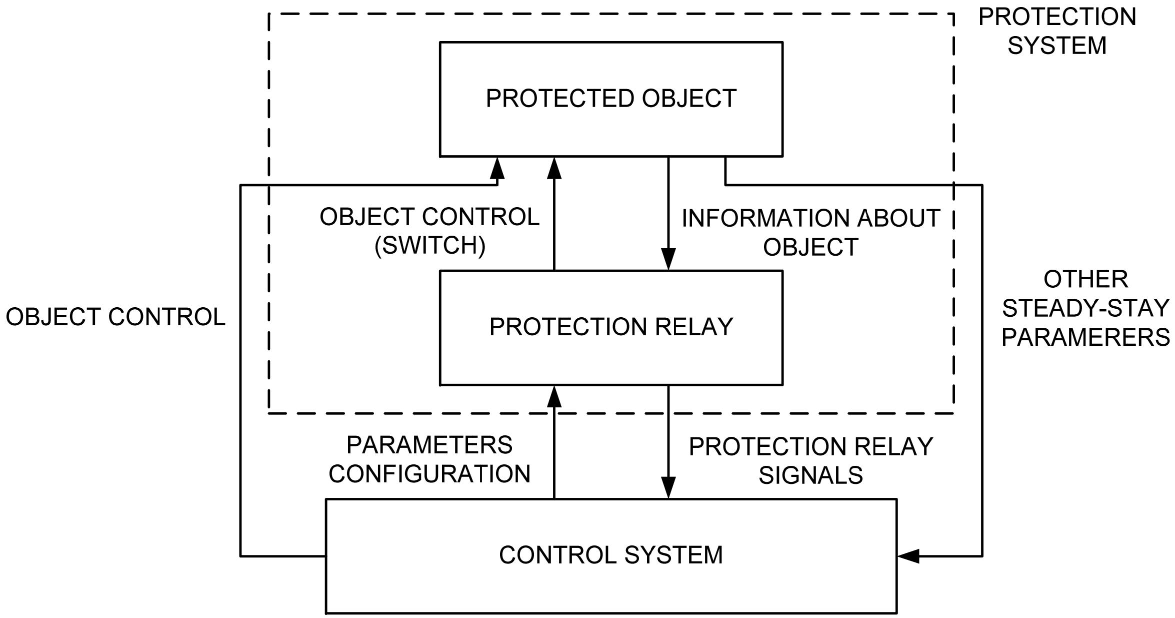
Electrical Protections Theory

Electrical protection – device checking power system part operation (G, T, V) = *protected object*, to ensure normal operation

Protected object – physical device for el. energy transmission, function characterized by current values of measurable physical quantities = *state quantities* (U, I, P, Q, f, T, F,…)

Protection operation – it receives information about quantities (CT, VT, sensors), executes them and evaluates normal operation and inadmissible values limits.
The protected device is switched off from the supplies in case of protected object fault (failure) state → accident preventing or fault consequences reducing. Also sending signals about action for the operator.



Fault – object physical change (quantities), object state out of the normal state, dangerous

Fault quantity – causes the fault, $u_2(t)$

Output quantities y(t) – high values U, I → protections connected to the CT, VT secondary circuits with a treatable signals levels

Electrical protections - definitions

Protection operation – information evaluation about the object state x(t) and during the fault activity on the object by its output v(t), i.e. fault consequences reducing or preventing from them

Protection input y(t) – protected object measured outputs

Protection output v(t) – protection activity on the object

Signal – quantity announcing protection operation

Protection algorithm F – protection function description, relation between inputs and outputs

Protection characteristic – algorithm graphic interpretation

Protection equation – algorithm mathematical form

$$v(t) = F[y(t), n]$$

Protection parameters – constants for setting F

Protection sensitivity – the measured quantity smallest value (element y(t)) to activate the protection

Protection adjustability – the range of all possible protection sensitivities

Protection resolution – ability to distinguish two close object states (failure and non-failure), their minimal deviation

Protection holding ratio – input state quantities ratio during returning to the block position and during the run to the acting position

$$\frac{x_i(t)_{return}}{x_i(t)_{\mathrm{pitch}}} < 1$$

Protection activity time t_p – time from the failure origin to a signal sending to the protection output

Protection overload capacity – protection input max. value not endangering the protection

Protection consumption – electric input necessary for the protection operation

Primary protection – it works without instrument transformers

Secondary protection – connected to CT, VT secondary circuits

Protection item – building element (relay, TRF, electromagnet, chip, processor, connector,…)

Protection element – set of items creating a function unit

Basic protection – basic object equipment

Reserve protection – delayed activity in comparison with the basic one, ev. other algorithm, for a higher safety

Fault states

Short-circuit

- phase-to-phase or phase-to-ground connection
- → possible electrical, heat, mechanical damaging, loss of synchronism

Overload

- too high current (power) through a device
- → heat, mechanical damaging

Overvoltage

- voltage over a permitted limit
- → insulation damaging and aging, additional losses, short-circuit danger
- atmospheric or switch influences, voltage control, capacitive load, no-load power line

Undervoltage

- voltage dip under a permitted limit
- current overloading, voltage control

Frequency decrease

- consumption surplus over production in ES
- → incorrect function, higher magnetizing currents and losses

Frequency increase

- production surplus over consumption in ES
- → incorrect function, mechanical stress

Unbalanced load

- single-phase load, el. traction
- → negative current component → additional losses in rotor, heating

Ground fault

- single-phase-to-ground connection in networks with insulated neutral point
- subsequent short-circuit probability

Power reverse flow

- turbine failure → steam input closing → motor operation

Loss of excitation

- excitation current drop under static stability limit → asynchronous operation
- → additional eddy current losses

Electrical protections sorting

a) according to protected object type

generator, motor, transformer, busbar, powerline, cable, switch, etc.

b) according to fault type

short-circuit, overload, undervoltage, overvoltage, under-, over-frequency, ground fault, reverse power flow, excitation loss, unbalance

c) according to functional principal

different characteristics

d) according to time activity

- immediate – activity time is limited only by information processing and protection reaction, i.e. it acts “immediately”
- dependent – activity time is proportional to the measured quantity
- time independent – constant activity time (adjustable)

e) according to construction

- electromechanical – relay elmag., inductive, heat, eldynamic,…
- transistor – semiconductor elements (diodes, transistors, integr. circuits)
- digital – discrete processing

Requirements for protections

a) **Speed**
Given by the activity time = protection time + switch activity. Speed choice depends on the fault type (short-circuit x overload).

b) **Selectivity**
Disconnecting as small as possible system part. Time, current, or place scaling.

c) **Sensitivity and precision**
Measured quantity minimal value reacted by the protection and its relative error.

d) **Reliability**
The ability to act during the fault and not to act if no fault. External conditions, protection mechanism, maintenance influence. Backup.

e) **Easy maintenance and check-up**

Generator protections

Protections against short-circuits and ground faults

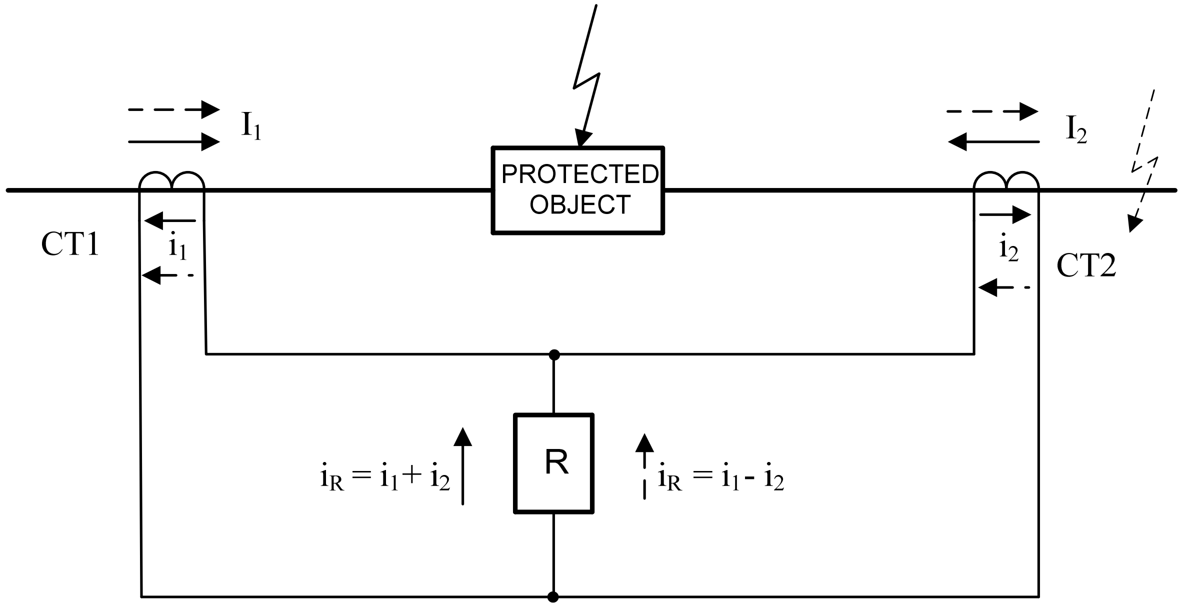
Serious faults → to ensure machine switching off.

