Current and Voltage Transformers Performance Requirements

Equivalent current transformer circuit

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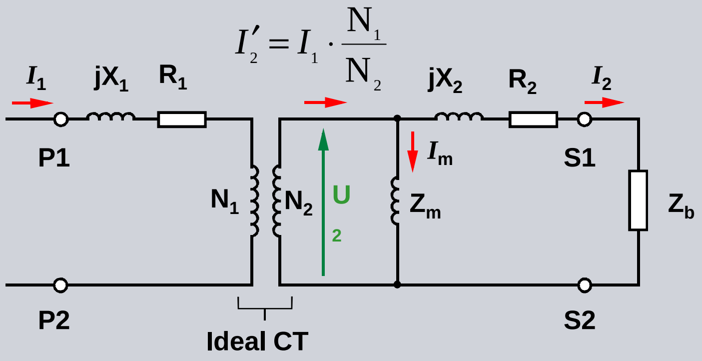
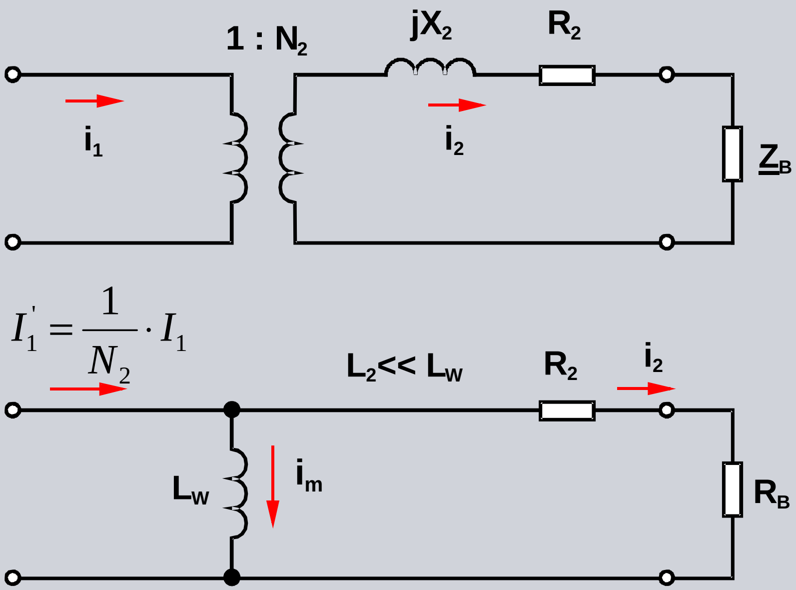


X_1 = Primary leakage reactance
R_1 = Primary winding resistance
X_2 = Secondary leakage reactance
Z_m = Magnetizing impedance
R_2 = Secondary winding resistance
Z_b = Secondary load

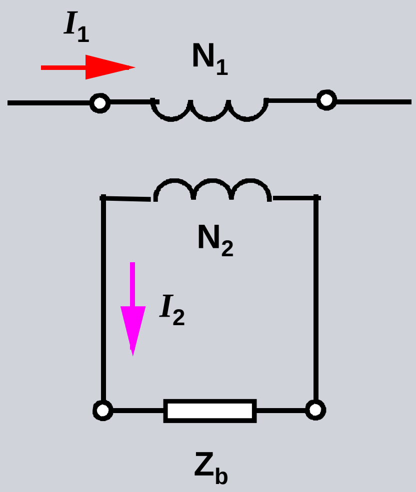
Note: Normally the leakage fluxes X_1 and X_2 can be neglected

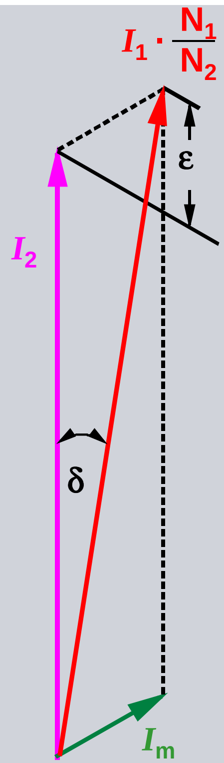
Current transformer, simplified equivalent circuit



$$I_1^{'} = \frac{1}{N_2} \cdot I_1$$

Current transformer:
Phase displacement (δ) and current ratio error (ε)





