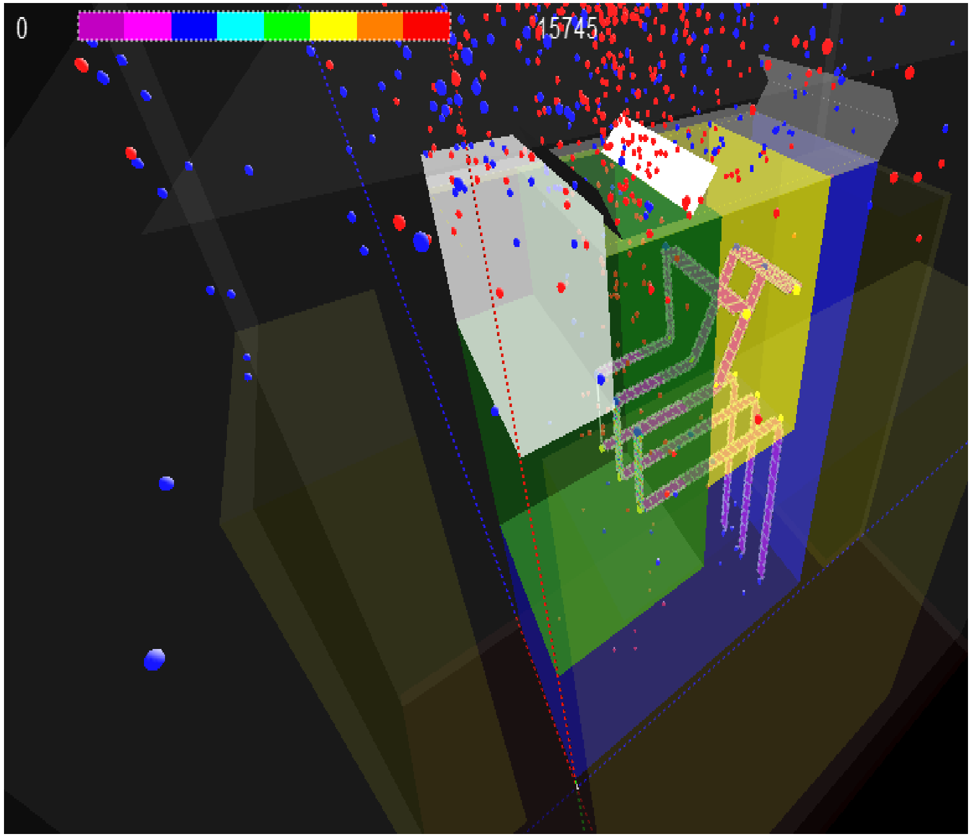
Reference text for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

Sergio Feitoza Costa



Reference text for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

Sergio Feitoza Costa

1ª Edição

Câmara Brasileira de Jovens Escritores

Câmara Brasileira de Jovens Escritores
Rua Marquês de Muritiba, 865 sala 201 – Cep21910-280
Rio de Janeiro – RJ
Tel : (21) 33932163
cbje@globo.com

Janeiro de 2013

Primeira Edição

Coordenação editorial: Gláucia Helena
Editor: Georges Martins
Produção gráfica: Sergio Feitoza Costa
Revisão do autor
Capa: Sergio Feitoza Costa

Sergio Feitoza Costa

Reference text for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

Janeiro 2013

Rio de Janeiro - Brasil

Message from Sergio Feitoza Costa

For a long time I had been taking the courage to leave, as a "free book", this text I use as reference for two training courses that I have been applying for many years all over the World. Now it is done and I hope that this material can be useful to professionals who did not participate in the courses, to teachers and to electrical engineering students.
I am still applying the courses but with a much lower frequency due to my increasing involvement with the design of electrical testing laboratories and with the consultancy work I do for equipment manufacturers in the development of products.
I am also making available the software SwitchgearDesign_307 developed by me for the design of switchgear, busways, isolators and other equipment for substations (part 7 of this book). The explanation on how to get both is in the first page of the site of Cognitor http://www.cognitor.com.br (in English, Spanish and Portuguese).

There you will find also "free", my recent non-technical book entitled "Between calculations, songs and meditations" and a link to hear the songs of my 3rd CD . There I I sing some of the songs I composed in the last 6 years. I have 30 registered now and some people say that they are not bad for an engineer. So, if any of the readers is a music producer looking for a new talent I'll be here. See also page 336 at the endof this text Divulgation is very welcome and for any comments please write to my email sergiofeitoza@cognitor.com.br .

With kind regards

Sergio

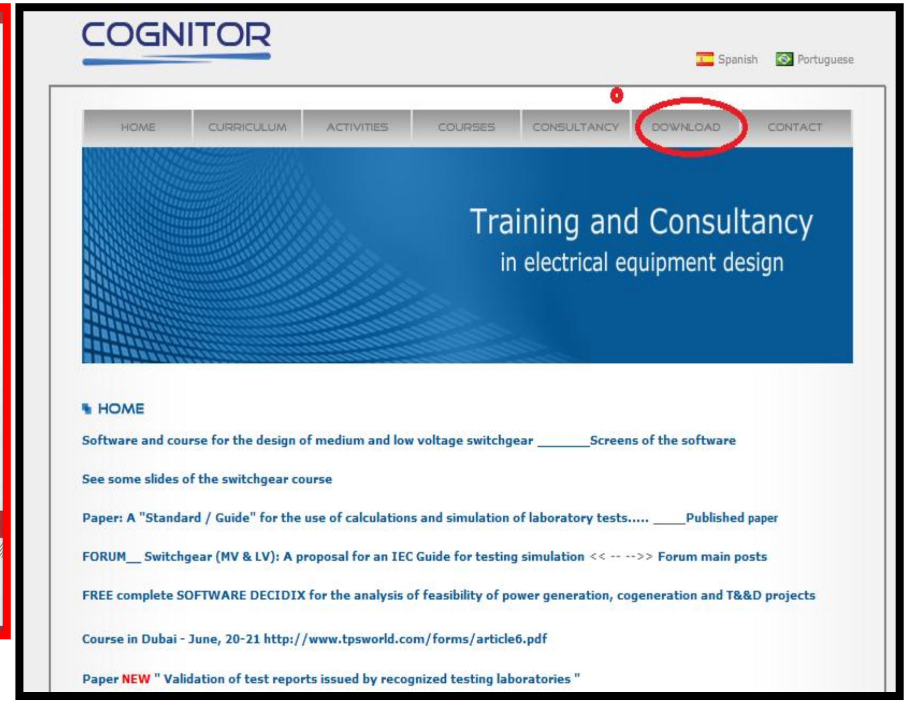
Author previous experience :

- Test engineer and manager of Brazilian high power, high voltage and other laboratories
- Chairman IEC -International Electro technical Commission –TC 32 - Fuses (1990-1994)
- Member WG A3.24 CIGRE International: Simulation .... Tools .
- Member WG IEC SC 17 C / WG31: Guidance for the extension of validity of type tests of ac metal-enclosed switchgear and controlgear
- Switchgear design development and simulation software development
- Training for substations and equipment design.
- Design of testing laboratories

Contact data:
Sergio Feitoza Costa
Cognitor – Consultancy, R&D and Training
Phone : (55) (21) 2465
Skipe sergiofeitoza1 (may speak in English, Portuguese, Spanish or French)

E-mail: sergiofeitoza@cognitor.com.br
Site: **http://www.cognitor.com.br**

Articles by Sergio at http://www.cognitor.com.br/en_download.htm



THE PROGRAM in 7 MODULES

1 STUDIES WHICH ARE THE BASE OF THE TECHNICAL SPECIFICATIONS

2 OVERVOLTAGES AND INSULATION COORDINATION

3 SHORT CIRCCUITS, AMPACITIES, OVERLOADS AND ELECTRICAL CONTACTS.

- TEMPERATURE RISE
- FORCES AND ELECTRODYNAMICAL FORCES DURING SHORT CIRCUIT.
- TRANSIENT RECOVERY VOLTAGES AND INTERRUTION PROCESSES

4 POWER ARCS AND SAFETY OF PERSONS AND INSTALATIONS

5 TECHNICAL SPECIFICATIONS ISSUED BY POWER UTILITIES

6 MEDIUM VOLTAGE AND LOW VOLTAGE SWITCHGEAR STANDARDS (IEC_62271-200 AND IEC_61439)

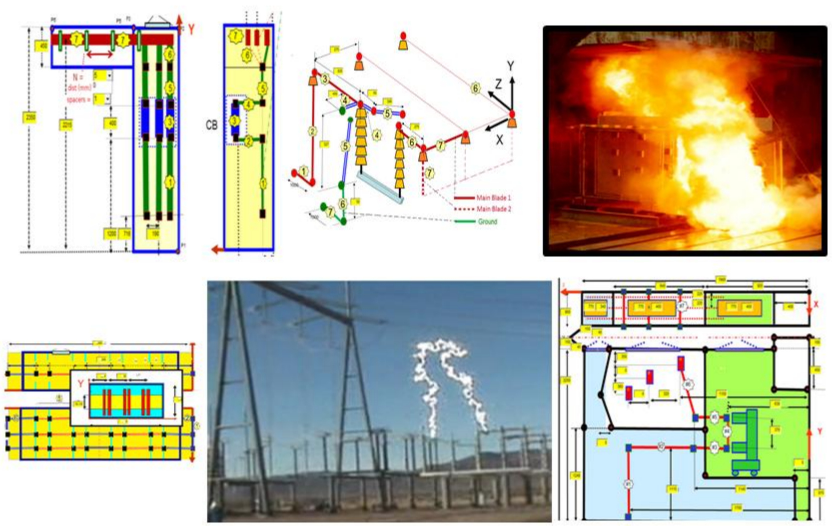
7 SIMULATION OF HIGH POWER TESTS AND USE OF THE SOFTWARE

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

(focus in design techniques, specification, tests and simulations)



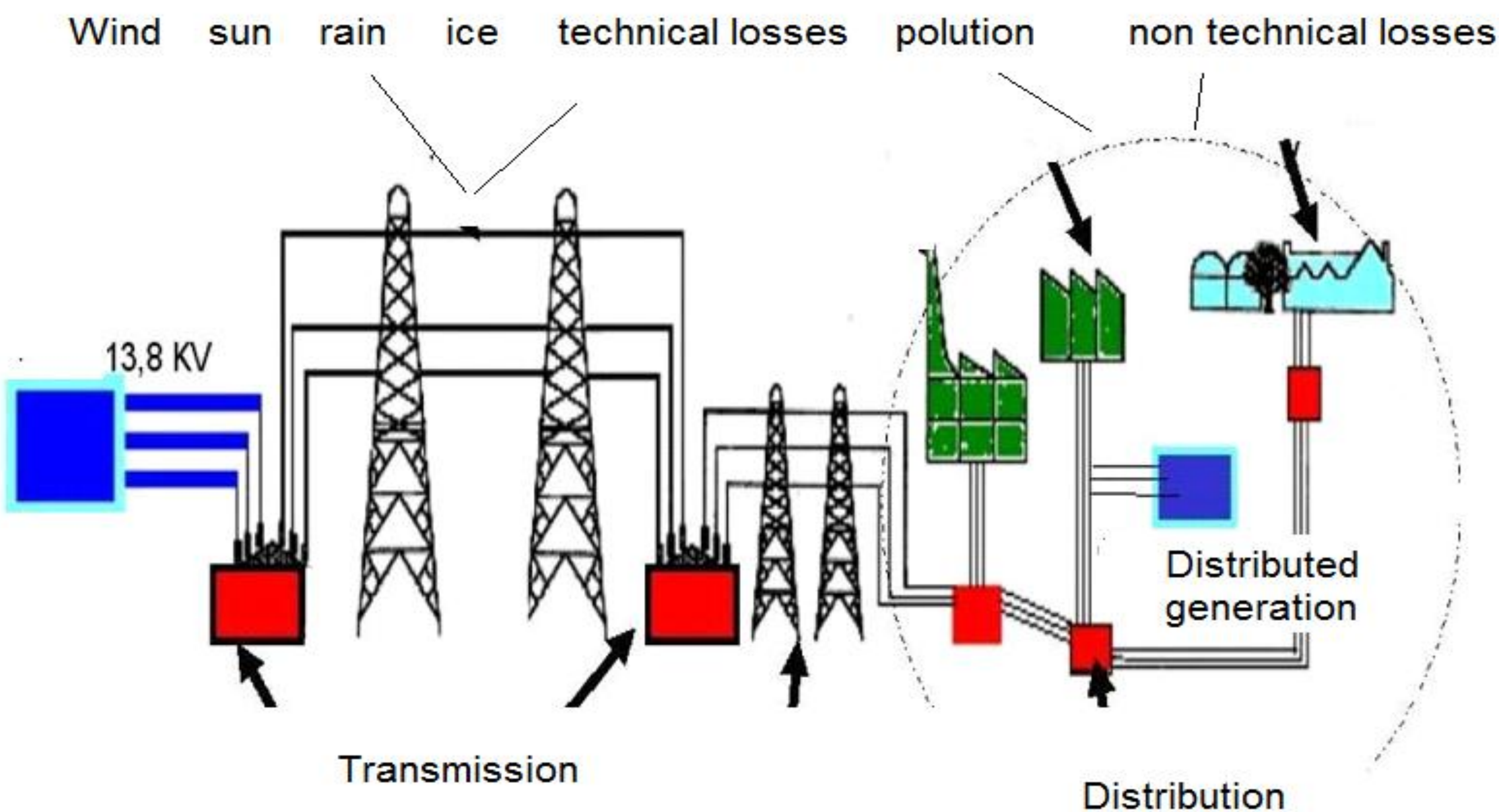
MODULE 1:

THE STUDIES WHICH ARE THE BASIS OF THE SPECIFICATIONS

by Sergio Feitoza Costa

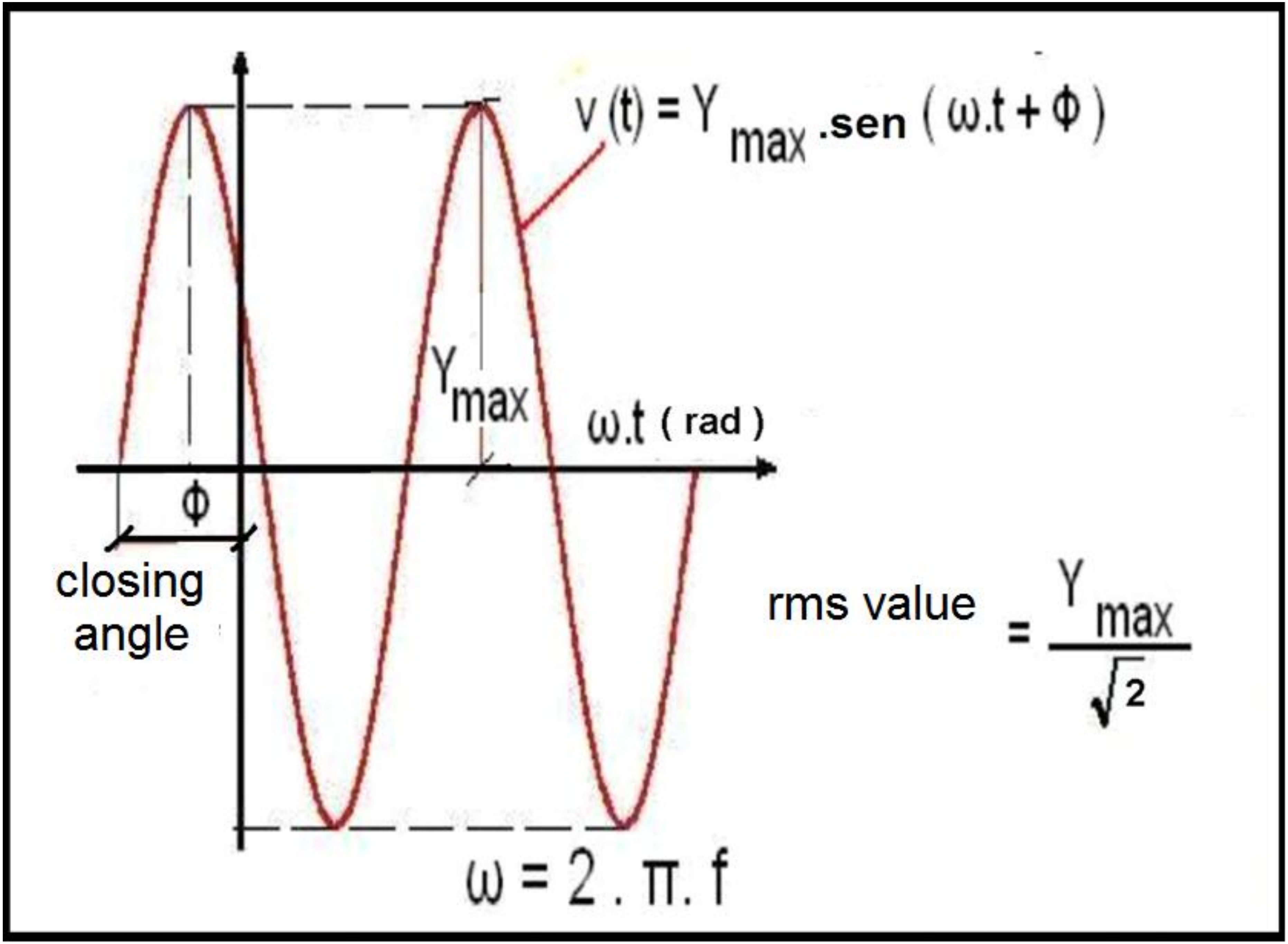
SOME DEFINITIONS
AND
REFERENCE CONCEPTS

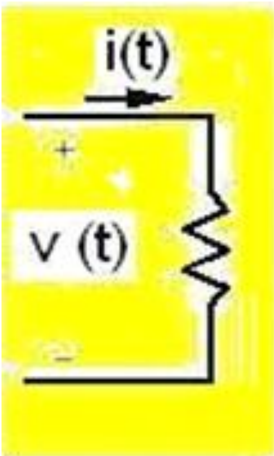
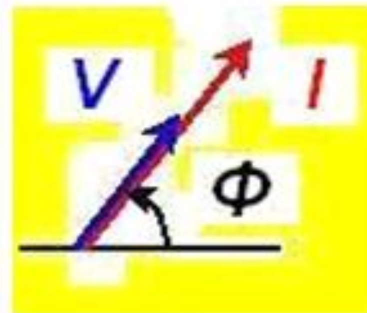
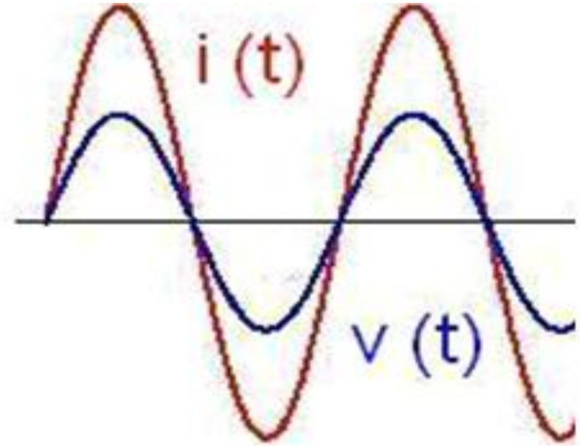
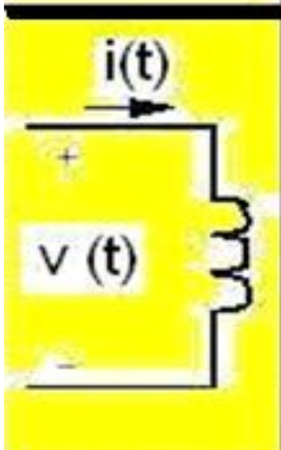
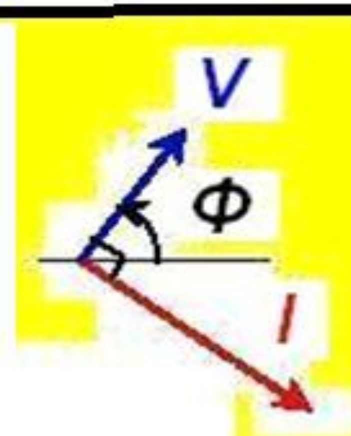
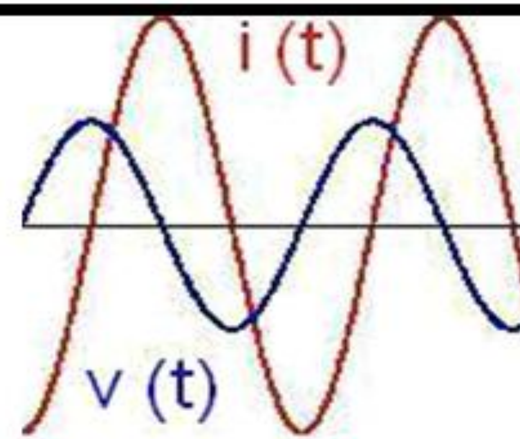
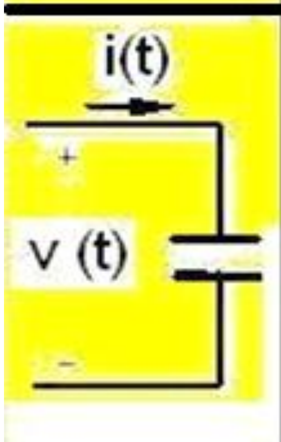
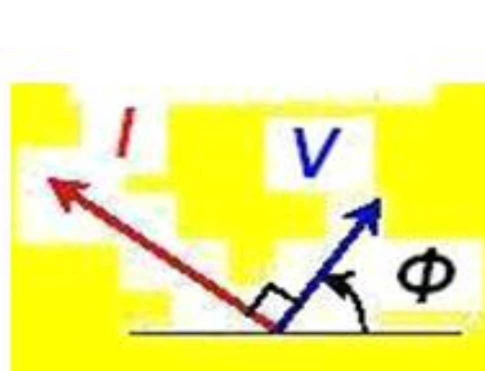
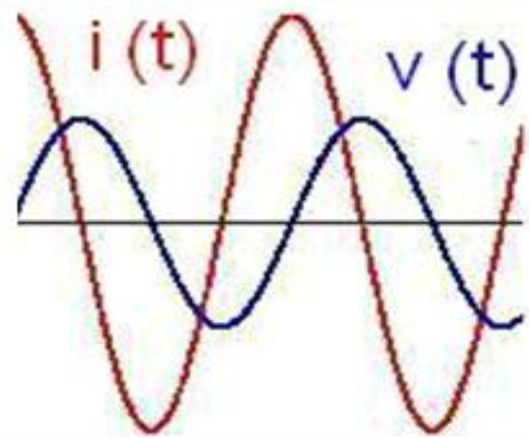
THE VALUES OF CURRENTS AND VOLTAGES

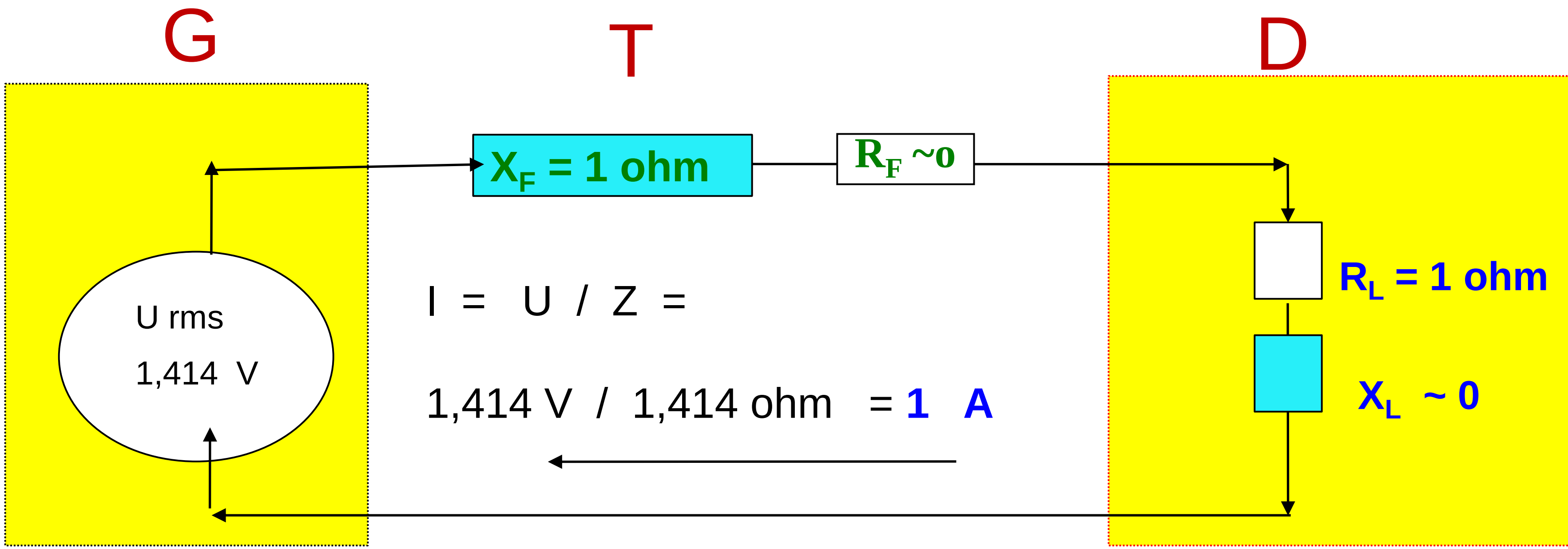


To transmit power = voltage x current from the generators to the loads with the minimum losses in the transmission system

NOMENCLATURE



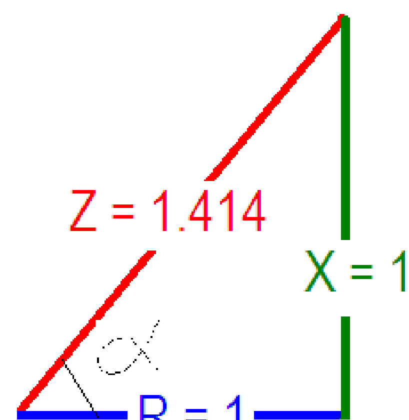
	$V = R \cdot I$		
	$V = X_L \cdot I$ $X_L = \omega \cdot L$ $\omega = 2 \cdot \pi \cdot f$		
	$V = X_C \cdot I$ $X_C = \dfrac{1}{\omega \cdot C}$		



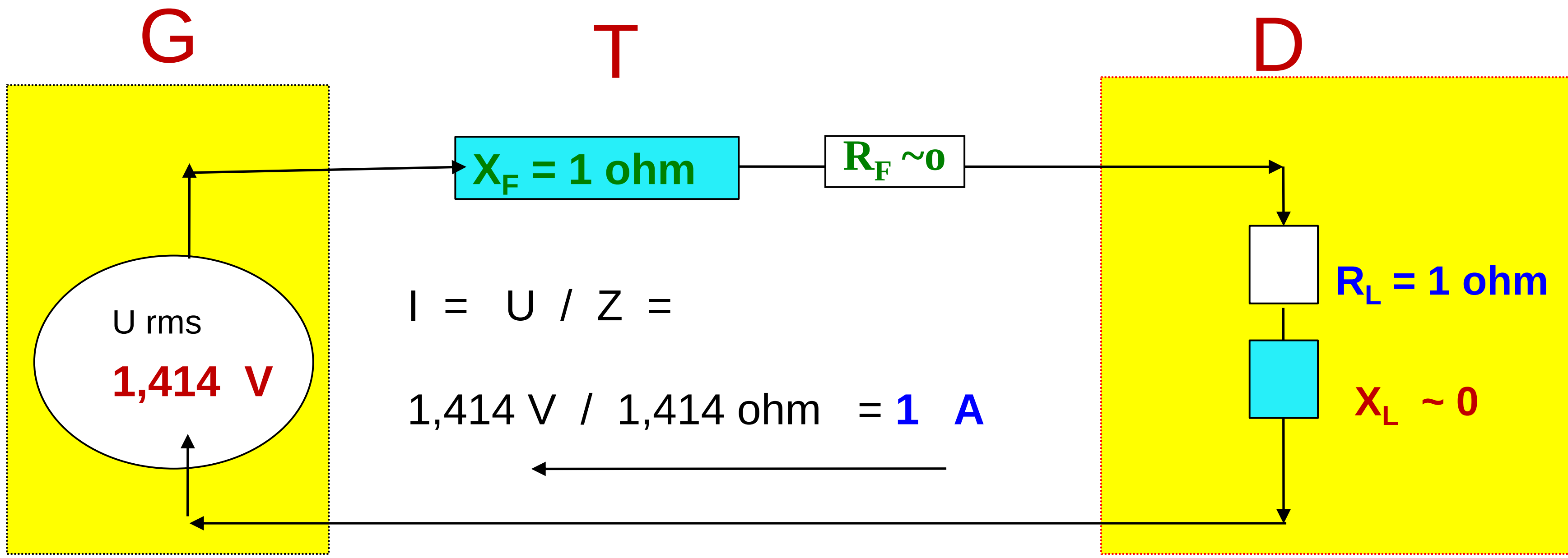
R = 1 Ohm

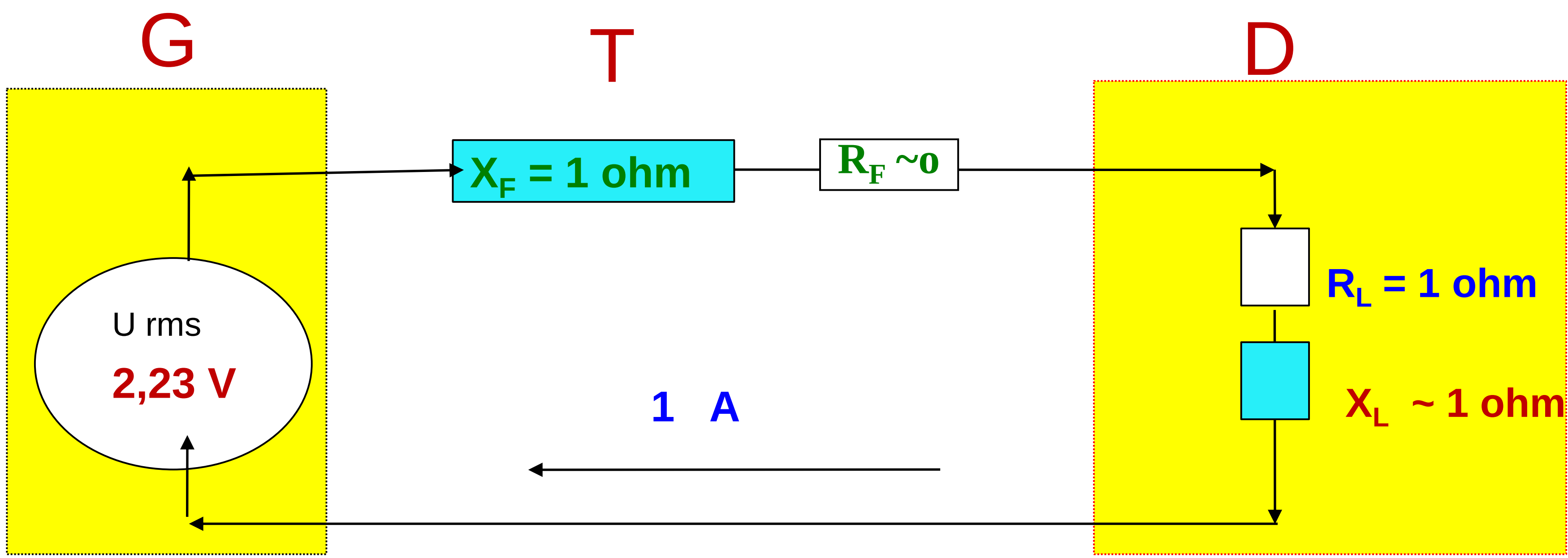
L = 0,0031 Henry

$$X = 2 \cdot \underbrace{pi}_{3,1416} \cdot \underbrace{f}_{50\ Hz} \cdot \underbrace{L}_{0,0031} = 1\ \text{Ohm}$$

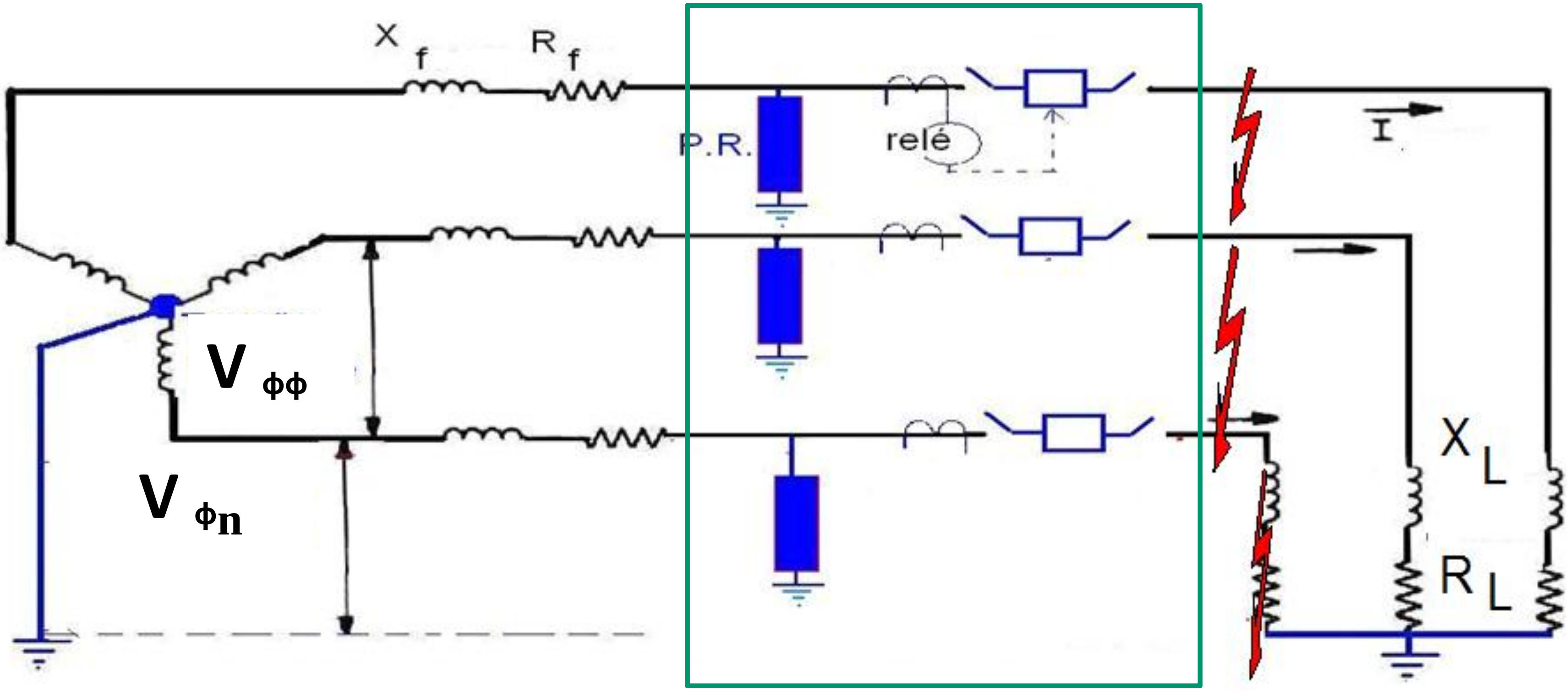


$$Z = \sqrt{R^2 + X^2} = 1,414\ \text{Ohms}$$


G
T
D
X_F = 1 ohm
R_F ~o
U rms
1,414 V
I = U / Z =
1,414 V / 1,414 ohm = 1 A
R_L = 1 ohm
X_L ~ 0


G
T
D
X_F = 1 ohm
R_F ~o
U rms
2,23 V
1 A
R_L = 1 ohm
X_L ~ 1 ohm

$X_F << X_L$ $R_F << R_L$



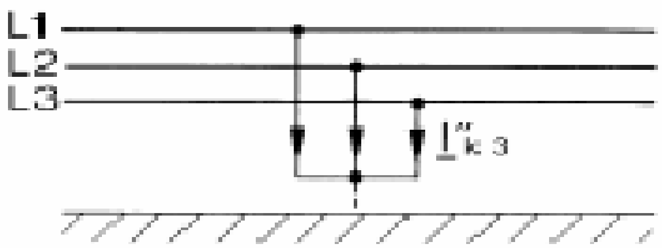
$V_{\phi\phi} = 145\ kV$ > $V_{\phi n} = 83{,}7\ kV$

$I_{SC} = 25\ kA_{rms}$

$P_{SC} = 1{,}732 \times 145\ kV \times 25\ kA = 6280\ MVA$

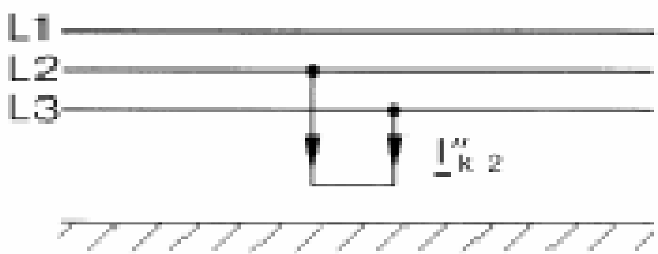
TYPES OF SHORT CIRCUIT

IEC 60909

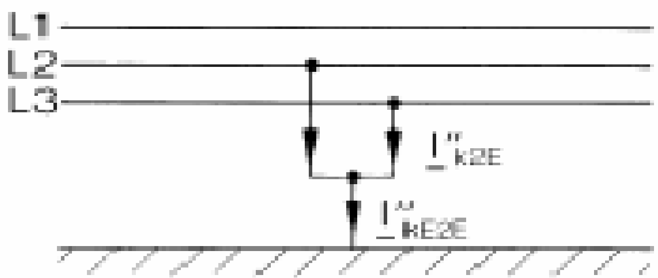


$$I''_{k3} = \frac{1.1 \cdot U_n}{\sqrt{3}\,|\underline{Z}_1|}$$

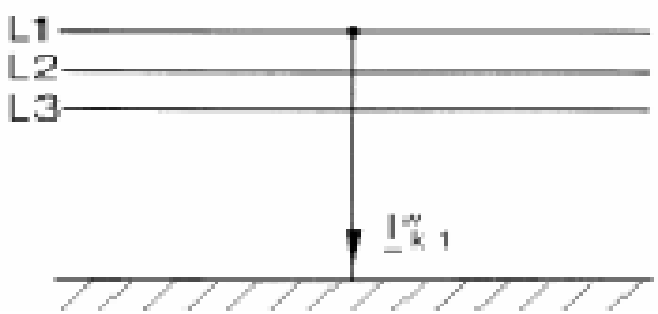
$$S''_k = \sqrt{3}\,U_n\,I''_{k3}$$



$$I''_{k2} = \frac{1.1 \cdot U_n}{|\underline{Z}_1 + \underline{Z}_2|}$$

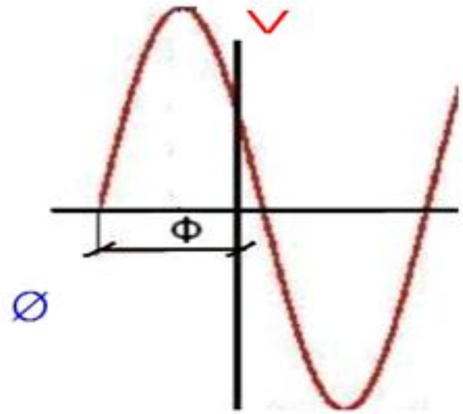


$$I''_{kE2E} = \frac{\sqrt{3} \cdot 1.1\,U_n}{\left|\underline{Z}_1 + \underline{Z}_0 + \underline{Z}_0 \dfrac{\underline{Z}_1}{\underline{Z}_2}\right|}$$

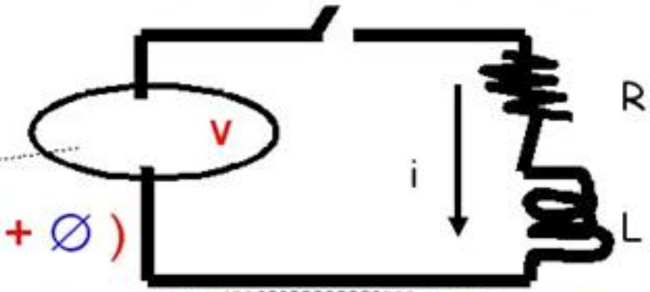


$$I''_{k1} = \frac{\sqrt{3} \cdot 1.1 \cdot U_n}{|\underline{Z}_1 + \underline{Z}_2 + \underline{Z}_0|}$$

CLOSING AN AC CIRCUIT AND CURRENT ASSYMETRY

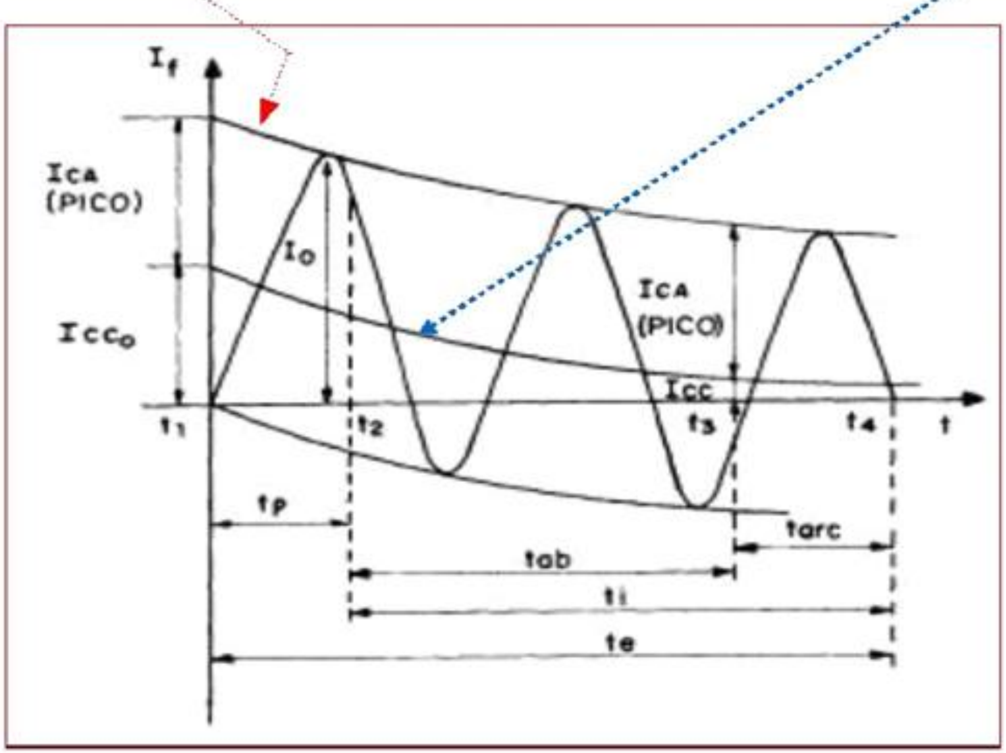


Closing a circuit breaker under a short circuit condition



$$v = V_{max} \; . \; sen\,(\,\omega t + \varnothing\,)$$

$$i = I_{max} \times sen\,(\,\omega t + \varnothing - \alpha\,) \;-\; I_{max} \times e^{-t/\sigma} \times sen\,(\varnothing - \alpha\,)$$



L= inductance ω L = reactance

R = resistance

t = time

σ = L/R = time constant

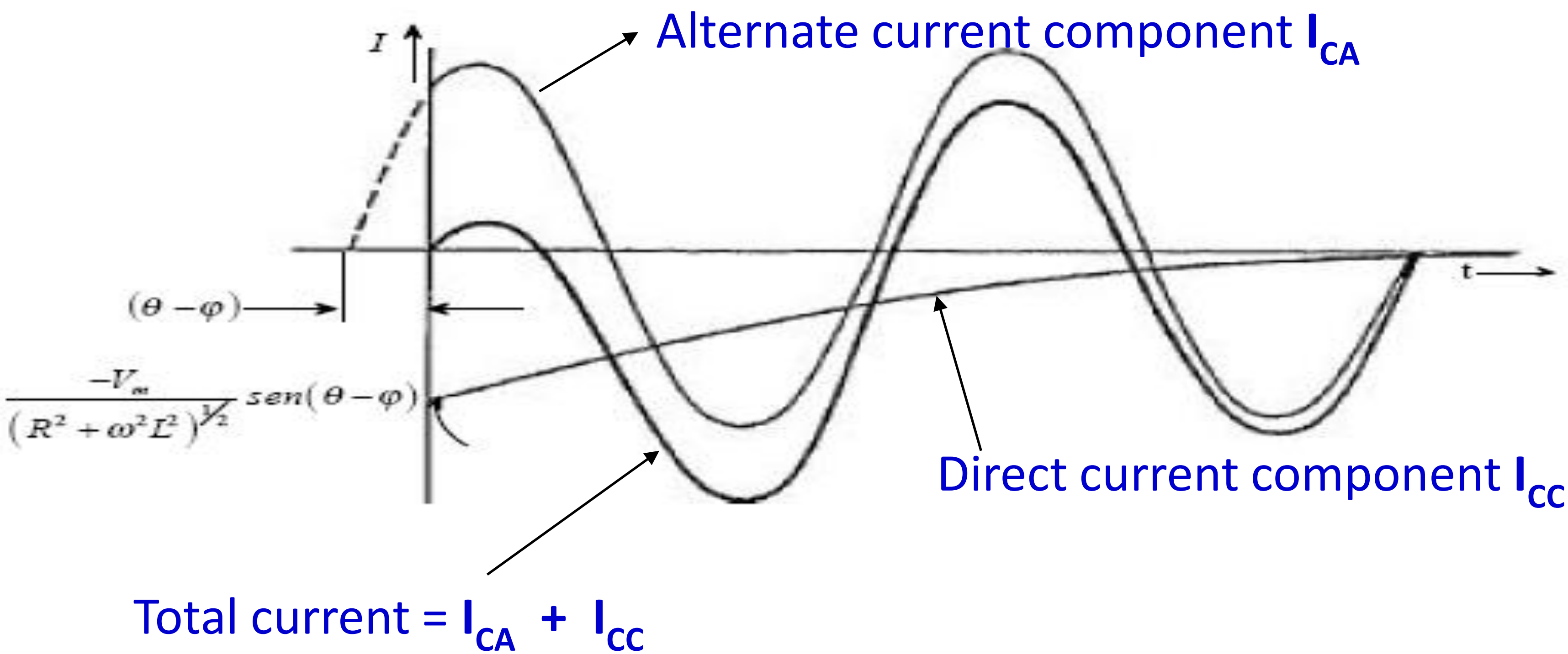
$\frac{X}{R}$

I_{max} = Vmax / Z

α = arctg (ω L / R)

$Z = (\;(\omega L)^2 + R^2\;)^{1/2}$

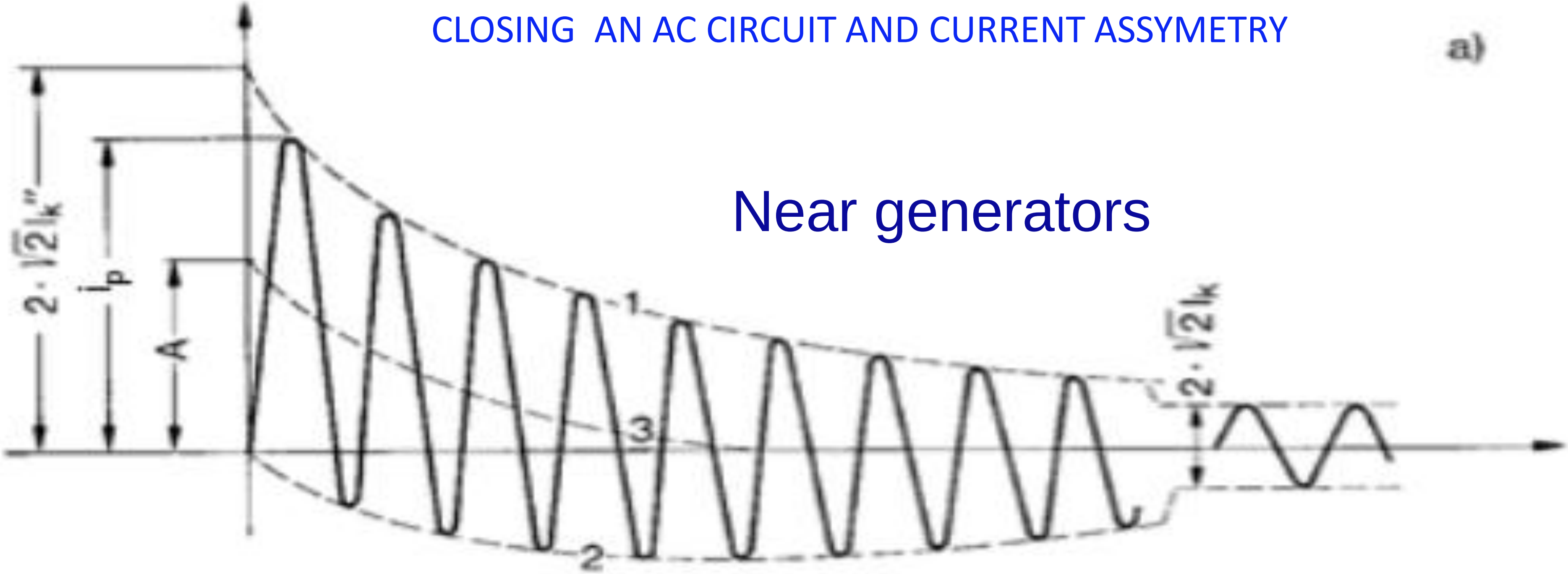
$\omega = 2 \times \Pi \times 60 = 377\ s^{-1}$

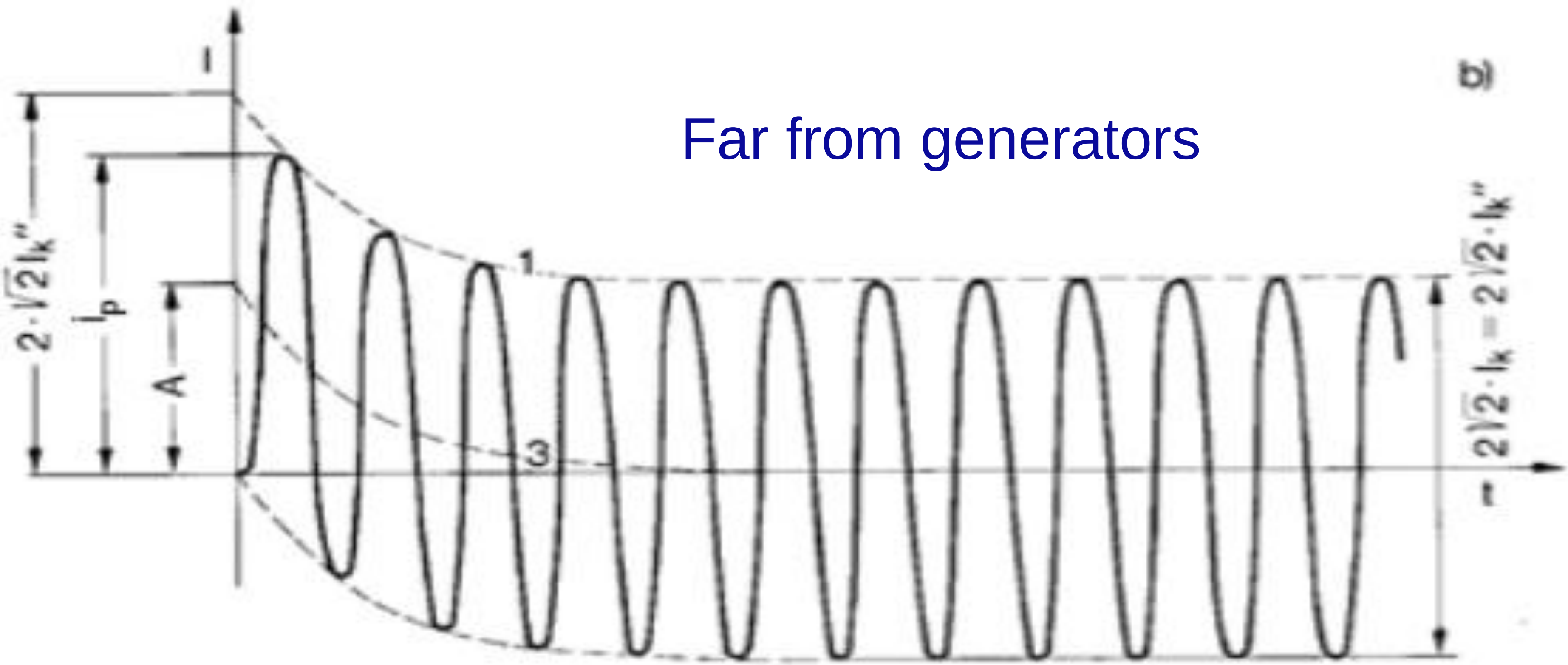


IEC: rms symmetrical (ICA) and current peak (first peak) for example "40kA$_{rms}$ during 1 s with 100 Ka$_{cr}$ “

ANSI : "asymmetrical rms value" which is at a certain instant = square root (ICA ^{2} + ICC ^{2})

CLOSING AN AC CIRCUIT AND CURRENT ASSYMETRY





Synchonous machines reactances(%)

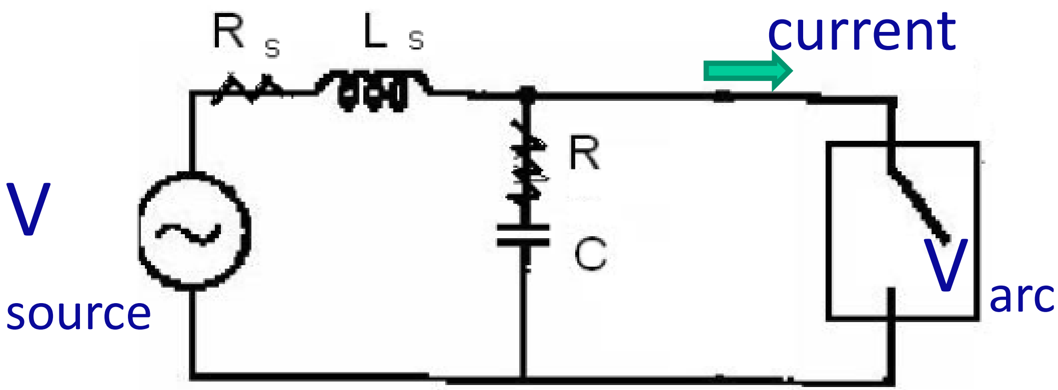
Generator type	Turbo generators	Salient poles	
		With / without damping winding	
Sub transient reactance x"	9…22	12…30[3)]	20…40[3)]
Transient reactance x''_d	14…35[4)]	20…45	20…40
Synchonous reactance x''_d	140…300	80…180	80…180

Transformers impedances

Typical values of short circuit impedances (%) for diferent values of primary voltages KV

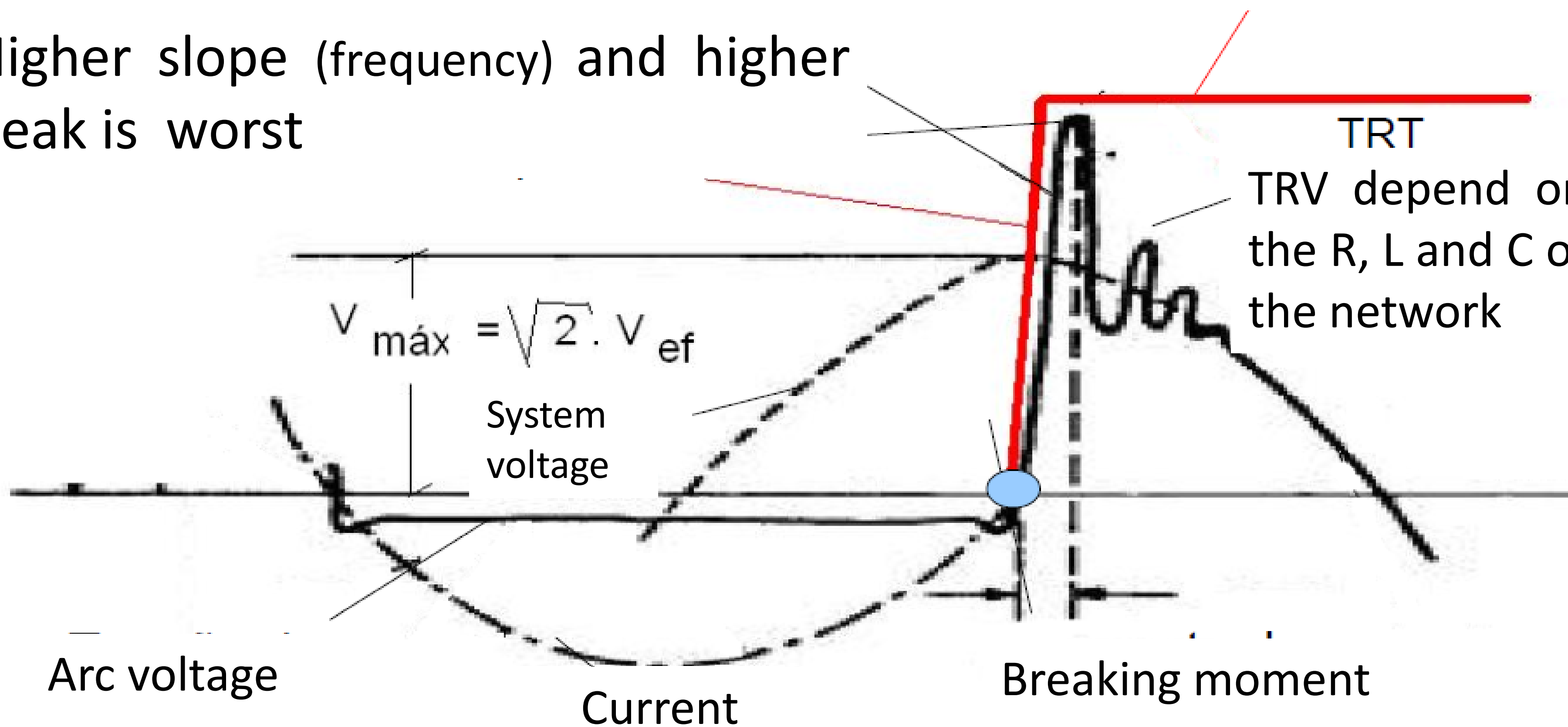
KV	5..20	30	60	110	220	400
u_k in %	3.5..8	6..9	7..10	9..12	10;;14	10..16

Current interruption in switchgear

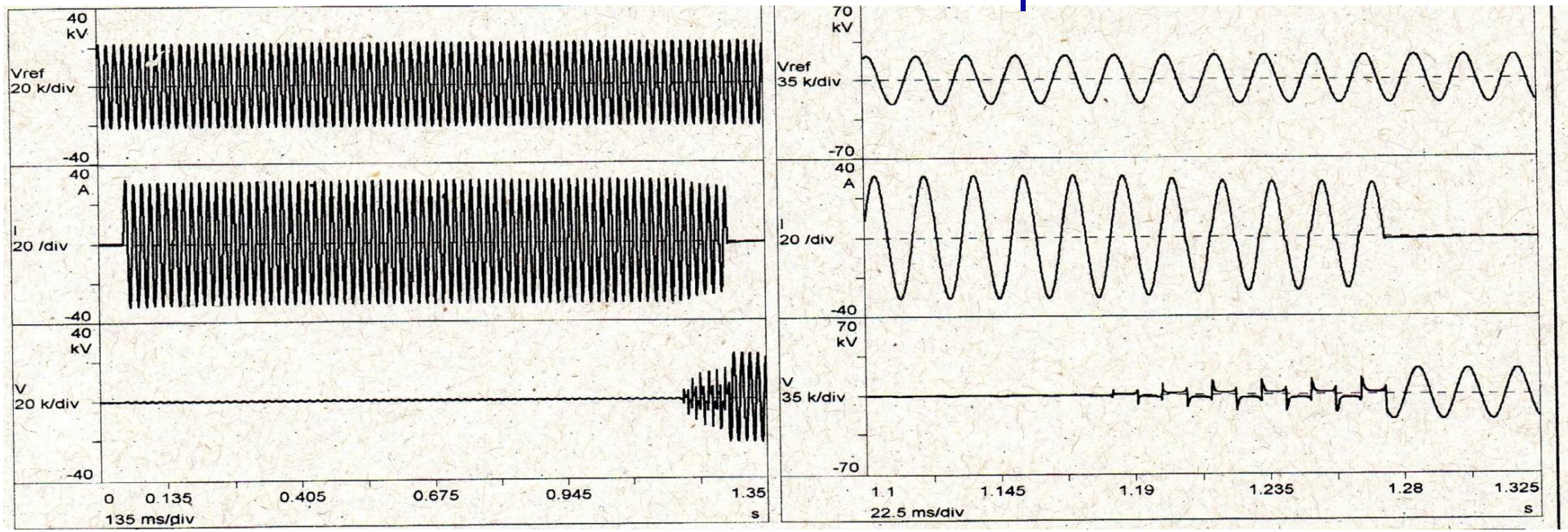


Cold characteristic of the circuit breaker above TRT

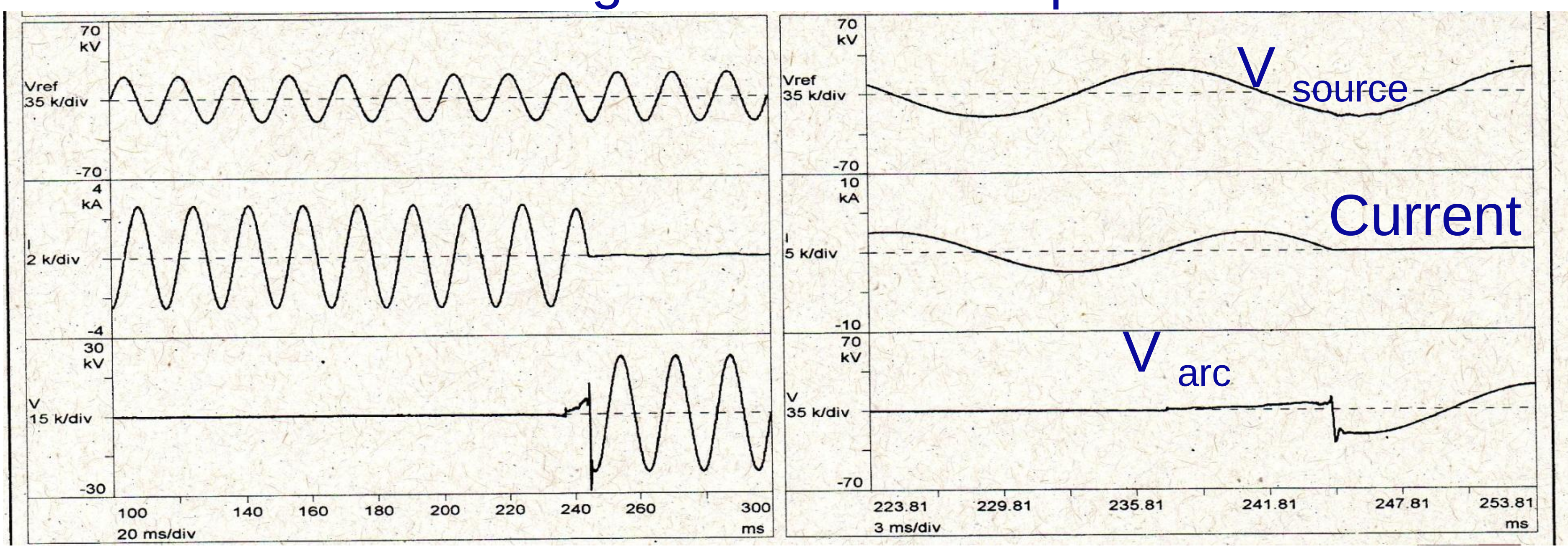
Higher slope (frequency) and higher peak is worst



Low current interruption

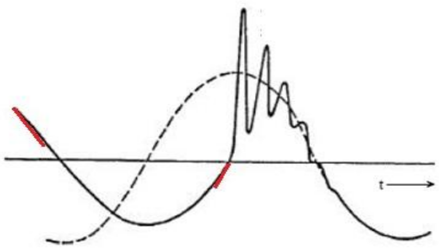


High current interruption

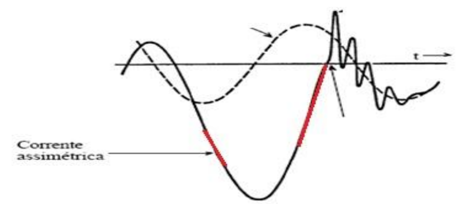


TRANSIENT RECOVERY VOLTAGE (TRV)

Symmetric current: high frequency component sum to max value of system voltage



Asymmetric:: high frequency sum to lower value



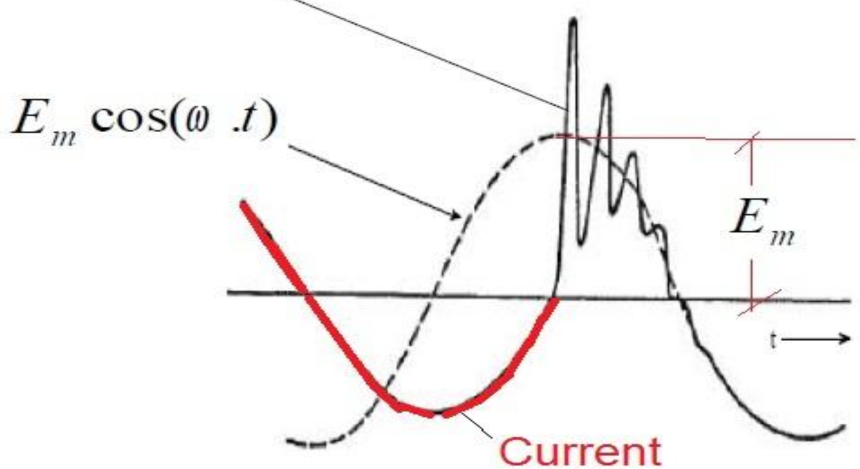
$$U(t) = E_m\left[\cos(\omega .t) - \frac{1}{\sqrt{1-\alpha^2}}e^{-\alpha .\omega_0 .t}\cos\left(\omega_0 .\sqrt{1-\alpha^2}.t + \tan^{-1}\left(\frac{\alpha}{\sqrt{1-\alpha^2}}\right)\right)\right]$$

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L.C} - \left(\frac{R}{2L}\right)^2}$$

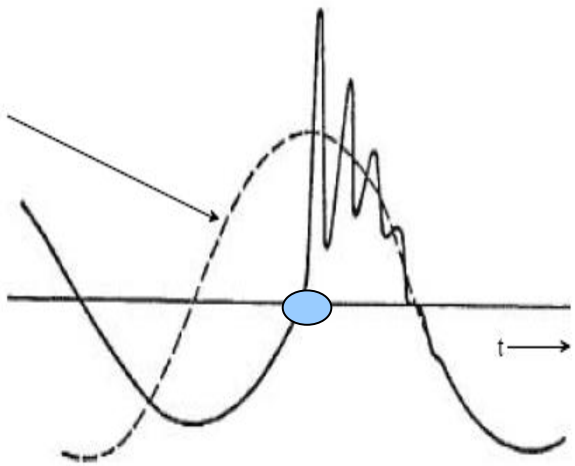
$$\omega = 2\pi f$$

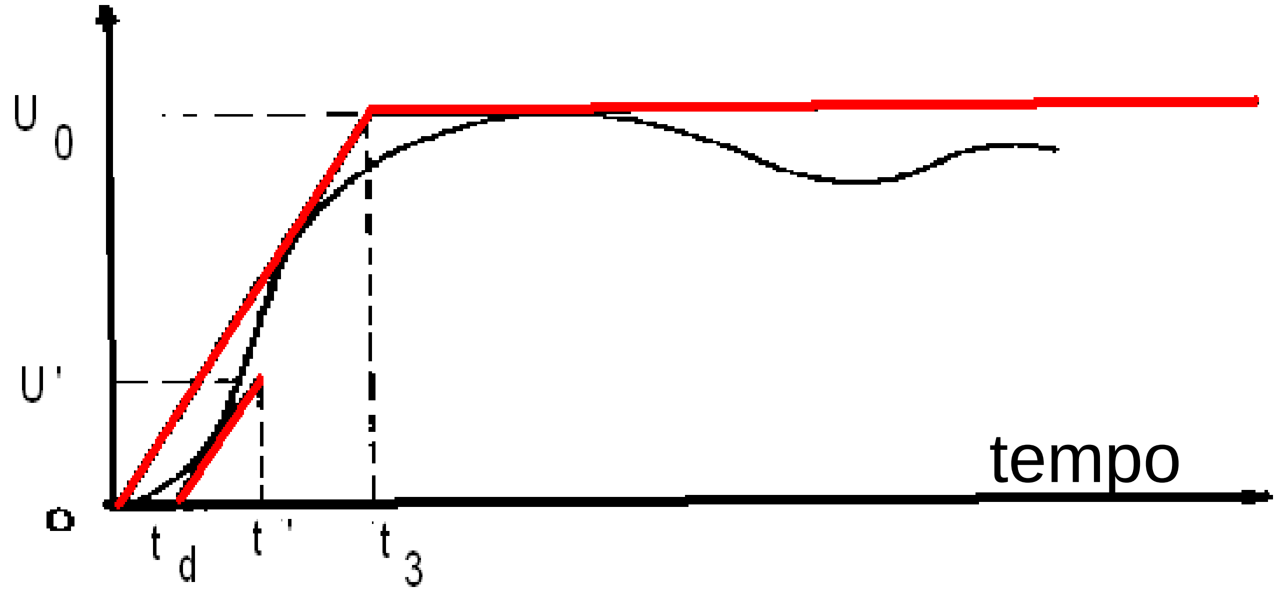
$$\alpha = \frac{R}{2\sqrt{L/C}}$$

$$\omega_o = \frac{1}{\sqrt{LC}}$$



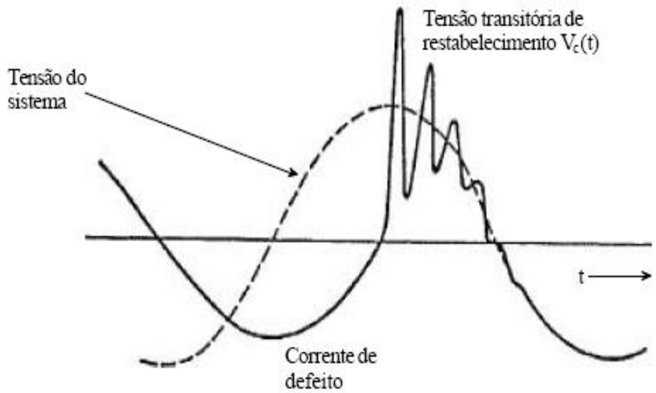
TRV by two parameters

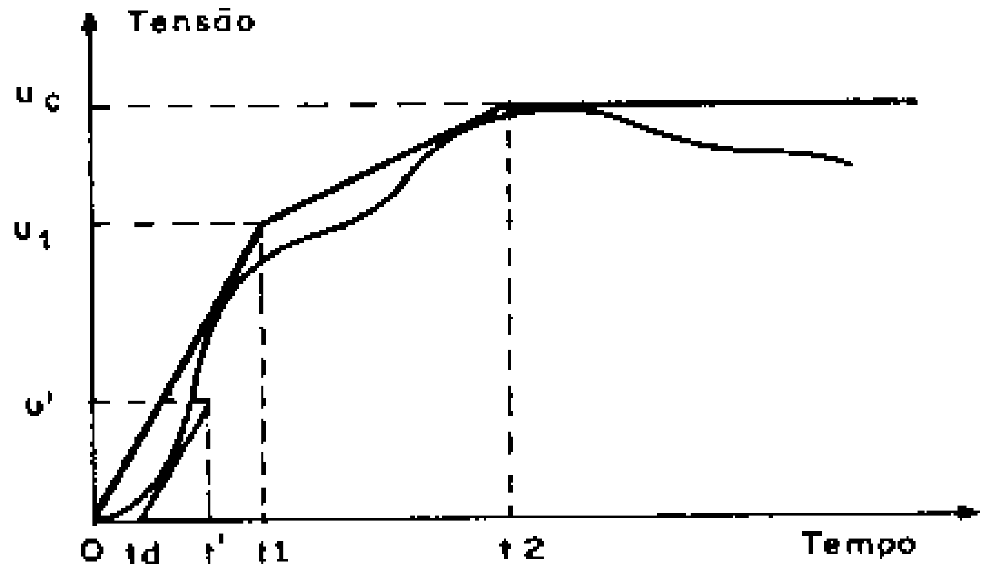




	Tensão Nominal U_r (kV)	Tipo da interrupção	Fator de primeiro polo k_{pp} (p.u.)	Fator de amplitude k_{af} (p.u.)	Valor de pico da TRT u_c (kV)	Tempo t_3 (µs)	Tempo de retardo t_d (µs)	Tensão u' (kV)	Tempo t' (µs)	TCTR[b] ** u_c / t_3 (kV/µs)
	4,76 [c]	Falta terminal	1,5	1,4	8,2	51	8	2,7	24	0,16
		Discordância de fases	2,5	1,25	12,1	101	15	4,0	48	0,12
	72,5 [a]	Falta terminal	1,5	1,4	124	165	8	41	63	0,75
		Falta quilométrica	1	1,4	83	166	8	28	64	0,50
		Discordância de fases	2,5	1,25	185	336	50	62	163	0,55

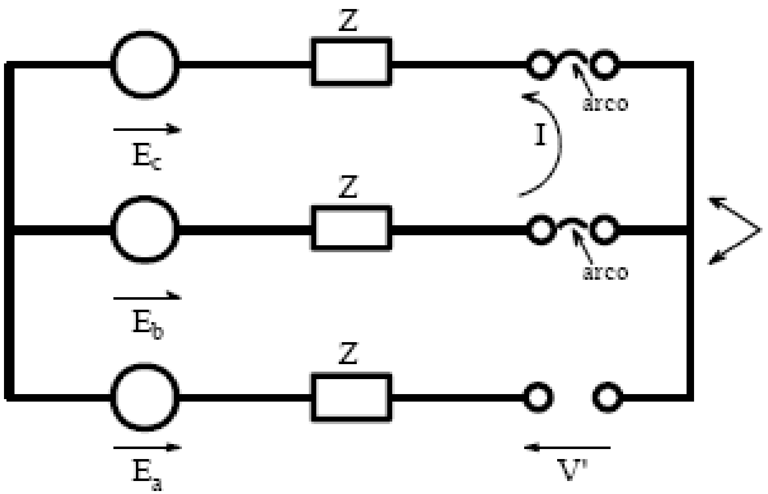
TRV by four parameters

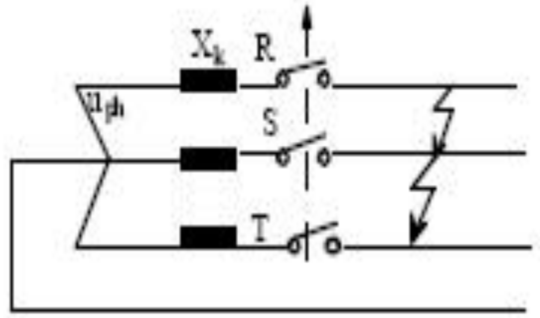




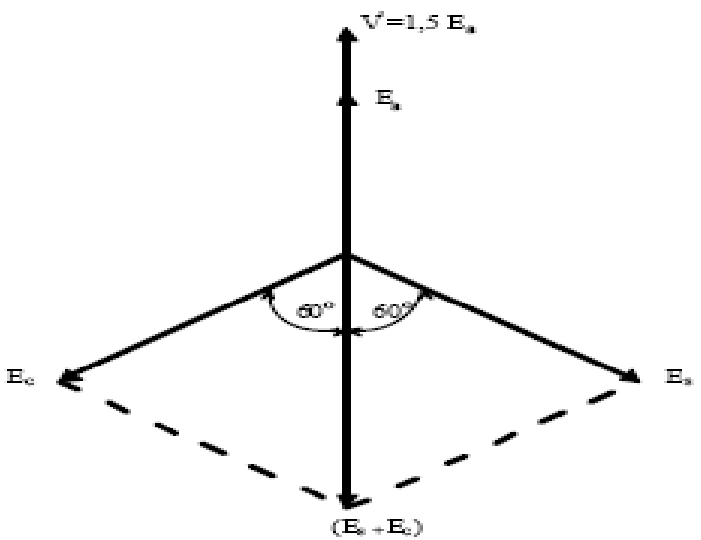
Tensão Nominal	Tipo da interrupção	Fator de primeiro polo	Fator de amplitude	Primeira tensão de referência	Tempo	Valor de pico da TRT	Tempo	Tempo de retardo	Tensão	Tempo	TCTR[b]
U_r (kV)		k_{pp} (p.u.)	k_{af} (p.u.)	u_1 (kV)	t_1 (μs)	u_c (kV)	t_2 (μs)	t_d (μs)	u' (kV)	t' (μs)	u_1 / t_1 (kV/μs)
245	Falta terminal	1,3	1,4	260	130	364	390	2	130	67	2
	Falta quilométrica	1,0	1,4	200	100	280	300	2	100	52	2
	Discordância de fases	2	1,25	400	260	500	780	49	200	179	1,54

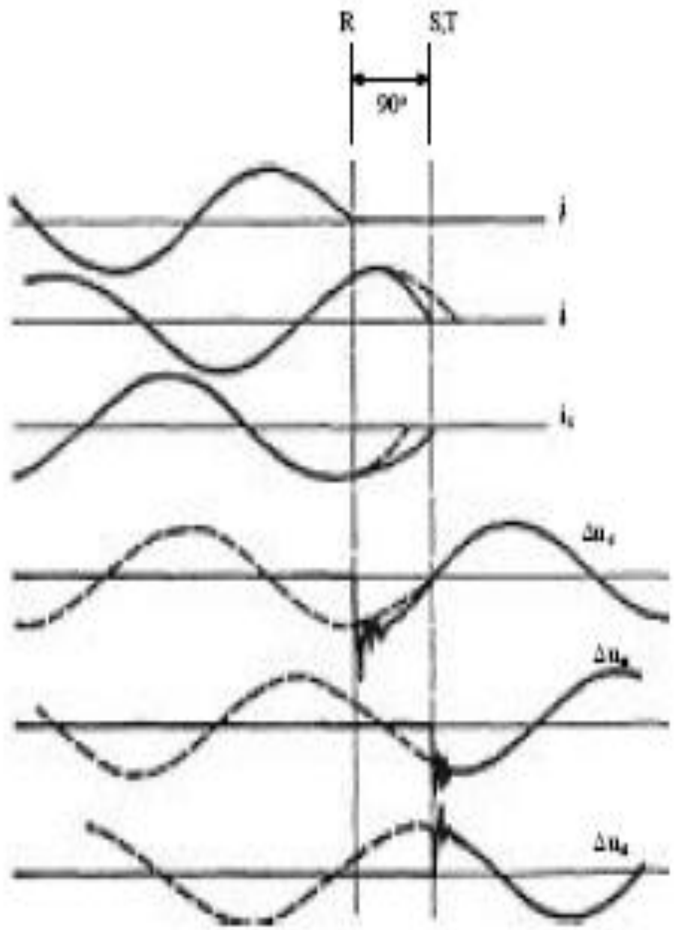
FIRST POLE TO CLEAR FACTOR





Voltages in the 1st pole to clear are 1,4 to 1,6 times the normal phase to ground voltage





SPECIFICATION OF VOLTAGES AND CURRENT VALUES IN A NEW SUBSTATION:

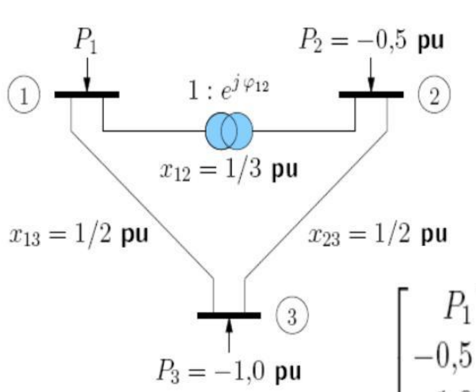
- Load flow studies
- Short-circuit studies
- Standardized values in technical standards
- To avoid exaggerated specifications reduce costs without any loss of quality.

LOAD FLOW STUDIES

For the system economical operation and expansion planning

Steady state information:

- loading of lines, generators, transformers, ...
- transmission losses
- modules and phase angles of the voltage in the bars.
- active and reactive power in transmission lines



Escolher barra 1 como referência $\Theta_1 = 0$

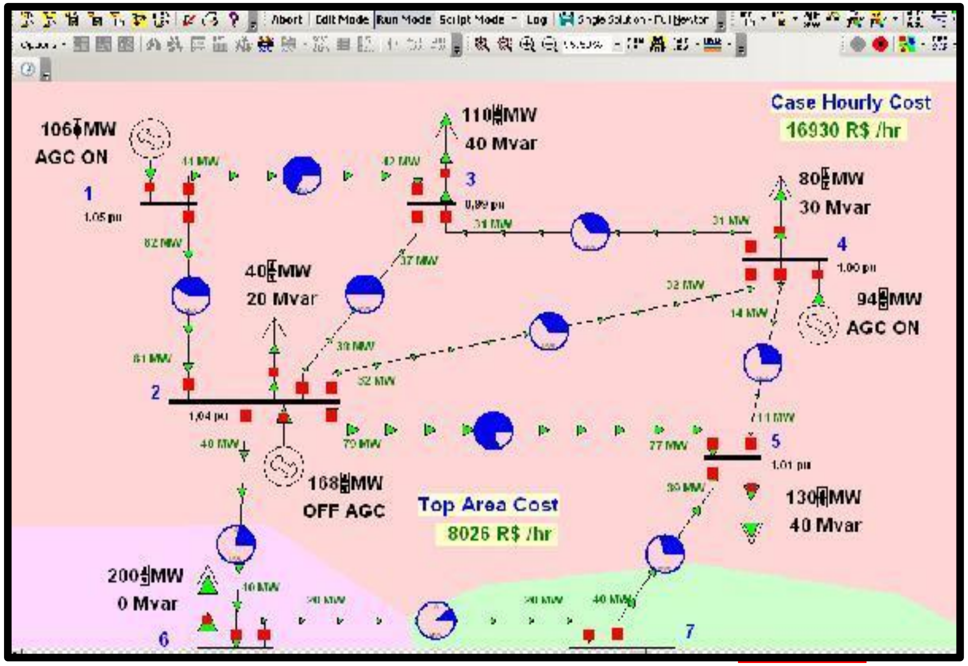
Tap do transformador defasador na posição nominal $\varphi_{12} = 0$

$$\begin{bmatrix} P_1 \\ -0{,}5 \\ -1{,}0 \end{bmatrix} = \begin{bmatrix} \infty & -3{,}0 & -2{,}0 \\ -3{,}0 & 5{,}0 & -2{,}0 \\ -2{,}0 & -2{,}0 & 4{,}0 \end{bmatrix} \cdot \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \end{bmatrix}$$

Resultados:

$\Theta_1 = 0$ $\quad \Theta_2 = -0{,}25$ $\quad \Theta_3 = -0{,}375$ rad

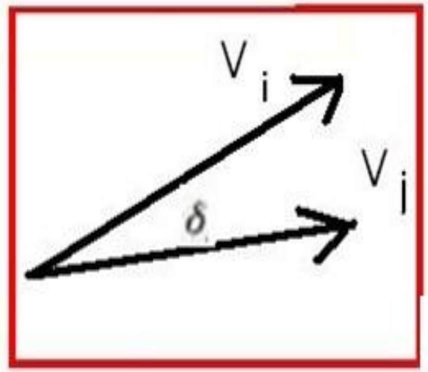
$P_{12} = \Theta_{12} / X_{12} = 0{,}75$ $\quad P_{13} = 0{,}75$ $\quad P_{23} = 0{,}25$ pu



LOAD FLOW STUDIES

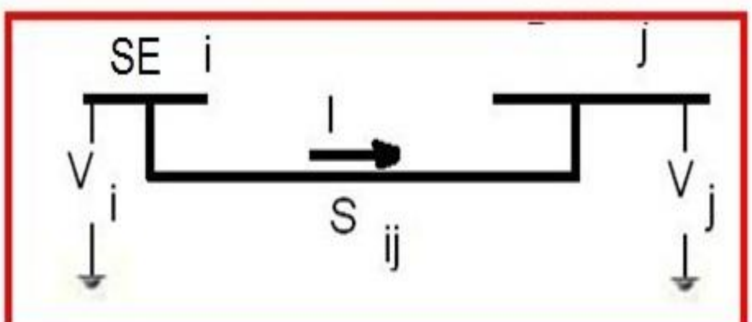
$$\boxed{I = \frac{V_i - V_j}{Z}} \qquad S_{ij} = P_{ij} + j\,Q_{ij} = V\,.\,I^{*} = \frac{V_i^{*} - V_j^{*}}{Z^{*}}$$

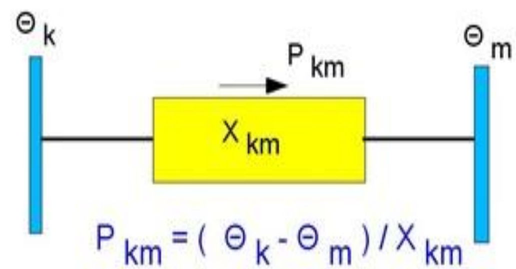
$$\delta = \angle V_i - \angle V_j$$

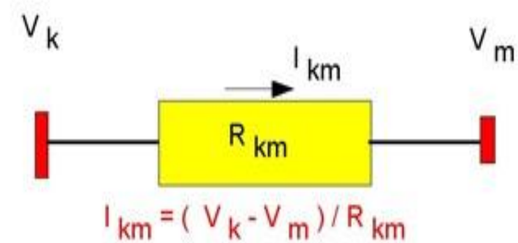


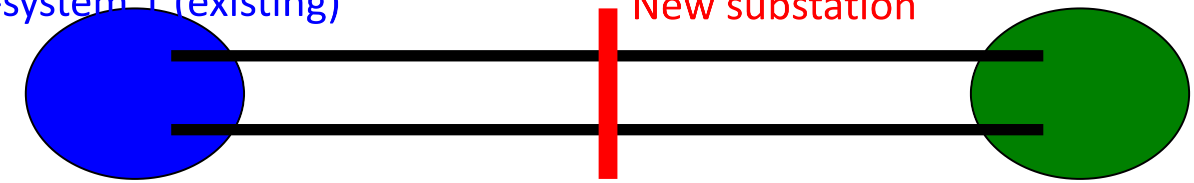
$$P_{ij} = \frac{1}{R^2 + X^2}\left(R\,|V_i|^2 - R\,|V_i|\,|V_j|\cos\delta + X\,|V_i|\,|V_j|\sin\delta\right)$$

$$Q_{ij} = \frac{1}{R^2 + X^2}\left(X\,|V_i|^2 - X\,|V_i|\,|V_j|\cos\delta - R\,|V_i|\,|V_j|\sin\delta\right)$$

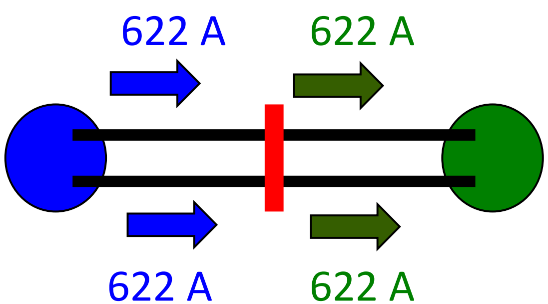




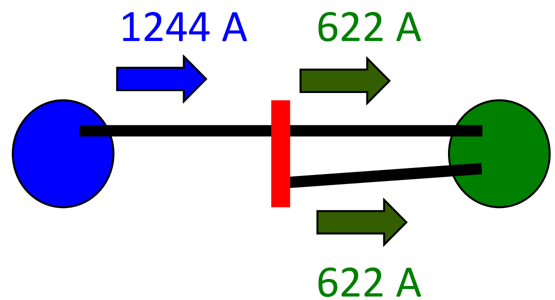




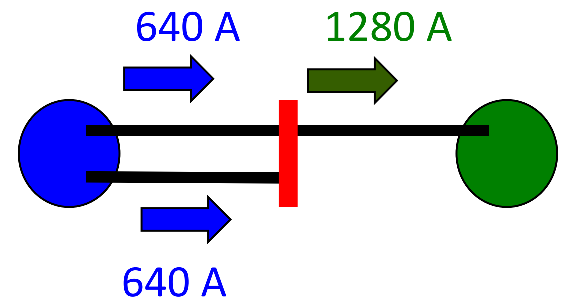
Low load normal operation

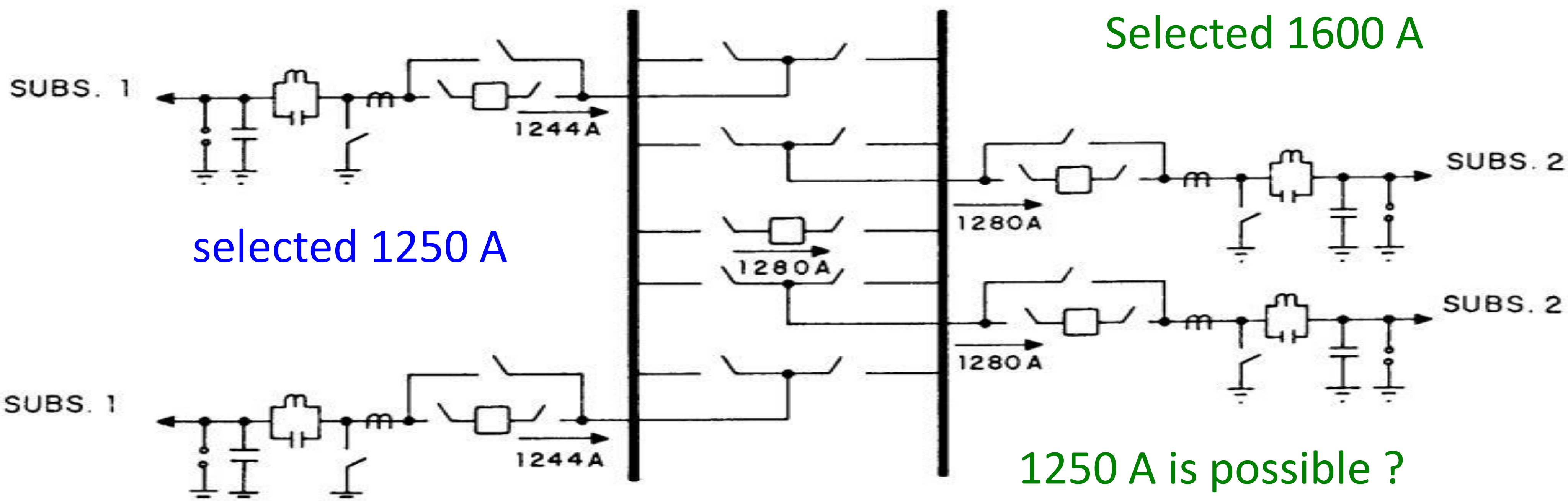


Emergency - low load



Emergency - peak load





Selected 1600 A

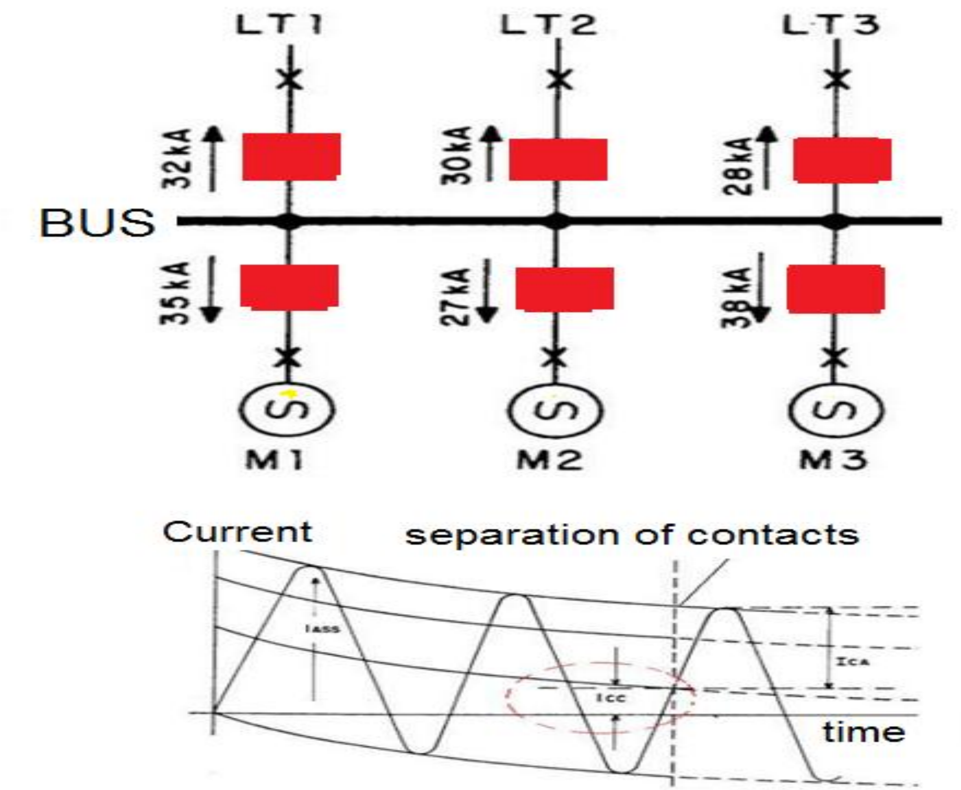
selected 1250 A

1250 A is possible ?

SHORT CIRCUIT STUDIES:

to specify the short time and peak currents and switchgear breaking capacities

- Determine X / R circuit (and L/ R time constant);
- Calculate short chains, the crest and maximum durations.
- Adjust to the standard values of IEC standard
- Find the values of DC / AC components in the separation of contacts



Circuit	Calculated current (kA rms)	Standard value (kA rms)
LT1	32	40,0
LT2	30	31,5
LT3	28	31,5
M1	35	40,0
M2	27	31,5
M3	38	40,0

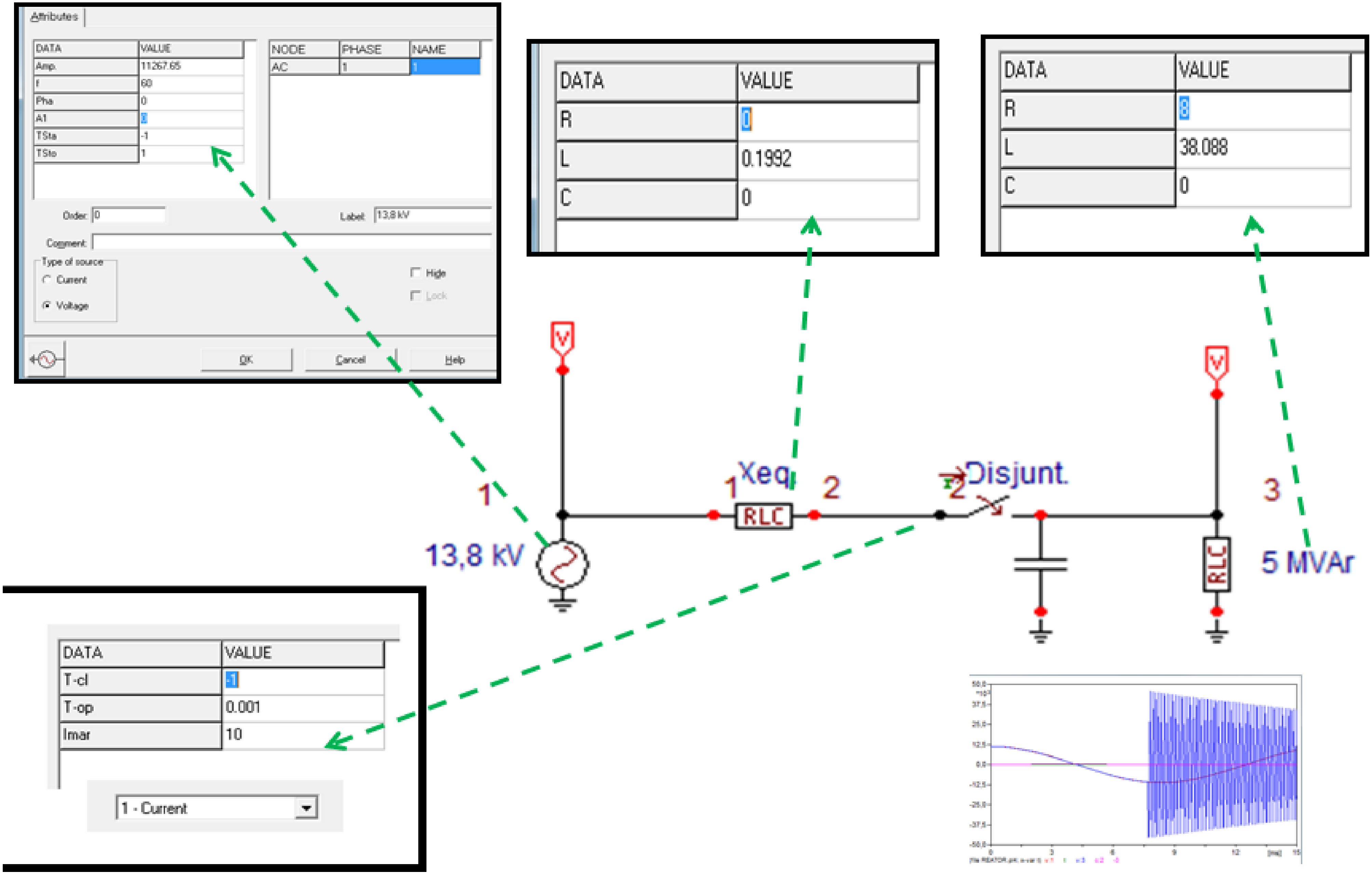
Information about the software

ATP / ATPDRAW

(Alternative Transient Program)

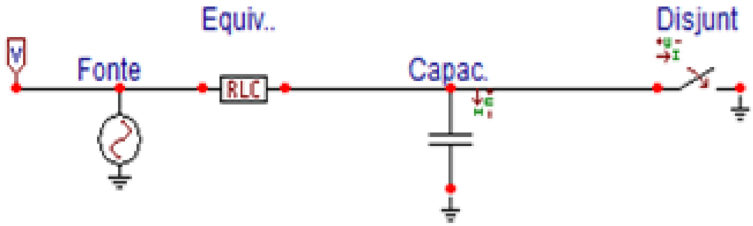
- Free software originated from the EMTP for the calculation of voltages and currents transients.
- Excellent tool for daily use.