Differential protection (DP)

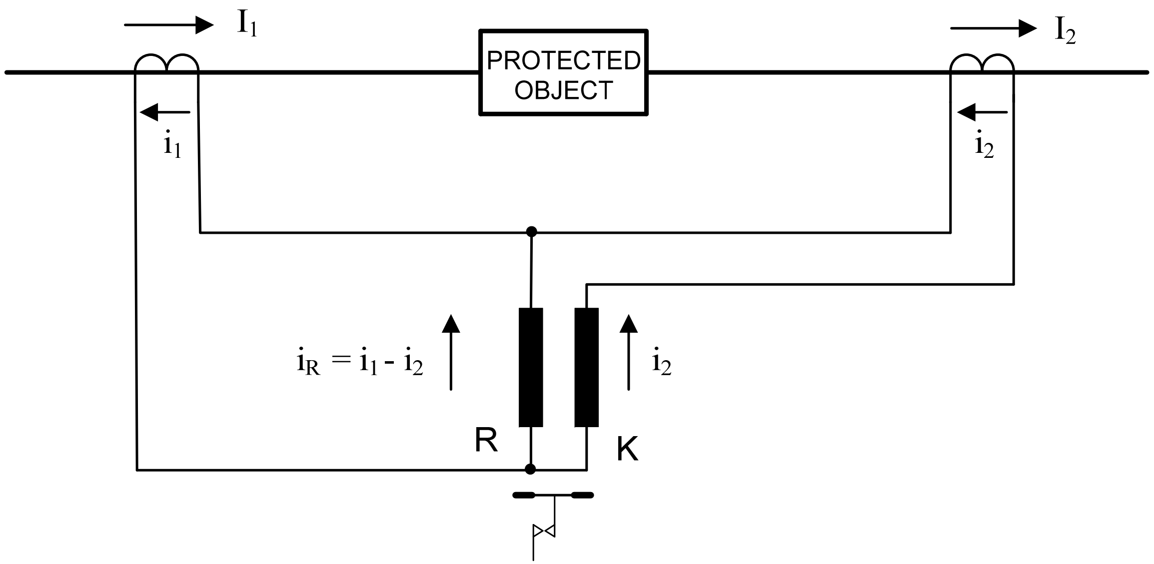
Longitudinal DP – compares object input and output (more often)

Cross DP – compares two objects inputs, i.e. protects two identical objects operating in parallel

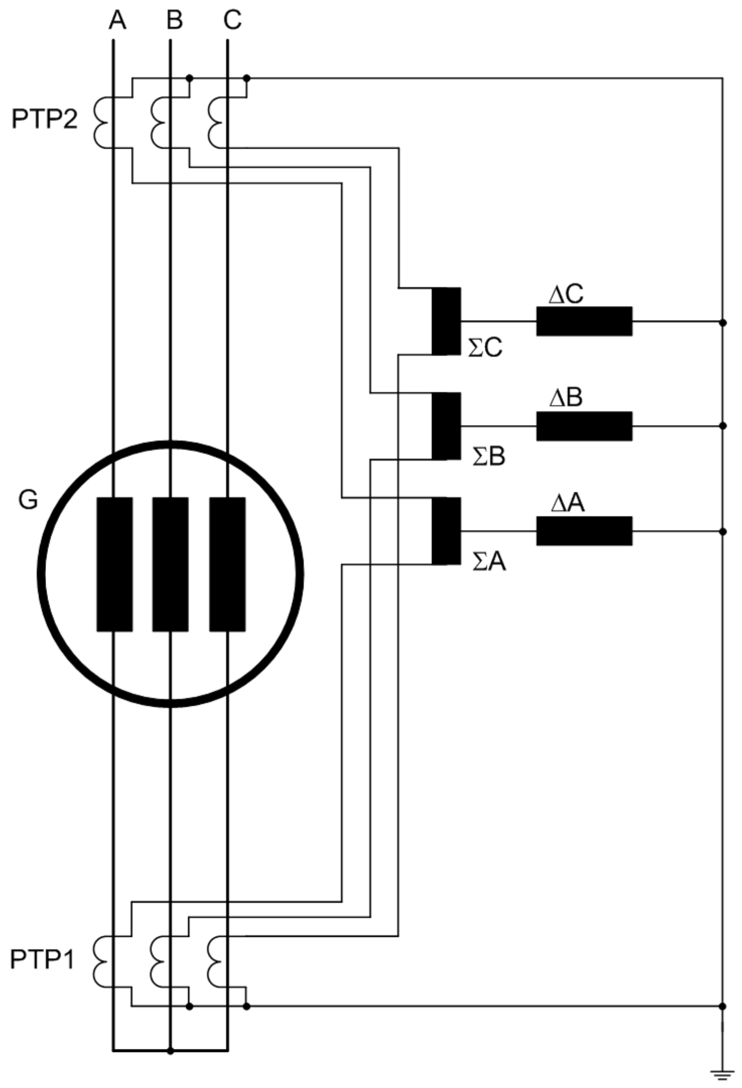
Longitudinal DP – activity in case of $i_R > i_{set} = 10x\ \%\ I_n$, complete immediate switching-off