Energy Automation

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Current transformer, Standard for steady-state performance

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IEC 60044-1 specifies the following classes:

Accuracy class	Current error at nominal current (In)	Angle error δ at rated current In	Total error at n x In (rated accuracy limit)
5P	**± 1 %**	**± 60 minutes**	**5 %**
10P	**± 3%**	———	**10 %**

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Current transformers, Standard for transient performance

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IEC 60044-6 specifies four classes (1992/3):

Class	Error at rated current		Maximum error at rated accuracy limit	Remanence
	Ratio error	Angle error		
TPX (closed iron core)	± 0,5 %	± 30 min	$\hat{\varepsilon} \leq 10\%$	no limit
TPY with anti-remanence air gap	± 1,0 %	± 60 min	$\hat{\varepsilon} \leq 10\%$	< 10 %
TPZ linear core	± 1,0 %	± 180 ± 18 min	$\hat{\varepsilon} \leq 10\%$ (a.c. current only)	negligible
TPS closed iron core	Special version for high impedance protection (Knee point voltage, internal secondary resistance)			No limit

Current transformer, Standard for steady-state performance

IEC 60044-1 (Edition 1.2 2003) specifies the following classes for low remanence:

Accuracy class	Current error at nominal current (In)	Angle error δ at rated current In	Total error at n x In (rated accuracy limit)
5PR	± 1 %	± 60 minutes	5 %
10PR	± 3%	———	10 %

The remanence factor K_r shall not exceed 10%

$$K_r = 100 \cdot \frac{\psi_r}{\psi_s}$$

Current transformer, Class PX

IEC 60044-1 (Edition 1.2 2003) specifies the Class PX:

- Rated turns ratio: turns ratio error < 0.25%
- Rated knee point emf.
- Max exciting current at rated knee point emf. And/or at a stated percentage thereof
- Max resistance of secondary winding

Current transformer saturation

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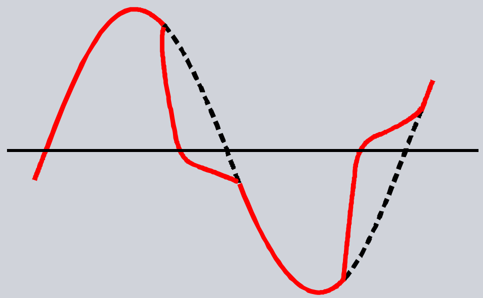
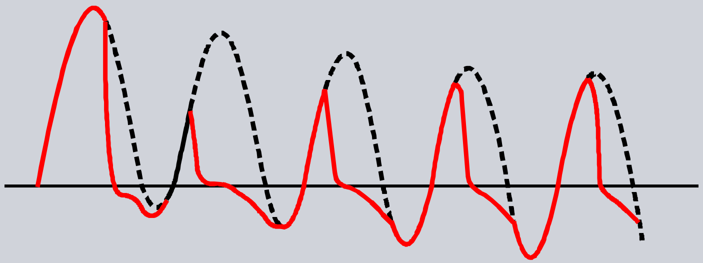


