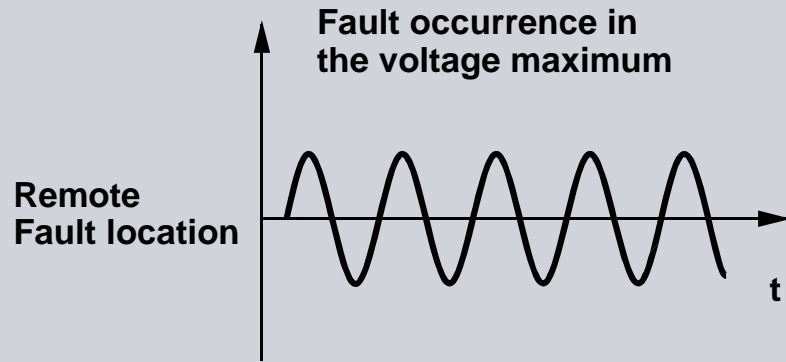
$$Z_{\text{Load}} = \frac{U_N^2}{S_N}$$

# Short-circuit calculation

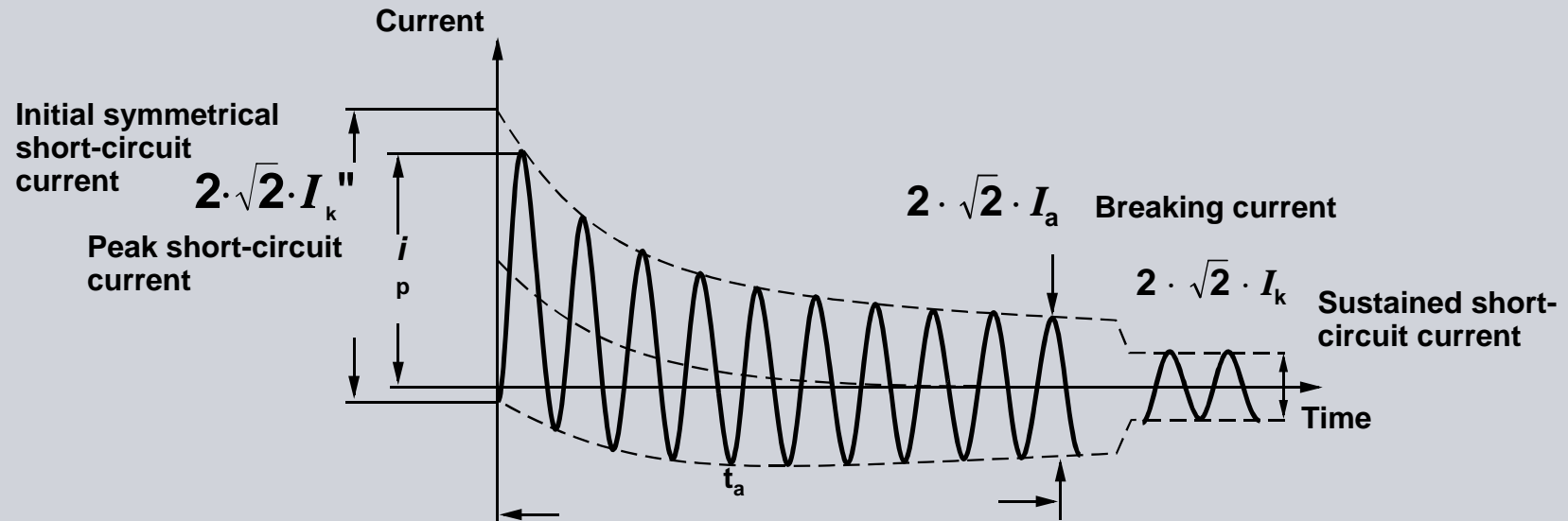


Ohms Law: 
$$I = \frac{U}{R}$$

# Time characteristics of short-circuit currents

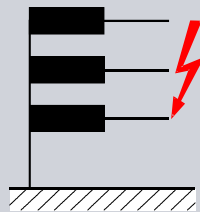


## Fault currents

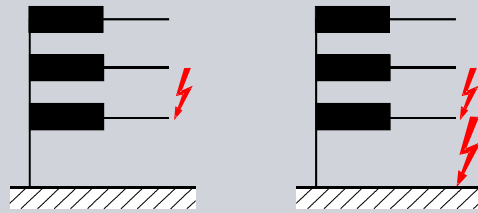


$I_{k3}$	$I_a$	$i_p$	$S_k''$	$S_a$
Fault current contributions			Fault current distribution in the system	
$I_{k2}$	$I_{k2E}$	$I_{EE}$		
$I_{k1}$				
$I_{k \max}$	$I_{k \min}$			
VDE	Preloaded short-circuit			