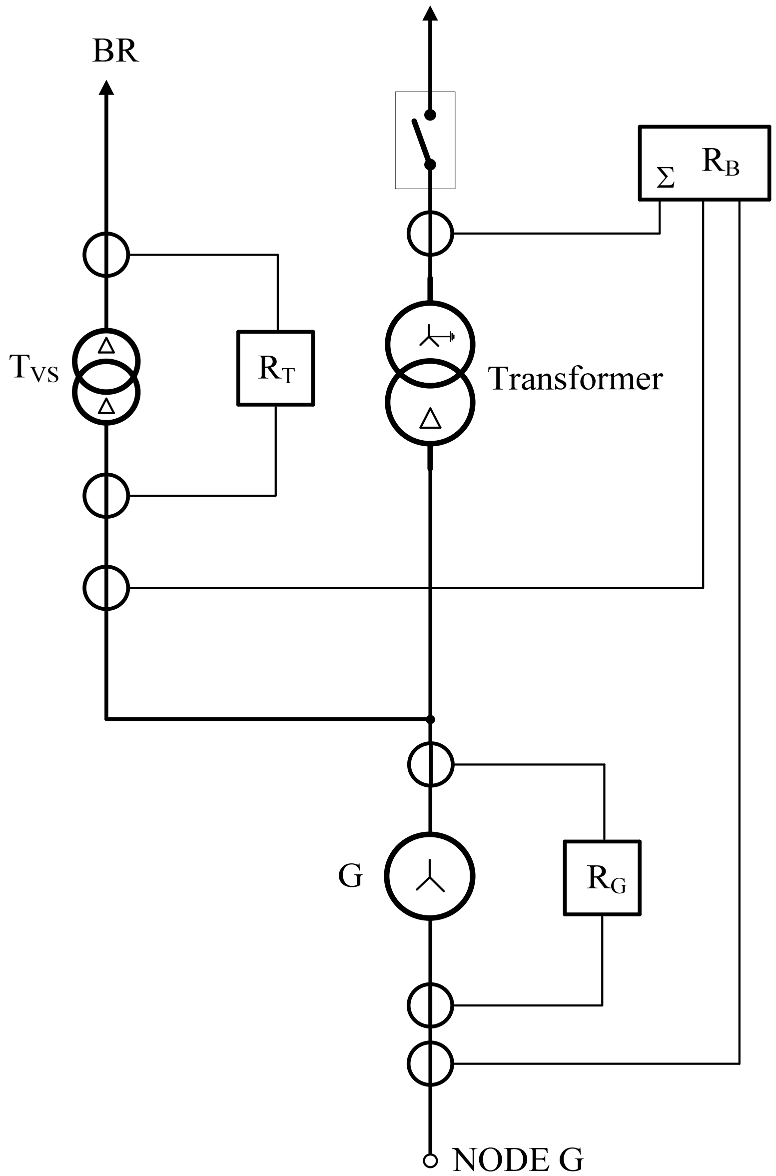
CT inaccuracy compensation



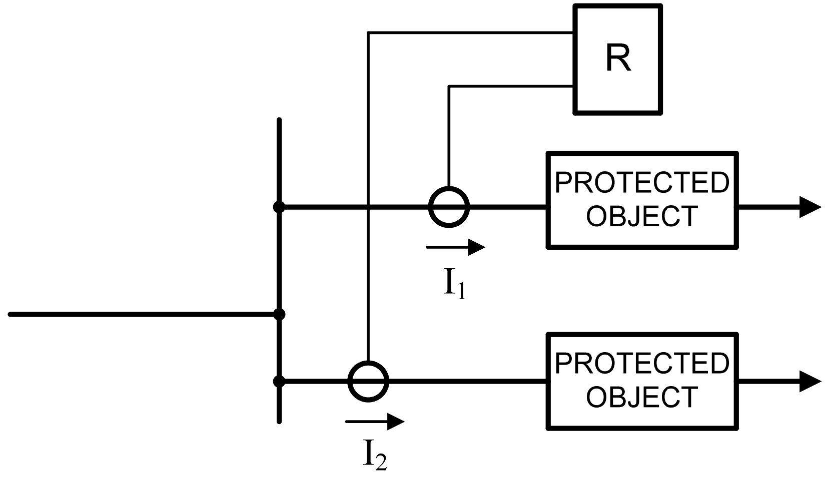
3ph DP at generator



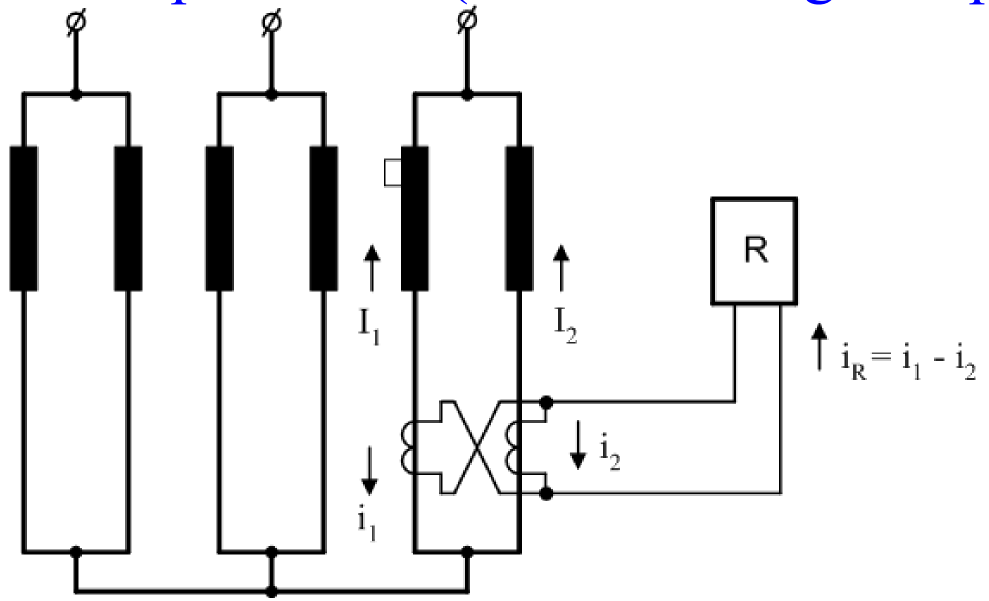
Longitudinal DP (R_B) for block in „3-point connection“ – as the R_G backup



Cross DP – in case of fault $I_1 \neq I_2$ and the protection acts

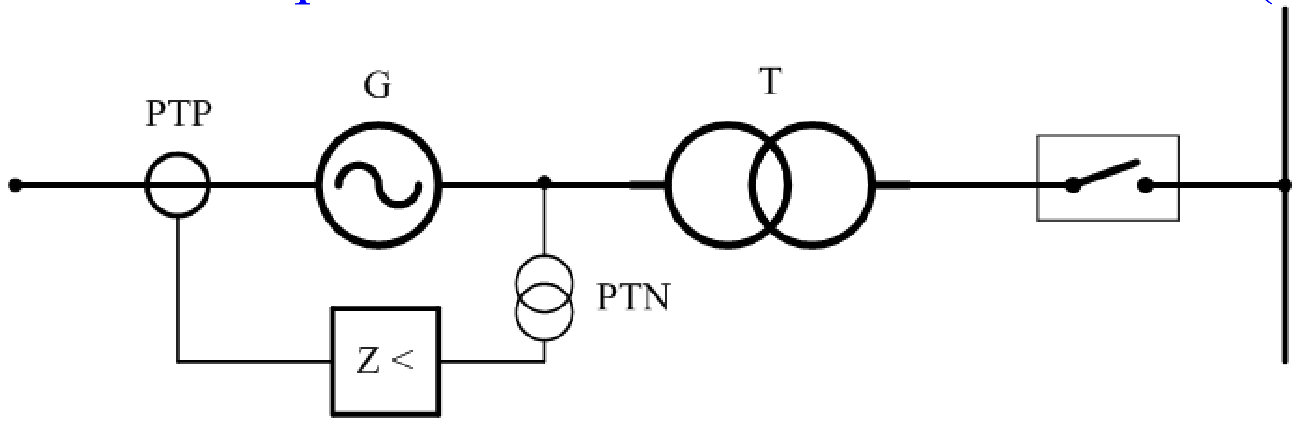


e.g. as the generator turn protection (stator winding of 2 parallel branches)



Overcurrent short-circuit protection

- for identifying outside short-circuits, also as the DP backup for inside short-circuits
- distance (impedance) protection principle
- short-circuit distance distinguishing
- activity doesn't depend on the short-circuit current size (in time)



Stator ground protection

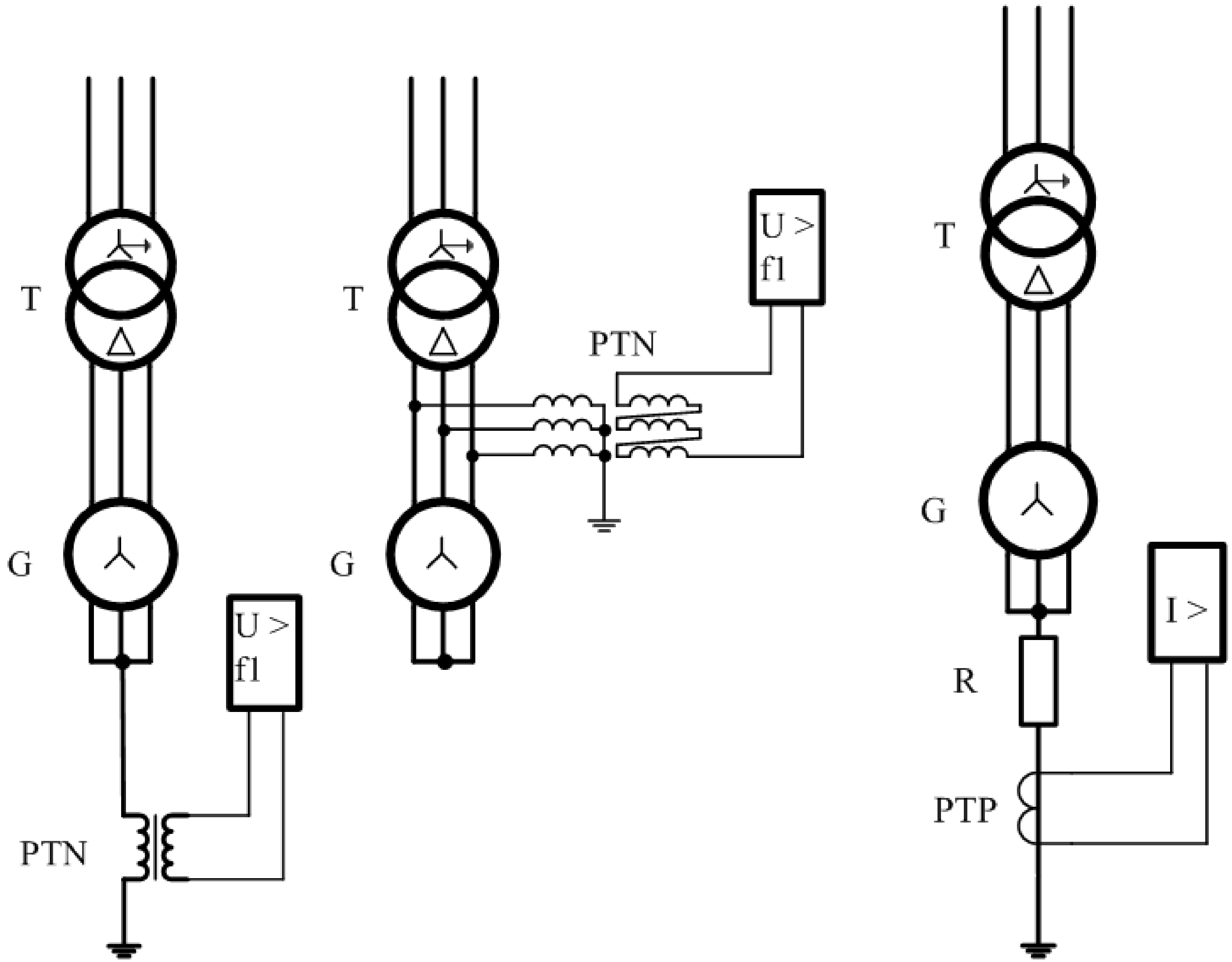
Stator winding ground fault → neutral point moving → its voltage to the ground non-zero (higher U if ground fault closer to machine terminals). Risks of unbalance, fault current, 2nd ground fault.

Voltage protection

- GF identifying up to 95% winding (also more – active injection)
- neutral point or zero component voltage (artificial neutral point and open triangle)
- frequency filter for 1st harmonic

Current protection

- resistance in the neutral point reduces ground current (plates burning-up)
- high R reduces protection range