OPENING A REACTOR

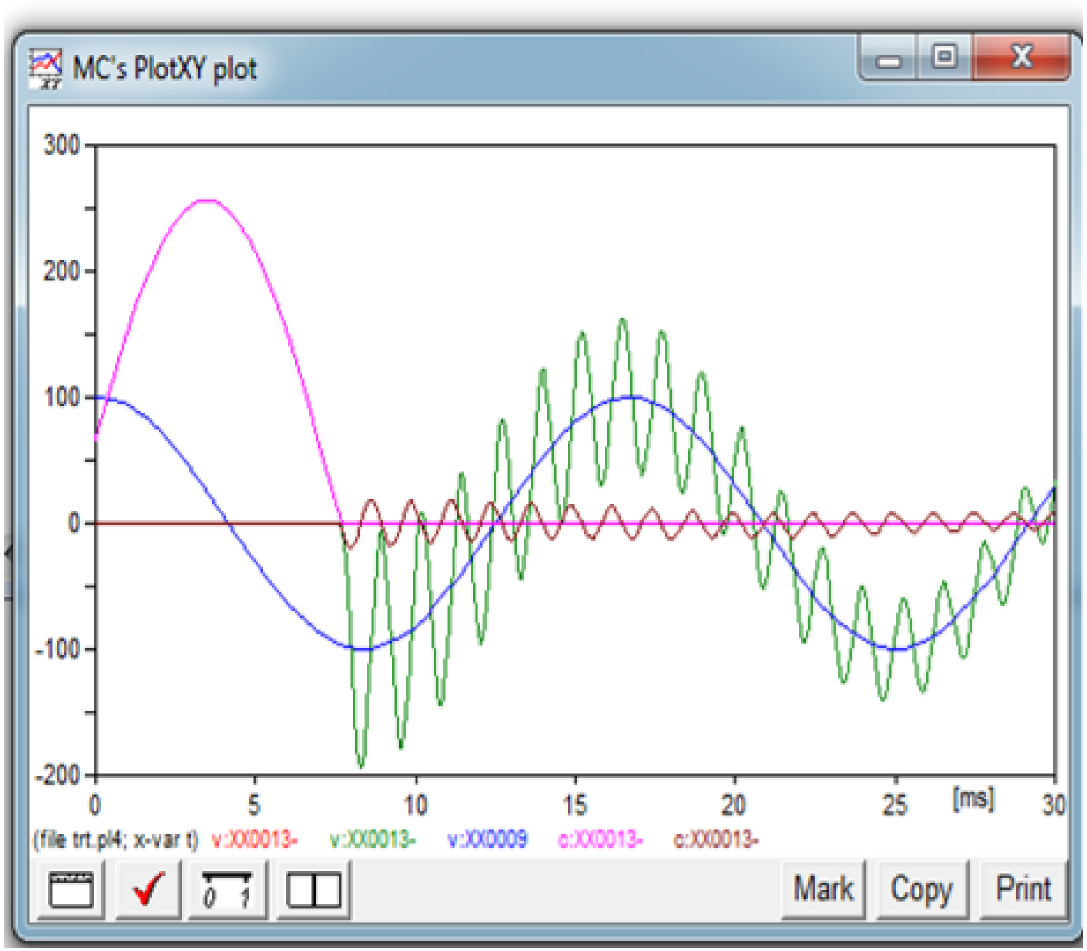


C:\0_CD_Conceitos\Curso_2012_SW_SE\CD_ATP_CBUE\ Exercicios\Abertura_Reator\Project\reator.adp

FAULT INTERRUPTION



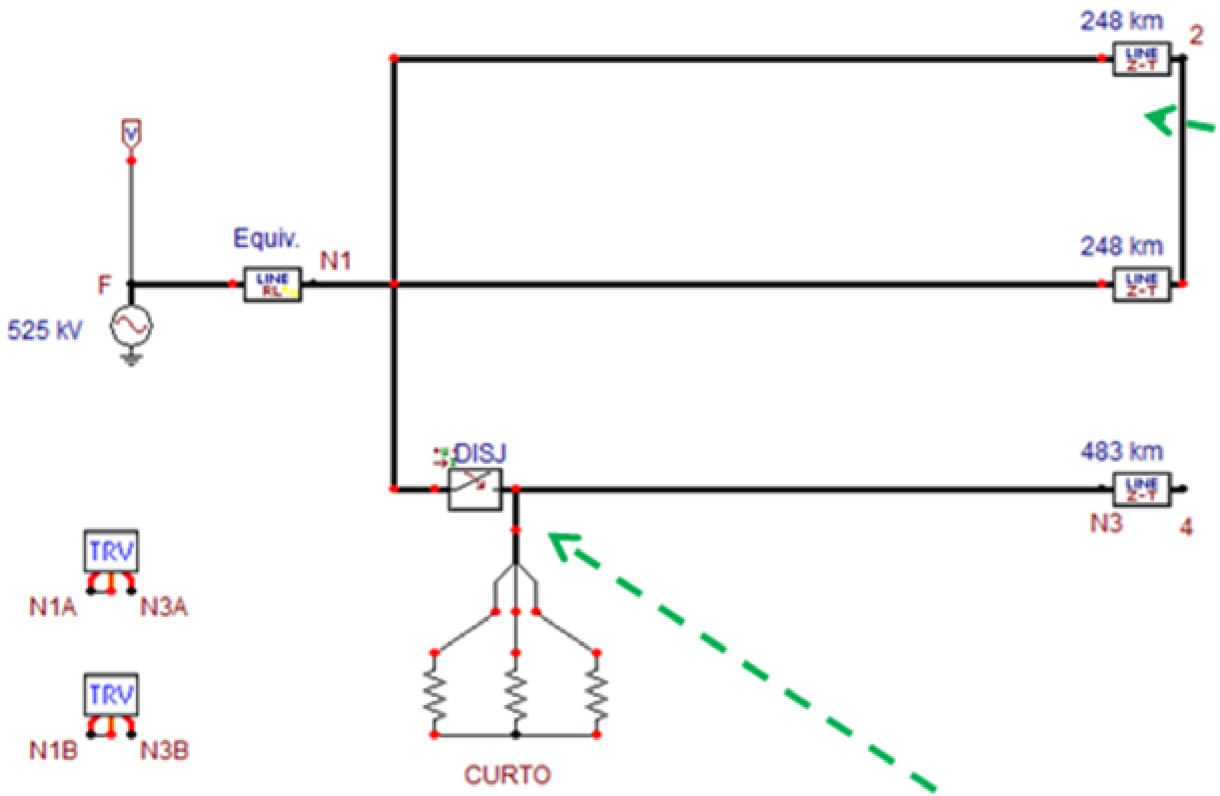
DATA	VALUE
R	0.1
L	1
C	0



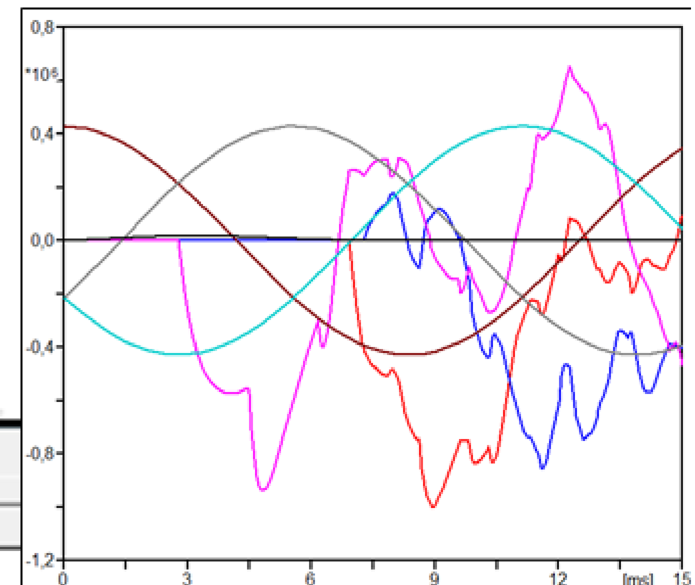
DATA	VALUE
T-cl	-1
T-op	0.001
Imar	0

C:\0_CD_Conceitos\Curso_2012_SW_SE\CD_ATP_CBUE\ Exercicios\Abertura_Reator\Project\trt.ADP

FAULT INTERRUPTION



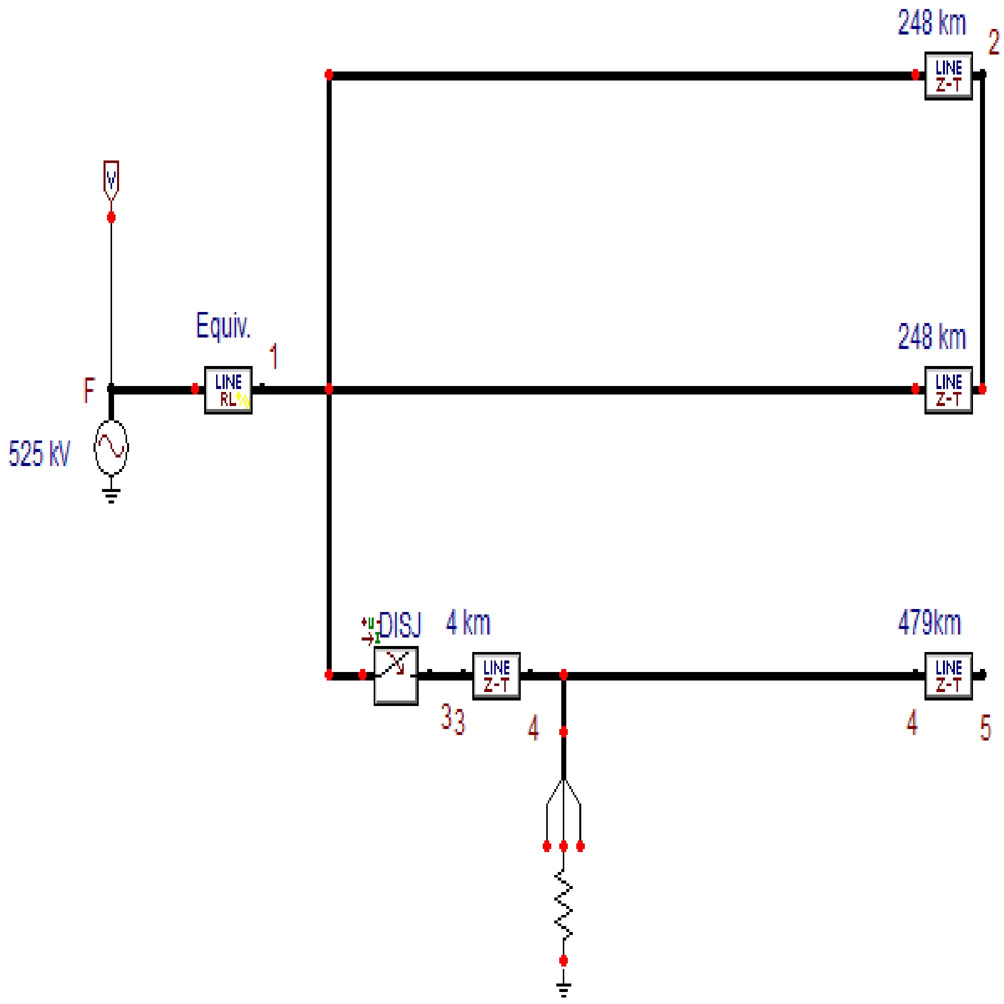
DATA	VALUE
R/l+	0.0229
R/l0	0.4212
A+	0.3482
A0	1.3356
B+	4.764
B0	3.121
l	248
ILINE	0

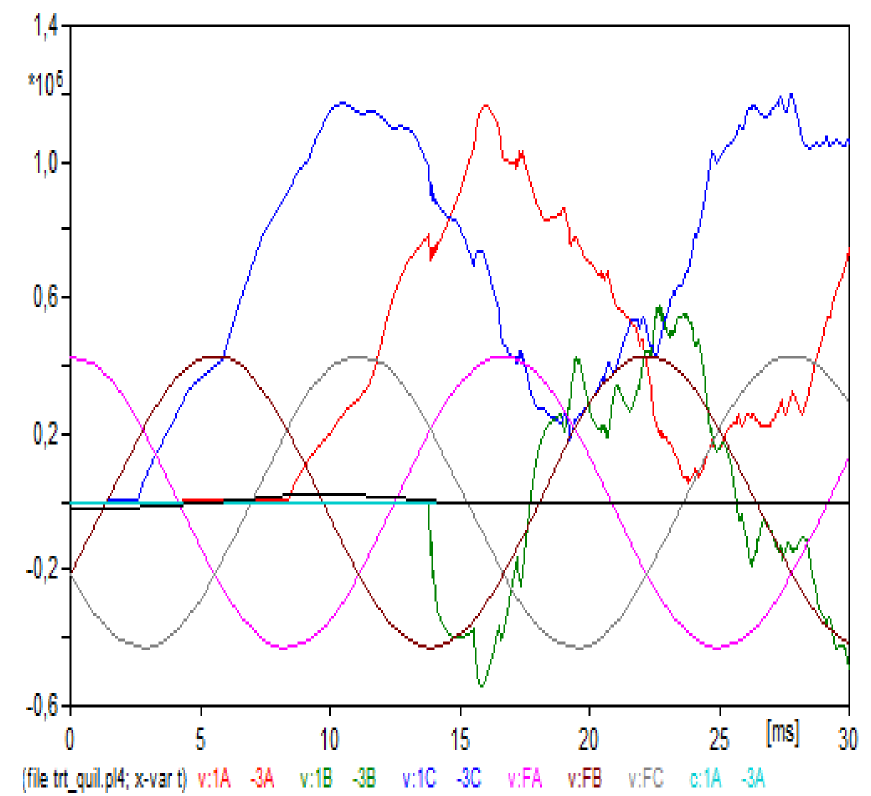


Attributes

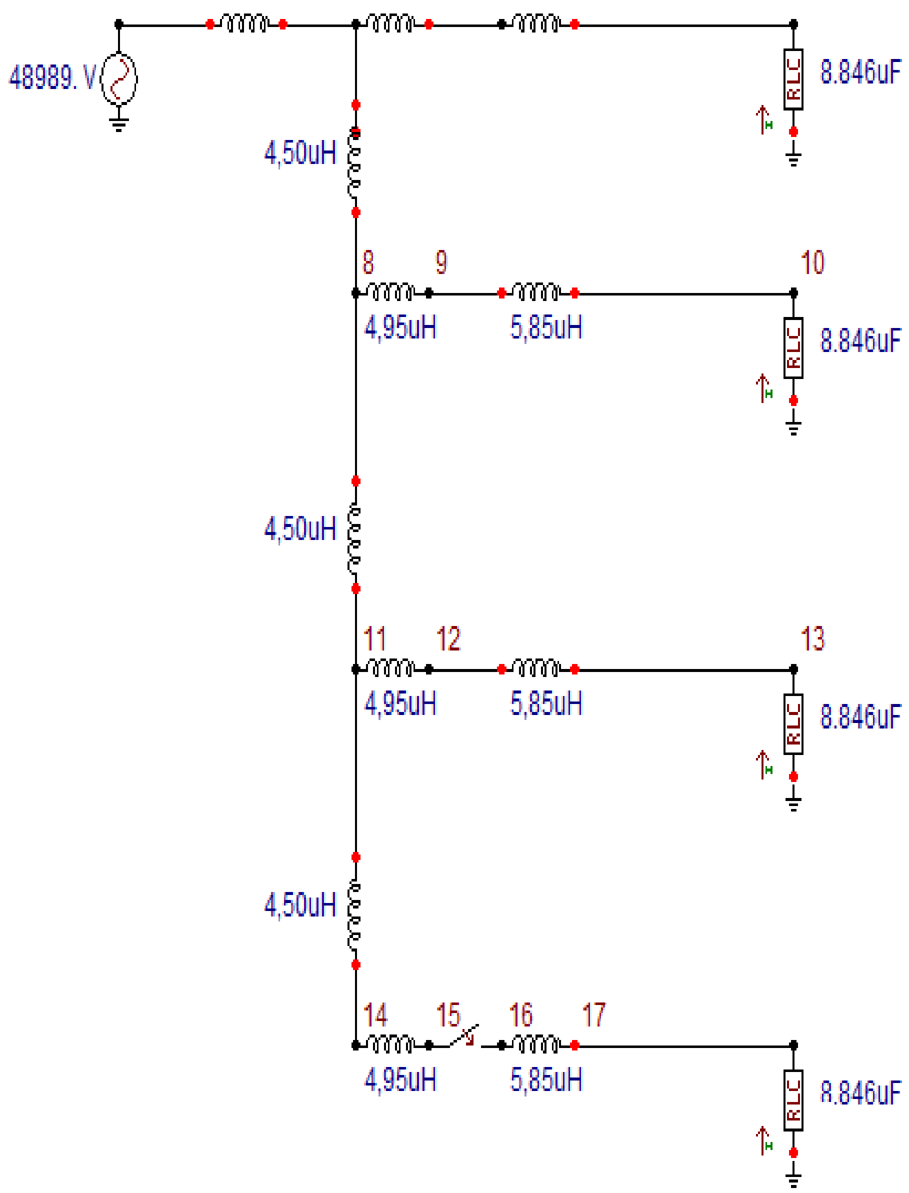
DATA	VALUE
T-cl_1	-1
T-op_1	0.001
T-cl_2	-1
T-op_2	0.001
T-cl_3	-1
T-op_3	0.001
Imar	0

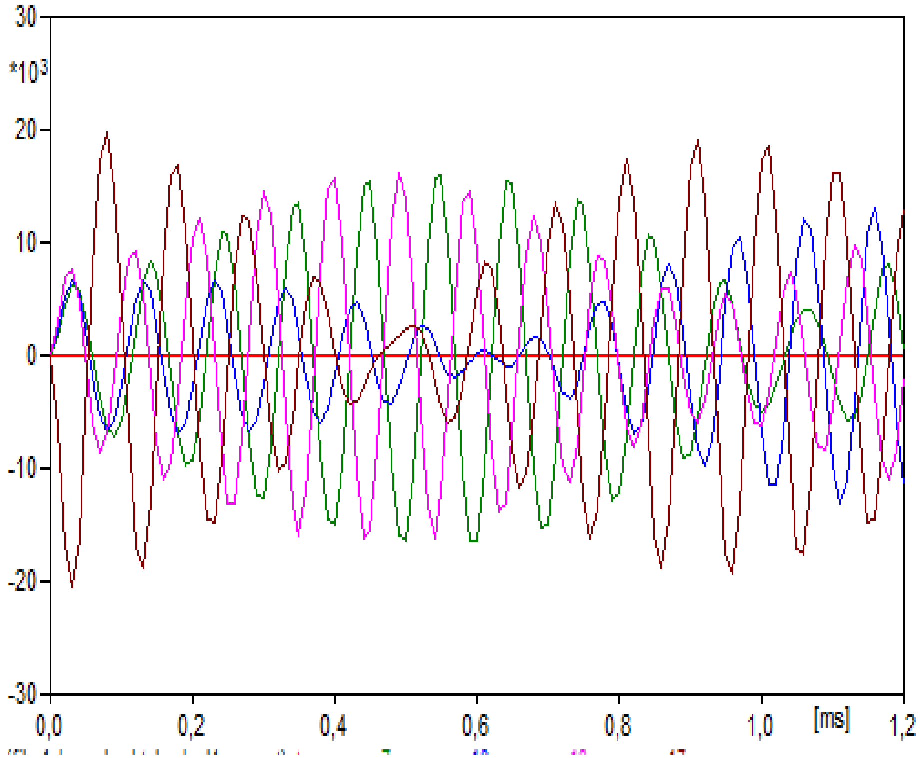
FAULT INTERRUPTION (SHORT LINE)

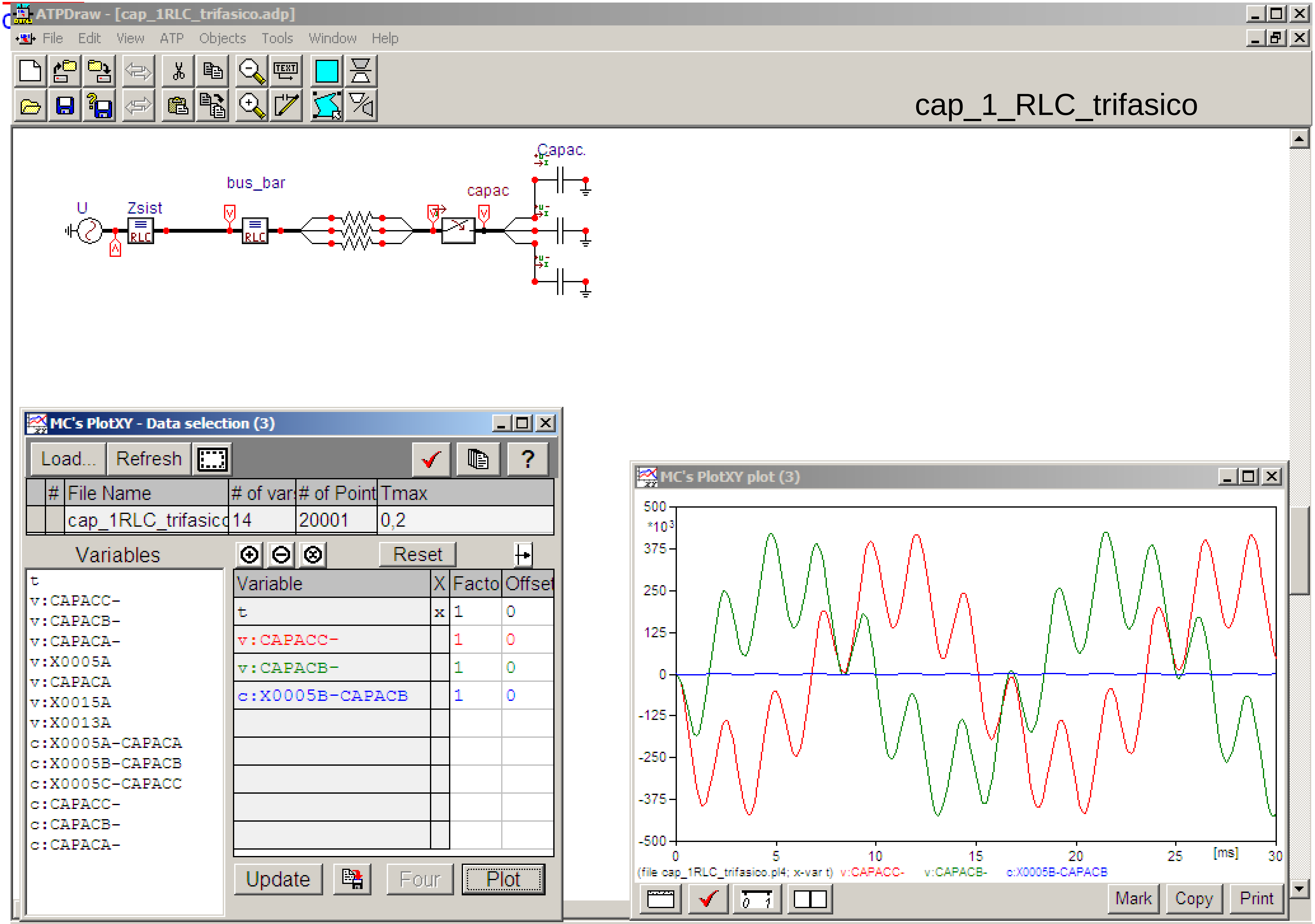




“BACK TO BACK” CAPACITORS

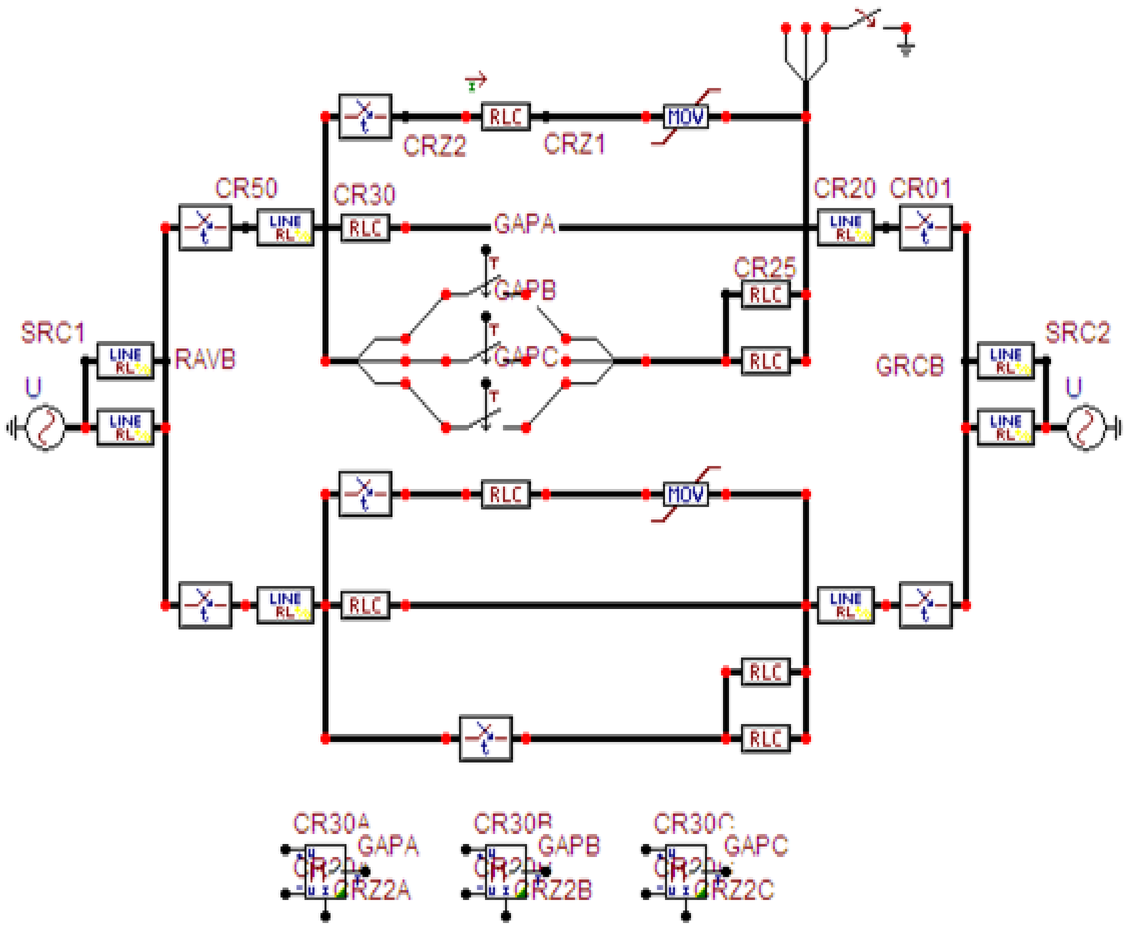


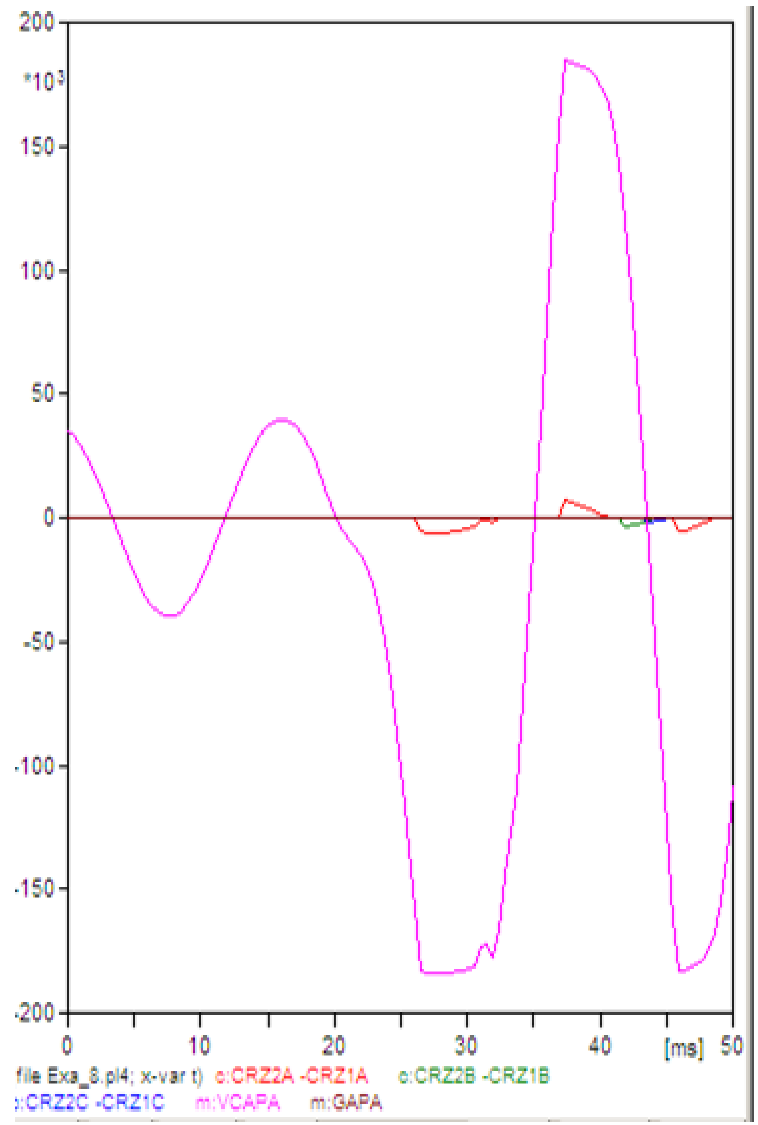




ATPDraw - [cap_1RLC_trifasico.adp]
File Edit View ATP Objects Tools Window Help
cap_1_RLC_trifasico
Capac.
bus_bar
capac
U
Zsist
MC's PlotXY - Data selection (3)
Load...
Refresh
File Name # of var # of Point Tmax
cap_1RLC_trifasico 14 20001 0,2
Variables
Reset
t
v:CAPACC-
v:CAPACB-
v:CAPACA-
v:X0005A
v:CAPACA
v:X0015A
v:X0013A
c:X0005A-CAPACA
c:X0005B-CAPACB
c:X0005C-CAPACC
c:CAPACC-
c:CAPACB-
c:CAPACA-
Variable X Facto Offset
t x 1 0
v:CAPACC- 1 0
v:CAPACB- 1 0
c:X0005B-CAPACB 1 0
Update
Four
Plot
MC's PlotXY plot (3)
500
*10³
375
250
125
0
-125
-250
-375
-500
0 5 10 15 20 25 [ms] 30
(file cap_1RLC_trifasico.pl4; x-var t) v:CAPACC- v:CAPACB- c:X0005B-CAPACB
Mark
Copy
Print

exa_8.adp


CRZ2
CRZ1
CR50
CR30
GAPA
CR20
CR01
GAPB
CR25
SRC1
RAVB
GAPC
GRCB
SRC2
U
U
CR30A
GAPA
CRZ2A
CR30B
GAPB
CRZ2B
CR30C
GAPC
CRZ2C


200
*10³
150
100
50
0
-50
-100
-150
-200
0
10
20
30
40
[ms]
50
file Exa_8.pl4; x-var t) c:CRZ2A -CRZ1A c:CRZ2B -CRZ1B
:CRZ2C -CRZ1C m:VCAPA m:GAPA

SOME REFERENCE BOOKS

ABB Switchgear Manual

ABB Switchgear Manual

More than 50 years after publication of the first edition of the BBC Switchgear Manual by A. Hoppner, we present to you the current edition of today's ABB Calor Emag Switchgear Manual in the internet the first time. As always, it is intended for both experienced switchgear professionals as well as beginners and students.

The ABB Calor Emag Switchgear Manual addresses all relevant aspects of switchgear technology for power transmission and distribution. Not only the technology of low, medium and high voltage switchgear and apparatus is considered but also related areas such as digital control systems, CAD/CAE methods, project planning, network calculation, electro-magnetic compatibility (EMC), etc.

Imprint
ABB Pocket Book - Switchgear Manual
10th revised edition

Edited by
ABB Calor Emag Schaltanlagen AG Mannheim and ABB Calor Emag Mittelspannung GmbH Ratingen

http://www.4shared.com/office/ErozeZWB/20269998-5068033-ABB-Switch-Ge.html

Transients in Power Systems – Lou Van de Sluis
John Wiley & Sons Ltd ISBN 0471486 396

END OF MODULE 1

Presented by Sergio Feitoza Costa

www.cognitor.com.br

COGNITOR

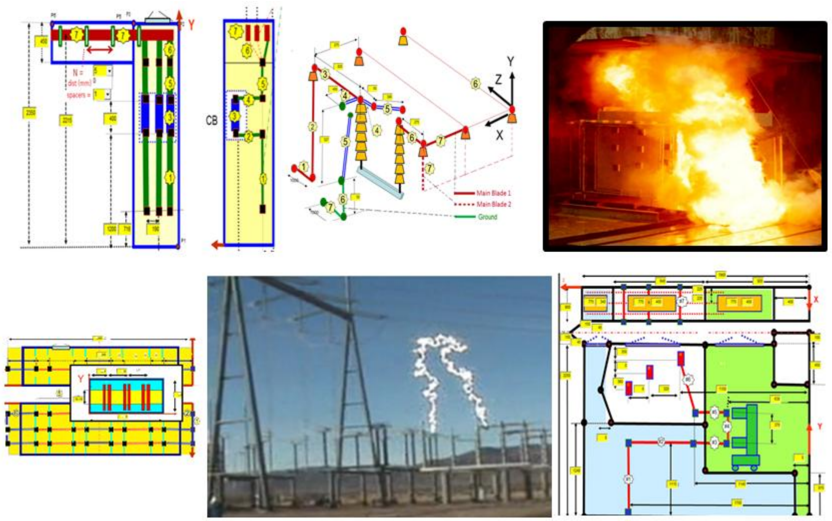
Reference materials for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

(focus in design techniques, specification, tests and simulations)



MODULE 2:

OVERVOLTAGES AND INSULATION COORDINATION

by Sergio Feitoza Costa

www.cognitor.com.br

COGNITOR

EFFECT OF CURRENTS AND VOLTAGES

Lower or equak the rated permanent values → **Aging "normal"** (as 20 years)

Long duration overcurrents (as 1,5 IN during 120 seconds → **Moderated temperature rises:** + aging

Short duration overcurrents (as 20,0 IN during 1s → **High temperatures like 180ºC for copper:** annealing, bending,

→ **Electrodynamical effects:** forces (tons) and mechanical stresses damaging insultators and busbar

Overvoltages

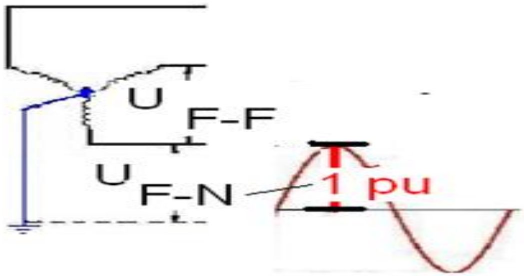
- **Long duration (dozen of seconds)**
- **Short duration(micro- seconds)**

→ **Imediate failure or isolation aging**

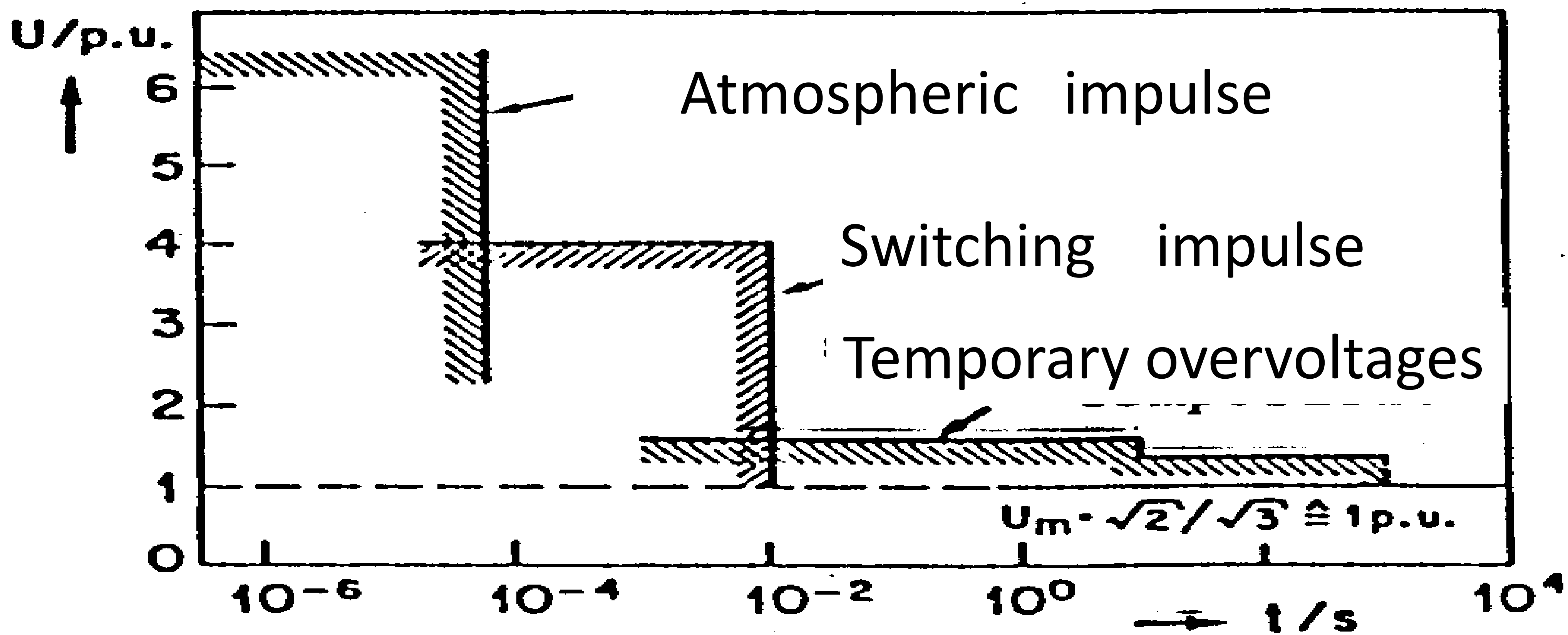
$I^2 t \sim V^2 t$?

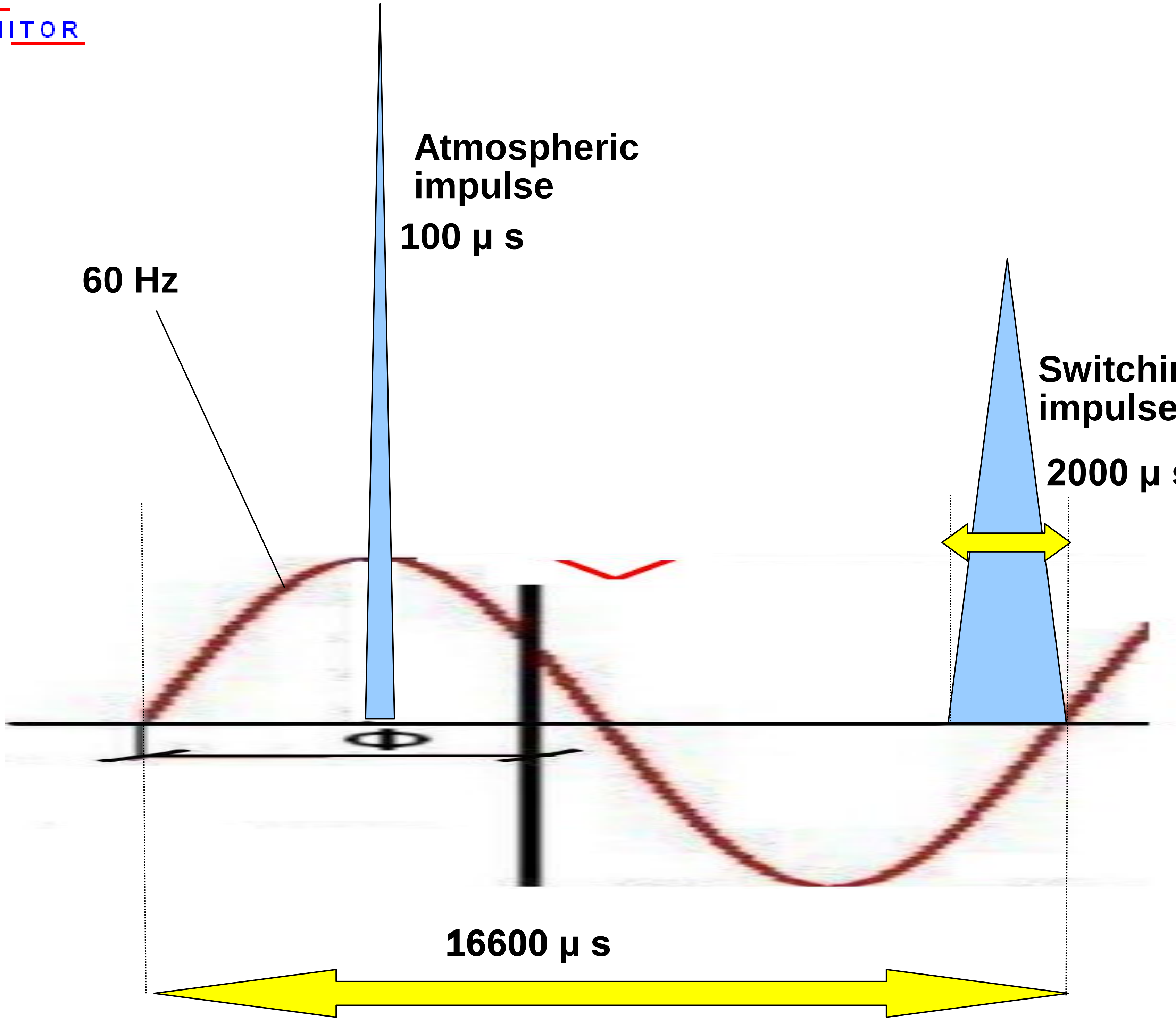
COGNITOR

OVERVOLTAGES CLASSIFICATION

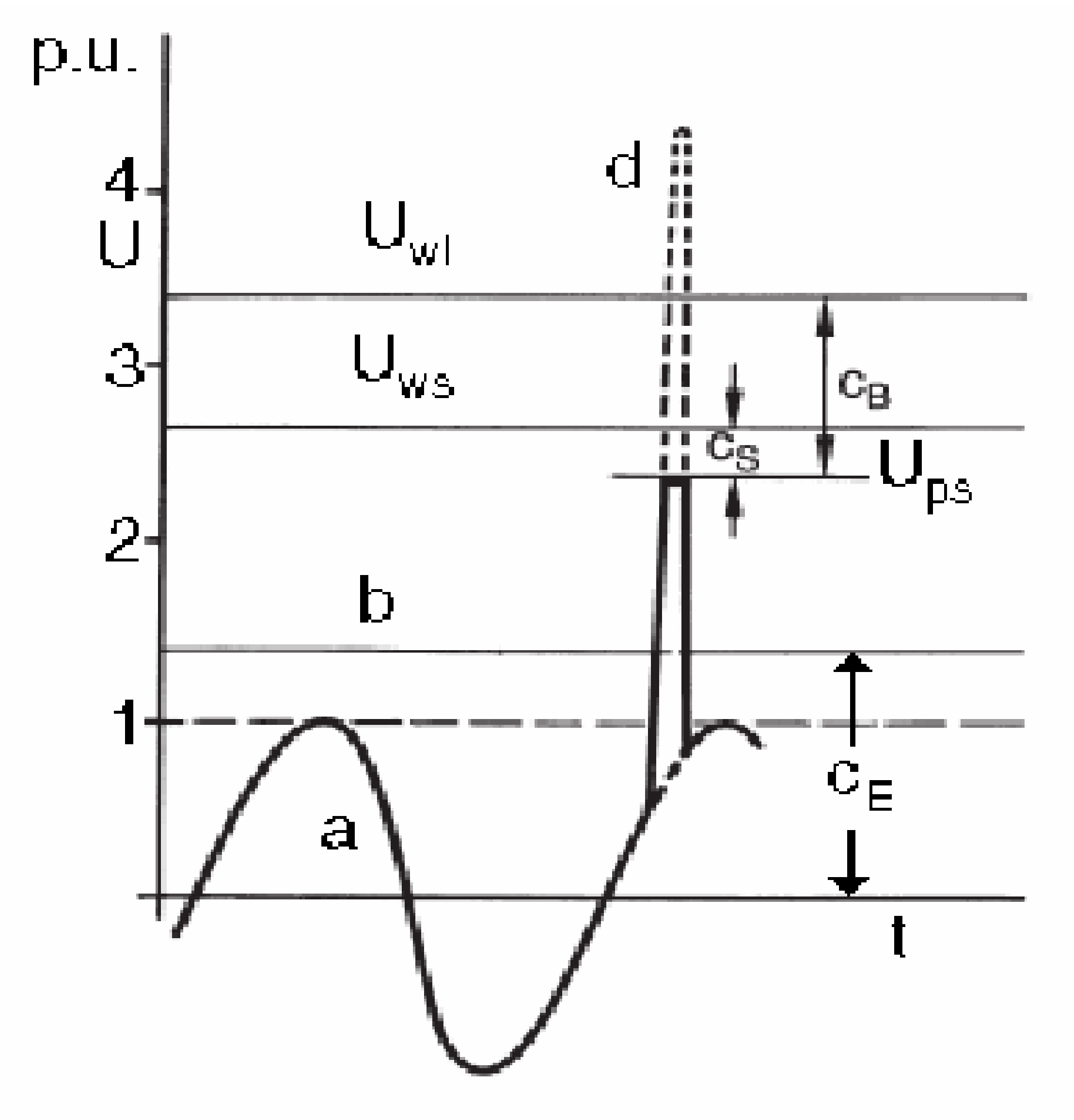


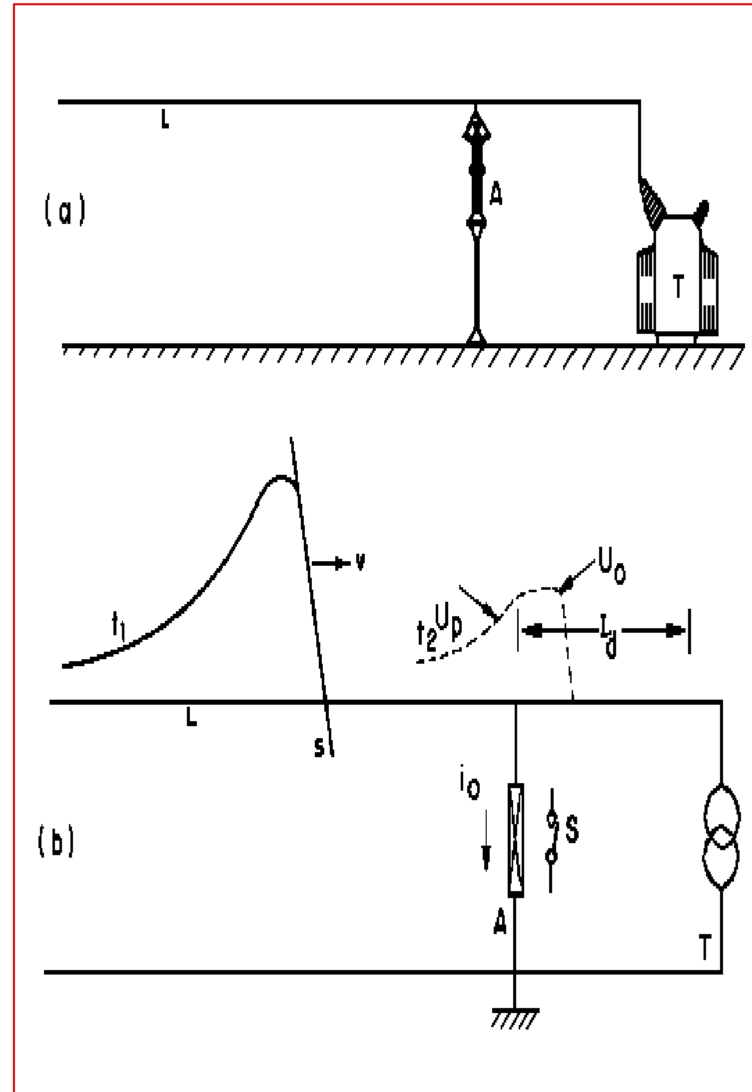
- Atmospheric
- Switching – connection and disconnection of elements , initiation or interruption of faults
    - Temporary: power frequency or harmonics and sustained or poorly damped
    - Switching: short and damped




Atmospheric
impulse
100 μ s
60 Hz
Φ
Switching
impulse
2000 μ s
16600 μ s

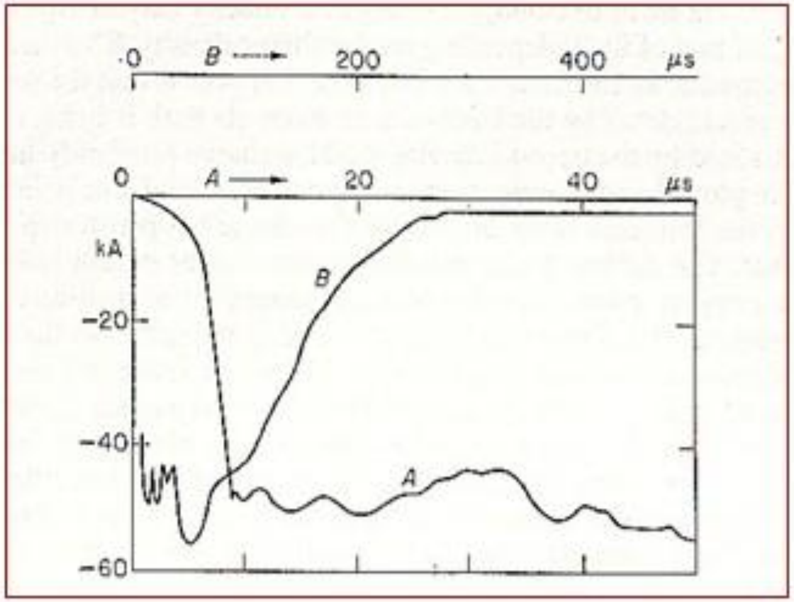
IMPULSES + RATED FREQUENCY VOLTAGES





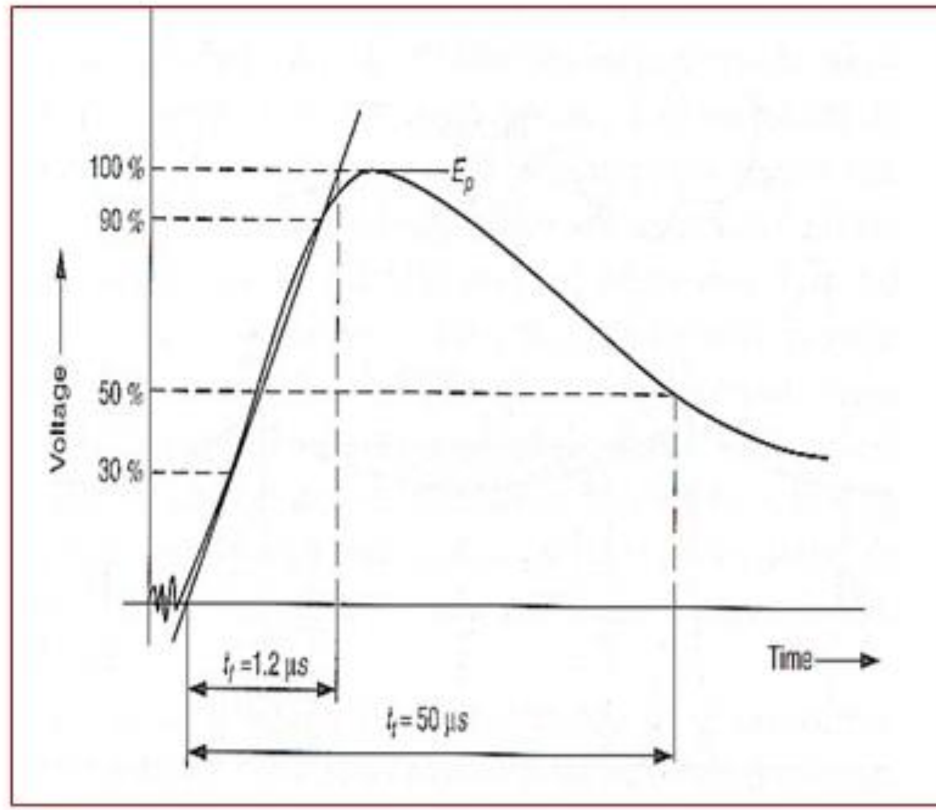
COGNITOR

Atmospheric IMPULSES (actual and laboratory)



Laboratory test

$t_1 = 1{,}2\ \mu s \quad t_2 = 50\ \mu s$



Switching

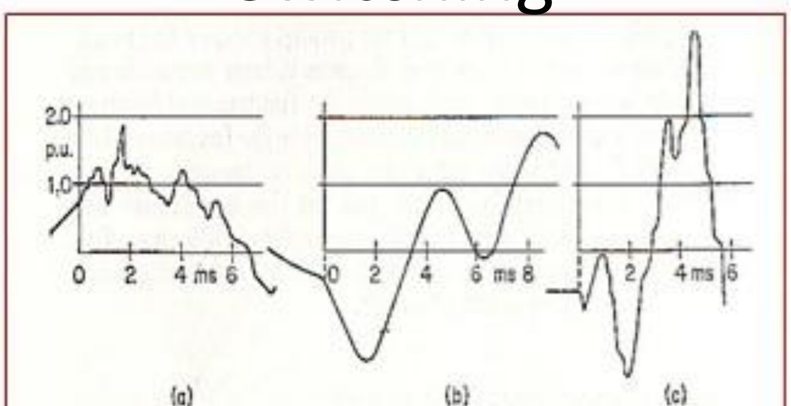


Figure 2.7. Typical switching surge waveshapes:
(a) fault initiation,
(b) fault clearing,
(c) line energising

$t_1 = 250\ \mu s \quad t_2 = 2500\ \mu s$

Transients frequency

Transformers connection	1 kHz
Ressonance (iron)	1 kHz
Connection of lines	20 KHz
TRV for terminal faults	20 KHz
TRV for short line faults	100 KHz
Atmospheric impulses	3000 KHz
GIS switching isolators	50.000 KHz

Fequency depend on L and C which depend from geometry and distances

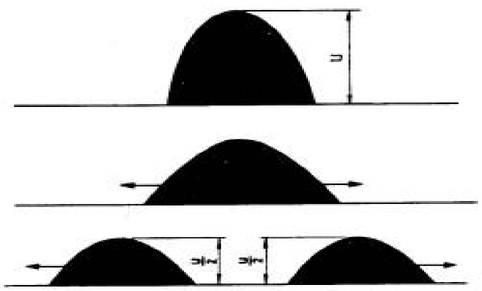
$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{L.C} - \left(\frac{R}{2L}\right)^2}$$

IMPULSES PROPAGATION

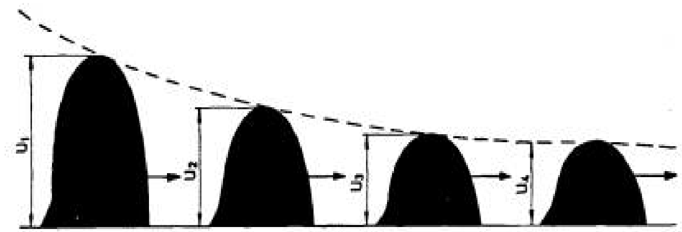
- Direct impact in the cable of phase: U = (I / 2) x Z
- Impact in the guard cable: "back-flashover.

$Z = \text{sqrt}(L/C)$

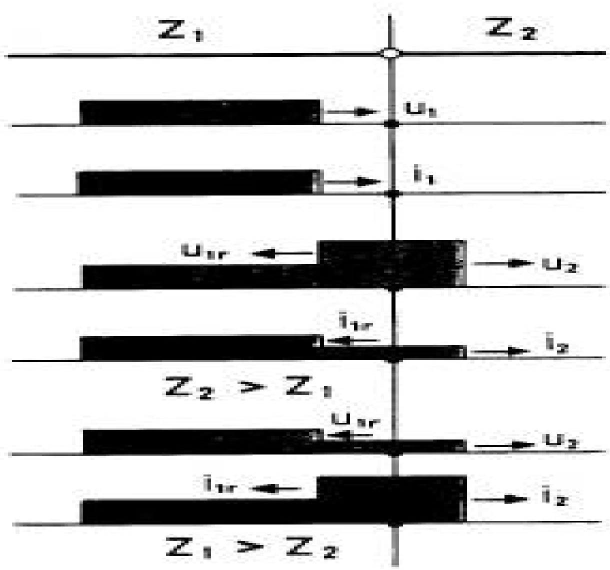
$v = 1 / \text{sqrt}(L*C)$



$$i_1 = i_2 = \frac{u}{2Z}$$



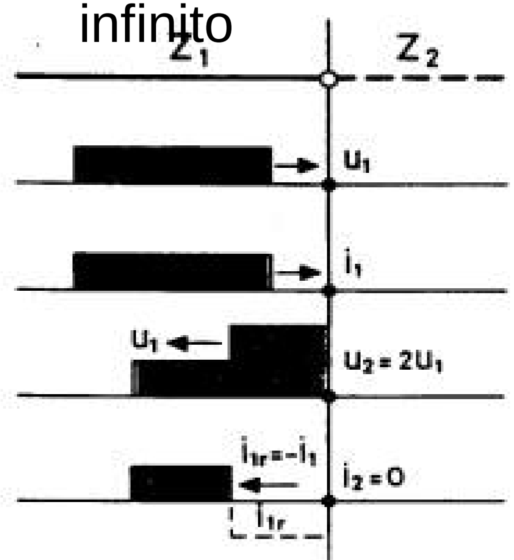
Changing the wave impedance medium



$$u_2 = u_1 \frac{2Z_2}{Z_1 + Z_2}$$

$$u_{1r} = u_1 \frac{Z_2 - Z_1}{Z_1 + Z_2}$$

transformador: Z_2 infinito



TEMPORARY OVERVOLTAGES

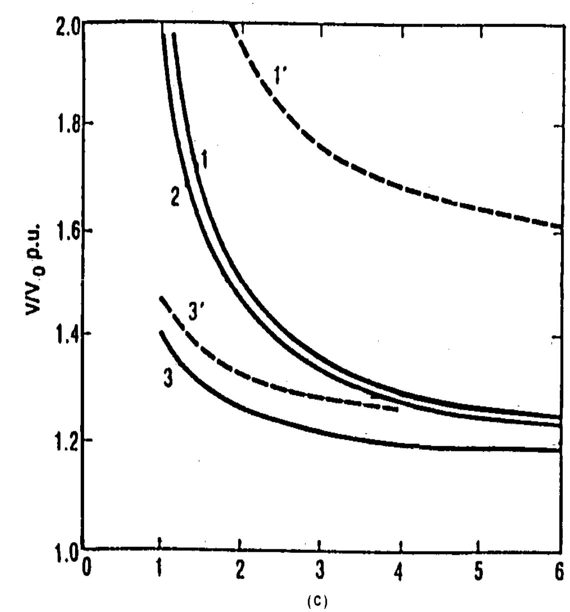
- Power frequency or harmonics sustained or poorly damped
- Range <1.5 P.U.
- Duration: few seconds depending on the type of system voltage control (even more if the intervention is manual)

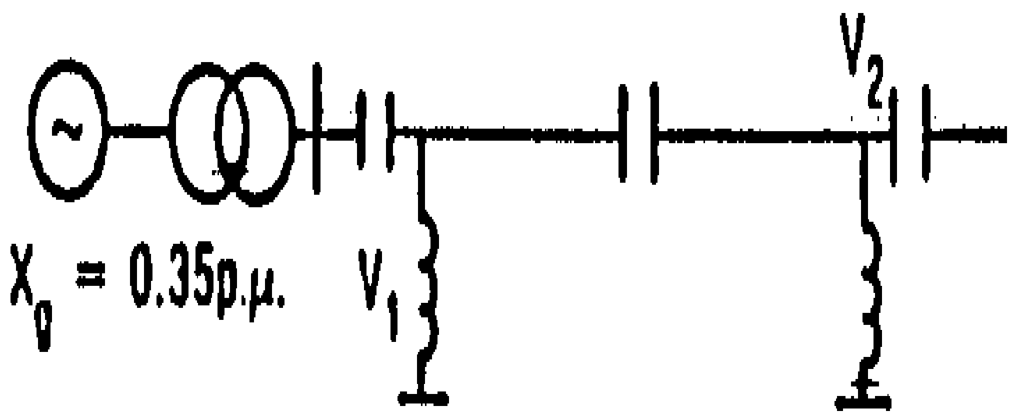
    ✓Some of the causes

    - ✓Sudden loss of load
    - ✓Unbalanced faults to earth
    - ✓Disconnection of inductive loads
    - ✓Connection of capacitive loads
    - ✓Connection of no-load lines

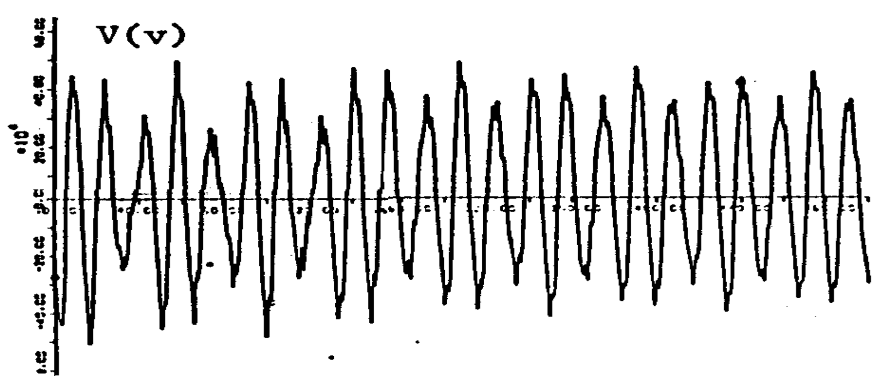
SUDDEN LOSS OF LOAD

- Line with most of the generator load is opened
- Generators accelerate / voltage grow up
- The more compensated and meshed is the system the lower are the overvoltages





V2



1,2,3 - Emitter 1', 3' - Receptor
1-1' - No compensation
3 / 3' - 50% capacitive series compensation / 70%_inductive in derivation

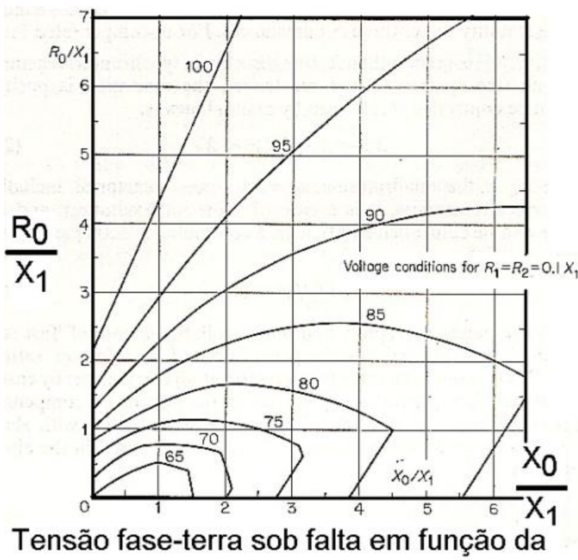
Fig. 4.4

UNBALANCED FAULTS TO GROUND

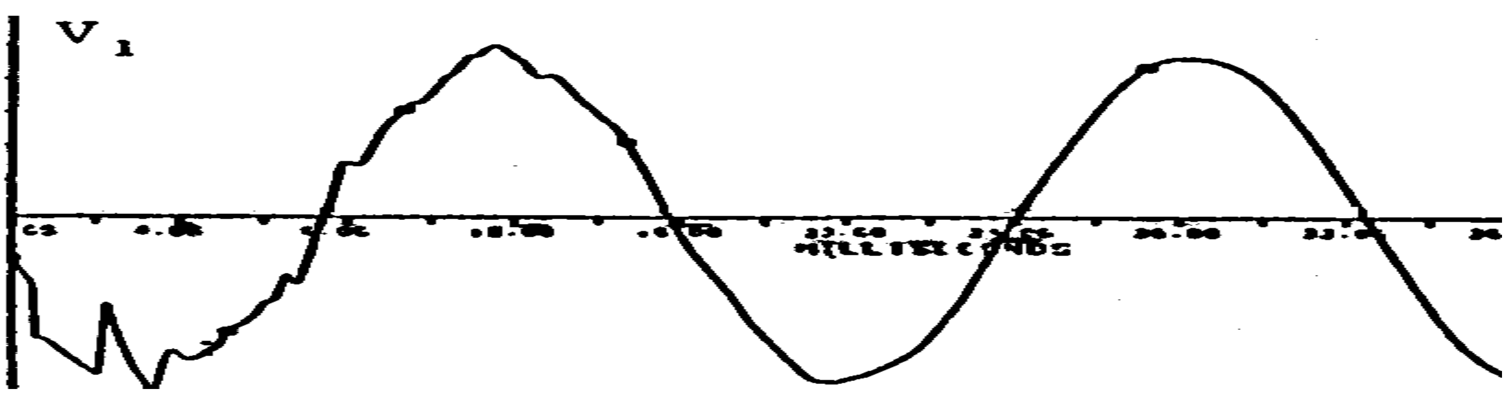
- Phase-to-earth fault in one of the phases causes an increase of the voltage in the other (unfaulted) phases

- Isolated systems: Phase to ground voltage on unfaulted phases can overcome the voltage-phase

- Solidly grounded systems: voltage rises but remains smaller than phase to phase voltage.

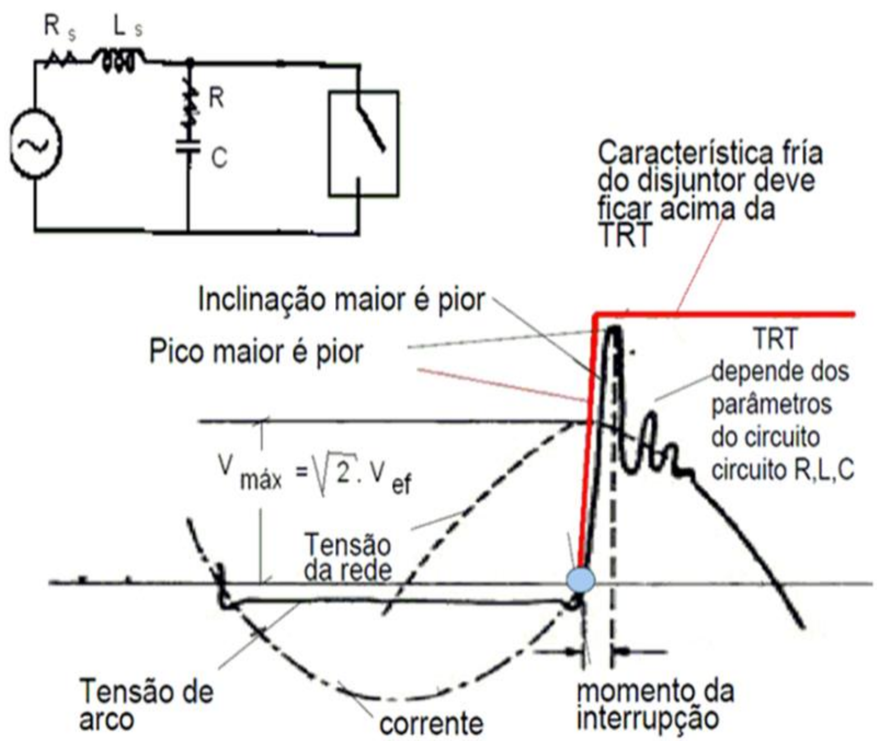


Tensão fase-terra sob falta em função da tensão fase-fase R_0 resistencia de sequencia zero, X_0, X_1, X_2 : reatâncias



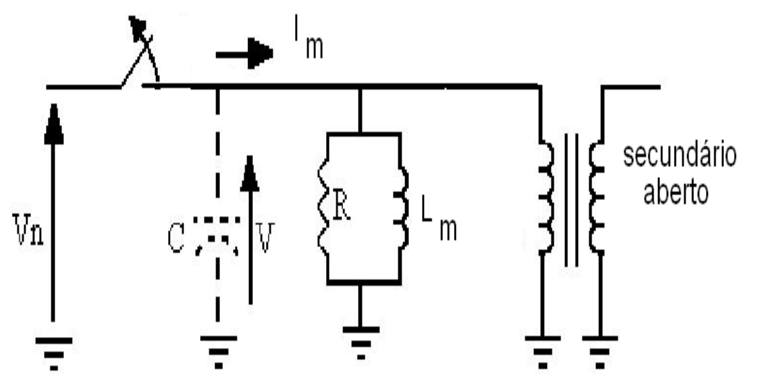
INTERRUPTION OF INDUCTIVE CURRENTS

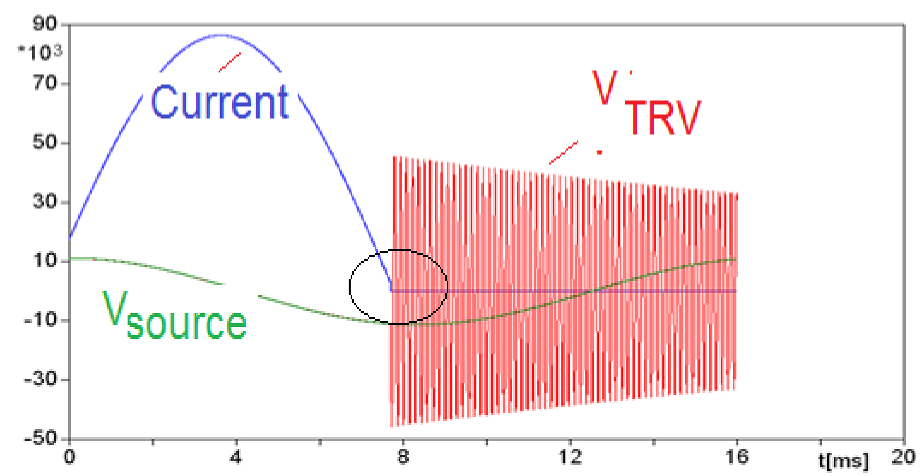
From IN to several IN



Small inductive currents in transformers

- I_m : 0,5 a 5% de I_n

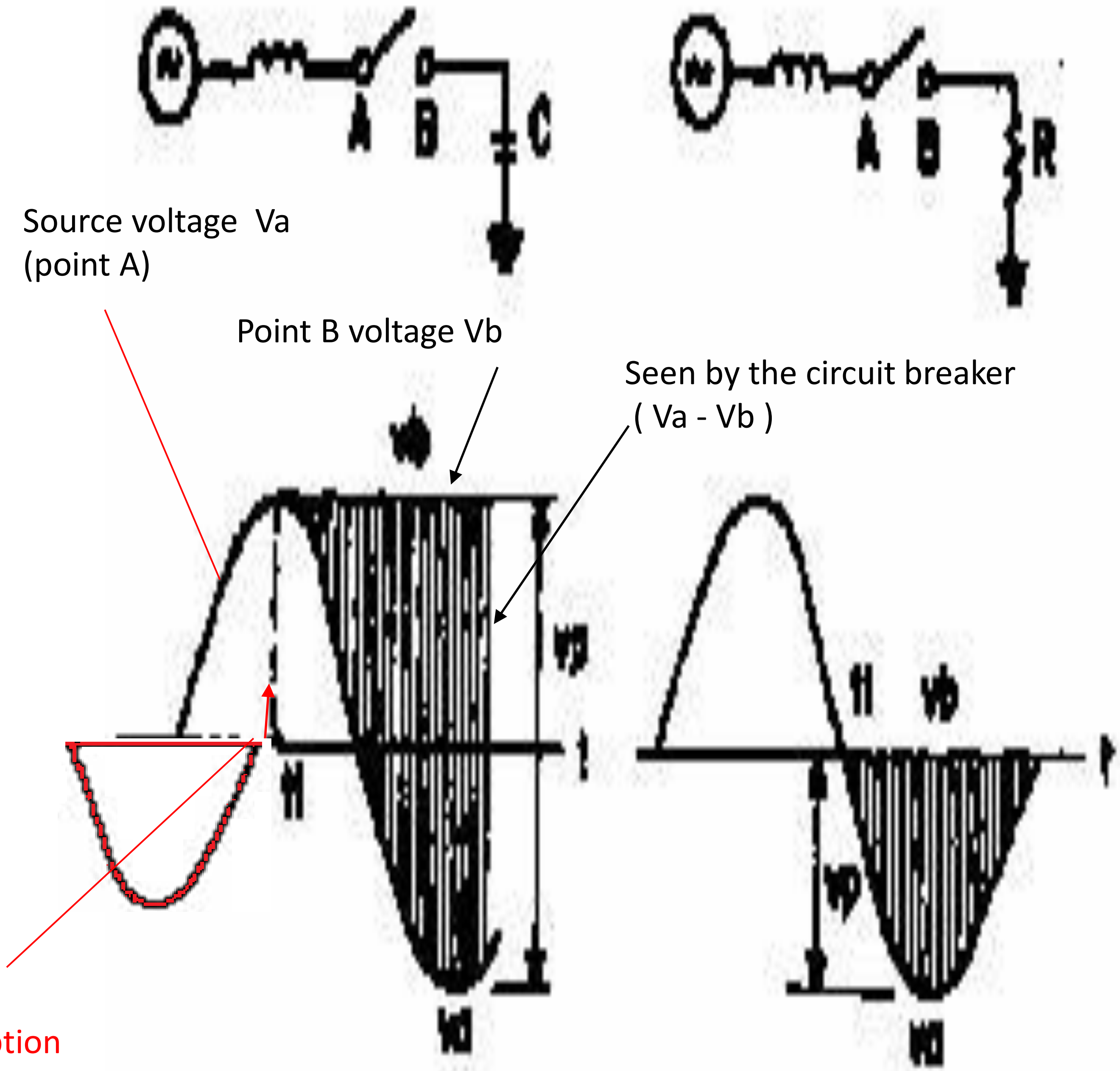




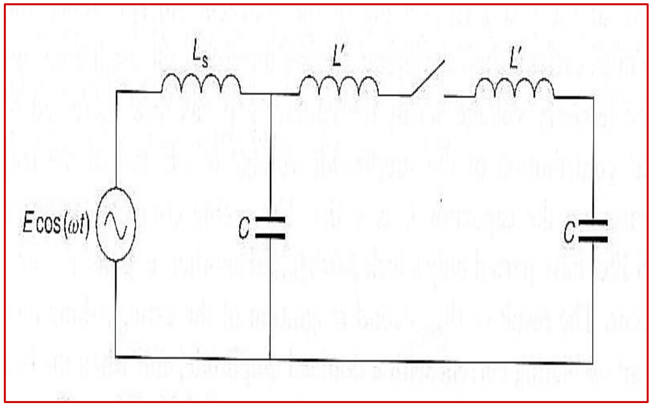
INTERRUPTION OF CAPACITIVE LOADS (cables, capacitors, ..)

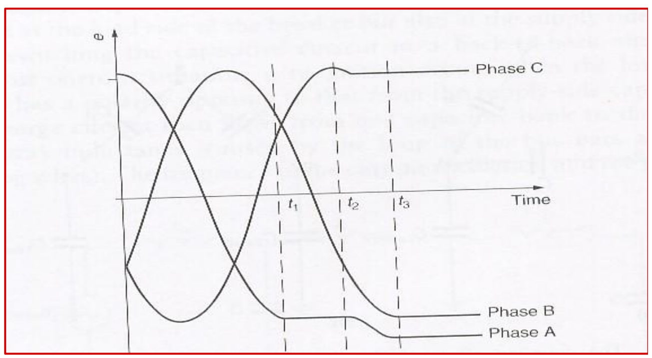
- TRV grows slowly making easier the interruption but V_{peak} = 2pu may cause reignition of the arc because there is not sufficient separation of the contacts

- If a new interruption happens, the voltage may be duplicated again to 4 pu

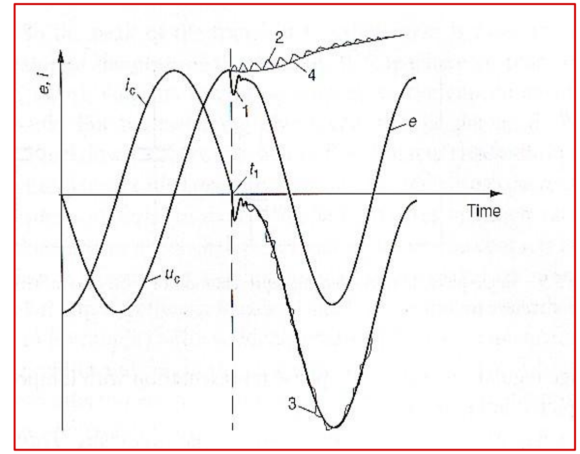


“Back-to-back” capacitors

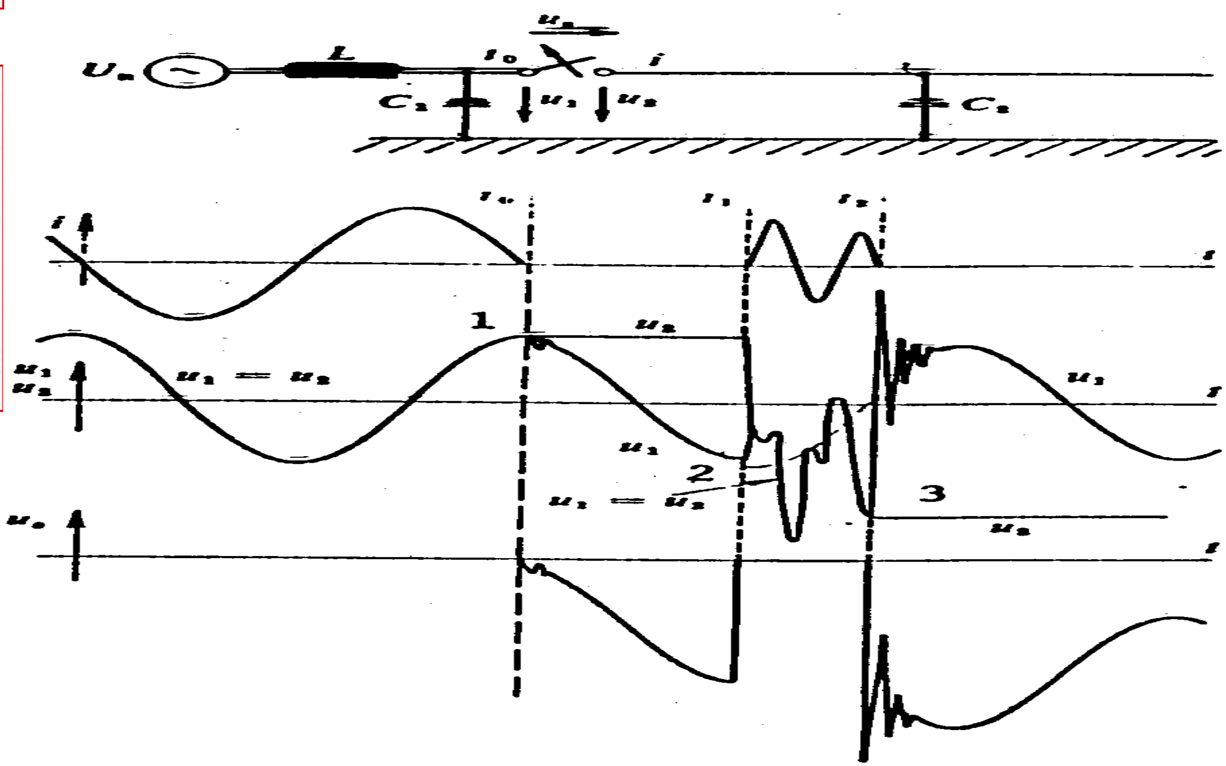




No-load lines



Reginition



SHORT LINE FAULTS

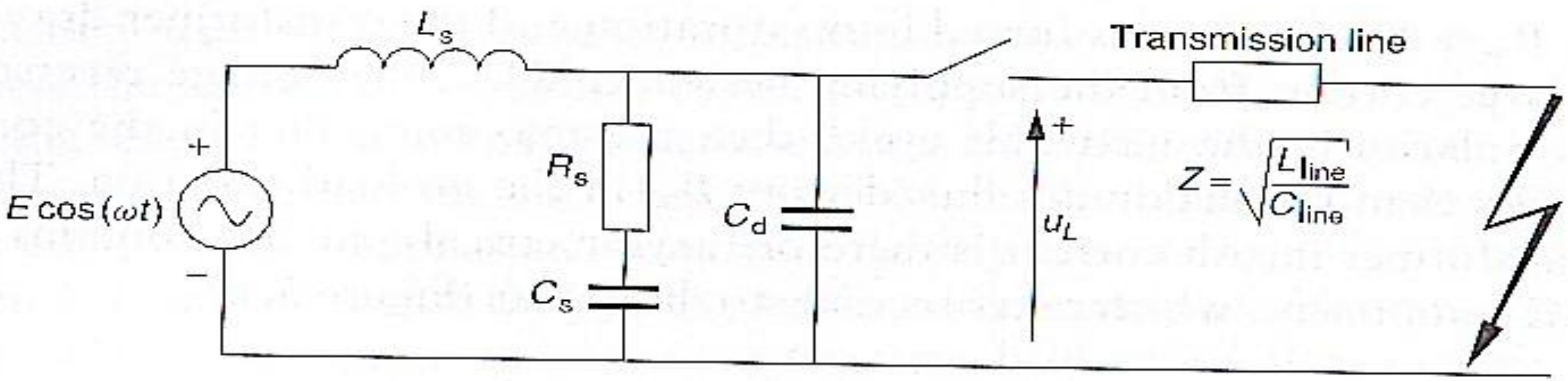
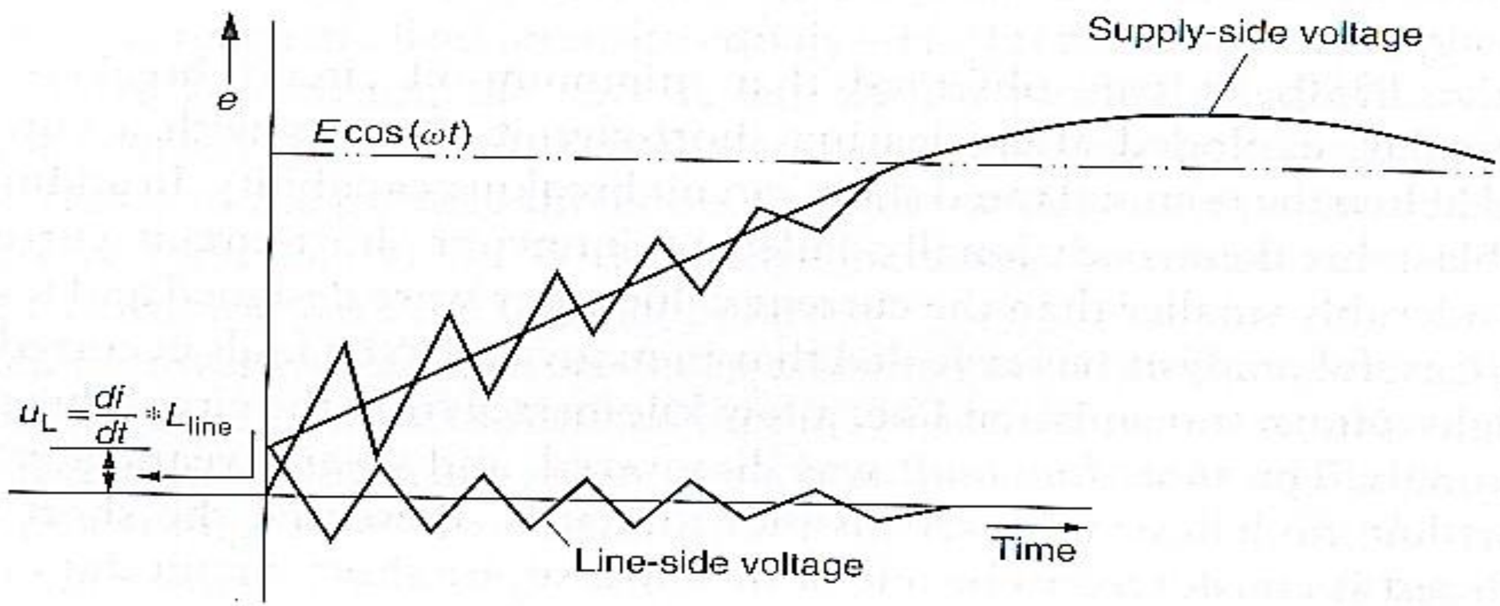
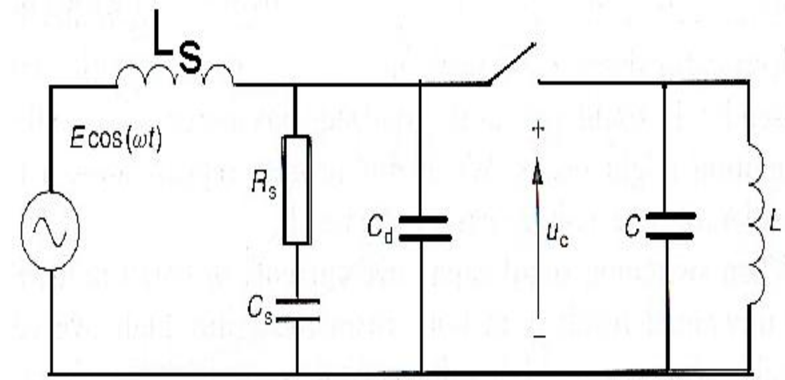


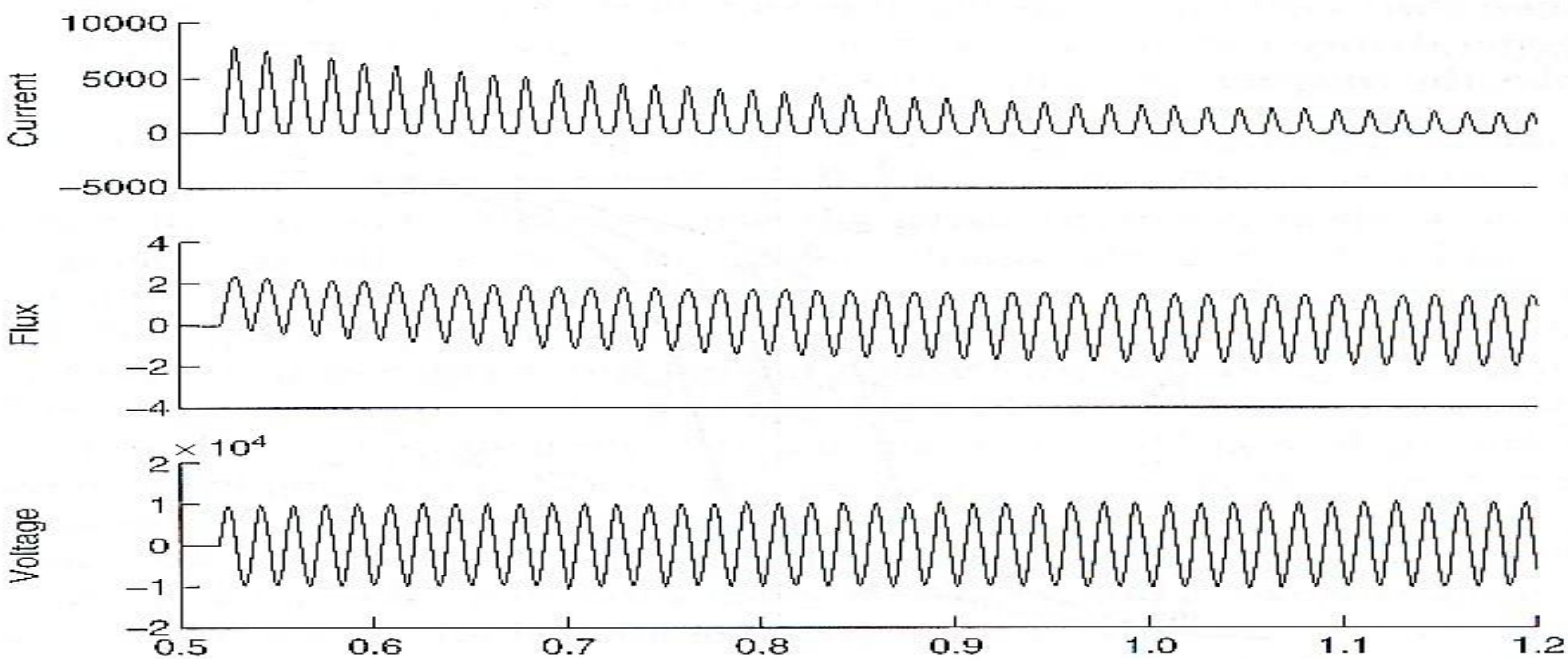
Figure 5.13 The short-line fault



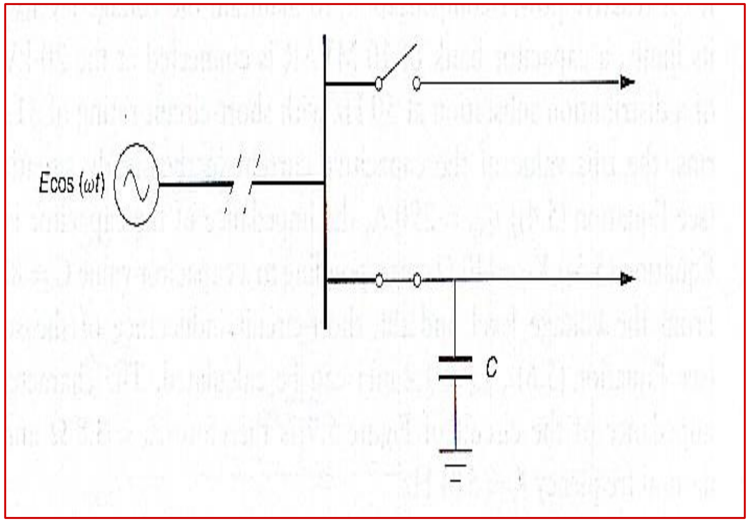
"INRUSH" CURRENTS IN POWER TRANSFORMERS

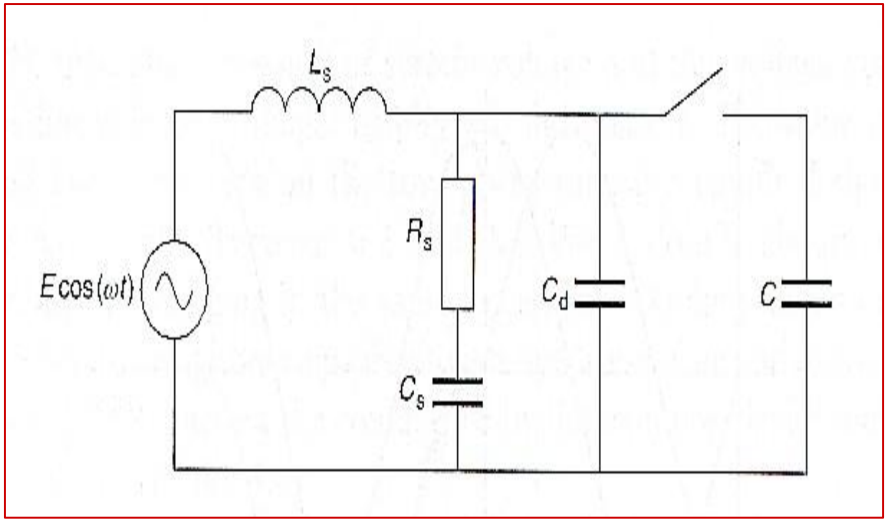
- Currents may reach 4 IN
- Depend on closing moment and remaining magnetic flux

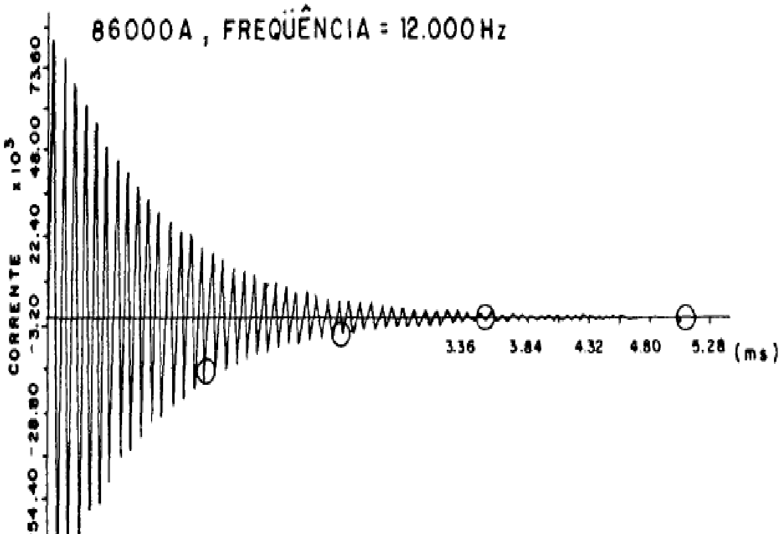




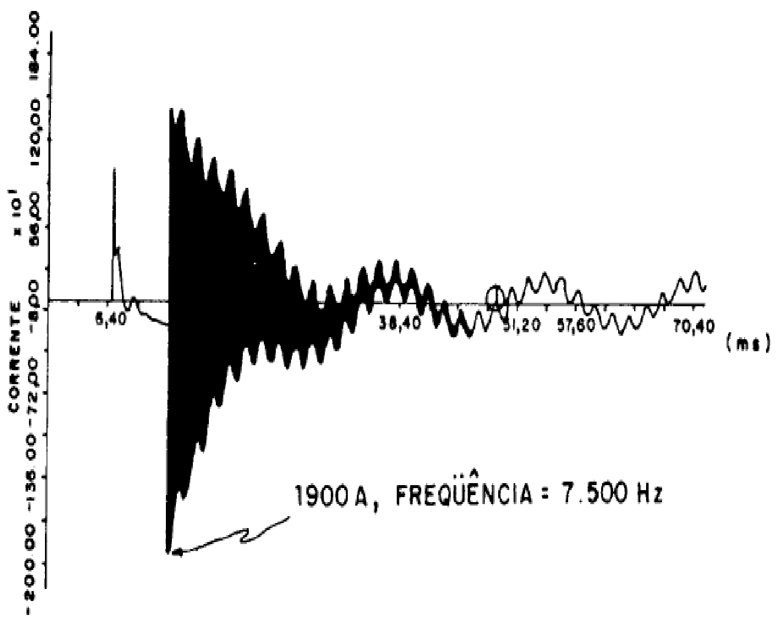
"INRUSH" CAPACITIVE CURRENTS





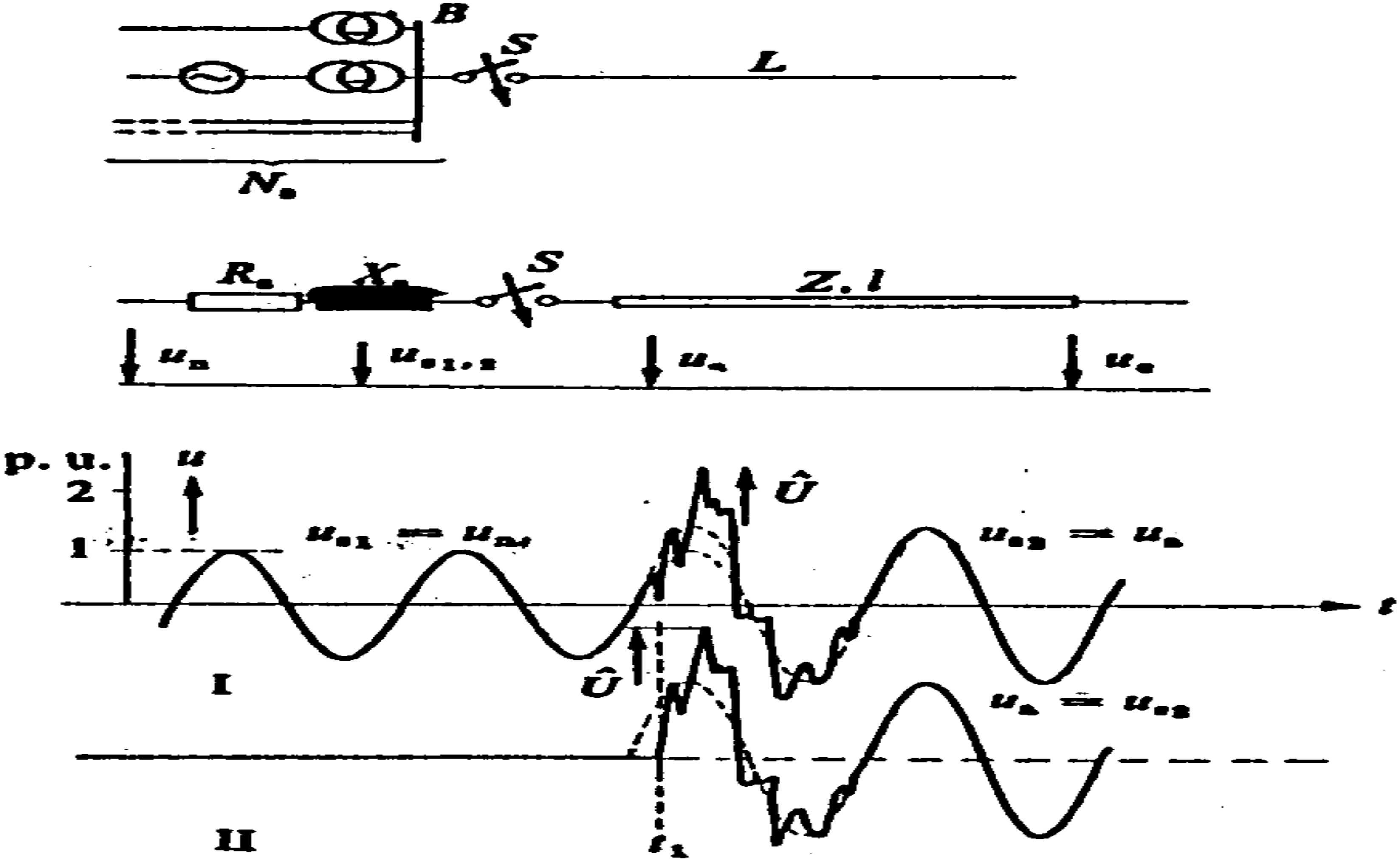


Curto-Circuito Próximo a um Banco de 162,5 MVAr, 345 kV



. Corrente de Energização, "Back-to-Back"(*) 125 MVAr, 138 kV

SWITCHING OF-LOAD LINES



OVERVOLTAGES CONTROL

PRE-INSERTION RESISTORS

- To reduce overvoltages in the switching operations for energization or reclosing of lines (closing)
- To reduce TRV during the opening operation
- Function of resistance and insertion duration (over price)

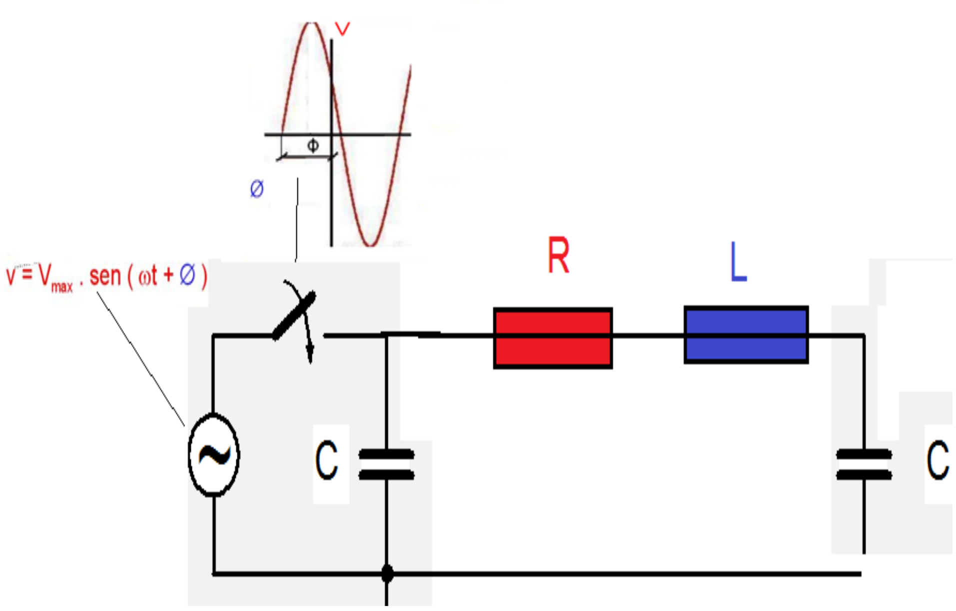
LIGHTNING ARRRESTERS : to reduce overvoltages to a level lower than the one supported by the protected equipment.