Steady-state saturation with AC current



Transient saturation with offset current

CT saturation
Currents and magnetising

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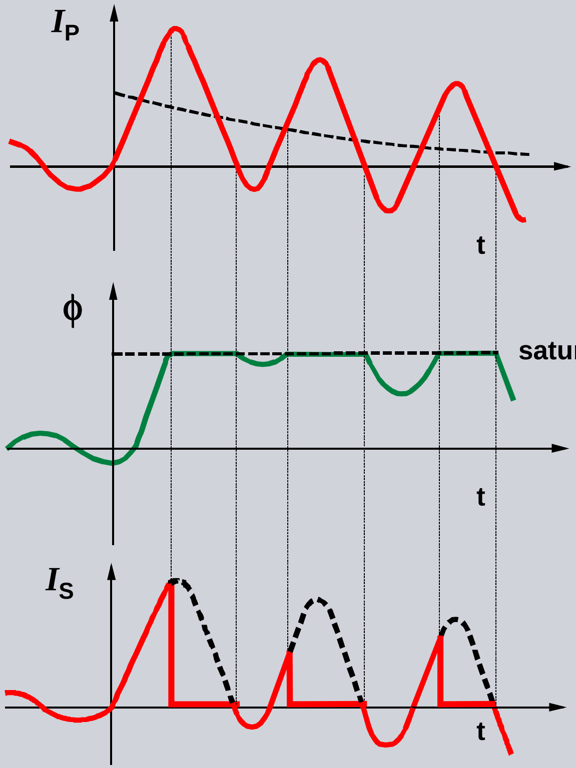

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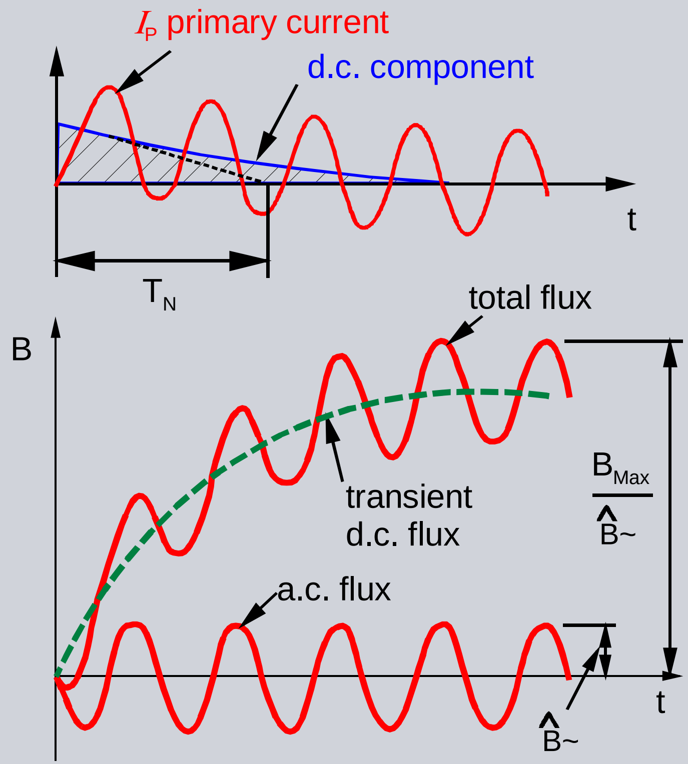
Course of CT-flux during off-set short-circuit current



$$\frac{B}{\hat{B}_{\sim}} = 1 + \frac{\omega \cdot T_N \cdot T_S}{T_N - T_S}\left(e^{-\frac{t}{T_N}} - e^{-\frac{t}{T_S}}\right)$$

$$\frac{B_{Max}}{B\sim} = 1 + \omega \cdot T_S \cdot \left(\frac{T_N}{T_S}\right)^{\frac{T_S}{T_S - T_N}}$$