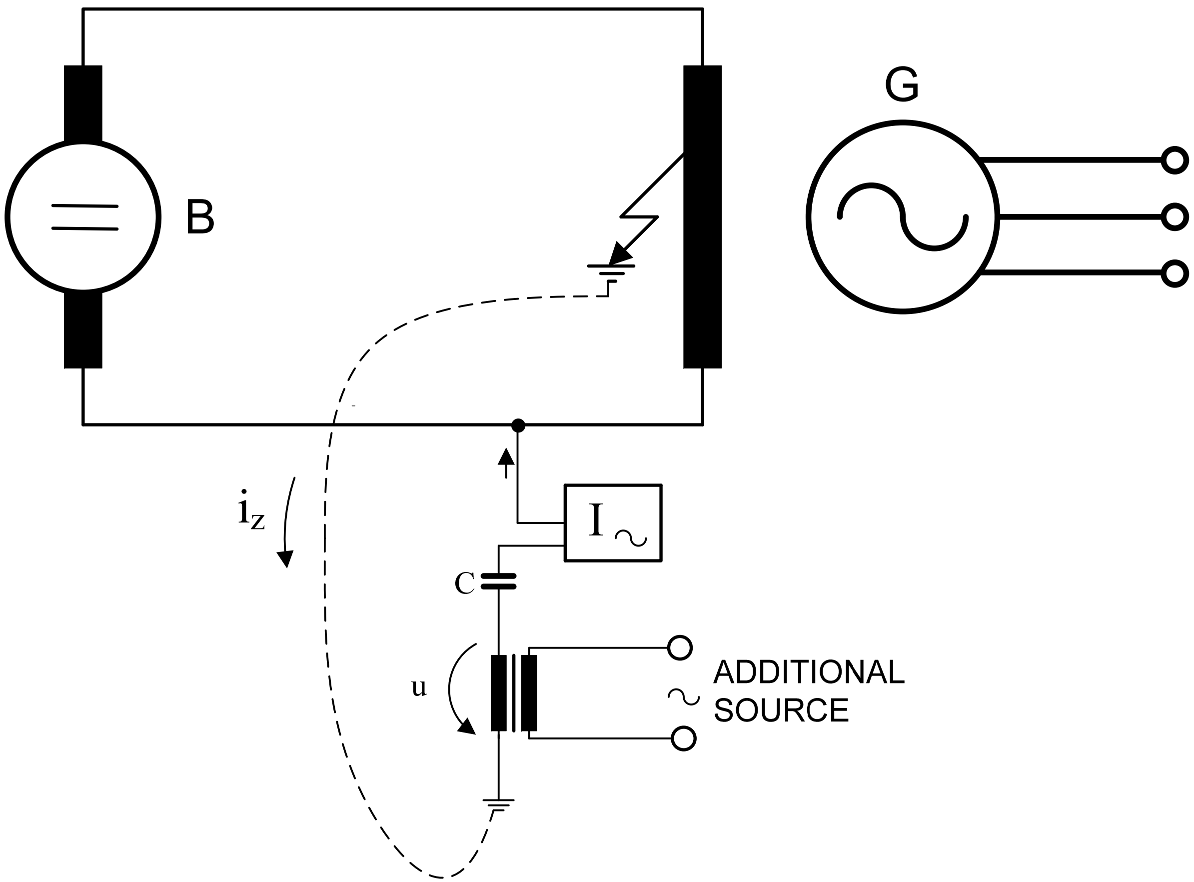


T
G
U >
f1
PTN
T
U >
f1
PTN
G
T
G
I >
R
PTP

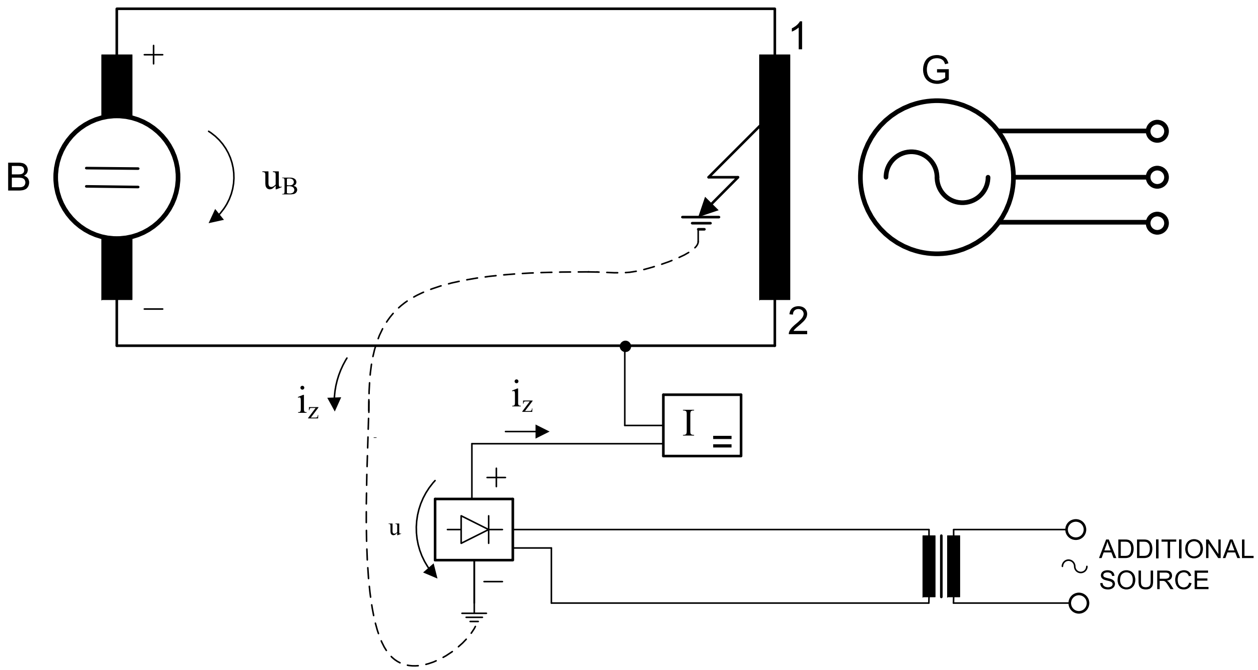
Rotor ground protection

Current circuit interconnection in case of GF → switching-off. In case of 2nd GF mag. field deformation and radial mechanical forces.

AC superposition



DC superposition



Protections against abnormal operating states

Protection against current overloading

- protects against heating (ageing, insulation break-out)
- often independent with a longer time 10x s (machine can endure short-time overload)

Protection against overvoltage

- protects against relieving, controller malfunction

Protection against reverse power flow

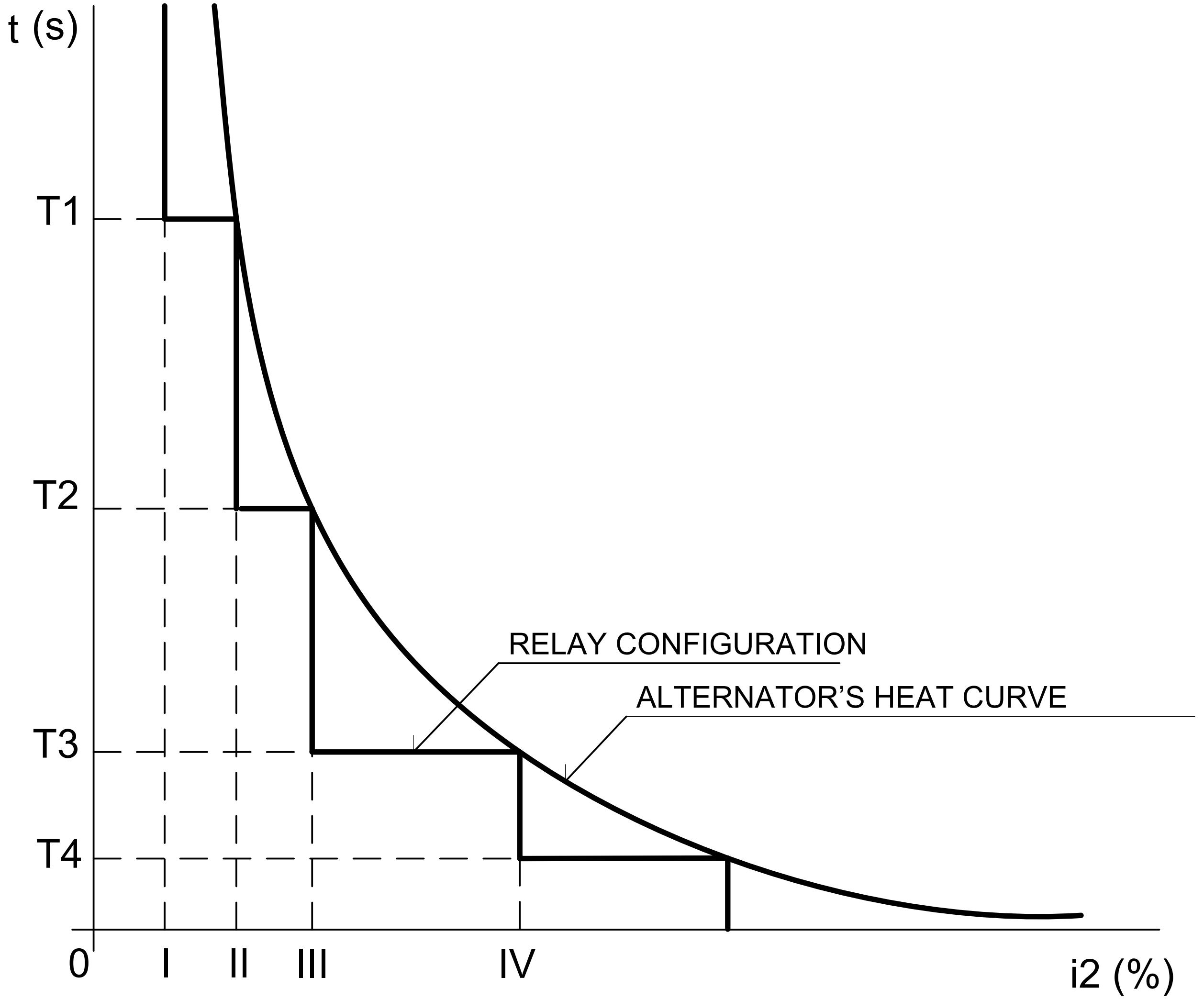
- to prevent motor operation in case of turbine failure, watt

Protection against unbalanced load

- unbalance → reverse magnetic field in the stator → eddy currents in the rotor and damper → dangerous heating, vibrations
- for the certain negative component value i_2 there is a permitted operation time according to the machine heating curve
- limit according to coefficient K_{max} by the producer

$$K(T) = \int_0^T i_2^2(t)\,dt$$

- multilevel protections, they measure i_2 from three phases
- also as a backup for unbalanced short-circuits