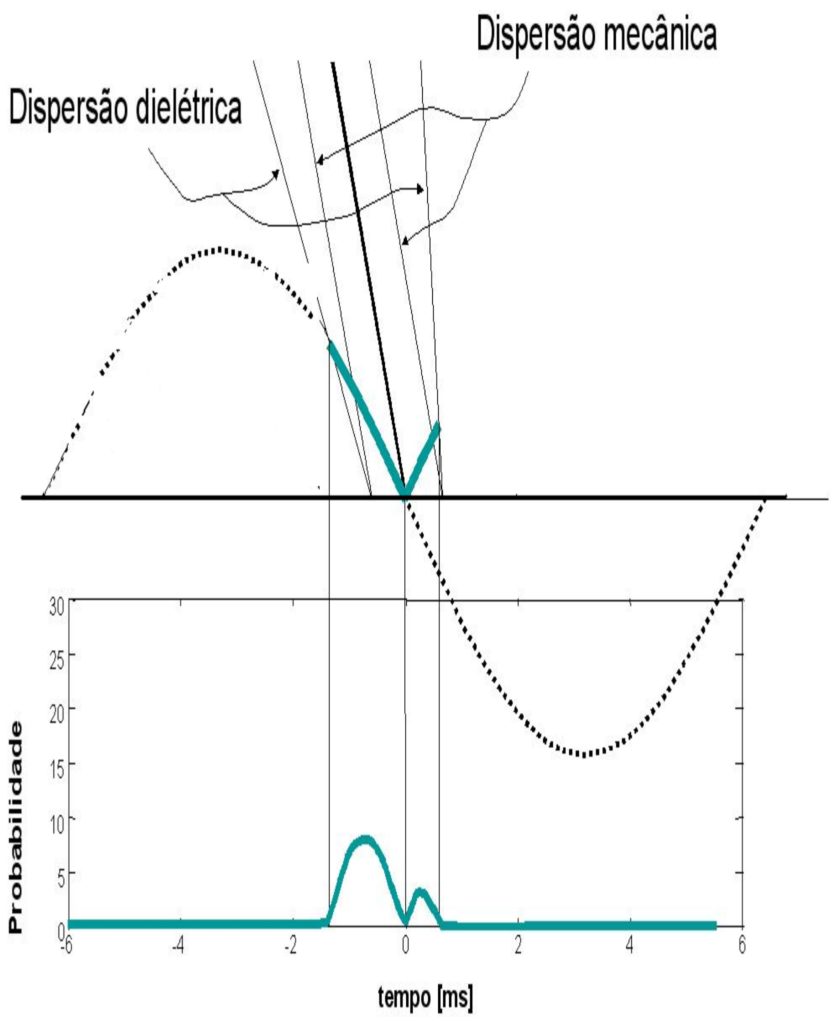
CAPACITORS in the terminals of circuit breakers to reduce TRV kV / µS.

SHIELDING OF SUBSTATIONS AND LINES AGAINST LIGHTNING (ground wires, protection rods) to avoid direct incidence in the conductors or busbars.

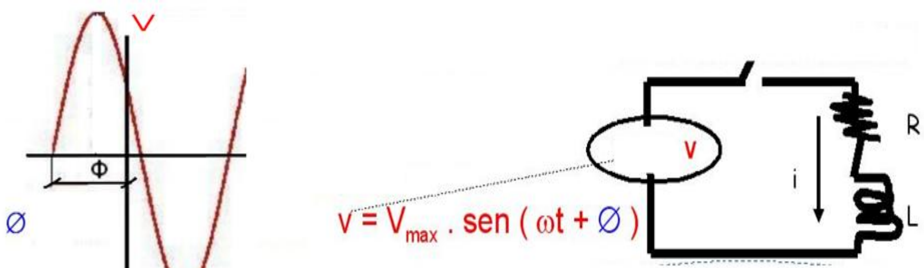
SYNCHRONIZERS: reduction of overvoltage or overcurrent by control of voltage wave angle

- Energization of no-load lines
- Energization of capacitive loads
- To avoid inrush currents

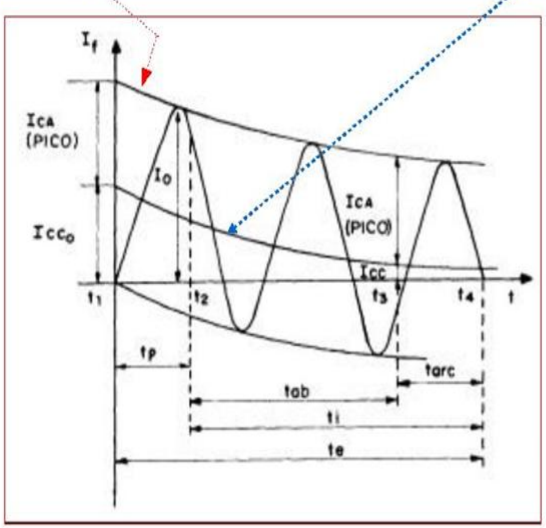




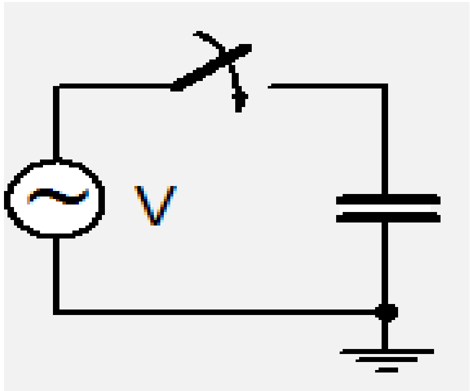
To reduce the asymmetry of the short circuit current : electrodynamical effects)

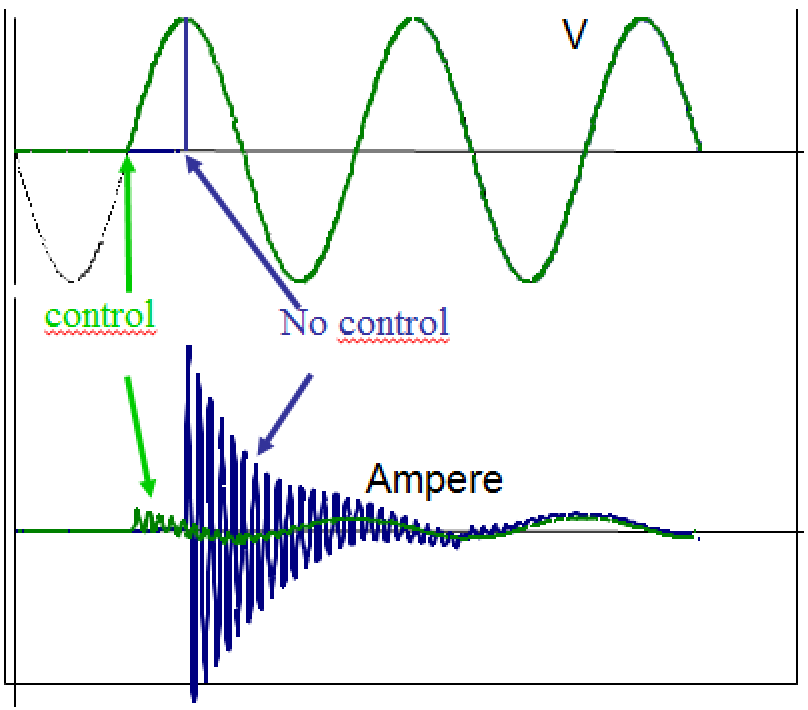


$$i = I_{max} \times sen (\omega t + \varnothing - \alpha) - I_{max} \times e^{-t/\sigma} \times sen (\varnothing - \alpha)$$

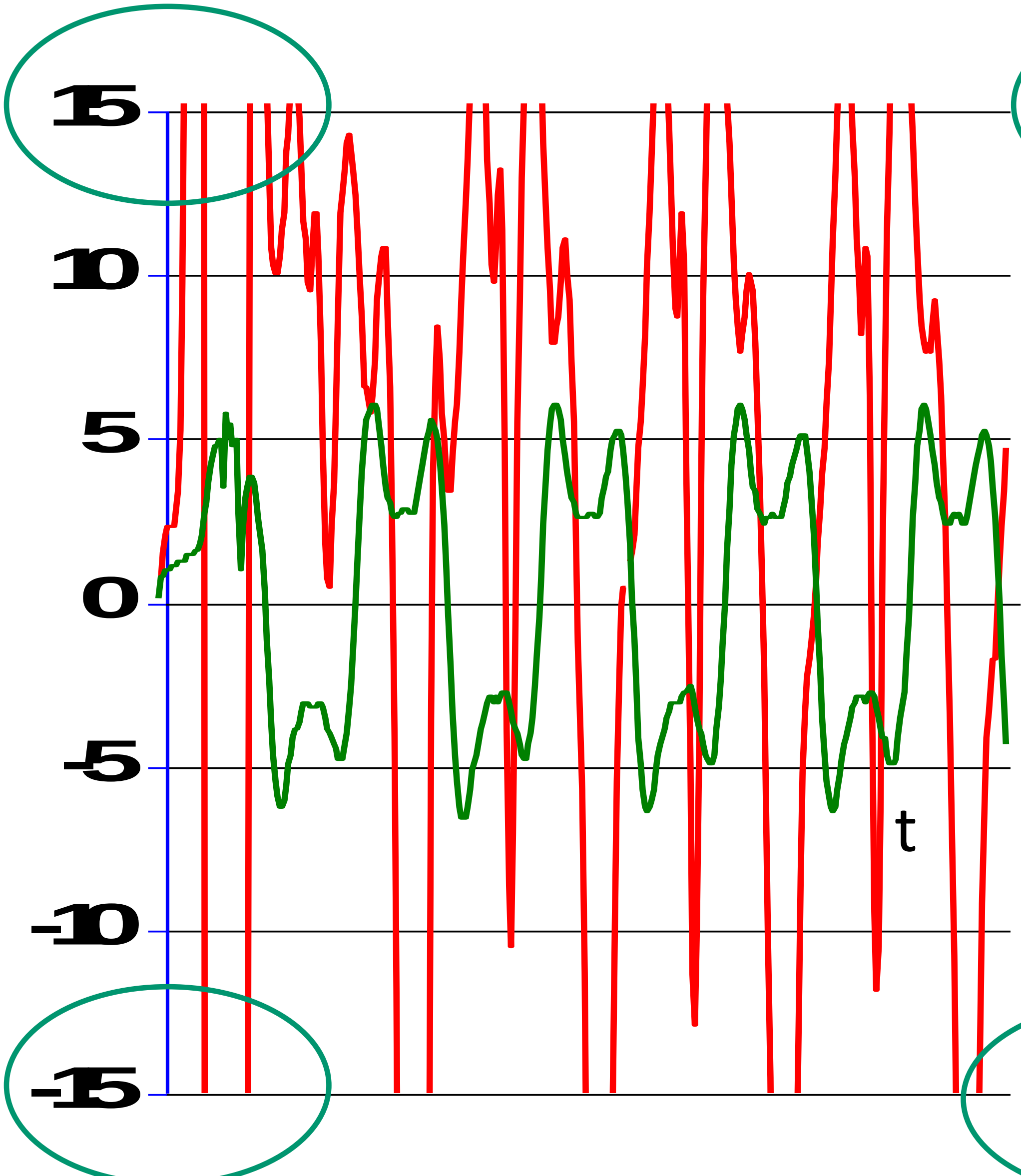


Switching on a capacitive load

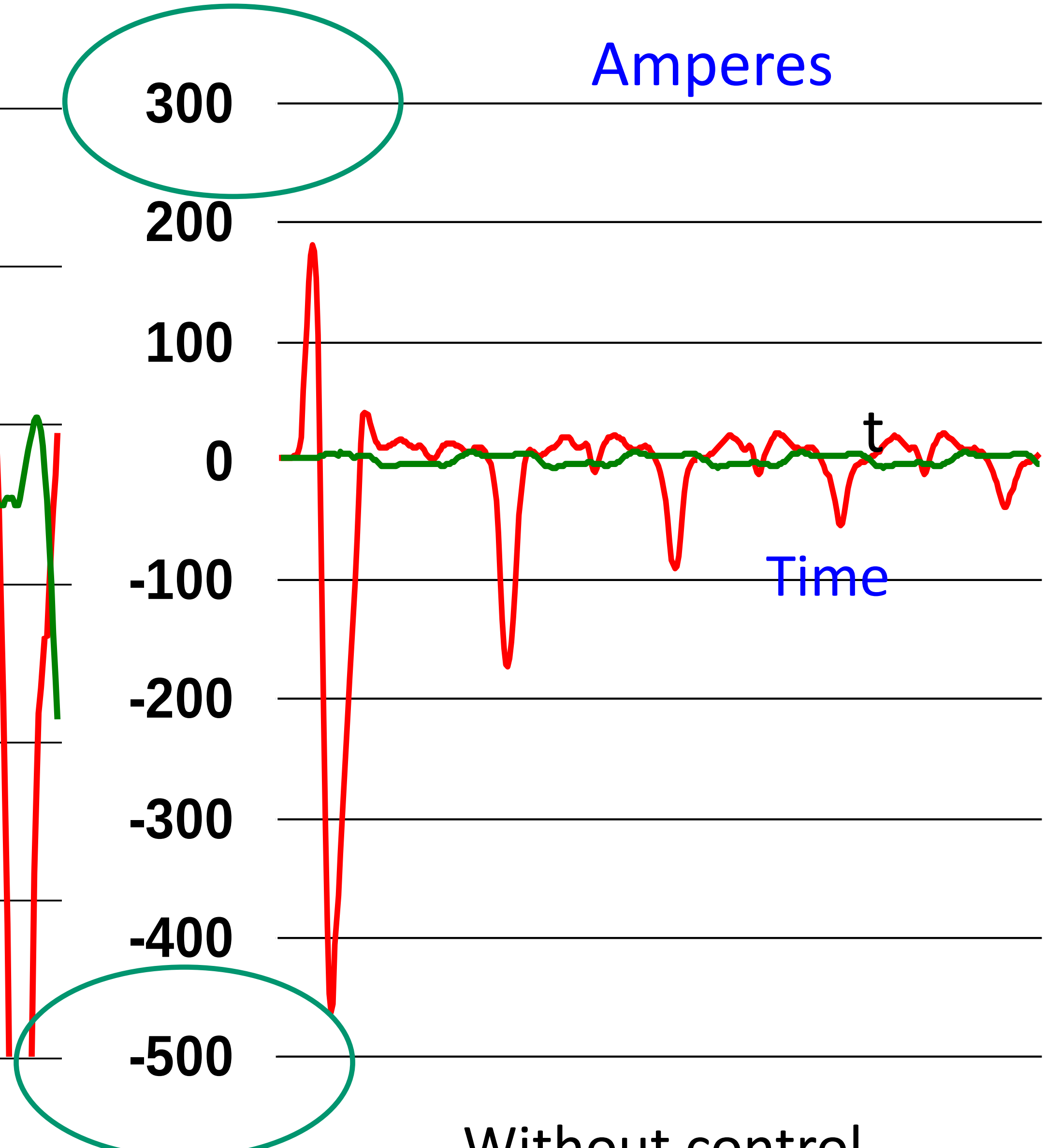




INRUSH CURRENT IN POWER TRANSFORMERS



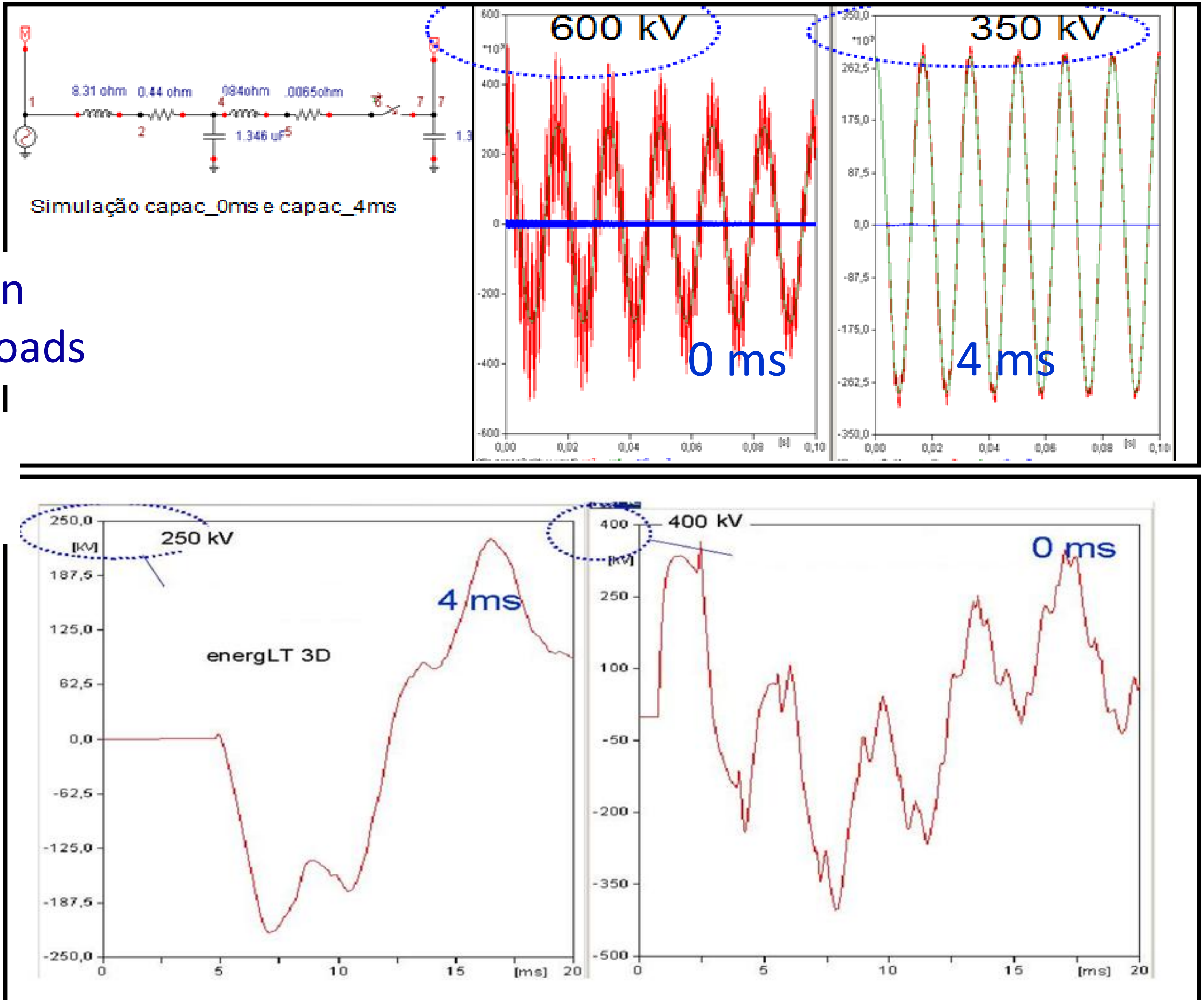
With control



Without control

Switching on capacitive loads

No-load lines



INSULATION (IEC 60071)

SELF-RESTORING :

after a short time, completely recovers its insulating properties after a disruptive discharge during test

- Distances between bus bars in neighbor phases
- Outside part of insulator columns

NON SELF-RESTORING :

loses its insulating properties, or does not recover them completely, after a disruptive discharge during test

- Paper impregnated with oil in transformers

CREEPAGE DISTANCES (KV / MM)

- Based on the maximum operating voltage, pollution, humidity and air density

INSULATION (IEC 60071)

Withstand voltage

value of the test voltage to be applied in a withstand voltage test, during which a specified number of disruptive discharges is tolerated. The withstand voltage is designated as:

a) conventional assumed withstand voltage, when the number of disruptive discharges tolerated is zero. It is deemed to correspond to a withstand probability P_w = 100 %;

b) statistical withstand voltage, when the number of disruptive discharges tolerated is related to a specified withstand probability. In this standard, the specified probability is P_w = 90 %.

NOTE ..., for non-self-restoring insulation are specified conventional assumed withstand voltages, and for self-restoring insulation are specified statistical withstand voltages.

INSULATION COORDINATION

- Determination of the overvoltages: magnitude, duration and probability of occurrence (ATP, TNA, ...)

- Selection of the insulation levels

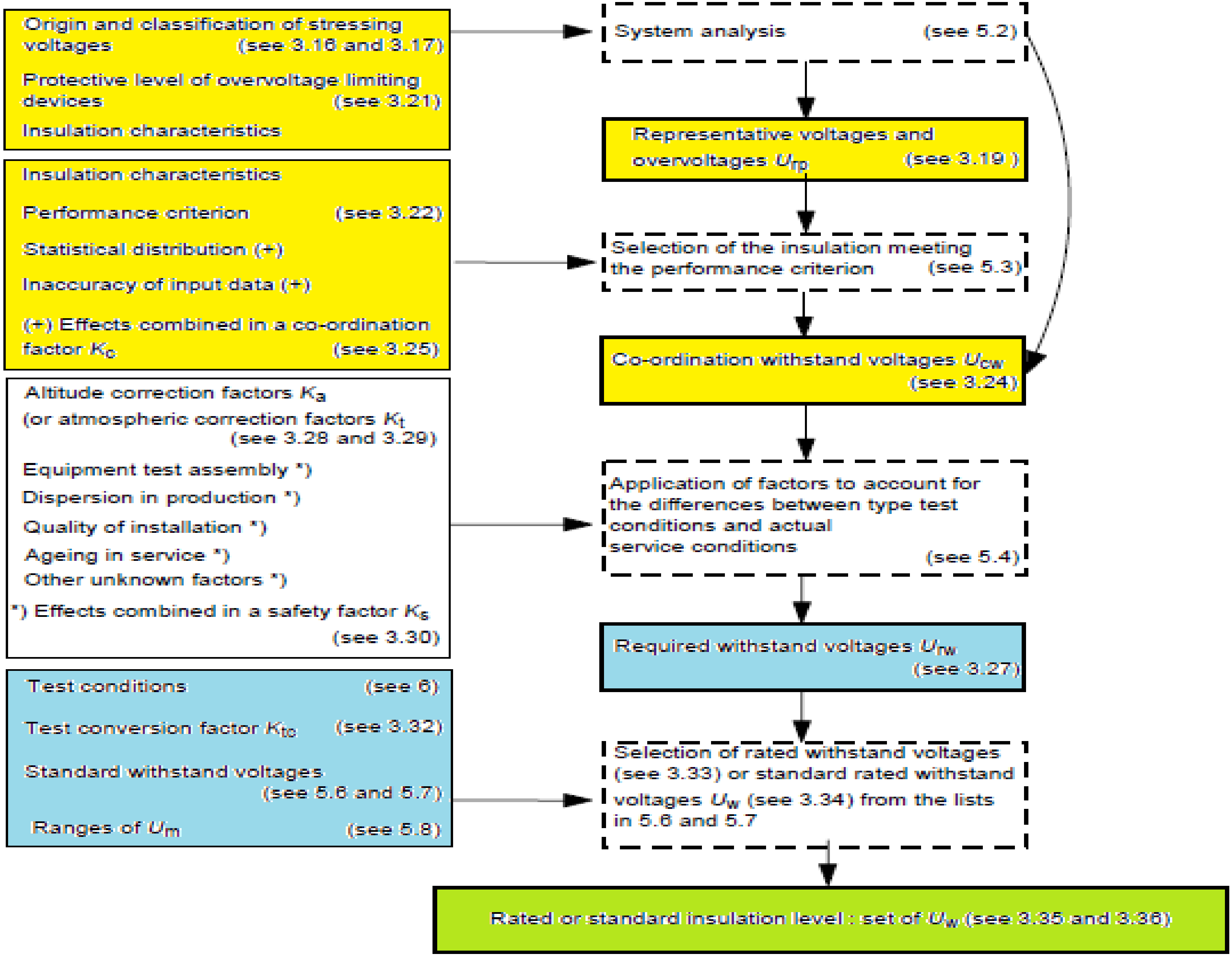
  - **Conventional method:** higher overvoltages + safety margin ((as 25%)

  - **Statistic method:** select a certain risk of failure taking

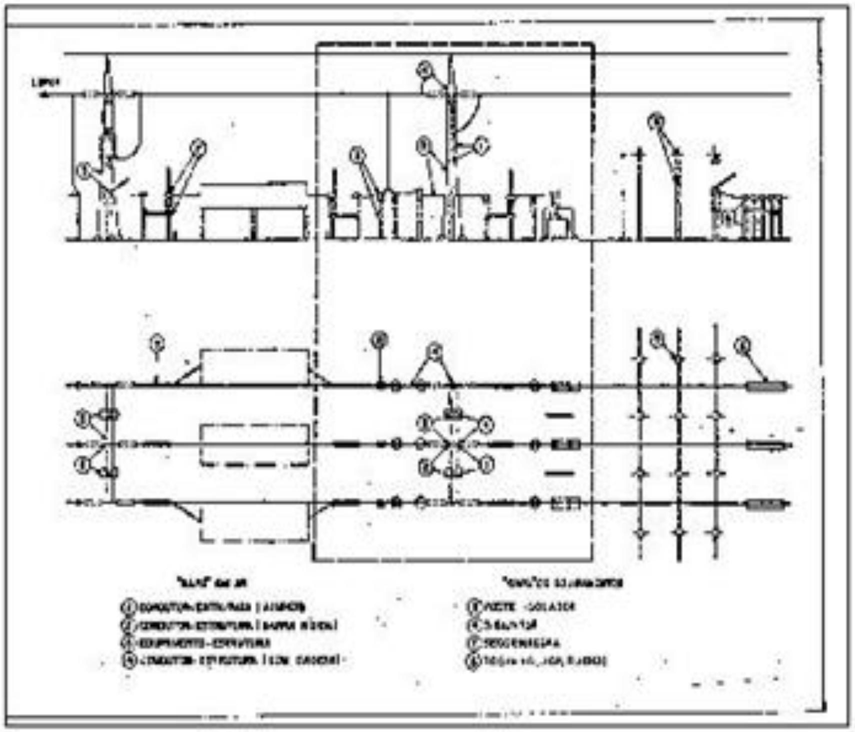
- Dielectric tests
  - Power frequency
  - Switching impulse (250 x 2500 µ S)
  - Atmospheric impulse (1,2 x 50 µ S)

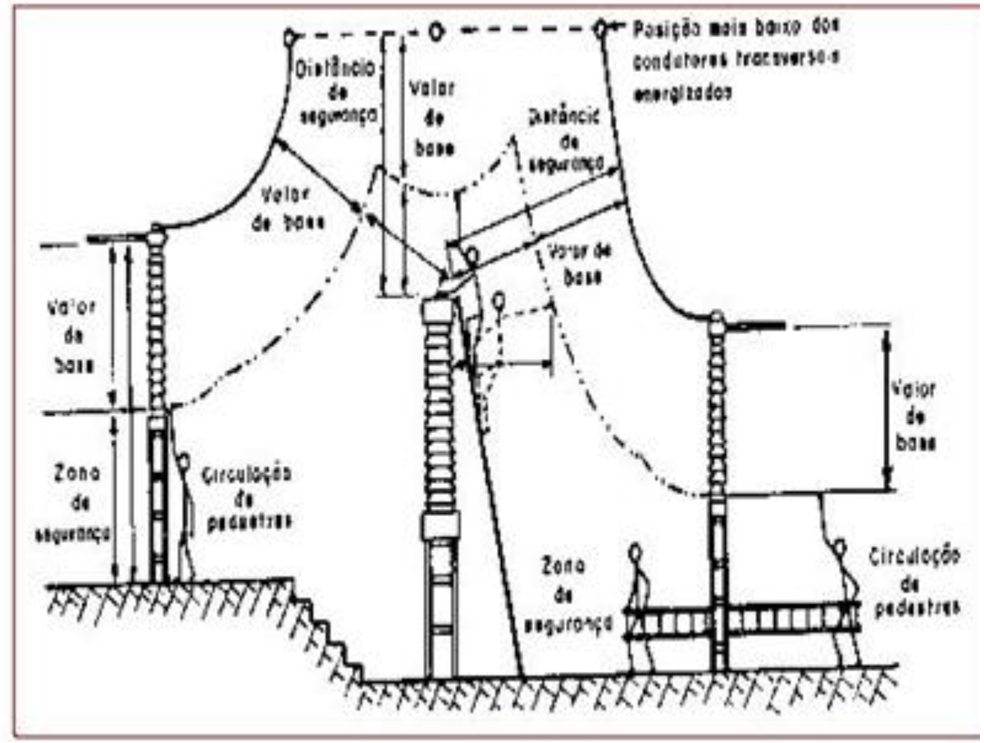
- Use of protection devices to reduce the overvoltages

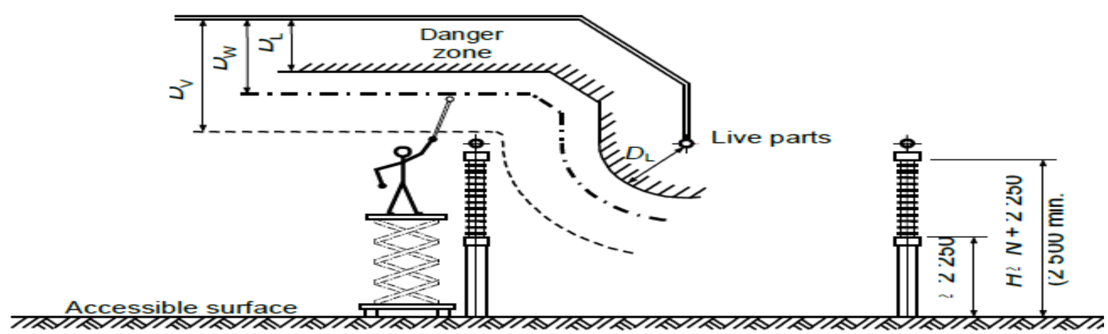
IEC 60071


Origin and classification of stressing voltages (see 3.16 and 3.17)
Protective level of overvoltage limiting devices (see 3.21)
Insulation characteristics
Insulation characteristics
Performance criterion (see 3.22)
Statistical distribution (+)
Inaccuracy of input data (+)
(+) Effects combined in a co-ordination factor K_c (see 3.25)
Altitude correction factors K_a
(or atmospheric correction factors K_t (see 3.28 and 3.29)
Equipment test assembly *)
Dispersion in production *)
Quality of installation *)
Ageing in service *)
Other unknown factors *)
*) Effects combined in a safety factor K_s (see 3.30)
Test conditions (see 6)
Test conversion factor K_{tc} (see 3.32)
Standard withstand voltages (see 5.6 and 5.7)
Ranges of U_m (see 5.8)
System analysis (see 5.2)
Representative voltages and overvoltages U_{rp} (see 3.19)
Selection of the insulation meeting the performance criterion (see 5.3)
Co-ordination withstand voltages U_{cw} (see 3.24)
Application of factors to account for the differences between type test conditions and actual service conditions (see 5.4)
Required withstand voltages U_{rw} (see 3.27)
Selection of rated withstand voltages (see 3.33) or standard rated withstand voltages U_w (see 3.34) from the lists in 5.6 and 5.7
Rated or standard insulation level : set of U_w (see 3.35 and 3.36)

SAFETY DISTANCES AND CLEARANCES (IEC 61936)







D_L = N
D_V = N + 1 000 for $U_n \leq 110$ kV
D_V = N + 2 000 for $U_n > 110$ kV
D_W = according to national standards or regulations
N = minimum clearance

IEC 61936-1 **POWER INSTALLATIONS EXCEEDING 1 kV AC – Part 1: Common rules**

5.1.2 In the voltage range I (1 kV < U_m ≤ 245 kV) the choice shall be based on the rated lightning impulse withstand voltages and the rated short-duration power-frequency withstand voltages of table 1; in the voltage range II (U_m > 245 kV) the choice shall be based on the rated switching impulse withstand voltages and the rated lightning impulse withstand voltages given in table 2. Values of rated insulation levels not standardized by IEC but based on current practice in some countries are listed in annex A (tables A.1, A.2 and A.3).

5.3.3 In voltage range II (see table 2) the clearances in air are determined by the rated switching impulse withstand voltage (SIWV). They substantially depend on the electrode configurations. In cases of difficulty in classifying the electrode configuration, it is recommended to make a choice based on the phase-to-earth clearances of the most unfavourable configuration such as, for example, the arm of an isolator against the tower construction (rod-structure).

IEC 61936 - Power installations exceeding 1 kV AC – Part 1: Common rules

Table 1 – Minimum clearances in air – Voltage range I (1 kV < U_m ≤ 245 kV)

Related to temporary overvoltages

Related to the impulse overvoltages

Voltage range	Nominal voltage of system	Highest voltage for equipment	Rated short-duration power-frequency withstand voltage	Rated lightning impulse withstand voltage [a]	Minimum phase-to-earth and phase-to-phase clearance, N [c]	
	U_n r.m.s.	U_m r.m.s.	r.m.s.	1,2/50 µs (peak value)	Indoor installations	Outdoor installations
	kV	kV	kV	kV	mm	mm
	3	3,6	10	20 40	60 60	120 120
	6	7,2	20	40 60	60 90	120 120
	10	12	28	60 75 95	90 120 160	150 150 160
	15	17,5	38	75 95	120 160	160 160
	20	24	50	95 125 145	160 220 270	
	30	36	70	145 170	270 320	
I	45	52	95	250	480	
	66	72,5	140	325	630	
	110	123	185 [b] 230	450 550	900 1 100	
	132	145	185 [b] 230 275	450 [b] 550 650	900 1 100 1 300	
	150	170	230 [b] 275 325	550 [b] 650 750	1 100 1 300 1 500	
	220	245	275 [b] 325 [b] 360 395 460	650 [b] 750 [b] 850 950 1 050	1 300 1 500 1 700 1 900 2 100	

Values applied in the tests

In equipment can be lower

Table 2 – Minimum clearances in air – Voltage range II (U_m > 245 kV)

Voltage range	Nominal voltage of system	Highest voltage for equipment [c]	Rated lightning impulse withstand voltage [a]	Rated switching impulse withstand voltage	Minimum phase-to-earth clearance		Rated switching impulse withstand voltage	Minimum phase-to-phase clearance	
	U_n r.m.s.	U_m r.m.s.	1,2/50 µs (peak value)	Phase-to-earth 250/2 500 µs (peak value)	Conductor – structure	Rod – structure *N*	Phase-to-phase 250/2 500 µs (peak value)	Conductor – conductor parallel	Rod – conductor
	kV	kV	kV	kV	mm		kV	mm	
II	275	300	850/950	750	1 600 1 700 [b]	1 900	1 125	2 300	2 600
			950/1 050	850	1 800 1 900 [b]	2 400	1 275	2 600	3 100
	330	362	950/1 050	850	1 800 1 900 [b]	2 400	1 275	2 600	3 100
			1 050/1 175	950	2 200	2 900	1 425	3 100	3 600
	380	420	1 050/1 175	850	1 900 2 200 [b]	2 400	1 360	2 900	3 400
			1 175/1 300	950	2 200 2 400 [b]	2 900	1 425	3 100	3 600
			1 300/1 425	1 050	2 600	3 400	1 575	3 600	4 200
	480	525 (550) [c]	1 175/1 300	950	2 200 2 400 [b]	2 900	1 615	3 700	4 300
			1 300/1 425	1 050	2 600	3 400	1 680	3 900	4 600
			1 425/1 550	1 175	3 100	4 100	1 763	4 200	5 000
	700	765 (800) [c]	1 675/1 800	1 300	3 600	4 800	2 210	6 100	7 400
			1 800/1 950	1 425	4 200	5 600	2 423	7 200	9 000
			1 950/2 100	1 550	4 900	6 400	2 480	7 600	9 400

Correction factors for altitude x insulation levels

Max. Altitude (m)	Correction factor
1 000	1,00
1 500	1,06
2 000	1,13
2 500	1,20
3 000	1,28

Correction factors for temperature rise x altitude

Max. Altitude (m)	Correction factor for rated current	Correction factor for temperature rise
1 000	1,00	1,00
1 500	0.99	0.98
3 000	0.96	0.92

End of module 2

COGNITOR

END OF MODULE 2

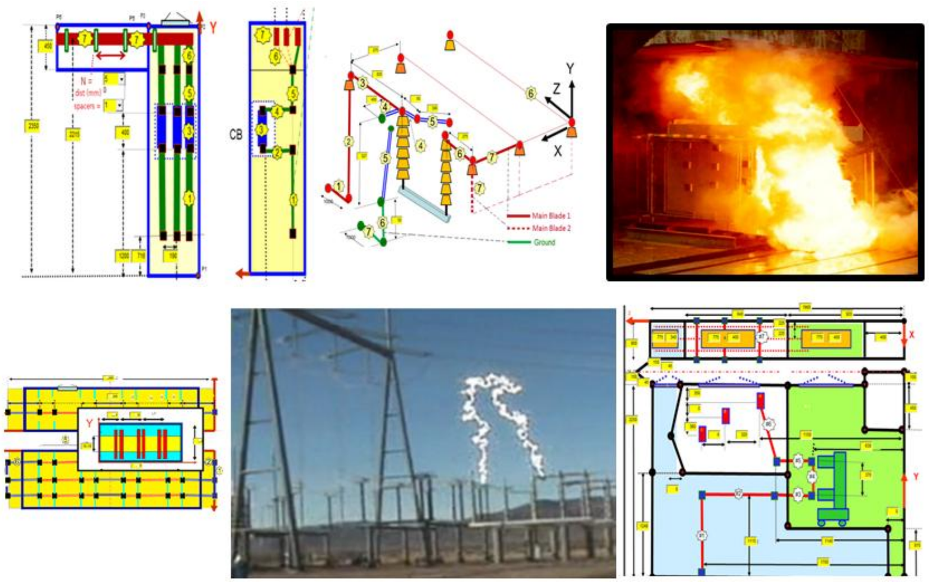
Reference materials for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

(focus in design techniques, specification, tests and simulations)



MODULE 3:

SHORT CIRCCUITS, AMPACITIES, OVERLOADS AND ELECTRICAL CONTACTS

by Sergio Feitoza Costa

www.cognitor.com.br

CURRENTS AND VOLTAGES (NORMAL AND FAULT)

Less than or equal to the nominal values

Normal ageing
(p.ex. 20 or 40 years)

Overcurrents long duration
(1,5 In during 120 seconds)

Moderate temperature rises: faster ageing or destruction

Overcurrents short duration
(20 In during 1 second)

High temperatures: annealing, melting, bending

Electrodynamical effects: forces of tons and damage to insulators and metal parts

Overvoltages

long duration (up to tens of seconds)

short duration (micro-seconds)

Imediate failure or faster ageing

TEMPERATURE RISE

- Supportability of materials, overloads, aging and reduced service life.
- Design aspects that affect test results of temperature rise.
- Transformers x overloads

EELECTRODYNAMICAL FORCES AND STRESSES

- Electromagnetic effects of short circuit currents.
- Calculation of forces and mechanical stresses and how to avoid design errors.
- Limit values for conductors and insulators.
- Short time and crest current tests

INTERRUPTION PROCESSES AND POWER ARCS

- Tecnologies: oil, compressed air, SF6, vaccum
- Effects of arcs in persons and installations
- Explosions and fires in power transformers

SHORT EXPLANATION ON THE SOFTWARE USED TO DEMONSTRATE THE CALCULATION AND DESIGN CONCEPTS

COMPLETE DETAILS ON HOW TO USE THE SOFTWARE ARE PRESENTED IN THE SLIDES OF MODULE 7.

- Screen for input data and geometry
- Screen for the presentation of the results

SCREENS AND SPECIFIC APPLICATIONS FOR :

- Busways
- Low and medium voltage switchgear
- Isolators
- High voltage fuses (not included in this course)
- Power transformers (not included in this course)

INITIAL SCREEN

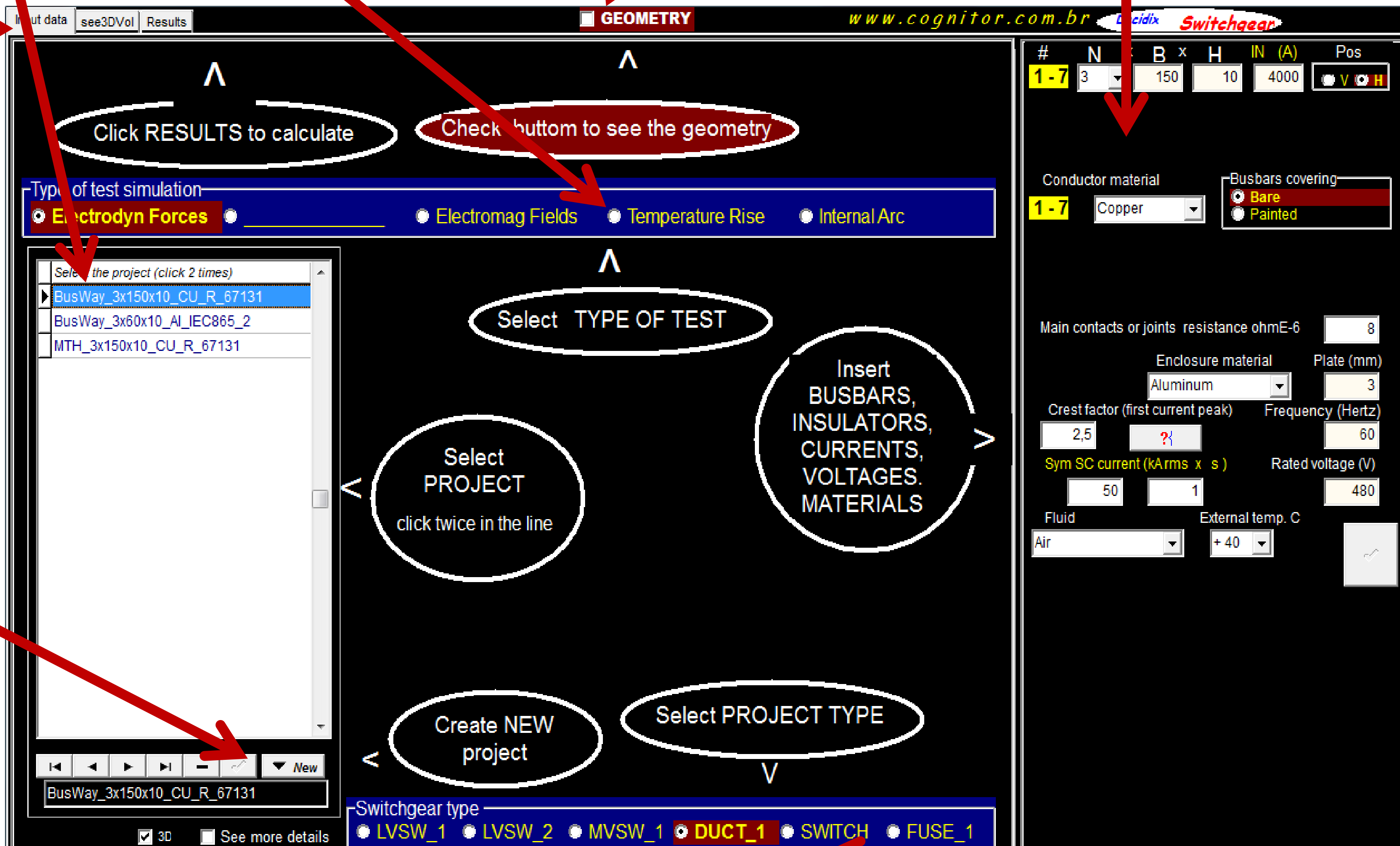
Project selected

Type of test to be simulated

Click here to see the geometry related to the PROJECT TYPE (type of equipment)

Data of the selected project(blue line in the left side)

Click INPUT DATA to change the data or click RESULTS to do the calculations and to see the test results



Click the button NEW to create a new project equal to the one which is selected (only the name is different) and them change the data and geometry

Type of equipment project to be simulated (LVSW 1 &2 = Low Voltage switchgear, MVSW1 – Medium Voltage Switchgear DUCT_1 = bus way , SWITCH = isolator)

INPUT DATA SCREEN BUSWAYS DUCT_1

Number assigned to each conductor (#1 to # 7) to visualize results

Number of subdivisions in conductors # 3 e 5 and corresponding distance between supports

Geometry and dimensions (mm)

Conductors # 1 to 7 formed by 3 bars per phase 150x10 mm

Current applied in the temperature rise test (A)

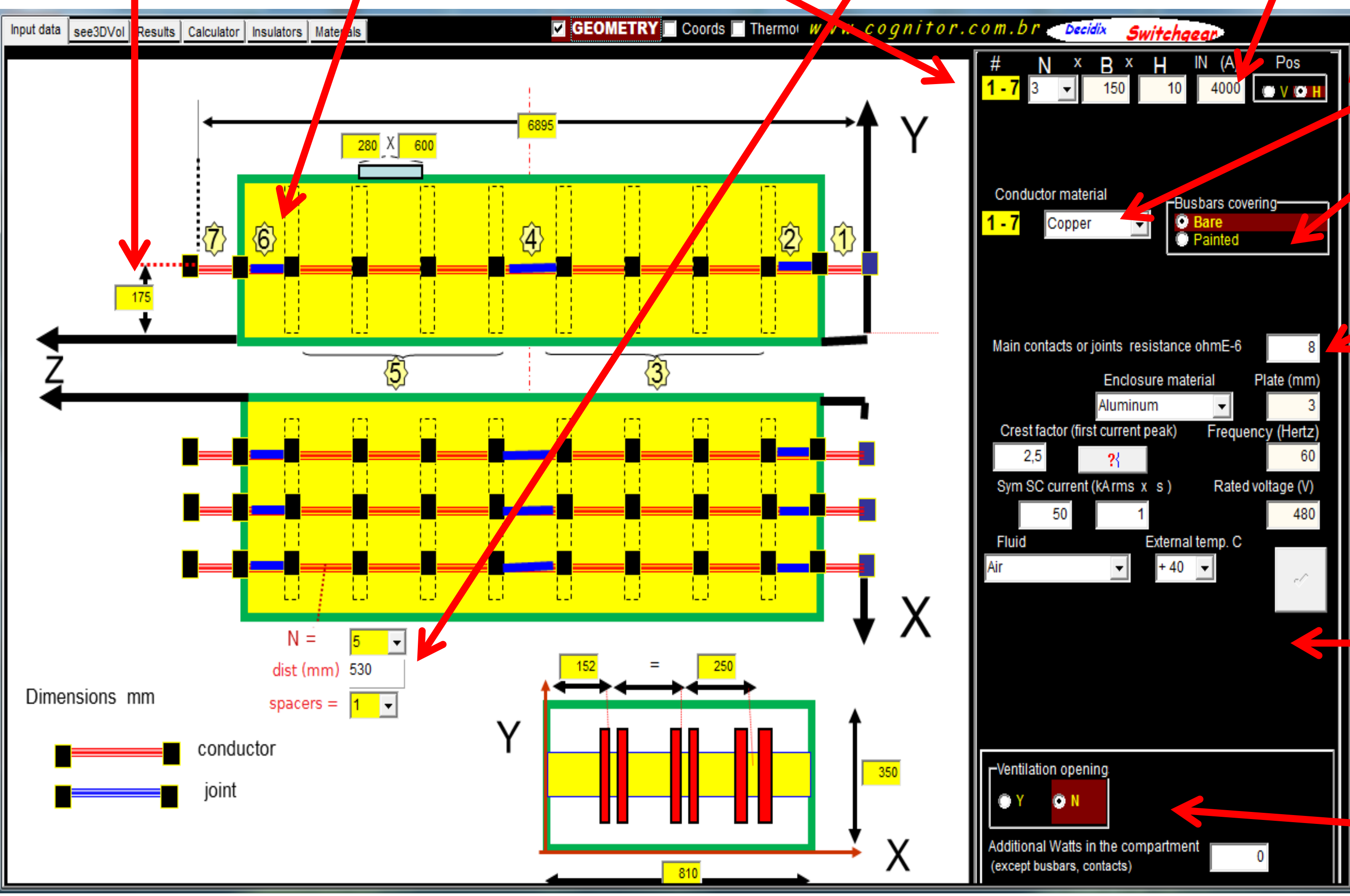
Bar in the Horizontal or Vertical position

Material: copper, aluminum

Bar coating: bare, painted

Joints resistance (μΩ) Conductors #2,4 e 6

Rated voltage (V)
Enclosure material
Fluid (air, SF6, óil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor



Ventilation openings area (IEC 60890)

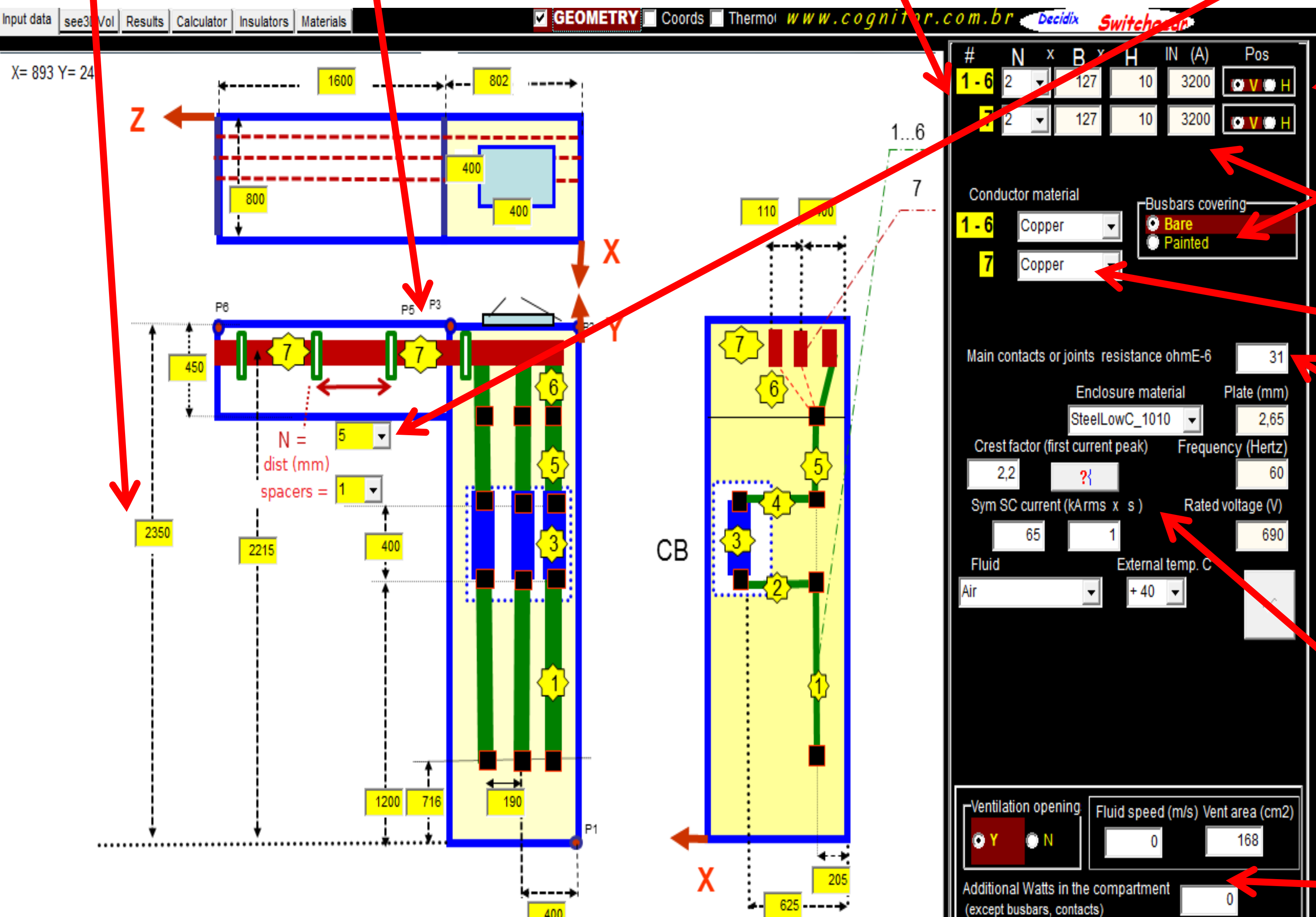
INPUT DATA LOW VOLTAGE SWITCHGEAR LVSW_1

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line is for conductors # 1 to # 6, in this example 2 bars per phase 127 x 10 mm
The second line is for conductor #7 which in this example 2 bars per phase 127 x 10 mm

Number of subdivisions in conductor # 7 and corresponding distance between supports (in # 1 to 6 is 1)

Geometry and dimensions (mm)



Bar in the Horizontal or Vertical position

Bar coating: bare, painted

Current applied in the temperature rise test (A)

Material: copper, aluminum

Circuit Breaker resistance (μΩ) Conductor s# 2, #3 and #4

Rated voltage (V)
Enclosure material
Fluid (air, SF6, oil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation area, additional power dissipation (IEC 60890)

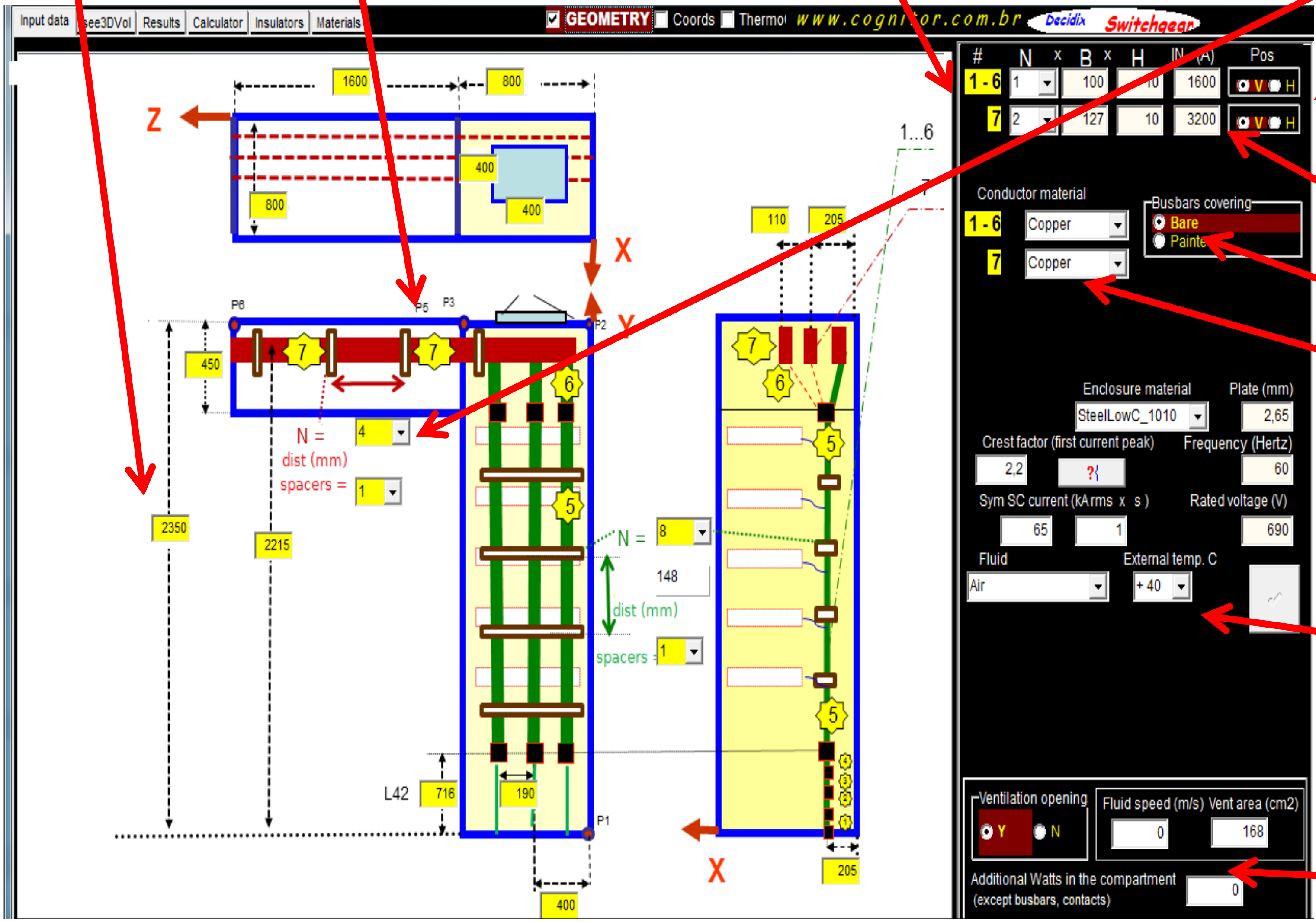
INPUT DATA LOW VOLTAGE SWITCHGEAR LVSW_2

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line is for conductors # 1 to # 6, in this example 1 bar per phase 100 x 10 mm
The second line is for conductor #7 in this example 2 bars per phase 127 x 10 mm

Number of subdivisions in conductor # 7 and corresponding distance between supports (in # 1 to 6 is 1)

Geometry and dimensions (mm)



Bar in the Horizontal or Vertical position

Current applied in the temperature rise test (A)

Bar coating: bare, painted

Material: copper, aluminum

Rated voltage (V)
Enclosure material
Fluid (air, SF6, oil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation area, additional power dissipation (IEC 60890)

COGNITOR

INPUT DATA MEDIUM VOLTAGE SWITCHGEAR MVSW_1

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line refers to conductors # 1 to # 6 , in this example 2 bars of 63,6 x 10 mm. The second line refers to conductor #7 (here 1x100x10 mm)

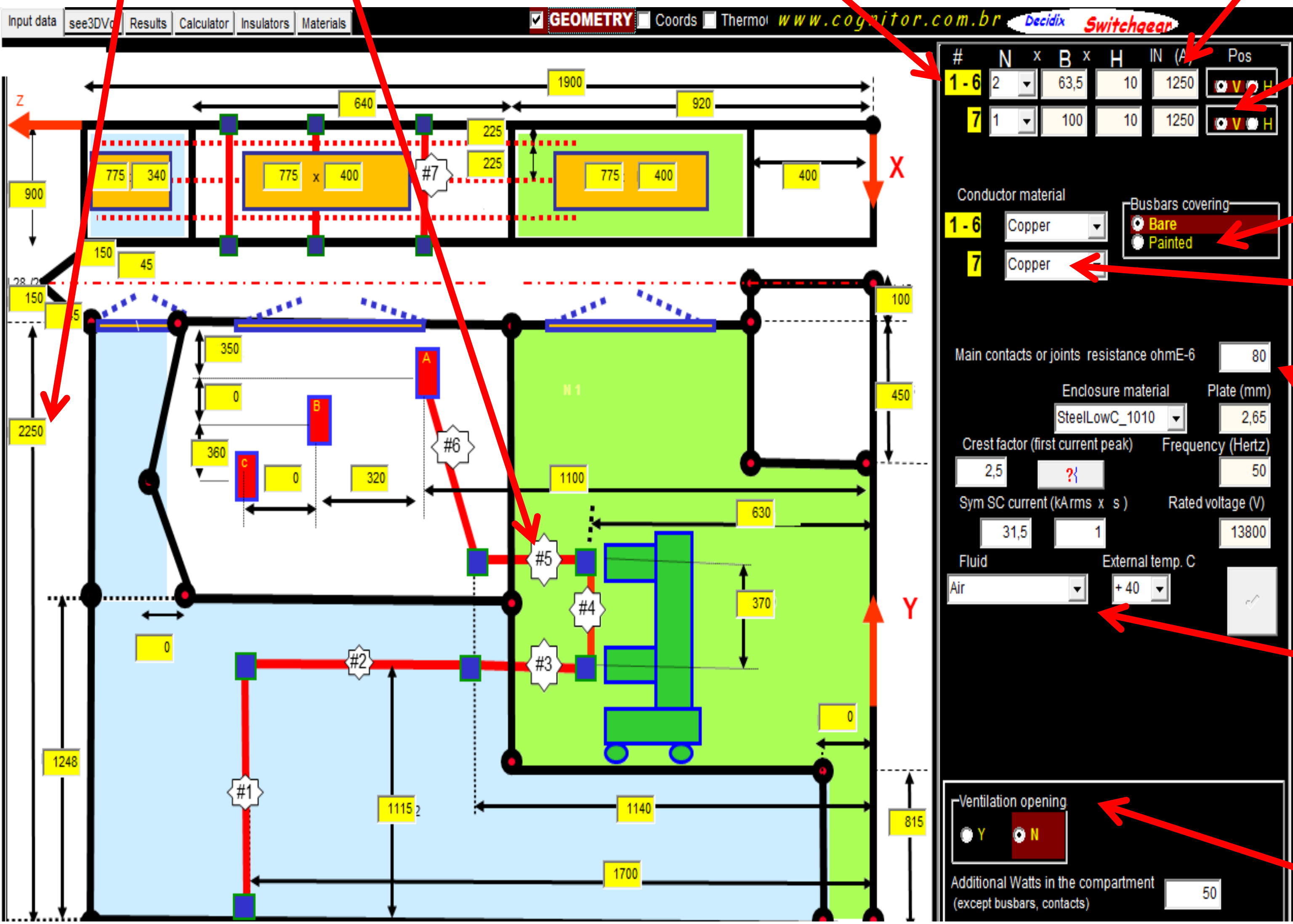
Current applied in the temperature rise test (A)

Geometry and dimensions (mm)

Bar in the Horizontal position

Bar coating: bare, painted

Material: copper, aluminum



Circuit breaker (CB) resistance (μΩ) CB represented by conductors #4, 5 and 6

Rated voltage (V)
Enclosure material
Fluid (air, SF6, oil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation area (IEC 60890)

COGNITOR

INPUT DATA ISOLATORS SWITCH_1

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line (1-3) refer to conductors #1 to # 3 in this example 1 bars of 40 x 12 mm. The second line (4-7) refer to conductors #4 to #7 (here 2 bars of 50 x 6 mm)

Current applied in the temperature rise test (A)

Geometry and dimensions (mm)

Bar in the Horizontal or Vertical position

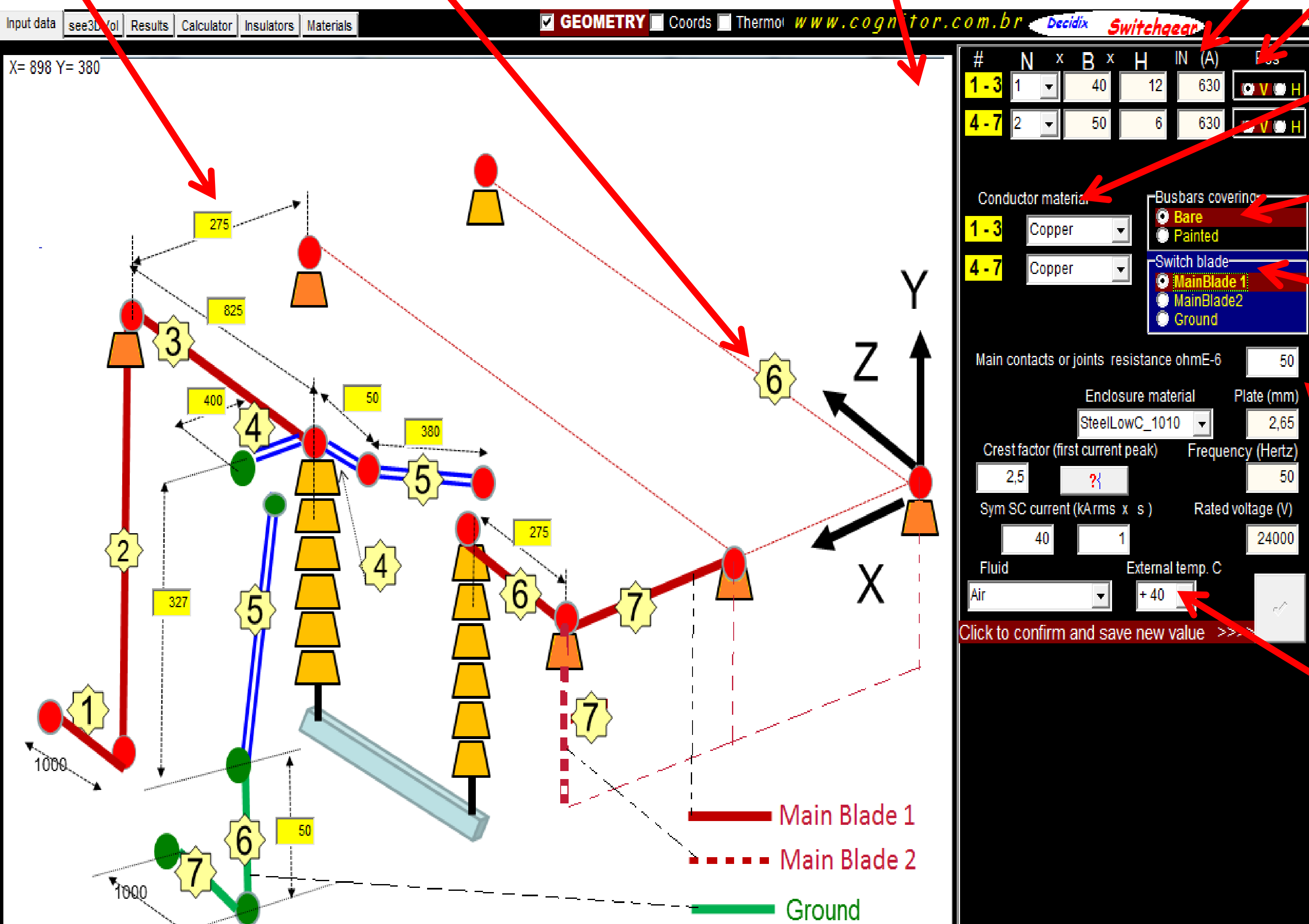
Material: copper, aluminum

Bar coating: bare, painted

Select the blade which will be calculated and the type of arrangement for the "Main Blade"

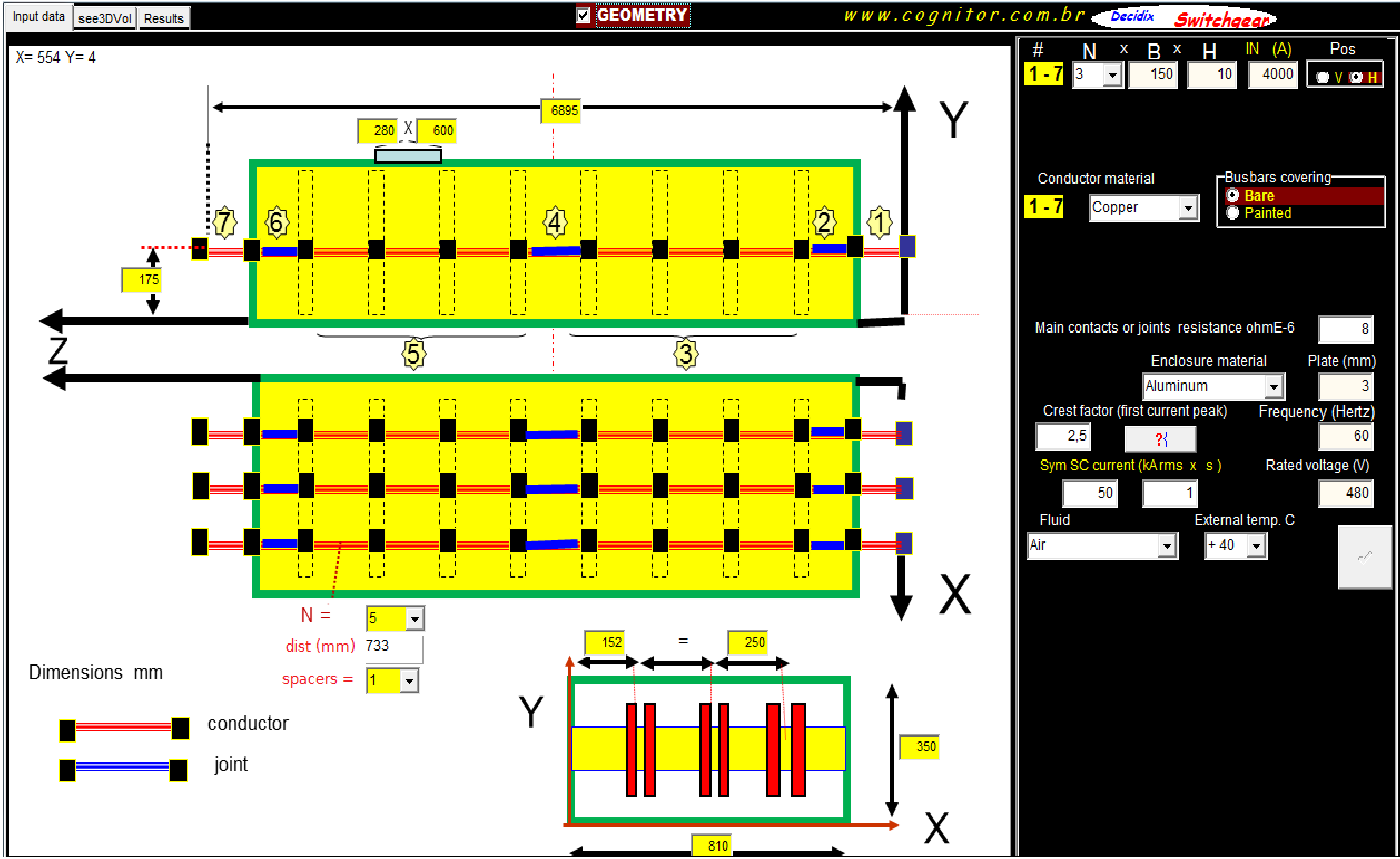
Joints resistance (μΩ) Conductor #5

Rated voltage (V)
Enclosure material
Fluid (air, SF6, óil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor



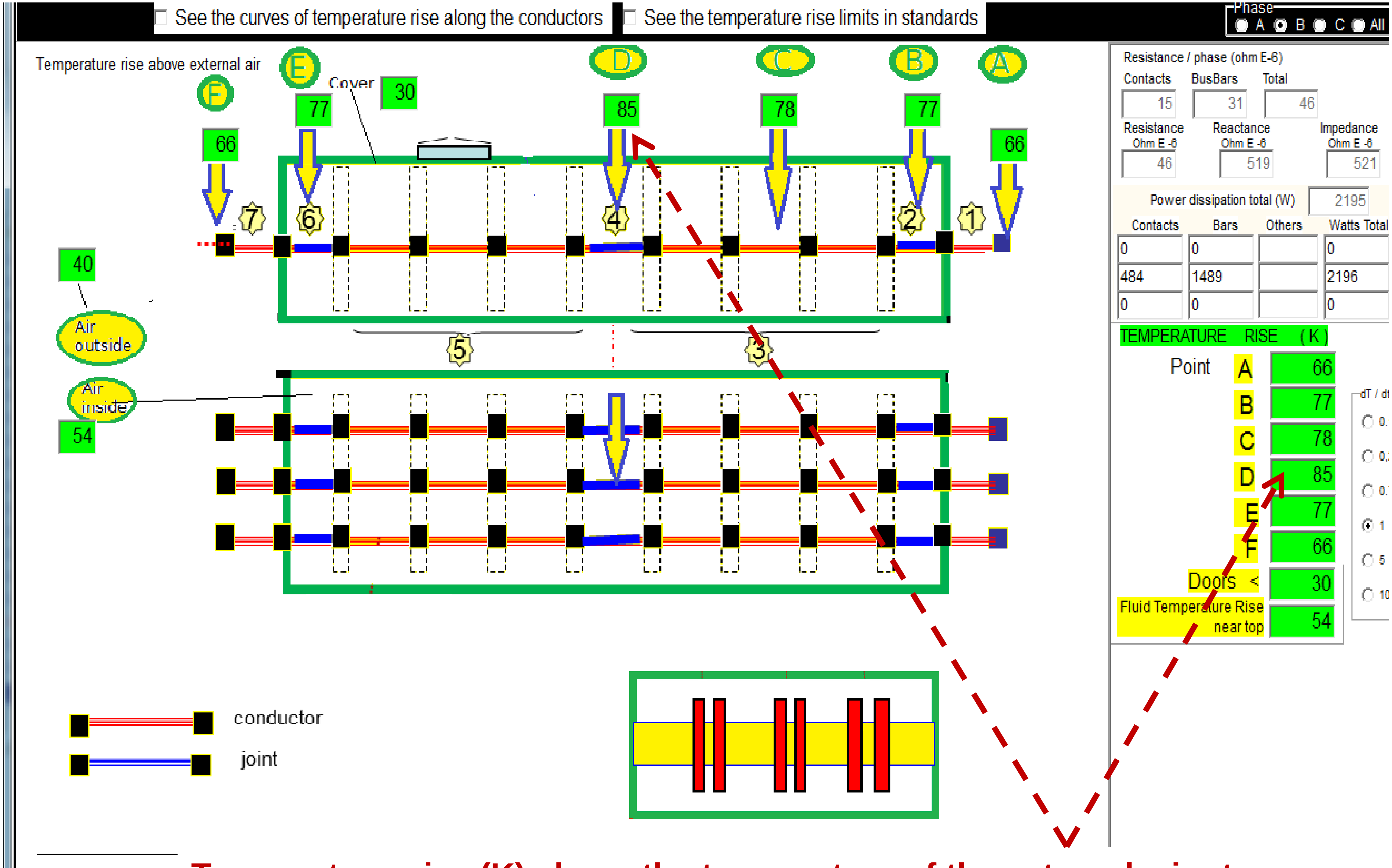
RESULTS VISUALIZATION - TEMPERATURE RISE TEST

BUSWAY (validated case BusWay_3x150x10_CU_R_67131)



RESULTS VISUALIZATION - TEMPERATURE RISE TEST

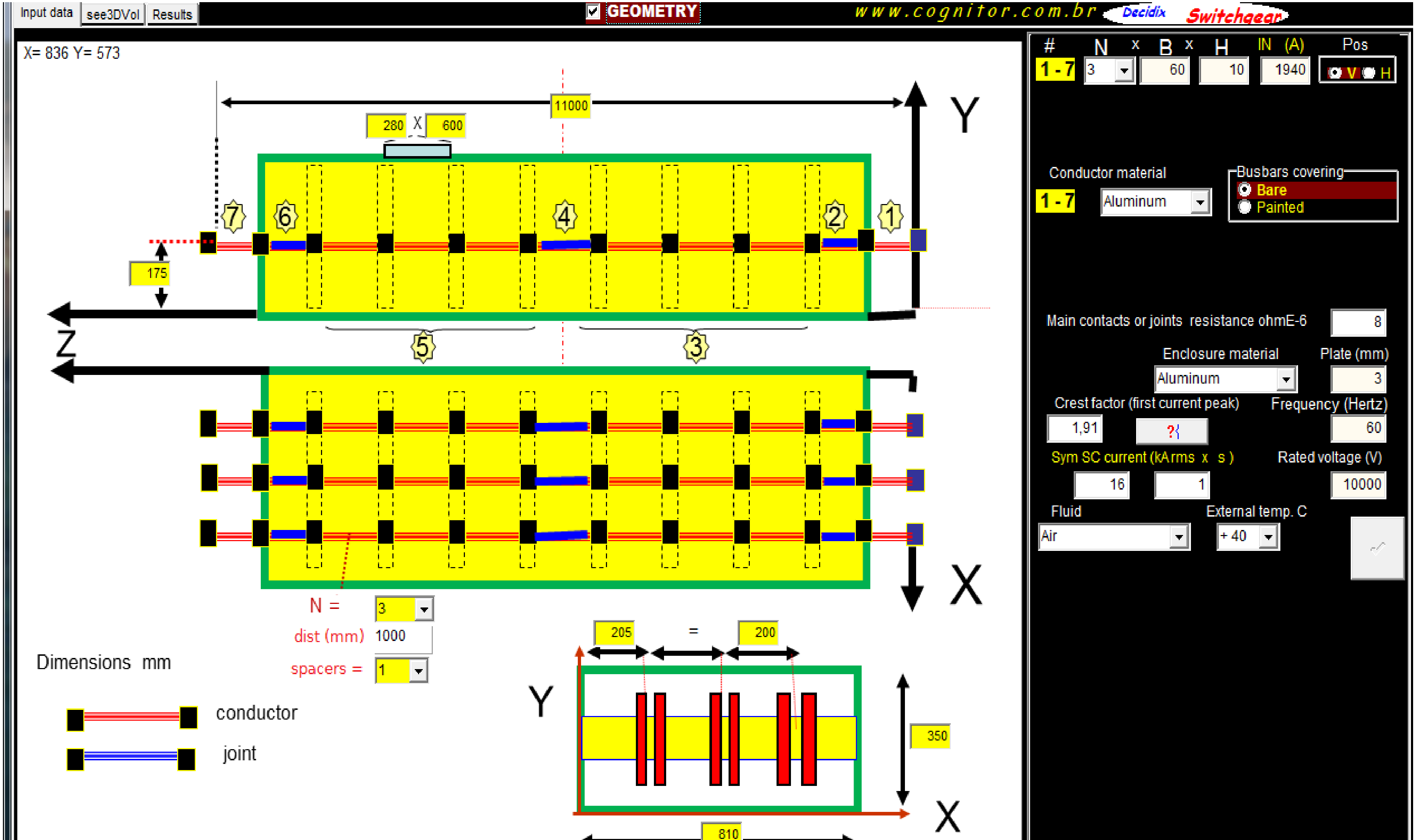
BUSWAY (validated case BusWay_3x150x10_CU_R_67131)



Temperature rise (K) above the temperature of the external air at different points

RESULTS VISUALIZATION - SHORT TIME CURRENT TEST

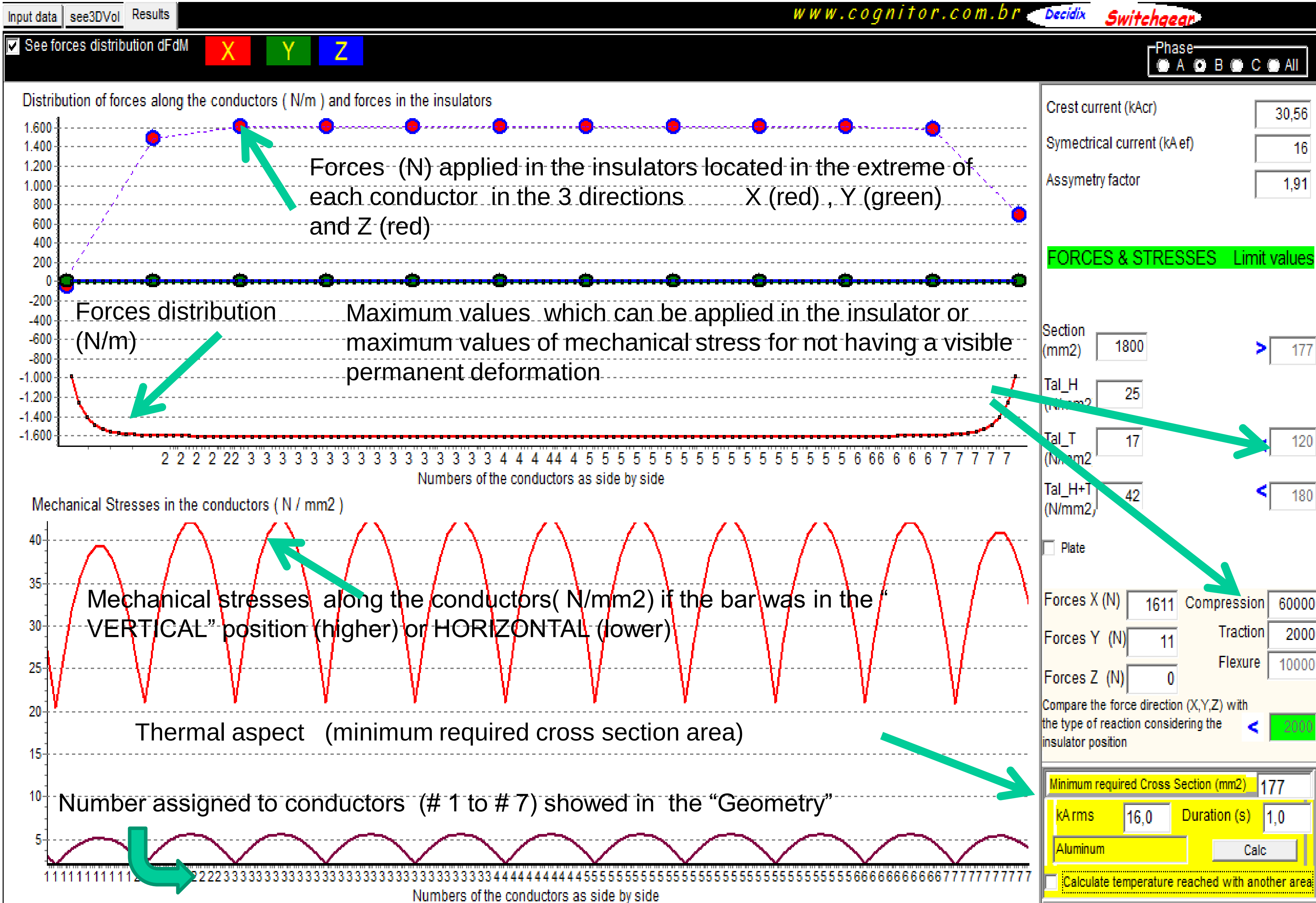
BUSWAY (validated case BusWay_3x60x10_Al_IEC865_2)



COGNITOR

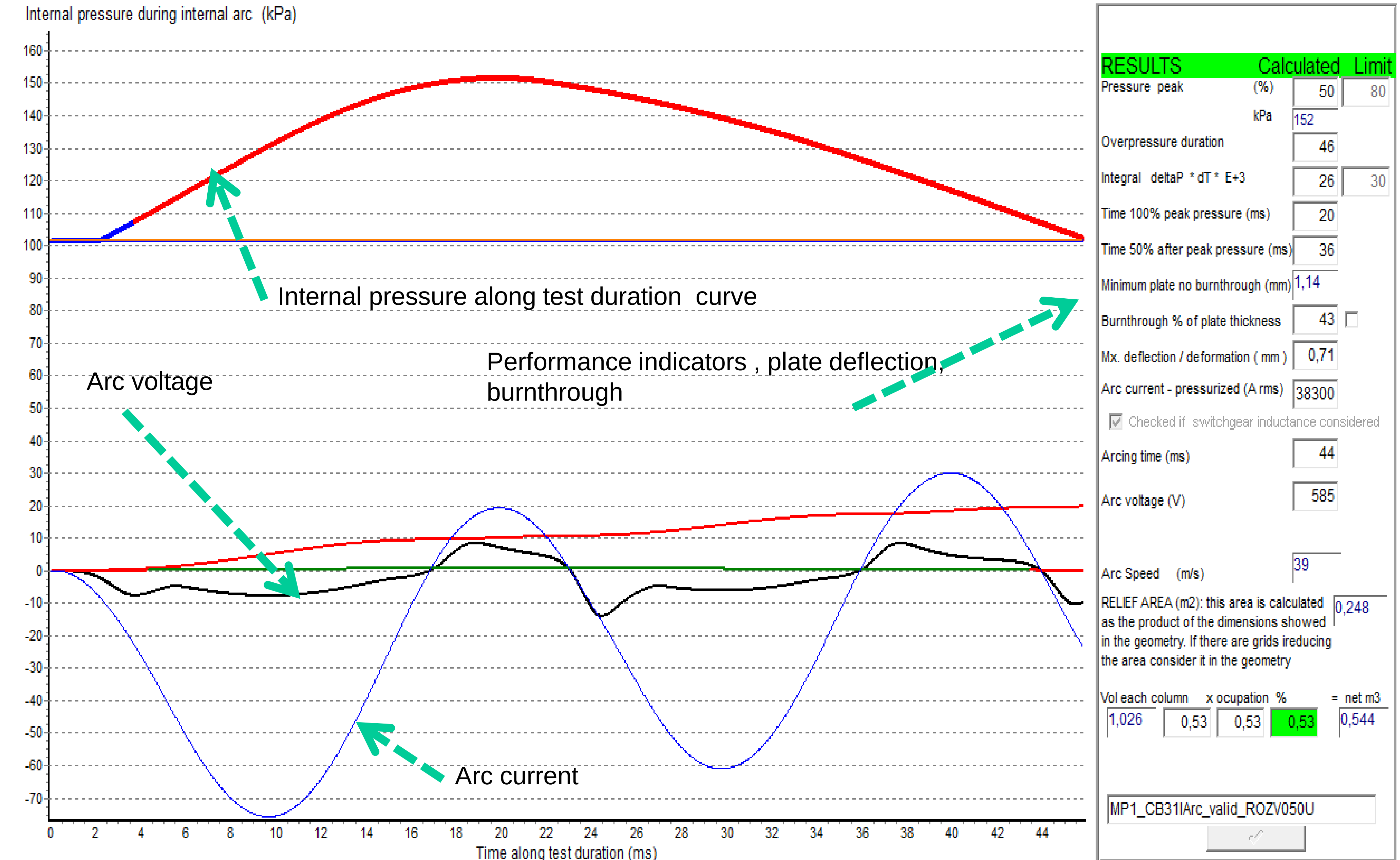
RESULTS VISUALIZATION - SHORT TIME CURRENT TEST

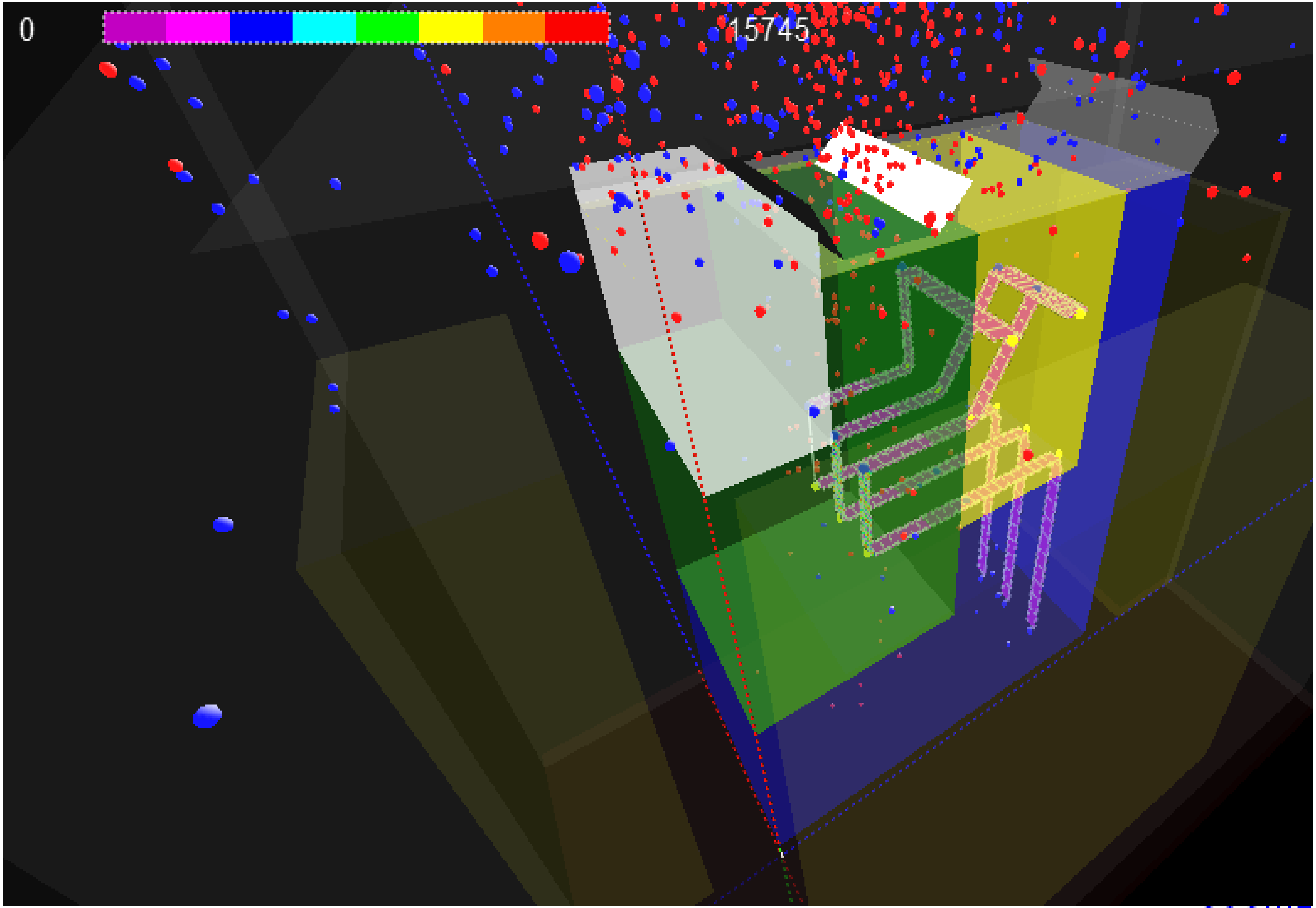
BUSWAY (validated case BusWay_3x60x10_Al_IEC865_2)



RESULTS VISUALIZATION - INTERNAL ARC TEST

Medium voltage switchgear (validated case MP1_CB31IArc_valid_ROZV050U



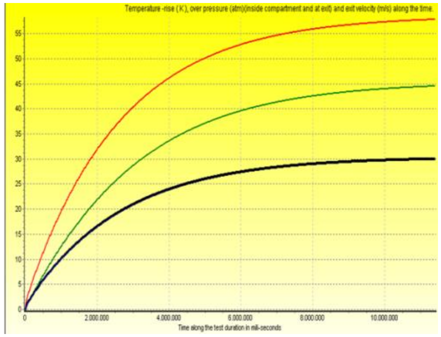

0
15745

TEMPERATURE RISE

Supportability of materials, overloads, ageing and loss of life.