$$t_{B\,Max} = \frac{T_N \cdot T_S}{T_S - T_N} \cdot \ln\frac{T_S}{T_N}$$

$$T_S = \frac{L_W}{R_i + R_B} = \frac{1}{\omega \cdot \tan\delta}$$

For 50 Hz: $T_S = \frac{10900}{\delta_{[min]}}[ms]$

CT transient over-dimensioning factor K_{TF}

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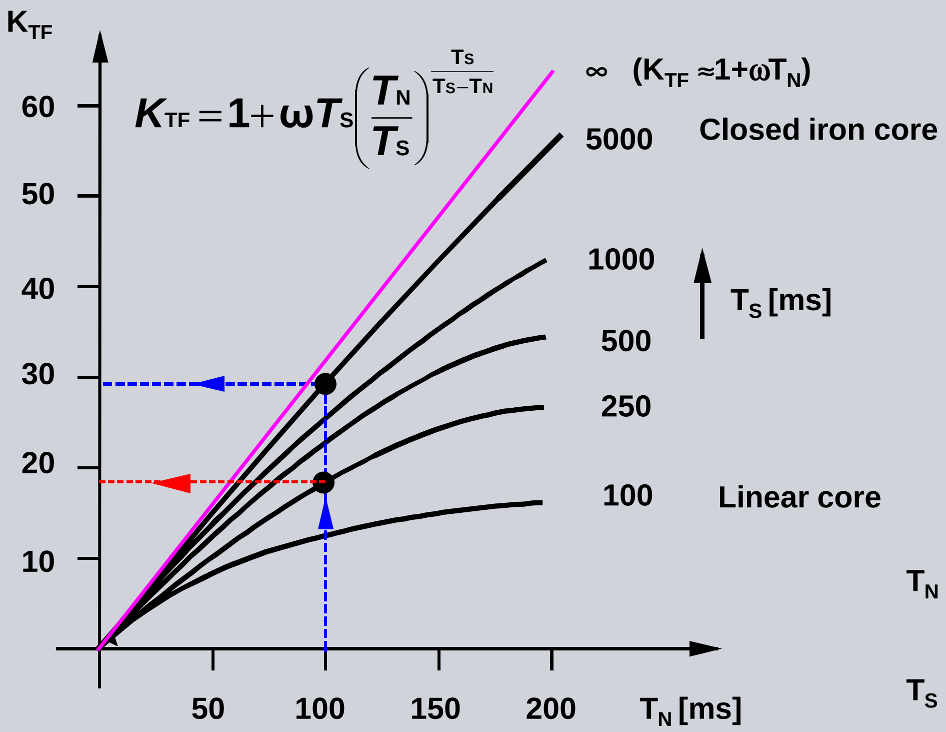

T_N = network time constant (short-circuit time constant)

T_S = CT secondary time constant

CT with closed iron core,
Over-dimensioning factor for a specified time to saturation (T_M)

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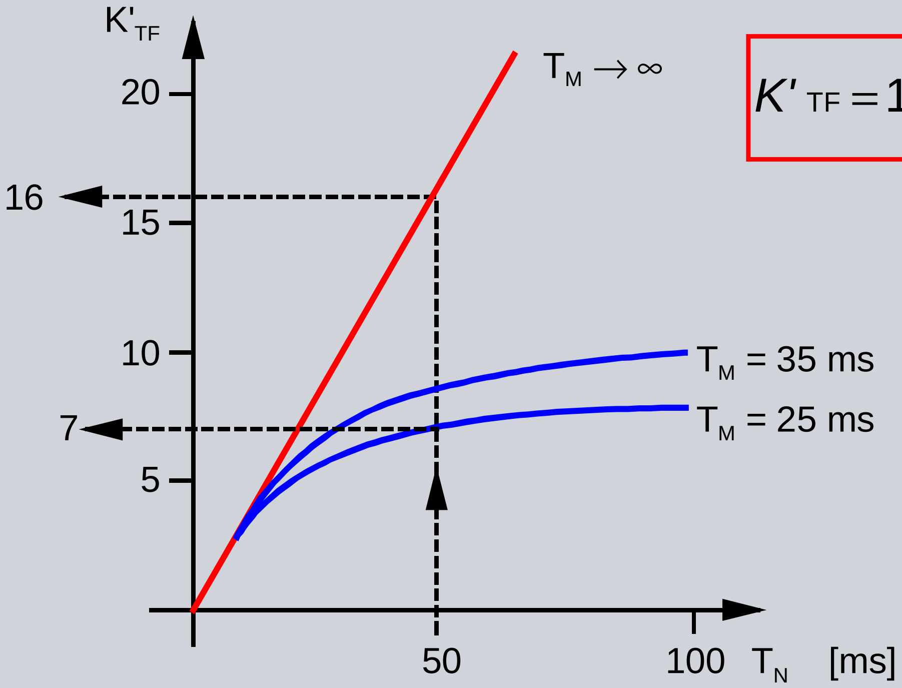