Transformers protections

Protections according to fault type

A. Transit faults (outside influence) – overcurrent and short-circuit protection
   1) Overload
   2) Outside short-circuit

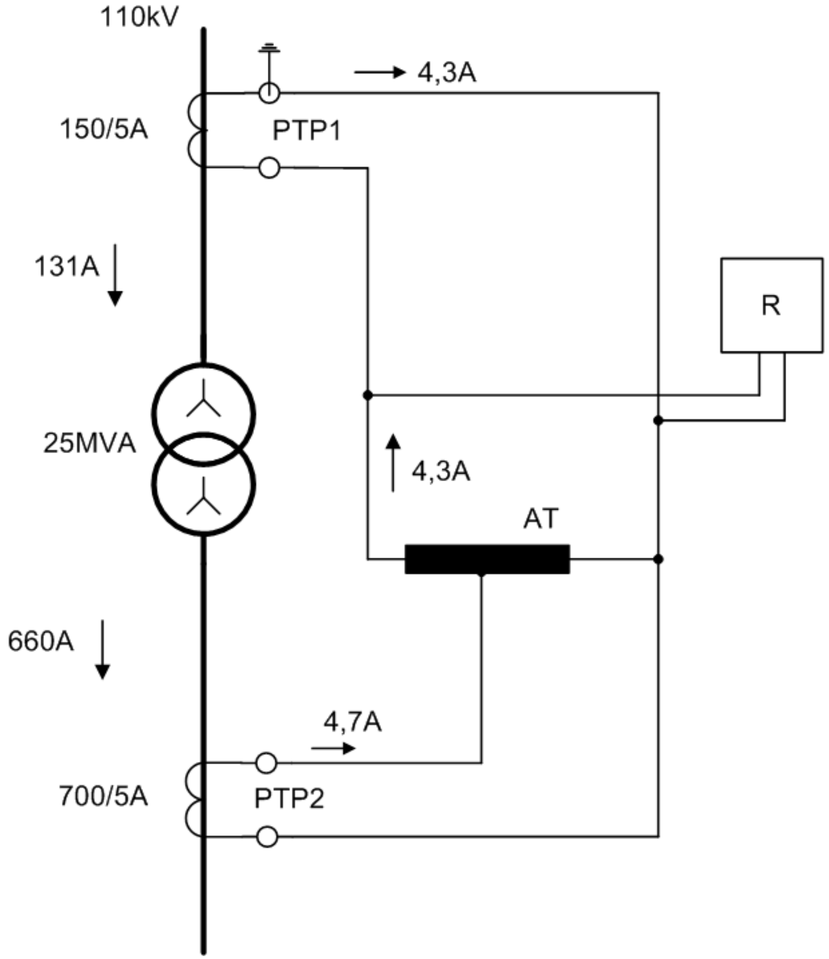
B. Inside faults
   a) Sudden – differential, gas relay, vessel (cage) protection
      1) Short-circuits on the terminals, winding
      2) Ground faults
   b) Gradual – gas relay
      1) Wrong plates insulation → arcs in the vessel
      2) Cooling failures → bubbles in the oil

Differential protection

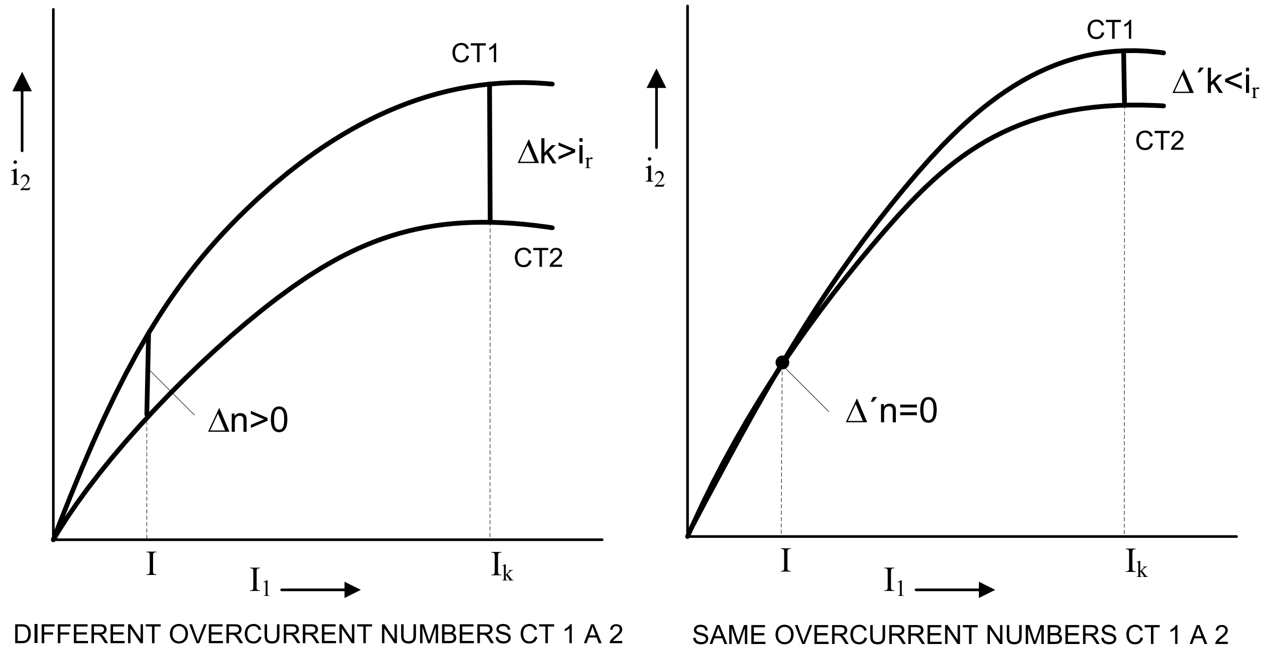
Basic protection against inside faults.

Principle as at the generators but difficulties:

a) unequal CT ratios – rated TRF currents but CT ratios normalized → incorrect activity during outside short-circuit



b) unequal CT construction – different overcurrent numbers



c) unequal primary and secondary winding connection → difference currents because of phasors turning → to connect CT windings as the opposite TRF winding (Y, D)

d) magnetizing current impact during TRF switching-on with open circuit → 2nd harmonic filter

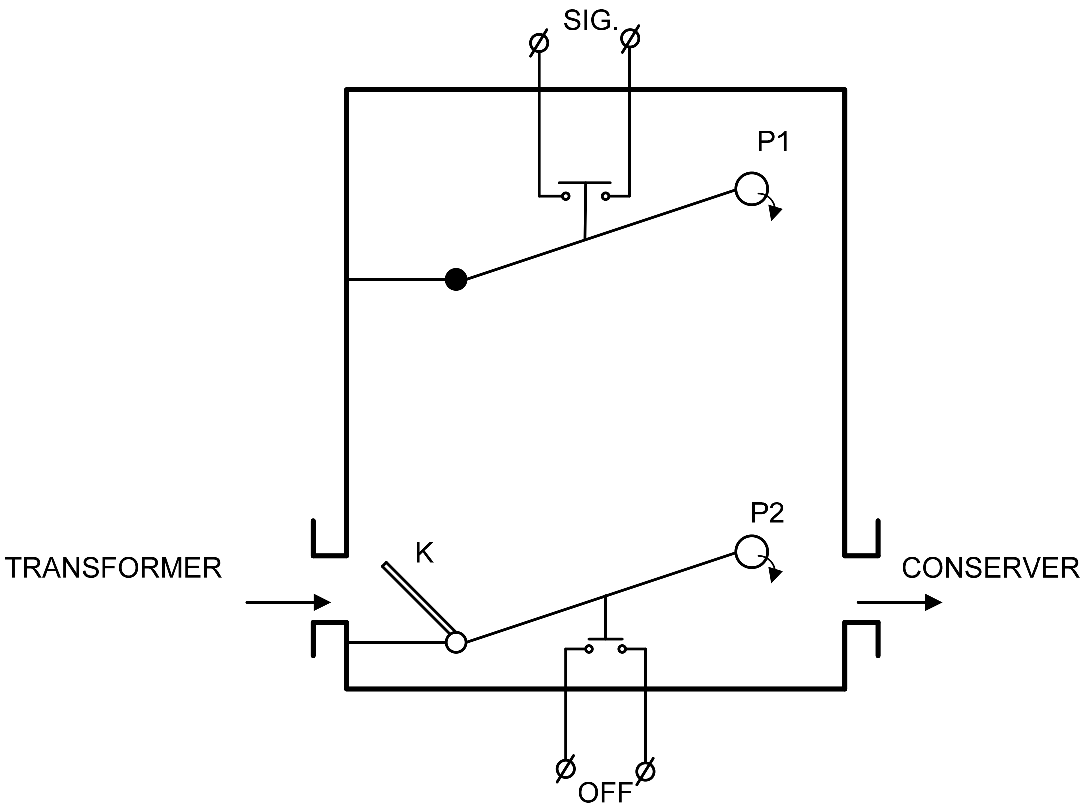
e) voltage control at tap-changing TRF → higher DP start-up current

Gas (Bucholz) relay

At TRF with oil cooling, between cover and conserver.

2 levels:

1) Signalization (float P1)
2) Switching-off (float P2 + clack K)
   Quick gas generation during short-circuit, oil leakage.