Design issues that affect temperature rise test results.

TEMPERATURE RISE TEST (fundaments)



- Mount the equipment as in normal use
- Site without air drafts
- Apply the permanent rated current
- Wait for the temperatures stabilization (hours)
- Measure the temperature rise of the relevant points specified in the technical standard (above the temperature of the external air)
- Compare the measured values with the limits prescribed in the standard

- Knowing the temperature rise during the test we can know what would be the temperatures if the outside air temperature was, eg 40 º C.

- Register in the test report the relevant parameters. Technical standards should specify this clearly but there are important omissions.

•As the standard do not emphasize what shall be identified, most test reports issued by laboratories are poor from the point of view of photos and drawings not permitting a reliable comparison between the equipment which was tested and the equipment which is commercialized.

READ THE FOLLOWING PAPERS AUTHORED BY SERGIO

VALIDATION OF TEST REPORTS ISSUED BY RECOGNIZED TESTING LABORATORIES
http://www.cognitor.com.br/ValidatingReports_Eng.pdf

A "GUIDE" FOR THE USE OF CALCULATIONS AND SIMULATION OF LABORATORY TESTS FOR INCREASING THE COMPETITIVENESS OF THE ELECTRIC INDUSTRY
http://www.cognitor.com.br/Article_Competitivity_Eng_04102011.pdf

VALIDATION OF SIMULATIONS OF ELECTRODYNAMICAL FORCES, TEMPERATURE-RISE AND INTERNAL ARC TESTS IN SWITCHGEAR (and main parts of a code to do them)
http://www.cognitor.com.br/Validation_Simulations_English.pdf
CIGRE Technical Seminar "Modeling and Testing of T&D Switchgear" March 24, 2010 Brisbane – Australia

SWITCHGEAR , BUSBAR SYSTEMS and ITS BUILT-IN COMPONENTS: SOMETHING IS MISSING IN IEC and IEEE STANDARDS
Published in Energy Pulse weekly, September, 28 , 2010
http://www.cognitor.com.br/Switchgear_Busbar_Standards_Review_English.pdf
http://www.energypulse.net/centers/article/article_display.cfm?a_id=2338

TEMPERATURE RISE TEST

Fundaments of the values of temperature rise specified in the IEC standards

- Avoid to accept test reports which do not inform whether the equipment passed or failed the test. It may not have passed and sometimes it's hard to know without knowing well the standard
- If certain limits specified in the technical standards are exceeded parts may have accelerated aging or even destroyed in a small time

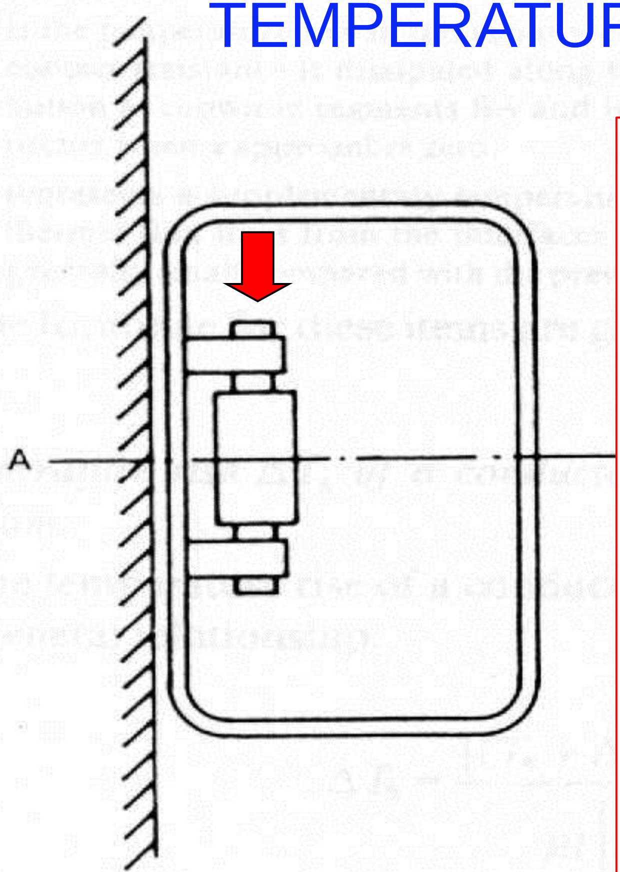
Part	Contact material and medium where it is used	Temperature Rise máx. (K) amb 20°C	Temperature máx. (°C) ambient 40°C	Comments
SPRING CONTACT	Copper and copper alloys uncoated - in air - in SF6 - in oil	35 50 40		
	Tinned , in air, SF6 oru oil	50		
	Silver or niquel plated - in air - in oil	65 50		
	For contactors in oil		105	Oil deterioration
BOLTED CONTACT	Copper , aluminum and alloys uncoated in air uncoated in SF6	50 65		
	Tinned, in air or SF6		105	Tin "creep point"
	Silver or niquel plated air or SF6	75		
	Silver or niquel plated in óleo		100	Oil deterioration
	For contactors in oil		105	Oil deterioration
METALIC PARTS	In contact with insulation class • Y / A / E • B / F / H		90 / 105 / 120 30 / 155 / 180	Isolation ageing
	• Acting as spring • In soldering position		caso a caso 100	Permanent deformation /Break
SURFACES	Can be touched (met / non met.) Acessible but not touched		70 / 80 80 / 90	Do not injure persons

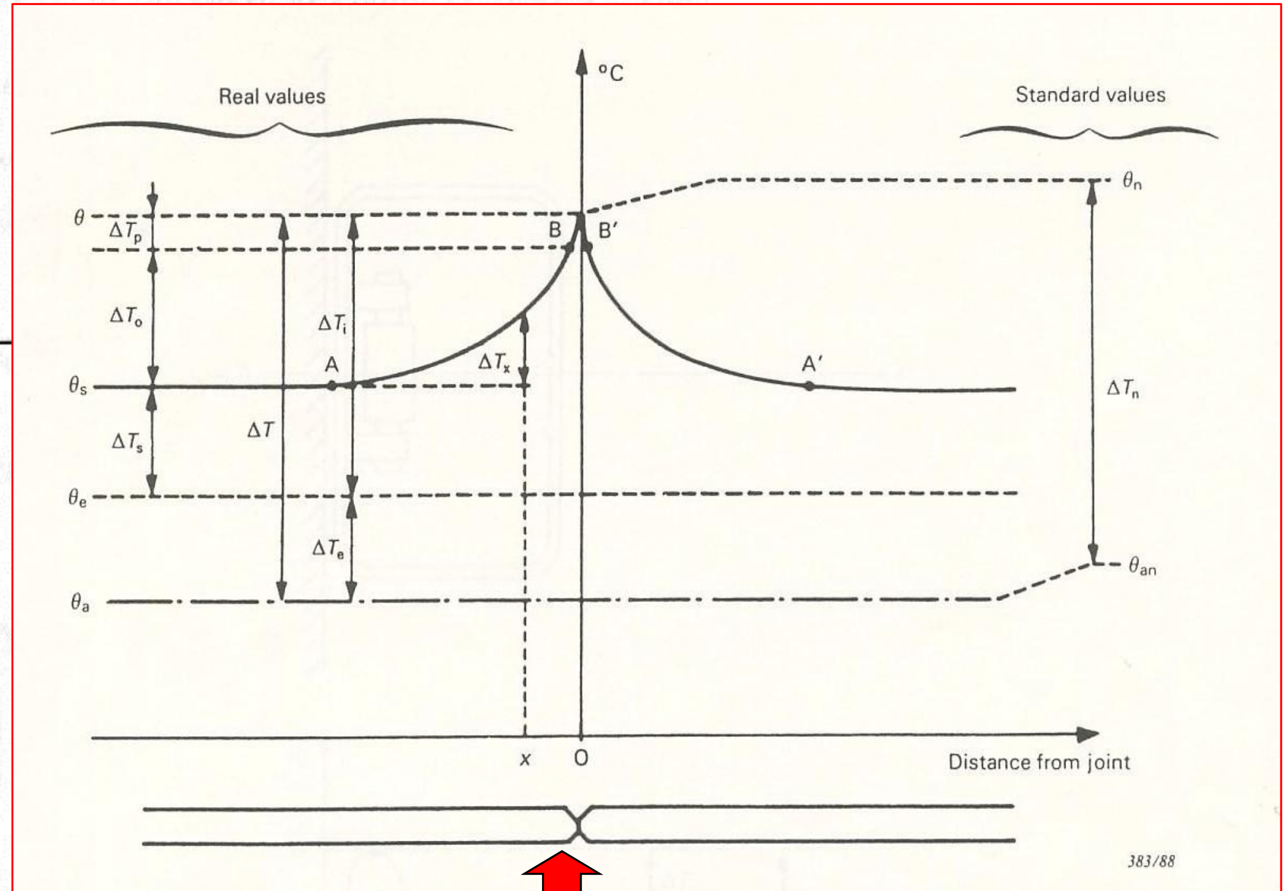
PARAMETERS IMPACTING THE RESULTS OF THE TEMPERATURE RISE TEST

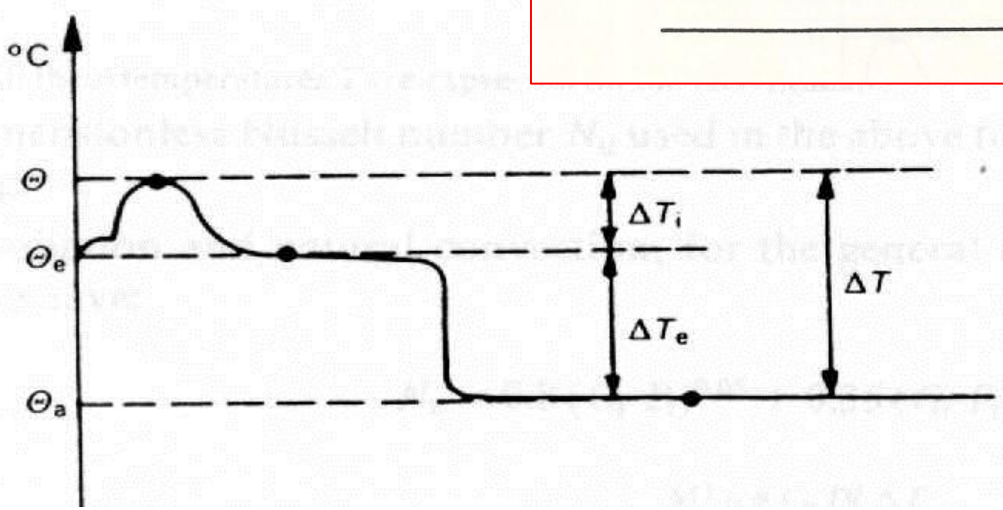
- Main contact resistances (and not only the total resistance per phase)
- Type and area of ventilation openings
- Cross section and geometric position of the bars (vertical, horizontal)
- Materials of the bus bars and their coating
- Air openings between compartments
- Pressure relief devices

Technical standards do not address the relationship between the temperature rise test and the internal arc test (should do it)

TEMPERATURE RISE X CONTACT RESISTANCES

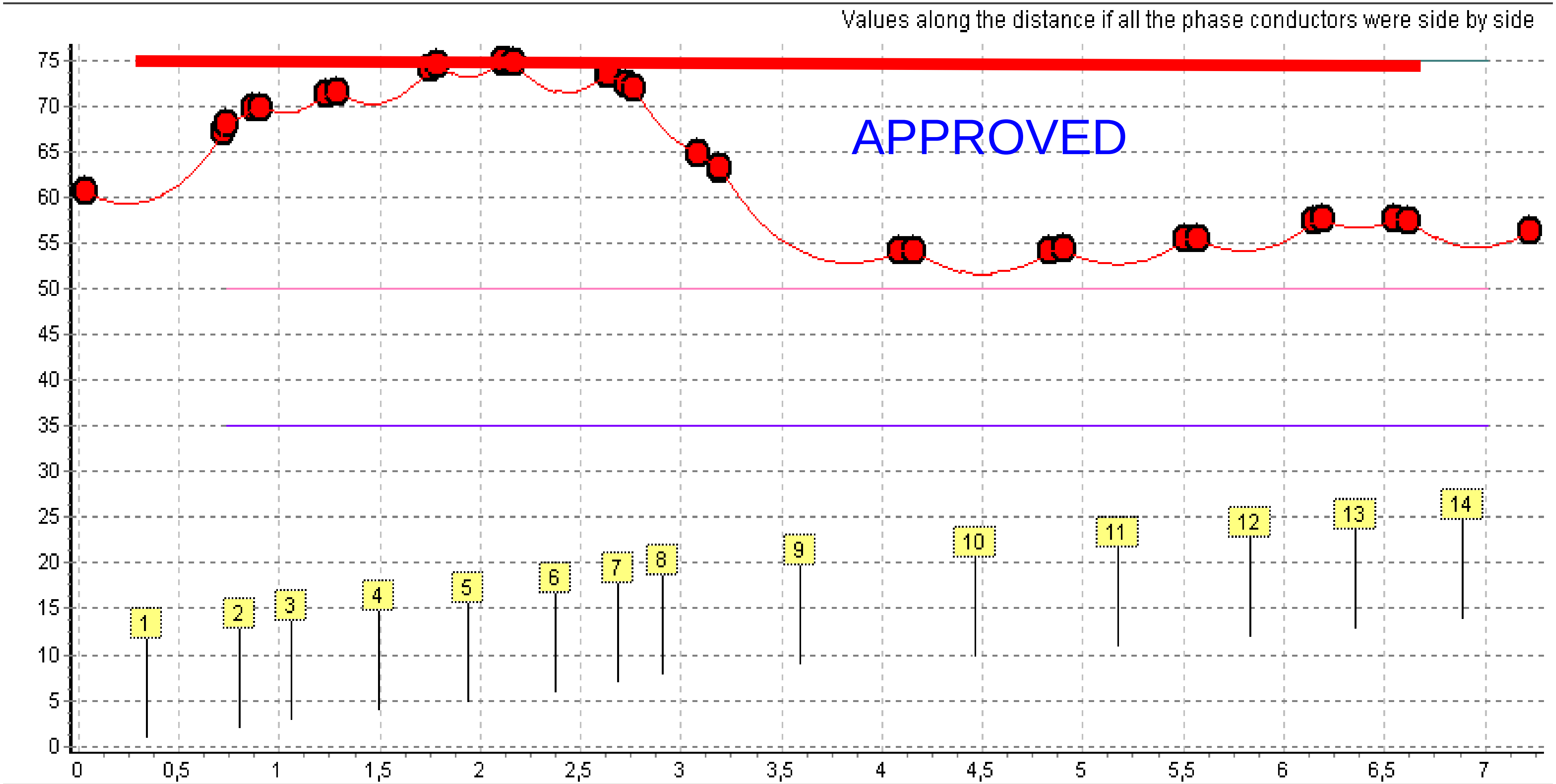






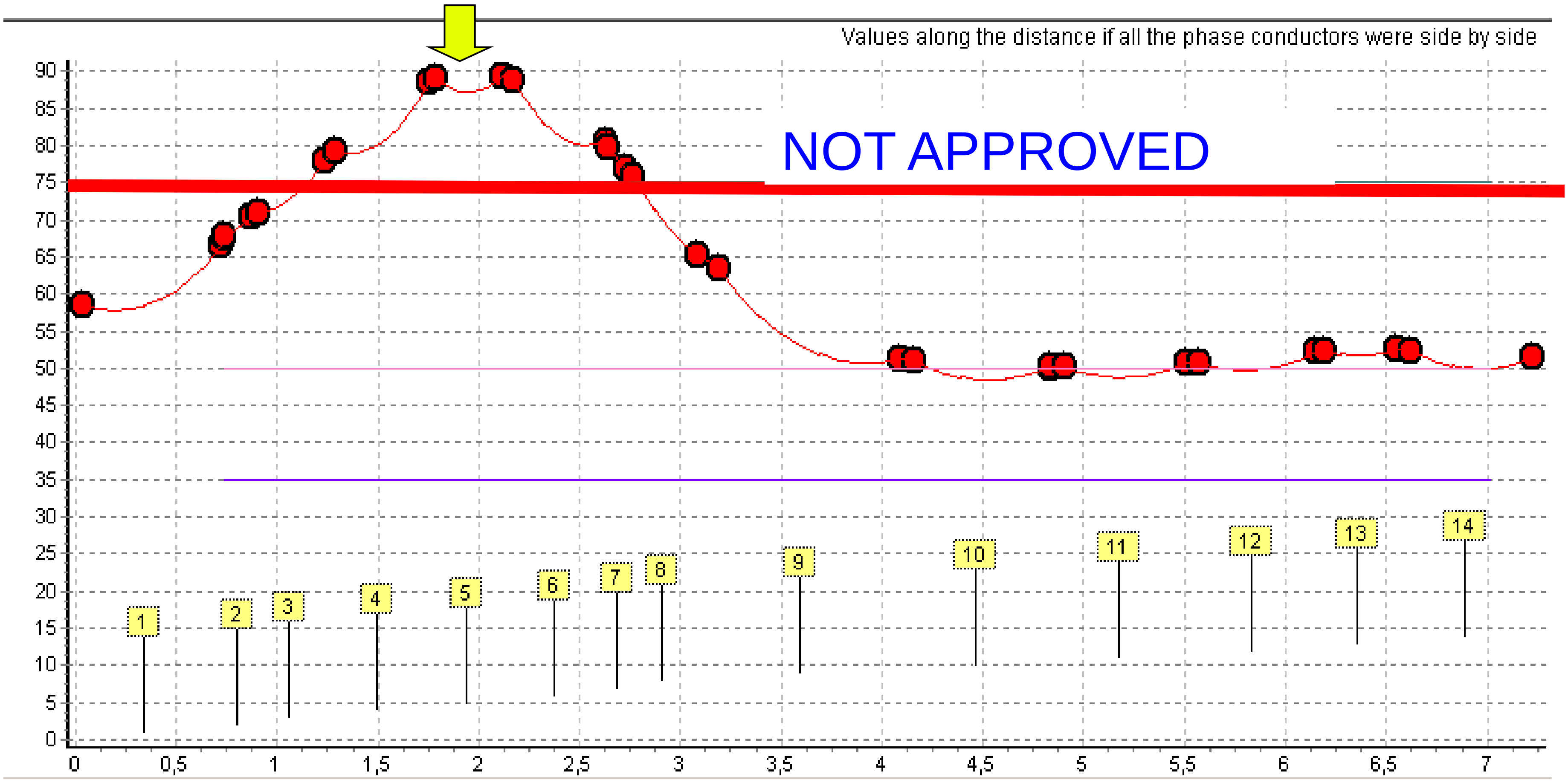
Why the standards should request the main contact resistances measurement and not only the total resistance per phase

Total resistance per phase (circuit breaker + busbar + connections) = **72 µΩ**
Circuit breaker resistance per phase = **18 µΩ**



Why the standards should request the main contact resistances measurement and not only the total resistance per phase

Total resistance per phase (circuit breaker + busbar + connections) = **72 µΩ**
Circuit breaker resistance per phase = **30 µΩ**



Contact resistance

- **N** small contacts

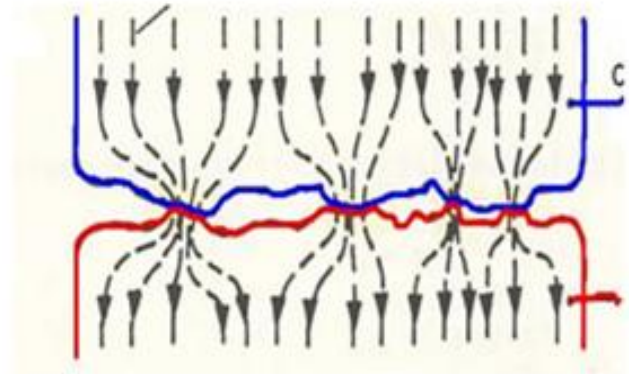
$$n = n_k . H^{0.625} F^{0.2}$$

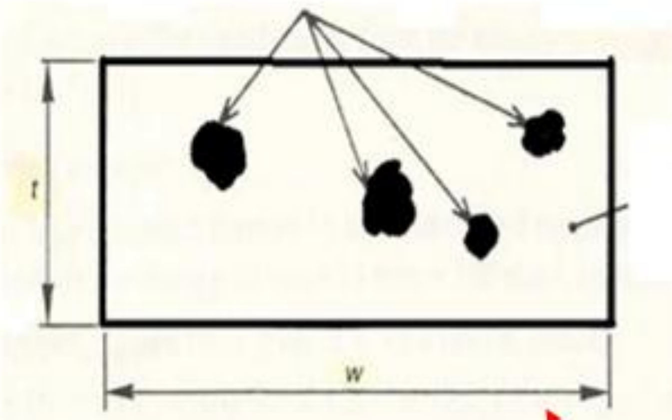
$$n_k \approx 2.5x10^{-5}(SI)$$

- with radius **a**

$$a = \sqrt{\frac{F}{\eta . \pi . \xi . H}}$$

- F = force in the contact
- H = hardness of the material
- ξ = roughness coefficient ~ 0.3 a 0.6





Virtual contact with **N** elements in paralel with a radius **a**

High temperatures accelerated the oxidization in the interface surface

$$R_c = \frac{\rho}{2.\eta.a} + \frac{\sigma_0}{\eta.\pi.a^2}$$

Constriction resistance (geometry)

Resistance due to the oxide layer in the interface of the contacts

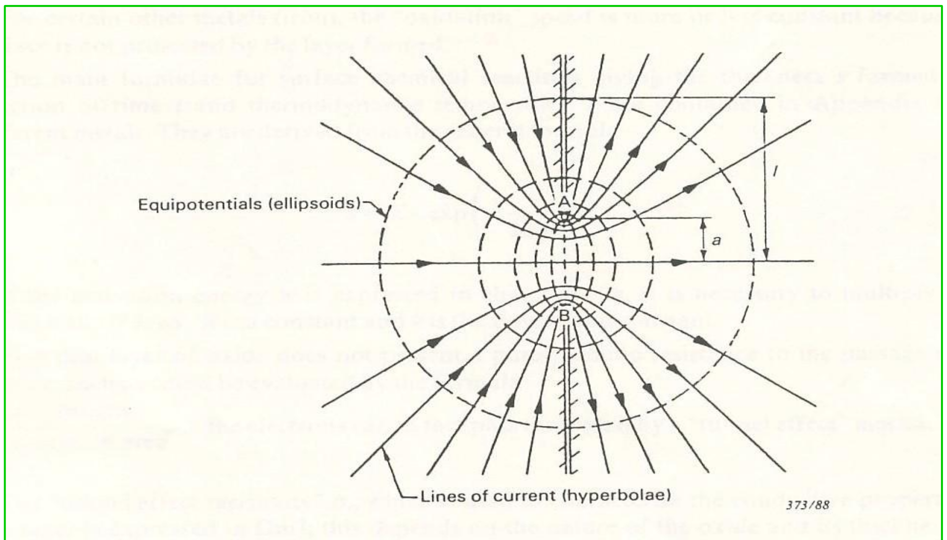
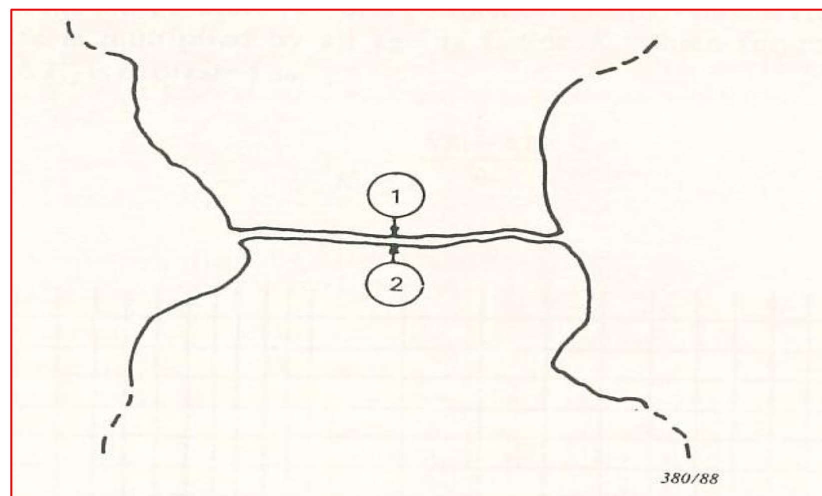


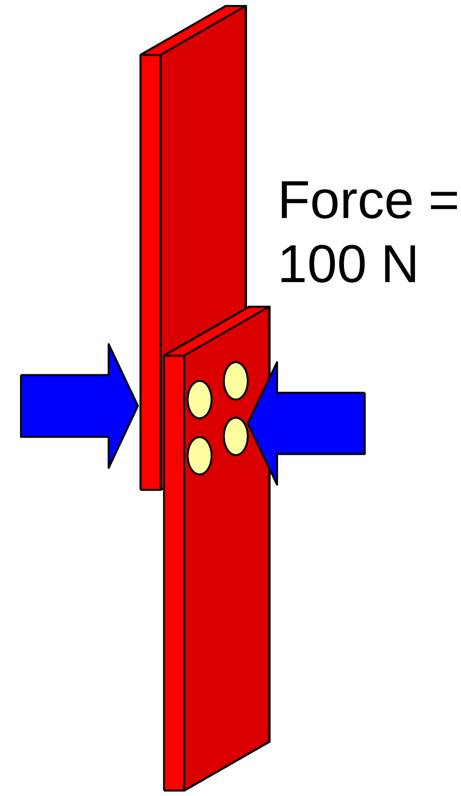
FIG. 2. — Equipotentials and lines of current at an elementary contact point.

σ_0 = surface resistivity (function of the thickness of the oxide layer)



ρ = material resistivity
a = radius of each small virtual contact
n = number of virtual contacts

CONTACT RESISTANCE



$$R_c = \frac{\rho}{2.\eta.a} + \frac{\sigma_0}{\eta.\pi.a^2}$$

$$a = \sqrt{\frac{100}{18.\pi.(0.45).(5.5x10^8)}} = 85x10^{-6}m$$

$$n = 2.5x10^{-5} \; x(5.5x10^8)^{0.625} x100^{0.2} = 18.2 = 18$$

ρ = 1.78 x 10^{-8} Ω.m

σ_0 = 5 x 10^{-12} Ω.m^2

R_c = 6 + 12 = 18 μΩ

CONTACT RESISTANCE

$$R_c = K_1 * F^{-0.6} + K_2 * \sigma_0 * F^{-1}$$

Metal	Constriction resistance k_1 $\times 10^{-6}$	Film resistance k_2 $\times 10^{6}$
Copper	90	247
Brass	360	450
Aluminium	130	135
Almelec	150	135
Silver	81	225
Tin	400	22,5
Nickel	420	585
Silvered copper	88	225
Tinned copper	57	22,5
Tinned aluminium	93	22,5
Silvered brass	310	225
Tinned brass	200	22,5

Table 1 – Typical values of tunnel resistivity

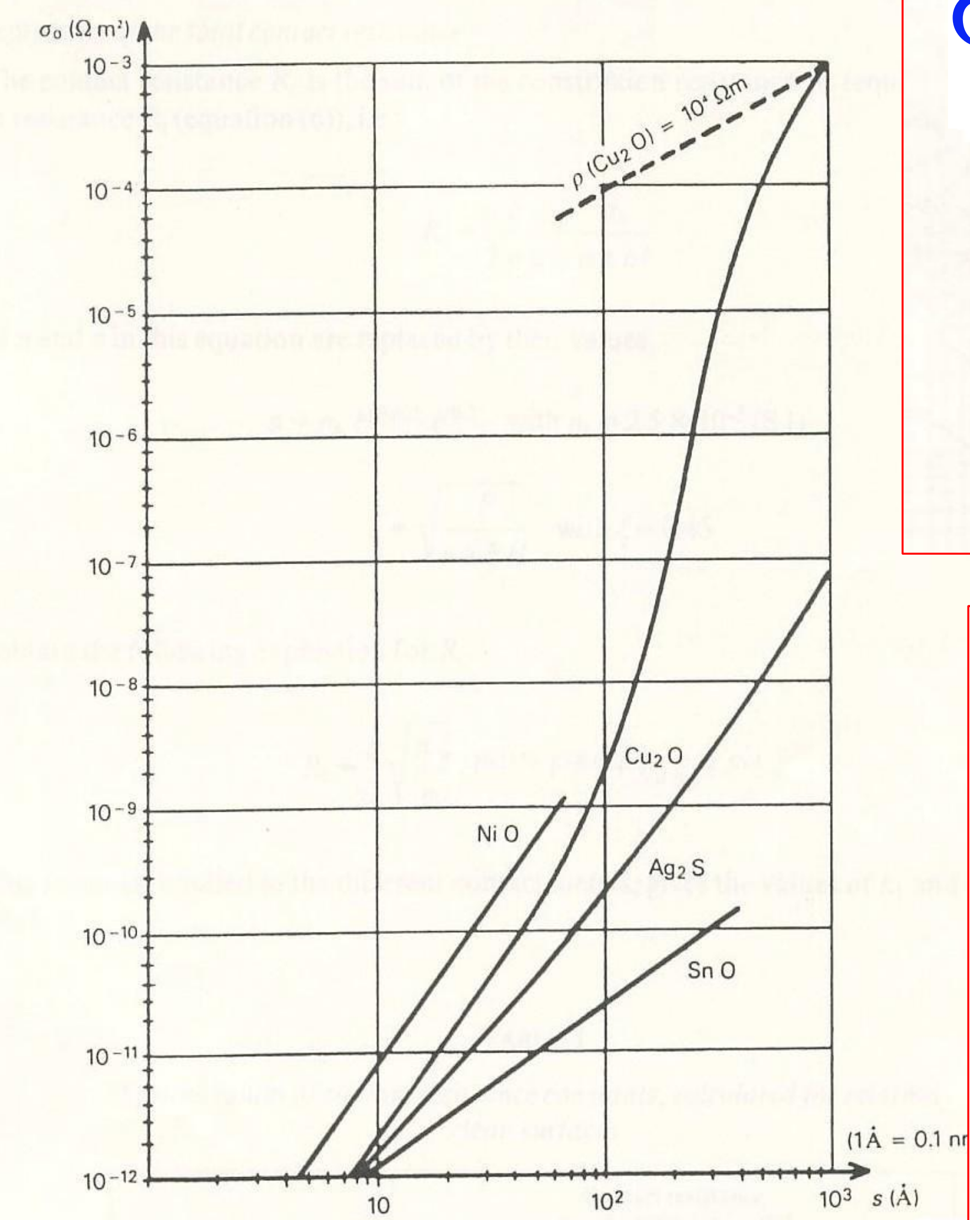
Metal	State	σ_0 $\Omega\, m^2$
Copper	New	2×10^{-12} to 3×10^{-11}
	Oxidised	10^{-10}
	Tinned	10^{-12} to 4×10^{-11}
Silver		$4,6 \times 10^{-13}$ to 4×10^{-12} exceptionally up to $2,5 \times 10^{-11}$
Aluminium		7×10^{-11} to 10^{-9}

Copper contact silver plated with force 100 N oxidized

$$R_c = 88 * 10^{-6} * 100^{-0.6} + 225 * 10^{6} * 5 * 10^{-12} * 100^{-1}$$

$$R_c = (5,55 + 11,2) * 10^{-6} = 16,7\ \mu\Omega$$

σ_0 typical values



Copper	New Oxidized Tinned	2×10^{-12} to 3×10^{-11} 10^{-10} 10^{-12} to 4×10^{-11}
Silver		4.6×10^{-13} to 4×10^{-12} and up to 2.5×10^{-11}
Aluminium		7×10^{-11} to 10^{-9}

VALORES TÍPICOS DAS CONSTANTES DE RESISTENCIA DE CONTATOS PARA SUPERFÍCIES RAZOAVELMENTE LIMPAS

$$R_c = \frac{\varrho}{2}\sqrt{\frac{\pi\,\xi}{n_k}}\,H^{0.1875}\,F^{-0.6} + \sigma_o\,\xi\,H\,F^{-1}$$

$$R_c = k_1\,F^{-0.6} + k_2\,\sigma_o\,F^{-1}$$

Metal	Constriction resistance $K_1 \times 10^{-5}$	Film resistance $K_2 \times 10^{+6}$
Copper	9	247
Brass	36	450
Aluminium (A5L)	13	135
Almelec	15	135
Silver	8.1	225
Tin	40	22.5
Nickel	42	585
Silvered copper	8.8	225
Tinned copper	5.7	22.5
Tinned aluminium	9.3	22.5
Silvered brass	31	225
Tinned brass	20	22.5

See IEC 60943

COGNITOR

TEMPERATURE RISE CALCULATION ΔT_s over the temperature of the surrounding air Te

Joule effect

Sun light if applicable

Eddy currents

$$\Delta T_s = \frac{[(T_e + \Delta T_s - 273.15)\,\alpha + 1]\; R_0\, I^2 + r\,\varphi_s\, S_r + W_{edy}}{Bl\left[\sigma\,\varepsilon\,\dfrac{(T_e + \Delta T_s)^4 - T_e^4}{\Delta T_s} + \dfrac{\lambda}{D_h}\, N_u\right]}$$

Lateral area

Radiation losses

Convection losses

Eddy currents= $W_{eddy} = K_1 * B^2 * \omega^2 * e^2 * \rho *$ volume $_{enclosure}$

K_1 = adjustment B = magnetic field $\omega = 2*\pi*f$

e = plate thickness ρ = plate resistivity

These tables are not sufficient to design because joints and contact resistances are not considered

Copper conductors of rectangular cross-section in indoor installations. Ambient temperature 35 °C. Conductor temperature 65 °C. Conductor width vertical: clearance between conductors equal to conductor thickness; with alternating current, clearance between phases > 0.8 x phase centre-line distance.

Width x thickness	Cross-section	Weight[1]	Material[3]	Continuous current in A, AC up to 60 Hz, painted, no. of conductors 1	2	3	4 (50[2])	bare, no. of conductors 1	2	3	4 (50[2])	Continuous current in A, DC and AC 16⅔ Hz, painted, no. of conductors 1	2	3	4	bare, no. of conductors 1	2	3	4
mm	mm²	kg/m		I	II	III	II II	I	II	III	II II	I	II	III	II II	I	II	III	II II
50 x 5	249	2.22	E-Cu F 37	679	1 140	1 330	2 010	583	994	1 240	1 920	703	1 170	1370		588	1 020	1 300	
50 x 10	499	4.44	E-Cu F 30	1 020	1 720	2 320	2 950	852	1510	2 040	2 600	1 050	1 830	2 360		875	1 610	2 220	
60 x 5	299	2.66	E-Cu F 30	826	1 330	1 510	2 310	688	1 150	1 440	2 210	836	1 370	1 580	2 060	696	1 190	1 500	1 970
60 x 10	599	5.33	E-Cu F 30	1 180	1 960	2 610	3 290	985	1 720	2 300	2 900	1 230	2 130	2 720	3 580	1 020	1 870	2 570	3 390
80 x 5	399	3.55	E-Cu F 30	1 070	1 680	1 830	2 830	885	1 450	1 750	2 720	1 090	1 770	1 990	2 570	902	1 530	1 890	2 460
80 x 10	799	7.11	E-Cu F 30	1 500	2 410	3 170	3 930	1 240	2 110	2 790	3 450	1 590	2 730	3 420	4 490	1 310	2 380	3 240	4 280
100 x 5	499	4.44	E-Cu F 30	1 300	2 010	2 150	3 300	1 080	1 730	2 050	3 190	1 340	2 160	2 380	3 080	1 110	1 810	2 270	2 960
100 x 10	988	8.89	E-Cu F 30	1 810	2 850	3 720	4 530	1 490	2 480	3 260	3 980	1 940	3 310	4100	5 310	1 600	2 890	3 900	5 150
120 x 10	1 200	10.7	E-Cu F 30	2 110	3 280	4 270	5 130	1 740	2 860	3 740	4 500	2 300	3 900	4 780	6 260	1 890	3 390	4 560	6 010
160 x 10	1 600	14.2	E-Cu F 30	2 700	4 130	5 360	6 320	2 220	3 590	4 680	5 530	3 010	5 060	6 130	8 010	2 470	4 400	5 860	7 710
200 x 10	2 000	17.8	E-Cu F 30	3 290	4 970	6 430	7 490	2 690	4 310	5 610	6 540	3 720	6 220	7 460	9 730	3 040	5 390	7 150	9 390

Busbars tables (without neighbor contact resistances)
X
Actual use with connections, circuit breakers, fuses

Current Amperes	Ventilation area cm^2	Watts Additional in the volume e.g boxes	Volume compartment m3	Busbars mm	Temperature rise K
1490	200	-	0,8 x 0,8 x 2,3	1 x 100 x 10 (nua)	29
1490	200	-	0,8 x 0,8 x 2,3	1 x 100 x 10 (painted)	24
1490	-	-	0,8 x 0,8 x 2,3	1 x 100 x 10 (bare)	34
1490	-	1000	0,8 x 0,8 x 2,3	1 x 100 x 10 (bare)	64
1490	-	Contact 45 µΩ (100W)	0,8 x 0,8 x 2,3	1 x 100 x 10 (bare)	54

(caso teste 1 x 100 x 10 mm Switchgear BT)

EFFECT OF THE PARAMETERS INFLUENCING THE TEST RESULTS

- Without ventilation openings
- With ventilation openings and with/without forced ventilation
- Changing the ventilation area
- Bars painted or bare
- Bars arranged horizontally or vertically
- Different values of contact resistance

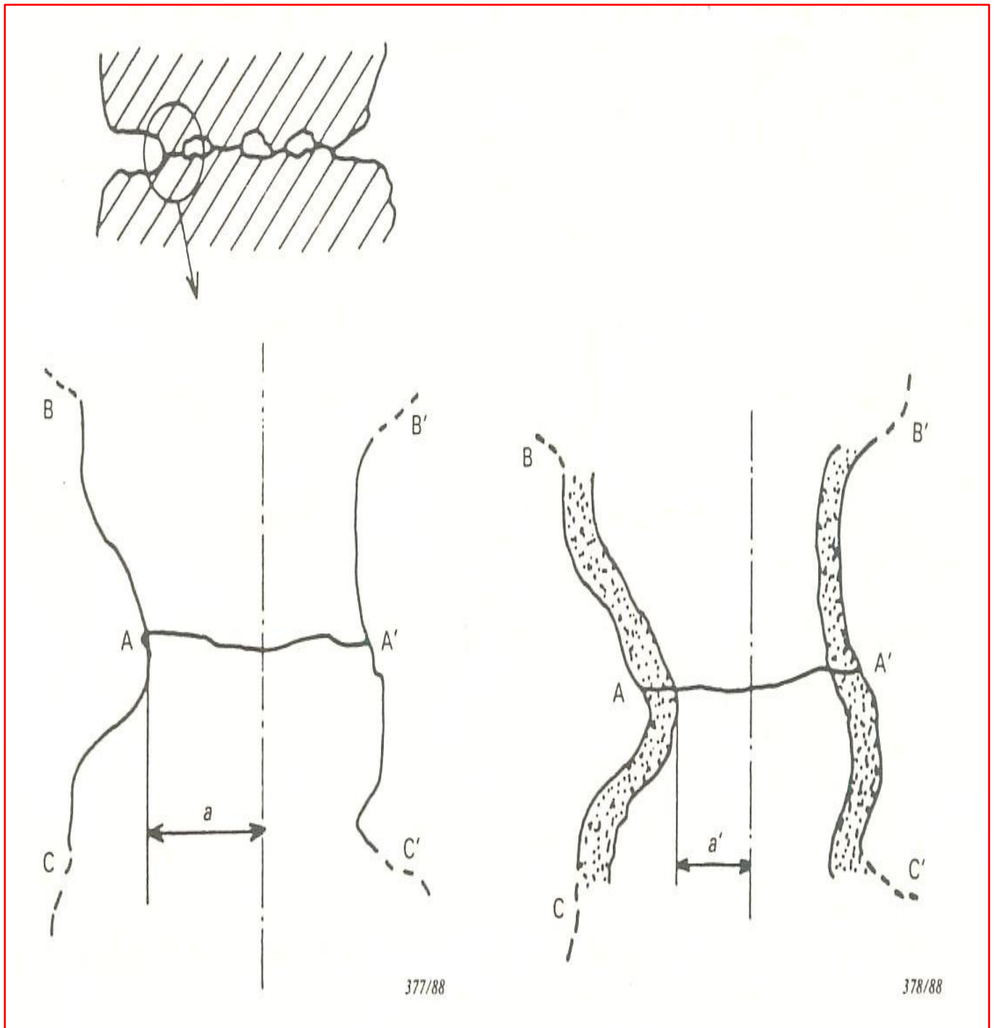
METHOD FOR THE CALCULATION OF TEMPERATURE RISE

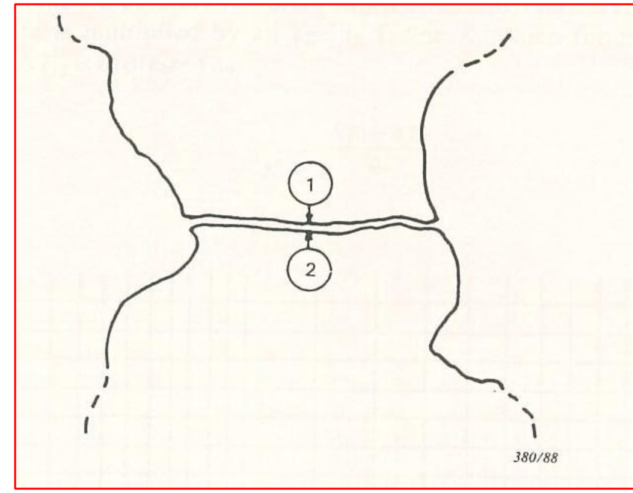
(See equations at the end of this file)

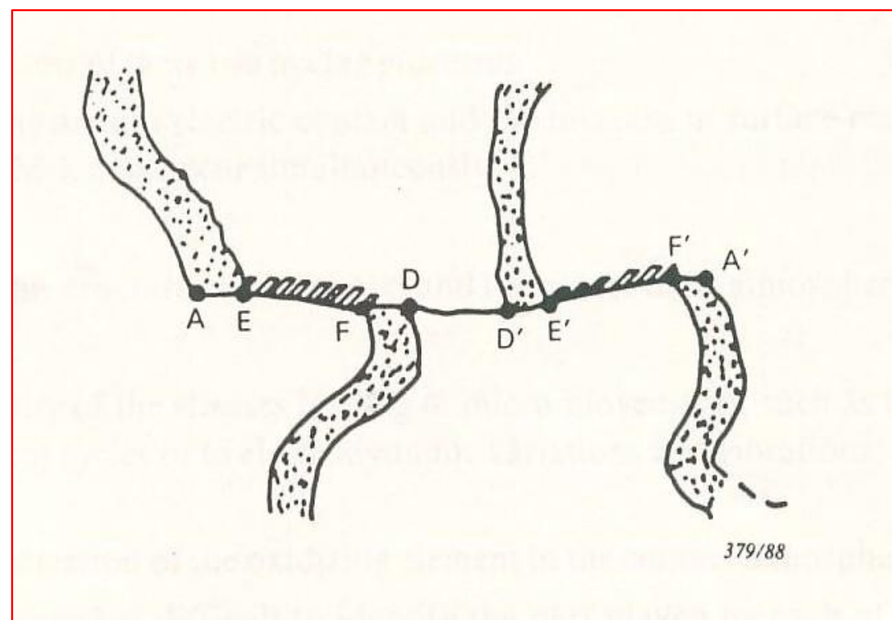
- Calculate the temperature rise of the internal fluid using **IEC 60890** method (see also **IEC 62208**)
- Calculate the temperature rise of the conductors above the temperature of the internal fluid
- Add the two values

AGING MECHANISMS - ELECTRICAL CONTACTS

- Bi-metallic contacts: higher voltage = more oxidation (acceptable <0.5 V)
- Reduction of the cross section of the elementary contacts
- Small relative movements which decrease further the area
- Growth of the oxide layer at the interface







HIGHER VOLTAGE = MORE OXIDATION (ACCEPTABLE <0.5 V)

TABLE III

Voltages in 10^{-2} V developed on bi-metallic contacts

Cathode (+) \ Anode (–)	Silver	Nickel	Monel (30% Cu)	Cupro-nickel (70-30)	Copper	Silver solder	Bronzes*	Red bronze	Brasses*	Stainless steels*	Tin	Tin-lead solder	Tin-silver solder	Lead	Cast-iron	Steels	Aluminium alloys*	Aluminium	Cadmium	Galvanized iron or steel	Zinc alloys*	Zinc	Magnesium alloy*
Silver	0	15	17	19	19	21	23	25	26	33	47	48	51	56	71	72	77	77	79	109	110	111	159
Nickel		0	02	04	04	06	08	10	11	16	32	33	36	41	53	57	62	62	64	94	95	96	144
Monel (30% Cu)			0	02	02	04	06	08	09	16	30	31	34	39	54	55	60	60	62	92	93	94	142
Cupro-nickel (70-30)				0	0	02	04	06	07	14	28	29	32	37	52	53	58	58	60	90	91	92	140
Copper					0	02	04	06	07	14	28	29	32	37	52	53	58	58	60	90	91	92	140
Silver solder						0	02	04	05	12	26	27	30	35	50	51	56	56	58	88	89	90	138
Bronzes*							0	02	03	10	24	25	28	33	48	49	54	54	56	86	87	88	136
Red bronze								0	01	06	22	23	26	31	46	47	52	52	54	84	85	86	134
Brasses*									0	07	21	22	25	30	45	46	51	51	53	83	84	85	133
Stainless steels*										0	14	15	18	23	38	39	44	44	46	76	77	78	128
Tin											0	01	04	09	24	25	30	30	32	62	63	64	112
Tin-lead solder												0	03	08	23	24	29	29	31	61	62	63	111
Tin-silver solder													0	05	20	21	26	26	28	58	59	60	108
Lead														0	15	16	21	21	23	53	54	55	103
Cast-iron															0	01	06	06	08	38	39	40	88
Steels																0	05	05	07	37	38	39	87
Aluminium alloys*																	0	0	02	32	33	34	82
Aluminium																		0	02	32	33	34	82
Cadmium																			0	30	31	32	80
Galvanized iron or steel																				0	01	02	50
Zinc alloys*																					0	01	49
Zinc																						0	45
Magnesium alloy*																							0

*Characteristic values.

ASSESSING THE AGING

Influence of the temperature (T_{e1} e T_{e2}) and temperature rise (ΔT_{i1} and ΔT_{i2}) in the aging

$$K = 2^{\frac{(\Delta T_{i1} - \Delta T_{i2})}{\Delta i} + \frac{(T_{e1} - T_{e2})}{\Delta_e}}$$

1 hour of operation in the condition 1

=

K x 1 hour of operation in the condition 2

Δ_e and Δ_i are functions of ΔT_i

Assessing the aging

$$K = 2^{\frac{(\Delta T_{i1} - \Delta T_{i2})}{\Delta i} + \frac{(T_{e1} - T_{e2})}{\Delta_e}}$$

- Copper electrical contact initially with temperature rise equal to 35K
- Apply overload so that the temperature rise above ambient becomes 45K
- Constant $\Delta_i = 6K$ for ΔT_{i1} = 35K (Figure B)

$$K = 2^{\frac{(35-45)}{6}} = 0.315$$

Life expectancy in the conditions of standard (suppose 10 years) will be multiplied by a factor of 0,31

You need to buy 3 contacts in 10 years instead of just one

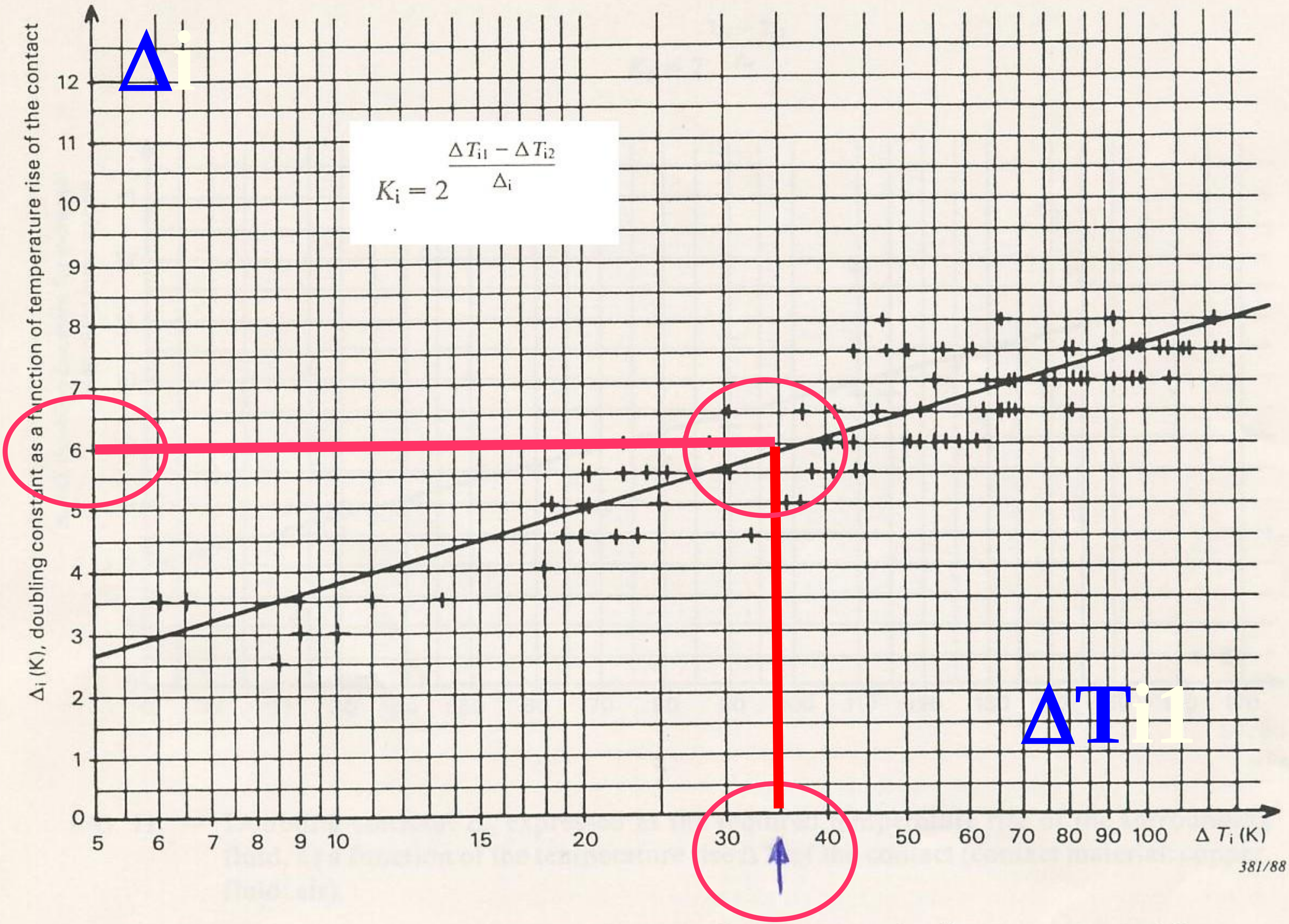


FIG. 10. — Doubling constant Δ_i as a function of temperature rise (for copper contacts).

COGNITOR

Example with $\Delta Ti1 = \Delta Ti2$

$$K = 2^{\frac{(\Delta T_{i1} - \Delta T_{i2})}{\Delta i} + \frac{(T_{e1} - T_{e2})}{\Delta_e}}$$

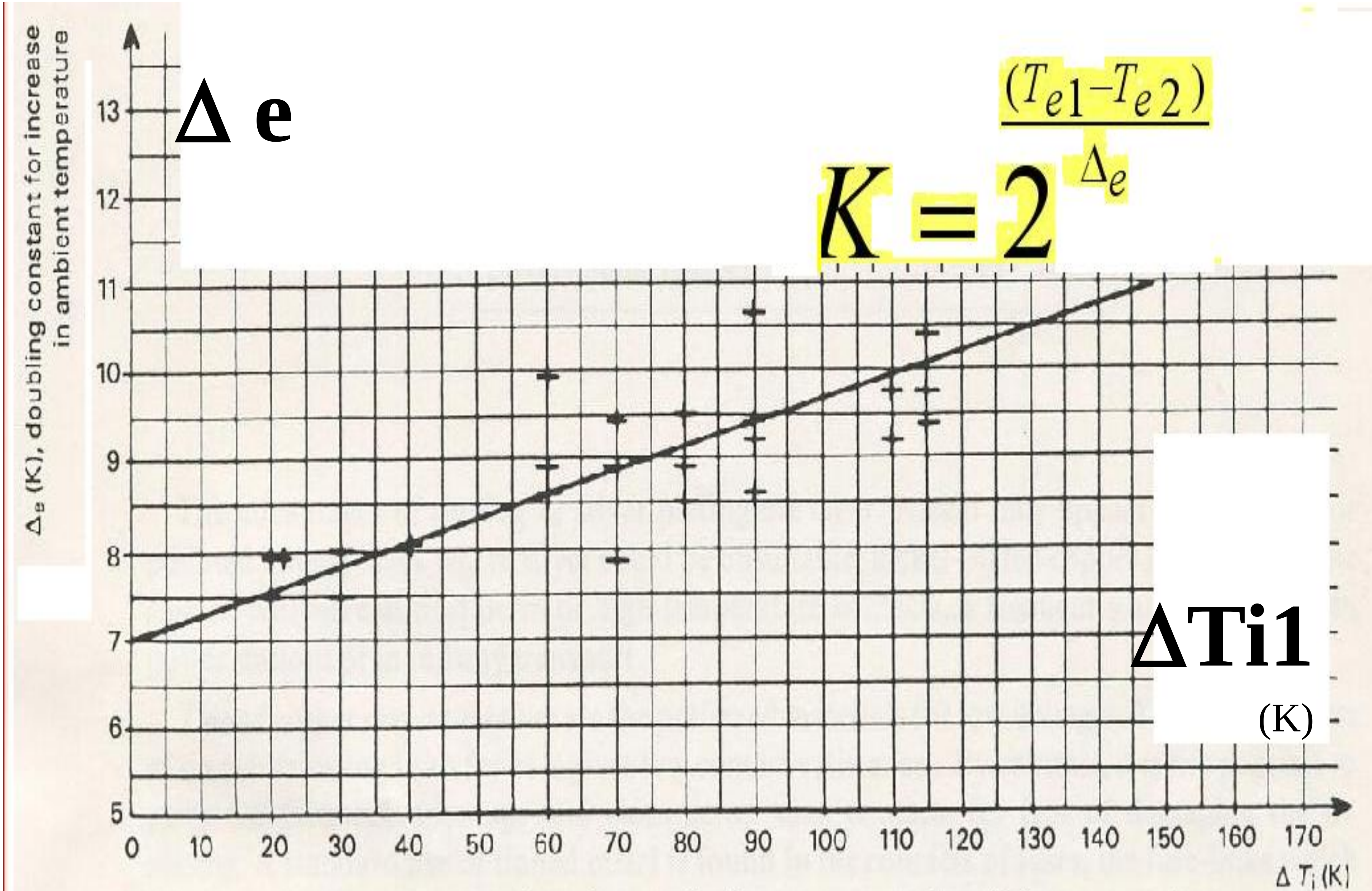
- Copper contact initially at temperature rise of 35K and room temperature 20^{0}C
- Increase the air temperature in 8K becoming 28^{0}C
- The doubling constant is Δe = 8K at ΔT_{i1} = 35K

$$K = 2^{\frac{(20-28)}{8}} = 0.5$$

Life expectancy is multiplied by 0.5

(if 10 years is reduced to 5 years)

$$K = 2^{\frac{(T_{e1} - T_{e2})}{\Delta_e}}$$



Doubling constant Δ_e expressed as the required temperature rise of the surrounding fluid, as a function of the temperature rise ΔT_i of the contact (contact material: copper, fluid: air).

TEMPERATURE RISE UNDER SHORT CIRCUIT

- Adiabatic process Q = mass x specific heat x temperature variation.
- The conductor cross section shall be sufficient to avoid that the conductor at an initial temperature Θ 1 do not reach the annealing temperature (180º C for aluminum or 200 º C for copper)

$$Q \times \mathrm{sqrt}\left(4.184 \times (C \times \rho_d / \rho_r \times \alpha) \times \ln[1 + (\alpha(\theta_{max} - \theta_1))]\right) = I_k \times 1000 \times \mathrm{sqrt}(T)$$

I_K = short circuit current rms symmetrical (e.g 50 kA)
T = duration in seconds (e.g 1 s)
Q = conductor cross section (mm^2)
C = specific heat (e.g. copper = 0,0941 cal / (gr.C)
P = density (e.g copper = 8,9 g/cm^3)
P_{r}, P_{20} = density at the desired temperature 20ºC or Θ_1
Θ_1 and Θ_{max} = initial temperature and annealing temperature

α = temperature coefficient (e.g. copper 0,004)

Example for grounding busbar:

Short circuit at I_k = 31,5 kAef t = 1 s

Calculate the area Q necessary to not pass the temperature of 200 ° C (annealing of copper) for a conductor initially at 40ºC.

31,5 kA x 1000 x sqrt (1 s)

=

Q x sqrt ((4,184*0,0941 x 8.9 / ρ_r . 0,004) . Ln [1 + 0,004 . (200 - 40)]))

$\rho_r = \rho_{20}$ x (1 + 0,004 . (40-20)) = 0.0178 x 1,08 = 0,0192

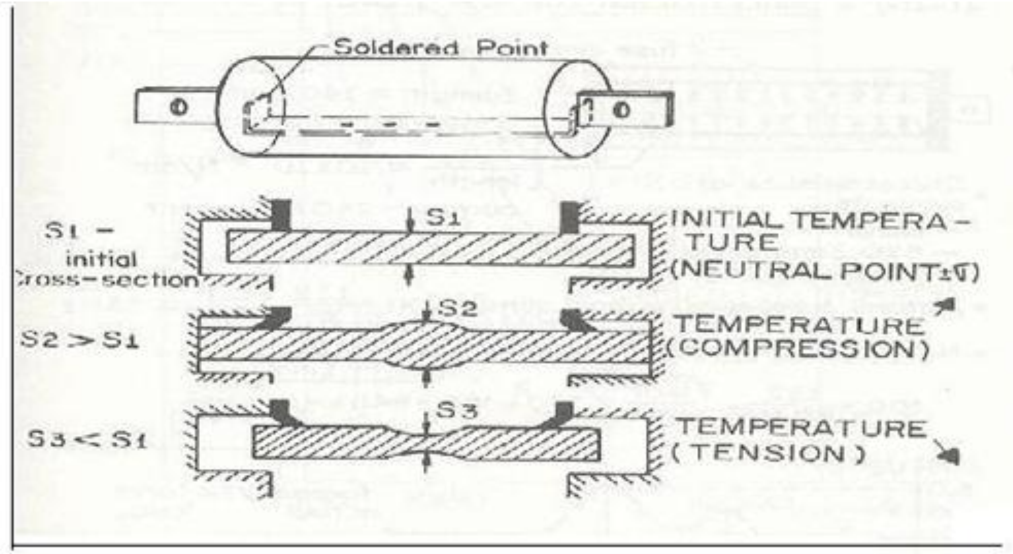
Q > 195 mm^2 (current density 161 A/mm^2)

For example a 50 mm x 10 mm would attend well the thermal requirements

THERMAL CYCLES

Publication

Overload Tests for Fuses Used in Rolling-Mils; International Conference on Fuses and their Applications, Nottingham-UK, 1991.



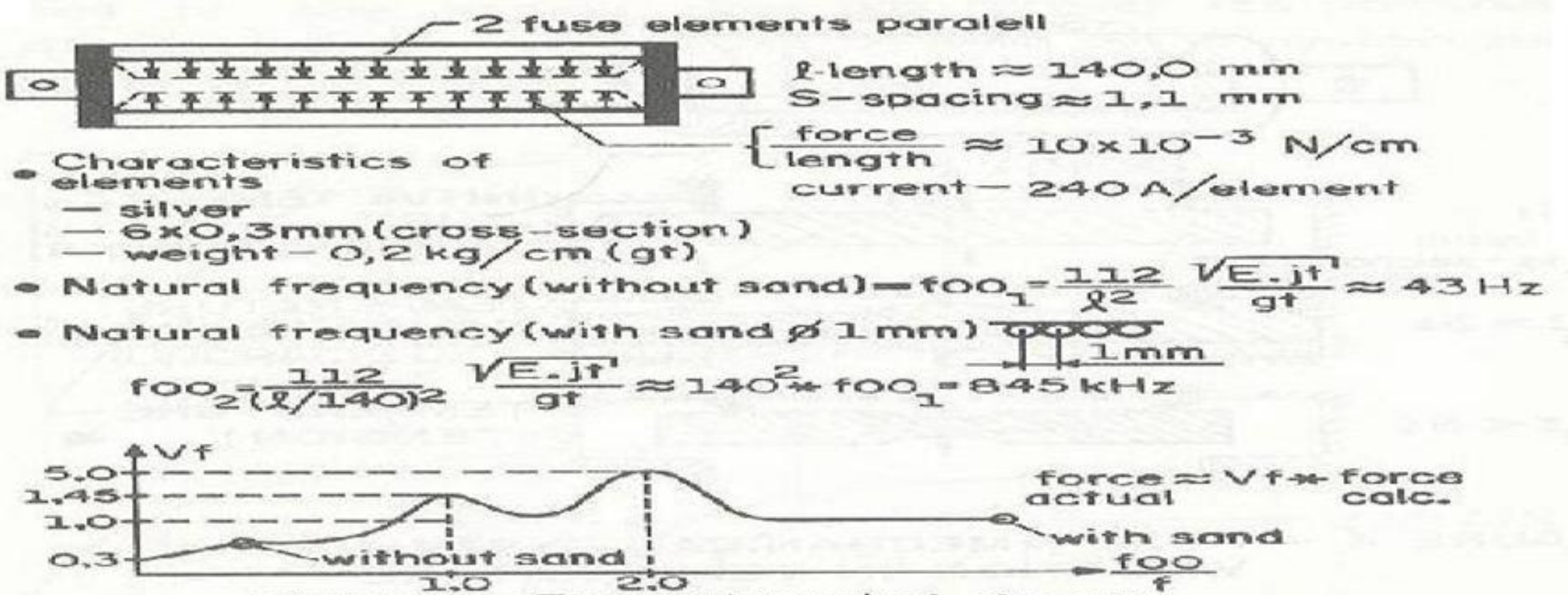


Figure 6 — Electrodynamical stresses

OVERLOADS IN POWER TRANSFORMERS
(previous)

Loading	P < = 100 MVA	P > 100 MVA
Normal condition	150%	130%
Emergency (long duration)	150%	130%
Emergency (short duration)	150%	140%

Loading	Temperature at top oil		Temperature hot spot	
	tr.55°C	tr.65°C	tr.55°C	tr.65°C
Normal condition	95°C	105°C	105°C	120°C
Emergency (long duration)	105°C	110°C	120°C	130°C
Emergency (short duration)	105°C	110°C	130°C	140°C

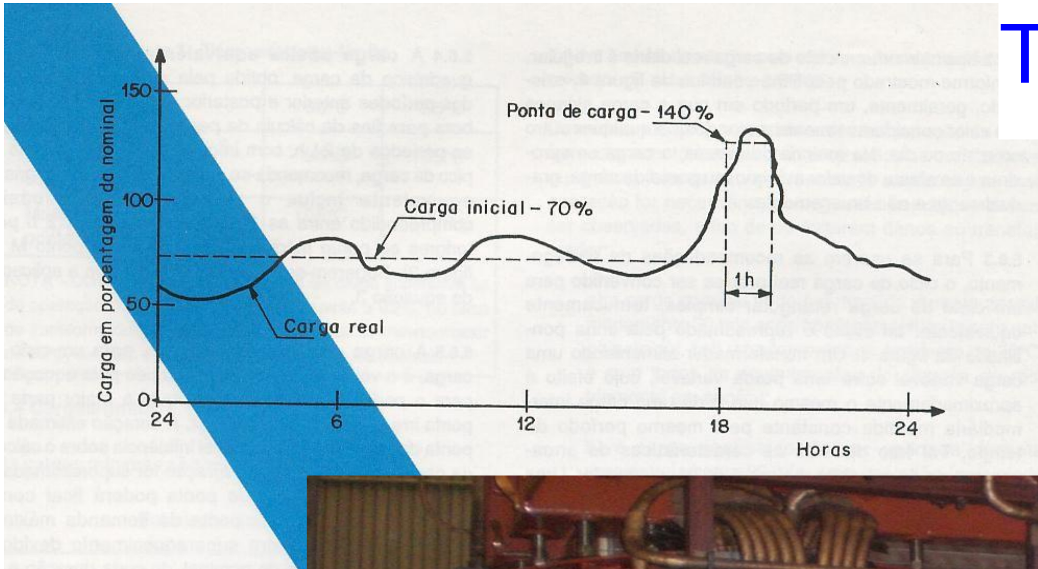
Temperature rise limits

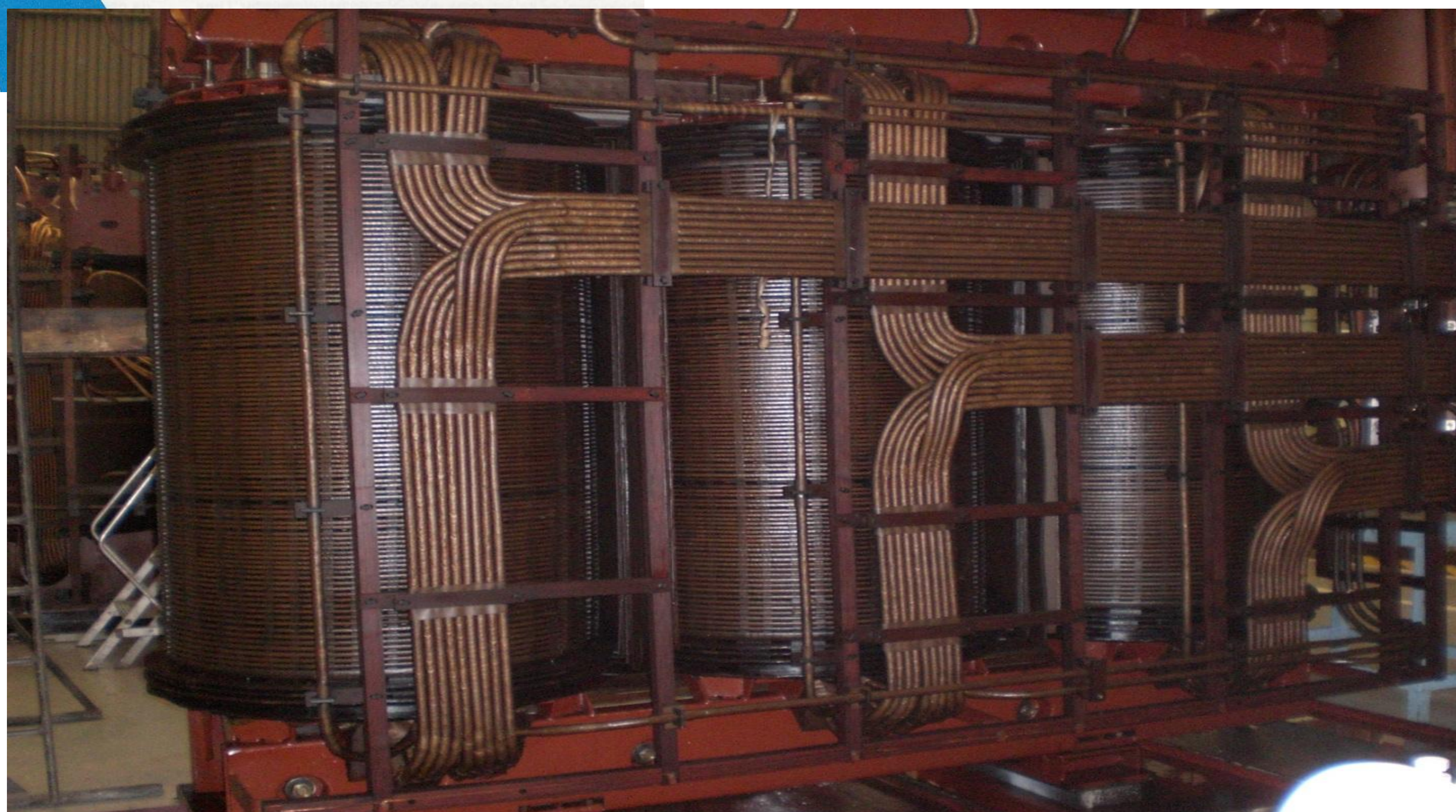
Requirements	Temperature rise limit K
Insulating liquid (top)	60
Winding (averge) ON ... OF OD	 65 70
Winding hot spot	78

H Fator "hot spot" = Q x S

Q – local temperature rise due to higher local losses
S - local temperature rise due to the variation of the insulating oil temperature along the height

TRANSIENT LOADING





IEC 60076-7 - Power transformers
Part 7: Loading guide for oil-immersed power transformers

Table 4 – Current and temperature limits applicable to loading beyond nameplate rating

Types of loading	Distribution transformers (see Note)	Medium power transformers (see Note)	Large power transformers (see Note)
Normal cyclic loading			
Current (p.u.)	1,5	1,5	1,3
Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C)	120	120	120
Other metallic hot-spot temperature (in contact with oil, aramid paper, glass fibre materials) (°C)	140	140	140
Top-oil temperature (°C)	105	105	105
Long-time emergency loading			
Current (p.u.)	1,8	1,5	1,3
Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C)	140	140	140
Other metallic hot-spot temperature (in contact with oil, aramid paper, glass-fibre materials) (°C)	160	160	160
Top-oil temperature (°C)	115	115	115
Short-time emergency loading			
Current (p.u.)	2,0	1,8	1,5
Winding hot-spot temperature and metallic parts in contact with cellulosic insulation material (°C)	See 7.2.1	160	160
Other metallic hot-spot temperature (in contact with oil, aramid paper, glass fibre materials) (°C)	See 7.2.1	180	180
Top-oil temperature (°C)	See 7.2.1	115	115

NOTE The temperature and current limits are not intended to be valid simultaneously. The current may be limited to a lower value than that shown in order to meet the temperature limitation requirement. Conversely, the temperature may be limited to a lower value than that shown in order to meet the current limitation requirement.

SHORT-TIME WITHSTAND CURRENT and PEAK WITHSTAND CURRENT TEST

(testing and simulations)

Electrodynamical forces, mechanical stresses and supportability of conductors and insulators.

$$F = F_x\ (x) + F_y\ (y) + F_z\ (z)$$

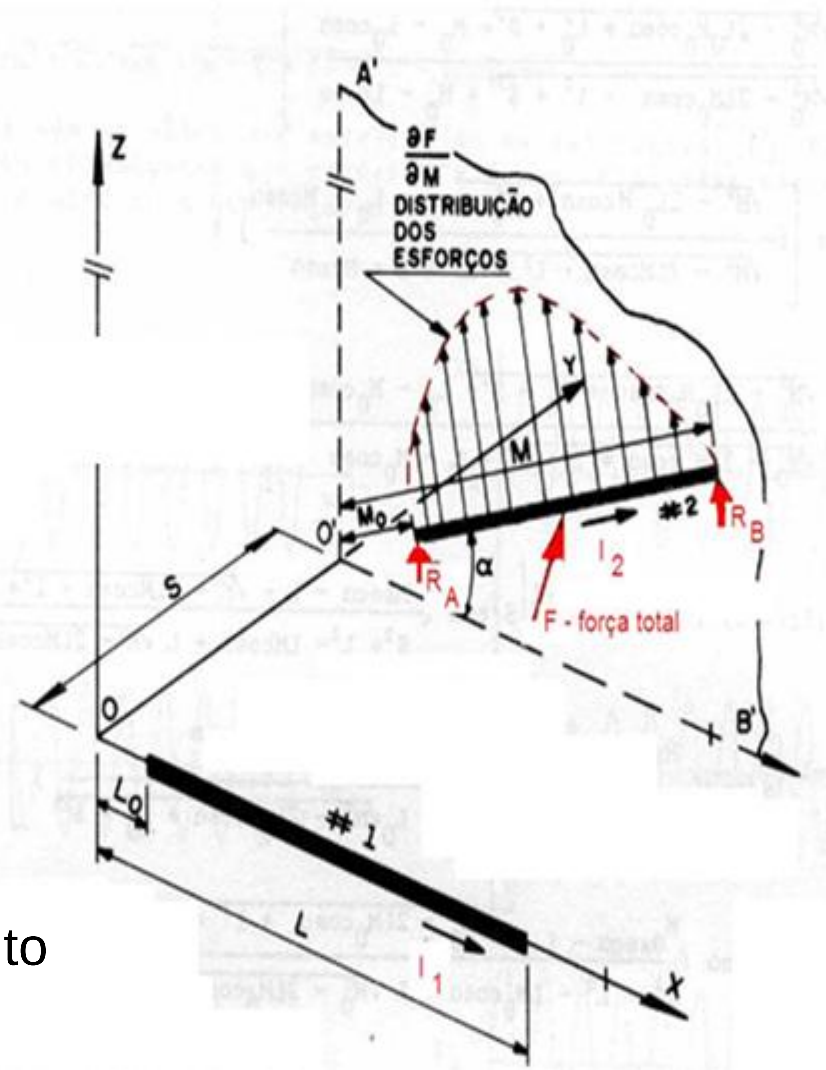
$$dF/dm = dF_x/dm\ (x) + dF_y/dm\ (y) + dF_z/dm\ (z)$$

Neighbor conductors

Current I_1 in conductor #1 produce magnetic field B1

Field B1 interact with current I_2 in conductor # 2 producing a force

$$dF_2 = I_2 . dl \times B_1$$



Forces bend the conductor and are transmited to the insulators

IEC 61117 – A method for assessing the short circuit withstand strength of partially type tested assemblies (PTTA)

with some adaptations by Sérgio

1) Calculating distributions of static forces by the equations
2) Convert “static forces” on "dynamic forces"
3) Calculate forces in insulators, shear forces and bending moments diagram.
4) Calculate mechanical stresses in the conductors (bending moment divided by the section moduli)
5) Compare tensions in the conductors and forces in the insulators with supportability limits

STEP 1) CALCULATING DISTRIBUTIONS OF FORCES (Sergio's M.Sc. thesis)

$$\boxed{\frac{\partial F_x}{\partial m}} = (\mu_0 I_1 I_2/4\pi).\operatorname{sen}^2\alpha.m\left\{\left[1/\left(\sqrt{m^2-2L_0\cos\alpha\ m+L_0^2+S^2}\ \left(\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2}+\right.\right.\right.\right.$$

$$\left.\left.\left.\left.+L_0-m\ \cos\alpha\right)\right)\right]-\left[1/\left(\sqrt{m^2-2L\cos\alpha\ m+L^2+S^2}\ \left(\sqrt{m^2-2L\cos\alpha m+L^2+S^2}+L-m\cos\alpha\right)\right)\right]\right\} \quad (3.1)$$

$$\boxed{\frac{\partial F_y}{\partial m}} = -(\mu_0 I_1 I_2/4\pi).\cos\alpha.S\left\{\left[1/\left(\sqrt{m^2-2L_0\cos\alpha m+L_0^2+S^2}\ \left(\sqrt{m^2-2L_0\cos\alpha m+L_0^2+S^2}+\right.\right.\right.\right.$$

$$\left.\left.\left.\left.+L_0-m\cos\alpha\right)\right]-\left[1/\left(\sqrt{m^2-2L\cos\alpha m+L^2+S^2}\ \left(\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}+L-m\cos\alpha\right)\right)\right]\right\} \quad (3.2)$$

$$\boxed{\frac{\partial F_z}{\partial m}} = -(\mu_0 I_1 I_2/4\pi).\cos\alpha.\operatorname{sen}\alpha.m\left\{\left[1/\left(\sqrt{m^2-2L_0\cos\alpha m+L_0^2+S^2}\ .\right.\right.\right.$$

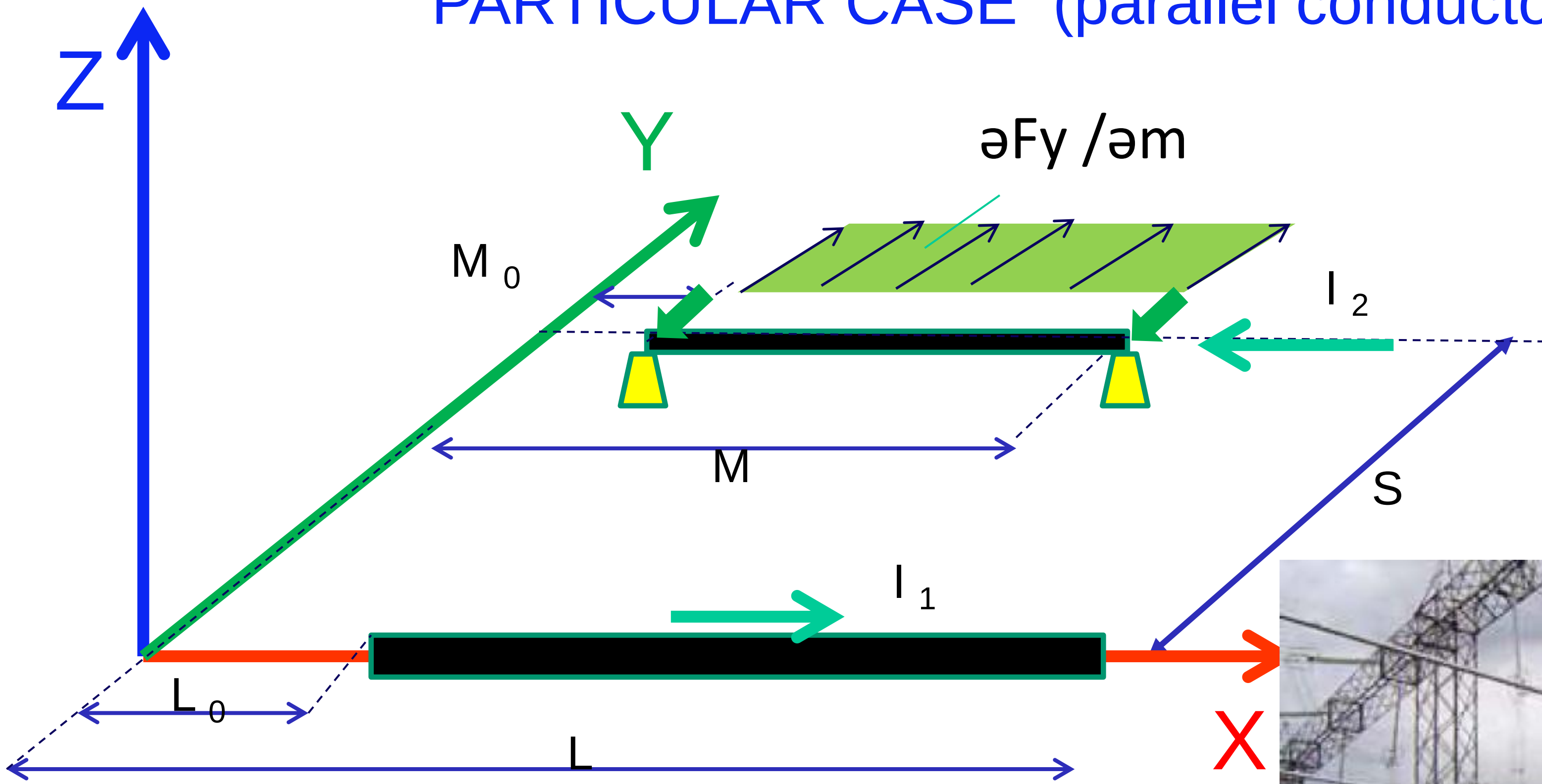
$$.\left(\sqrt{m^2-2L_0\cos\alpha m+L_0^2+S^2}+L_0-m\cos\alpha\right)\Big)\Big]-\Big[1/\Big(\sqrt{m^2-2L\cos\alpha m+L^2+S^2}\ .$$

$$\left.\left.\left..\left(\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}+L-m\cos\alpha\right)\right)\right]\right\} \quad (3.3)$$

PARAMETERS INFLUENCING IN THE ELECTRODYNAMICAL FORCES AND STRESSES

- Geometry and distances between phases
- materials
- Short circuit currents and its asymmetry.
- Supportability (tensile, compression and bending) and distance between insulators

PARTICULAR CASE (parallel conductors



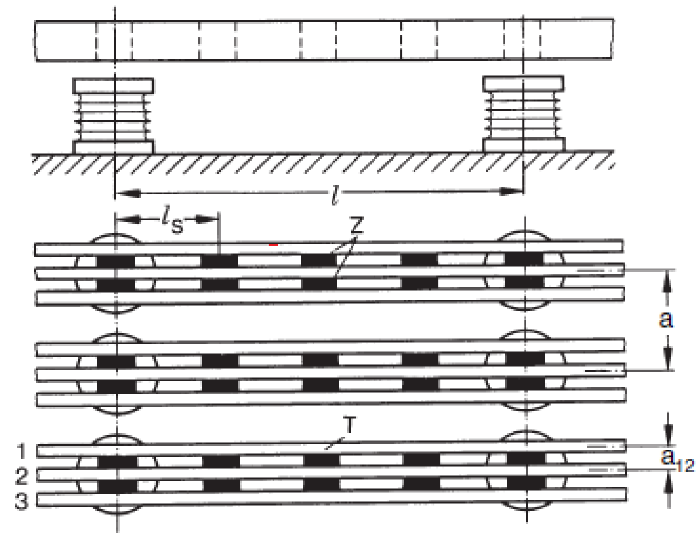
Several "non-parallel conductors")

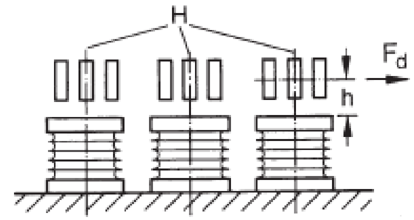
$$\frac{\partial F_x}{\partial m} = 0$$

$$\frac{\partial F_y}{\partial m} = -(\mu_0 I_1 I_2/4\pi)\cdot S\left\{\left[1/\left(\sqrt{m^2-2L_0 m+L_0^2+S^2}\left(\sqrt{m^2-2L_0 m+L_0^2+S^2}+L_0-m\right)\right)\right]-\left[1/\left(\sqrt{m^2-2Lm+L^2+S^2}\left(\sqrt{m^2-2Lm+L^2+S^2}+L-m\right)\right)\right]\right\}$$

$$\frac{\partial F_z}{\partial m} = 0$$

CALCULATION OF PARALLEL CONDUCTORS





Main conductor stress: $\sigma_m = V_\sigma \cdot V_r \cdot \beta \cdot \frac{F_m \cdot l}{8 \cdot Z}$

Sub-conductor stress: $\sigma_s = V_{\sigma s} \cdot V_r \cdot \frac{F_s \cdot l_s}{16 \cdot Z_s}$

When considering the plastic deformation

$V_\sigma \cdot V_r = V_{\sigma s} \cdot V_r = 1$ in two-phase a.c. systems

$V_\sigma \cdot V_r = V_{\sigma s} \cdot V_r = 1$ in three-phase systems without three-phase auto-reclosure

$V_\sigma \cdot V_r = V_{\sigma s} \cdot V_r = 1.8$ in three-phase systems with three-phase auto-reclosure

The resulting conductor stress is a combination of the main and sub-conductor stress:

$\sigma_{tot} = \sigma_m + \sigma_s$

The force F_d on each support:

$F_d = V_F \cdot V_r \cdot \alpha \cdot F_m$

with

$V_F \cdot V_r = 1$ for $\sigma_{tot} \geq 0.8 \cdot R'_{p0.2}$

$V_F \cdot V_r = \frac{0.8 \cdot R'_{p0.2}}{\sigma_{tot}}$ for $\sigma_{tot} < 0.8 \cdot R'_{p0.2}$

However, in two-phase a.c. systems $V_F \cdot V_r$ does not require a value greater than 2 and in three-phase systems no greater than 2.7.