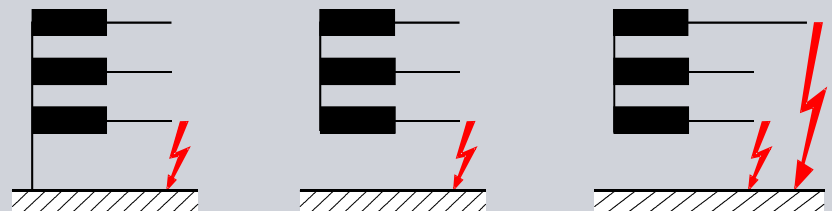
# Types of short-circuits in three-phase systems



3-pole

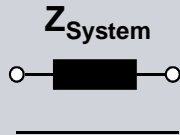
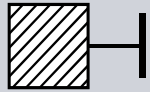


2-pole



1-pole

## Typical equipment data Network

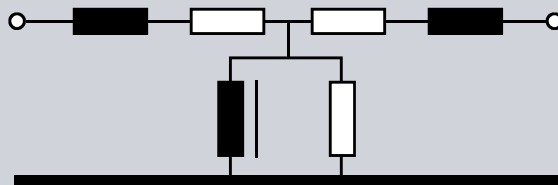
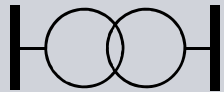


$$S_k'' = \sqrt{3} \cdot U_N \cdot I_k''$$

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

$U_N$	$S_k''$	$I_k''$	$Z_{\text{System}}$
380 kV	26 GVA	40 kA	5.5 $\Omega$
110 kV	1 GVA	5 kA	12.1 $\Omega$
	5 GVA	26 kA	2.4 $\Omega$
20 kV	350 MVA	10 kA	1.1 $\Omega$
	500 MVA	14 kA	0.8 $\Omega$
10 kV	500 MVA	28 kA	0.2 $\Omega$

## Typical equipment data Transformer



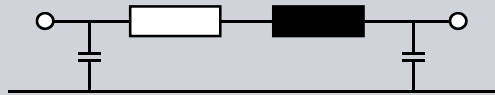
$$Z_{\text{Transf.}} = \frac{U_N^2}{S_N} \cdot u_K$$

$Z_{\text{transf.}}$

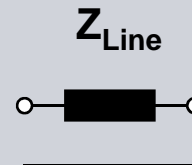


$U_{N1}/U_{N2}$	$S_N$	$u_K$	$Z_{\text{Transf.}}$		
			380 kV	110 kV	20 kV
380/110 kV	300 MVA	15 %	72 $\Omega$	6 $\Omega$	0.2 $\Omega$
110/20 kV	40 MVA	15 %		45 $\Omega$	1.5 $\Omega$
20/0.4 kV	630 kVA	6 %			37.0 $\Omega$

## Typical equipment data Line



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



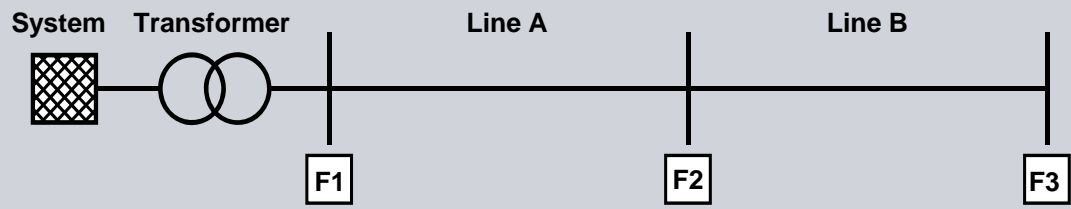
		$R'_1$	$X'_1$	$Z'_1$	$C'_1$
380 kV	Overhead line	0.03	+ j 0.25 $\Omega$ /km	0.25 $\Omega$ /km	14 nF/km
	Cable	0.04	+ j 0.11 $\Omega$ /km	0.12 $\Omega$ /km	400 nF/km
110 kV	Overhead line	0.07	+ j 0.38 $\Omega$ /km	0.39 $\Omega$ /km	10 nF/km
	Cable	0.04	+ j 0.11 $\Omega$ /km	0.12 $\Omega$ /km	400 nF/km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



## Short-circuit current calculation Results

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

# Short-circuit current calculation Results



<b>7.7 kA</b>	<b>4.8 kA</b>	<b>3.5 kA</b>	<b>Cable</b>
<b>(7.7 kA)</b>	<b>(3.1 kA)</b>	<b>(1.9 kA)</b>	<b>Overhead line</b>