$$K'_{TF} = 1 + \omega T_N = 1 + \frac{X_N}{R_N}$$

$$K'_{TF} = 1 + \omega T_N \left(1 - e^{-\frac{T_M}{T_N}}\right)$$

 Energy Automation
Energy Sector

Current transformer
magnetising curve and point of remanence

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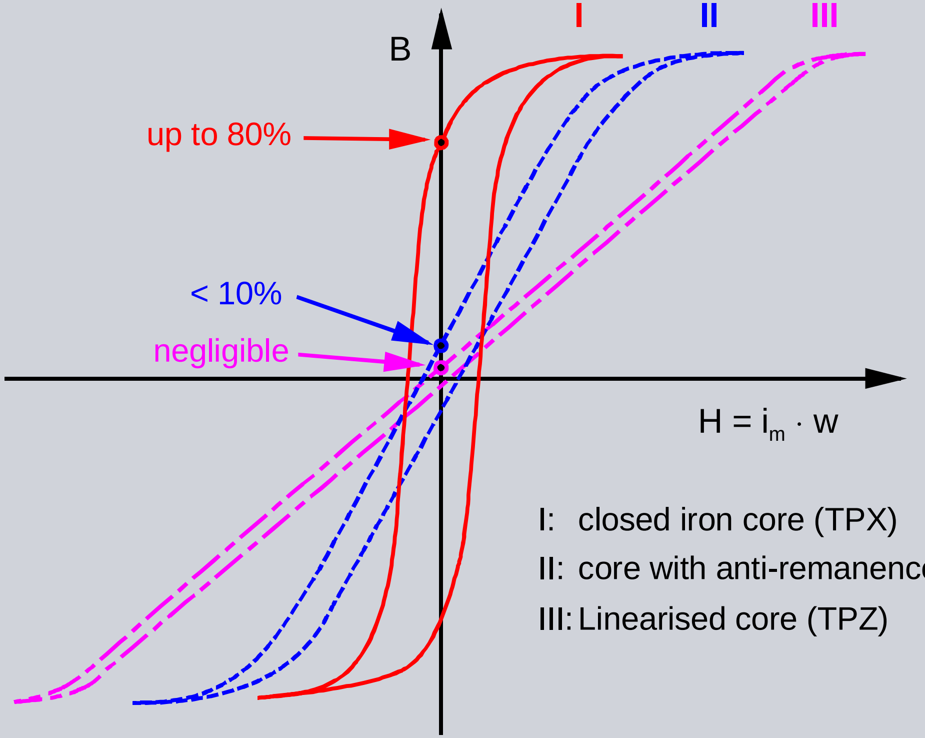

I: closed iron core (TPX)

II: core with anti-remanence air-gaps (TPY)

III: Linearised core (TPZ)

Standards of voltage transformers

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VT classes to IEC 60044-3

Class designation	Permissible error at 0.05 $\cdot U_N$ and 1.0 $\cdot U_N$	
	Voltage error F_U	Angle error δ
3P	± 3.0 %	120 minutes
5P	± 6.0 %	240 minutes

VT classes for measurement and protection VDE 0141, Teil 3

Class designation	Permissible voltage error in %		Permissible angle error in minutes	
	at 1.0 $\cdot U_N$	at 0.05 $\cdot U_N$	at 1.0$\cdot U_N$	at 0.05 $\cdot U_N$
0.1	0.1	1.0	5	40
0.2	0.2	1.0	10	40
0.5	0.5	1.0	20	40
1	1	2.0	30	80
3	3	6.0	40	120