The electrodynamic force

between the main conductors through which the same current flows is

$$F_m = \frac{\mu_0}{2\,\pi} \cdot i_p^2 \cdot \frac{l}{a}$$

or as a numerical equation

$$F_m = 0.2 \cdot i_{p2}^2 \cdot \frac{l}{a} \text{ or } F_m = 0.173 \cdot i_{p3}^2 \cdot \frac{l}{a}.$$

If the main conductor consists of t single conductors, the electrodynamic force F_s between the sub-conductors is

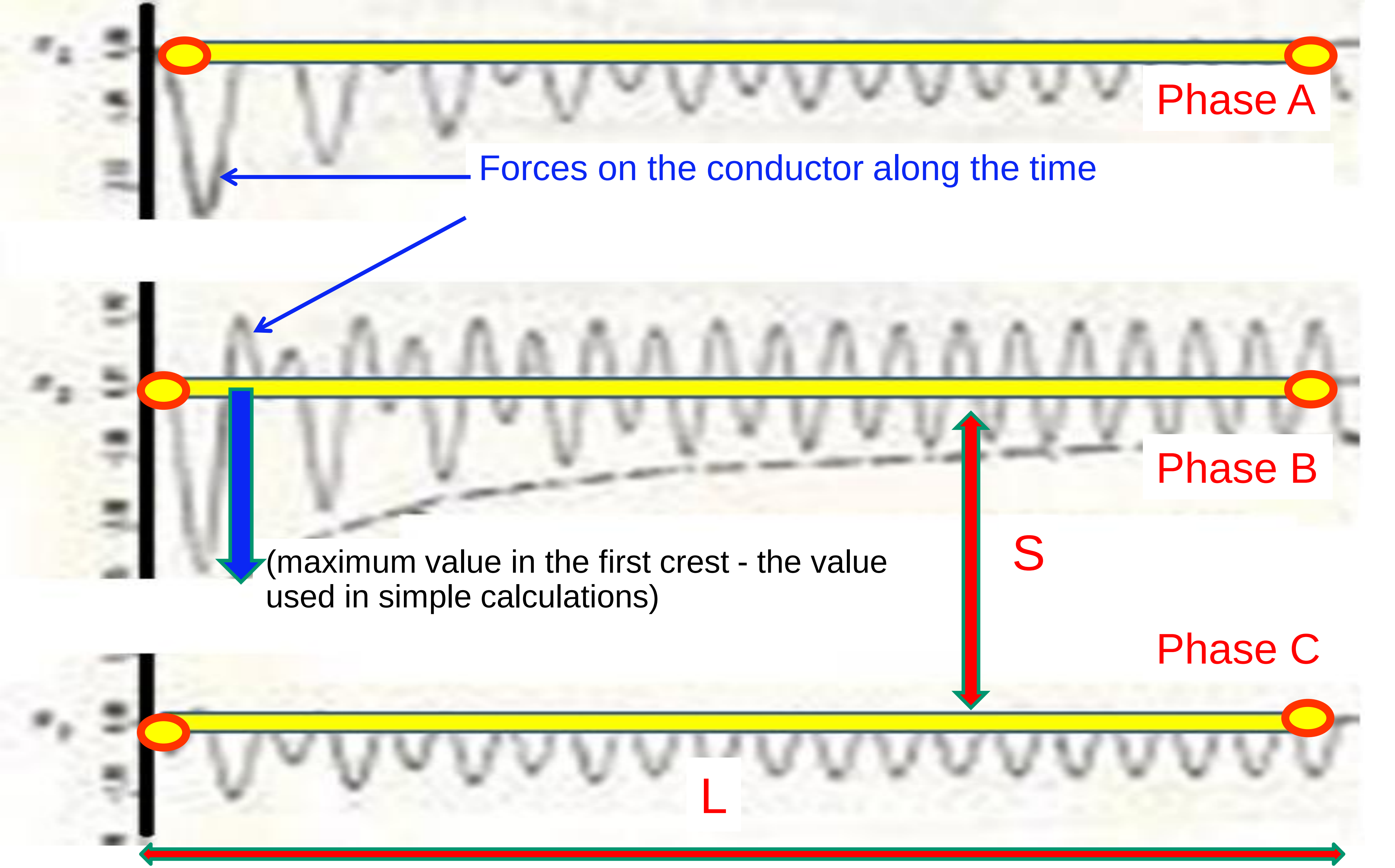
$$F_s = \frac{\mu_0}{2\,\pi} \cdot \left(\frac{i_p}{t}\right)^2 \cdot \frac{l_s}{a_s}$$

or as a numerical equation

$$F_s = 0.2 \cdot \left(\frac{i_p}{t}\right)^2 \cdot \frac{l_s}{a_s}$$

Numerical equations with i_p in kA, F_m in N and l in the same unit as a.

ABB Switchgear Manual
ABB Pocket Book - Switchgear Manual - 10th revised edition
Edited by ABB Calor Emag Schaltanlagen AG Mannheim and ABB Calor Emag Mittelspannung GmbH Ratingen
Published at: Cornelsen Verlag, Berlin ISBN 3-46448236-7



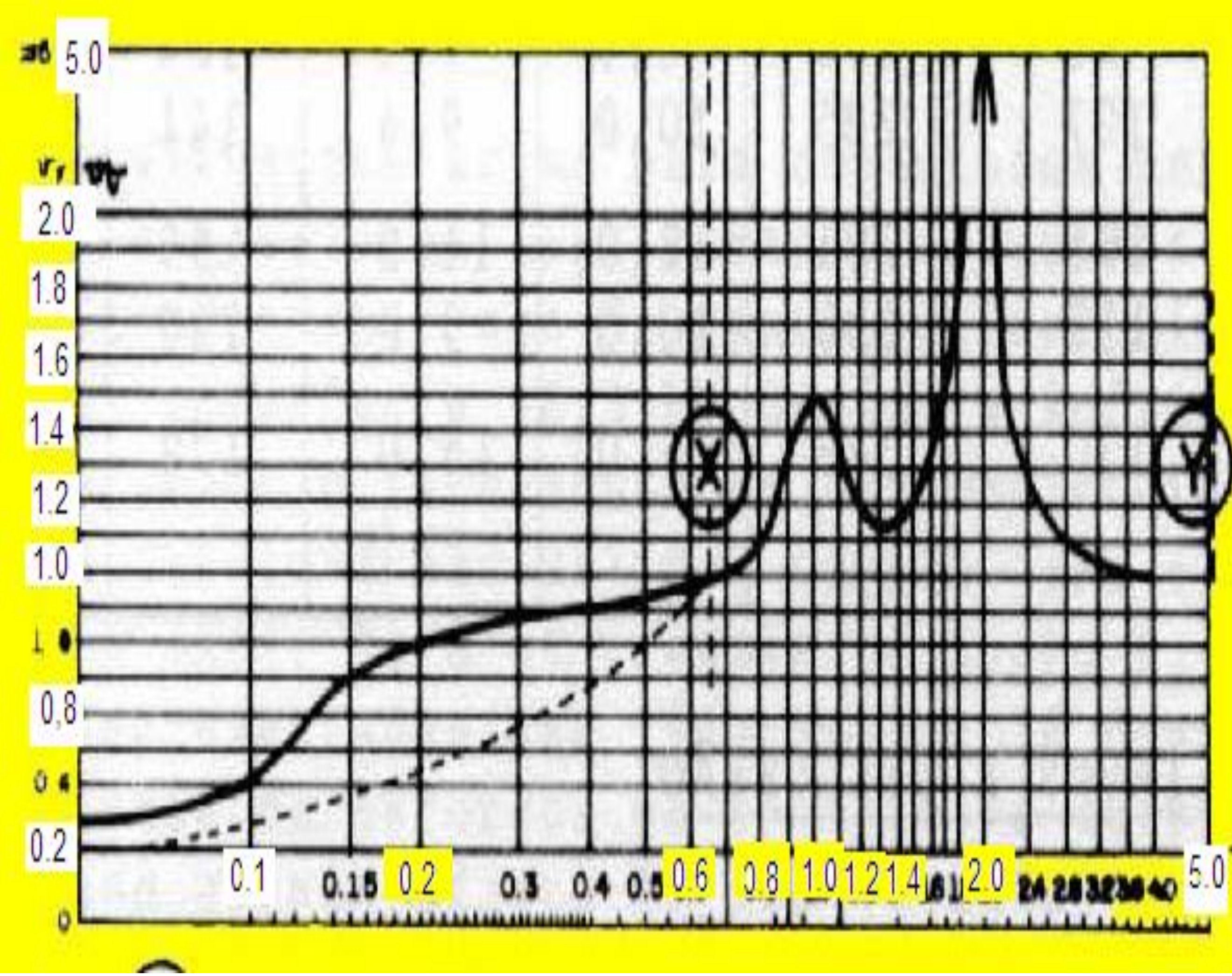
maximum forces are in the central Phase B if highest crest in the external pole (Phase A)

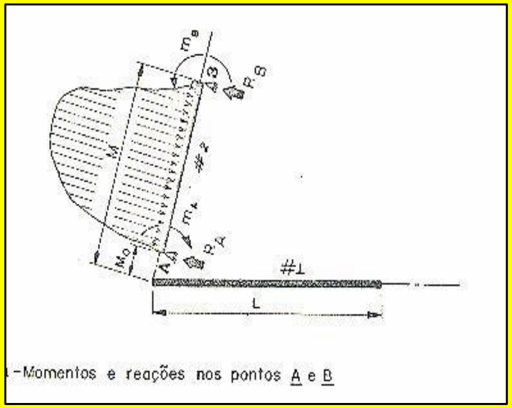
Three-phase short circuit - 3 bars of length L and distance S between phases

STEP 2)

CONVERT “STATIC FORCES” ON "DYNAMIC FORCES"

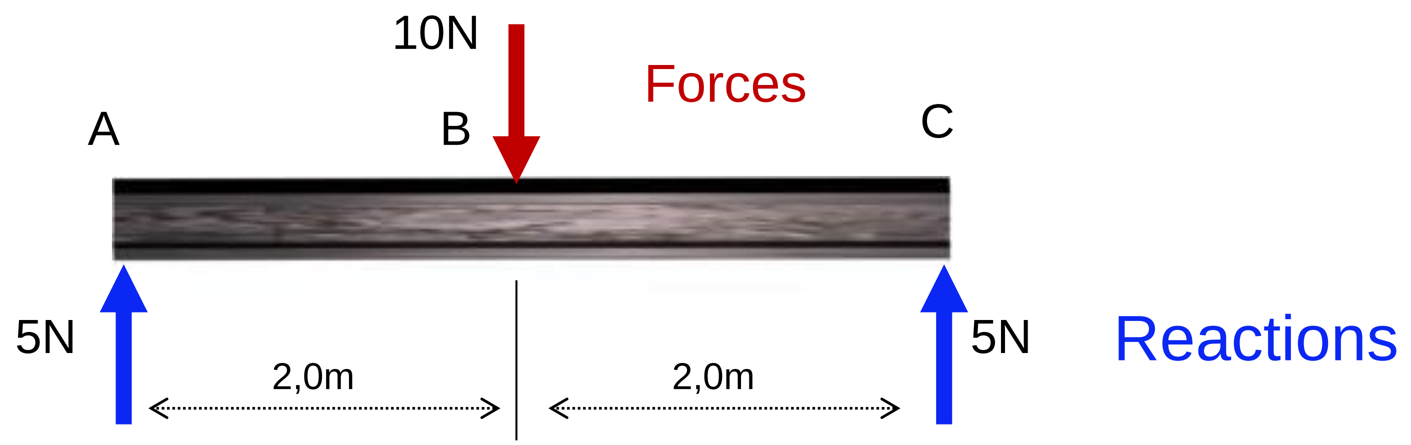
$F_{dynamical} = F_{static} \times$ Y value factor (function of fo / f in X axis)



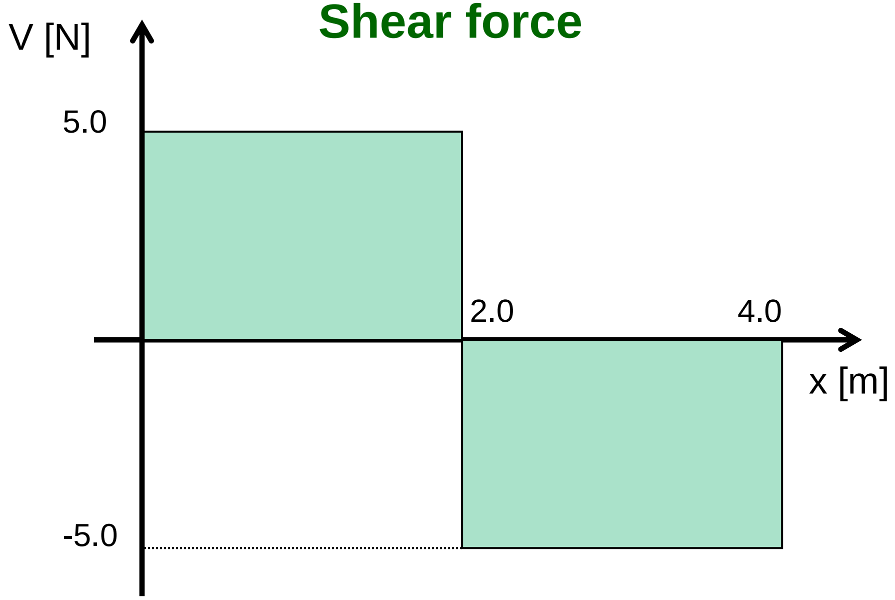


$$\frac{f_0}{f} = \frac{1,866}{\ell^2}\sqrt{\frac{E \cdot Jt}{gt}}$$

Step 3) CALCULATING FORCES IN INSULATORS, SHEAR FORCES AND BENDING MOMENTS

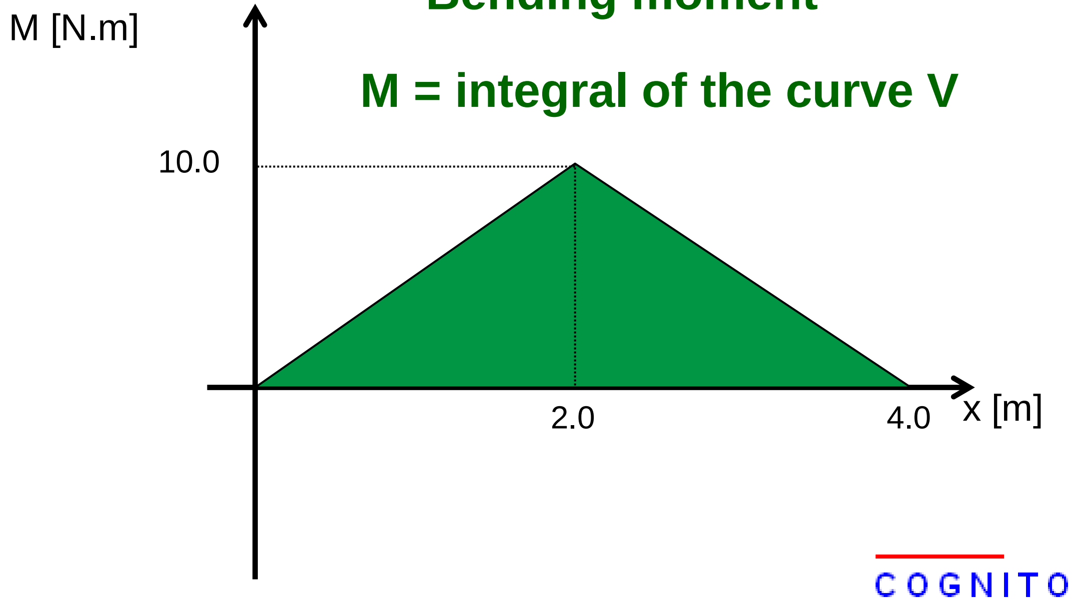


Shear force



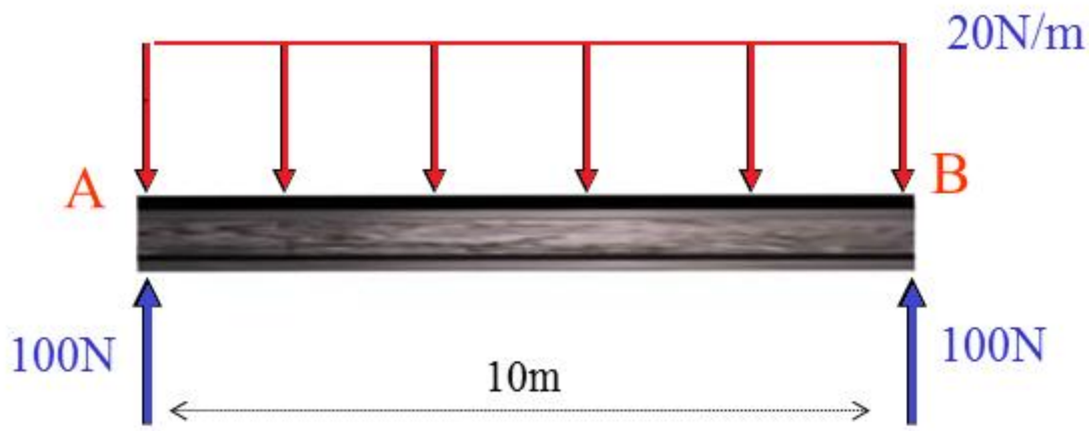
Bending moment

M = integral of the curve V



Step 3) CALCULATING FORCES IN INSULATORS, SHEAR FORCES AND BENDING MOMENTS

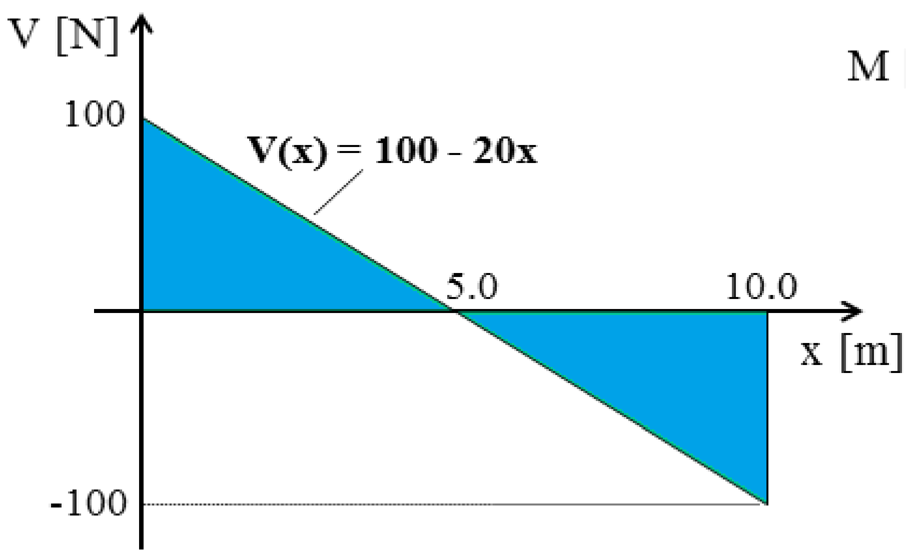
Forces



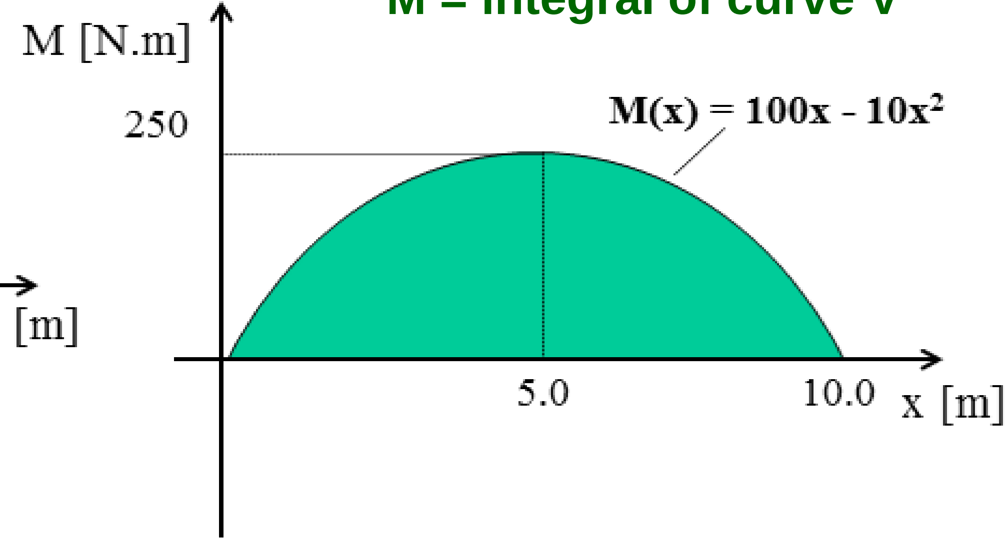
Reactions

Shear force

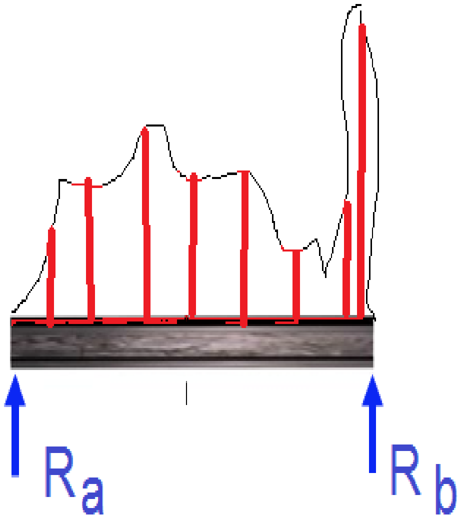
Bending moment



M = integral of curve V



Step 3) CALCULATING FORCES IN INSULATORS, SHEAR FORCES AND BENDING MOMENTS



- We have in each conductor the values of

$\partial F_x / \partial m \qquad \partial F_y / \partial m \qquad \partial F_z / \partial m$

obtained from the general equations and then multiplied by a factor dependent on f_0/f

- Calculate the reactions R_a and R_b by the method of moments.

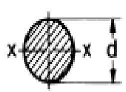
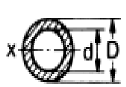
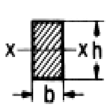
- Calculate the shear forces diagram

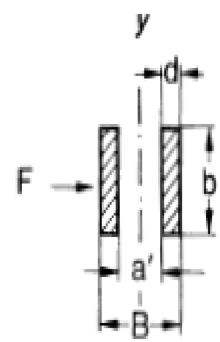
- Calculate the bending moment diagram

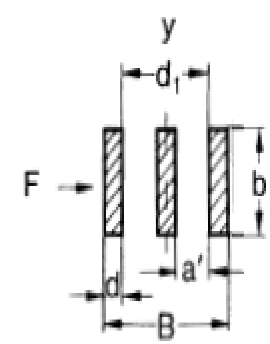
Step 4) CALCULATE MECHANICAL STRESSES IN CONDUCTORS

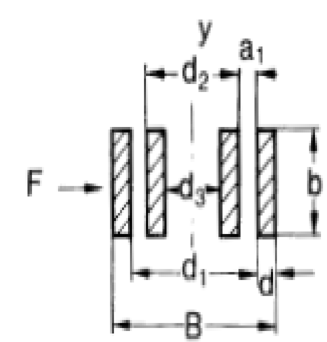
$$\text{Mechanical stress} = \frac{\text{Bending moment at the point}}{\text{Section moduli to bending}}$$

$$\text{Section moduli to bending (W)} = \frac{\text{Inertia moment of the beam}}{\text{Highest distance from the axis to any part of the beam}}$$

Cross-section	Moment of resistance bending[1] W[4] cm^3	Moment of inertia axial[2] J cm^4
	$\approx 0.1\,d^3$	$\approx 0.05\,d^4$
	$0.098\,\frac{D^4 - d^4}{D}$	$\approx \frac{D^4 - d^4}{20}$
	$\frac{b\,h^2}{6}$	$\frac{b\,h^3}{12}$







$$J_y = \frac{b}{12}(B^3 - a'^3) \qquad J_y = \frac{b}{12}(B^3 - d_1^3 + d^3) \qquad J_y = \frac{b}{12}(B^3 - d_1^3 + d_2^3 - d_3^3)$$

$$Z_y = \frac{D}{6\,B}(B^3 - a'^3) \qquad Z_y = \frac{D}{6\,B}(B^3 - d_1^3 + d^3) \qquad Z_y = \frac{D}{6\,B}(B^3 - d_1^3 + d_2^3 - d_3^3)$$

Step 5) COMPARE STRESSES IN THE CONDUCTORS AND FORCES IN THE INSULATORS WITH SUPPORTABILITY LIMITS

STRESSES - CONDUCTORS

$$\sigma_T < \sigma_{0.2}$$

$$\sigma_H + \sigma_T < 1.5 * \sigma_{0.2}$$

$\sigma_{0.2}$ copper = 250 N / mm^2

$\sigma_{0.2}$ alumínum = 120 N / mm^2

FORCES - INSULATORS

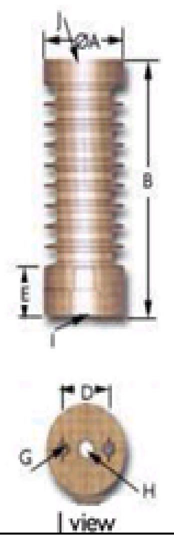
(traction, compression and flexure)

ONTACT US
GISTER
ARCH
CK

ISO 9001

Also available in cycle-aliphatic resin for outdoor applications.

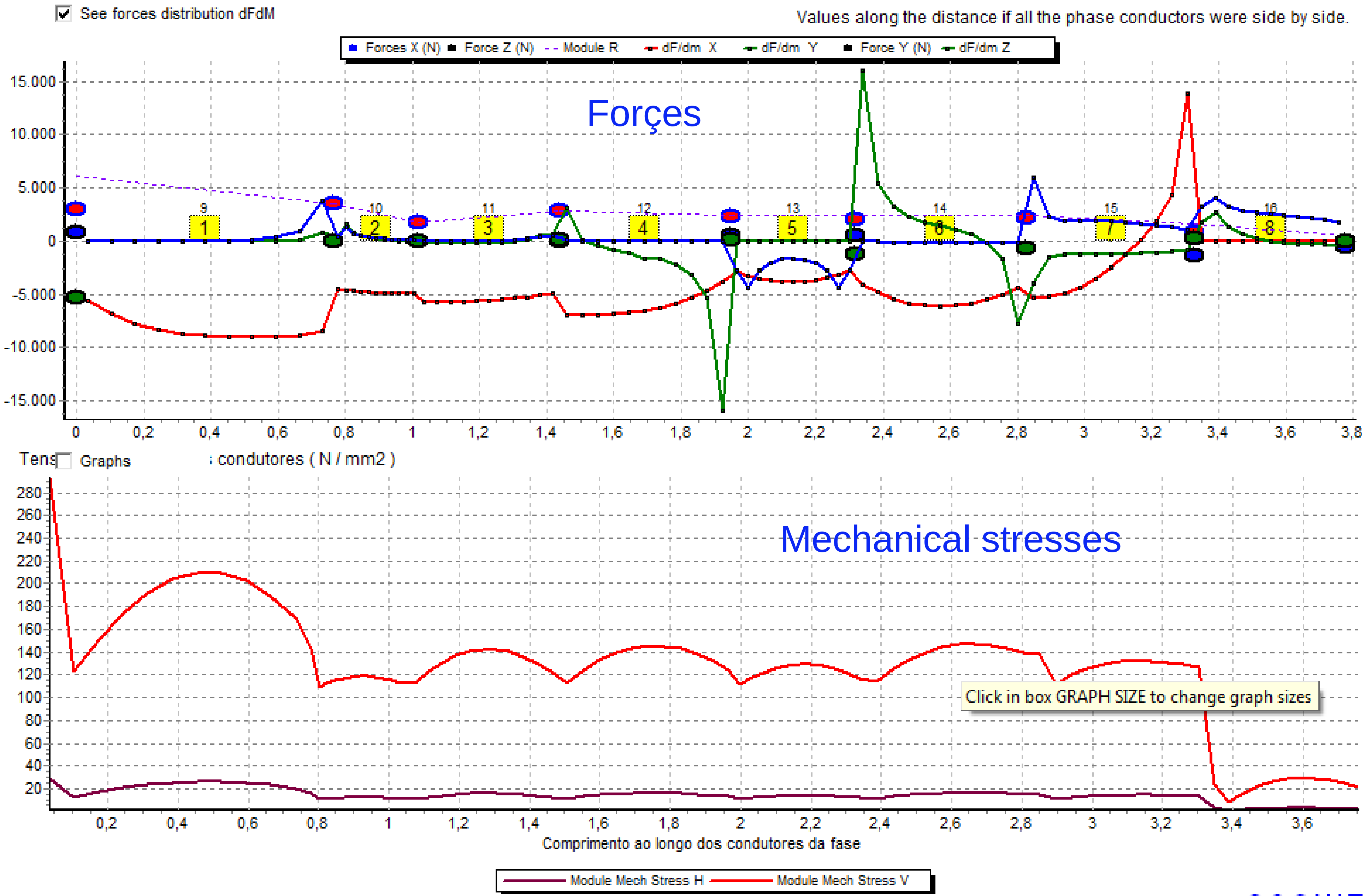
Cat. No.	Nom. Voltage (kV)	NBI (kV)	Withstand Voltage	Dimensions Ø (mm) A	B	C	D	E	Qty. of sheds	Leakage Distance (+/- 5 mm)
AT/S-59/95 MLT	8	60	20	59	95	38	36	10	2	115
AT/S-72/95 MLT	8	60	20	72	95	45	46	10	2	119
AT/S-96/102 MLT	8	60	20	96	102	-	-	-	3	120
AT/S-61/130 MLT	10	60	28	61	130	38	36	20	5	175
AT/S-77/130 MLT	10	60	28	77	130	45	46	20	5	190
AT/S-91/130 MLT	10	60	28	91	130	55	65	20	4	180
AT/S-118/130 MLT	10	75	28	118	130	65	-	10	4	207
AT/S-75/150 MLT	15	95	34	75	150	45	-	20	4	220
AT/S-75/175 MLT	20	110	50	75	175	45	36	20	6	270
AT/S-83/175 MLT	20	110	50	83	175	50	46	20	6	250
AT/S-75/210 MLT	24	150	50	75	210	45	36	20	8	335
AT/S-90/210 MLT	24	150	50	90	210	50	46	25	8	300
AT/S-82/300 MLT	36	170	70	82	300	45	36	20	11	505
AT/S-90/300 MLT	36	170	70	90	300	40	36	20	11	545
AT/S-98/300 MLT	36	170	70	98	300	60	46	20	11	480
AT/S-104/372 MLT	36	170	70	104	372	-	-	20	11	550

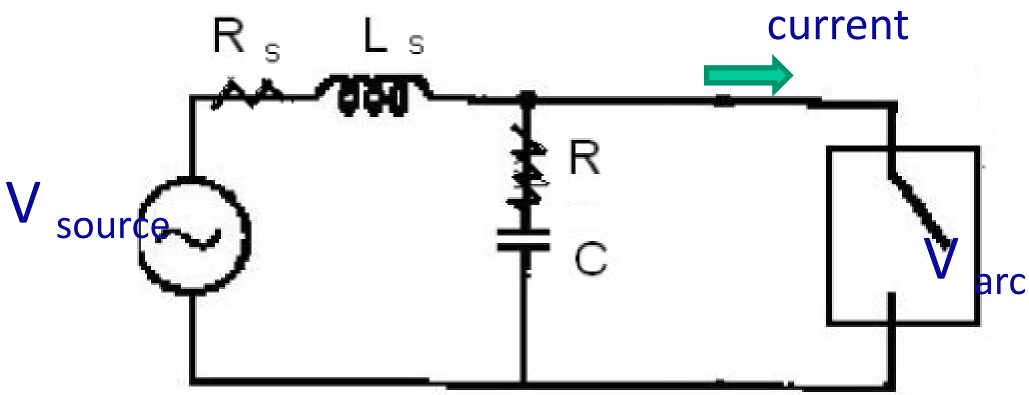


Cont...

Cat. No.	Threads F Type Ø	F Depth.	G Type Ø	G Depth.	H Type Ø	H Depth.	Approx. Weight (g)	Bending Surface Distance (Kgf)	Traction (Kgf)	Compression (Kgf)
AT/S-59/95 MLT	M16	25	M6	9	M10	15	420	500/30	1000	>6.000
AT/S-72/95 MLT	M16	26	M10	15	M16	25	650	1000/40	200	>6.000
AT/S-96/102 MLT	M12	32	-	-	M12	32	1290	1000/20	2000	>6.000
AT/S-61/130 MLT	M16	25	M6	9	M10	15	570	500/30	1200	>6.000

Examples with the software

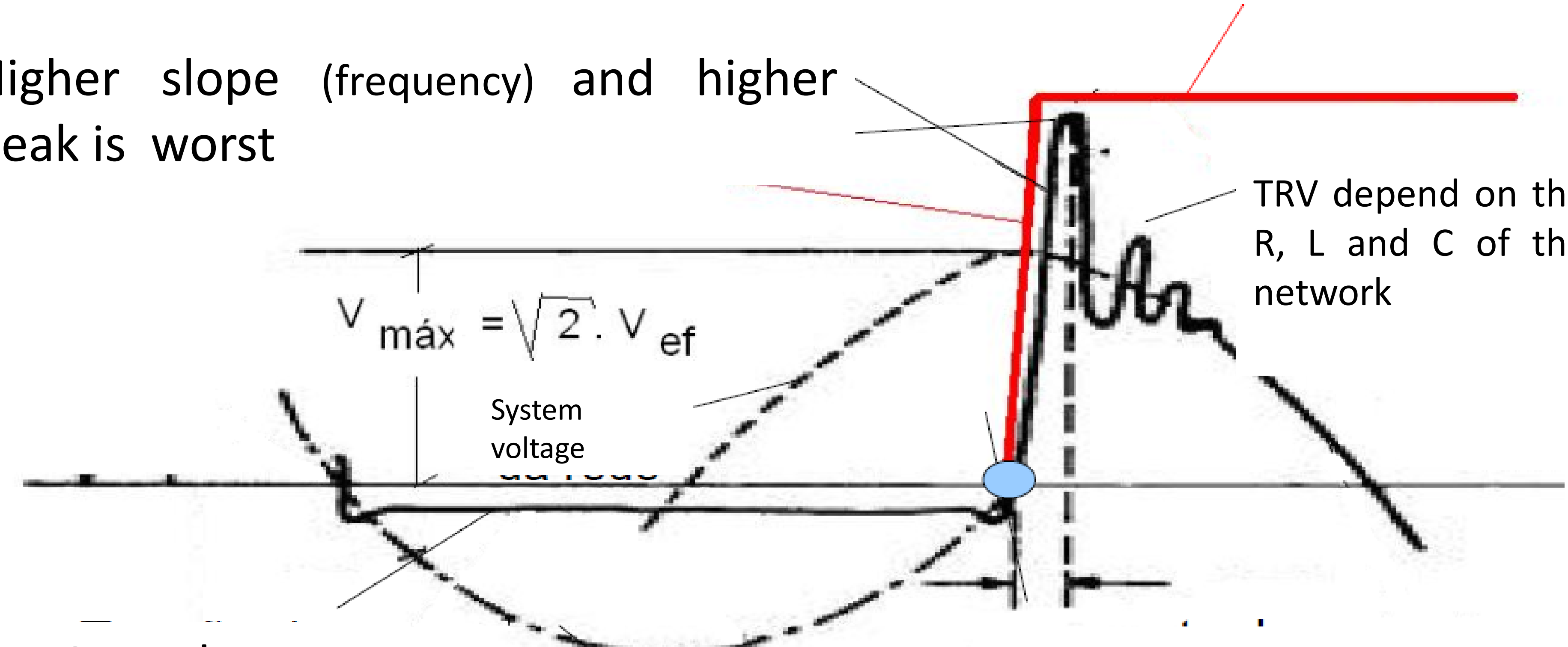




CURRENT INTERRUPTION IN CIRCUIT BREAKERS, FUSES AND SWITCHES

Cold characteristic of the circuit breaker above TRT

Higher slope (frequency) and higher peak is worst

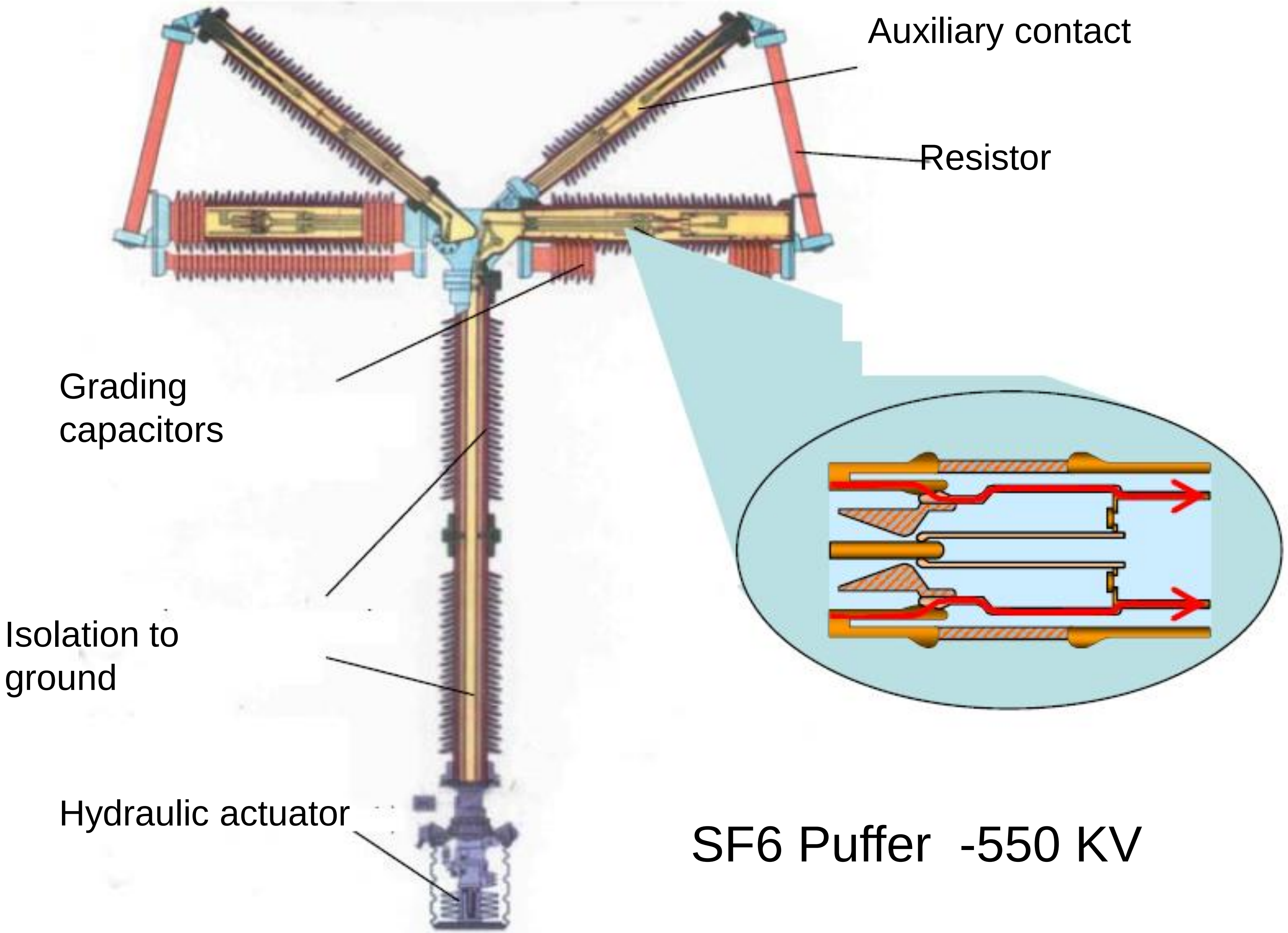


TRV depend on the R, L and C of the network

Arc voltage

Current

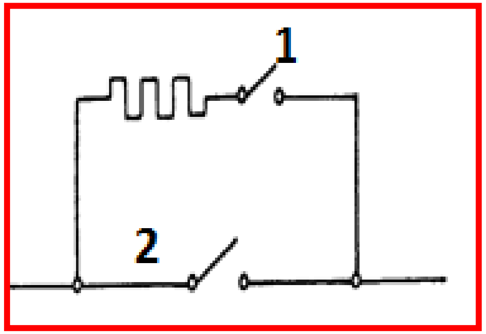
Breaking moment



SF6 Puffer -550 KV

RESISTORS (before making / after breaking)

MAKING



- Close contact 1
- After time interval close contact 2
- Opens contact 1

Typical 400 Ohm during 6 to 8 ms

- Capacitor bank switching (energizzation and back-to-back)
- energization and reclosing of long lines
- "inrush" currents reduction and no load transformers switching

BREAKING:

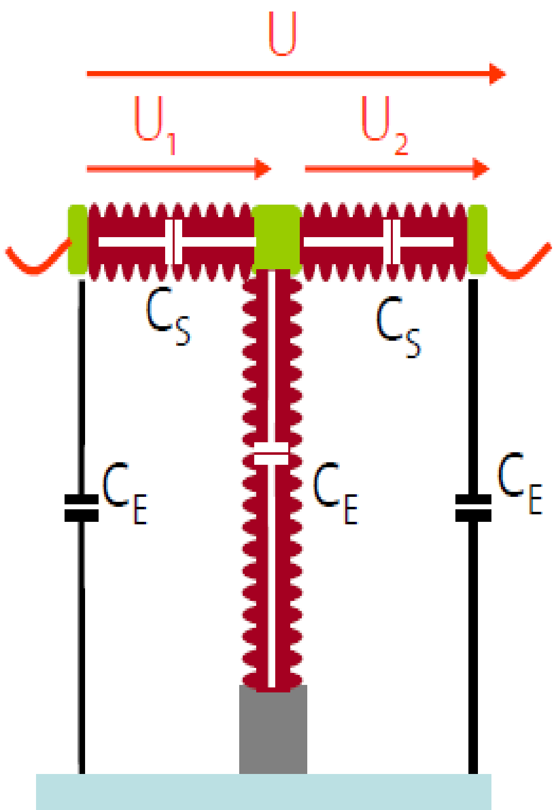
- Close contact 1
- Opens contact 2
- After time interval opens contact 1

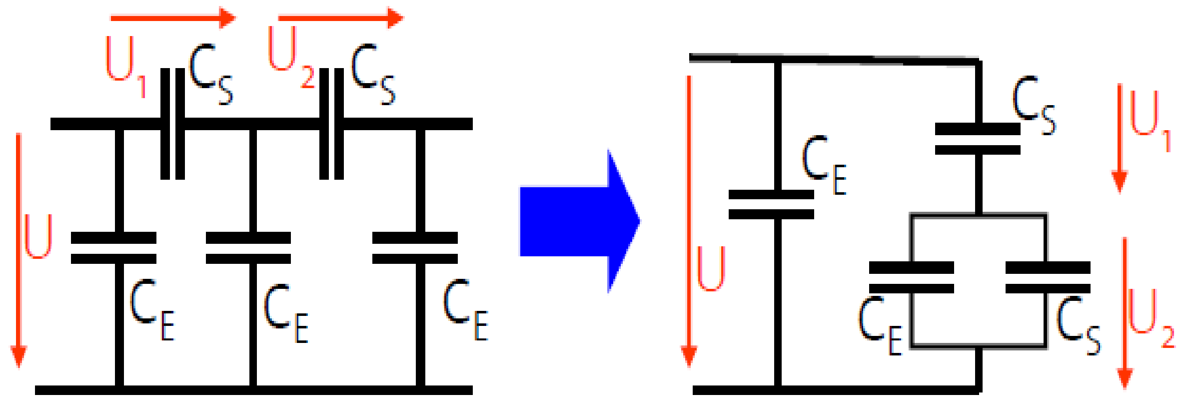
Typical 600 Ohm during 16 ms

- equalization of voltage in chamber (50 000 ohm)
- reduction of TRV for terminal faults and km faults
- reduction of overvoltages in breaking small capacitive and inductive currents

CAPACITORS FOR EQUALIZATION

Increase C_s puting $C_{Grading}$ in paralel with C_s





$$\frac{U_2}{U} = \frac{U_2}{U_1 + U_2} = \frac{C_S}{2C_s + C_E}$$

Typical values:

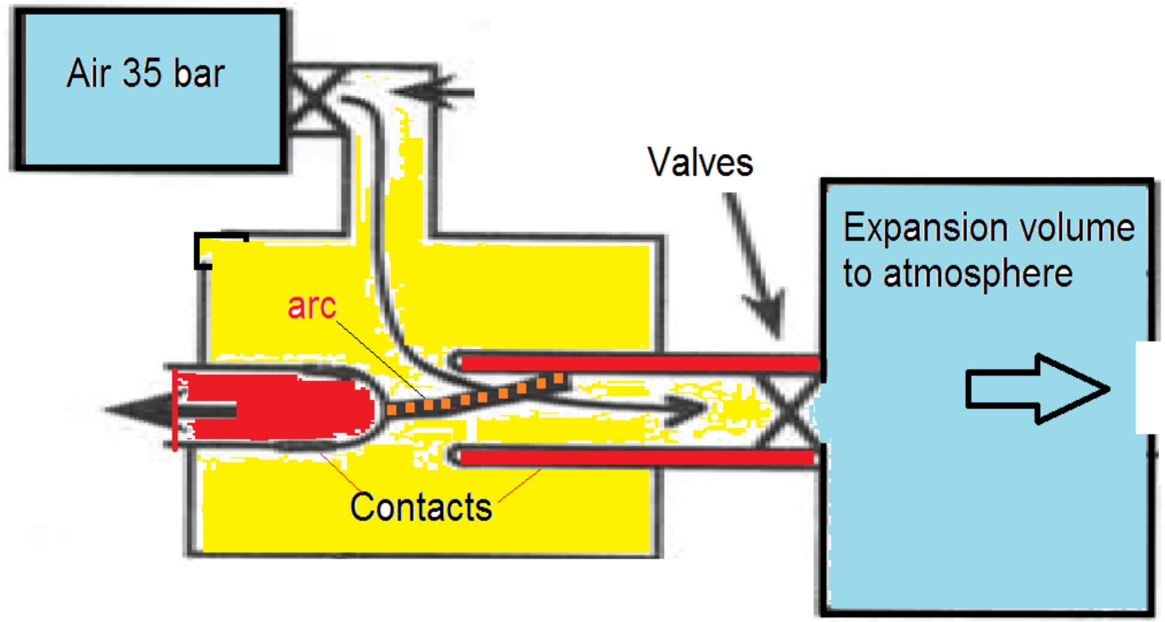
C_s	= 5-20 pF
C_E (substation)	= 5-10 pF
C_E (SF_6)	= 50-400 pF
$C_{grading\ cap.}$	= 100-2000 pF

145 kV - 1 chamber
245 kV - 2
362 kV - 2 - 4
500 kV - 4
800 kV - 8

COMPRESSED AIR CIRCUIT BREAKER

Arc extinction by compressed air stored at high pressure

Blow in the contacts area , cools and compresses the arc

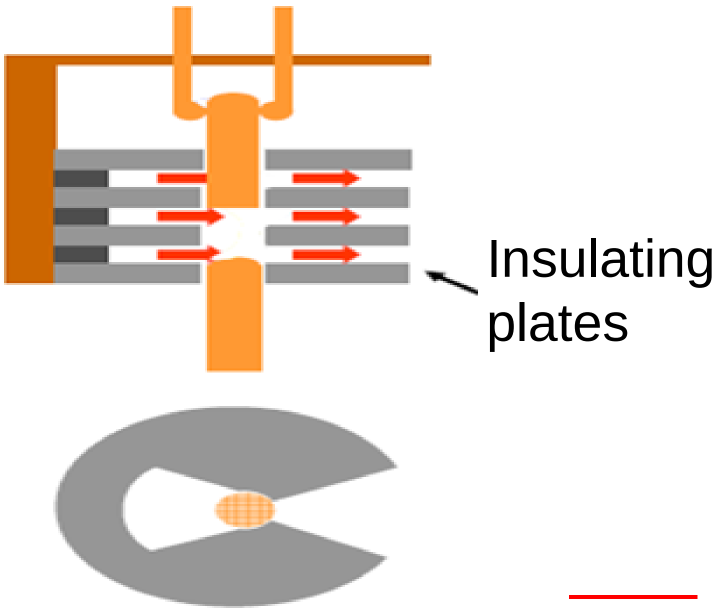


OIL CIRCUIT BREAKER

Decomposition of oil produces gases

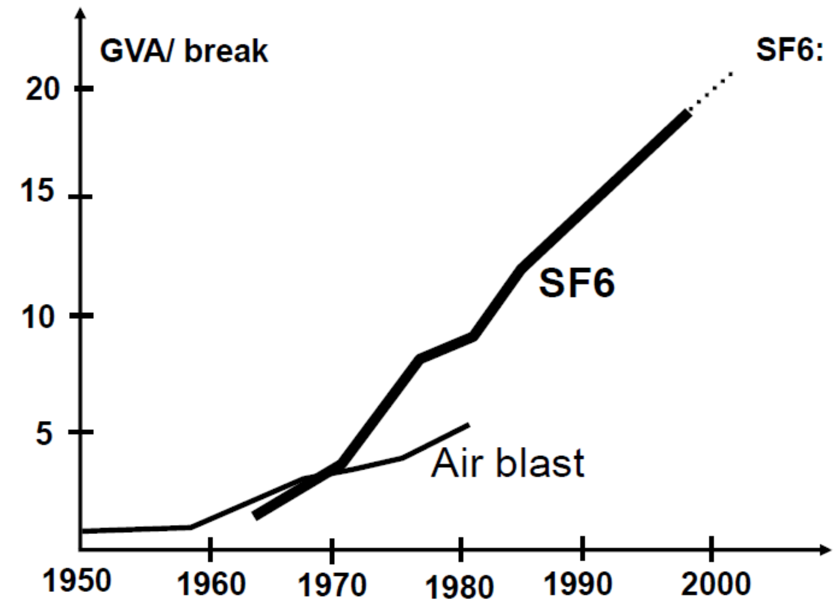
Contacts move away exposing openings through which gases pass the chamber due to the high pressures..

Arc elongates and is interrupted when current passes through zero, at which instant there is not released energy

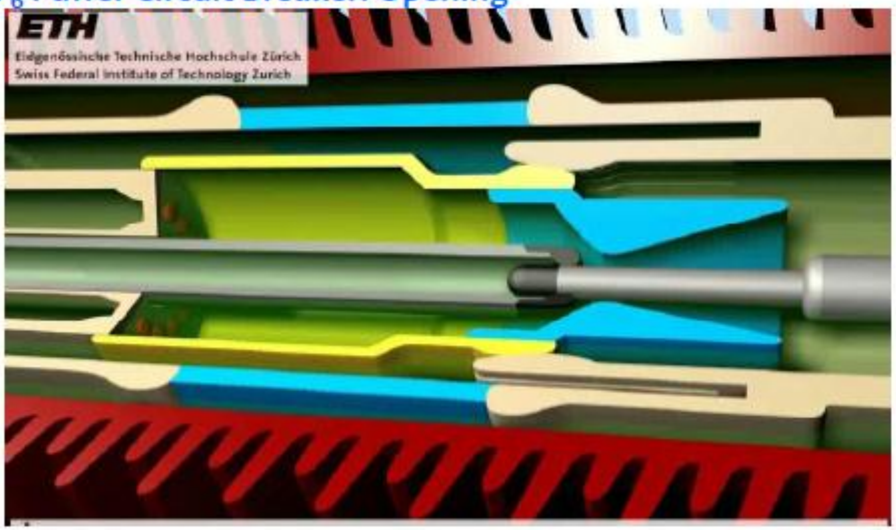


CIRCUIT BREAKER SF_6

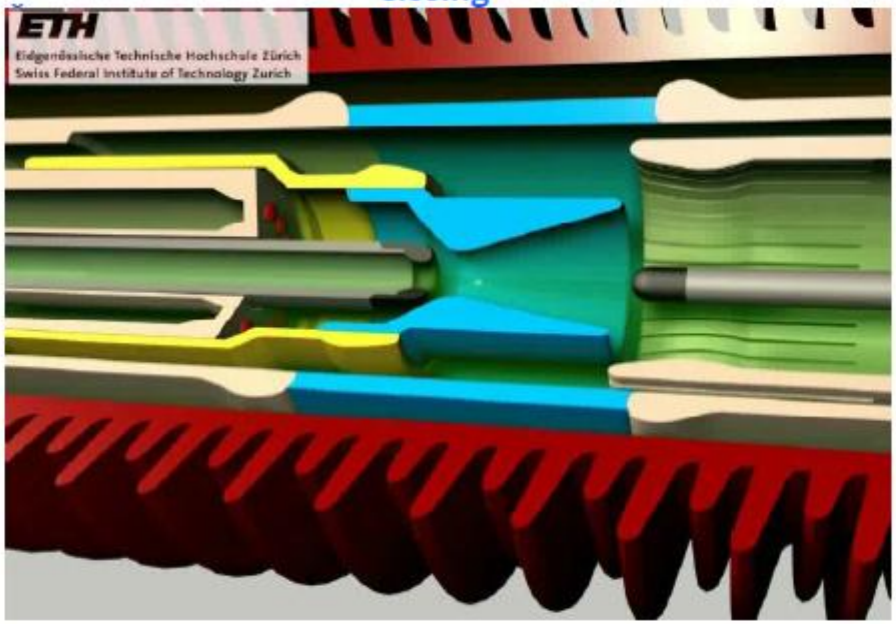
- SF6: stable and inert and 5 x heavier than air
- Dielectric strength 2.5 times greater than air.
- Contamination by air: 20% air 5% reduces the dielectric strength of the gas.
- "Puffer" with single pressure (3 ~ 6 bar)
- Piston moves and compresses the gas to pressures of ~ 6 times the initial.
- Gas flows through contacts at high speed



SF_6 Puffer Circuit Breaker: Opening



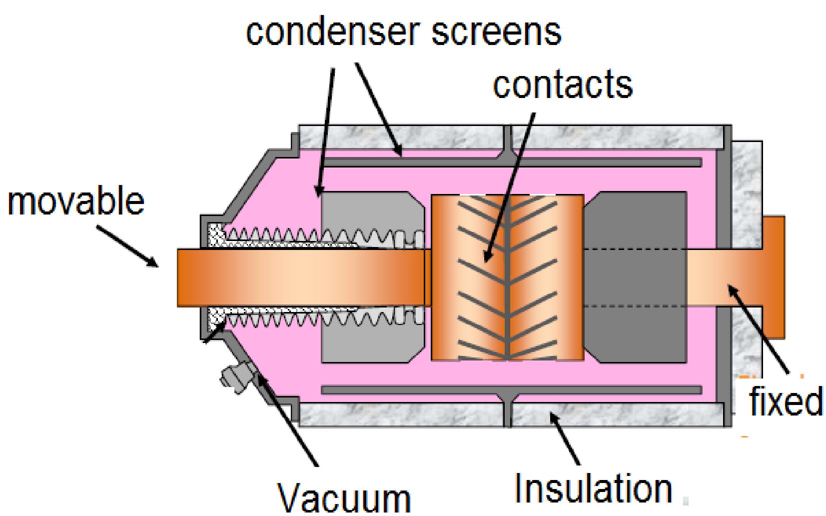
Closing

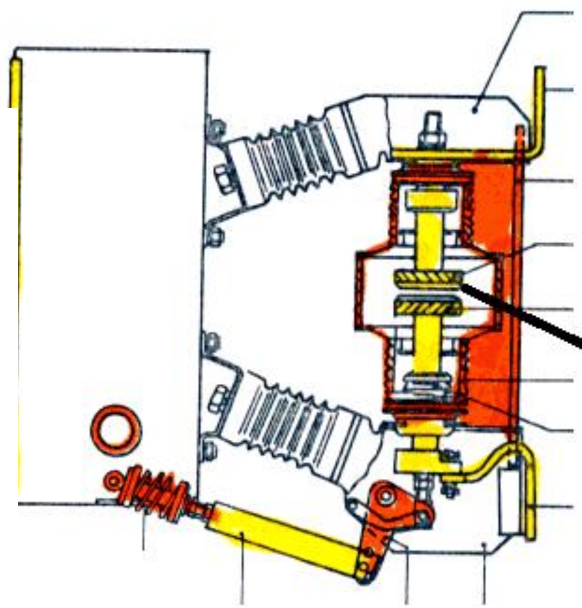


VACUUM CIRCUIT BREAKER

Arc formed between contacts unlike other types of circuit breaker, being held by ions coming from the metallic material vaporized contacts.

At current zero the space between the contacts is rapidly deionized (condensation of metal vapors in the electrodes)





SEQUENCE OF OPERATION FOR CIRCUIT BREAKERS

O - t - CO - t' - CO

t = 3 minutes for circuit breakers without fast reclosing.

t = 0.3 s for circuit breakers with fast reclosing.

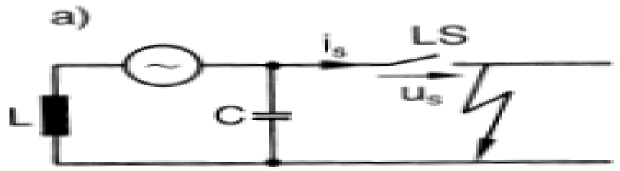
t '= 3 minutes

CO – t'' - CO

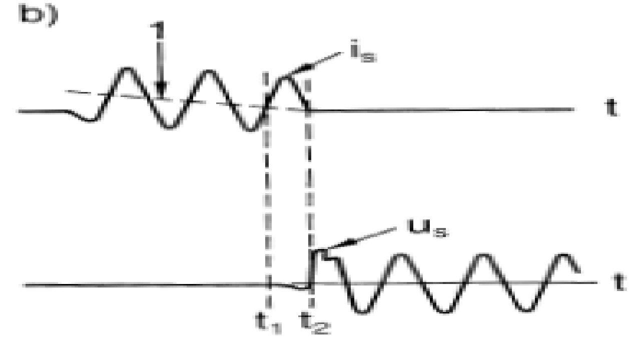
t''= 15 s, for circuit breakers without fast reclosing.

Terminal faults interruption

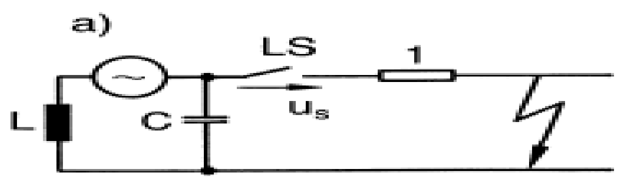
Terminal fault (asymmetrical short-circuit current), Fig. 10-13

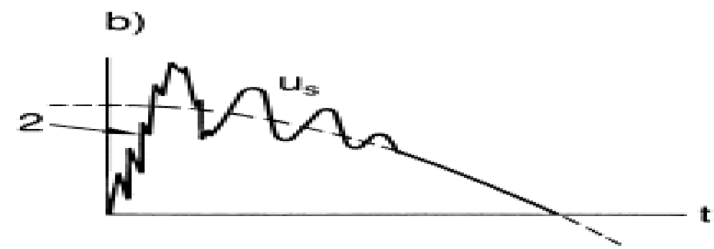


Short line faults interruption



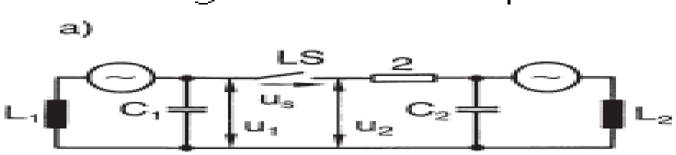
Short-line fault, Fig. 10-14



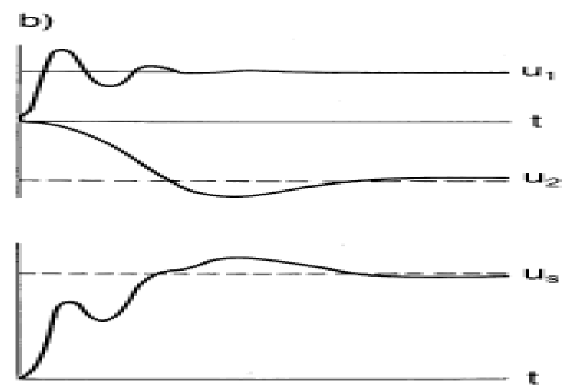


Out of phase interruption

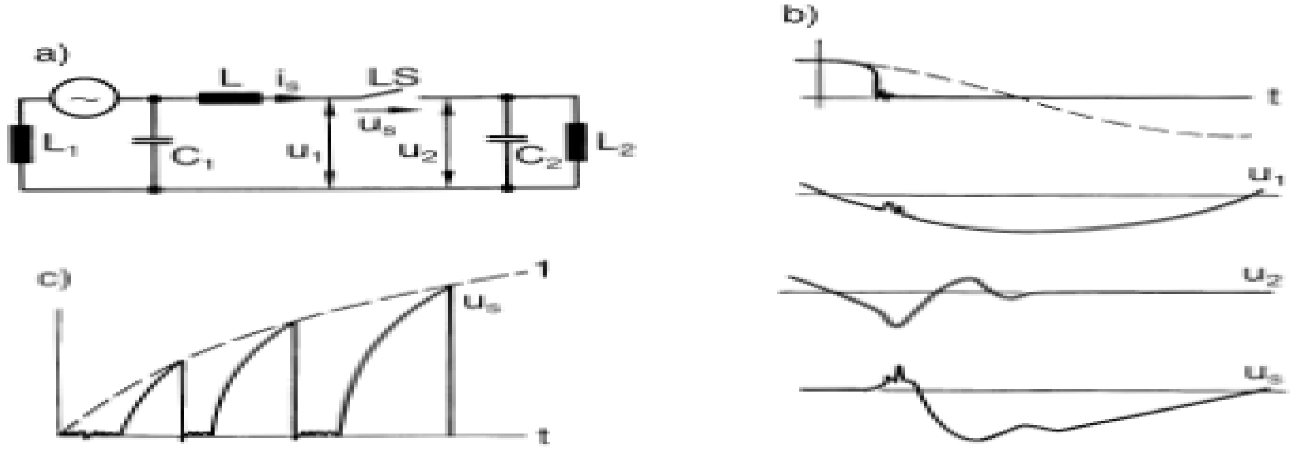
Switching under out-of-phase conditions (phase opposition)



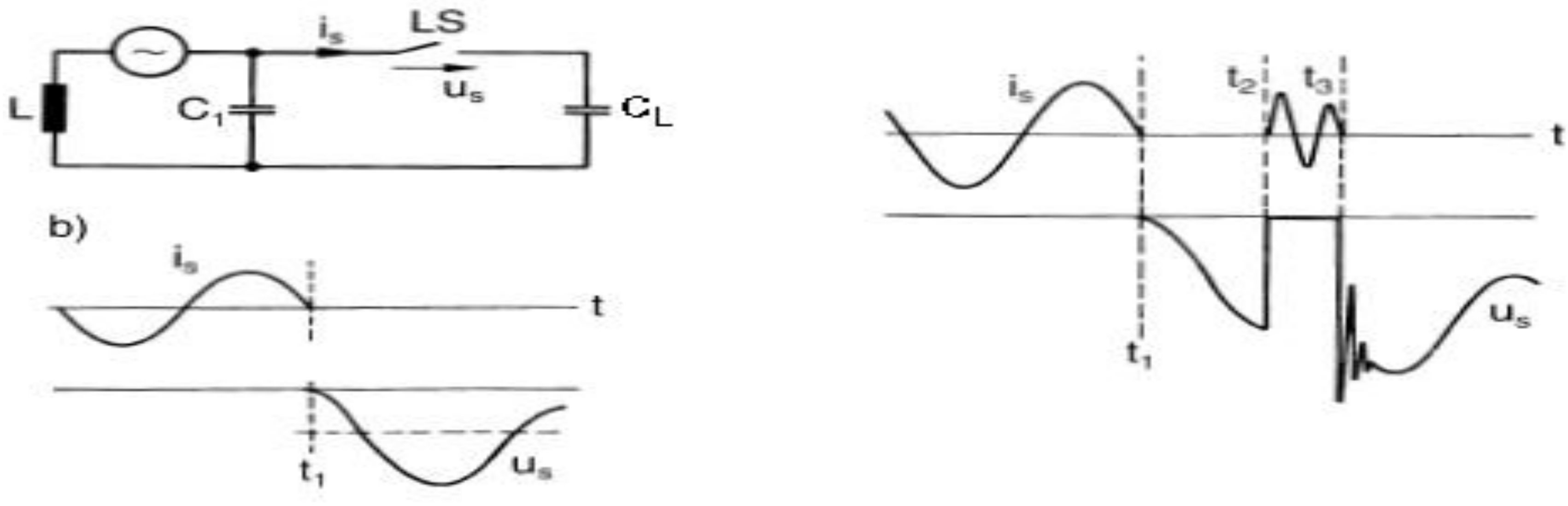
Switching under out-of-phase conditions,
a) simplified equivalent circuit,
b) voltage stress on circuit-breaker



Small inductive currents interruption



Out of load lines and cables



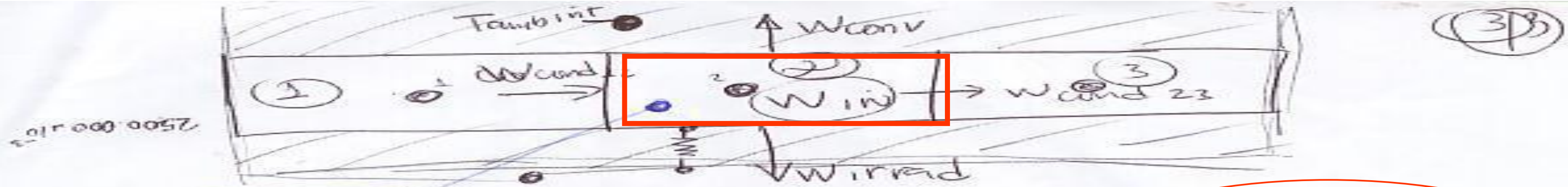
COGNITOR

SUPPLEMENTAL MATERIAL FOR STUDY

TEMPERATURE RISE CALCULATION

- Calculus equations to prepare a software
- Calculating the temperature rise of the conductors above the air temperature
- Calculating the temperature rise of the fluid (air, ...) by the method of IEC 60890
- Properties of insulating materials
- Properties of conductive material
- Comments on contact materials
- Effects of different atmospheres in the oxidation

TEMPERATURE RISE CALCULATION EQUATIONS



+Wabs

$$W_{cond\,12} + W_{in} = W_{cond\,23} + W_{conv} + W_{irrad} + massa \cdot CM \cdot \frac{\Delta t}{dt}$$

$(\Delta T_2 + t_{ref}) - (\Delta T_1 + t_{ref})$

ideia

+Wabs
+W interruption + W Latente
ideia

$$\frac{K_{12} \cdot S_{12}\,(T_2 - T_1)}{\Delta m_{12}} + W_{in} = \frac{K_{23} \cdot S_{23}\,(T_3 - T_2)}{\Delta m_{23}} + W_{conv} + W_{irrad} + massa \cdot CM \cdot \left(\frac{T_2 - T_2^{old}}{dt}\right)$$

⇓ passou a ΔT

$$+\frac{K_{12} S_{12}}{\Delta m}(\Delta T_1) + \left(-\frac{K_{12} S_{12}}{\Delta m_{12}} - \frac{K_{23} S_{23}}{\Delta m_{23}} - \frac{massa \cdot CM}{dt}\right)\Delta T_2 + \frac{K_{23} S_{23}}{\Delta m_{23}}(\Delta T_3)$$

$$- W_{conv} - W_{irrad} = - W_{in} - \frac{massa \cdot CM\,\Delta T_2\,old}{dt}$$

ou

aux 1

$kg \cdot \frac{J}{kg \cdot K} = \frac{W}{K}$

$-W_{conv}$ abs $-W_{irrad}$ absorver

$$\left.\begin{array}{l} +\dfrac{K_{12} S_{12}}{\Delta m_{12}}(\Delta T_1) \\ +\dfrac{K_{23} S_{23}}{\Delta m_{23}}(\Delta T_3) \end{array}\right\} + \left(-\frac{K_{12} S_{12}}{\Delta m_{12}} - \frac{K_{23} \cdot S_{23}}{\Delta m_{23}} - \frac{massa \cdot CM}{dt} - \frac{W_{conv}}{\Delta T_2} - \frac{W_{irrad}}{\Delta T_2}\right)\Delta T_2 =$$

$$= - W_{in} - \frac{massa \cdot CM \cdot \Delta T_2\,old}{dt}$$

⊕ W latente ⊕ W interrupt

aux 2

Então $W_{out} =$

$\frac{W}{K}$

Veloc. $= 0{,}065\,\frac{m}{s}$

Velocidade tem + impacto se 1 barra.

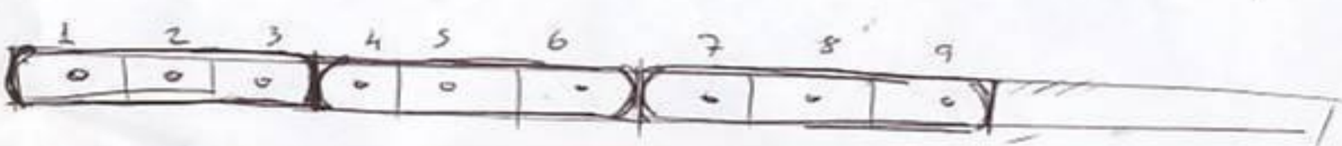
W_{conv} absorber =

W_{irrad} absorber =

TEMPERATURE RISE CALCULATION EQUATIONS

1 A MATRIZ DE ELEVAÇÃO DE TEMPERATURAS (1/3)

aux 1									ΔT_1		aux 2
W_{cond12}	aux 1	W_{cond23}							ΔT_2		aux 2
	W_{cond12}	aux 1	W_{cond23}						ΔT_3		aux 2
		W_{cond12}	aux 1	W_{cond23}					ΔT_4		aux 2
			W_{cond12}	aux 1	W_{cond23}				ΔT_5		aux 2
				W_{cond12}	aux 1	W_{cond23}			ΔT_6	=	aux 2
					W_{cond12}	aux 1	W_{cond23}		ΔT_7		aux 2
						W_{cond12}	aux 1	W_{cond23}	ΔT_8		aux 2
							W_{cond12}	aux 1	ΔT_9		aux 2



TEMPERATURE RISE CALCULATION EQUATIONS

Os termos ① ②

2/2

$$aux1 = -W_{cond12} - W_{cond23} - W_{conv\_div\_K} - W_{irad\_div\_K} - MC_{wire\,air}\_div\_dT$$
$$- W_{conv\_div\_K\ absorber} - W_{irad\_div\_K\ absorber}$$

$$aux2 = -W_{in}[pt] + W_{statechange} + W_{out\ interruption} - old\_MCD$$

$$\frac{W}{m \cdot K} * \frac{m^2}{m} = \frac{W}{K}$$

$$W_{out}[pt] = W_{cond12} + W_{cond23} + W_{conv\_div\_K} + W_{irad\_div\_K} + W_{out\_interrup.}$$
$$+ W_{conv\_div\_K\ absorber} + W_{irad\_div\_K\ absorber}$$

$$W_{cond12} = W_{cond} = \frac{Km_1 a * Secsheta}{\Delta x(\text{condutor})}$$

positivo ou negativo?

$$W_{in}[pt] = W\_wire + W\_arc + W_{constrict} + W\_ext$$

$$old\_MCD = \frac{oldTrise[pt] * CondMass[pt] * CM_{1a}}{DT_{req}}$$

$$MC\_div\_DT = \frac{CondMass[pt] * CM_{ea}}{DT}$$

$$W_{irad\_div\_K} = S_{lateral} * Stefan * \varepsilon * T_{amb}^3$$

$$W_{conv\_div\_K} = \frac{S_{lateral} * Km_{1}\,air * Nusselt}{DH}$$

MATERIAL PROPERTIES (CONDUCTORS)

	Symbol	Atomic weight	Atomic number	Density (kg/m^3)	Softening temperature (℃)	Melting temperature (℃)	Hardness H (10^8 Pa)	Temperature ℃	Temperature K	Resistivity ($10^{-8}\Omega m$)	Temperature resistivity coefficient ($10^{-3}K^{-1}$)	Specific heat ($J/kg \cdot K$)	Thermal conductivity ($W/m \cdot K$)	Total emissivity Bare	Total emissivity Oxidized	Remarks
Copper (annealed)	Cu	63.546	29	8 889	190	1 083	3.5 to 7.0	0 20 36.85 60	273.15 293.15 310 333.15	1.5881 1.7241 1.838 1.995	4.265 3.93 3.69	382 386 389 394	390 387 382 378	0.05	0.7	Cold-drawn copper: $\varrho_{20℃} = 1.759 \times 10^{-8}\Omega \cdot m$ Copper conductors in cables: $\varrho_{20℃} = 1.8 \times 10^{-8}\Omega \cdot m$
Brass	70 Cu. 30 Zn			8 530		915	~10	0 20	273.15 293.15	6 6.2	1.53 1.484	377	119 121	0.04	0.6	
Cupro-tungsten	W. 35 Cu. 0.5 Ni			13 600			15	20	293.15	5.3	6		150	0.1	0.5	
Aluminium (A5L)	Al	26.9815	13	2 700	150	658	1.5 to 8.0	0 20 36.85 60	273.15 293.15 310 333.15	2.6 2.8264 3.02 3.28	4.383 4.03 3.77	881 891 900 910	202 203 204 205	0.07	0.6	Aluminium cable conductors: $\varrho_{20℃} = 3.06 \times 10^{-8}\Omega \cdot m$
Almelec (AG5L)	Al. 0.5 Mg. 0.5 Si			2 700		552		0 20 36.85	273.15 293.15 310	3.016 3.25 3.45	3.88 3.6 3.39	890	185	0.07	0.6	Cabled Almelec: $\varrho_{20℃} = 3.3 \times 10^{-8}\Omega \cdot m$
Al. alloy (AG3)				2 700				20	293.15	5.5		890	125	0.07	0.6	
Ductalex	Be. Cu. Mg			2 700				20	293.15	2.826	3.9	890		0.07	0.6	Alloy still at experimental stage
Silver	Ag	107.868	47	10 500	180	962	2.6 to 6.0	0 20	273.15 293.15	1.47 1.59	4.08 3.77	234 235	418			
Tin	Sn	118.69	50	7 300	100	232	0.45 to 0.6	0 20 60	273.15 293.15 333.15	11 12 14	4.47	223.5 226.4 232.2	62.8 62.5 62.0	0.08	0.55	Amorphous state (β)
Nickel	Ni	58.71	28	8 900	520	1453	7.0 to 20.0	0 20 60	273.15 293.15 333.15	5.9 6.84 8.73	6.9	398 412 442	95.2 92.5 87.8	0.02		Pure nickel
Exconal	Copper plated aluminium (15% Cu by volume)			3 630				20	293.15	2.65	4.1	710	240	0.05	0.7	Contact surface equivalent to annealed copper

PROPERTIES OF INSULATING MATERIALS

	Pressure (bar) $(10^5$ Pa)	Temperature °C	Temperature K	Density ϱ (kg/m³)	Thermal conductivity λ (W/m · K)	Dynamic viscosity μ_d $(10^{-5}$ Pa · s)	Compressibility β $(10^{-3}$ K$^{-1})$	Specific heat C_p (J/kg · K)	Remarks
Air	1	−23.15	250	1.4133	0.02227	1.599	4.017	1005.4	
		0	273.15	1.2928	0.02419	1.728	3.67	1005.6	
		20	293.15	1.205	0.02585	1.822	3.40	1006.3	
		46.85	320	1.1033	0.02779	1.939	3.131	1007.3	
SF_6	1.3	20	293.15	7.95	0.01355	1.52	3.33	655	
Sulphur	3	20	293.15	18.65	0.01355	1.52	3.33	655	
hexa-	5	87.5	360.65	25.3	0.0142	1.82	2.78	766	
fluoride	Liquid	20	293.15	1371	0.150	29.1	7.1	1557	Indicative values
Oil	1	20	293.15	870	0.13	26	0.764	1880	Indicative values

EFFECTS OF DIFFERENT ATMOSPHERES IN OXIDATION

Metal	Reactant	Reaction product	Oxidation formula obtained	Units Remarks	Sources	Examples: Temperature (℃)	Examples: Thickness formed $\times 10^{-10}$ m, After 1 000 h	Examples: Thickness formed $\times 10^{-10}$ m, After 100 000 h
Copper	Atmospheric oxygen	Cu_2O	$s = \sqrt{s_0^2 + t \cdot e^{\left(34.31 - \frac{11\,700}{T_c}\right)}}$	s, s_0 in angströms*; ($s_0 \simeq 20$ Å, oxide thickness immediately formed on the metal) t = time in hours T_c = temperature in kelvins (thermodynamic temperature)	Rönnquist, quoted by Holm (Electric Contacts, Springer Verlag)	20 55 60 85 100	21.7 35 39 87 150	37 170 210 690 1 300
Aluminium	Atmospheric oxygen	Al_2O_3	The thickness of Al_2O_3 oxide formed on the aluminium does not exceed 50 Å, the initial oxidation of 20 Å being attained after a few seconds. The film obtained is insulating and must be broken to allow the passage of current in the case of electric contacts. The presence of water vapour favours the growth of the film which can continue for months, but very slowly.			50 Å (unusable without preparation as contact material)		
Tin	Atmospheric oxygen	SnO	$s = 5.22 \ln 47\, t \cdot e^{\left(7.92 - \frac{2400}{T_c}\right)}$	s in angströms*, t in hours, T_c in kelvins ($s_0 \simeq 15$ Å)	Britton and Bright, Metallurgica 56 (1957), p. 163	20 55 60 85 100	42 103 114 188 250	61 146 162 260 360

EFFECTS OF DIFFERENT ATMOSPHERES IN OXIDATION

Metal	Reactant	Reaction product	Oxidation formula obtained	Units Remarks	Sources	Examples		
						Temperature (°C)	Thickness formed $\times 10^{-10}$ m After 1 000 h	Thickness formed $\times 10^{-10}$ m After 100 000 h
Nickel	Atmospheric oxygen	NiO	$s = \sqrt{s_o^2 + t \cdot e^{\left(4.68 - \frac{1800}{T_c}\right)}}$	s in angströms*, t in hours, T_c in kelvins ($s_o \simeq 10$ Å)	Pilling and Bedworth, quoted by Holm (Electric Contacts, Springer Verlag)	20 55 60 85 100	15.5 21 22 27 34	150 210 220 270 340
Silver	H_2S and sulphurous vapours	Ag_2S	$t < 40: s = 60\, t^{1/3} e^{\left(27.5 - \frac{8000}{T_c}\right)}$ $40 < t < 70: s = 0.121\, t^{2.57} e^{\left(27.5 - \frac{8000}{T_c}\right)}$ $t > 70: s = 3\,750\, t^{0.15} e^{\left(27.5 - \frac{8000}{T_c}\right)}$	In saturated damp air at 20 °C containing 2% by volume of hydrogen sulphide	Frischmeister and Drott, Acta Metallurgica, vol. 7 (Dec. 1959), p. 777	Depends on the concentration of sulphurous vapours. The danger threshold is about $1/10^9$ (in volume)		
	Ozone	Ag_2O	Remains very thin (<10 Å) and decomposes at 200 °C – its presence is not a problem with contacts			<10 Å		
	Atmospheric sulphur	Ag_2S	$s = \sqrt{s_o^2 + t \cdot e^{\left(29 - \frac{8000}{T_c}\right)}}$	s in angströms*, t in hours, T_c in kelvins ($s_o \simeq 16$ Å)	According to W.E. Campbell, Electrical Contacts, IIT 1972, p. 185	Does not depend on humidity, but on the air circulation speed. The action of free sulphur S appears preponderant vis-à-vis H_2S or SO_2		

* 1Å = 10^{-10} m.

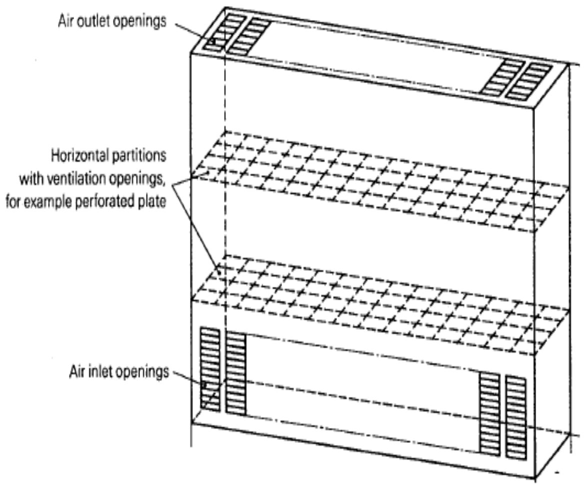
CHECKING THE AIR TEMPERATURE RISE

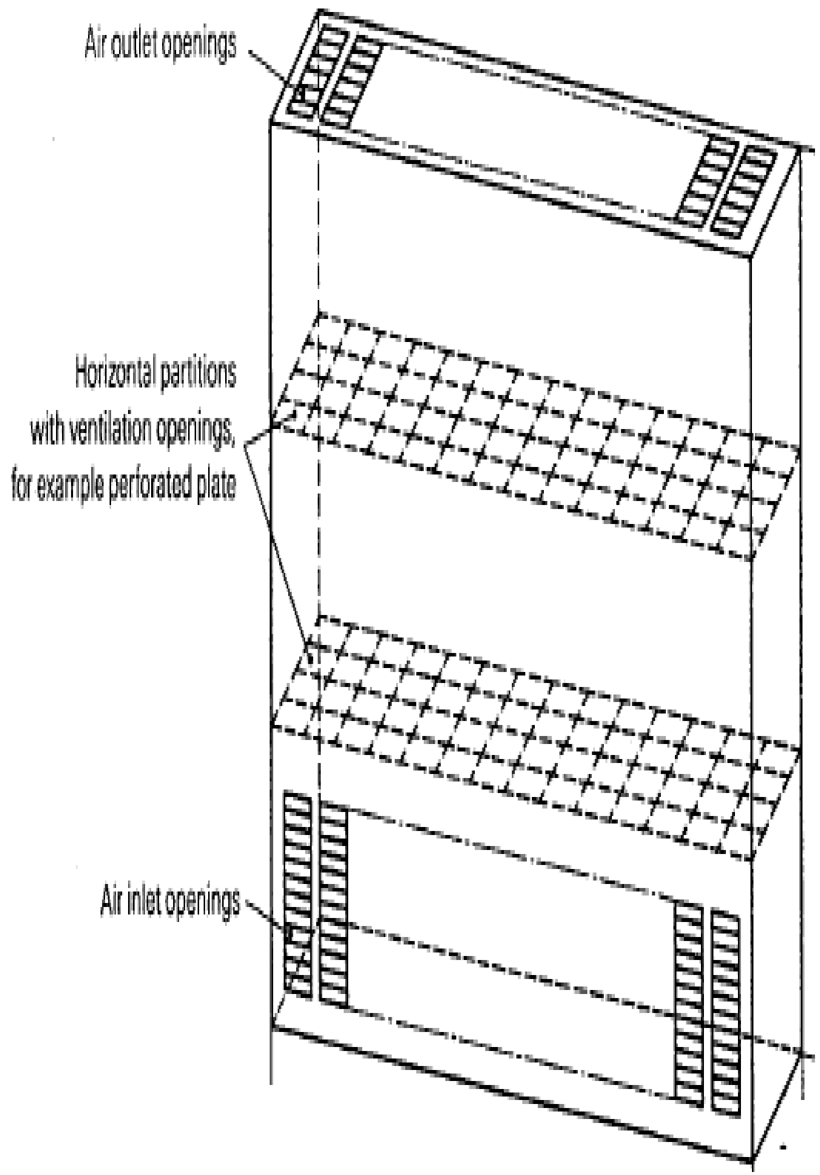
TECHNICAL REPORT

IEC 890

A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low-voltage switchgear and controlgear

Estimating the ambient temperature inside a metal enclosure with or without openings and with a certain electric power dissipated inside





- Without air ventilation
- ~ even distribution of power losses inside the enclosure
- Air circulation is but little impeded
- Eddy currents are negligible
- For enclosures with ventilation openings the cross section of the air outlet openings is at least 1.1 times the cross section of the inlet air openings
- No more than 3 horizontal partitions
- Surface of ventilation openings is at least 50 % of the horizontal cross section if there are partitions

Calculation of the temperature rise at 50% and 100% of the height

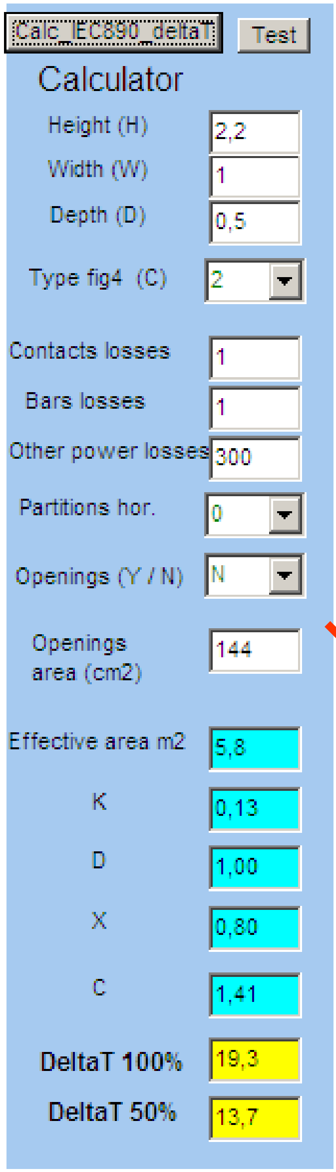
TABLE I *Method of calculation, application, formulae and characteristics*

1	2	3	4	5	6	7	8	9	10	11
Formula			Enclosure		Characteristic					Curve
Effective cooling surface Ae	Temperature rise		Effective cooling surface Ae		Factors				Exponent	Plotting
	50% height	100% height			b See	k See	d See	c See	x	
Ae = Sum of areas X b	k x d x P^x	c x 50% value (3)	> 1,25 m^2	Enclosure without openings	Tab III	Fig 3	Tab IV	Fig 4	0,804	.See 5.2.4.1
				Enclosure with openings		Fig 5	Tab V	Fig 6	0,715	
			< 1,25 m^2	Enclosure without openings		Fig 7	–	Fig 8	0,804	.See 5.2.4.2

CALCULATION SEQUENCE

TABLE I *Method of calculation, application, formulae and characteristics*

1	2	3	4	5	6	7	8	9	10	11
Formula			Enclosure		Characteristic					Curve
Effective cooling surface Ae	Temperature rise		Effective cooling surface Ae		Factors				Exponent	Plotting
	50% height	**100% height**			b See	k See	d See	c See	x	
Ae = Sum of areas X b (1)	k x d x P^x	c x 50% value (3)	> 1,25 m^2	Enclosure without openings	Tab III	Fig 3	Tab IV	Fig 4	**0,804**	.See 5.2.4.1
				Enclosure with openings		Fig 5	Tab V	Fig 6	**0,715**	
			< 1,25 m^2	Enclosure without openings		Fig 7	–	Fig 8	**0,804**	.See 5.2.4.2



Dimensions

Type of installation

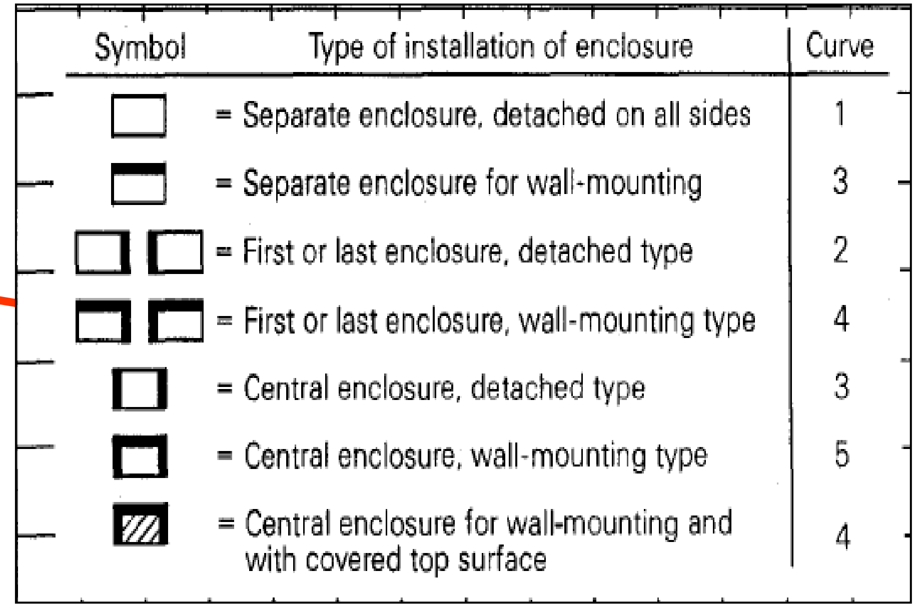
Watts internal

Partitions

Are there ventilation openings ?

Openings area

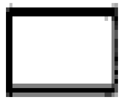
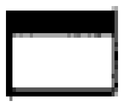
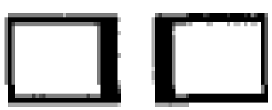
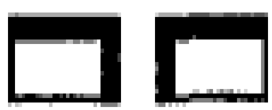
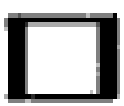
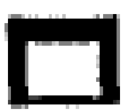
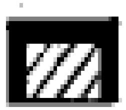
Temperature rise of the internal air



Symbol	Type of installation of enclosure	Curve
	= Separate enclosure, detached on all sides	1
	= Separate enclosure for wall-mounting	3
	= First or last enclosure, detached type	2
	= First or last enclosure, wall-mounting type	4
	= Central enclosure, detached type	3
	= Central enclosure, wall-mounting type	5
	= Central enclosure for wall-mounting and with covered top surface	4

A0 = surface of external sides of enclosure (m2)
Ab = surface of base (m2)
Ae = effective cooling surface (m2)
B = surface factor
C = temperature distribution factor
D = factor for horizontal partitions
F = height / base factor
H, W = enclosure height and width (m)
K = enclosure constant
N = number of horizontal partitions
P effective powwer loss inside (Watts)
X = expoent
ΔT 0.5 = temperature rise at 50% of the height

Type of installation (Figure 4)

Symbol	Type of installation of enclosure	Curve
	= Separate enclosure, detached on all sides	1
	= Separate enclosure for wall-mounting	3
	= First or last enclosure, detached type	2
	= First or last enclosure, wall-mounting type	4
	= Central enclosure, detached type	3
	= Central enclosure, wall-mounting type	5
	= Central enclosure for wall-mounting and with covered top surface	4

Factor B (to calculate effective area in column 1)

Type of installation		Surface factor b
Exposed top surface	1	1.4
Covered top surface, e.g. of built-in enclosures	2	0.7
Exposed side faces, e.g. front, rear and side walls	3	0.9
Covered side faces, e.g. rear side of wall-mounted enclosures	4	0.5
Side faces of central enclosures	5	0.5
Floor surface	6	not taken into account

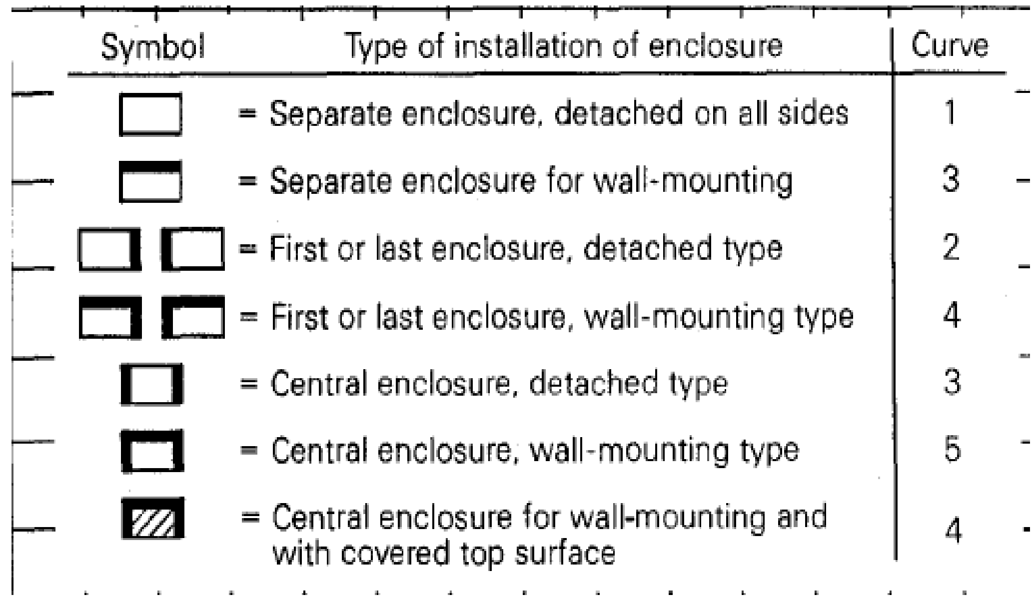
Factor D

	Partitions			
Factor D Without ventilation openings $A_e > 1{,}25\ m^2$	1,00	1,05	1,15	1,30
Factor D With ventilation openings $A_e > 1{,}25\ m^2$	1,03	1,05	1,10	1,15

COGNITOR

- Dimensions of the enclosure (H x W x D)

- Type of installation (Figure 4)



Symbol	Type of installation of enclosure	Curve
	= Separate enclosure, detached on all sides	1
	= Separate enclosure for wall-mounting	3
	= First or last enclosure, detached type	2
	= First or last enclosure, wall-mounting type	4
	= Central enclosure, detached type	3
	= Central enclosure, wall-mounting type	5
	= Central enclosure for wall-mounting and with covered top surface	4

- Calculate the efective area using factor b and table 3

- Calculate $\Delta T (50\%) = k \,.\, d \,.\, P^{x}$

- Design with or without ventilation openings

- Number of internal horizontal partitions

- Effective power loss of equipment installed in enclosure

Figure 3 Factor K
without ventilation openings for Ae > 1,25 m2

```
     If effectiveArea < 0.5  then K:= 1                                   // Fig. 3
else If effectiveArea < 1.0  then K:= 0.6 - 0.8    * (effectiveArea - 1)
else If effectiveArea < 3.5  then K:= 0.2 - 0.16   * (effectiveArea - 3.5)
else If effectiveArea <= 9.31 then K:= 0.079 - 0.0153* (effectiveArea - 9.31 )
else If effectiveArea <= 15.0 then K:= 0.050 - 0.00722* (effectiveArea - 15 )
else If effectiveArea <= 300  then K:= 0.00027 * (300- effectiveArea)
else                               K:= 0.00027;
```

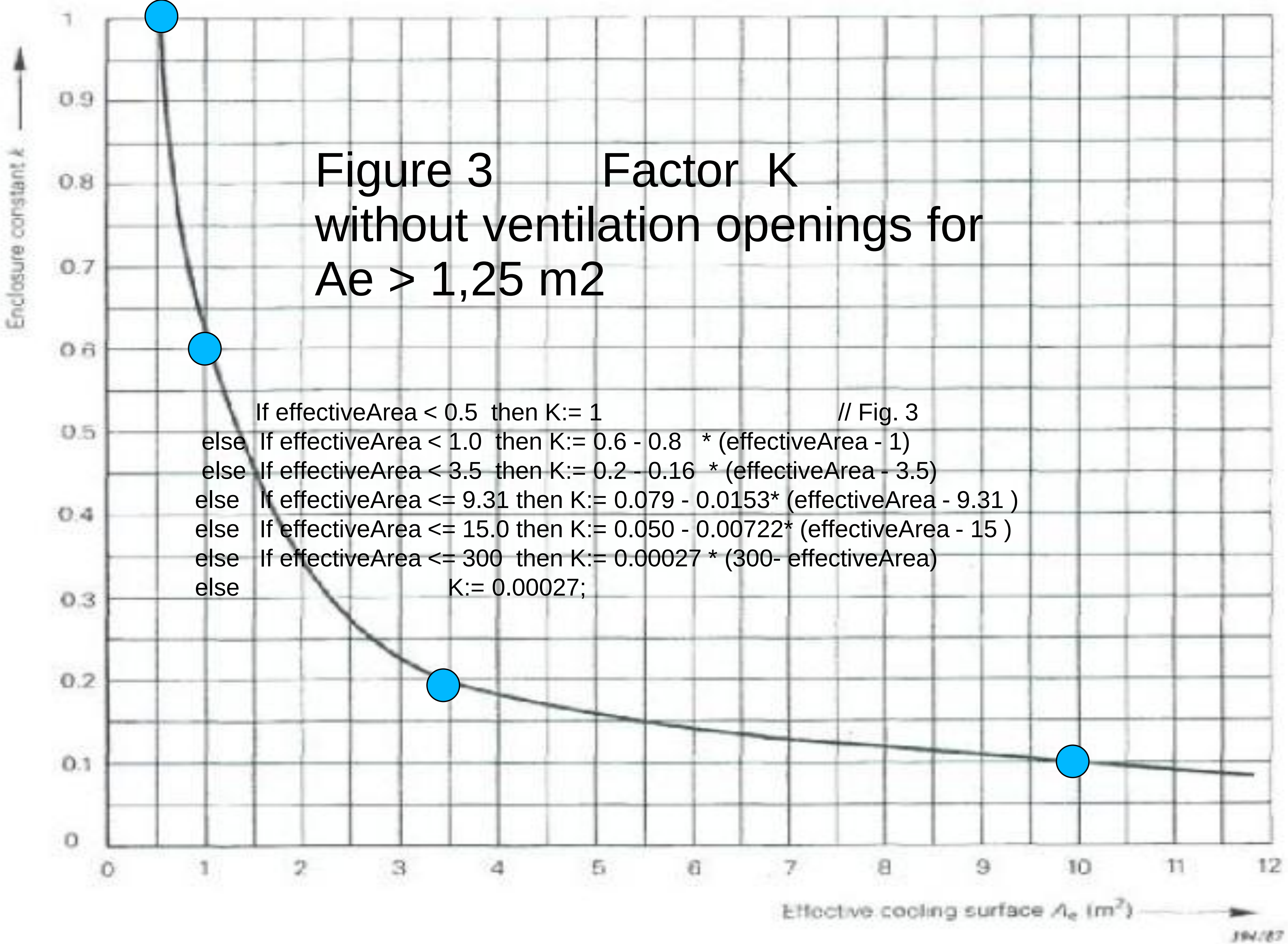


FIG. 3. — Enclosure constant k for enclosures without ventilation openings, with an effective cooling surface $A_e > 1.25$ m².