Power line protections

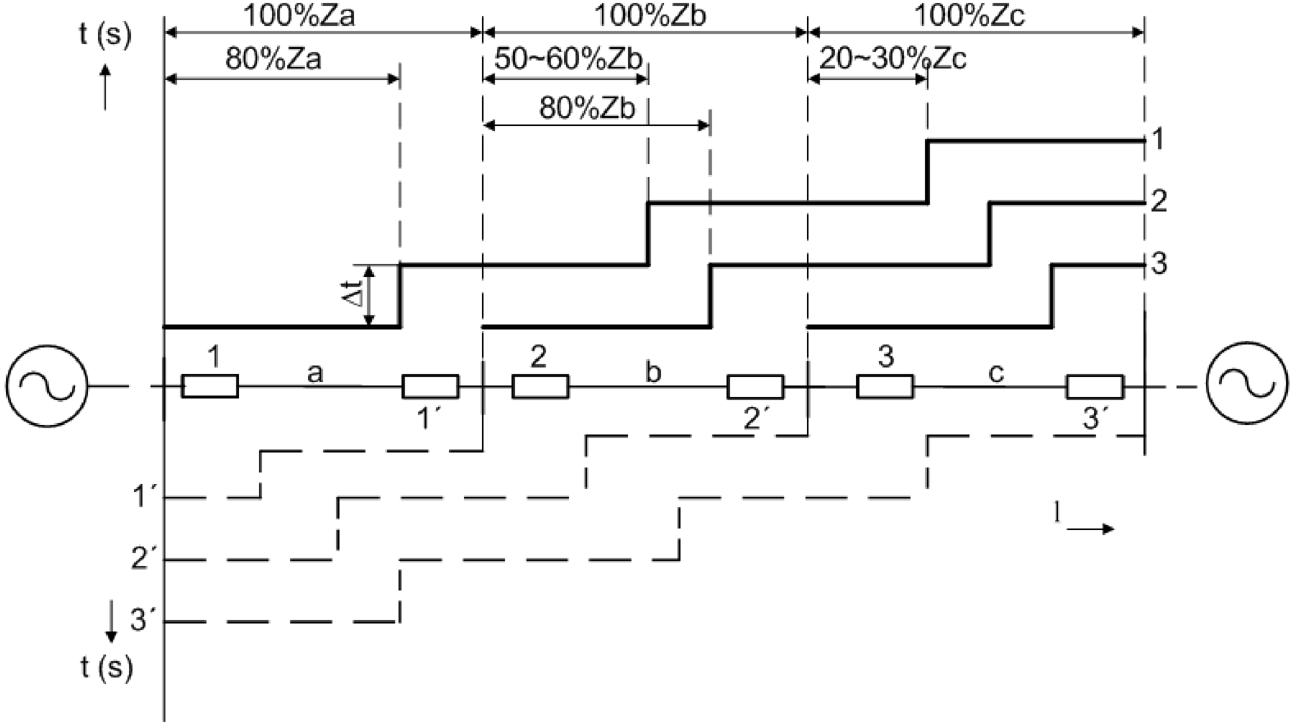
Against short-circuits, overload, overvoltage, ground fault.
Against short-circuits:

- overcurrent – simple powerlines (alt. with the directional element)
- comparative – meshed networks
- distance – meshed networks

Distance protections

- measures power line impedance (u/i) from the protection to the short-circuit place
- switching-off time proportional to the impedance
- good selectivity
- collaboration with AR (auto-reclosing) system

Switching-off characteristics



1st level: $0{,}8\ z_a$

0,01 – 0,02 s (immediate)

2nd level $0{,}8(z_a + 0{,}8\ z_b)$

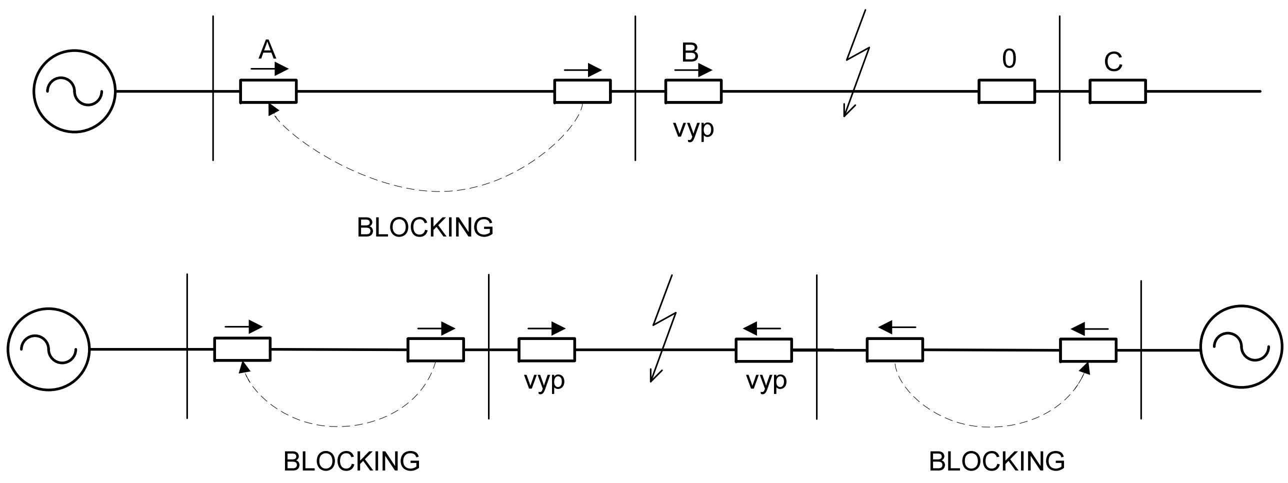
0,6 s

3rd level $0{,}8[z_a + 0{,}8(z_b + 0{,}8\ z_c)]$

1,1 - 1,2 s

Comparative protections

- compares el. values at the beginning and at the end (direction of I, P, Q, phase of I)
- identifies only values inequality
- disconnects immediately and only one powerline section → "sectional protection"
- auxiliary connection (communication) of both stations for the comparison purpose
- collaboration with AR (auto-reclosing) system



Motors protection

Asynchronous motors

Protections according to faults:

1) bearing failure – bearing temperature measuring
2) inside short-circuits – differential, current pr.
3) ground fault – ground protection
4) overload – current dependent, start-up, thermal picture
5) unbalance – negative component measuring
6) undervoltage – contactor, undervoltage protection
7) one phase disconnecting

Synchronous motors

AM + others:

8) start-up protection – asynchronous start-up
9) protection against excitation loss – loss of synchronism danger (mechanical surges) → power angle monitoring
10) protection against reverse power flow

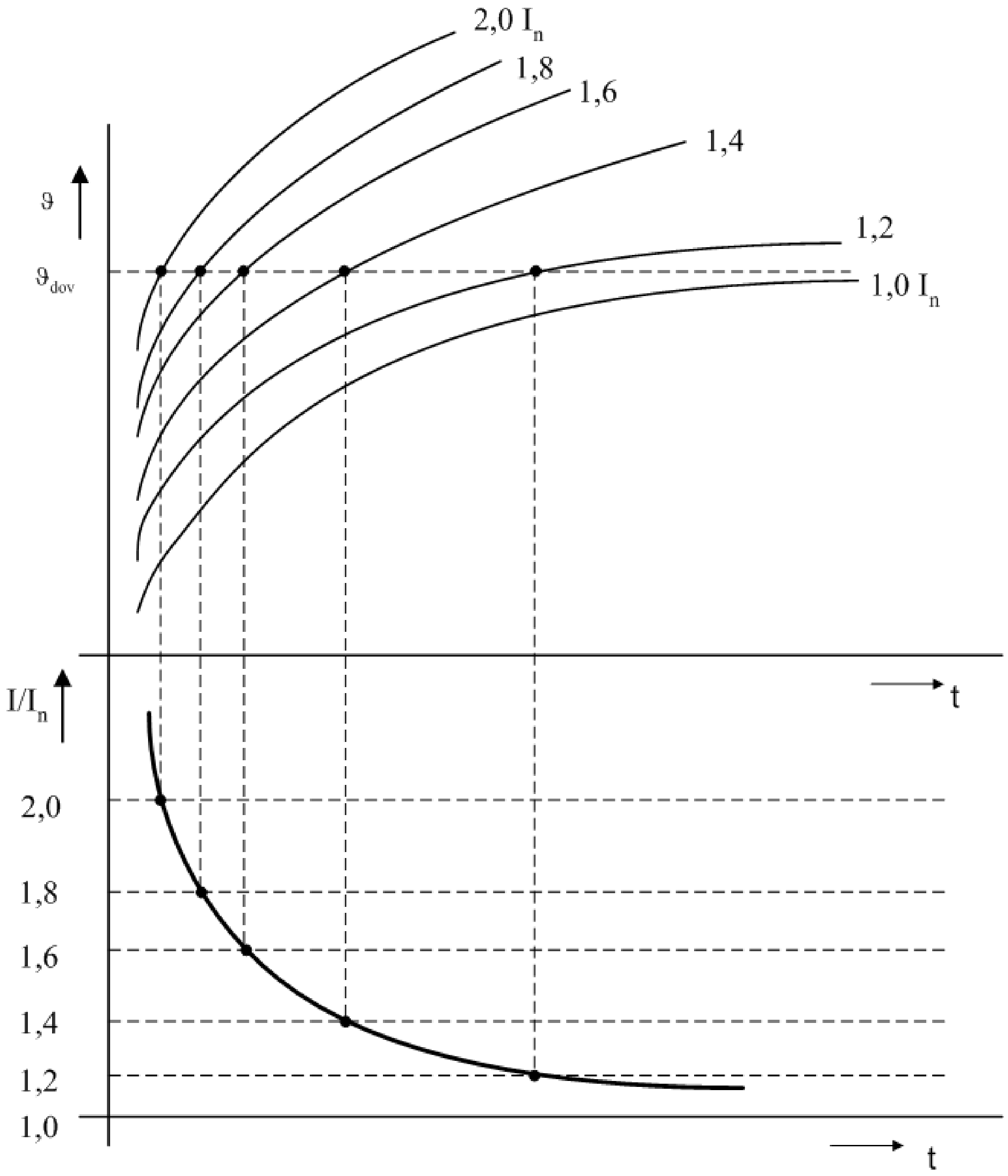
DC motors

1) short-circuit protection – immediate, depends on commutation
2) protection against overload – current dependent pr.
3) loss of excitation – speed and stator current increase, undercurrent protection
4) ground protection
5) bearing protection