Capacitive voltage transformer, Equivalent circuit

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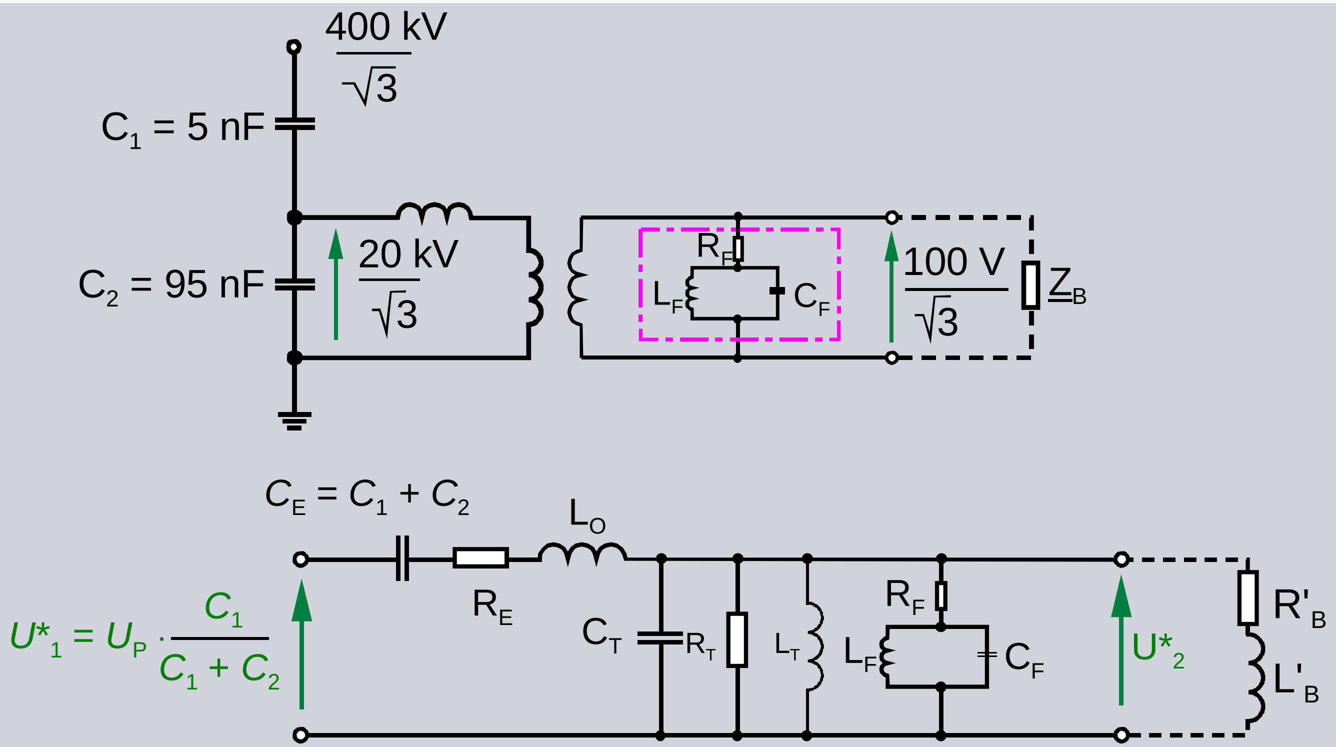

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Transient performance of CVTs, Recommendations acc. to IEC 60044-5

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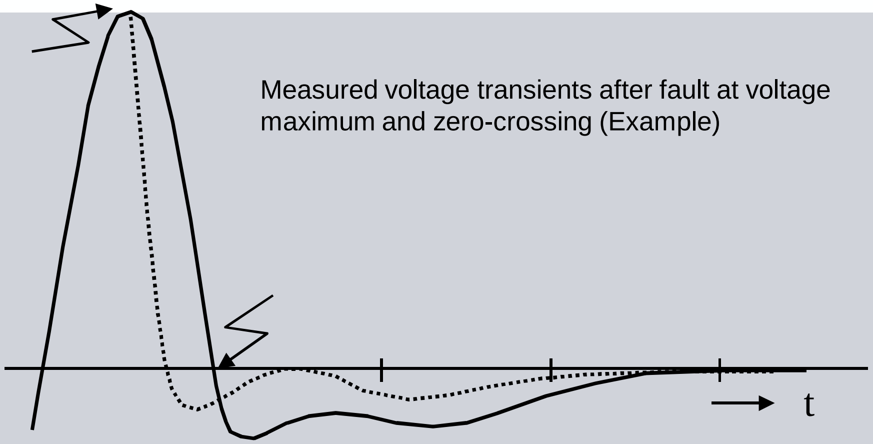
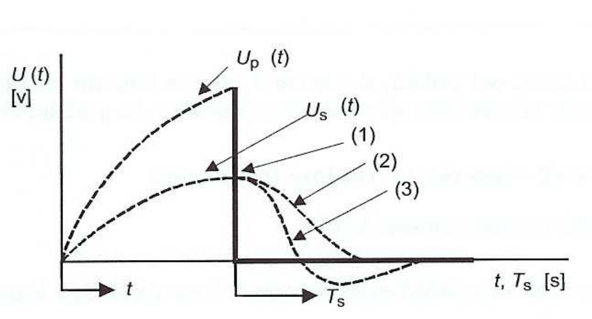