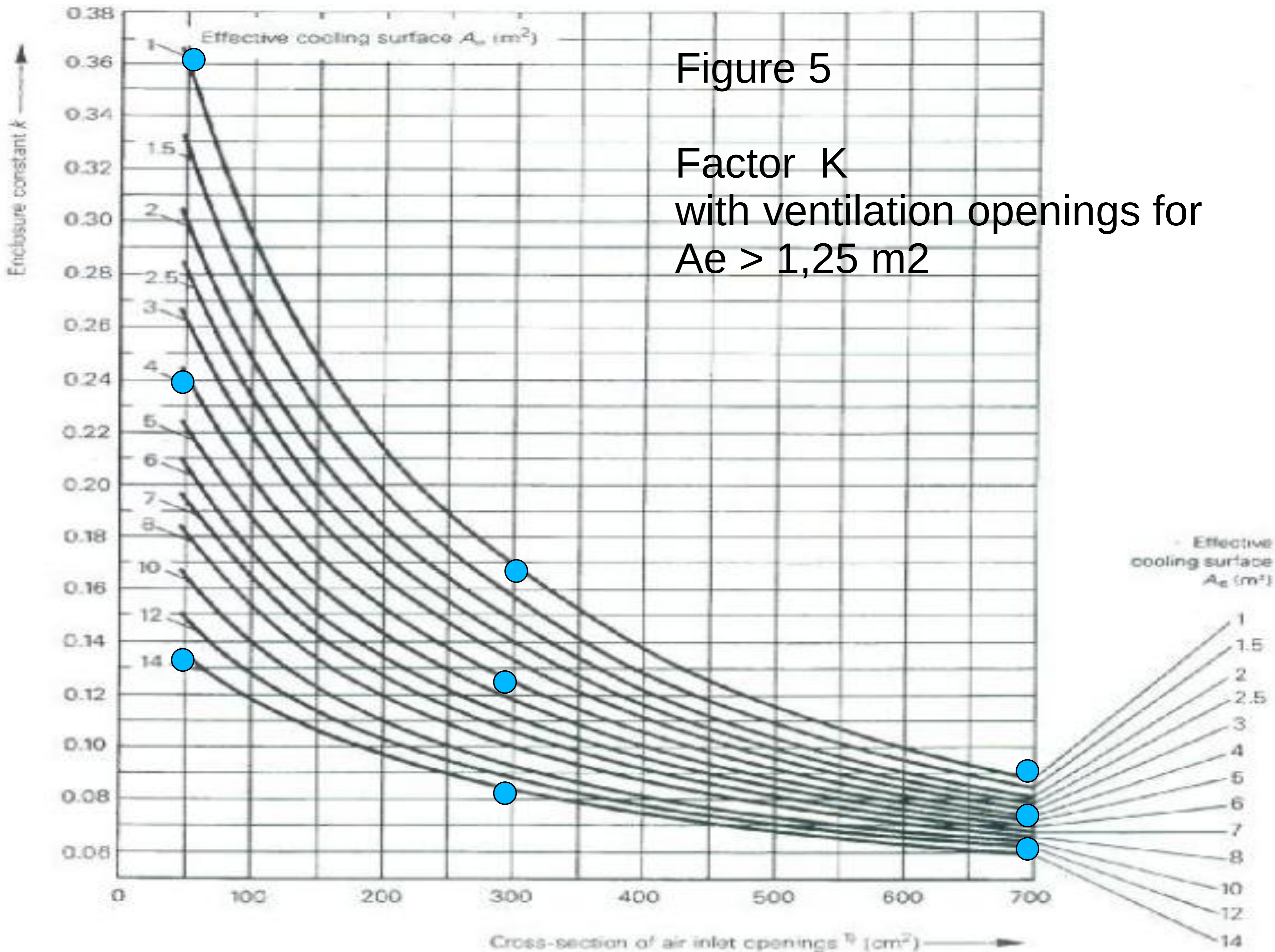


FIG. 5. — Enclosure constant k for enclosures with ventilation openings and an effective cooling surface $A_e > 1.25$ m².

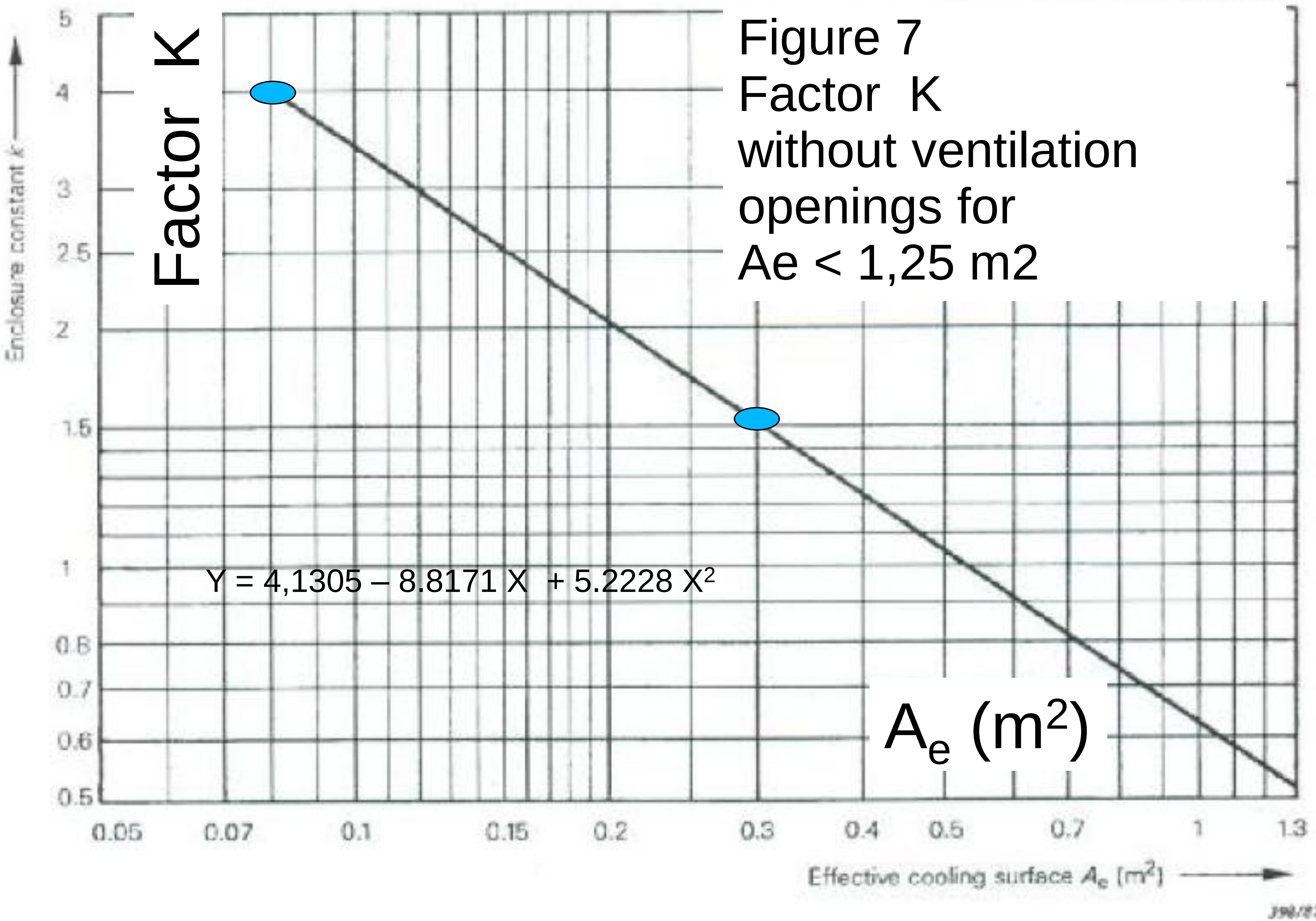


FIG. 7. — Enclosure constant k for enclosures without ventilation openings and with an effective cooling surface $A_e < 1.25\ m^2$.

R

Factor F to calculate C in figure 4

5.2.3 *Determination of the internal temperature rise $\Delta t_{1.0}$ of air at the top of the enclosure*

The calculation is made according to formula (3) in column 3 of Table I.

Factor *c* allows for the temperature distribution inside an enclosure. Its determination varies with the design and installation of the assembly as follows:

a) For enclosures without ventilation openings and with an effective cooling surface: $A_e > 1.25\ m^2$	The factor *c* from Figure 4, page 25, depends on the type of installation and the height/base factor *f*, where: $f = \frac{h^{1.35}}{A_b}$
b) For enclosures with ventilation openings and with an effective cooling surface: $A_e > 1.25\ m^2$	The factor *c* from Figure 6, page 29, depends on the cross-section of air inlet openings and the height/base factor *f*, where: $f = \frac{h^{1.35}}{A_b}$
c) For enclosures without ventilation openings and with an effective cooling surface: $A_e \leq 1.25\ m^2$	The factor *c* from Figure 8, page 33, depends on the height/width factor *g*, where: $g = \frac{h}{w}$

where:

h is the enclosure height, in metres
A_b is the surface area of the enclosure base, in square metres
w is the enclosure width, in metres

TYPES OF INSTALATION X TEMPERATURE DISTRIBUTION FACTOR (C)

FACTOR (C)

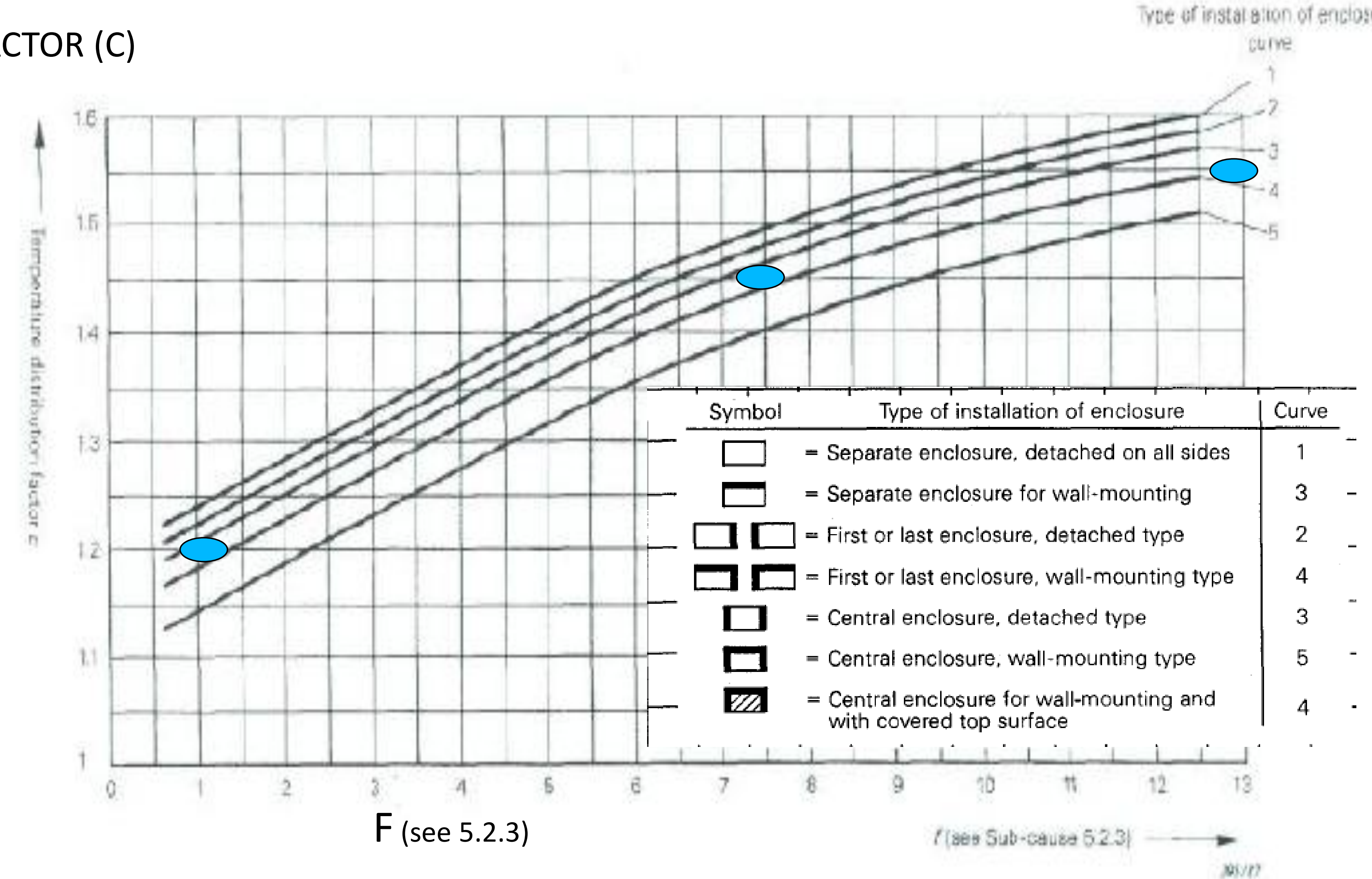
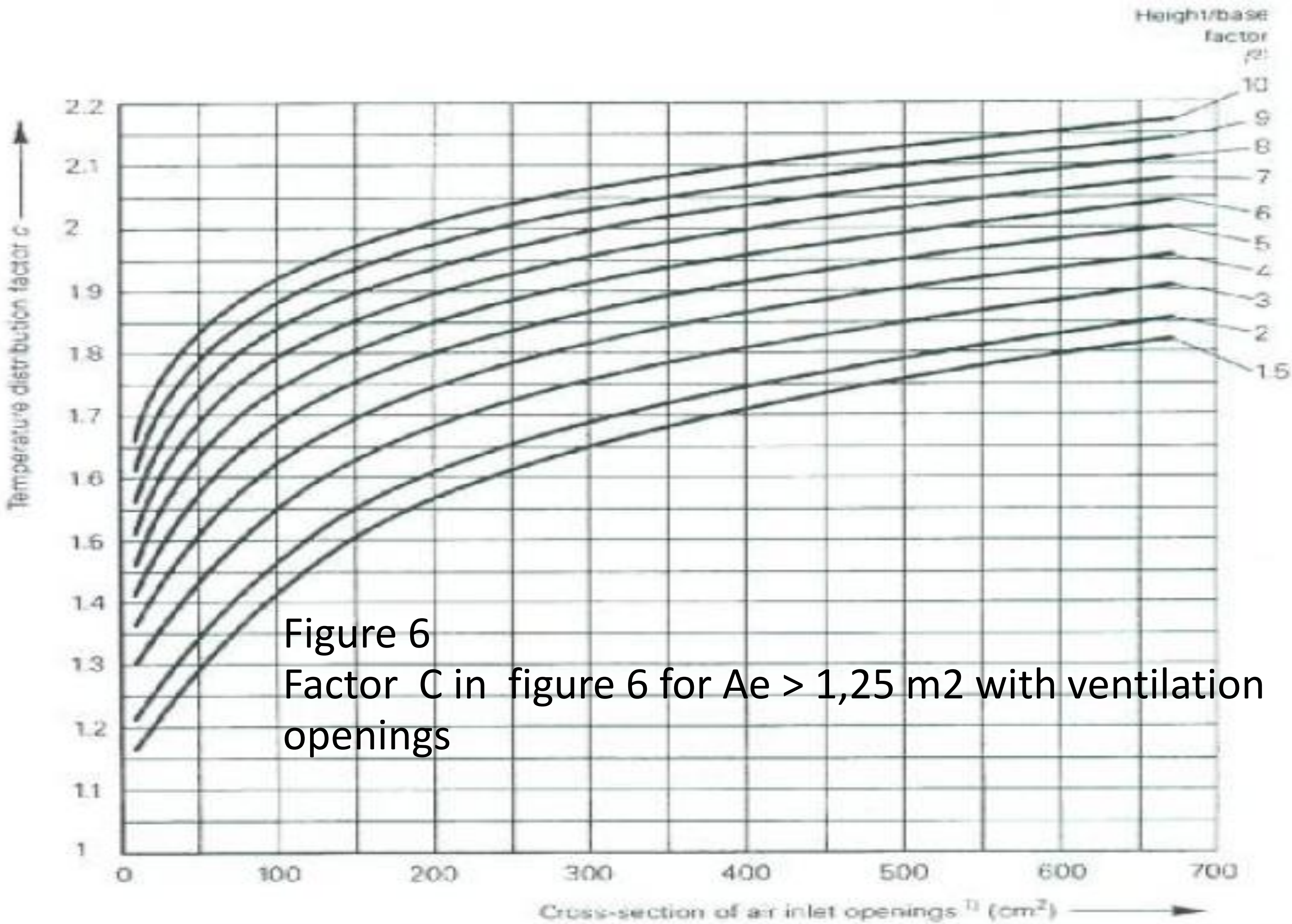


FIG. 4. — Temperature distribution factor c for enclosures without ventilation openings and with an effective cooling surface $A_e > 1.25\ m^2$.



[1] The cross-section of the corresponding air outlet openings should be at least 1.1 times that of the air inlet openings.
[2] Height/base factor, see Sub-clause 5.2.3.

FIG. 6. — Temperature distribution factor c for enclosures with ventilation openings and an effective cooling surface $A_e > 1.25$ m².

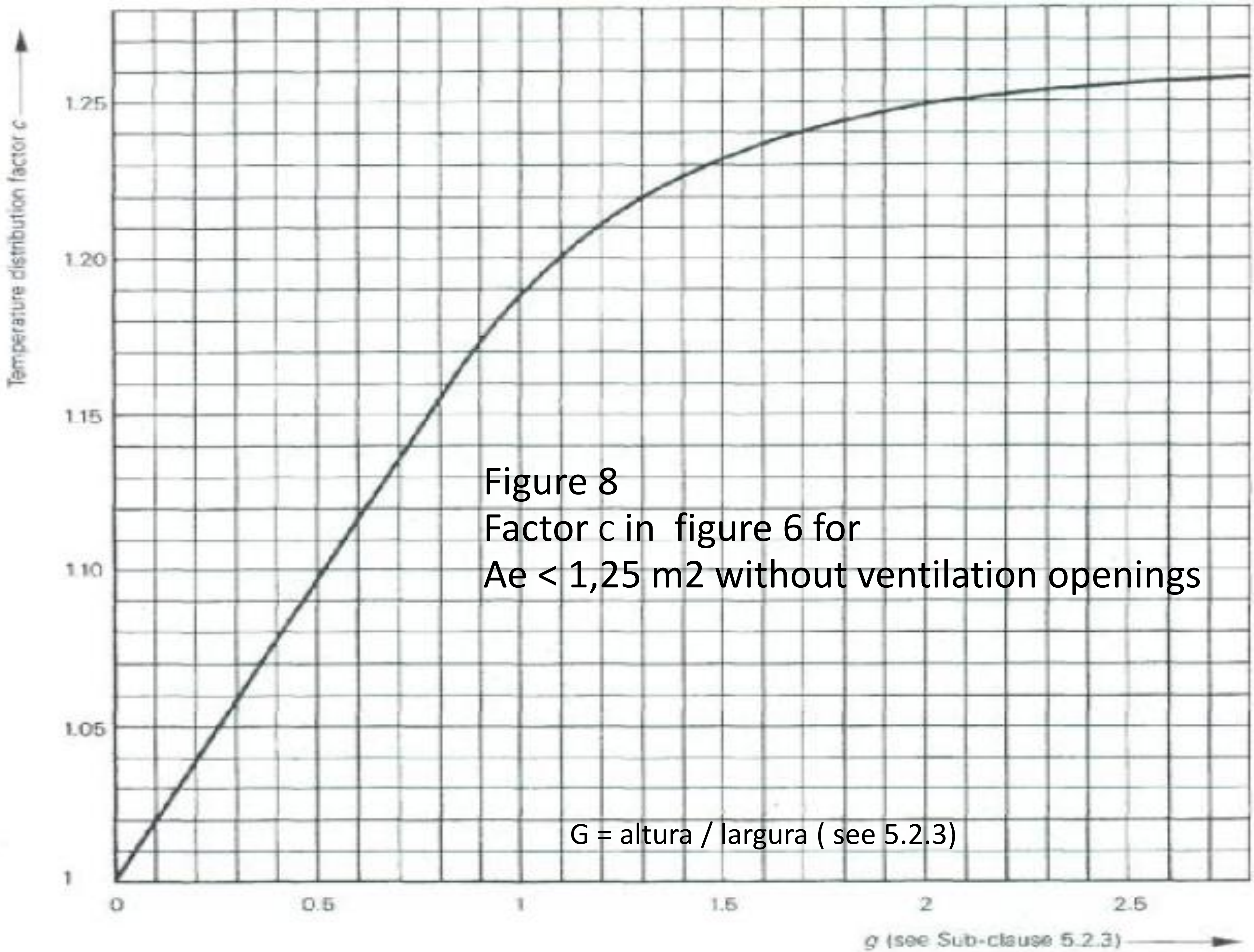


FIG. 8. — Temperature distribution factor c for enclosures without ventilation openings and with an effective cooling surface $A_e \leq 1.25$ m².

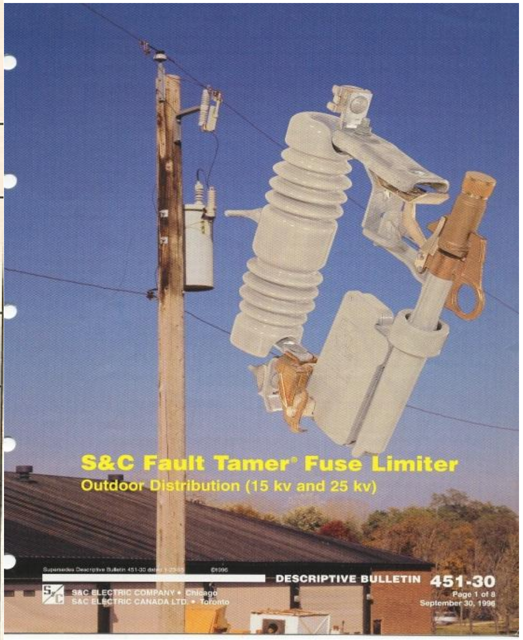
Table 6 – Test parameters

Parameters	Class	Test-duties 1		2		3		4	5
		1		2		3		4	5
Power-frequency recovery voltage	A to C	(Note 5)		Rated voltage $^{+5}_{\ 0}$ %					
Prospective TRV characteristics	A B C	Table 8 Table 9 Table 10		Table 8 Table 9 Table 11		Table 8 Table 9 Table 12		Table 13 Table 14 Table 14	(Note 7)
Prospective current (r.m.s. value of the a.c. component)	A to C	I_1 $^{+5}_{\ 0}$ % (Note 5)		I_2 from 0,6 I_1 to 0,8 I_1		I_3 from 0,2 I_1 to 0,3 I_1		I_4 from 400 A to 500 A (Notes 1 and 2)	I_5 from 2,7 I_r to 3,3 I_r (Notes 1 and 10)
Power-factor	A B C	Lower than 0,15 Lower than 0,10 Lower than 0,10						See table 7	From 0,6 to 0,8
Making angle related to voltage zero (degrees) (Note 9)	A to C	1st test: −5 to +15 2nd test: 85 to 105 3rd test: 130 to 150		1st test: −5 to +15 2nd test: 85 to 105 3rd test: 130 to 150		For all tests, from 85 to 105		Random timing	
Duration of power frequency recovery voltage after interruption (Note 11)	A to C (drop-out)	Not less than drop-out time, or 0,5 s, whichever is greater							
	A to C (non drop-out)	10 min (Note 8)						1 min	
Rated current of fuse-links (Note 6)	A to C	min.	max.	min.	max.	min.	max.	min.	min.
Number of tests	A to C	3	3	3	3	1	1	2	2
Number of tests before replacing fuse-carriers (Note 3)	A to C	3	3	3	3	2		4	
Number of fuse-carriers	A to C	1	1	1	1	1		1	
Maximum number of fuse-bases (Note 4)	A to C	1	1	1	1	1		1	

(See notes on next page)

HIGH VOLTAGE EXPULSION TYPE FUSES

(IEC 60282-2)



End of module 3

END OF MODULE 3

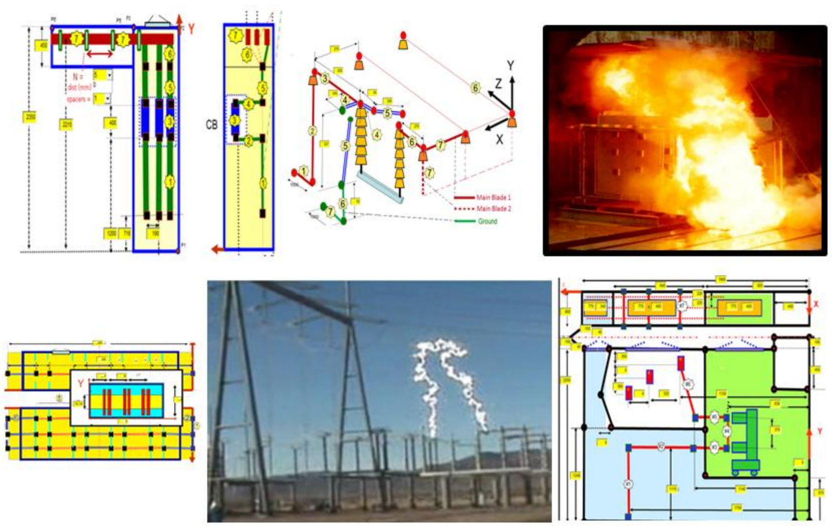
Reference materials for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

(focus in design techniques, specification, tests and simulations)



MODULE 4:

ELECTRICAL ARCS

AND SAFETY OF PERSONS

AND

INSTALLATIONS

by Sergio Feitoza Costa

- OVERPRESSURES CAUSED BY INTERNAL ARCS IN SWITCHGEAR

- TRANSFORMERS (OIL): FIRE AND EXPLOSIONS DUE TO INTERNAL ARCS.

- POWER ARCS ON INSULATORS STRINGS

OVERPRESSURES DUE TO INTERNAL ARCS

- Normal and short-circuit currents: increasing levels as always.
- Requirements: occupy less space and "remain usable" upon the occurrence of a fault.
- Specifications:
  - Some temperatures must not be exceeded under normal use
  - To withstand overpressures of arc to avoid risks to persons and to damage installations and support justice actions
  - Electrodynamical forces in insulators and conductors
- The more compact and higher are the currents more difficult to meet these specifications
- Relationship between temperature rise tests, IP and internal arc: ventilation openings area and other data not registered in test reports

INTERNAL ARC TEST

- Initiation of the arc is followed by vaporization of copper and other materials increasing the pressure up to the opening of the relief devices

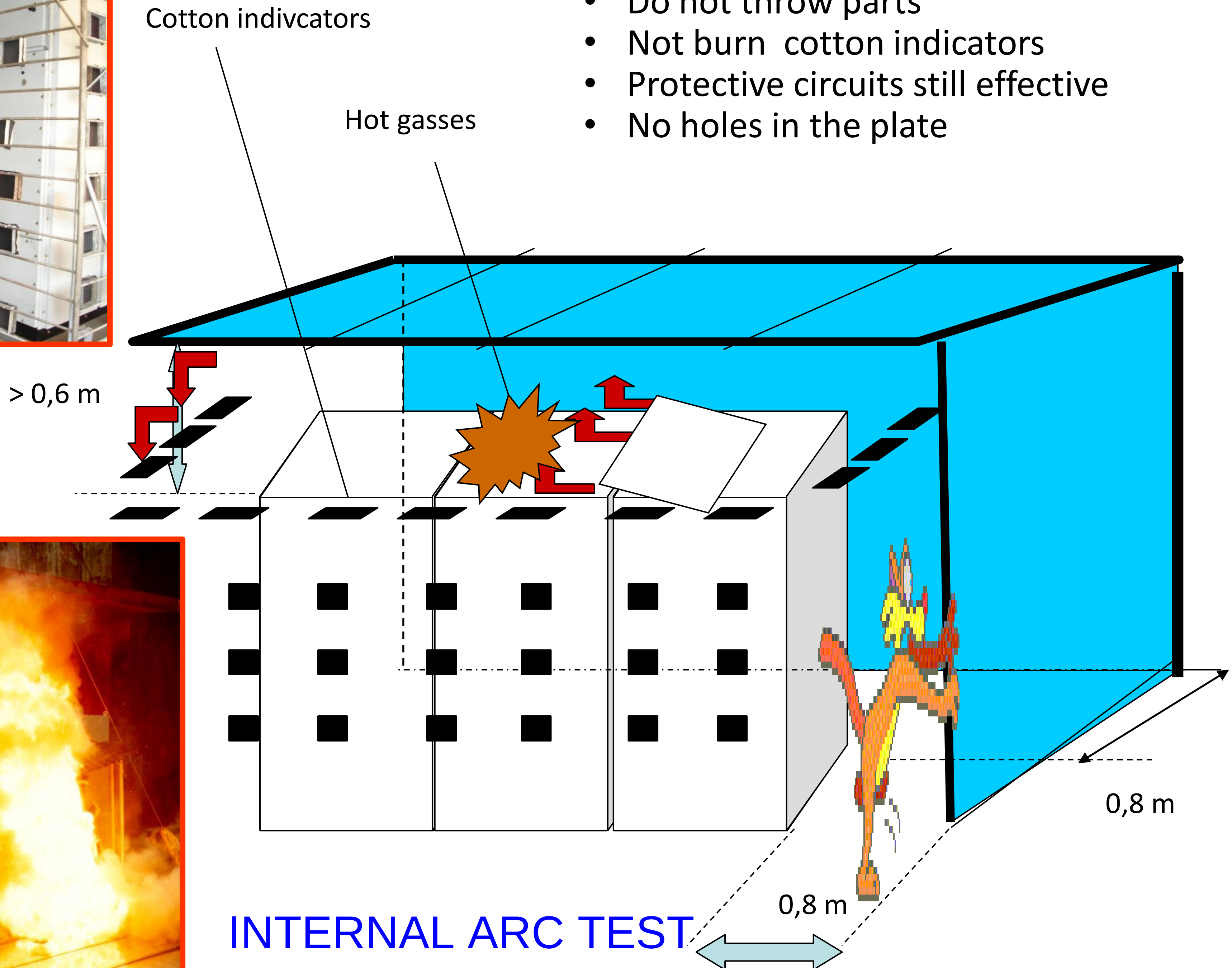
- Level of protection to people near the equipment

- Media voltage: (IEC 62271-200) : type test for classification IAC

- Low voltage: (IEC TR 61641): not a type test but the market request. (protection of people, equipment and limited operation after internal arc)

- Details of the standards in section 6

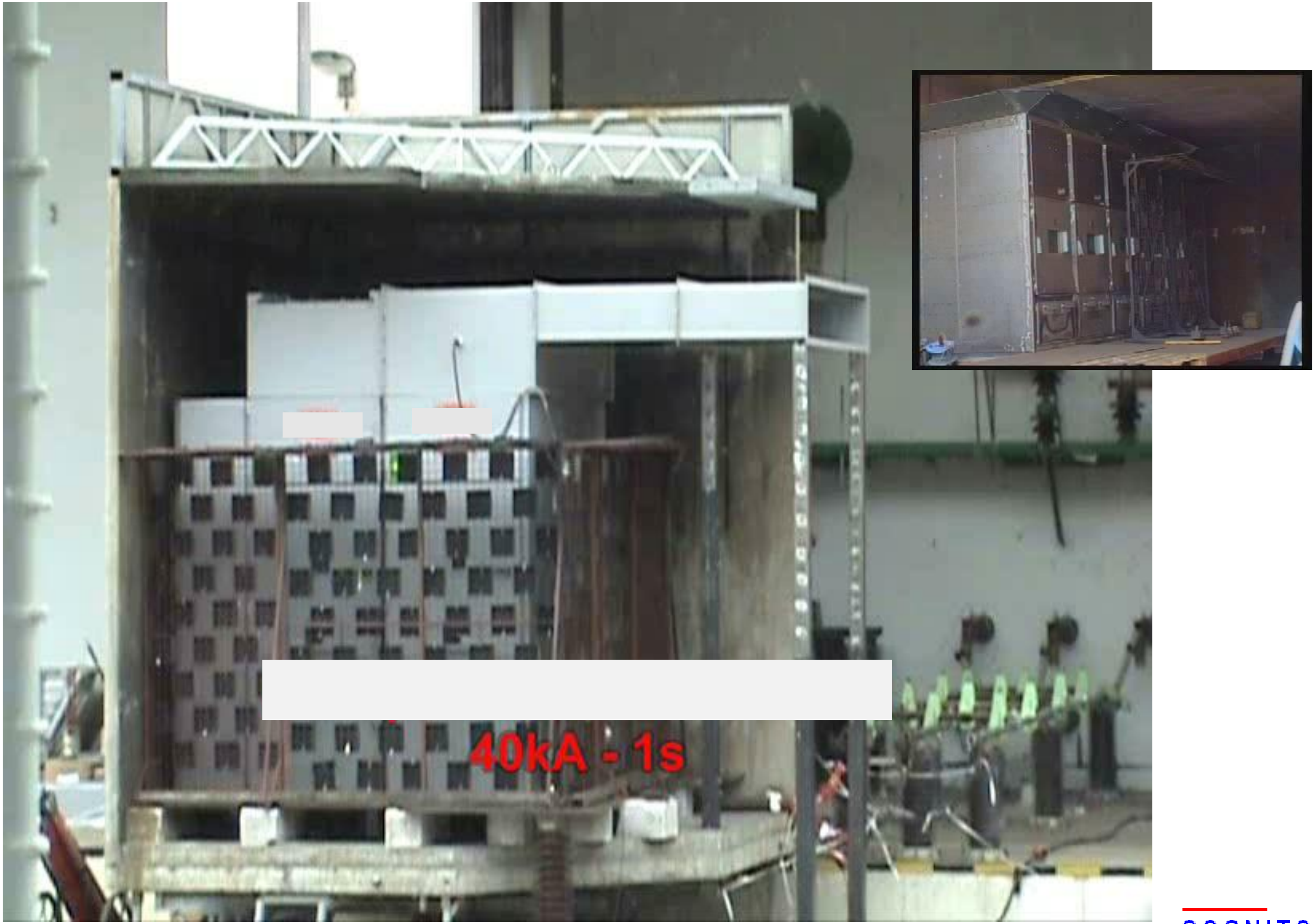
- Doors should not open
- Do not throw parts
- Not burn cotton indicators
- Protective circuits still effective
- No holes in the plate



INTERNAL ARC TEST

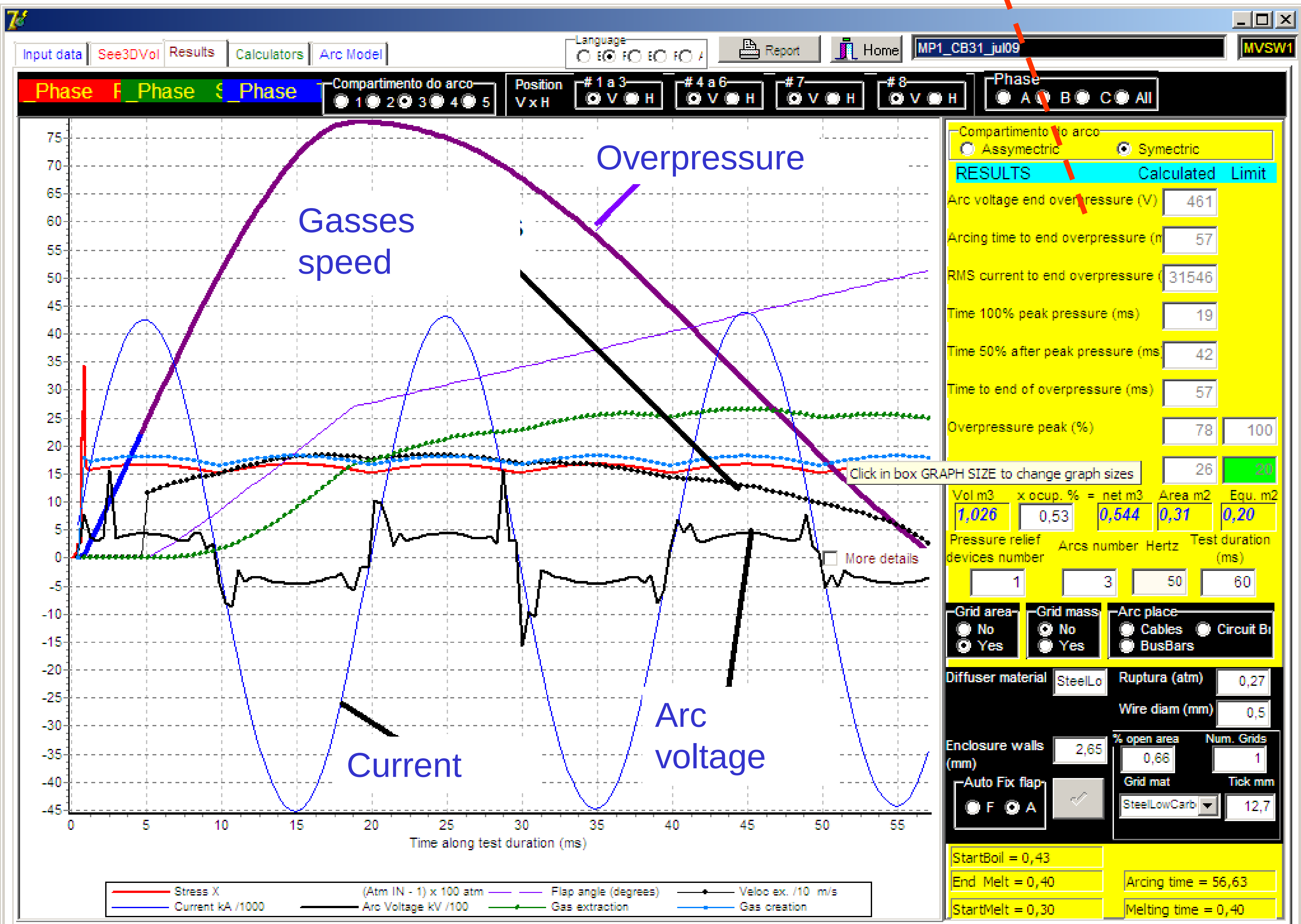
INTERNAL ARC TEST 15 kV – 25 kA rms MOVIE

INTERNAL ARC TEST 15 kV – 40 kA rms MOVIE

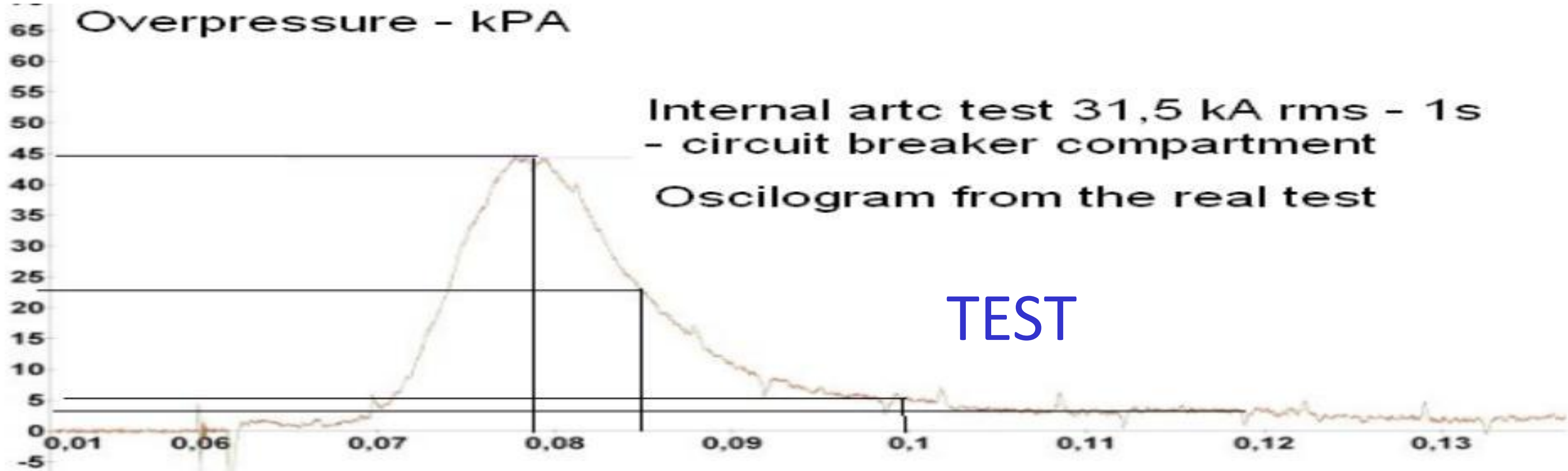


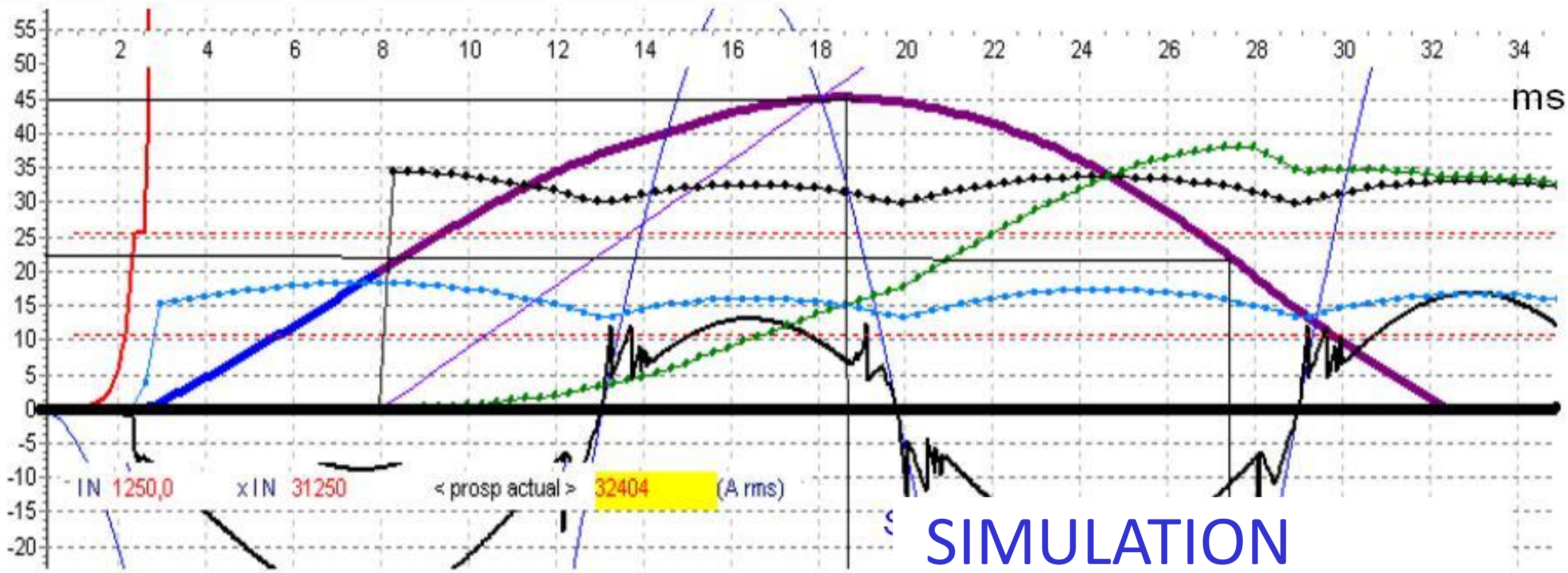
COGNITOR

Overpressures and design criteria (simulation)



OVERPRESSURE x LAB TEST x SIMULATION





PERFORMANCE UNDER INTERNAL ARC (PARAMETERS)

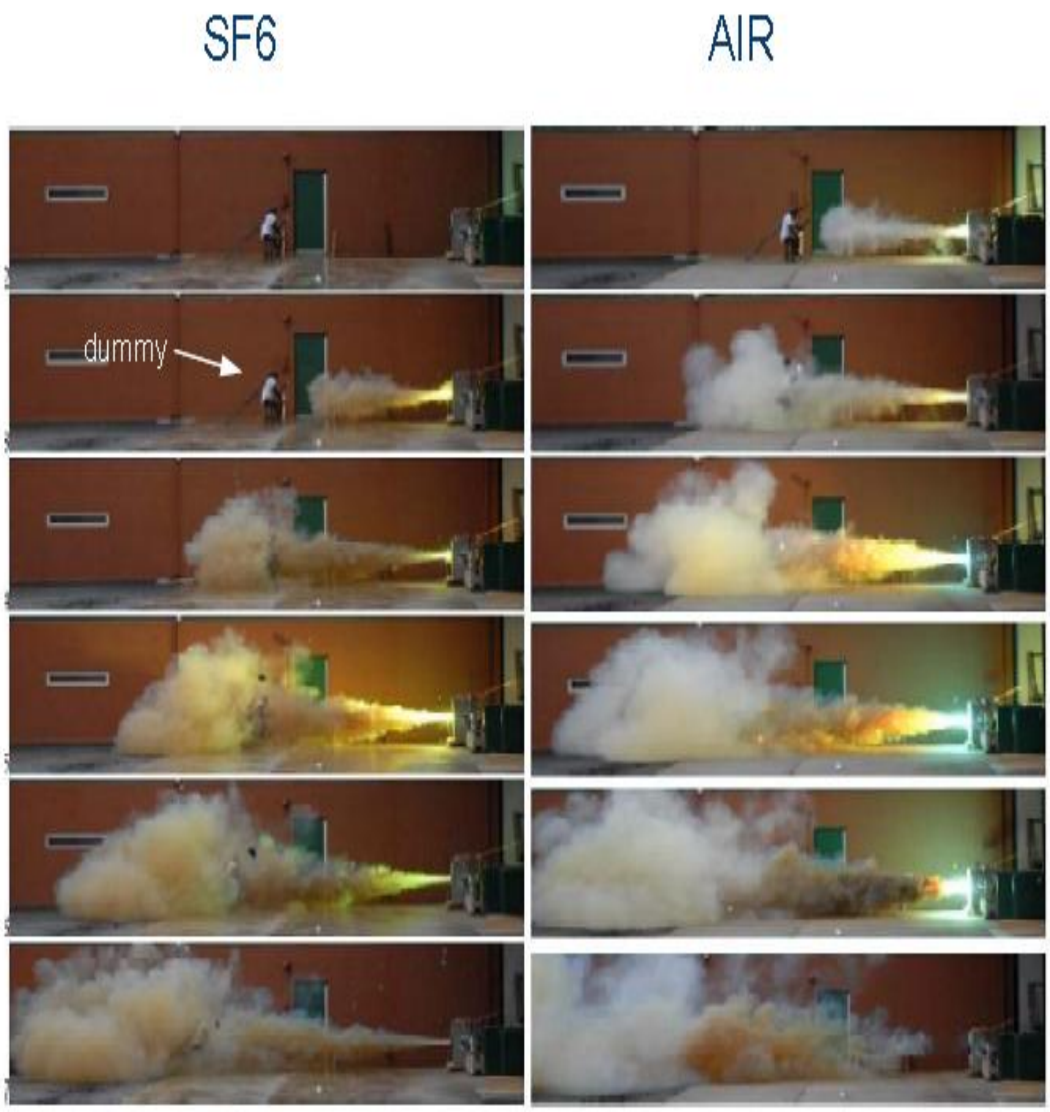
- Fluid compartment volume, area, velocity and characteristics of pressure relief devices
- Technical standards do not address properly the relationship between the temperature rise and internal arc (test reports)
- IEC working groups (HV and LV) and CIGRE studying.
- Methods for calculating
  - (a) "Brochure" group CIGRE WG A3-24 -publication 2013
  - (b) Method " temperature rise" but considering up to the vaporization of conductors

CIGRÈ WG A3. 24 : TOOLS FOR SIMULATING INTERNAL ARC AND CURRENT WITHSTAND TESTING

- Simulations to predict the results of internal arc tests on SF6 equipment if SF6 is replaced with air.

- Reason: environmental reasons, tests release SF6 to the environment

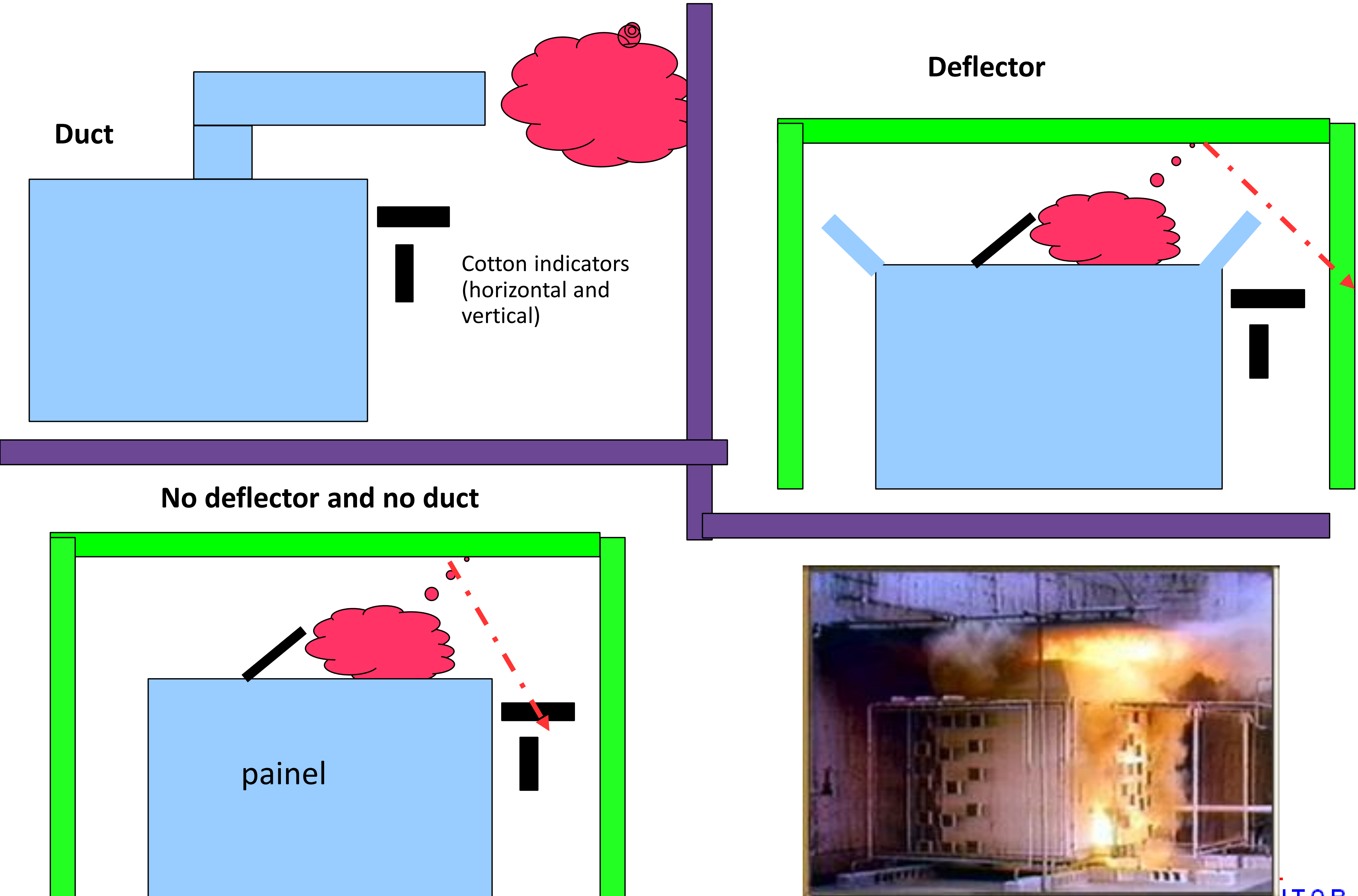
- Use of simulations to reduce the number of internal arc tests



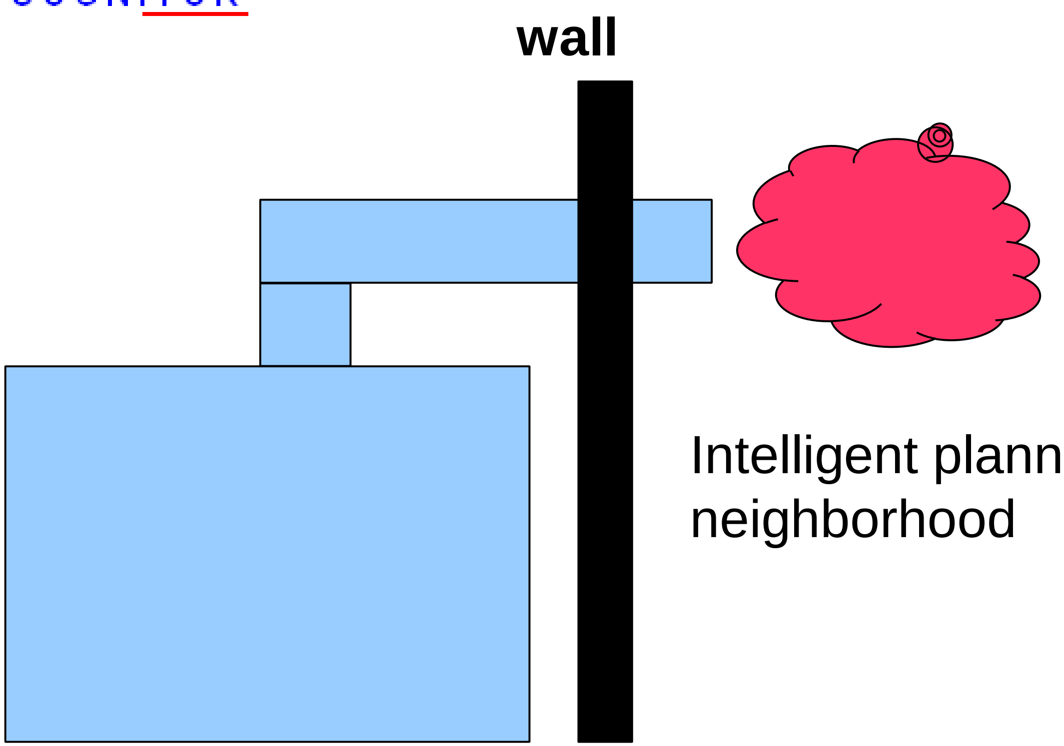
CIGRÈ WG A3. 24 : Brochure TOOLS FOR SIMULATION OF PRESSURE RISE DUE TO INTERNAL ARC IN MV AND HV SWITCHGEAR

Name	First Name	Country	Company
del Rio	Luis	Spain	ORMAZABAL CORPORATE T
Douchin	Jerome	France	Schneider Electric
Dullni	Edgar	Germany	ABB
Feitoza Costa	Sergio	Brazil	Cognitor
Fjeld	Elin	Norway	Telemark University
Glinkowski	Mietek	USA	ABB
Kim	Hong-Kyu	Korea	KERI
Kriegel	Martin	Switzerland	Axpo
Lopez-Roldan	Jose	Australia	Powerlink
Pater	Ryszard	Canada	Hydro-Québec
Pietsch	Gerhard	Germany	RWTH Aachen
Reiher	Thomas	Germany	Siemens
Robin-Jouan	Phillipe	France	Areva
Schoonenberg	Gerard	Netherlands	Eaton
Smeets	Rene	Netherlands	KEMA
Uchii	Toshiyuki (Tc	Japan	Toshiba
Uzelac	Nenad	USA	G&W
Van der Sluis	Lou	Netherlands	TU Delft
Vinson	Paul	France	Areva
Yoshida	Daisuke	Japan	Mitsubishi Electric Corpartion

DESIGN OPTIONS x SHORT CIRCUIT CURRENT

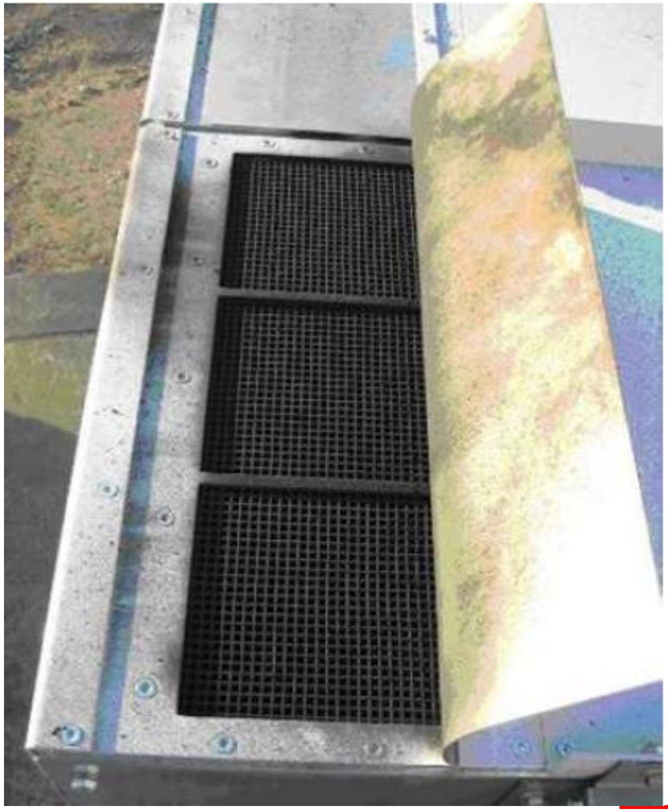


DESIGN OPTIONS

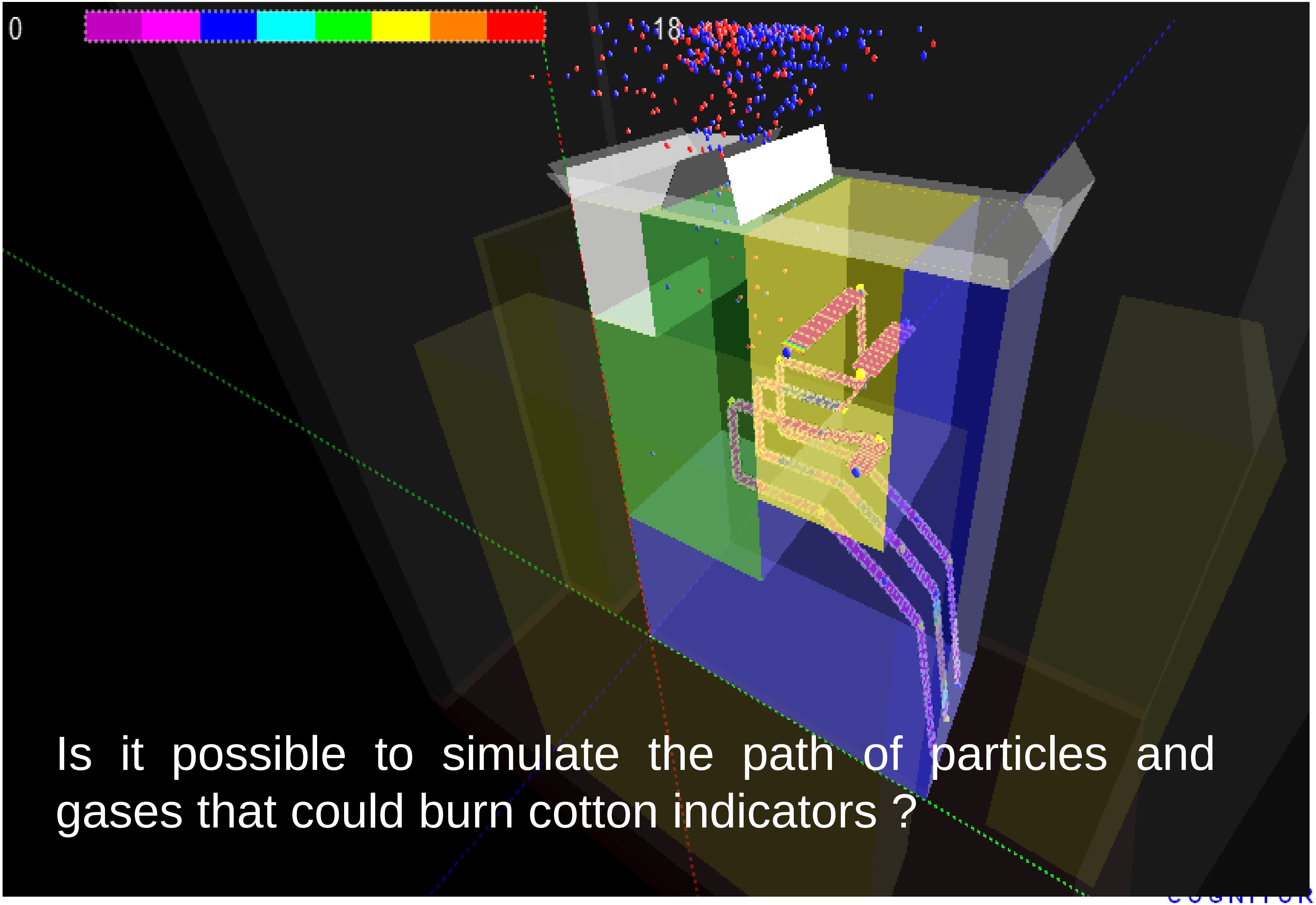


Intelligent planning, ducts and exhaust volumes in the neighborhood

Use of heat absorbers for removing heat in the exhaust gases



15 kV – 25 kA – circuit breaker compartment



Is it possible to simulate the path of particles and gases that could burn cotton indicators ?

• INTERNAL ARC IN POWER TRANSFORMERS

- ✓Arc in contact with oil produces explosive gases.
- ✓Internal arc cause pressure rises and break the tank (transformers support ~ 1 bar overpressure)
- ✓If tank ruptures oxygen in the air comes into contact with explosive gasses (explosion and fire).
- ✓Prevention systems to relieve pressure before it reaches the limit of the tank
- ✓Circuit breakers are not fast enough but bursting disc are
- ✓Reasons for explosions

The goal is to lead the gasses to burn in a safe place

There is a Brazilian technical standard with a test to check this

(Sergio coordinated its preparation years ago)

INTERNAL ARC IN POWER TRANSFORMERS

420 EXPLOSIONS INCIDENTS – USA March, 11 to July, 31 ,2002		
Number of dead persons		**4**
Injured persons		**247**
Persons affected by the blackout		**1.6 millions**
Number of states		**44**
Number of power companies involved		**117**
Number of power companies involved in at least 3 explosions		**27**
Site of the incident	Generation plants and substations	**80**
	Nuclear power plants	**7**
	Residential areas	**19**
	Urban areas	**29**
	Public squares and buildings	**54**
	Schools and universities	**25**

- BRAZILIAN TECHNICAL STANDARDS PUBLISHED IN 2006
  - (preparation coordinated by Sergio)

✓NBR 13231: Fire Protection in power substations.

✓**NBR 8222 - Protection systems for power transformers and reactors, by depressurization (*)**

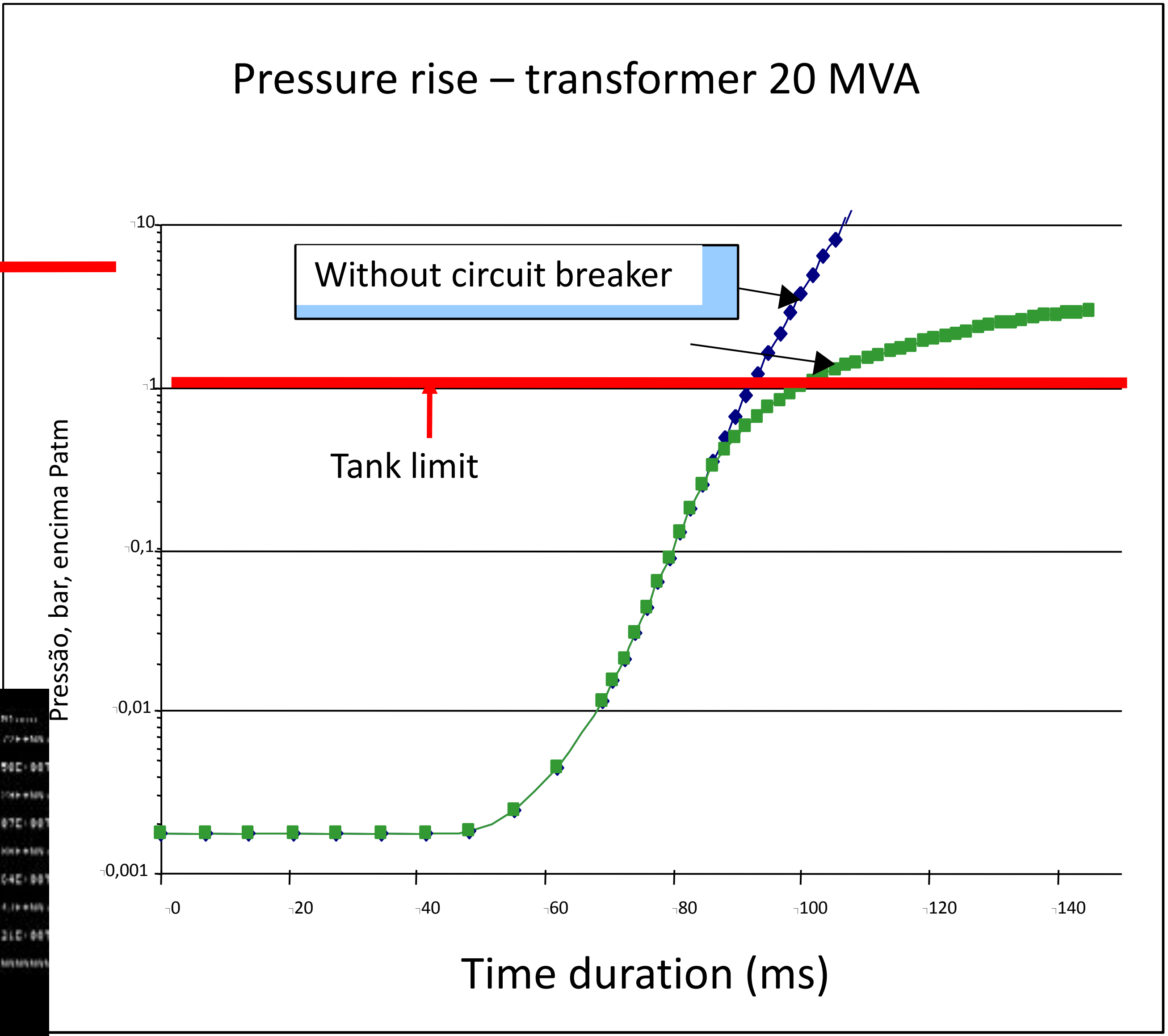
✓NBR 8674 : Water spray systems

✓ NBR 12232 : Carbon dioxide systems

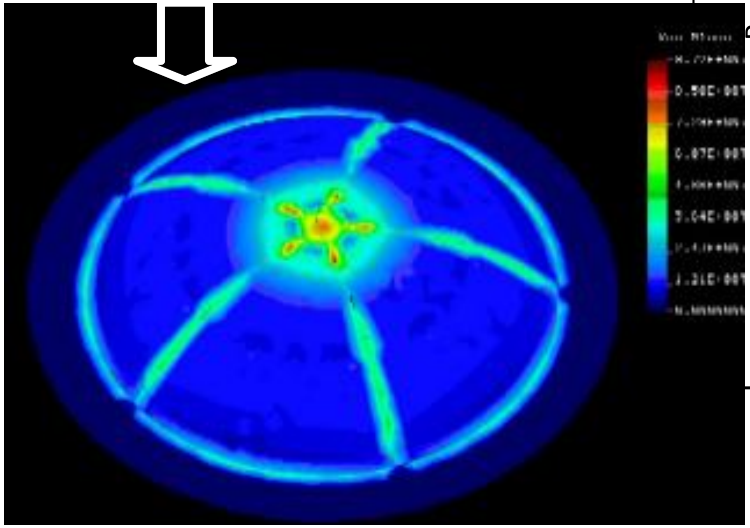
(*) standard with internal arc test on transformers

Transformer tanks are dimensioned to withstand pressure of around 1 bar above atmospheric pressure..

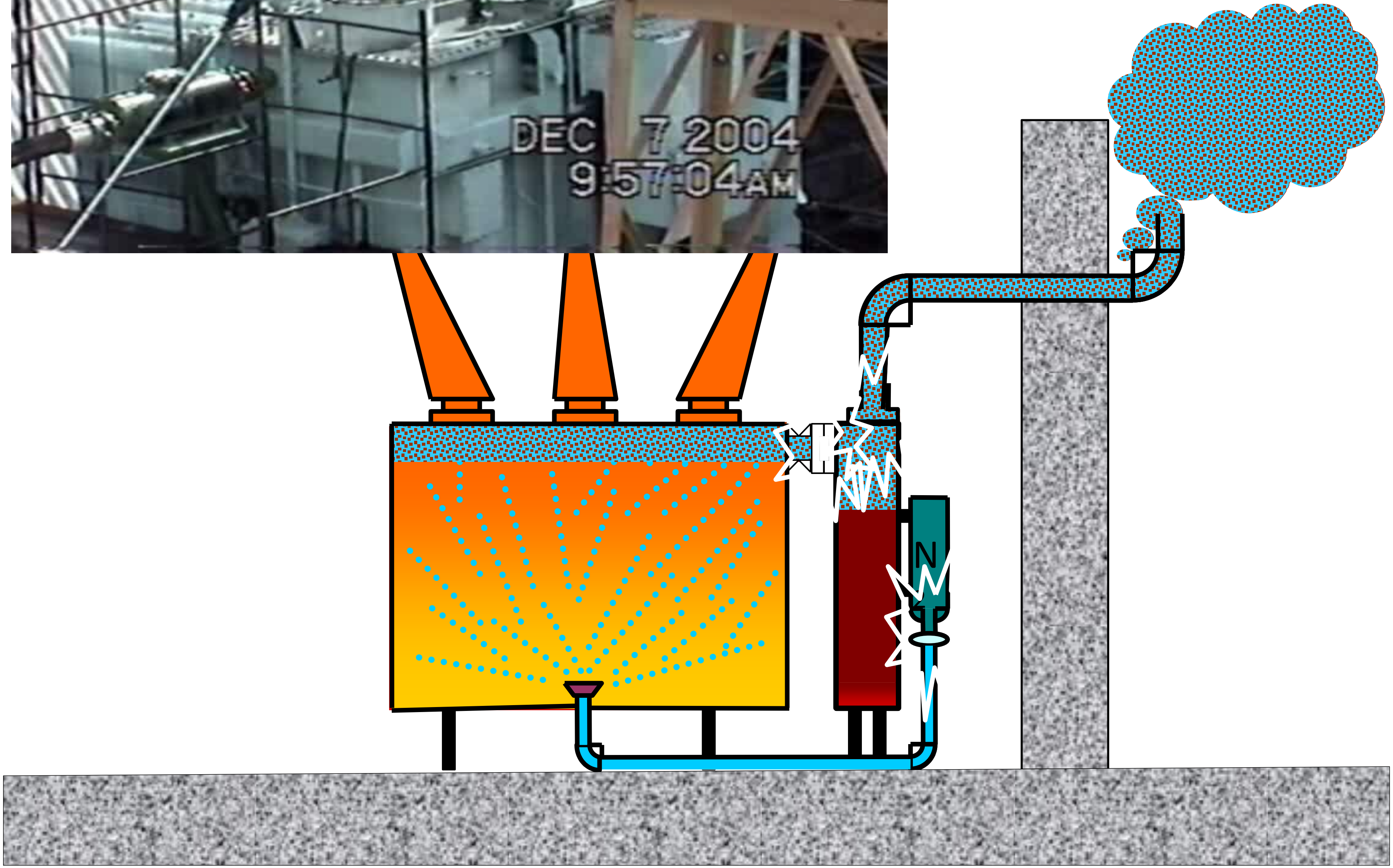
Circuit breaker is not fast enough to avoid the explosion



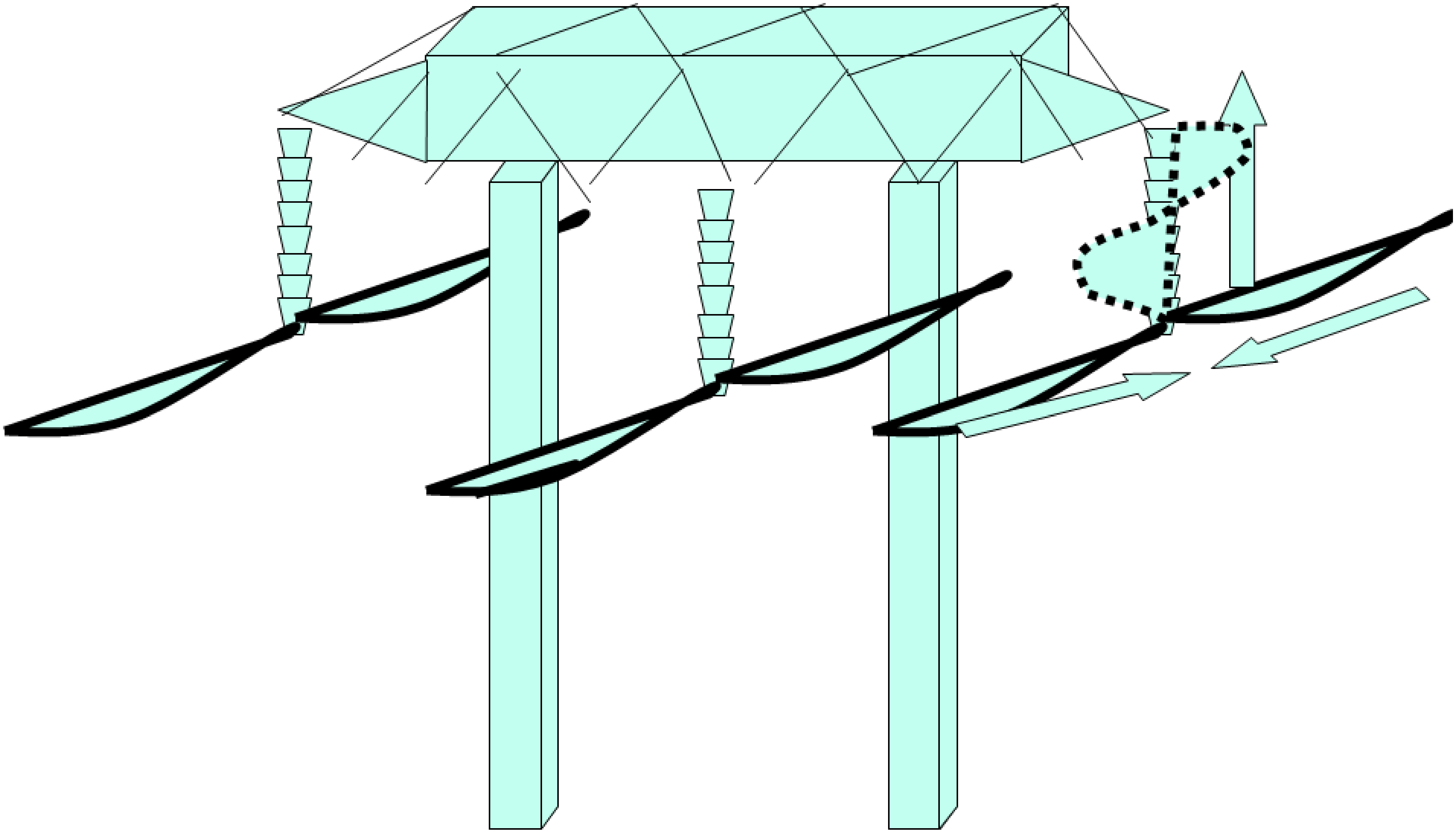
Busting disk



MOVIE



POWER ARCS IN INSULATORS STRINGS



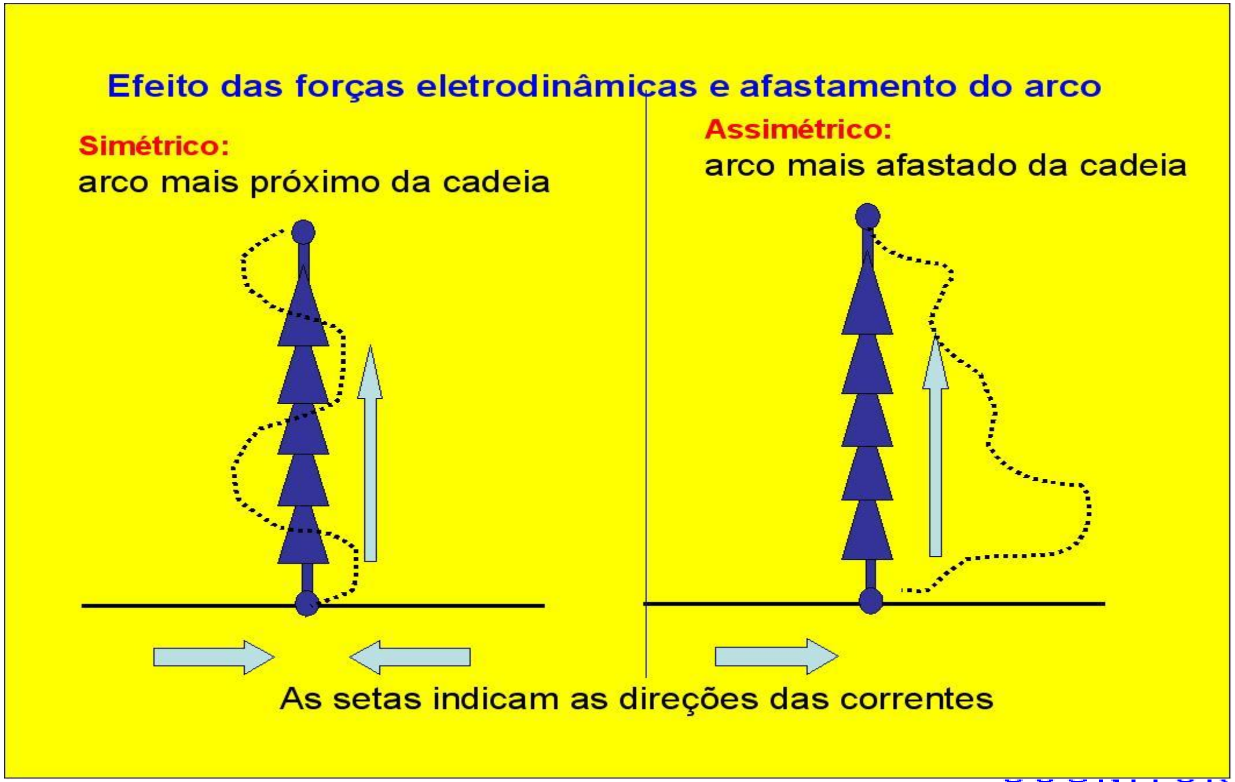
POWER ARCS IN INSULATORS STRINGS

- Discharge occurs and opens a "path" for passage of the short circuit current of 50/60 Hz, w, ex. 40 KAef for 0.2 s
- Arc cause wear on fittings supporting the cables and break insulator
- Later another discharge occurs ..
- Factors to consider (amount, duration and number of events)
- Physical arrangement (symmetric or asymmetric means that arc is more or less close to the insulators due to electrodynamical forces)
- The weight of the string

- What to check after the test

Damaged insulators and fittings for damage?

There can be no falling and good general aspect



END OF MODULE 4

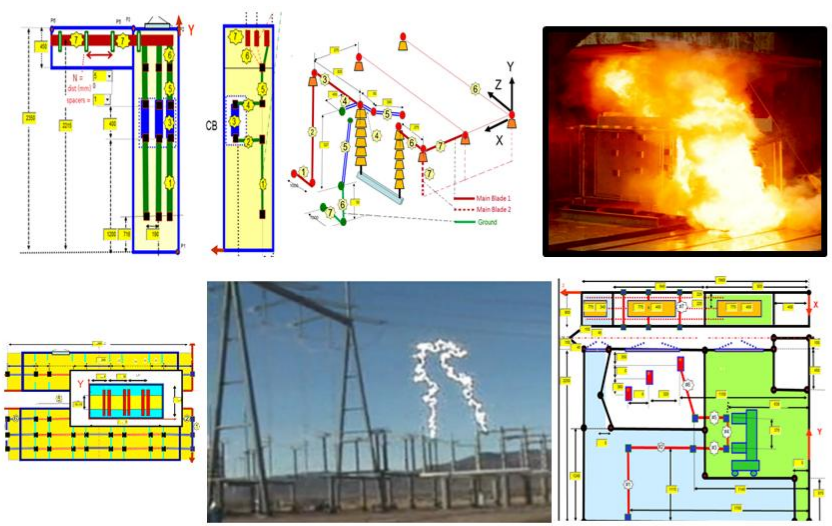
Reference materials for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

(focus in design techniques, specification, tests and simulations)



MODULE 5:

TECHNICAL SPECIFICATIONS USED BY POWER UTILITIES

by Sergio Feitoza Costa

www.cognitor.com.br

TECHNICAL SPECIFICATIONS (PRINCIPLES)

- The most efficient specification is the IEC technical standard or the equivalent national standard if it is updated.
- To refer to an existing official standard is much better than to rewrite the standard within the company specification

Example

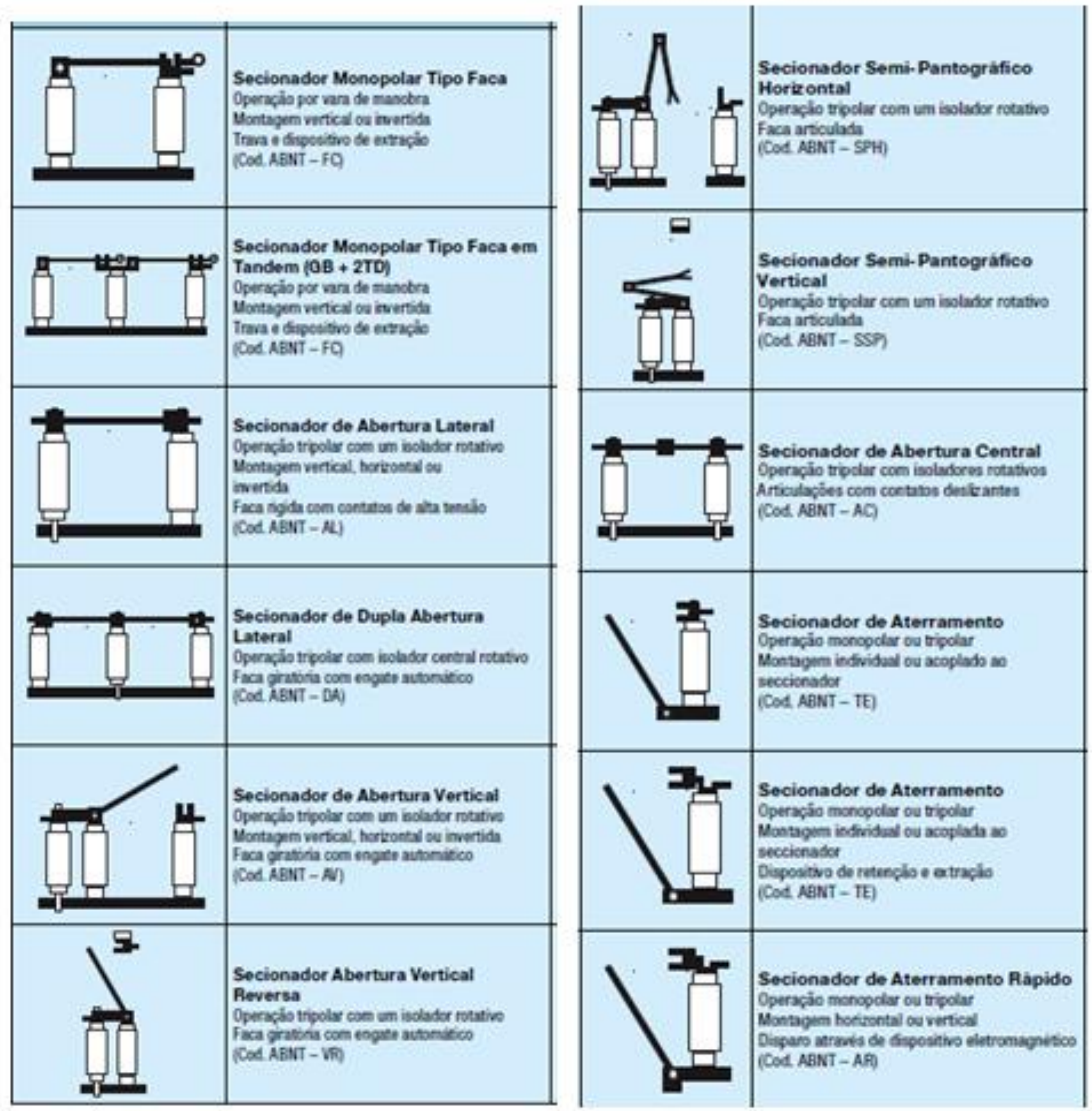
WRONG: The temperature rise should be 53 ˚ C
(as opposed to "the maximum temperature rise should be 53K)

CORRECT: … should attend the temperature rise requirements of IEC-62271-1: Common clauses to high voltage equipment

WHAT TO AVOID

- *The design of the contacts must be done so that the electromechanical forces can not open it.*
    - *Specify the short time current and crest test*
- *Use the best quality materials technology, new and of recent manufacture.*
    - *Specify materials according to NEMA, ASTM ...*
- *Quality of manufacturing: the highest quality and according to the best modern practices of high quality.*
    - *Specification without means of verification*

SPECIFICATION OF HIGH VOLTAGE ISOLATORS / DISCONNECTORS



Secionador Monopolar Tipo Faca Operação por vara de manobra Montagem vertical ou invertida Trava e dispositivo de extração (Cod. ABNT – FC)	**Secionador Semi-Pantográfico Horizontal** Operação tripolar com um isolador rotativo Faca articulada (Cod. ABNT – SPH)
Secionador Monopolar Tipo Faca em Tandem (GB + 2TD) Operação por vara de manobra Montagem vertical ou invertida Trava e dispositivo de extração (Cod. ABNT – FC)	**Secionador Semi-Pantográfico Vertical** Operação tripolar com um isolador rotativo Faca articulada (Cod. ABNT – SSP)
Secionador de Abertura Lateral Operação tripolar com um isolador rotativo Montagem vertical, horizontal ou invertida Faca rígida com contatos de alta tensão (Cod. ABNT – AL)	**Secionador de Abertura Central** Operação tripolar com isoladores rotativos Articulações com contatos deslizantes (Cod. ABNT – AC)
Secionador de Dupla Abertura Lateral Operação tripolar com isolador central rotativo Faca giratória com engate automático (Cod. ABNT – DA)	**Secionador de Aterramento** Operação monopolar ou tripolar Montagem individual ou acoplado ao seccionador (Cod. ABNT – TE)
Secionador de Abertura Vertical Operação tripolar com um isolador rotativo Montagem vertical, horizontal ou invertida Faca giratória com engate automático (Cod. ABNT – AV)	**Secionador de Aterramento** Operação monopolar ou tripolar Montagem individual ou acoplada ao seccionador Dispositivo de retenção e extração (Cod. ABNT – TE)
Secionador Abertura Vertical Reversa Operação tripolar com um isolador rotativo Faca giratória com engate automático (Cod. ABNT – VR)	**Secionador de Aterramento Rápido** Operação monopolar ou tripolar Montagem horizontal ou vertical Disparo através de dispositivo eletromagnético (Cod. ABNT – AR)

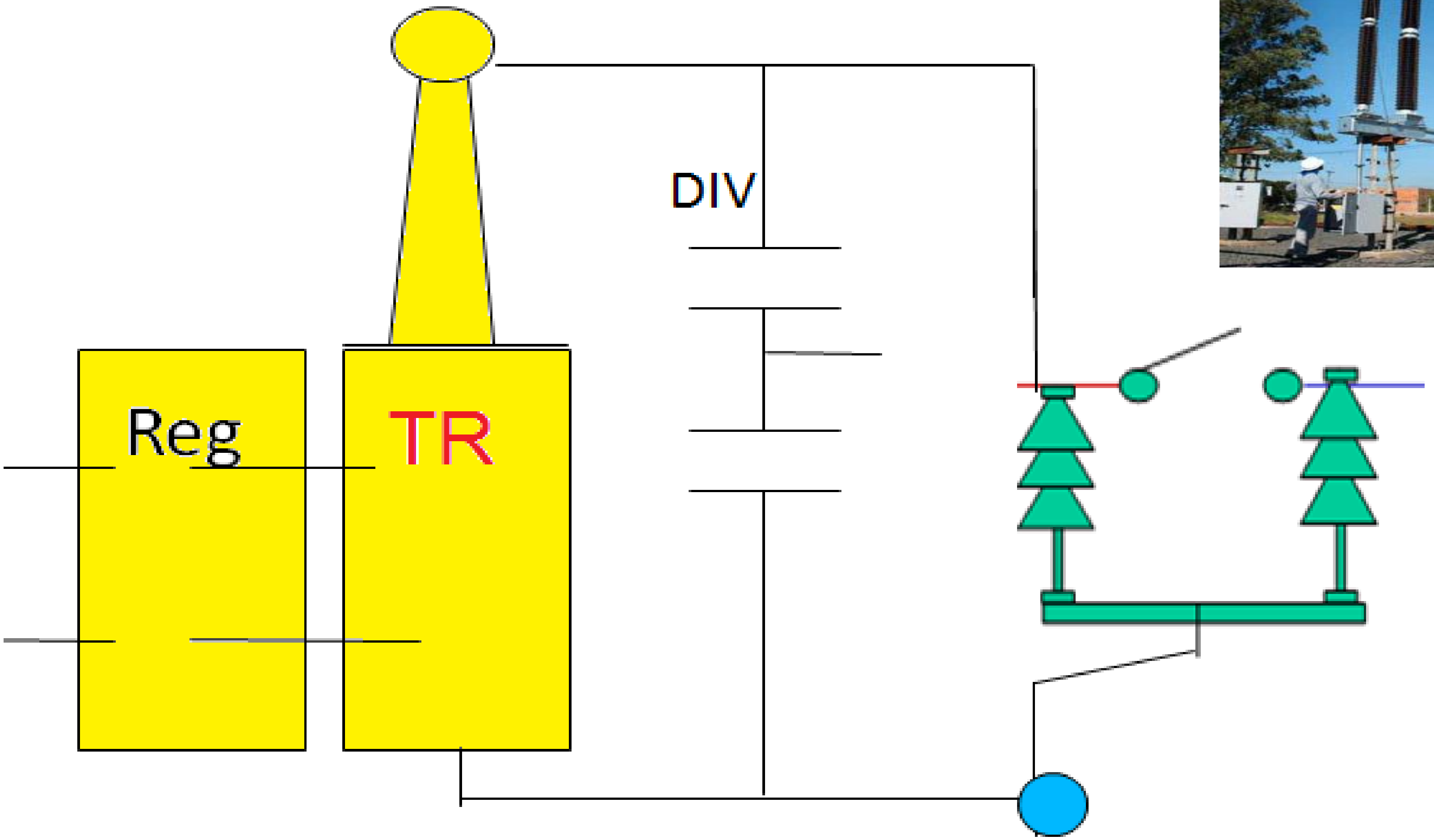
Technical data		Requirement
Rated voltage	Rated voltage (phase to phase)	230 KV rms
	Maximum continuous operating voltage (ph-ph)	242 KV rms
Frequency	Rated frequency	60 Hz
Insulation levels	Power Frequency withstand voltage	Closed to ground 395 kV Open contacts: 460kV
	Lightning Impulse withstand voltage	Closed to ground 950 kVcr Open contacts: 950 kVcr + 140kV 1min – 60Hz
	Power Frequency withstand voltage (auxiliary and control circuits)	3 kV
Number of poles		3
Rated current	Rated current	2000 Arms
Short circuit	Short time withstand and crest	40 kArms during 3s / 100 kAcr
RIV	Radio interference voltage	500 µV
Corona	Extinction and start minimum voltage	154 KVrms

Interruption capability for small currents at the maximum operating voltage (Amperes corresponding to a capacitance of ______ pF)

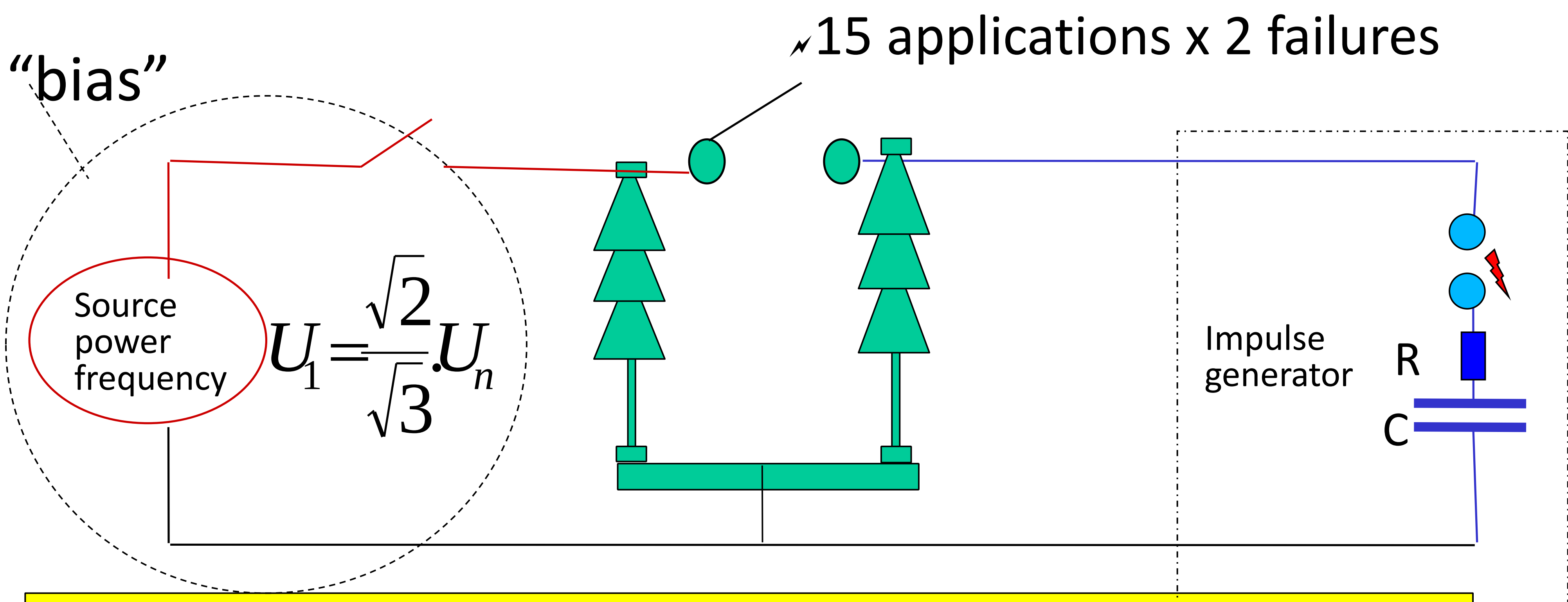
SOME TYPE TESTS AND WHAT THEY ARE

- Atmospheric impulse test.
- Switching impulse test (dry / wet).
- Short-duration power-frequency withstand voltage tests
  dry (1min) wet (10 s)
- Temperature rise test.
- Short-time withstand current and peak withstand current tests .
- Mechanical supportability and operation.
- Radio interference voltage test.
- Visual corona.