Protections in LV distribution

Fuses

- the oldest protective principle against overcurrents
- artificially made the weakest place in the circuit where the current flow is broken
- a calibrated wire (belt) is remelted
- remelting in the extinguishing environment (soft sand)
- (+) simplicity, reliability
- (-) necessary exchange after activity, possibility of remelting only in one phase (at 3ph consumers)
- they mustn't be repaired unprofessionally
- usage in LV, MV x not in HV
- normal (quick) and slow (delay for start-up current)
- time-current characteristic construction from heating curves for different overloads
- time-current char. is dependent



2,0 I
n
1,8
1,6
1,4
1,2
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n
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I/I
n
2,0
1,8
1,6
1,4
1,2
1,0
t

Fuses dividing according to the construction

- *screw-in* – lower currents
- *leg* – higher currents, quick → „power“
- *with contact flags* – very quick (x ms), limiting ability, for semiconductor elements
- *apparatuses* – weak glass tubes, fusible wire in the air
- *car* – ceramic cylinder
- *others* – belts, coils,…

Circuit-breakers

- self-acting overcurrent breakers
- overcurrent (bimetal, overload) and short-circuit (electromagnet, short-circuits) trigger
- they switch off in the current zero, don’t have limiting ability
- sometimes to add fuse for short-circuits if insufficient breaking capacity

- (+) repeatable function, multi-pole construction for 3ph consumers
- (-) complication, costs

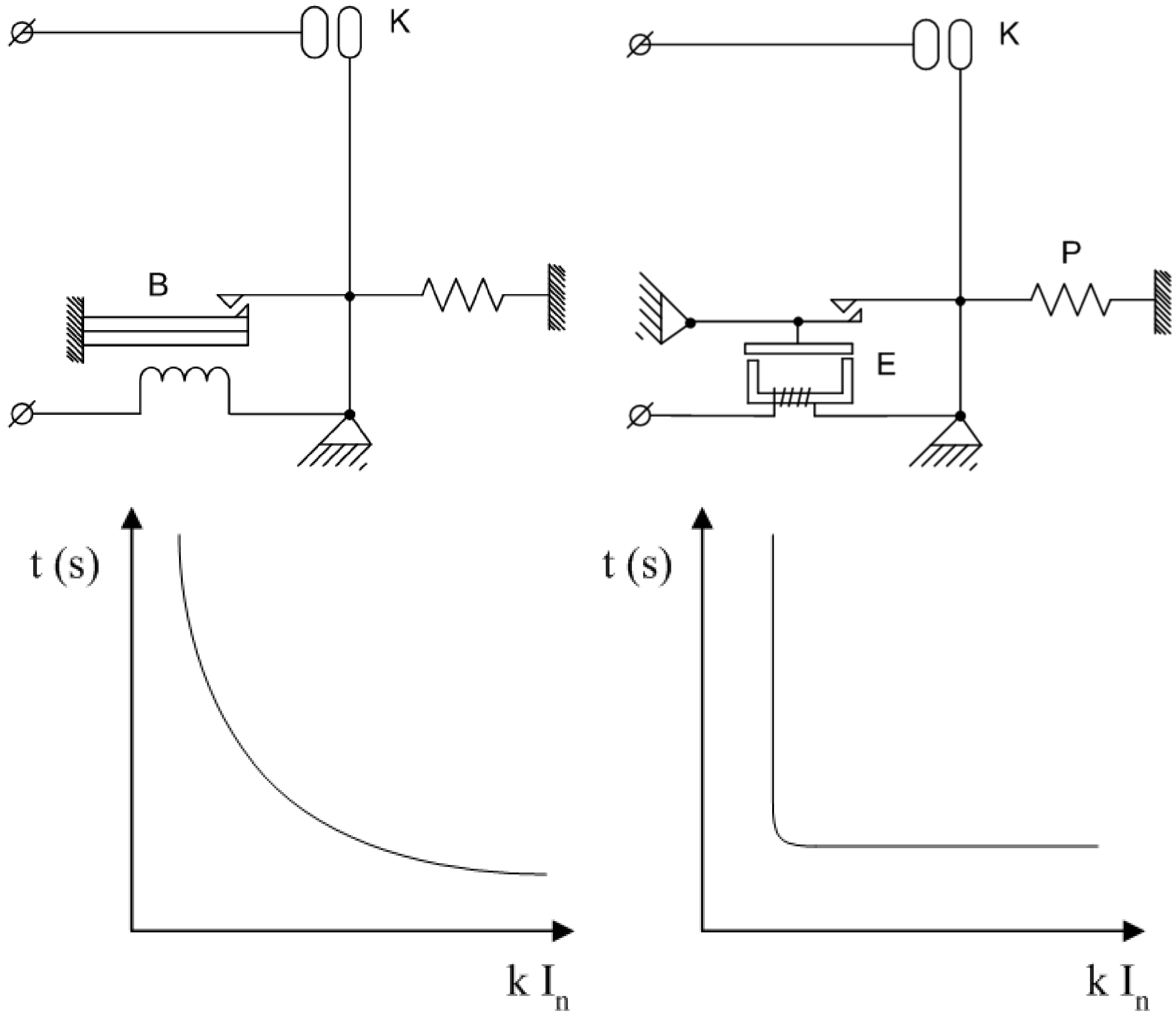


Table of symbols:
P….spring
K….contacts
B….bimetall belt
E….electromagnet

Circuit-breakers dividing

- *I_n size* – small (to 25A, 500V AC, 250V DC), higher (over 25A, to 1000V AC, 1200V DC)
- *purpose* – for power line, motor (delay for start-up), protective (with voltage trigger)
- *poles number* – 1 (1ph), 2 (DC), 3 (3ph), 4 (special)
- *contacts placing* – air, oil (only 3-pole, also for motors switching)

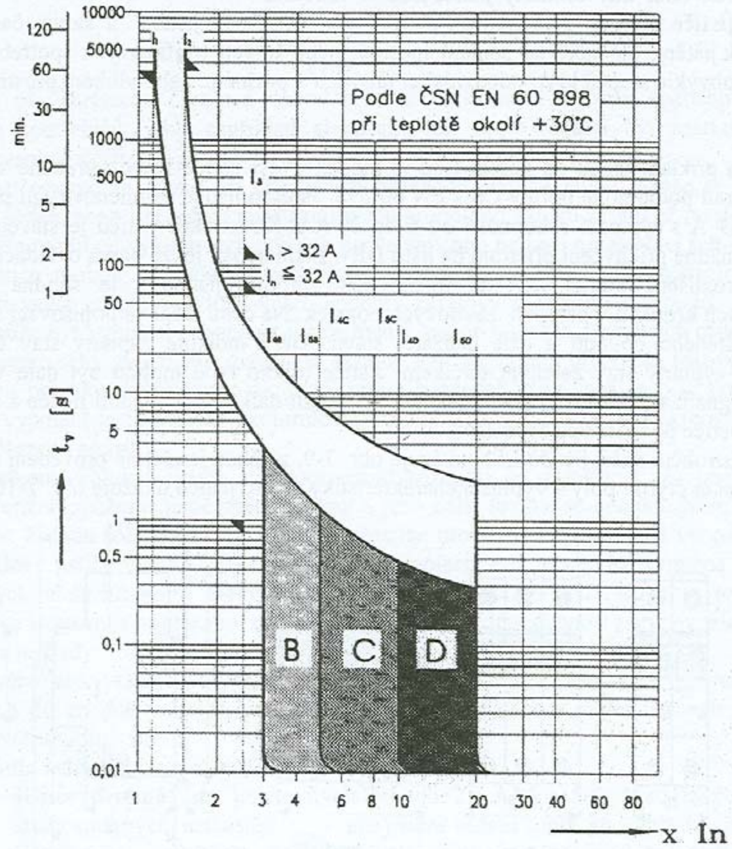
VYPÍNACÍ CHARAKTERISTIKY

Použiti : pro jištěni elektrických obvodů -

B - se zařízenimi, které nezpůsobují proudové rázy (jištěni vedeni)

C - se zařízenimi, které způsobují proudové rázy (žárovkové skupiny, vedeni s motory)

D - se zařízenimi s vysokými proudovými rázy (transformátory, 2-pólové motory)