Time Ts in ms	Ratio $\frac{U_S(t)}{\sqrt{2} \cdot U_S} \cdot 100\%$		
	Classes		
	3PT1 6PT1	3PT2 6PT2	3PT3 6PT3
10	---	≤ 25	≤ 4
20	≤ 10	≤ 10	≤ 2
40	≤ 10	≤ 2	≤ 2
60	≤ 10	≤ 0.6	≤ 2
90	≤ 10	≤ 0.2	≤ 2

Recommendations to IEC 60044-5



Legend:

$U_P(t)$ Primary voltage

$U_S(t)$ Secondary voltage

(1) Fault inception

(2) Aperiodic damping of $U_S(t)$

(3) Periodic damping of $U_S(t)$

CT dimensioning

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$$ALF' = ALF \cdot \frac{P_i + P_{BN}}{P_i + P_B} = ALF \cdot \frac{R_{CT} + R_{BN}}{R_{CT} + R_B}$$

rated CT burden: P_{BN}

internal burden of the CT: $P_i = R_i \cdot I_{2N}^2$

$$ALF = ALF' \cdot \frac{P_i + P_B}{P_i + P_{BN}} = ALF' \cdot \frac{R_{CT} + R_B}{R_{CT} + R_{BN}}$$

Actual connected burden : $P_B = R_B \cdot I_{2N}^2$

$R_B = R_l + R_R$ = burden resistance

R_l = resistance of connecting cables

R_R = burden resistance of the relay

with $ALF' \geq K_{OD} \cdot \frac{I_K}{I_N}$

$$K_{OD} \geq K_{TF} \cdot K_{Rem}$$

$$K_{Rem} = \frac{1}{1 - \frac{\%\ Remanence}{100}}$$

Theory:

No saturation for the total short-circuit duration: $K'_{TF} = \frac{B_{Max}}{\hat{B}_{\sim}} = 1 + \omega T_N = 1 + \frac{X_N}{R_N}$

No saturation for the specified time t_M: $K''_{TF} = \left[1 + \frac{\omega \cdot T_N \cdot T_S}{T_N - T_S}\left(e^{-\frac{t_M}{T_N}} - e^{-\frac{t_M}{T_S}}\right)\right]$

Note: this equation is not fully valid for very small t_M (less than 1 cycle)

Practice: Use of K_{TF} - values recommended by vendors

Distance relays, practical CT requirements
Transient over-dimensioning factors K_{TF} (ARC not considered)

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7SA510 / 511

- Close-in fault
  - $K_{TF} \geq 2 \quad if \quad T_N < 50ms$
  - $K_{TF} \geq 3 \quad if \quad 50ms \leq T_N < 100ms$
- Fault at balance point
  - $K_{TF} \geq 10$

7SA513

- Close-in fault
  - $K_{TF} \geq 2$
- Fault at balance point
  - $K_{TF} \geq 5 \quad if \quad T_N < 50ms$
  - $K_{TF} \geq 10 \quad if \quad T_N \geq 50ms$

7SA6 / 7SA522

- Close-in fault
  - $K_{TF} \geq 2 \quad (\geq 1 \;\; if \;\; T_N < 30ms)$
- Fault at balance point
  - $K_{TF} \geq 5$

7SA6 / 7SA522: Operating time with CT saturation
Influence of CT dimensioning

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