SHORT-DURATION POWER-FREQUENCY WITHSTAND VOLTAGE TESTS



IMPULSE TEST



$$U_1 = \frac{\sqrt{2}}{\sqrt{3}} . U_n$$

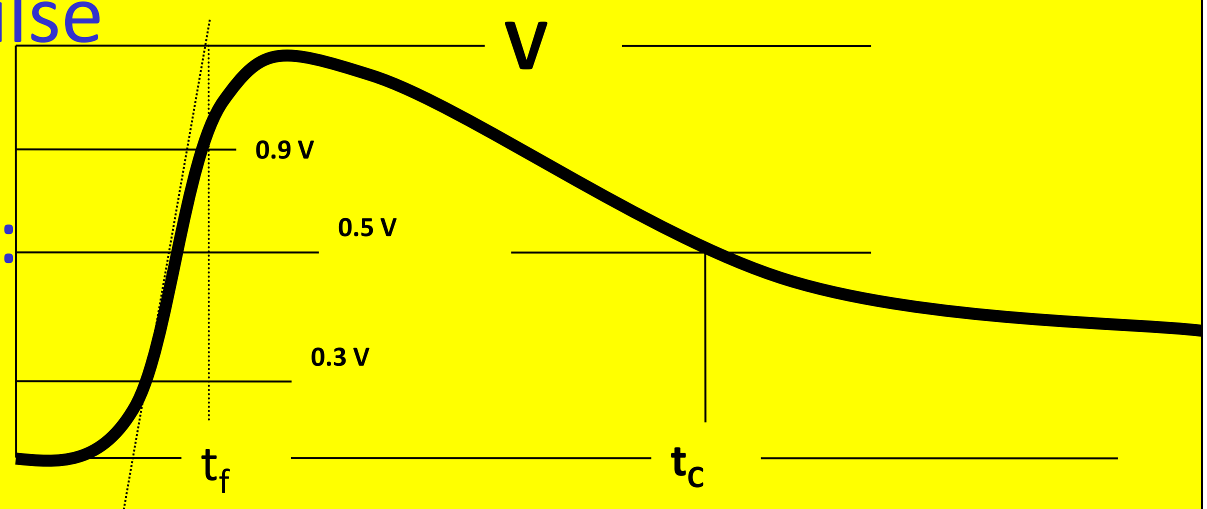
Atmospheric impulse

tf = 1,2 µs; tc = 50 µs

Switching impulse:

tf = 250 µs; tc = 2500 µs

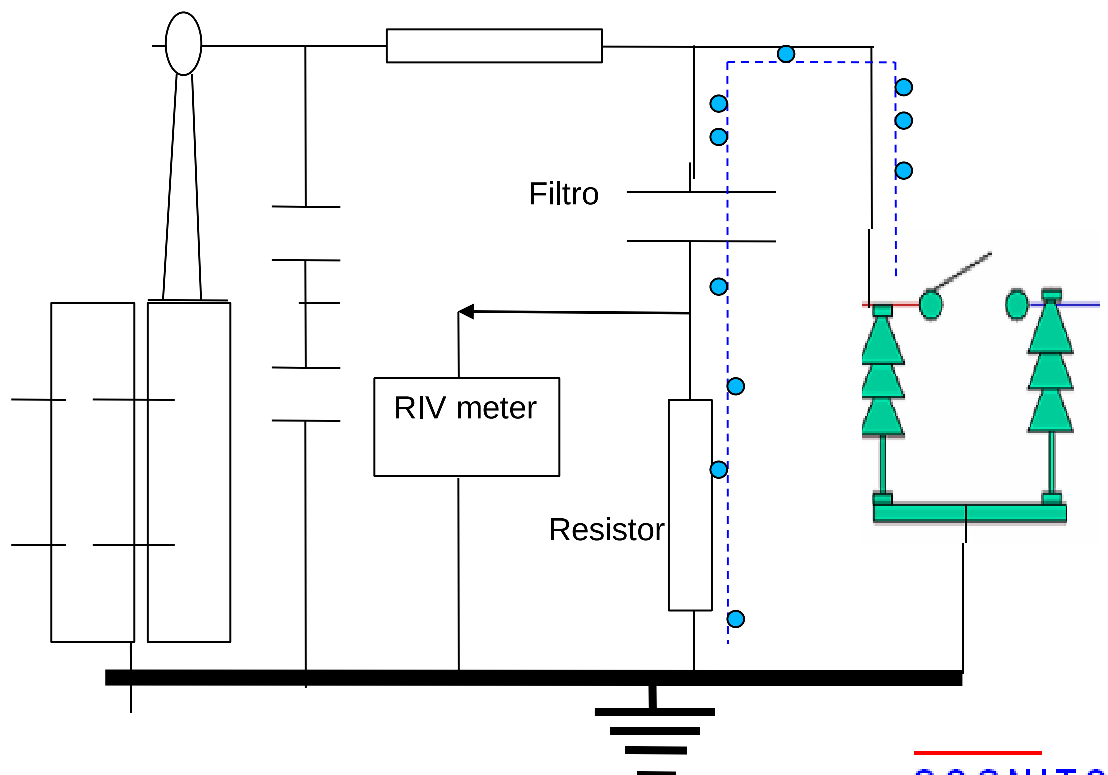
Positive and negative polarities



RADIO INTERFERENCE VOLTAGE TEST.

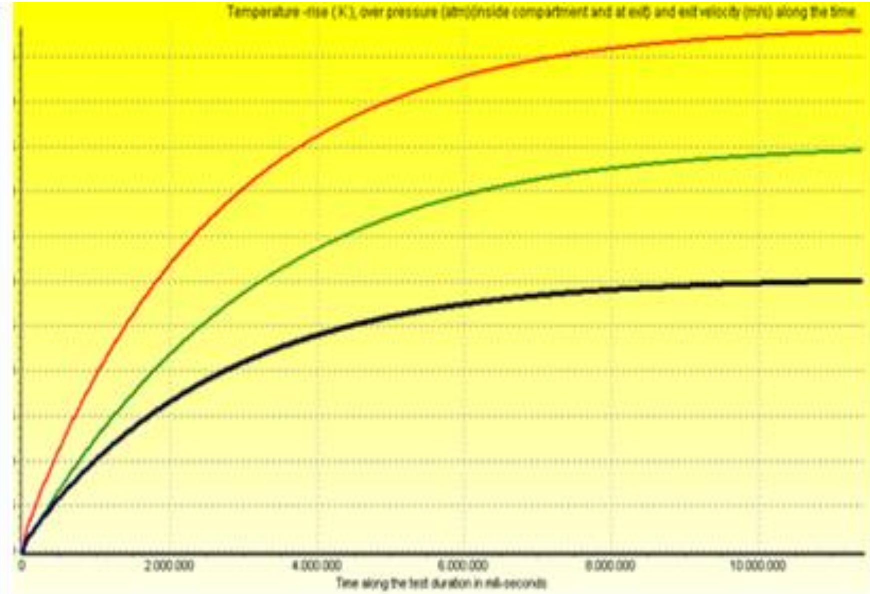
- High frequency pulses generated by equipment and lines are propagated through conductors or irradiated
- Interfere with radios (especially on the AM band).
- Equipment: 50-1000 μ V (function of distance).
- Laboratory : propagated.
- Transmission lines: radiated
- Verification of external insulations

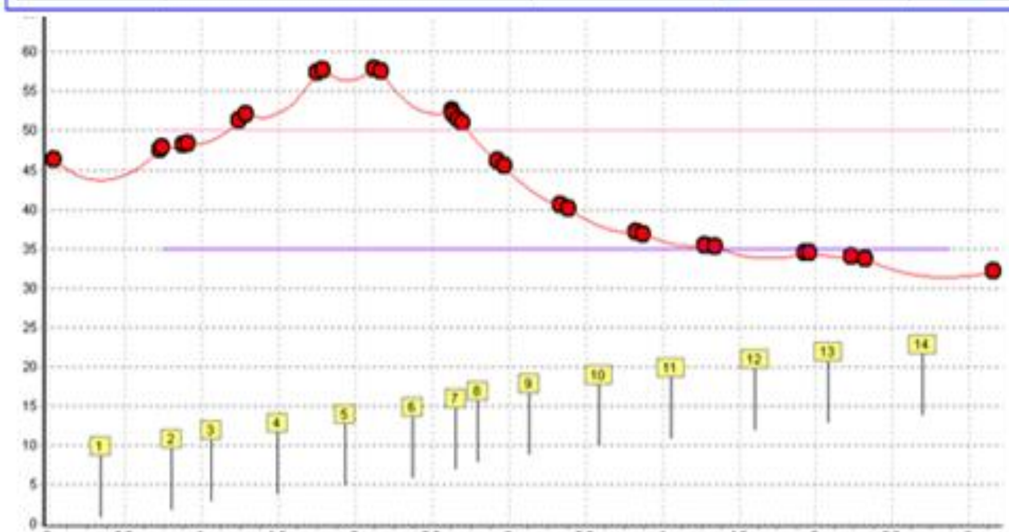
- Apply 1.1 U FT between terminals and base (closed or open position).
- Reduce to 0.3 U in steps of 0,1 U and return to 1,1 U
- RI voltage curve < limit value

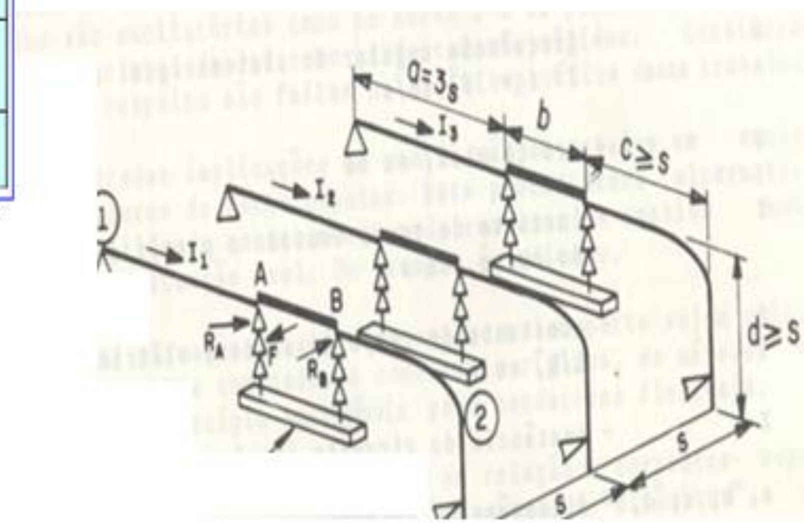


TEMPERATURE RISE TEST

Part	Contact material and medium where it is used	Temperature Rise máx. (K) amb 20°C	Temperature máx. (°C) ambient 40°C	Comments
SPRING CONTACT	Copper and copper alloys uncoated - in air - in SF6 - in oil	 35 50 40		
	Tinned , in air, SF6 oru oil	50		
	Silver or niquel plated - in air - in oil	65 50		
	For contactors in oil		105	Oil deterioration
BOLTED CONTACT	Copper , aluminum and alloys uncoated in air uncoated in SF6	 50 65		
	Tinned, in air or SF6		105	Tin "creep point"
	Silver or niquel plated air or SF6	75		
	Silver or niquel plated in óleo		100	Oil deterioration
	For contactors in oil		105	Oil deterioration
METALIC PARTS	In contact with insulation class • Y / A / E • B / F / H		 90 / 105 / 120 30 / 155 / 180	Isolation ageing
	• Acting as spring • In soldering position		caso a caso 100	Permanent deformation /Break
SURFACES	Can be touched (met / non met.) Acessible but not touched		70 / 80 80 / 90	Do not injure persons







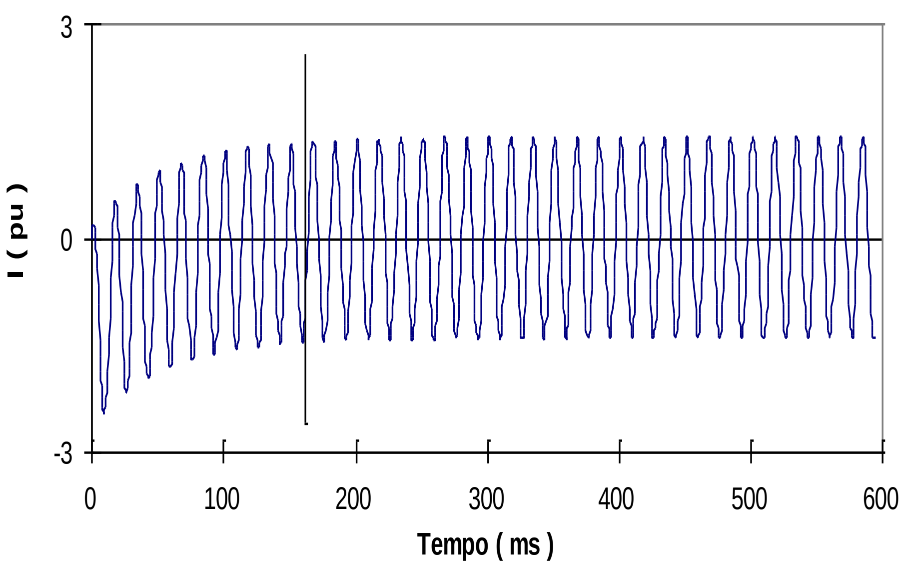
SHORT-TIME WITHSTAND CURRENT AND PEAK WITHSTAND CURRENT TEST .

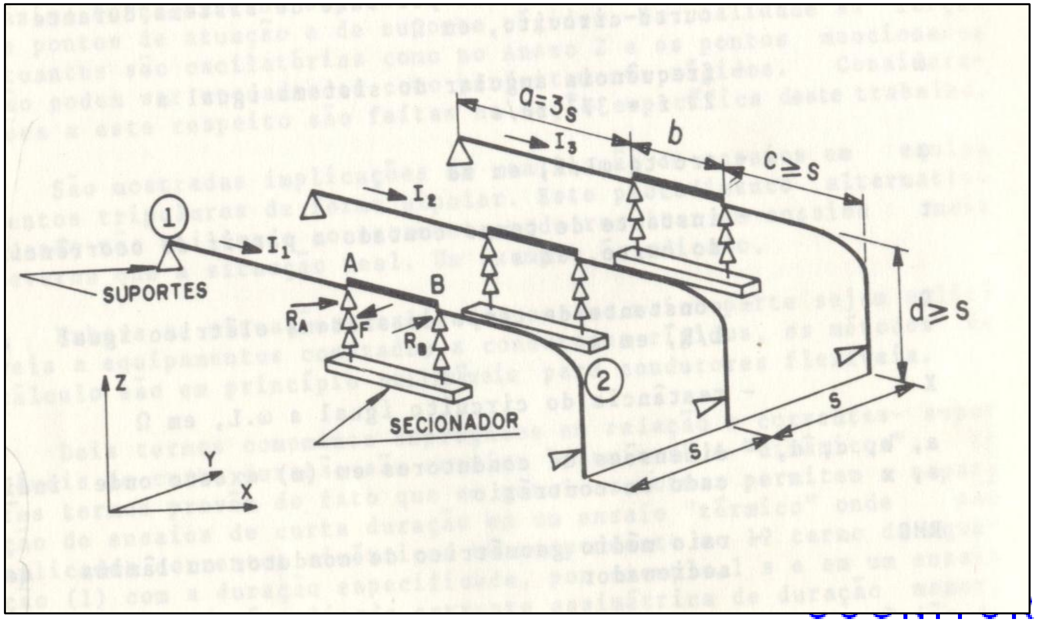
- Ability to withstand thermal and dynamic effects of short circuit current

- Thermal Effects I2. t: variations in materials and loss of characteristics (annealing, melting ....)

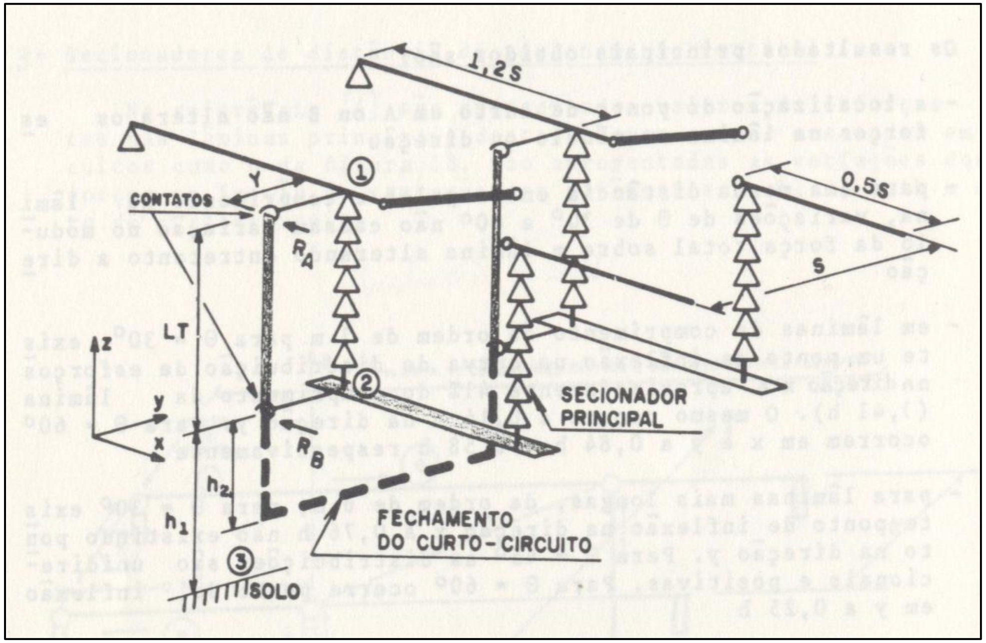
- Dynamic Effects (I2xL / S): Break contacts, insulators, warping of parts

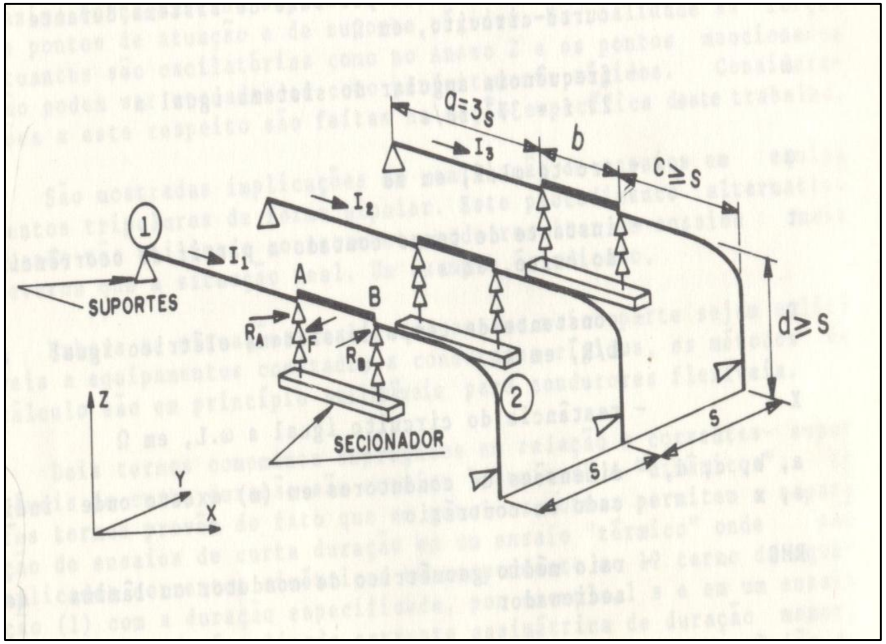
- Physical arrangement: single phase test in “big” three-phase equipment





SHORT-TIME WITHSTAND CURRENT AND PEAK WITHSTAND CURRENT TEST .





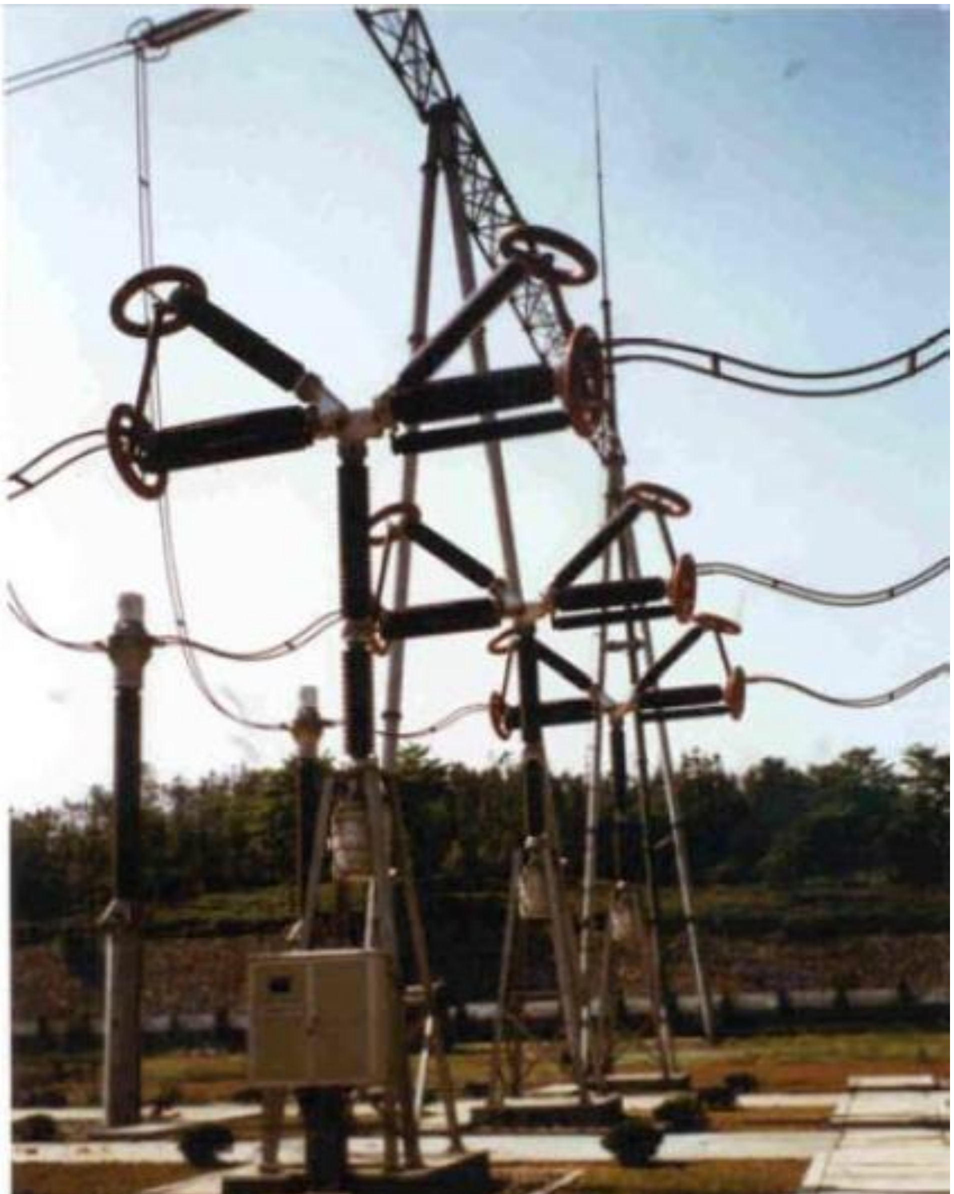
After the test:

- operation without load and contacts should open on the first try;

- measure resistance of the main circuit (except for grounding disconnectors).

- If increased by over 20% and can not confirm the condition of the contacts by visual inspection test run additional temperature rise test.

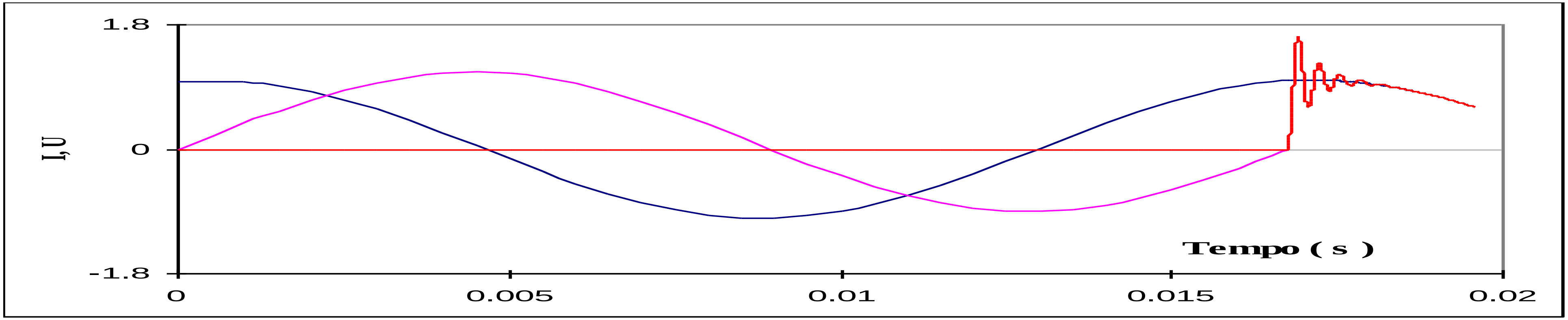
SPECIFICATION OF HIGH VOLTAGE CIRCUIT BREAKERS

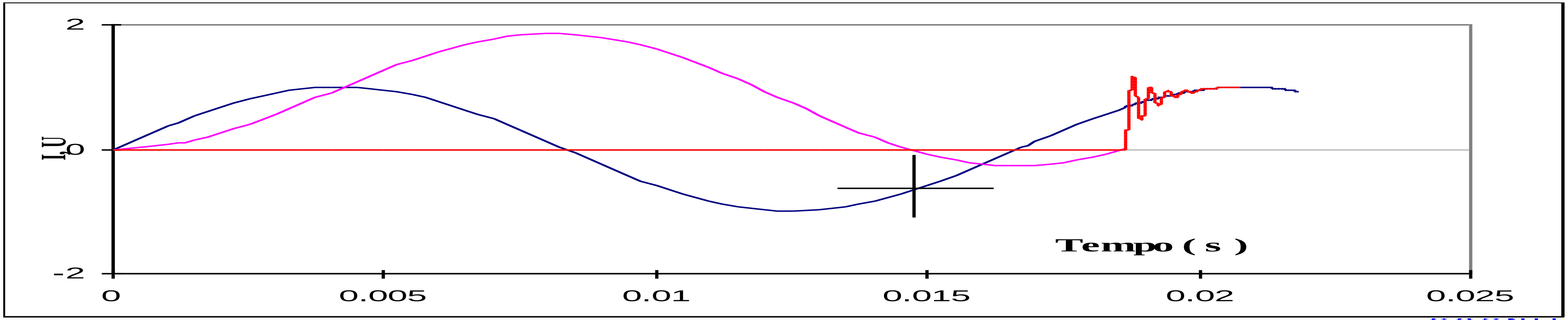


BREAKING TESTS

- ✓ Fault type to represent (voltage, current and power factor)
- ✓ % asymmetry in the current interruption
- ✓ Transient recovery voltage (TRV)
- ✓ First pole to clear factor

- ✓ **Terminal faults**
- ✓ 10%, 30%, 60%, 100% symmetrical e 100% asymmetrical Icc





BREAKING TESTS

- Short line fault: 90%, 75% e 60% I_{cc}

- Out of phase switching

  - Interconnection circuit breakers I_1 = 20 to 40% I_{disc}

  - I_2 =100 to 110% I_{disc} - voltage 2 to 2,5 U ØN

- Capacitive currents switching :
  - No-load lines
  - No-load cables;
  - Back to back capacitor banks;
  - Capacitor banks.

- Small inductive currents switching.

SPECIFICATION OF HIGH VOLTAGE CIRCUIT BREAKERS

Technical data		Requirement
	Other specifications like the isolator	
Short circuit	Rated breaking capacity Component AC (kArms) Component CC (%) Rated Duration (s)	 40 kArms 50% 3 s
Interruptions	Number of interruptions without maintenance	
TRV for terminal faults	Representation: 2 or 4 parameters First pole to clear factor First reference voltage U1 Time T1 related to voltage U1 Second reference voltage Uc Time T2 related to voltage Uc Delay time Td Voltage U' Time T' Rate of rise U1/T1	4 1,5 296 kVcr 148 µS 415 kVcr 444 µS 2 µS 148 kVcr 76 µS 2 kV/ µS
Operating cycle		O - 0,3s – CO - 3min - CO

SPECIFICATION OF HIGH VOLTAGE CIRCUIT BREAKERS

Technical data		Requirement
Line Characteristics	Surge impedance Rated crest factor Rate of rise of the recovery voltage	450 Ω 1,6 0,240 kV/ µS.kA
TRV for terminal faults	Representation: 2 or 4 parameters First reference voltage U1 Time T1 related to voltage U1 Second reference voltage Uc Time T2 related to voltage Uc Delay time Td Voltage U’ Time T’ Rate of rise U1/T1	4 198 kVcr 99 µS 277 kVcr 297 µS 2 µS 98,8 kVcr 51,5 µS 2 kV/ µS
	Rated breaking time	3 cycles
No load line	Rated breaking current (Arms) Surge factor at line closing Number of operations without maintenance	125 A rms 1,4

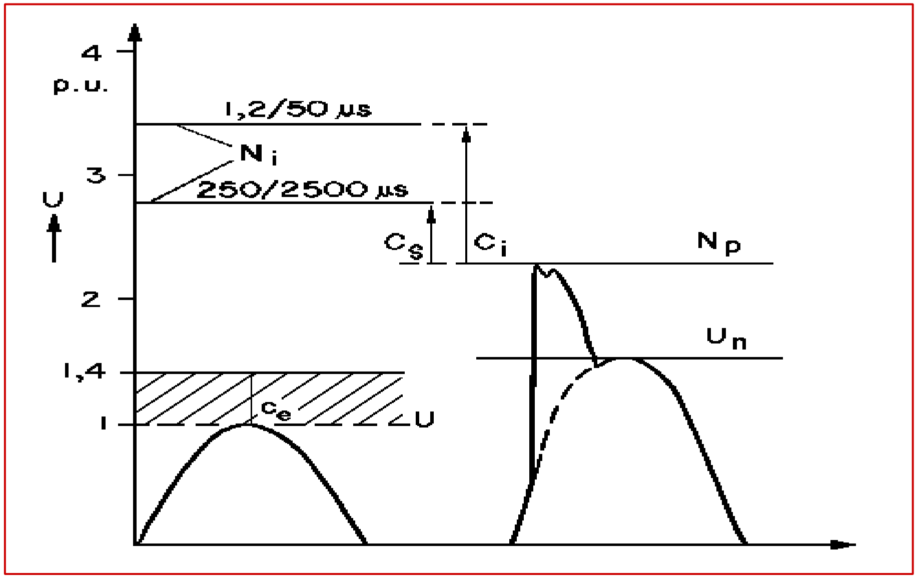
SPECIFICATION OF HIGH VOLTAGE CIRCUIT BREAKERS

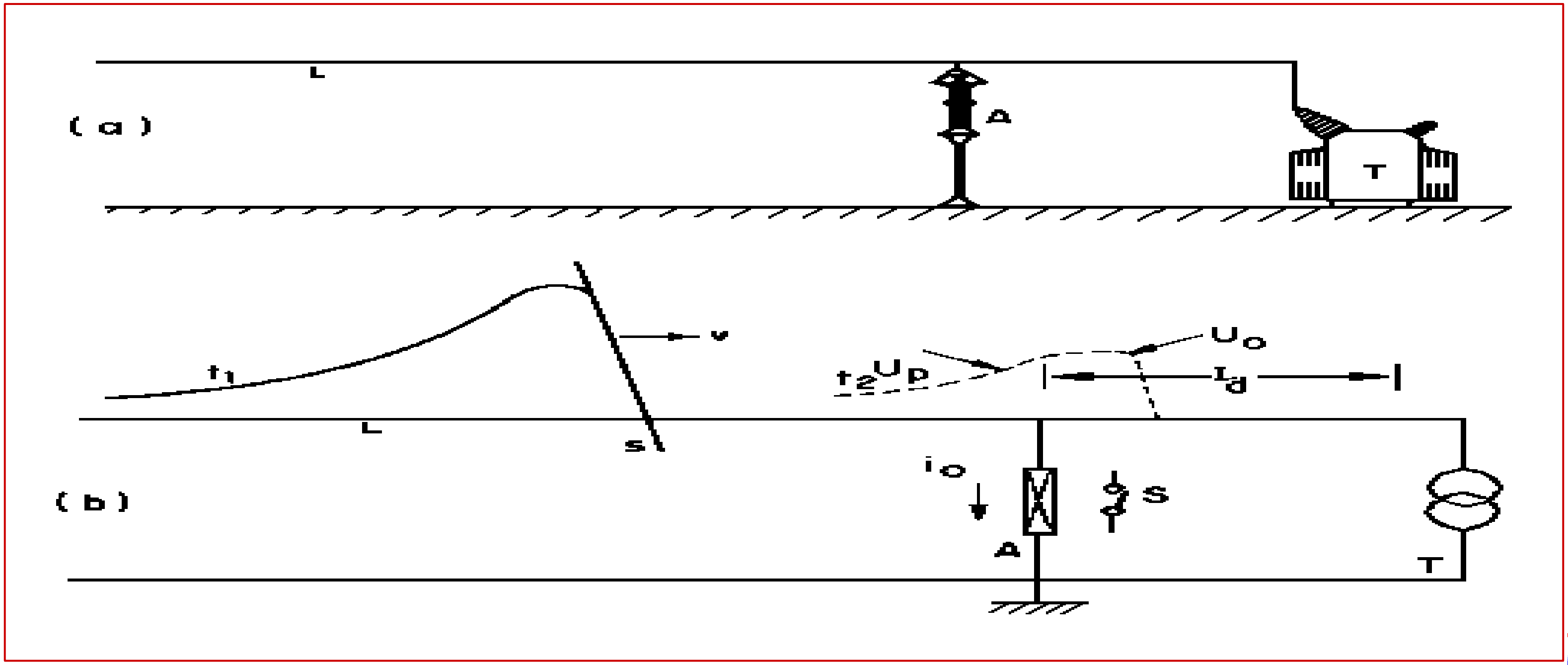
Technical data		Requirement
Interruption	Interruption of small inductive current Maximum overvoltage	5 A rms 2 pu
Out of phase switching	Breaking current Applied voltage ________________ First reference voltage U1 Time T1 related to voltage U1 Rate of rise U1/T1	4o kA rms 279 kV rms __________ 400 kVcr 260 µS 1,25 kV/ µS

SURGE ARRESTERS

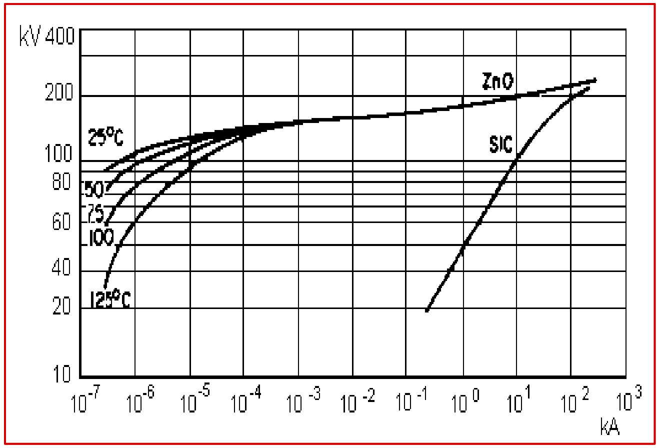
Divert surges to the ground preventing them from being applied to the protected equipment.

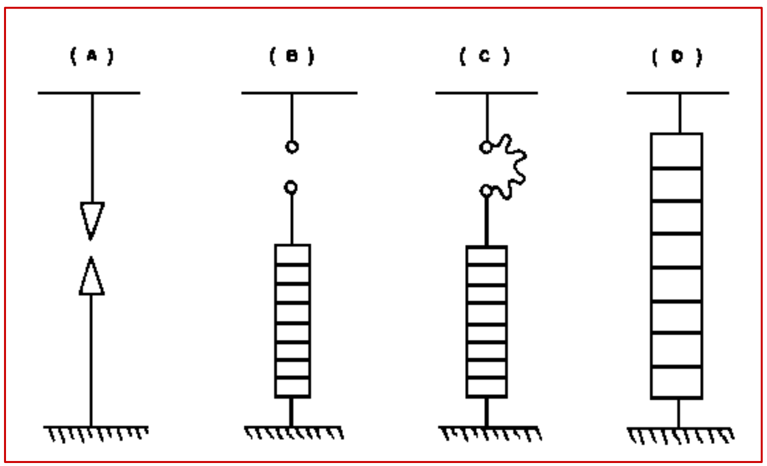
Overvoltages: power frequency, switching and atmospheric impulses

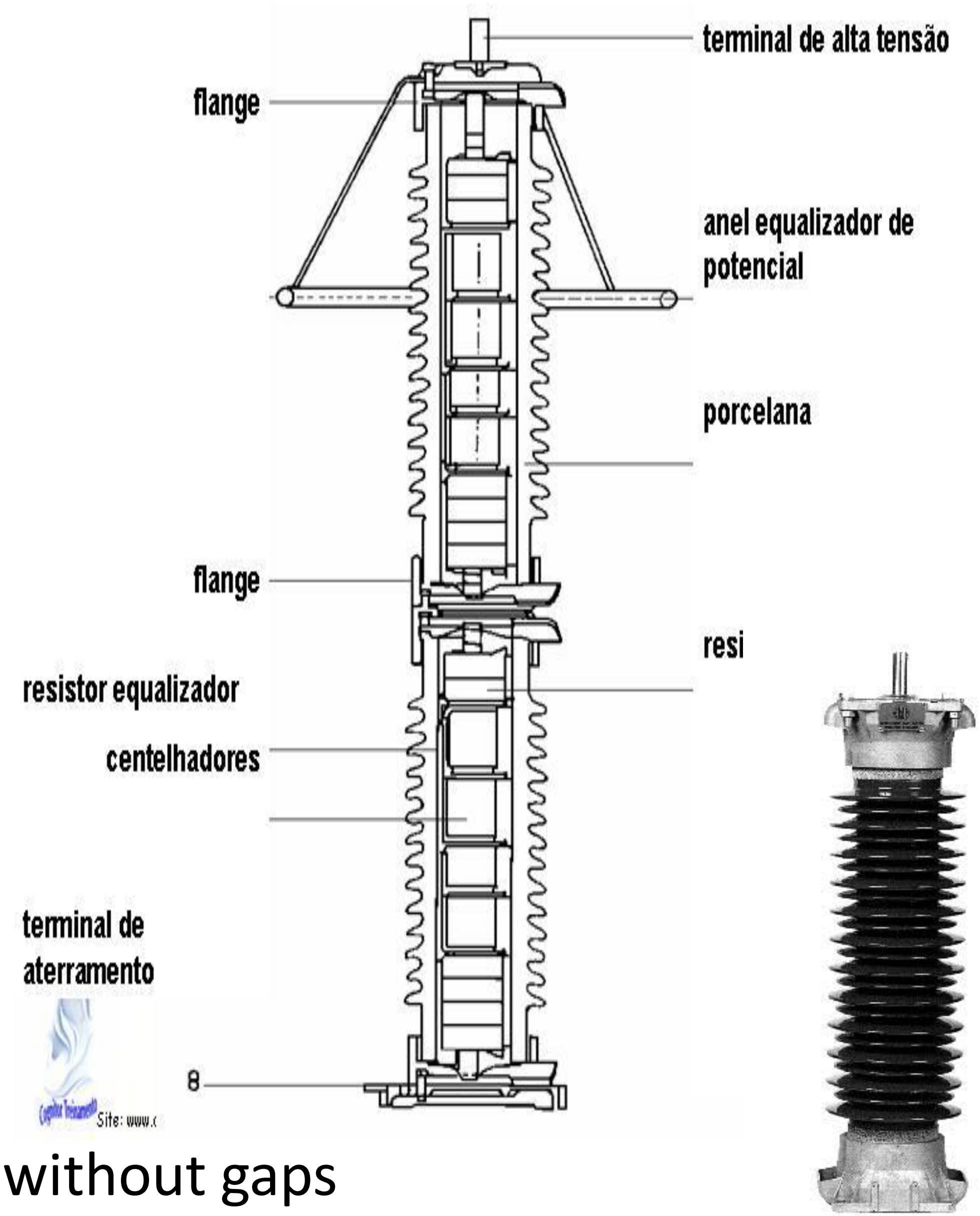




SURGE ARRESTERS EVOLUTION

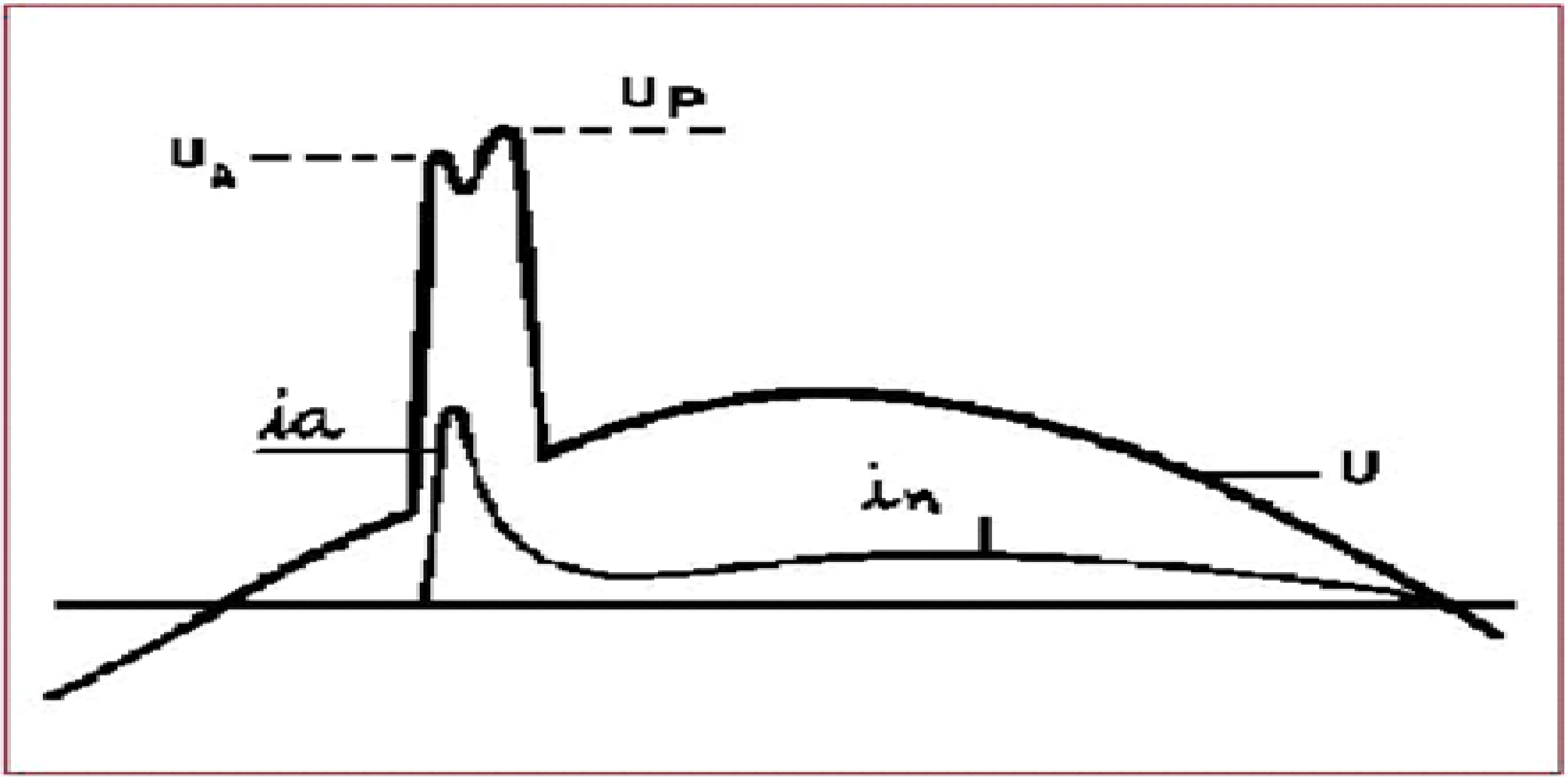






- Air dischargers
- SiC surge arresters with gaps
- Metal-oxide ZnO surge arresters without gaps
- Polymeric and porcelain

SiC SURGE ARRESTERS WITH GAPS



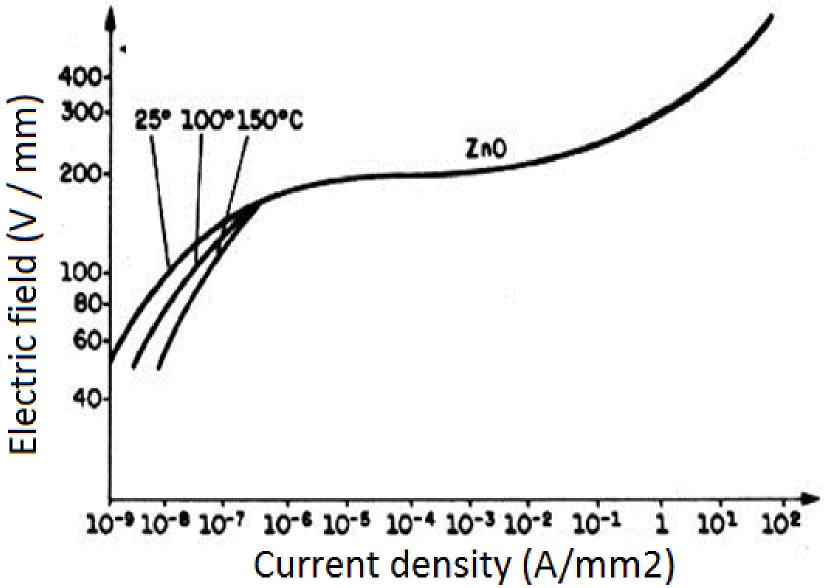
- I a = discharge current
- In = Subsequent current
- Ua = trigger voltage
- Up = residual voltage
- U = system voltage

METAL-OXIDE ZnO SURGE ARRESTERS WITHOUT GAPS

- Set of nonlinear resistors of ZnO.
- Protective characteristics well defined due to no spark gaps.
- No subsequent current (do not wait zero current).
- Greater capacity for energy absorption.
- Possibility of division of power between columns in parallel

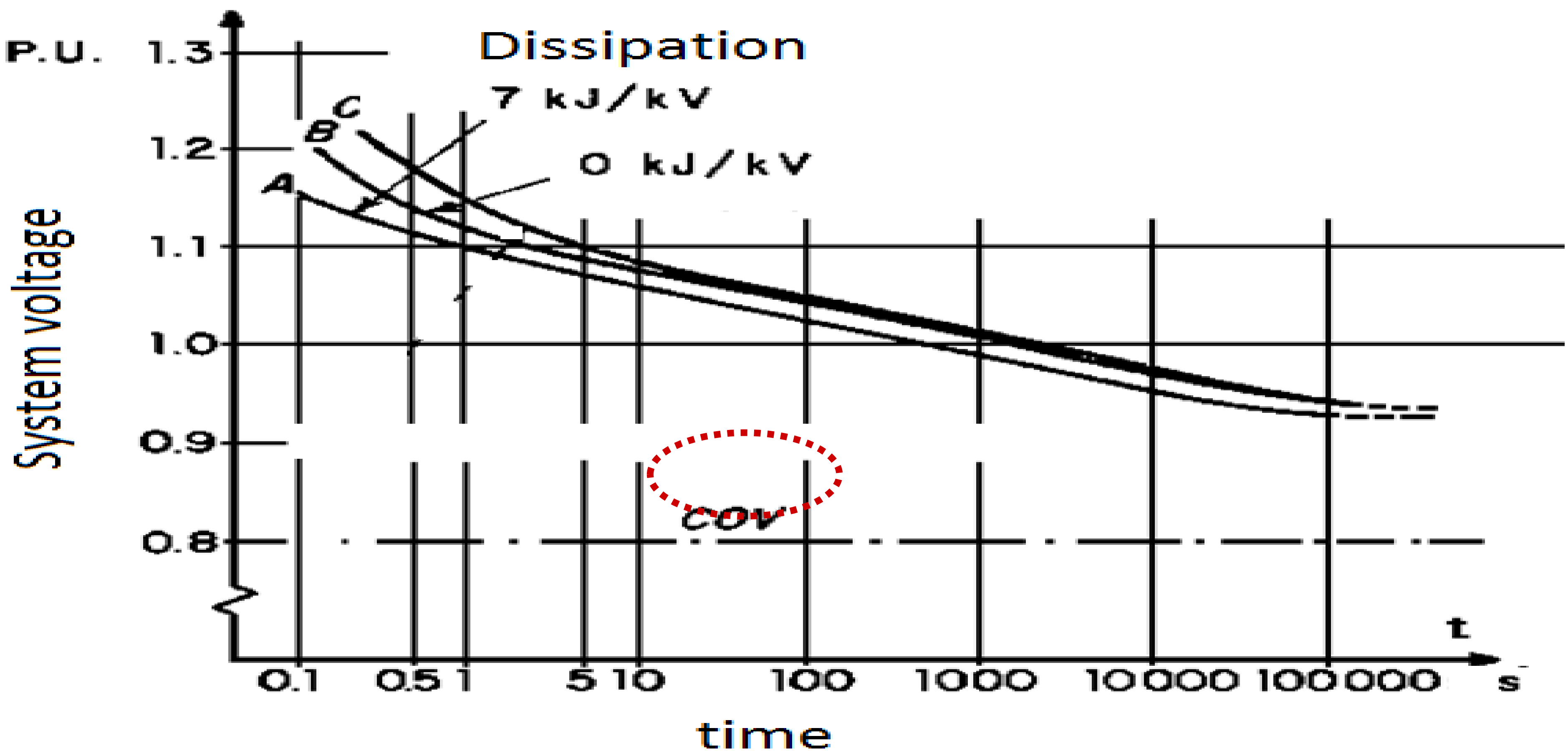
Polymeric

- Less air spacing = less moisture penetration
- No fragmentation of the enclosure = can be closer to the transformer.
- Without pressure relief devices is cheaper and 50% of weight.



METAL-OXIDE ZnO SURGE ARRESTERS WITHOUT GAPS

- Rated voltage Ur (kV): maximum value of power frequency voltage applied to the terminals for which it is designed to operate under conditions of temporary overvoltages in test operation cycle (10s).
- Continuous operating voltage Uc (kV): maximum value for continuous operation under the same conditions for Ur. (MCOV)
- Withstand voltage x time characteristic



METAL-OXIDE ZnO SURGE ARRESTERS WITHOUT GAPS

- ✓Rated Discharge currentl (In): peak value of the atmospheric impulse current used to classify the surge arrester 8x20 µS

- ✓Impulso de alta corrente: peak value of the discharge current 4x10 µS (to test stability under atmospheric discharges)

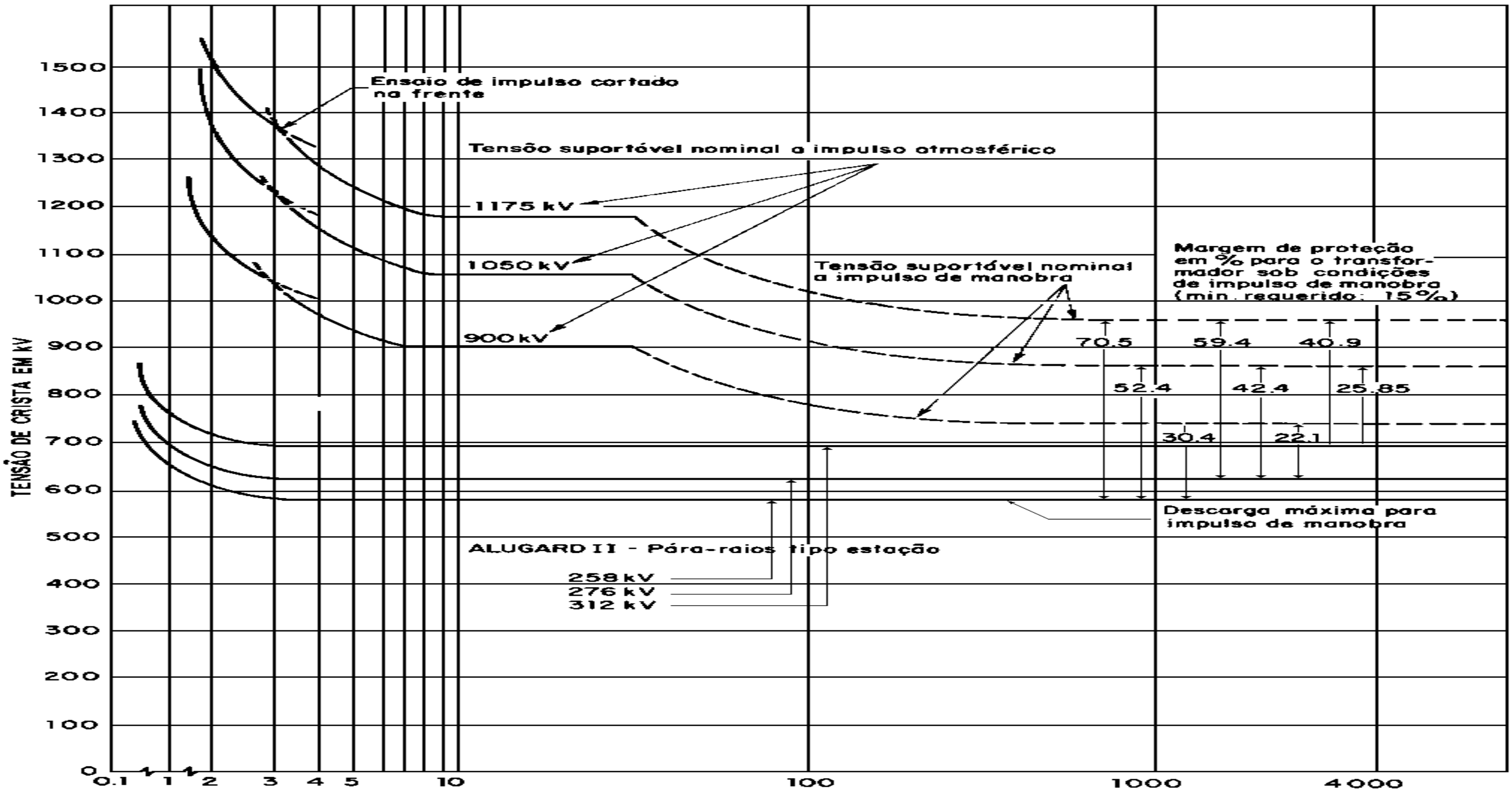
- ✓Switching impulse current: peak value of the discharge current with front time between 30 and 100 µS .

- ✓Reference current : peak value of the resistive component of the industrial frequecy current

- ✓Residual voltage (Ures): peak value of the voltage appearing between the terminals during a discharge

ZnO SURGE ARRESTER SELECTION

- Maximum continuous operating voltage;
- Protective characteristics for different overvoltages
- Durability
- Overpressure relief in case of failure;



One should ensure that:

- (1) MCOV equals or exceeds the maximum operating voltage of the system at the point of application
- (2) for sustained overvoltages, the arrester curve is above the system overvoltages curve

ZnO SURGE ARRESTER SPECIFICATION

1. Manufacturer model:		
System rated voltage (phase to phase; kVef)	230	
Rated frequency (Hz):	60	
System maximum continuous operation voltage (phase to phase; kVef)	242	
Maximum continuous operation voltage(phase -neutral kVef):	160	
Surge arrester rated voltage(kVef):	228	

ZnO SURGE ARRESTER SPECIFICATION

Residual voltage for wave front (max kVcr):	590
Residual voltage for atmospheric impulse (max kVcr):	___?
Residual voltage for switching (max kVcr):	480
Residual voltage for rated discharge current (max kVcr):	600
Rated discharge current (A crista):	20.000A
Long duration discharge class (IEC 99-4) KA	4 kA
Pressure relief withstand current	
1) Component AC of the high intensity current (kArms):	40 kArms
2) Maximum peak current (kAcr):	100 kAcr
3) Low intensity current (Arms)	800 Arms
Reference voltage (kV rms) : Maximum and minimum values	-------
Minimum withstand temporary overvoltage post-discharge by (kVef): for the durations 10 s -------1 s -------0,1s	216 kV during 10 s
Leakage current at the rated voltage and frequency. (mA):	

ZnO SURGE ARRESTER SPECIFICATION

Daily switching protection – Maximum voltage for 100 A rms A :	400 kVcr
SPECIFICATIONS FOR PORCELAIN AS DONE FOR DISCONNECTORS	
Minimum distance along insulator	20 mm / kV
Maximum values of residual voltage for switching currents from 50 to 2000A	kVcr
Energy absorption capacity	8 kJ / kV

SYSTEMS (3 different ones 220 / 132 / 66 KV rms)

Normal system voltage	220 / 132 / 66 KV
Highest system voltage	245 / 145 / 72.5 KV
System frequency	50 Hz $\pm$ 1.5
Number of phases	3 (Three)
Prospective symmetrical faults current.	40KA rms
Neutral earthing	Effectively earth
Max. Duration of earth faults.	3 Sec.

EQUIPMENT TO BE PROTECTED:

220 / 132 / 66 KV Transformers

a) Lightning impulse	1050 / 650 / 350 KVp
b) Power frequency withstand	460 / 275 / 140 KV rms

SURGE ARRESTER SPECIFICATION

	Particulars	220 KV LA	132 KV LA	66 KV
1	Type of Arrestors	Station Class, heavy duty, gapless metal oxide surge arrestor.		
2	Installation	Out door		
3	Application standard	IEC : 60099-4 on metal oxide surge arrestors for AC system		
4	Rated Voltage KV	220	132	66
5	Highest System Voltage KV	245	145	72.5
6	Corona Extn. Voltage	198 KV rms	120 KV rms	60 KV rms
7	Nominal discharge current (for 8/20 microsecond wave)	10 KA		
8	Long duration discharge class (line discharge class)	Class - III		Class -II
7	Anticipated voltage level of Temporary over voltage with stand capability (KV rms) - Voltage - Duration	- 1.3 times rated voltage of arrester - 1 to 10 Seconds		
8	Pressure Relief Class	A , 40 KA rms		
9	One minute dry power frequency withstand voltage of arrestor housing KV rms	460	275	140
10	Impulse withstand voltage of arrestor housing with 1.2/50 micro second wave. KVP	1050	650	350

SURGE ARRESTER SPECIFICATION

		220 KV	132 KV	66 KV
11	**Creepage distance of porcelain housing**	**-6125 mm for LAs to be supplied at stations other than KLTPS (25mm/KV)** **- 7595 mm for LAs to be supplied at KLTPS (31 mm/KV)**	**4495 mm for LAs to be supplied at Sikka TPS (31 mm/KV)**	**2248 mm for LAs to be supplied at Sikka TPS (31 mm/KV)**
12	Ratio of switching impulse residual voltage to rated voltage of arrester	Not more than two		
13	Max RIV when energized at MCOV	1000 micro volts		
14	Partial discharge value	50 pc (max)		
15	Bimetallic compression type Terminal connector	As per site requirement		
16	Type of Mounting	Pedestal (On structure)		

MAIN TESTS

Tests on metal oxide blocks

- Steep Current Impulse Residual Voltage test
- Lightning impulse Residual voltage test
- Switching impulse Residual voltage test
- Long duration current impulse withstand
- Operating duty test
  - High Current Impulse operating duty test
  - Switching Surge Operating Duty test
- P. F. voltage x time characteristic
- Reference voltage test
- Accelerated ageing test

Tests on Arrester Housing

- Impulse voltage withstand test on insulator
- P.F. (Dry) voltage withstand test on insulator
- P.F. (Wet) voltage withstand test on insulator
- Bending test on assembly

Tests on Arrester

- Artificial pollution test
- Seismic test
- High current pressure relief test
- Low current pressure relief test

General

- STC on Terminal connector (40 kA for 3 sec)
- Degree of Protection test on counter/surge monitor
- Uniformity of Zinc coating

P. F = Power frequency

3P*

Nominal Discharge Current : 10 kA peak

Long Duration Current : 750 A peak / 2000 ?sec

Energy Withstand : 10 kJ/kV

-4P*

Nominal Discharge Current : 20 kA peak

Long Duration Current : 1000 A peak / 2000 ?sec

Energy Withstand : 13 kJ/kV

-5P*

Nominal Discharge Current : 30 kA peak

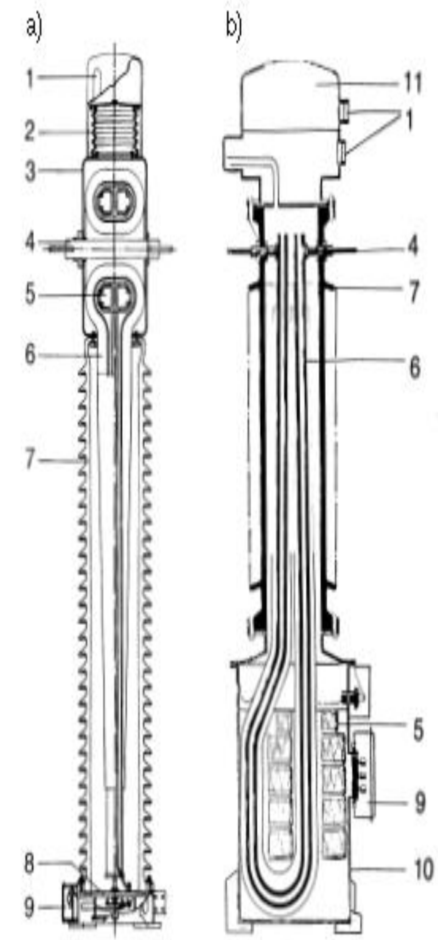
Long Duration Current : 1250 A peak / 2000 ?sec

Energy Withstand : 16 kJ/kV

	Rated voltage Ur kV rms	Max cont. operating voltage MCOV kV rms	Temporary over-voltage for 1 sec. TOV kV rms	Max residual voltage with current wave (kV peak)					
				8/20 µS			Switching 30/90 µS		Steep 1/2µS
				5 kAp	10 kAp	20 kAp	125 Ap	500 Ap	10 kAp
-3P3S108	108	86.4	126	333	351	399	257	264	414
-3P4S132	132	105.6	154	408	440	492	314	322	508
-3P5S150	150	120	175	460	500	560	355	368	575
-3P6S198	198	158.4	231	612	660	738	471	483	762
-3P6S216	216	172.8	252	666	702	798	513	528	828
-3P7S250	250	201.6	294	777	819	931	599	616	966
-4P9S324	324	259.2	378	999	1053	1197	770	792	1242
4P10S345	345	273.6	399	1053	1120	1267	812	837	1311
4P10S360	360	288	420	1110	1170	1330	855	880	1380
4P11S396	396	316.8	462	1221	1287	1463	940	968	1518
5P12S432	432	345.6	504	1332	1404	1596	1026	1056	1656
5P13S468	468	374.4	546	1443	1521	1729	1112	1144	1794

CURRENT TRANSFORMERS

Relações de transformação		
• secundários de proteção	300/400/600 – 5-5-5-5A	
• secundários de medição	300/400/600 – 5-5 A	
Fator térmico	1,3	
Quantidade de enrolamentos secundários	6	
Secundários de medição	2	
Secundários de proteção	4	
Características do núcleo de medição:		
• Domínio nominal de utilização, para freqüências variando entre	58 a 61	Hz
• Limites de erros	0,3%(Iprimária=1,0xIn ; FtxIn) ; 0,6%(Iprim= e item 2.2.4	
• Cargas	Vide item 2.2.4	
• as cargas e classe de exatidão devem ser mantidas na variação de:	5% a 100% da carga nominal, para a r relação de transformação, e as características conforme norma NBR- (inclusive figuras 1,2 e 3 do anexo B)	
• Com carga secundária de 75 a 100% da carga de exatidão nominal máxima e com corrente primária de 50 kAef, a corrente secundária nos núcleos de medição deve ser	50 A ef	



núcleos de proteção:		
Domínio nominal de utilização, para freqüências variando entre	55 a 65	
as cargas e classe de exatidão devem ser mantidas na variação de:	5% a 100% da carga nominal, relação de transformação, características conforme norma N	
Limite de Erro	10% (vide item 2.2.	
Cargas	Vide item 2.2.4	
Fator limite de Exatidão	Núcleos de proteção	83,3 x In

- *Ensayo De Arco Interno*

A fin de verificar, ya sea la capacidad del transformador de resistir las solicitaciones producidas a consecuencia de un arco interno, ya sea el correcto funcionamiento del dispositivo de seguridad contra las sobrepresiones, se debe realizar un ensayo produciendo en el interior del transformador un arco de potencia por la aplicación de la corriente de cortocircuito durante 300 ms.
El arco se debe iniciar en la zona(1) en la cual el gradiente del campo eléctrico es el presumiblemente más elevado ó sostenido más significativo, mediante un hilo conductor de pequeña sección que deberá fundirse casi instantaneamente.

El ensayo puede efectuarse con una tensión sensiblemente inferior a la tensión nominal procurando que la corriente de arco sea prácticamente sinusoidal y el arco no se extinga antes del tiempo establecido.
Los parámetros del circuito y la sincronización del interruptor de cierre deben ser tales que, el valor de cresta del primer pico de la corriente sea igual a 1,7÷2,5 veces el valor eficaz de la corriente permanente.
Durante el curso de la prueba se debe registrar el valor de los parámetros eléctricos y el tiempo de actuación de la válvula de sobrepresión.
El ensayo se debe realizar a la presión nominal de funcionamiento.
La prueba se considera un éxito si no se observa rotura externa sobre el transformador además de la actuación del dispositivo de seguridad contra la sobrepresión.
La ejecución de la prueba no es necesaria si ya fue realizada sobre otro aparato perteneciente a la misma serie proyectada, en tal caso el Fabricante debe demostrar el cumplimiento del ensayo mediante certificación del resultado de la verificación ya efectuada.

POWER TRANSFORMERS AND REACTORS

Certificates of type tests and special tests.

Memory for calculating short-circuit, indicating:

- calculating the maximum current short-circuit by winding;
- calculation of thermal capacity to withstand short circuits according to NBR 5356;
- calculating the dynamic ability to withstand short circuits.
- methods of calculations of radial and axial forces;
- Data input and output calculation forces radial and axial;
- Maximum allowable forces

REACTOR

System rated voltage	230 ± 5%	kV
System rated frequency	60 ± 0,1	Hz
Insulation level at 230 kV		
• Atmospheric impulse (BIL)	950	kV
• Switching impulse (BSL)	750	kV
Short circuit level at the bus 230 kV 230 KV		
Phase to ground short circuit	8,8 to 21	kA
Three – phase short circuit	6,3 to 15	kA

OVERVOLTAGE	DURATION
1,8 pu	50 ms
1,4 pu	200 ms
1,3 pu	1 segundo
1,2 pu	10 segundos
1,1 pu	3 horas

SOME REQUIREMENTS

Description		Un	OBS
Cooling:	Mineral oil naphthenic		
Number of phases	1		
Rated frequency	60	Hz	
Rated voltage	$242/\sqrt{3}$	kV_{ef}	
Rated power	x	MVAr	[1]
Windings connection	x		[1]
Cooling method	x		[1]
Temperature rise limit (hot spot)	65	K	
Noise Level - Decibels below value in the table 12, NBR 5119 (Item 14.16)	x	dB	[1]
Radio interference voltage as in 14:17, NBR 5119	x	μV	[1]

[1] Characteristics defined by the manufacturer

SOME REQUIREMENTS

DESCRIPTION			Un	OBS
Windings insulation lels	Line	Neutral		
Atmospheric impulse withstand voltage	950	x	kV_p	[1]
Atmospheric impulse withstand voltage (cut wave)	1045	-	kV_p	[1]
Switching impulse withstand voltage	750	-	kV_p	[1]
Industrial frequency withstand voltage	395	x	kV_{ef}	[1]
Bushings insulation level				
Atmospheric impulse withstand voltage (full wave)	1050	x	kV_p	[1]
Atmospheric impulse withstand voltage (cut wave 3 µS)		x	kV_p	[1]
Switching impulse withstand voltage	850	-	kV_p	[1]
Industrial frequency withstand voltage dry	460	x	kV_{ef}	[1]
Industrial frequency withstand voltage wet		185	kV_{ef}	
Minimum creepage distance	25	25	mm/kV	

SOME REQUIREMENTS

- Excitation current:
- The knee of the curve should be at saturation value of 125% of rated voltage of 242 kV or above.

- The supplier shall provide the saturation curve obtained by test

- Withstand to dynamic overvoltages
- The equipment shall be capable of withstanding voltage levels of 4.2

- Requirements of overload:
- Apart from the NBR 5416 requirement, the transformer and accessories shall withstand daily overloads of short duration (less than a half-hour period) of 1.35 times the rated power of the transformer and long-term (less than four hours), 1.25 times the rated power of the transformer.

SOME REQUIREMENTS

- Routine Tests: the ones in NBR 5356 + verification of paint scheme

- Type tests: temperature rise test and noise level

- Especial tests
  - Measurement of zero sequence impedance
  - Measurement of harmonics of the excitation current
  - Chromatographic analysis of gases dissolved in the insulating oil;
  - Power factor of the insulation;
  - internal vacuum;
  - Test of degree of polymerization.
  - Raising the saturation curve to show that the knee of the curve is at the specified value, or above

END OF MODULE 5

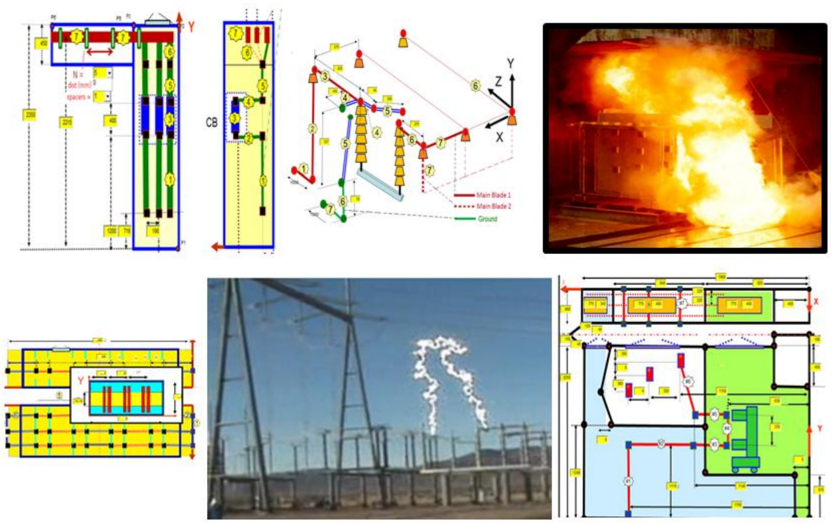
Reference materials for the courses

SWITCHGEAR, BUSWAYS & ISOLATORS

and

SUBSTATIONS AND LINES EQUIPMENT

(focus in design techniques, specification, tests and simulations)



MODULE 6:

TECHNICAL STANDARDS

FOR SWITCHGEAR

Medium voltage (IEC 62271-200)

Low Voltage (IEC 61439)

by Sergio Feitoza Costa

www.cognitor.com.br

TECHNICAL STANDARDS FOR MEDIUM VOLTAGE SWITCHGEAR

IEC 62271-200 : High voltage switchgear and controlgear - Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV

- Enclosures with fixed and removable components filled with fluid (liquid or gas) .
- Gas pressure <= 300 kPa. (~ 3 atm)
- Flammable atmospheres: additional requirements.
- Category of loss of service continuity (LSC): keeping other compartments energized if a main circuit compartment is opened.

IEC 62271-200 - ASSEMBLY CLASSIFIED AS INTERNAL ARC PROOF (IAC)

- If criteria for protection of people are met in the case of an internal arc, as demonstrated by suitable tests

- Meets standard if is designed and manufactured to prevent the occurrence of internal faults.

- If installed, operated and maintained properly there is small possibility of internal arc. but it can not be disregarded.

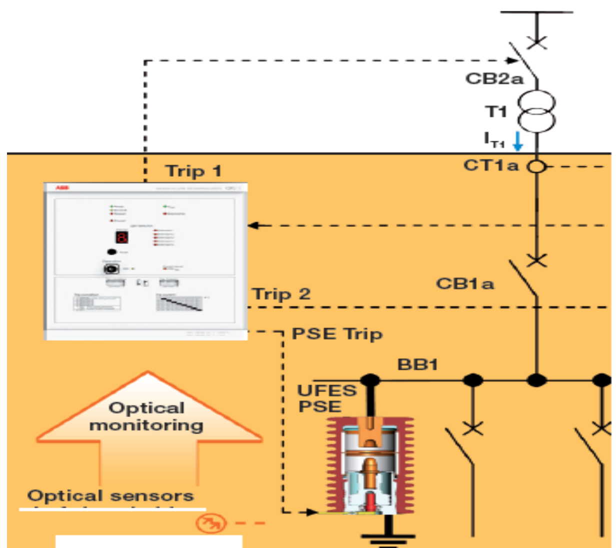
- Failures in the enclosure, bad or exceptional service conditions or operation error , can start arc that poses a risk to people.

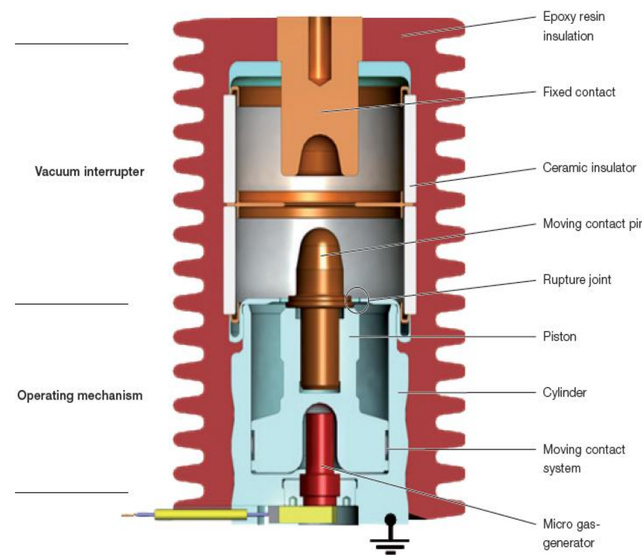
HOW TO AVOID INTERNAL ARCS

Elimination of fault by sensors sensitive to light, pressure or heat

Current limiting fuses or limiters

Rapid elimination of arc deviating it to metallic short-circuit





Remote control

Insertion or extraction of extractable portion only with closed door.

IEC 62271-200

TYPE TESTS

- Verification of the insulation level
  - Power-frequency voltage tests
  - Lightning impulse voltage tests
  - Partial discharge tests
- *Temperature rise and resistance of circuits:*
- *Short-time withstand current and peak withstand current*
- Making and breaking capacity of the switching devices:
- Operation of the switching devices and removable parts
- Protection of persons against access to hazardous parts
- and protection of equipment against solid foreign objects
- Protection of persons against dangerous electrical effects
- Strength of gas-filled compartments:
- Tightness of gas or liquid filled compartments:
- *Effects of arcing due to an internal fault (IAC)*
- Electromagnetic compatibility tests (EMC)

INTERNAL ARC CLASSIFICATION IAC

- Types of accessibility **A, B , C**

+

- **Corrente** de ensaio em kA e **duração** (s).

+

F Frontal **L** Lateral **R** Rear

a) ASSEMBLY NOT MOUNTED IN POLE

Aceesibility A: authorized personnel.

Aceesibility B: public access

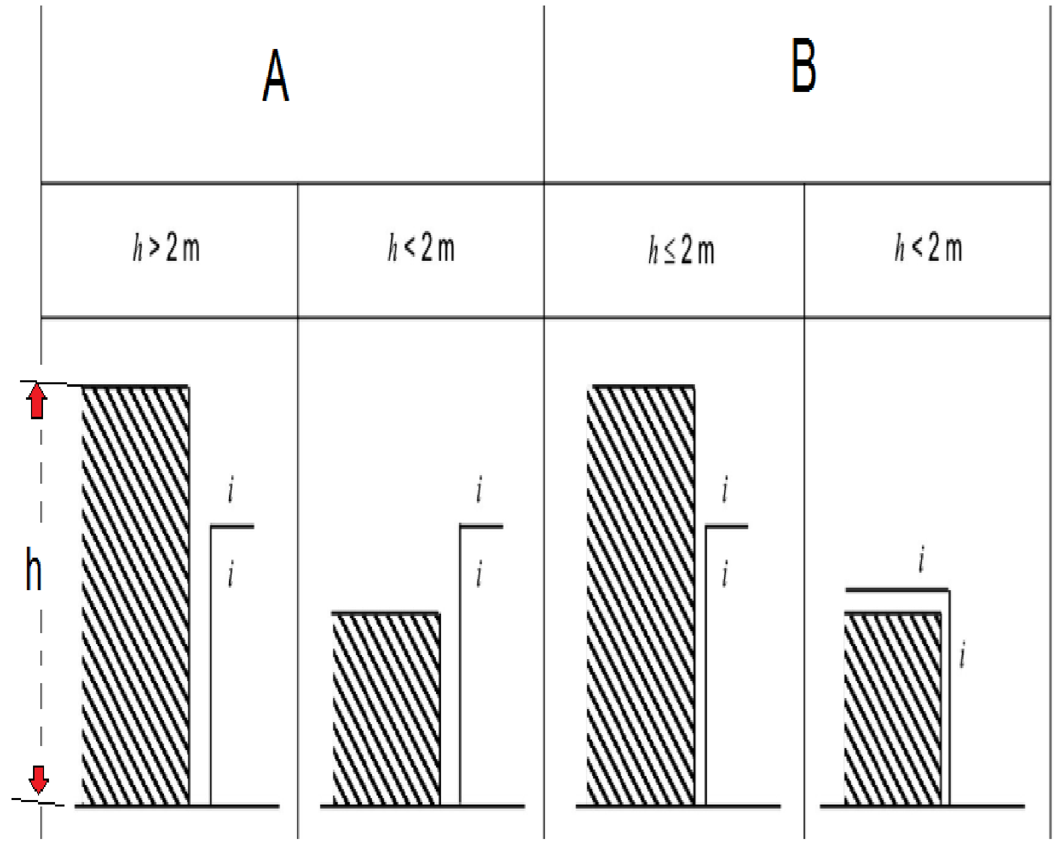
b) ASSEMBLY MOUNTED IN POLE

Aceesibility C: restricted by installation out of reach

INTERNAL ARC CLASSIFICATION IAC

Example 1: 12,5 kArms - 0,5 s : public accessibility and tested with indicators placed in front, side and rear:

Classification IAC BFLR
Internal arc:12,5 kA 0,5 s



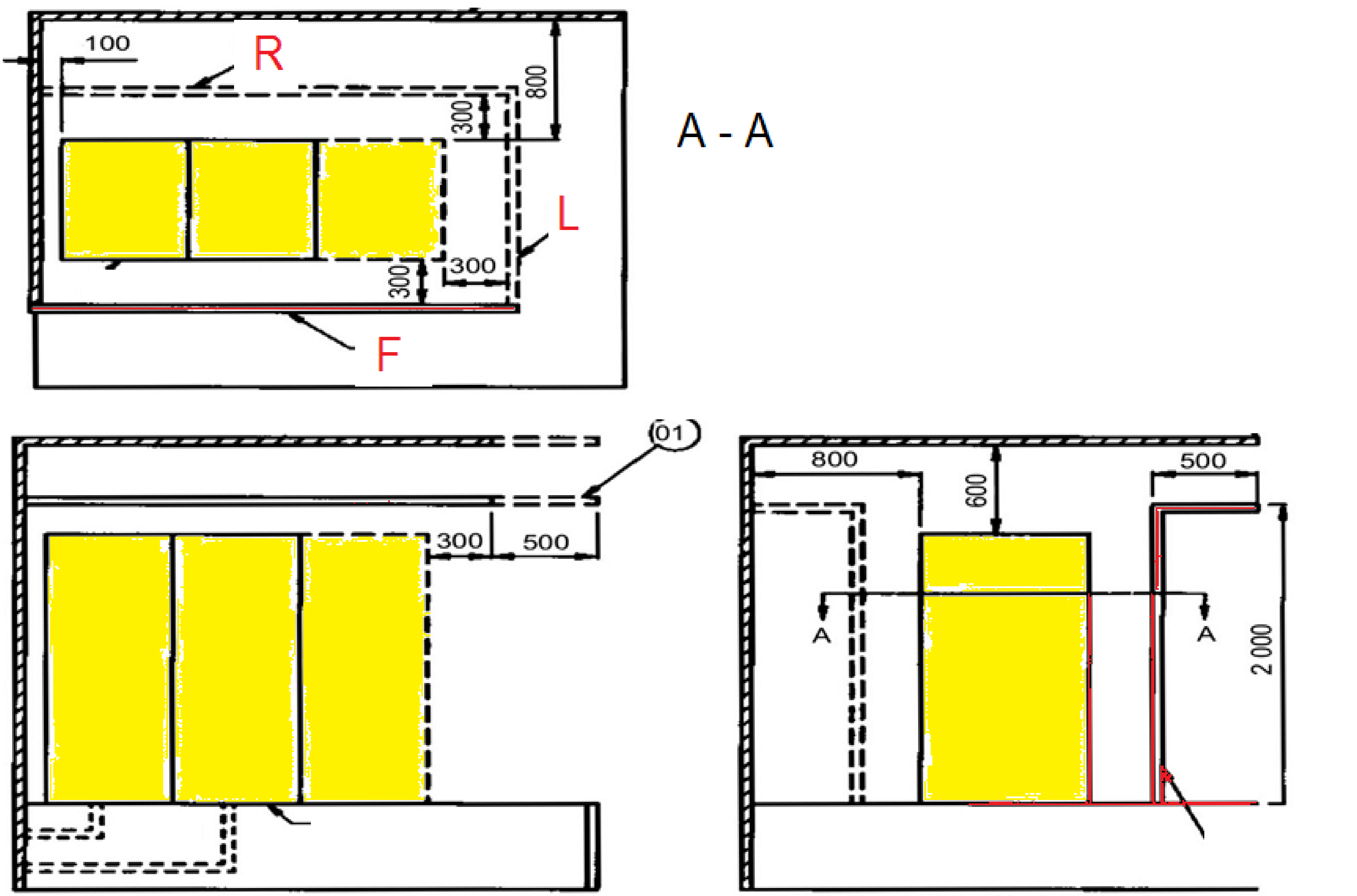
Example 2:
16 kArms - 1 s, tested as:

front: public accessibility
rear: restricted to operators
side: not accessible

Classification IAC BF-AR
Internal arc 16 kA 1 s.

Room simulation and indicators - accessibility A (h >1,5 m)

A - A



TECHNICAL STANDARDS FOR LOW VOLTAGE SWITCHGEAR

IEC 60439-1 (1999)

Low Voltage Switchgear and Controlgear
Part1 – Type tested and partially tested assemblies
(TTA and PTTA)

Séries January – 2009

IEC 61439 - Low-voltage switchgear and controlgear assemblies

Important change of concept with the DESIGN RULES (possibly the most advanced concept in any technical standard)

IEC 61439 STANDARDS SERIES

61439-1: General rules

61439-2: Power switchgear and controlgear assemblies

61439-3: Distribution boards

61439-4: Assemblies for construction sites

61439-5: Assemblies for power distribution

61439-6: Busbar trunking systems

IEC 61439 CONCEPTS

- Discrimination between "TTA" and "PTTA" replaced by the approach "verification"
- Word "tested" replaced by "verified"

- The design verification can be done by applying one or more of the following <u>alternative and equivalent</u> methods
  - Calculations and measurements
  - Validation of DESIGN RULES
  - Laboratory tests.

IEC 61439 DESIGN RULES

	Rule (T = temperature F = force P = pressure)	T	F	P
1	Short time current lower or equal to the tested one ?		x	x
2	Bus bar cross section lower or equal to the tested one ?	x		
3	Distance between phases greater or equal to the tested one ?	x	x	
4	Bus bar supports of same type and distance between insulators of same phase lower or equal ... ?		x	
5	Materials, mounting ... equal?	x	x	x
6	Short circuit devices are equivalent / same type and manufacturer ?			
7	Length of live conductor lower or equal ...?			
8	Compartments were included in the original tests ?	x	x	x
9	Compartments are of the same type and dimensions higher or equal ?	x		x
10	Compartments have the same mechanical conception ?	x		x

" YES : to all items NO TEST and NO CALCULATION
"NO to some of the rules then additional verification by calculations

Table 13 – Short-circuit verification by design rules: check list

Item No.	Requirements to be considered	YES	NO
1	Is the short-circuit withstand rating of each circuit of the ASSEMBLY to be assessed, less than or equal to, that of the reference design?		
2	Is the cross sectional dimensions of the busbars and connections of each circuit of the ASSEMBLY to be assessed, greater than or equal to, those of the reference design?		
3	Is the spacing of the busbars and connections of each circuit of the ASSEMBLY to be assessed, greater than or equal to, those of the reference design?		
4	Are the busbar supports of each circuit of the ASSEMBLY to be assessed of the same type, shape and material and have, the same or smaller spacing, along the length of the busbar as the reference design?		
5	Are the material and the material properties of the conductors of each circuit of the ASSEMBLY to be assessed the same as those of the reference design?		
6	Are the short-circuit protective devices of each circuit of the ASSEMBLY to be assessed equivalent, that is of the same make and series[a] with the same or better limitation characteristics (I^2t, I_{pk}) based on the device manufacturer's data, and with the same arrangement as the reference design?		
7	Is the length of unprotected live conductors, in accordance with 8.6.4, of each non-protected circuit of the ASSEMBLY to be assessed less than or equal to those of the reference design?		
8	If the ASSEMBLY to be assessed includes an enclosure, did the reference design include an enclosure when verified by test?		
9	Is the enclosure of the ASSEMBLY to be assessed of the same design, type and have at least the same dimensions to that of the reference design?		
10	Are the compartments of each circuit of the ASSEMBLY to be assessed of the same mechanical design and at least the same dimensions as those of the reference design?		
'YES' to all requirements – no further verification required. 'NO' to any one requirement – further verification is required, see 10.11.4 and 10.11.5.			

THE FUTURE IEC 62271-307 (medium / high voltage)

HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR :

Part 307 Guidance for the extension of validity of type tests

- This guide refers to …enclosed switchgear and controlgear assemblies for AC - > 1 kV and ≤ 52 kV as specified in 62271-200 and 62271-201

- Can be used for the extension of the validity of type tests performed on one sample with a defined set of ratings to another switchgear assembly of the same family with different set of ratings or different arrangements.

- It supports the selection of representative test samples composed of functional units of a family of switchgear aimed at the optimization of type tests in order to …. conformity assessment.

- Use sound technical and physical principles, industry experience and calculations to establish rules for various design and rating aspects.

10.1 - IEC 61439-1 (DESIGN VERIFICATION)

If the tests were made by IEC 60439, before the publication of the product standard of series IEC_61439 and the results met the requirements of IEC 61439 tests need not be repeated.

Assembly verified by the original manufacturer and made or assembled by another manufacturer does not require that checks be repeated (if the original manufacturer's requirements and instructions were followed).

Checking routine: in all assemblies

10.1 - IEC 61439-1 (DESIGN VERIFICATION)

CONSTRUCTION

- Checking the strength of materials and parts;
- Degree of protection of enclosure;
- Checking the creepage and sectioning distances
- Protection against electric shock ....
- Internal electrical circuits and connections;
- Terminals for external conductors.