Vypínací charakteristika	tepelná spoušť			elektromagnetická spoušť		
	zkušební proud		vypínací doba	zkušební proud		vypínací doba
	I_1	I_2	t	I_4	I_5	t
B	1,13xI_n		≧1hod	3xI_n		≧0,1s
		1,45xI_n	<1hod		5xI_n	<0,1s
C	1,13xI_n		≧1hod	5xI_n		≧0,1s
		1,45xI_n	<1hod		10xI_n	<0,1s
D	1,13xI_n		≧1hod	10xI_n		≧0,1s
		1,45xI_n	<1hod		20xI_n	<0,1s

Pro I_3 = 2,55xI_n platí: pro I_n ≦ 32A 1s<t<60s
pro I_n > 32A 1s<t<120s

Protective overcurrent relays

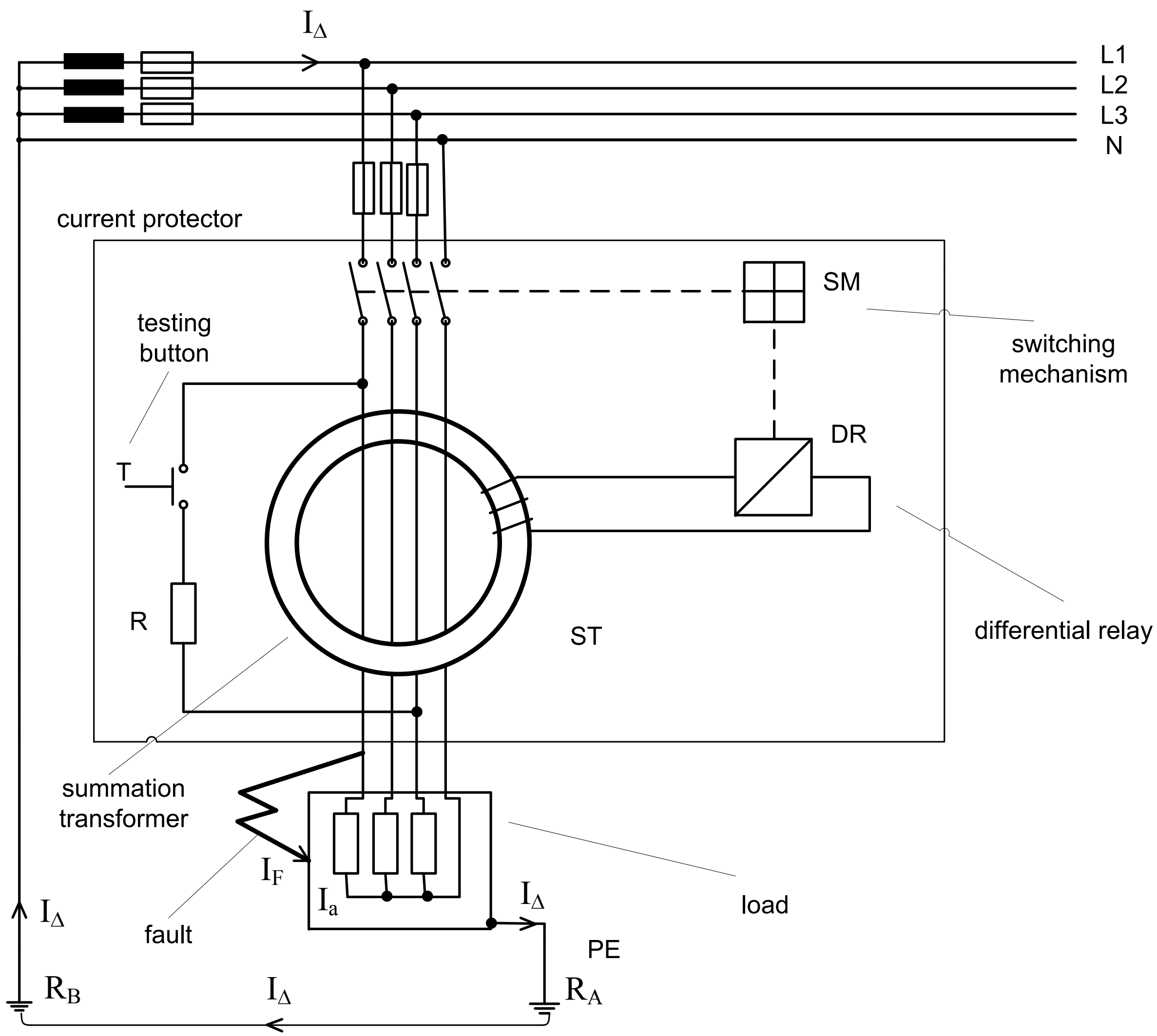
- protection against overload, 2-phase operation
- not against short-circuits (small breaking capacity)
- often collaboration with contactor (disconnects power circuit or only contactor coil)
- adjustable current trigger (±20 % I_n)
- dependent time-current char.

Protectors

- self-acting fault disconnecting in a very short time
- in places with a higher accident danger (recommendation or prescription)
- additional protection against danger contact

Current protector

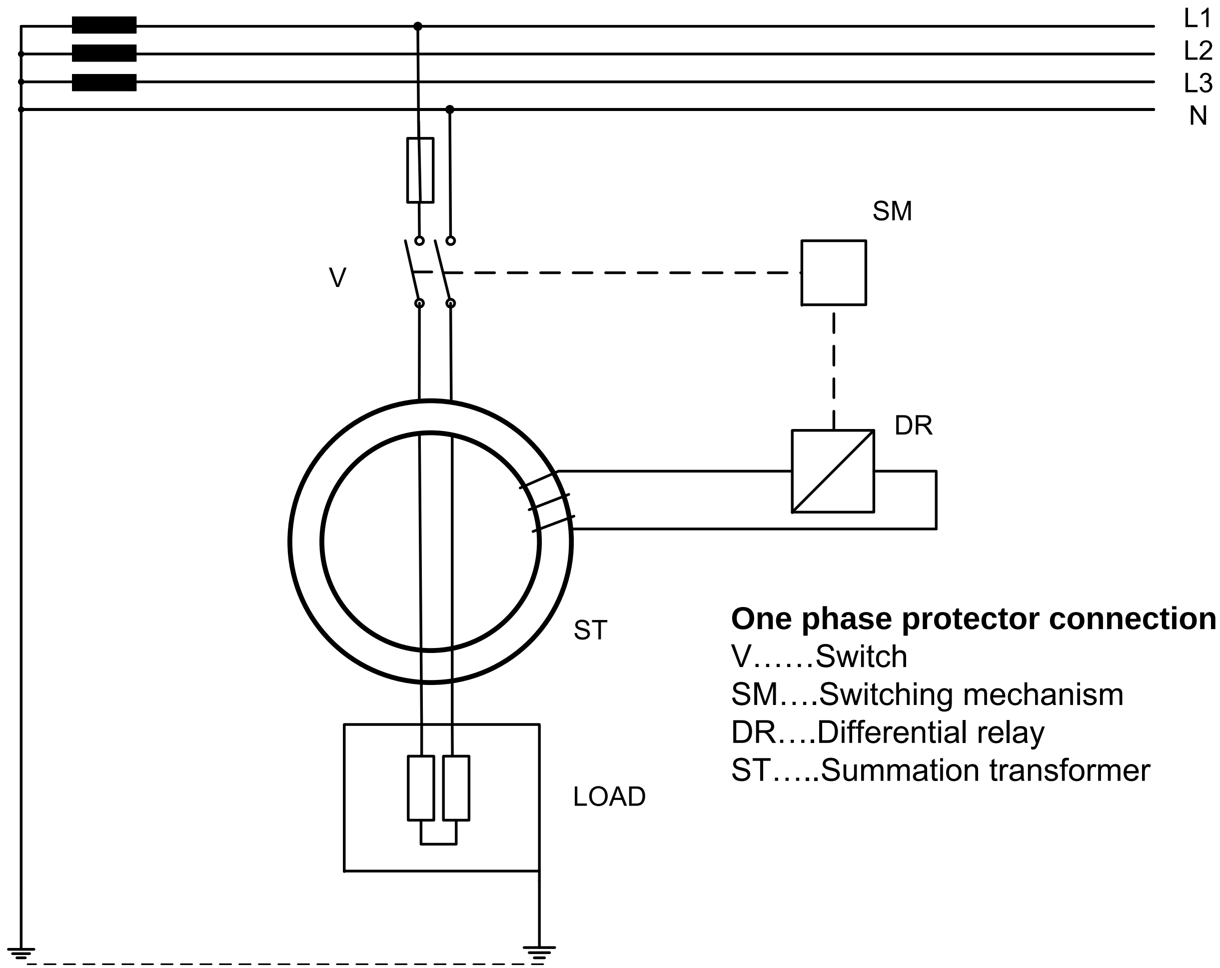
- currents sum of all operating conductors
- during the fault $\sum i \neq 0$ (summation transformer)
- residual current trips a relay, all operating conductors are disconnected
- disconnecting caused by tripping residual current (e.g. 50 % $I_{\Delta n}$)
- $I_{\Delta n}$ = 15, 30, 100,… mA
- testing button
- sometimes with implemented circuit-breaker against overload



$I_\Delta = I_F + I_a$ I_Δ……residual current

I_F……fault current

I_a……conductive current – usually neglected



One phase protector connection

V……Switch

SM….Switching mechanism

DR….Differential relay

ST…..Summation transformer

Voltage protector

- grounded switching-off coil to the case
- it disconnects at adjusted voltage (permitted touch voltage)
- it disconnects all operating conductors (also neutral conductor) → 2-pole, 4-pole