PERFORMANCE:

•Dielectric properties;

•Verification of the temperature rise;

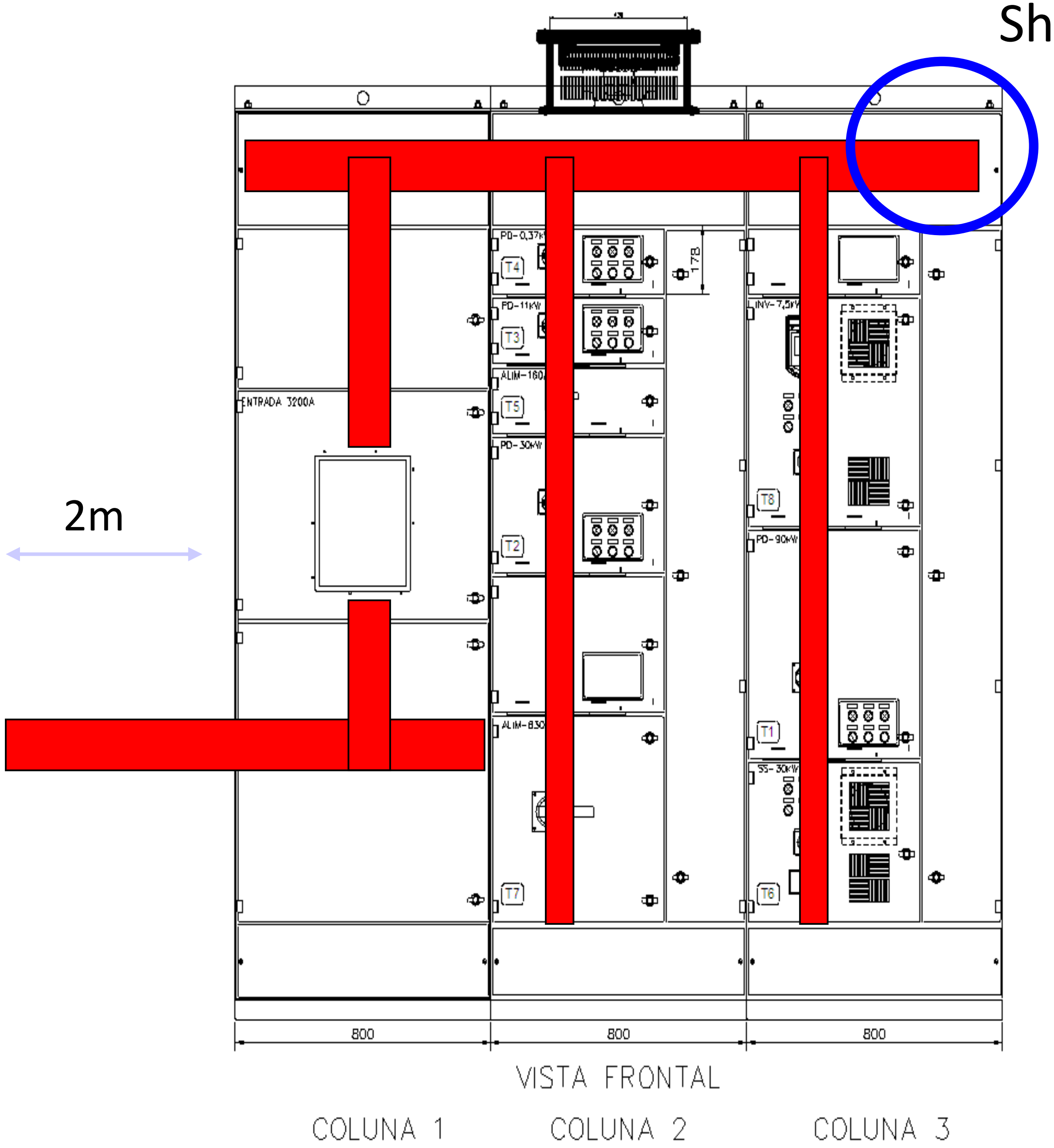
•Verification of the short circuit withstand current

•Electromagnetic compatibility;

•Mechanical operation.

TEMPERATURE RISE TEST

Short circuit point



Dissipated power simulated by resistors

IEC 62208 - Empty enclosures for low-voltage switchgear and controlgear assemblies - General requirement

6.3.1 General

The manufacturer's documentation shall include all relevant constructional, mechanical characteristics, the enclosure classification (see Clause 4) and any instruction necessary for the correct handling, assembling, mounting and service conditions of the enclosure as well as reference to this standard:

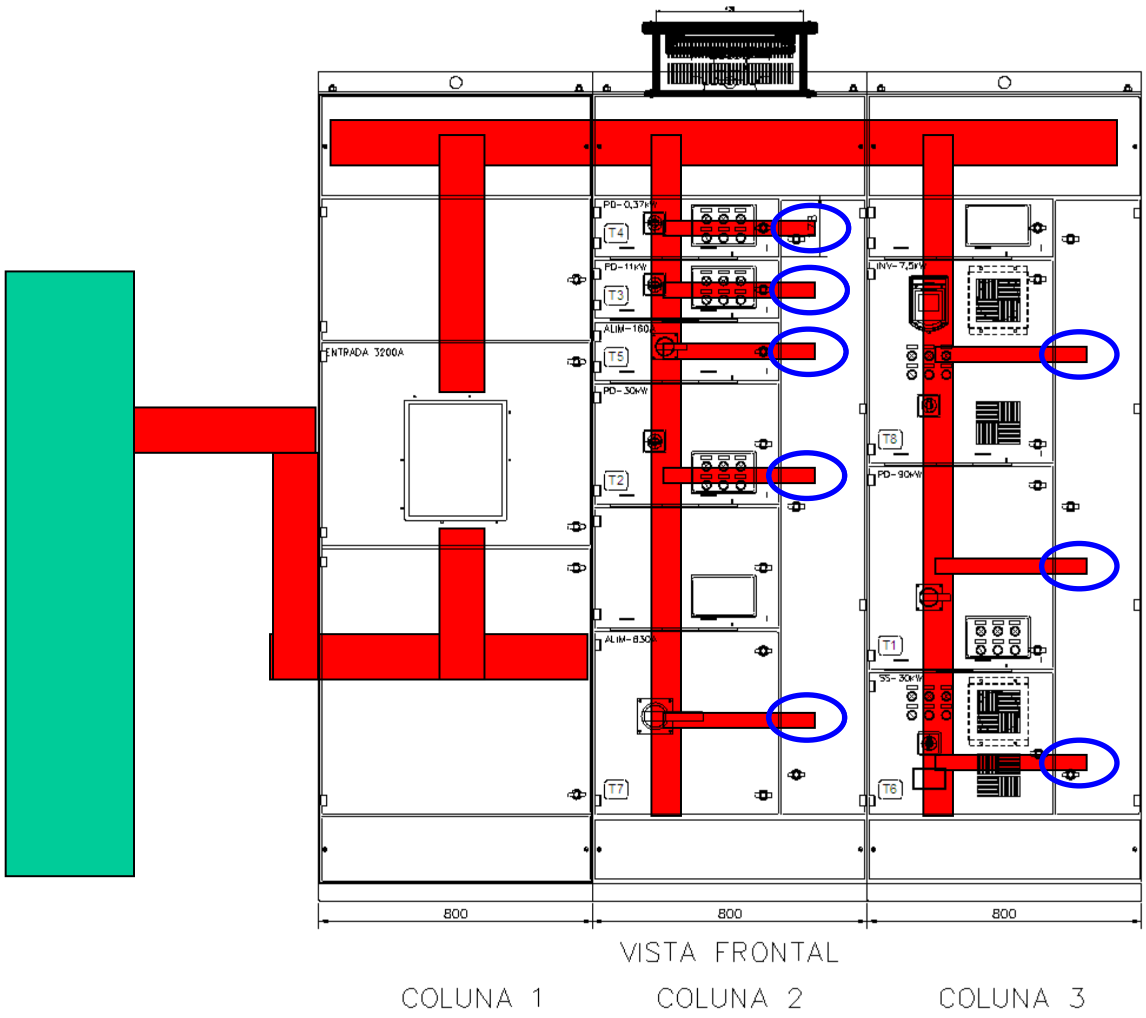
- dimensions (see 6.3.2);
- mounting arrangements (see 6.3.3);
- permissible loads (see 6.3.4);
- lifting devices, if necessary (see 6.3.5);
- provisions for protection against electric shock (see 6.3.6);
- applicable service conditions (see Clause 7);
- location and size of protected space;
- data of thermal power dissipation capability;
- rated insulation voltage of enclosures constructed of an insulating material;
- degree of protection (IK and IP codes, see 8.7 and 8.8).

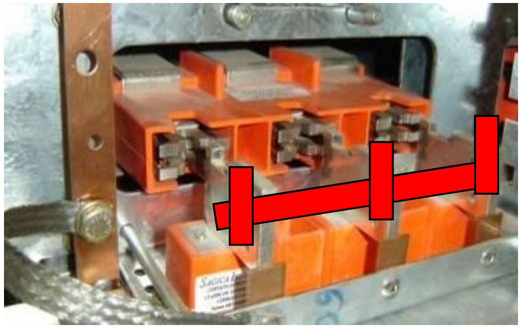
The data for the thermal power dissipation capability are a function of the admissible temperature inside the enclosure. They shall be provided for the different installation methods (e.g. flush mounting, surface mounting) of the enclosure and of the design of the enclosure, i.e. with or without ventilation openings and number of horizontal partitions. They shall include at least temperature rise inside the enclosure, at the top, and external surfaces temperature rise, for a given power loss inside the enclosure. This will provide the user with the correct data for the selection of the enclosure according to electrical equipment to be installed. For the purpose of the calculation, it is assumed that the heat generated by the selected equipment is distributed uniformly inside the protected space.

9.14 Thermal power dissipation capability

The thermal power dissipation data provided by the manufacturer (see 6.3.1) shall be determined by test in accordance with 10.10.4.2.2 of IEC 61439-1:2011, or by a calculation method, e.g. according to IEC/TR 60890.

SHORT CIRCUIT WITHSTAND CURRENT





Short circuit point 65kA – 380V – 60Hz

INTERNAL ARC IN LOW VOLTAGE ASSEMBLIES

- Same concept of testing medium voltage but no horizontal indicators
- To be informed by the manufacturer:

  Permissible current and arc duration (0.1 .... 0.5 s)
  or
  conditional short circuit current under arc

- 105% Vn test voltage
- Cotton indicators 300 mm
- Criteria for approval
- According to the IEC the interested part (and not the lab) decides the number of applications to perform (up to 5)

INTERNAL ARC CLASSIFICATION AND CRITERIA

(a) Protection to persons

- Do not open doors
- You can not throw parts and pieces
- No holes in the outer parts
- Do not burn vertical indicators
- Protective circuit of accessible parts is effective

(b) Protection to persons and to the equipment

- Arc restricted to the ignition area and do not propagate to others .

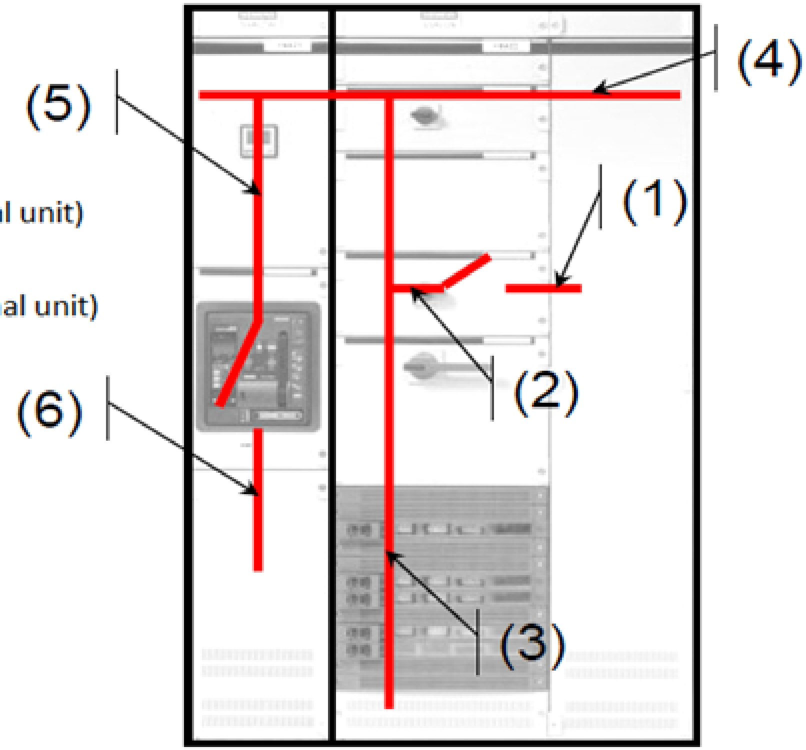
(c) After the arc is able to operate in a limited way.

- Dielectric test at 1,5 V x 1 min

Test implementation – ignition points

The following ignition points have to be considered in the test:

- (1) Load side of a feeder (outgoing functional unit)
- (2) supply side of a feeder (outgoing functional unit)
- (3) Along distribution busbars
- (4) Along main busbars
- (5) Load side of an incoming functional unit
- (6) supply side of an incoming functional unit

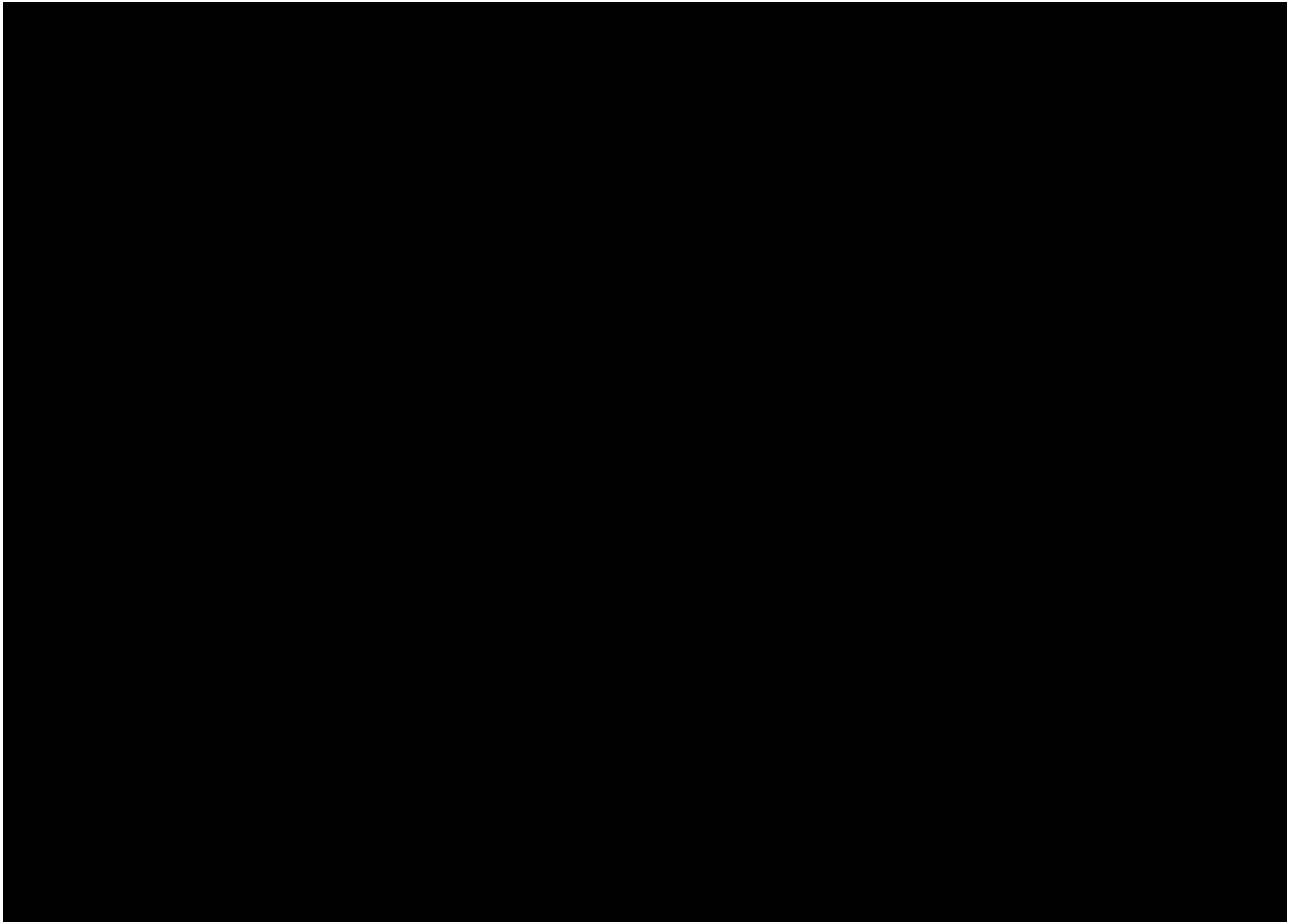


No test is required if these ignition points fulfill the criteria of an arcing-free zone. Insulation material must not be destroyed, removed or punctured during attachment of the ignition wire.

COMMENTS ON POINTS OF APPLICATION:
It is optional whether or not to leave the circuit breakers enabled. The most used are:

- Breaker input not enabled - between 5 and 4 (so really there is an arc. Some customers require even not actually happening)
- Breaker enabled in the drawer – between 1 and 2 - possibly will open and no arc. To use this feature you need to make an adjustment with 10 cycles (electrodynamical stress there and not only outside)
- More severe depending on the volumes : 2 and 5 volumes

MOVIE



END OF MODULE 6

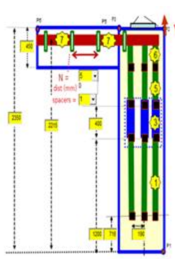
Reference materials for the courses

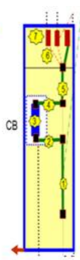
SWITCHGEAR, BUSWAYS & ISOLATORS

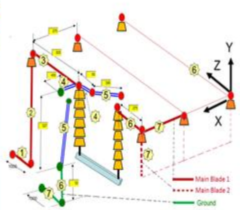
and

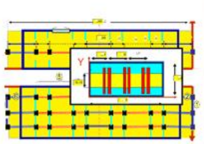
SUBSTATIONS AND LINES EQUIPMENT

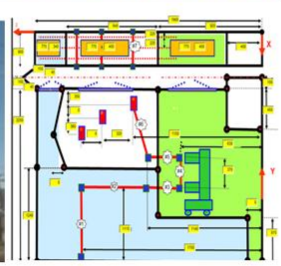
(focus in design techniques, specification, tests and simulations)











MODULE 7:

SIMULATION OF

HIGH POWER TESTS AND

THE USE OF THE SOFTWARE

SwitchgearDesign_307

Software developed by Sergio Feitoza Costa

Author of the software SwitchgearDesign_307

• Test engineer and manager of Brazilian high power, high voltage and other laboratories

• Chairman IEC -International Electro technical Commission –TC 32 - Fuses (1990-1994)

• Member WG A3.24 CIGRE International: Simulation .... Tools .

• Member WG IEC SC 17 C / WG31: Guidance for the extension of validity of type tests

of ac metal-enclosed switchgear and controlgear

•Switchgear design development and simulation software development

•Training for substations and equipment design.

•Design of testing laboratories including the new lab in Brazil

Contact data:
Sergio Feitoza Costa
Cognitor – Consultancy, R&D and Training
Phone : (55) (21) 2465
Skipe sergiofeitoza1 (we may speak in English, Portuguese, Spanish or French)
E-mail: sergiofeitoza@cognitor.com.br
Site: **http://www.cognitor.com.br**

Software *SwitchgearDesign_307*

The software was developed by Sergio Costa Feitoza over the past 14 years to help in his consulting work to develop equipment for substations (medium and low voltage) mainly PANELS, CUBICLES, BUSWAYS, BUS DUCTS, SWITCHES, ISOLATORS, DISCONNECTORS, CCM's (including the previously named TTA / PTTA).

It is mainly applicable to products of the standards **IEC 62271** , **IEC 61439** and the related national standards

THE SOFTWARE ALLOWS SIMULATING THE FOLLOWING TESTS AND MEASUREMENTS**:**

- Short time and crest withstand current (electrodynamical stress, mechanical stress).
- Temperature rise tests.
- Internal arc test (calculation of overpressure, burnthrough and supportability)
- Mapping of electric and magnetic fields (coming soon)

Software *SwitchgearDesign_307*

It is a unique tool (search the Internet and try to find any) and it was not designed for commercial purposes. The goal is to allow small and medium manufacturers, with limited access to testing laboratories, to perform virtual testing to develop their products before going to a testing laboratory for getting an expensive type test report which can be used for commercialization.

For designers who go through the, they learn to use the software and, much more than this, to better understand the design concepts and technical standards. The tool greatly reduces the time and cost of product development. The software was designed to be as simple as possible, based on the experience of Sergio of more than 25 years in testing and design of equipment and testing laboratories. Joined is also a long time experience in the participation in IEC and CIGRE working groups and committees.

Through simulations of these tests that, when performed in laboratories, are costly and time consuming, a company can develop the equipment using less copper and aluminum, less insulators and other items that lead to a more economical, safe and competitive product design.

VERSIONS:

The software is available in three versions shown in Table 1. The ideal is the "Version Distributed in the Course" that is received by the participants of the training. With the direct explanation by the software developer the use is easier.

The "Version sent via Internet" was developed as an option for those who want to evaluate the software without first attending the training. It is expected that even without training, it is possible for a designer with some experience using most of the features in this release.

There is also a "Free Demo Version" which seeks to allow the applicant to assess whether it would be able to use alone ,before a training, the "Version sent via Internet"

Table 1: Versions of the software *SwitchgearDesign_307*

Features of this version	Version " Demo"	Version "Sent via Internet"	Version "Distributed in the Course"
Simulation of temperature rise test	Yes	Yes	Yes
Simulation of electrodynamical forces (short circuit tests)	Yes	Yes	Yes
Simulation of internal arc test	Yes	Yes	Yes
3D geometry visualization	Yes	No	Yes
Mapping of magnetic field	No	No	Yes
Module MVSW1 (medium voltage cubicle)	Yes	Just one executable exe file for each specific module sent separately (you chose one of MVSW1, LVSW_1, LVSW_2, DUCT_1 or SWITCH)	A single executable exe file including all the 4 types / modules MVSW1, LVSW_1, LVSW_2, DUCT_1, e SWITCH
Modules LVSW1 e LVSW2 (low voltage cubicle)	Yes		
Module DUCT_1 (busways)	Yes		
Module SWITCH (isolators / disconnectors)	Yes		
Module FUSE_1 (expulsion type fuses)	No		No
Database and possibilities to modify, save and create new cases.	Only one case per each module and type which cannot be modified or saved as another	Up to 10 cases for each type or module. You can change and save the changes in each of the 10 cases, but not create additional cases, eg to stay with 15 cases instead of 10.	Comes with some cases for each module and you can create as many more as you wish. In general, along the daily use of a designer, it is not necessary to create more than about 10 cases per module
TWO DAYS TRAINING IN an OPEN COURSE	No	No	Yes
Customized software including physical arrangements and other cases not included in the above versions.	Under request	Under request	Under request

TRAINING PROGRAM Read the program at http://www.cognitor.com.br/SoftwareEN.pdf

DIDATIC MATERIAL FOR THE COURSE

A free and complete version of the course (in English) can be downloaded at http://www.cognitor.com.br/BookSwitchgearEN.pdf

The versions in Portuguese or Spanish are distributed only to the participants of the course. The teaching material in this book includes the following chapters or **modules**

1. Studies Which Are The Base of the Technical Specifications
2. Overvoltages and Insulation Coordination
3. Short Circuits, Ampacities, Overloads and Electrical Contacts.
    - Temperature Rise
    - Forces and Electrodynamical Forces during Short Circuit.
    - Transient Recovery Voltages and Interruption Processes
4. Power Arcs and Safety of Persons and Installations
5. Technical Specifications Issued By Power Utilities
6. Medium Voltage and Low Voltage Switchgear Standards (IEC_62271-200 and IEC 61439)
7. Simulation Of High Power Tests and Use Of The Software SwitchgearDesign_307

INSTRUCTIONS FOR USE OF SOFTWARE

The instructions for using the software are formed mainly by Module 7.

TERMS OF USE AND VALIDATION SOFTWARE

Due to the complexity of the calculations and number of variables involved the ideal situation is that you have attended the course to be better able to interpret specific results and how these results relate to the specifications included in the technical standards. Cognitor applies a training course for use of the software (open course or "In Company"). This training can be applied in English or Portuguese or Spanish..

Regarding the **RESPONSIBILITY FOR THE RESULTS**, the program can be used for the account and risk of the user and neither the author of the software nor Cognitor are responsible for any uses or results that may be given to the results obtained.

Regarding the VALIDATION OF RESULTS some of the cases that come with the software relate to tests effectively performed in testing laboratories. These “validated cases" are shown in several articles published by the author of the software that can be downloaded on the website http://www.cognitor.com.br .

The difficulties of obtaining more information for validation of results are mainly due to certain deficiencies and omissions in the current editions of some technical standards regarding the information that should be included in test reports issued by laboratories but are not included.

The article “VALIDATION OF TEST REPORTS ISSUED BY RECOGNIZED TESTING LABORATORIES” published in the magazine “O Setor Eletrico - Issue 82 - November 2012” and available here on http://www.cognitor.com.br/ValidatingReports_Eng.pdf shows details of these aspects

SIMULATIONS OF HIGH POWER TESTS AND USE OF SOFTWARE

- State of the art of the use of simulations to replace some laboratory tests
- Screens and how to use the software *SwitchgearDesign_307*
- Simulation of short-time withstand current and peak tests (calculation of electrodynamical forces, mechanical stresses and how to optimize a design)
- Simulation of temperature rise / heating tests (calculations and how to optimize the design)
- Simulation of internal arc tests (overpressures, burn-through and supportability)
- Case studies with the software.

STATE OF THE ART OF THE USE OF SIMULATIONS TO REPLACE some LABORATORY TESTS

- Simulation and calculation techniques can be used to foreseen testing results at low cost.

- Examples of applications are the internal arc tests in medium and low voltage switchgear (performance under overpressures), short-time and peak withstand current tests (electrodynamical and thermal stresses) and temperature rise tests.

- This was not easy to do 25 years ago but now it is easy and many manufacturers do it.

- Within limits, testing simulation may be used to extrapolate or even to replace results of an already done laboratory test to other similar, but not equal, equipment.

IEC 60076 - Power Transformers (short circuit tests)

Previous LV switchgear IEC 60439 : all type tests (TTA) or tests + calculations (PTTA)

IEC 61439 (3 alternative and equivalent methods for design verification)

- **TESTS:** original manufacturer do all the type tests.
- If untested equipment follow the instructions of the original manufacturer and attend all the **"DESIGN RULES"** no need to test (declarations)
- If some rules are not attended there is a possibility for **CALCULATIONS** (temperature rise and electro dynamical forces)

Design rules IEC 61439

	Rule (T = temperature F = force P = pressure)	T	F	P
1	Short time current lower or equal to the tested one ?		x	x
2	Bus bar cross section lower or equal to the tested one ?	x		
3	Distance between phases greater or equal to the tested one ?	x	x	
4	Bus bar supports of same type and distance between insulators of same phase lower or equal ... ?		x	
5	Materials, mounting ... equal?	x	x	x
6	Short circuit devices are equivalent / same type and manufacturer ?			
7	Length of live conductor lower or equal ...?			
8	Compartments were included in the original tests ?	x	x	x
9	Compartments are of the same type and dimensions higher or equal ?	x		x
10	Compartments have the same mechanical conception ?	x		x

" YES : to all items NO TEST and NO CALCULATION
"NO to some of the rules then additional verification by calculations

STATE OF THE ART OF THE USE OF SIMULATIONS TO REPLACE some LABORATORY TESTS

- The working group CIGRE WG A3. 24 - Tools for Simulating Internal Arc and Current Withstand Testing is working with this theme.

- Recognizing an increasing role of commercial modelling software in the power industry, SCA3 decided to evaluate existing simulation tools to determine to which extent they can be used as verification tools.

- WG A3.20 concluded that simulation is an excellent and instructive tool in particular in the development process.

- Good prediction of performance can often be possible in cases where performance is proven by tests on similar designs (interpolation).

- Extrapolation of test results and performance prediction of "new" equipment designs seems to be possible in some cases.

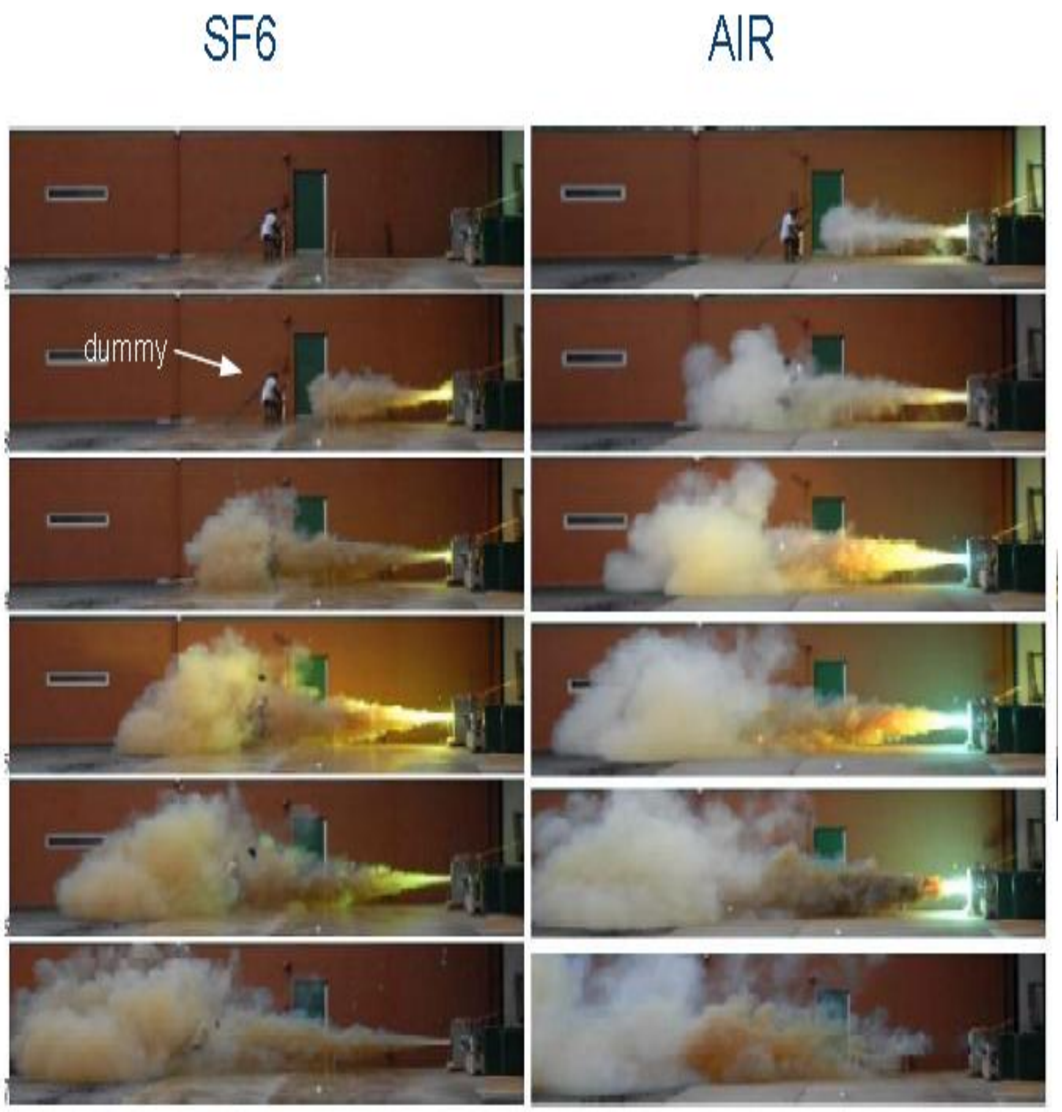
- "Brochure Internal Arcs" group CIGRE WG A3-24 - 2013

CIGRÈ WG A3. 24 : TOOLS FOR SIMULATING INTERNAL ARC AND CURRENT WITHSTAND TESTING

•Simulations to predict the results of internal arc tests on SF6 equipment if SF6 is replaced with air.

•Reason: environmental reasons, tests release SF6 to the environment

•Use of simulations to reduce the number of internal arc tests



CIGRÈ WG A3. 24 : **Brochure TOOLS FOR SIMULATION OF PRESSURE RISE DUE TO INTERNAL ARC IN MV AND HV SWITCHGEAR**

Name	First Name	Country	Company
del Rio	Luis	Spain	ORMAZABAL CORPORATE T
Douchin	Jerome	France	Schneider Electric
Dullni	Edgar	Germany	ABB
Feitoza Costa	Sergio	Brazil	Cognitor
Fjeld	Elin	Norway	Telemark University
Glinkowski	Mietek	USA	ABB
Kim	Hong-Kyu	Korea	KERI
Kriegel	Martin	Switzerland	Axpo
Lopez-Roldan	Jose	Australia	Powerlink
Pater	Ryszard	Canada	Hydro-Québec
Pietsch	Gerhard	Germany	RWTH Aachen
Reiher	Thomas	Germany	Siemens
Robin-Jouan	Phillipe	France	Areva
Schoonenberg	Gerard	Netherlands	Eaton
Smeets	Rene	Netherlands	KEMA
Uchii	Toshiyuki (Tc	Japan	Toshiba
Uzelac	Nenad	USA	G&W
Van der Sluis	Lou	Netherlands	TU Delft
Vinson	Paul	France	Areva
Yoshida	Daisuke	Japan	Mitsubishi Electric Corportion

Paper presented in the CIGRE / Paris August 2008

21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

A3-210

CIGRE 2008

SIMULATIONS AND CALCULATIONS AS VERIFICATION TOOLS FOR DESIGN AND PERFORMANCE OF HIGH-VOLTAGE EQUIPMENT

M. KRIEGEL, X. ZHU, H. DIGARD, S. FEITOZA, M. GLINKOWSKI, A. GRUND, H.K. KIM, J. LOPEZ-ROLDAN, P. ROBIN-JOUAN, L. VAN DER SLUIS, R.P.P. SMEETS, T. UCHII, D. YOSHIDA

Cigré WG A3-20

Paper presented in the CIGRE / Rio de Janeiro – Brazil 2007

CIGRÉ INTERNATIONAL TECHNICAL COLLOQUIUM
SEPTEMBER 12 th-13th, 2007
RIO DE JANEIRO - BRAZIL

CFD, IEC STANDARDS AND TESTING LABORATORIES: JOINING THE PIECES FOR HIGHER QUALITY HV EQUIPMENT.

Author name:	Affiliation:
Sergio Feitoza Costa	Cognitor – Consultancy, Research and Training Ltd.

C_I_G_R_E___P_o_s_t_CIGRE POST 2012e_Paris__2012

TOOLS FOR THE SIMULATION OF PRESSURE RISE DUE TO INTERNAL ARC IN MV AND HV SWITCHGEAR
N. Uzelac, Convenor (US) M. Glinkowski, Secretary, (US), L. del Rio (ES), J. Douchin (FR), E. Dullni (DE), S. Feitoza Costa (BR), E. Fjeld (FI), M. Glinkovski (US), K. Hong-Kyu (KR), M. Kriegel (CH), J. Lopez-Roldan (AU), R. Pater (CA), G. Pietsch (DE), T. Reiher (DE), G. Schoonenberg (NL), S. Singh (FR), R. Smeets (NL), T. Uchii (JP), L. Van der Sluis (NL), P. Vinson (FR), Y. Daisuke (JP)

http://www.cognitor.com.br/Pos_Ter_2012.pdf

Some articles here

http://www.cognitor.com.br/en_download.htm

CIGRE Technical Seminar

Modelling and Testing of Transmission and Distribution Switchgear

ENGINEERS AUSTRALIA

March 24, 2010 BRISBANE - AUSTRALIA

VALIDATION OF SIMULATIONS OF ELECTRODYNAMICAL FORCES, TEMPERATURE-RISE AND INTERNAL ARC TESTS IN SWITCHGEAR

(and main parts of a code to do them)

Author name:
Sergio Feitoza Costa

Affiliation:
COGNITOR – Consultancy, Research and Training Ltd.

Email: sergiofeitoza@cognitor.com.br Site : www.cognitor.com.br

Standards development > How we work > Technical Committees & Subcommittees > TC 17 > SC 17C > WG 31

SC 17C High-voltage switchgear and controlgear assemblies

Scope | Structure | Projects / Publications | Documents | Votes | Meetings | Collaboration Tools

Working Groups > TC 17/SC 17C/WG 31

Log in En Fr

WG 31 Convenor & Members

Convenor	National Committee
Mr Edgar Dullni	DE

Member	National Committee
Mr Michael Adams	GB
Mr Marc Arens	BE
Mr Eldridge Byron	US
Mr Sergio Feitoza Costa	BR
Mr Didier Fulchiron	FR
Mr Samuel Griot	FR
Mr Martin Grote	DE
Mr José Manuel Inchausti	ES
Mr Neil Keeler	GB
Mr Matthias Kluge	DE
Mr M. Lusing	NL
Mr Rafael Muñoz LópezVillalta	ES
Mr Osvaldo Prestini	IT
Mr Alberto Sironi	IT
Mr David T Stone	US
Mr R Sait Sulluoglu	TR

Title & Task

WG 31

IEC/TS 62271-307: Guidance for the extension of validity of type tests

To develop a guide which is applicable to factory-assembled metal-enclosed switchgear and controlgear for alternating current of rated voltages above 1 kV and <= 52 kV and equipment included in the same enclosure with any possible mutual influence.

To enable the acceptance of calculations , by users, it is needed to have in some IEC document

GUIDELINES FOR THE USE OF SIMULATIONS AND CALCULATIONS
(An idea prepared by Sergio Feitoza Costa)

Complete text of the guide in
http://www.cognitor.com.br/GUIDE_Simulations_v0_October2010.pdf

explained in the article
http://www.cognitor.com.br/Article_Competitivity_Eng_04102011.pdf)

Complete suggestion formally sent to the Brazilian National Association Committee in April 2011.

Support of more than 20 companies interested in participating in the working group (15 equipment manufacturers, mostly high and low voltage switchgear, testing laboratories, certification bodies, utilities and users).

Part of the presentation done by Sergio Feitoza Costa in the meeting of the IEC working group WG 31 / SC 17C held in Brussels -October 9-10, 2012

GUIDELINES FOR THE USE OF SIMULATIONS AND CALCULATIONS

2.2) SCOPE OF THE GUIDELINES

Guidelines for systematization of the use of simulations and calculations used to replace some laboratory tests in situations where the common sense shows it is reasonable to use it.

The use of simulations to replace tests **is possible only when certain specific measurements and registers are specified in the relevant product standards and are presented in the laboratory test report.**

This Guide specifies minimum measurements and photographic registers that shall be done and registered in test reports, during laboratory tests specified in product standards.

It is not an objective of this Guide to present calculation methods for testing simulation.

A model or method is acceptable when it produces validated simulation results within acceptable tolerances when compared with the real test results and this can be demonstrated in a transparent way.

Type of test	Parameter to compare	Typical values of acceptable tolerance for the calculated values
Temperature rise test	Temperature rise in solid and fluid parts	1% to 5%
Internal arc test	Overpressure in the enclosure above the atmospheric pressure (crest and duration)	5% to 10%
Short-time withstand current and peak withstand current tests	Electrodynamical forces and mechanical stresses	5% to 15%

DEFINITIONS

2.3.3 - Reproducibility of a simulation or calculation method

The capability of to obtain, for a specified set of input data the same test results or the same simulation results in two ore more different occasions or two different test laboratories.

2.3.4 - Validation of a simulation /calculation method or a laboratory test report

A method of comparison between the results showed in a well-documented test report issued at a test laboratory and the results of a simulation method.
A simulation method is generally acceptable, from the point of view of users, when it is reproducible and gives a difference between simulation and laboratory results not higher than a certain acceptable tolerance.

2.3.5 - Data to register in temperature rise test reports

- . the circulating electric current,
- the total power dissipation inside the fluid compartment
- the materials used in the conductor and insulating parts
- the contact resistances and its coatings (total per phase and also the ones of the individual parts like circuit breakers, fuses , isolators)
- the ambient gas or liquid fluid temperature (at the bottom , top and 50% of the height of the enclosure),
- the fluid velocity
- the geometry and spatial position of the conductors
- the volume of fluid inside the compartments
- The input and output areas for ventilation
- The number of horizontal partitions inside the enclosure
- The relative position of the equipment in relation to walls, ceiling and neighbor equipment (as presented in IEC 60890)

3.6 - Data to register in internal arc tests laboratory test reports

The curve overpressure x time is the main performance indicator.

The data affecting the test and the simulations results :

- the circulating electric current,
- the materials used in the conductor and insulating parts
- the geometry and spatial position of the conductors
- the volume of fluid inside the compartments
- The input and output areas for ventilation and devices to close it during the arc
- The areas for pressure relief after the arc
- The relative position of the equipment in relation to walls and ceiling

- The measurement of the internal overpressure along the test should be registered.

2.3.6 - Data to be registered in short-time withstand current and peak withstand current test report

The objective of the test is to verify the supportability to the effects of electrodynamical forces on insulators and conductors occurring during a short circuit without arc. The verification is done by visual inspection and measurement of the resistances per phase.

The data affecting the test and the simulations results

- The circulating electric current,
- The materials used in the conductor and insulating parts.
- The mechanical resistances of the insulators to compression, traction and flexion
- The geometry and spatial position of the conductors
- The measurement of the total per phase and partial electrical contacts resistances, before and after the test, shall be registered in laboratory test report.
- If visible permanent deformations are noted after test, they shall be registered by photos and an estimate of the maximum deformation

Question: Is it possible to include some "indications" for measurements and information to register in the test report in an annex called in Section 4.3 (documentation) ?

EXPLANATION ABOUT THE SOFTWARE

SwitchgearDesign_307

- Screen for input data and geometry
- Screen for the presentation of the results

SCREENS AND SPECIFIC APPLICATIONS FOR :

- Busways
- Low and medium voltage switchgear
- Isolators
- High voltage fuses (not included in this course)
- Power transformers (not included in this course)

INSTALLATION, BUGS and SIMILAR

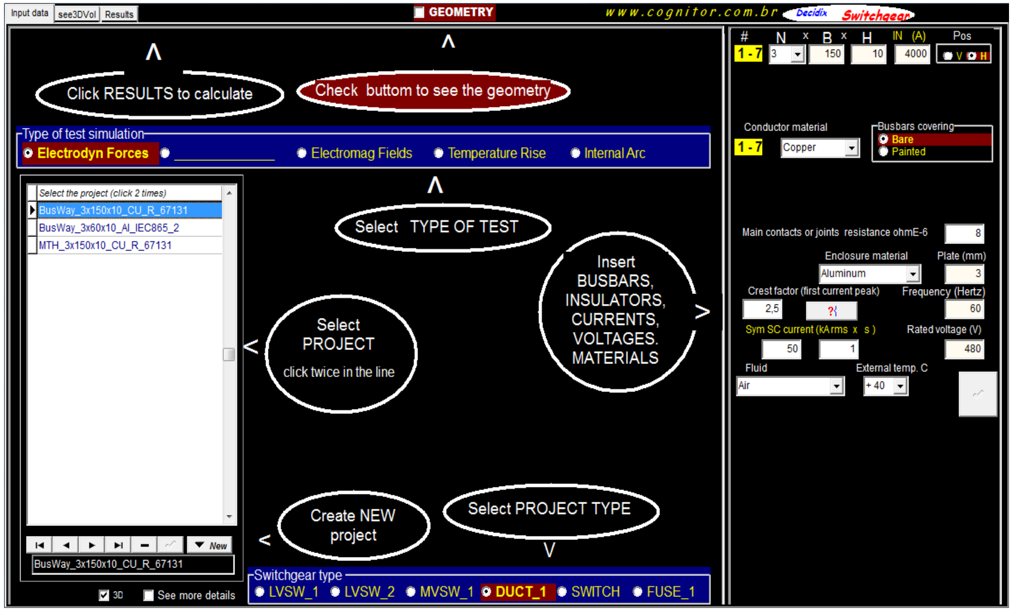
- After having the installation file (file size is approximately 4XXX MB) save it in some directory of your computer.
- To install SwitchgearDesign_307 just click on the file and give OK to all the questions.
- The installer will create in your computer only one directory named c://SergioFeitoza (if does it not still have one)
- If it was not created please create a short cut in the desktop for the file C:\SergioFeitoza\SwitchgearDesign.exe
- The *.exe file , the tables with the database and all the few files will be installed in this directory and its subdirectories. No other file or directory will be created anywhere
- It is not expected to occur but if you have any problems with the installation please send me an email from your private email to the email sergiofeitoza@cognitor.com.br informing what happened.

INSTALLATION, BUGS and SIMILAR

- Please do not use the LinkedIn group for technical questions or installation doubts
- Instead of this write from your private email to sergiofeitoza@cognitor.com.br
- Please identify yourself to enable us to know who you are, if you got the “version via Internet” or already participated in the course.
- As we are just starting to distribute the software it is expected that some minor problems may arise.
- We are not referring to calculation problems but minor operational problems that we can see only that many people start to use the software.
- For each one we will do the best to correct quickly sending you a new installer with the problem solved.

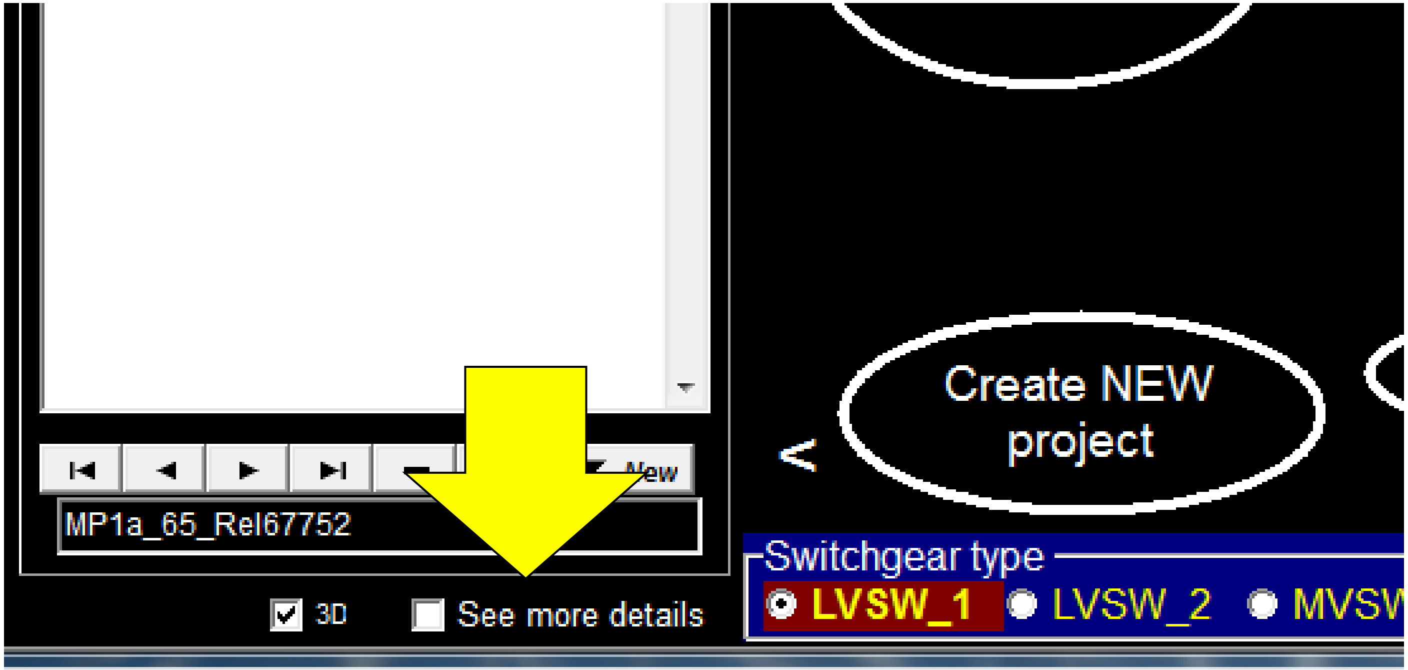
STARTING TO USE THE SOFTWARE

- After the software is installed click on the icon and the next page screen will open
- First of all , before starting to click everything , let´s understand the possibilities of selections in this page .
- If you do this and follow the step by step it will be easy.



STARTING TO USE THE SOFTWARE

- If you did not have yet the training, in the initial moment, do not check the box " See more details" in the lower left side. If you check some screens will be more confusing because will show refinements details only useful in special cases.



INITIAL SCREEN

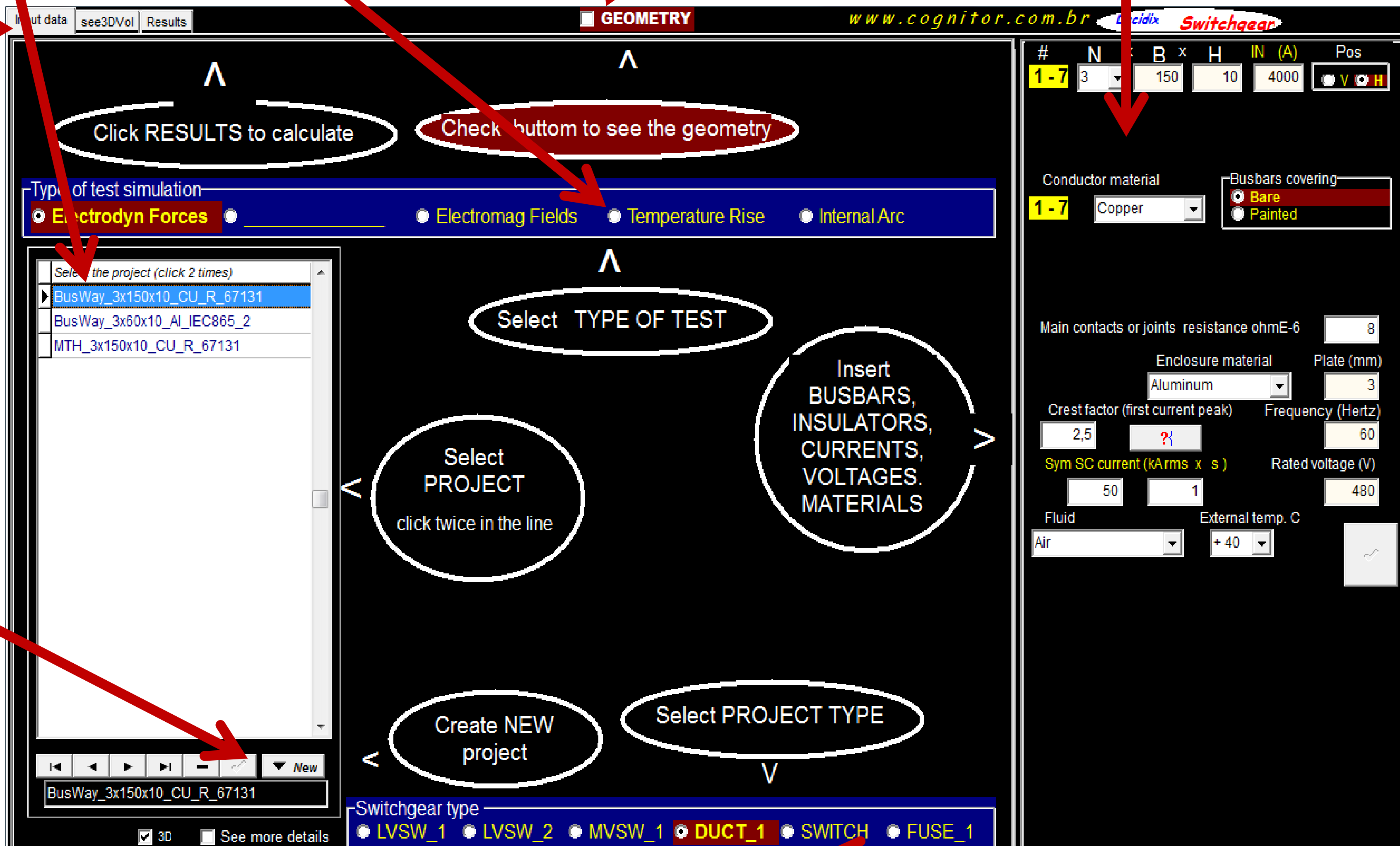
Project selected

Type of test to be simulated

Click here to see the geometry related to the PROJECT TYPE (type of equipment)

Data of the selected project(blue line in the left side)

Click INPUT DATA to change the data or click RESULTS to do the calculations and to see the test results



Click the button NEW to create a new project equal to the one which is selected (only the name is different) and them change the data and geometry

Type of equipment project to be simulated (LVSW 1 &2 = Low Voltage switchgear, MVSW1 – Medium Voltage Switchgear DUCT_1 = bus way , SWITCH = isolator)

STARTING TO USE THE SOFTWARE

- The first possibility of selection is the box SWITCHGEAR TYPE which represents the "Type of equipment project to be simulated" and is in the bottom of the page.
- Select the option LVSW1 and after click (check) the box GEOMETRY in the top of the page

- A figure will appear showing the Circuit Breaker incoming column of a low voltage switchgear. There you can see the dimensions which enable you to change the geometry and many other data.
- Uncheck the box GEOMETRY and the figure will disappear showing again the original screen.
- Do the same with the other options LVSW2, MVSW1, DUCT1, SWITCH and FUSE_1. In the next page we describe them.

Explanation about the software SwitchgearDesign_307

- **LVSW1**: Circuit breaker column of a low voltage switchgear.
- **LVSW2**: Drawers column of a low voltage switchgear.
- **MVSW1**: Medium voltage switchgear with CB, cables and busbar compartments.
- **DUCT_1**: Bus way or bus duct (low voltage or medium voltage)
- **SWITCH**: Isolator or disconnector
- **FUSE_1**: Expulsion type fuse

- Becoming more used with the GEOMETRY figures you will see that you may create any imaginable design
- After some time of use you will see that this input data is the relevant. There are design aspects that have very small impact in the overall results. Examples are if the corners of the bars are rounded or not and the color of the painting of the busbar.
- By the other side there are design aspects that influence so much in the results and even the technical standards do not specify their importance properly. Examples are the ventilation area and the resistance per phase of the switching devices.
- Simulations enable the designer to see things which would be impossible to detect because would need hundreds of expensive tests.

COGNITOR

INITIAL SCREEN

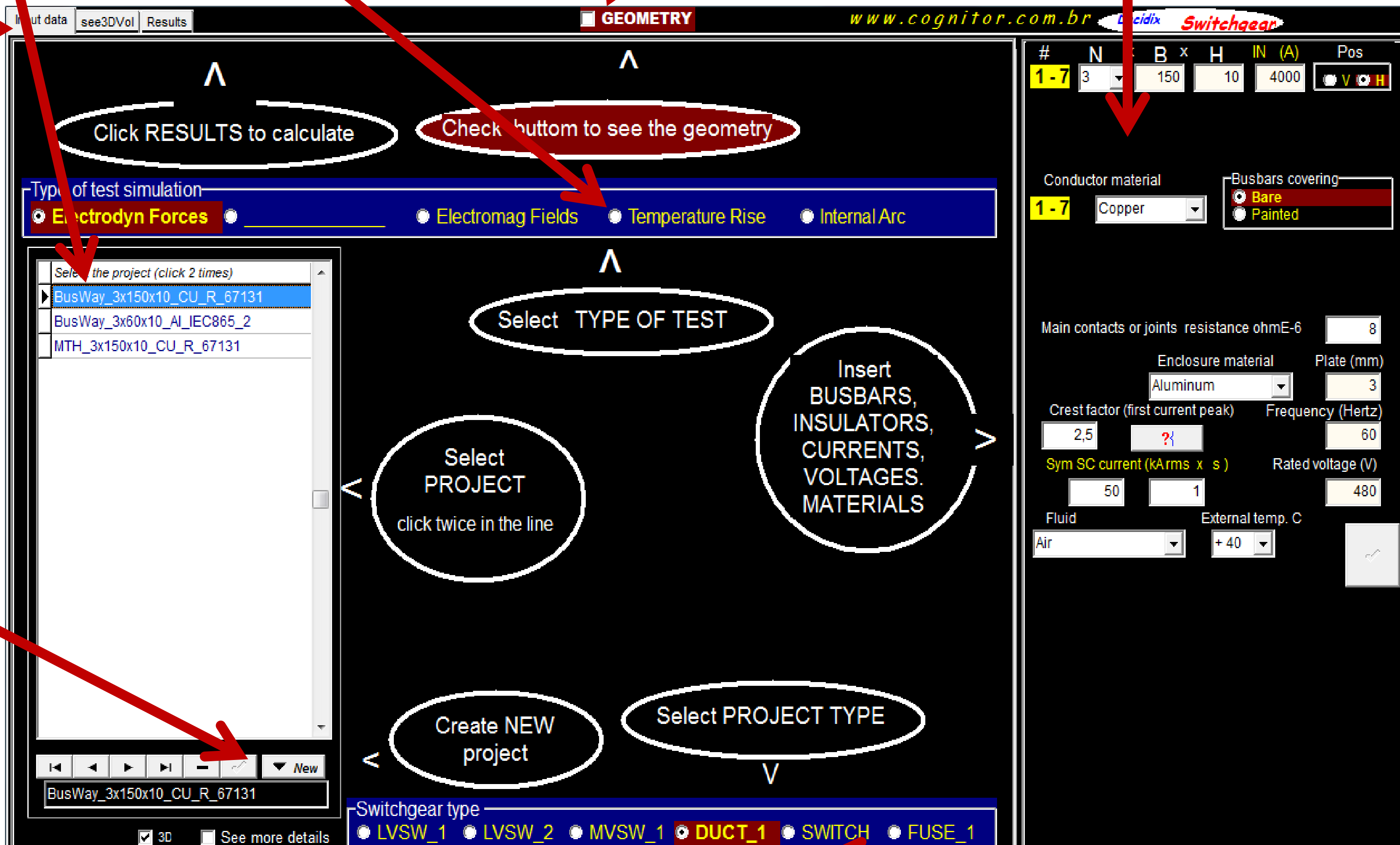
Type of test to be simulated

Project selected

Click here to see the geometry related to the PROJECT TYPE (type of equipment)

Data of the selected project(blue line in the left side)

Click INPUT DATA to change the data or click RESULTS to do the calculations and to see the test results



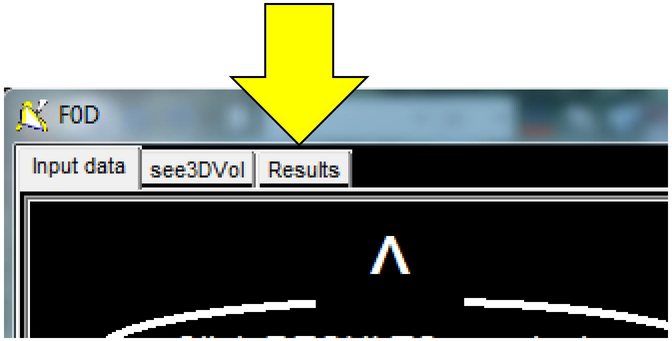
Click the button NEW to create a new project equal to the one which is selected (only the name is different) and them change the data and geometry

Type of equipment project to be simulated (LVSW 1 &2 = Low Voltage switchgear, MVSW1 – Medium Voltage Switchgear DUCT_1 = bus way , SWITCH = isolator)

COGNITOR

- The second possibility of selection is the box **TYPE OF TEST SIMULATION**

- When you select an option that will be the calculation which will be done and whose RESULTS will be shown in a new screen when you click in the tab **Results** in the top – left side of the page



- The option Eletromagnetic fields will be operational soon. We are still completing it.

INITIAL SCREEN

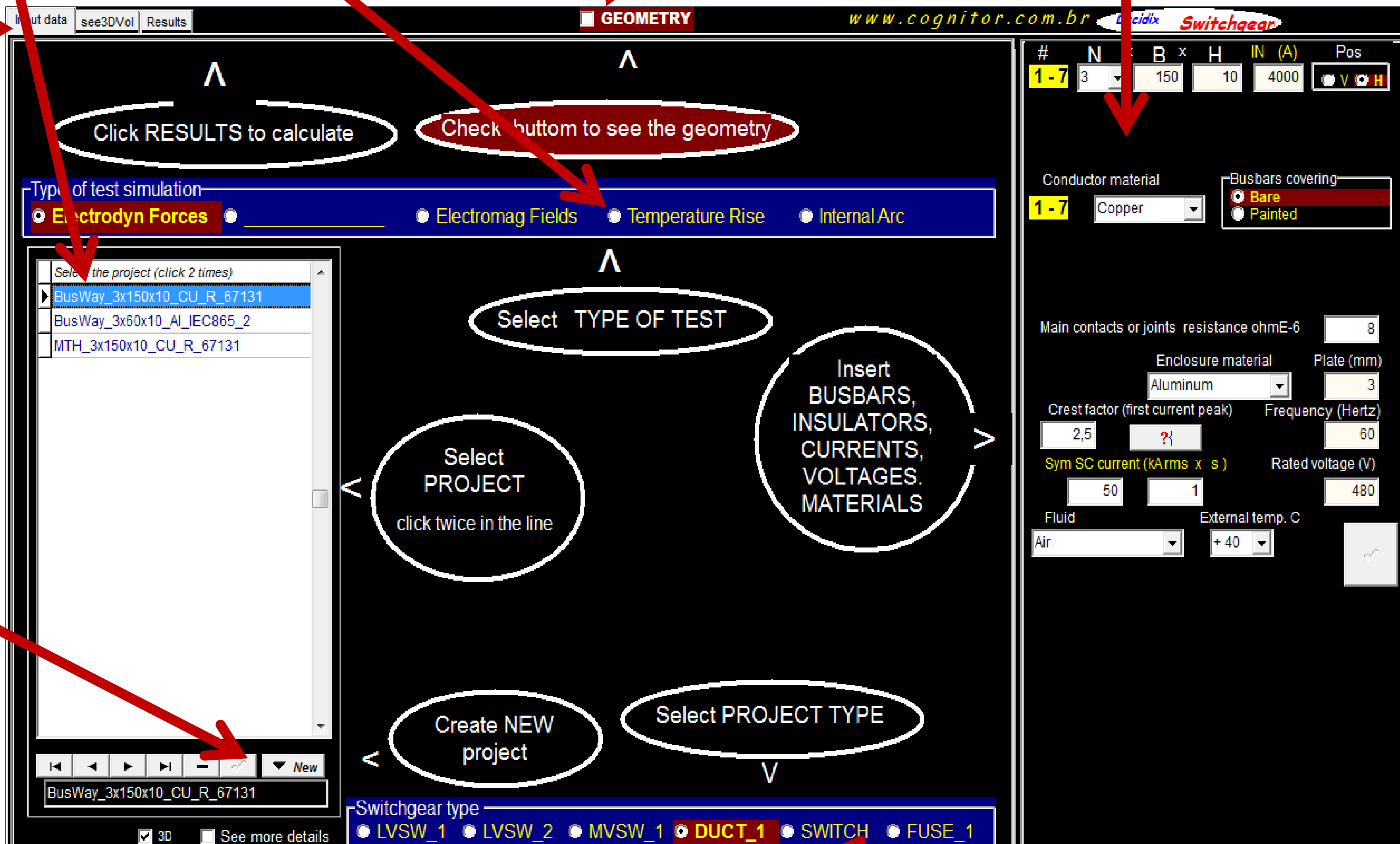
Project selected

Type of test to be simulated

Click here to see the geometry related to the PROJECT TYPE (type of equipment)

Data of the selected project(blue line in the left side)

Click INPUT DATA to change the data or click RESULTS to do the calculations and to see the test results

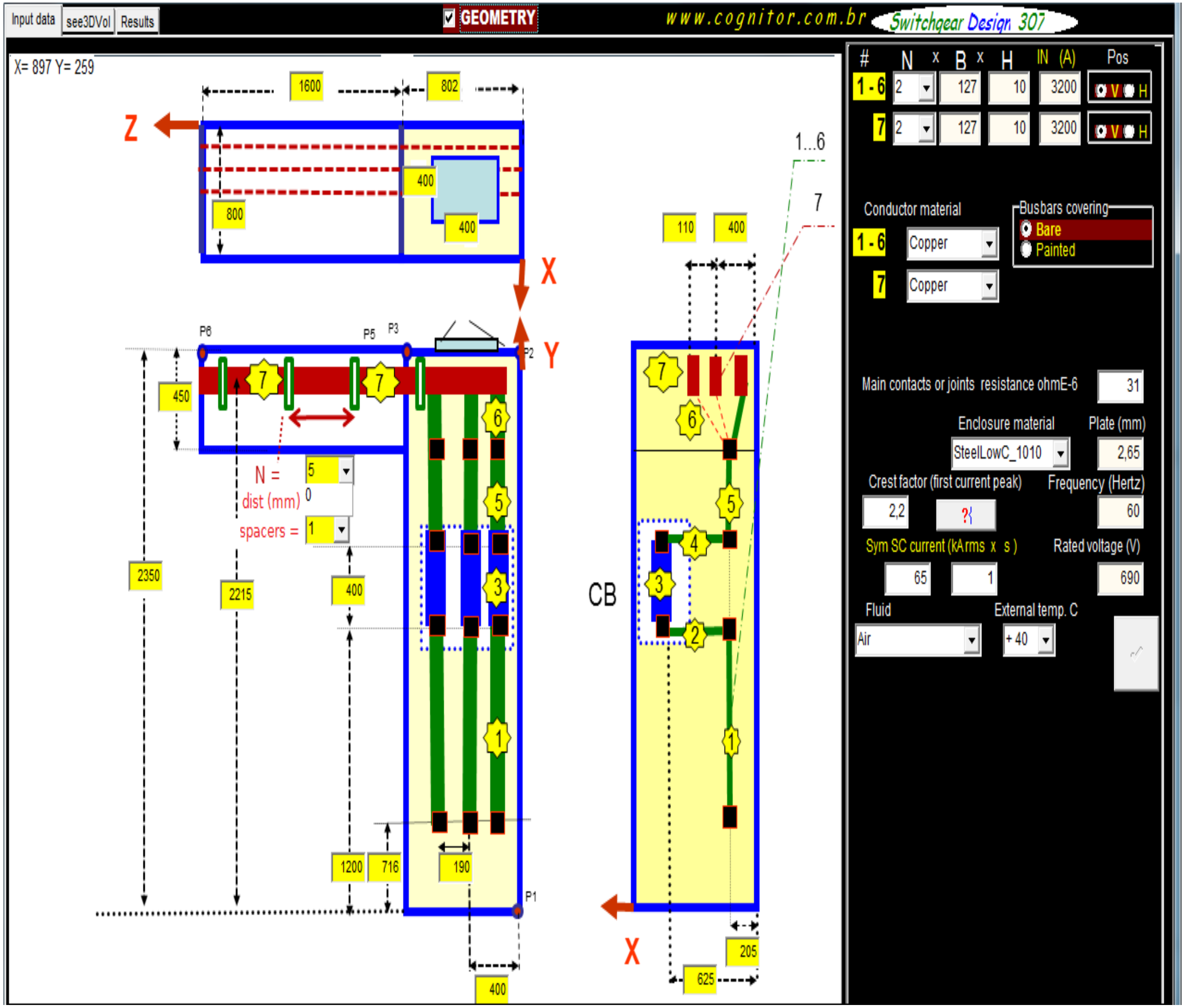


Click the button NEW to create a new project equal to the one which is selected (only the name is different) and them change the data and geometry

Type of equipment project to be simulated (LVSW 1 &2 = Low Voltage switchgear, MVSW1 – Medium Voltage Switchgear DUCT_1 = bus way , SWITCH = isolator)

The third boxes to fill are the ones showed in the right side of the page and the geometry. Select LVSW1 in the bottom and check the box GEOMETRY in the top of the page

- Depending on the type of project selected the items in the right side will appear slightly different
- For example, if LVSW1 is selected you will see the 1-6 conductors line and also the 7 conductor line
- This will enable you to use different dimensions, numbers of bars in parallel, currents and even materials for each group
- If you are using DUCT_1 boxes named 1-7 will appear because all the conductors are equal



- In the next pages I do , for each type of equipment, the explanation of what you should write in each box
- Have in mind I tried to use the minimum number of variables possible
- If after reading all of them carefully you still do not understand how to fill the boxes the write to sergiofeitoza@cognitor.com.br with a detailed description of your doubt
- Based on this I will be improving these slides and I will reply you
- Remember that the number of input data variables is big and by this reason wrong combinations of numbers which may lead to nonsense results or message errors.
- So be aware that the software is focused in people having some experience in equipment design and able to identify that a certain result is very far from expected.
- If this happens first check if the input data is correct . If you think this is not the problem please write me..
- With many people using the software and having doubts in few months these aspects will be improved and the software use will be easier.

INPUT DATA SCREEN BUSWAYS DUCT_1

Number assigned to each conductor (#1 to # 7) to visualize results

Number of subdivisions in conductors # 3 e 5 and corresponding distance between supports

Geometry and dimensions (mm)

Conductors # 1 to 7 formed by 3 bars per phase 150x10 mm

Current applied in the temperature rise test (A)

Bar in the Horizontal or Vertical position

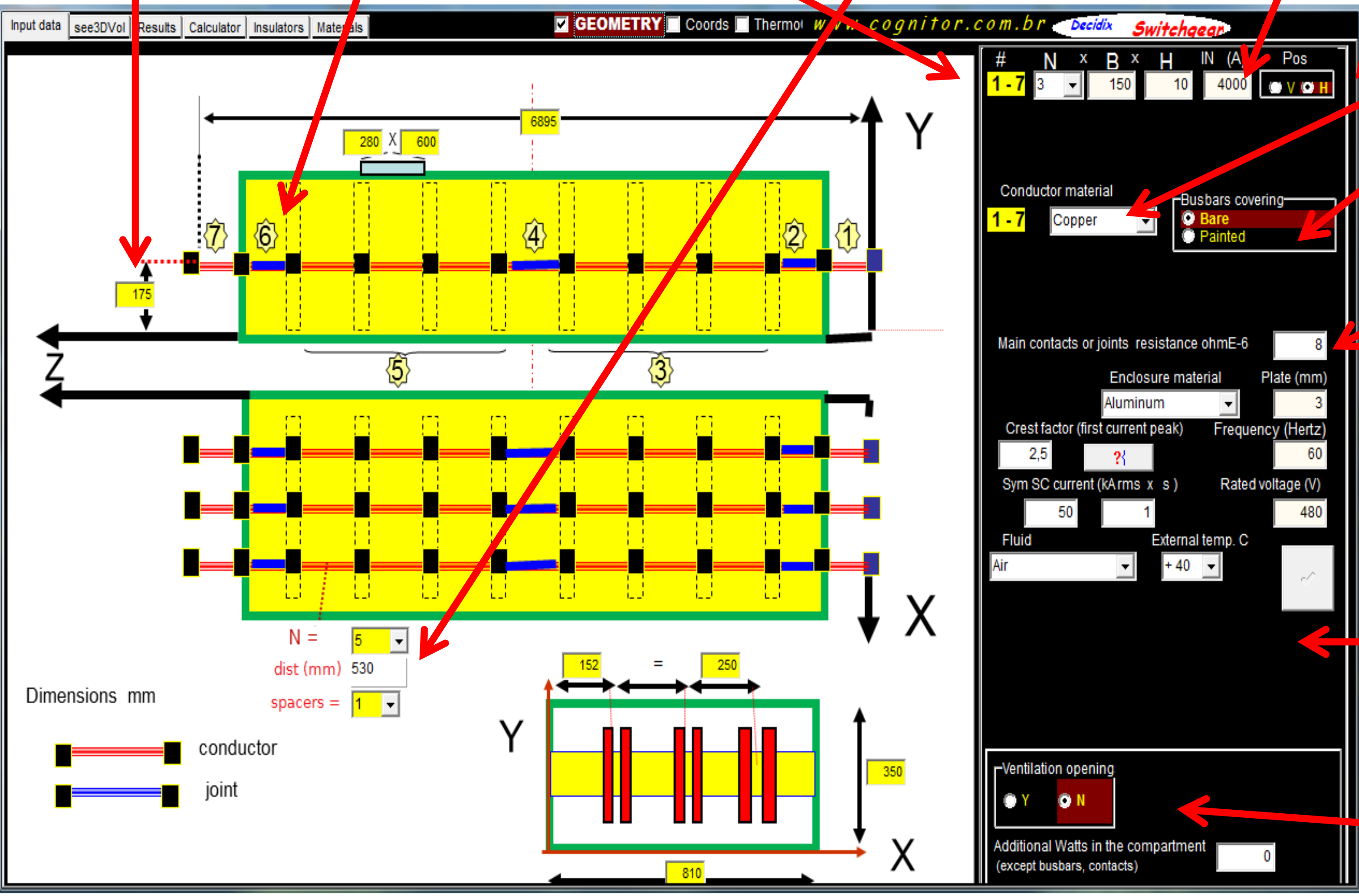
Material: copper, aluminum

Bar coating: bare, painted

Joints resistance (μΩ) Conductors #2,4 e 6

Rated voltage (V)
Enclosure material
Fluid (air, SF6, óil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation openings area (IEC 60890)



COGNITOR

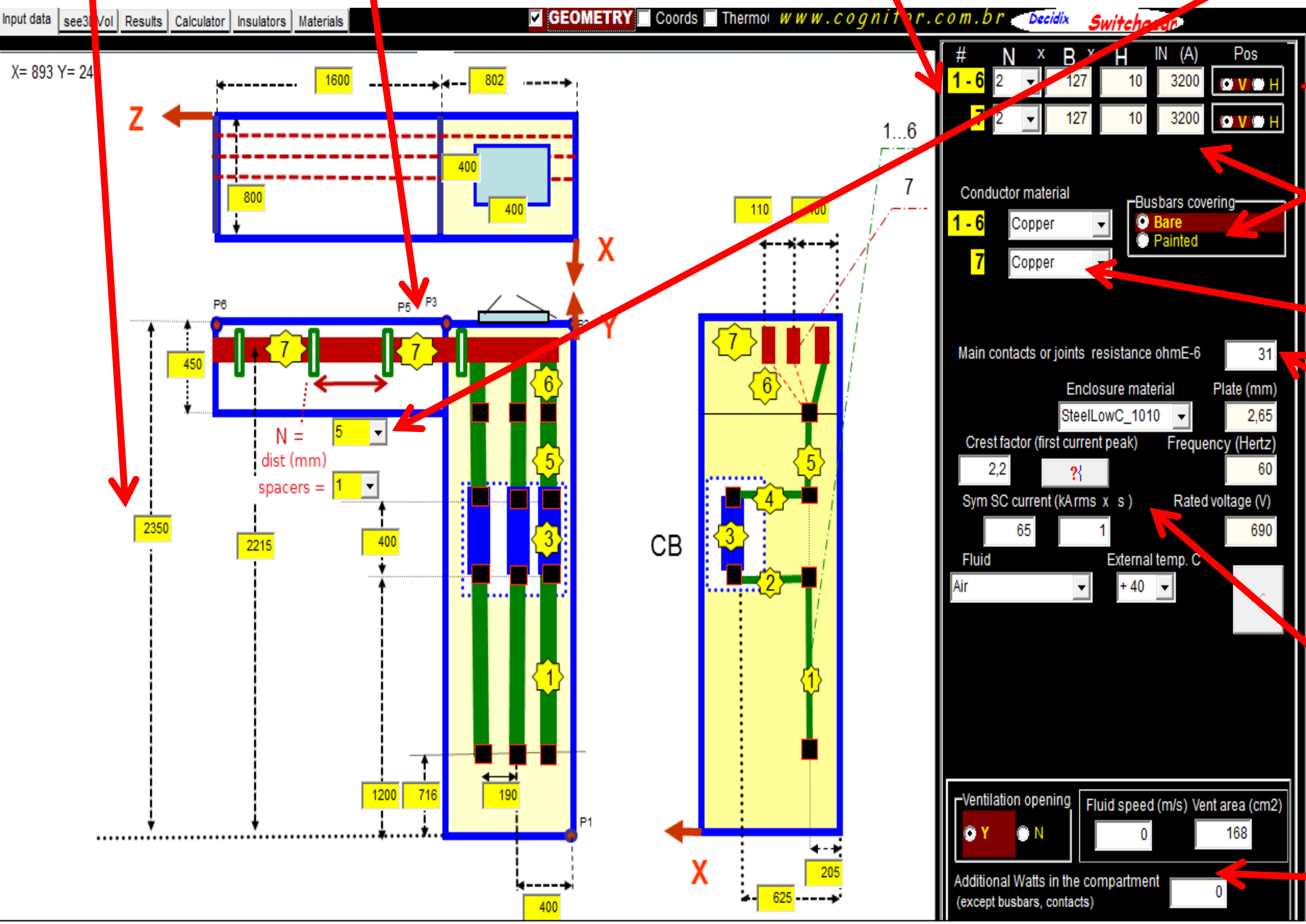
INPUT DATA LOW VOLTAGE SWITCHGEAR LVSW_1

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line is for conductors # 1 to # 6, in this example 2 bars per phase 127 x 10 mm
The second line is for conductor #7 which in this example 2 bars per phase 127 x 10 mm

Number of subdivisions in conductor # 7 and corresponding distance between supports (in # 1 to 6 is 1)

Geometry and dimensions (mm)



Bar in the Horizontal or Vertical position

Bar coating: bare, painted

Current applied in the temperature rise test (A)

Material: copper, aluminum

Circuit Breaker resistance (μΩ)
Conductor s# 2, #3 and #4

Rated voltage (V)
Enclosure material
Fluid (air, SF6, oil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation area, additional power dissipation (IEC 60890)

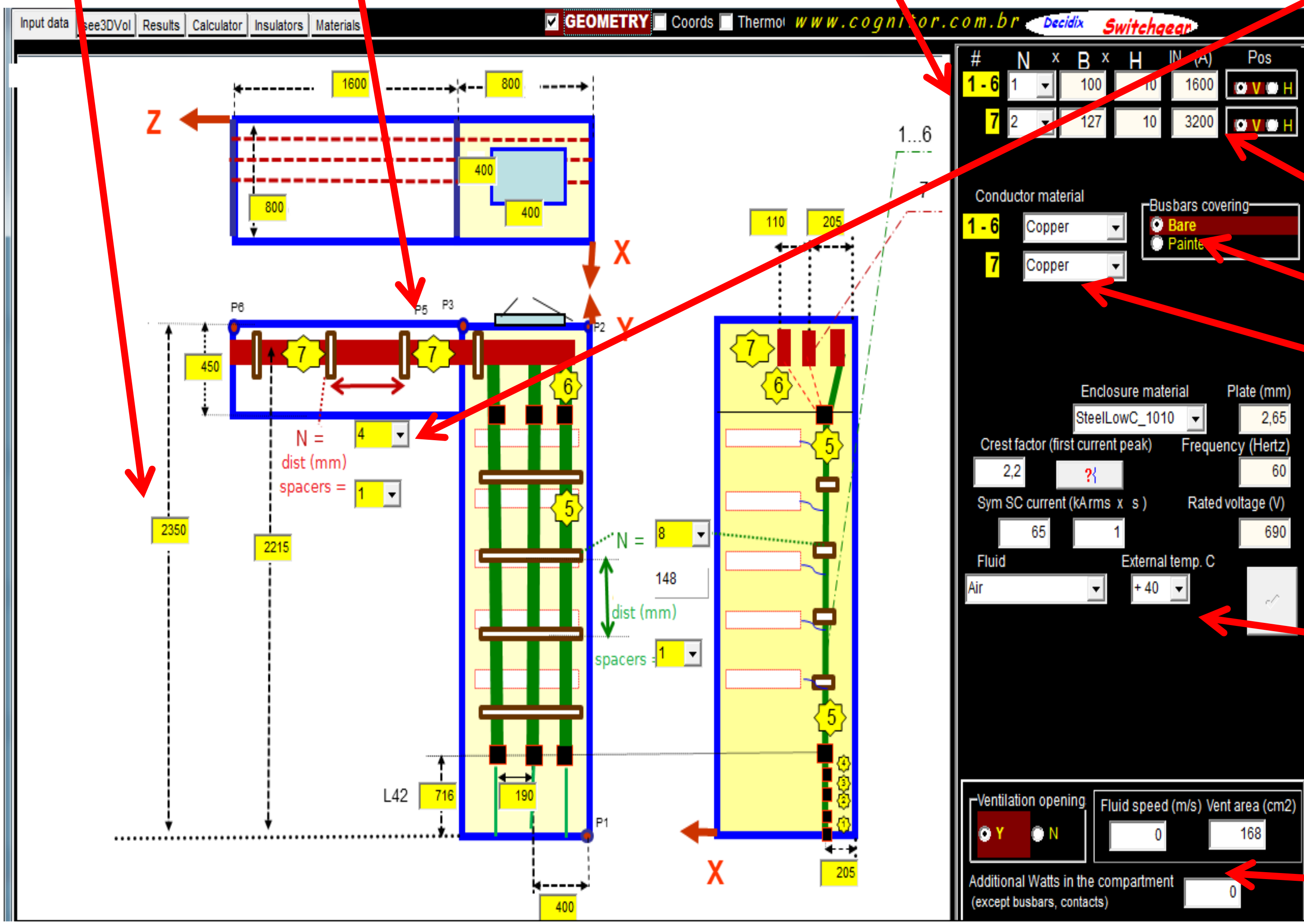
INPUT DATA LOW VOLTAGE SWITCHGEAR LVSW_2

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line is for conductors # 1 to # 6, in this example 1 bar per phase 100 x 10 mm
The second line is for conductor #7 in this example 2 bars per phase 127 x 10 mm

Number of subdivisions in conductor # 7 and corresponding distance between supports (in # 1 to 6 is 1)

Geometry and dimensions (mm)



Bar in the Horizontal or Vertical position

Current applied in the temperature rise test (A)

Bar coating: bare, painted

Material: copper, aluminum

Rated voltage (V)
Enclosure material
Fluid (air, SF6, oil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation area, additional power dissipation (IEC 60890)

COGNITOR

INPUT DATA MEDIUM VOLTAGE SWITCHGEAR MVSW_1

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line refers to conductors # 1 to # 6 , in this example 2 bars of 63,6 x 10 mm. The second line refers to conductor #7 (here 1x100x10 mm)

Current applied in the temperature rise test (A)

Geometry and dimensions (mm)

Bar in the Horizontal position

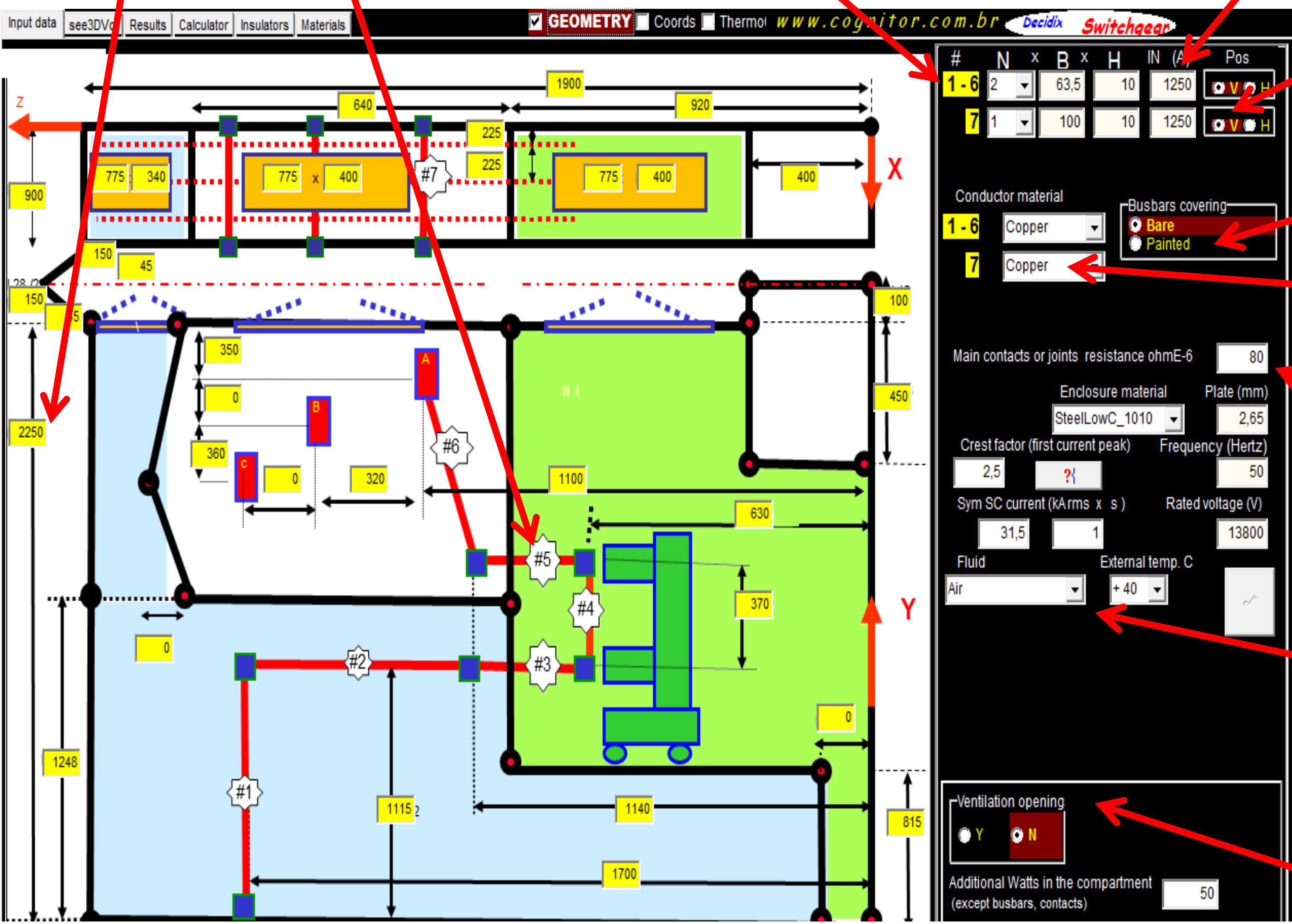
Bar coating: bare, painted

Material: copper, aluminum

Circuit breaker (CB) resistance (μΩ) CB represented by conductors #4, 5 and 6

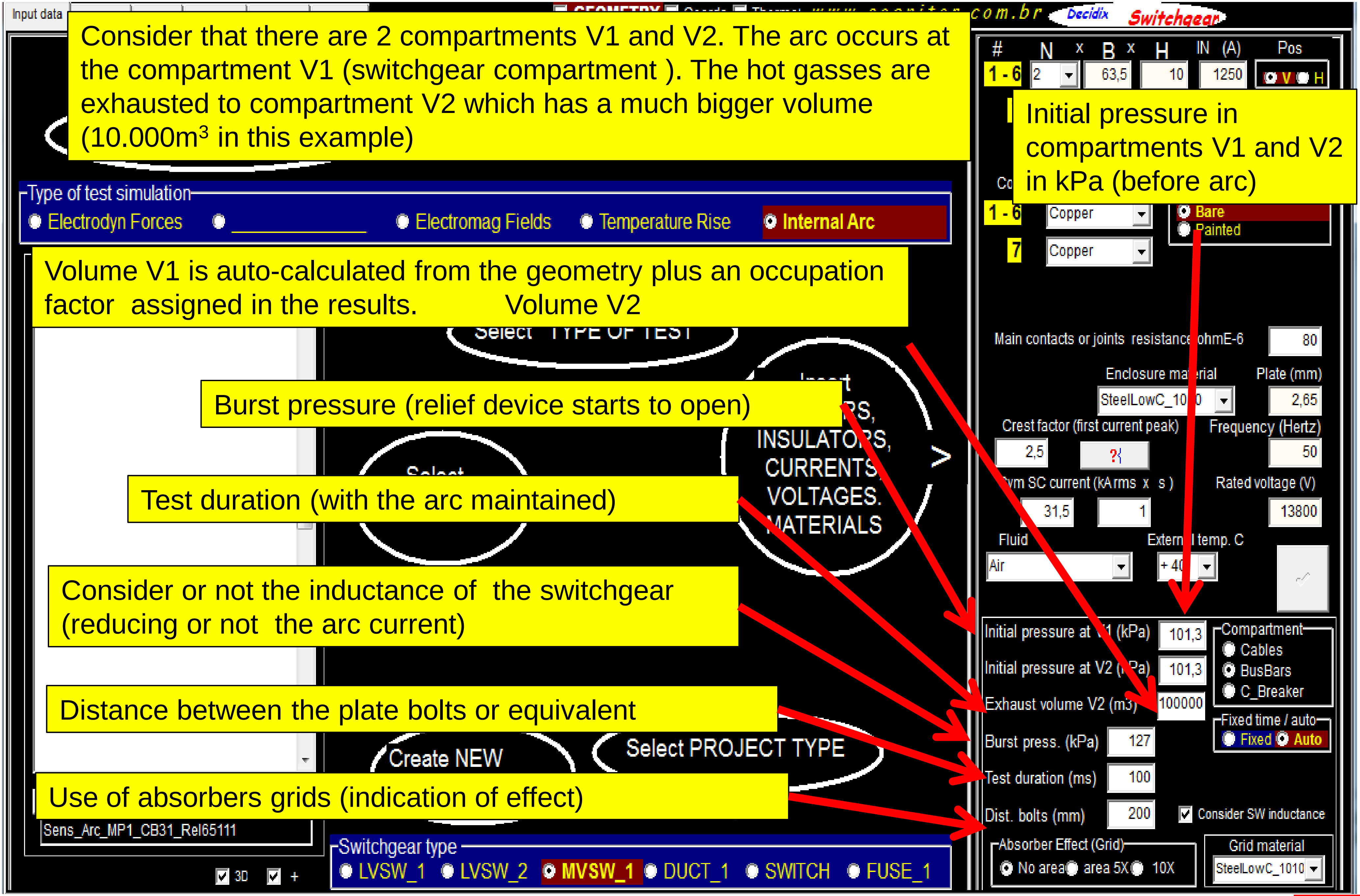
Rated voltage (V)
Enclosure material
Fluid (air, SF6, oil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor

Ventilation area (IEC 60890)



INTERNAL ARC TEST (ADDITIONAL DATA)

INPUT DATA SCREEN   BUSWAYS & SWITCHGEAR



INPUT DATA ISOLATORS SWITCH_1

Number assigned to each conductor (#1 to # 7) to visualize results

The upper line (1-3) refer to conductors #1 to # 3 in this example 1 bars of 40 x 12 mm. The second line (4-7) refer to conductors #4 to #7 (here 2 bars of 50 x 6 mm)

Geometry and dimensions (mm)

Current applied in the temperature rise test (A)

Bar in the Horizontal or Vertical position

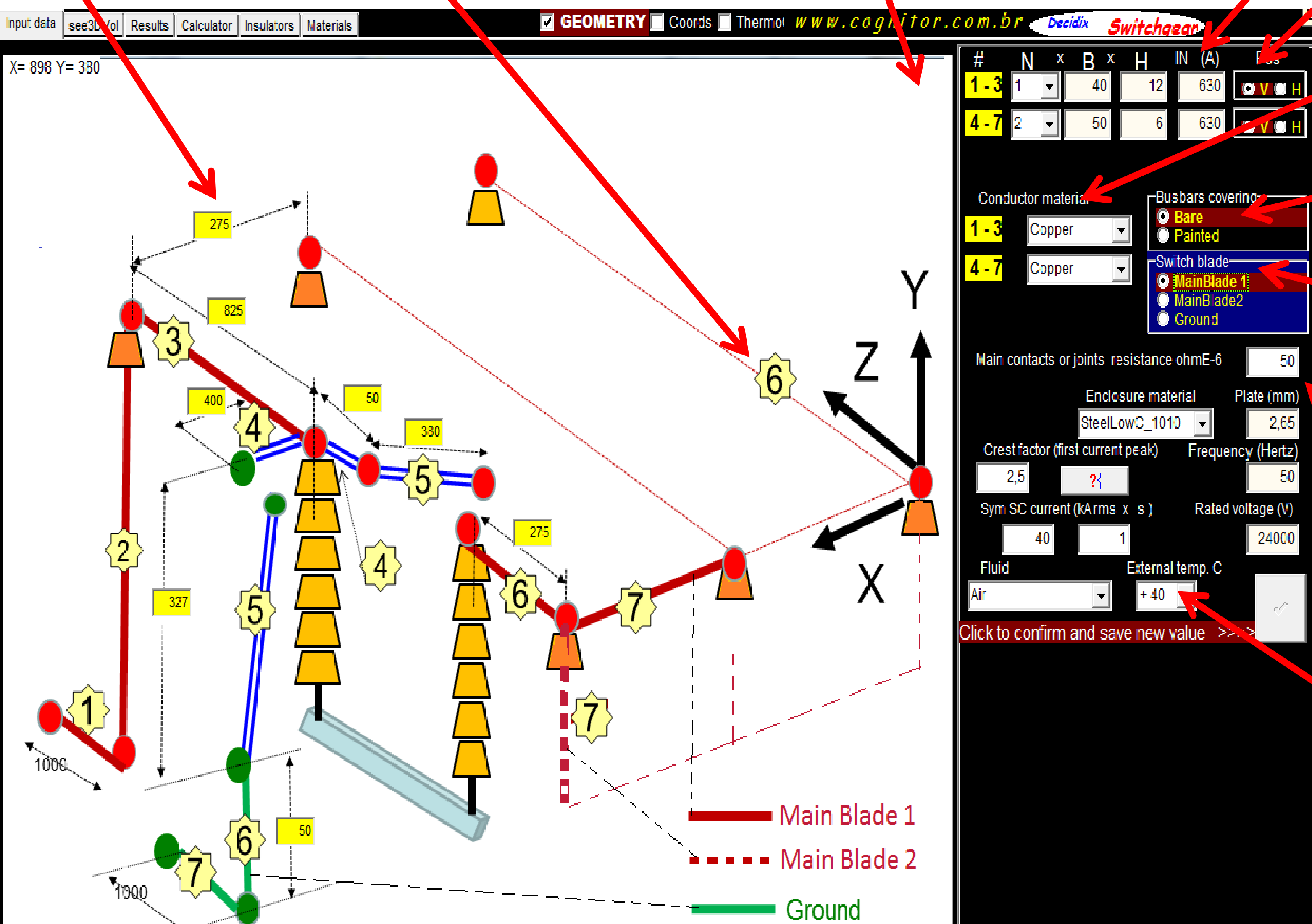
Material: copper, aluminum

Bar coating: bare, painted

Select the blade which will be calculated and the type of arrangement for the "Main Blade"

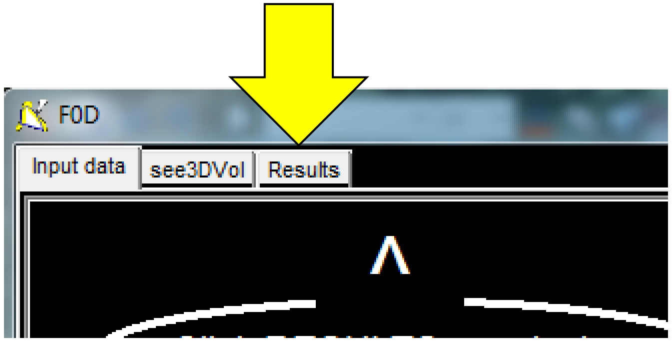
Joints resistance (μΩ) Conductor #5

Rated voltage (V)
Enclosure material
Fluid (air, SF6, óil ...)
Frequency
Short circuit current (kA_{rms}), duration (s) and crest factor



RESULTS VISUALIZATION

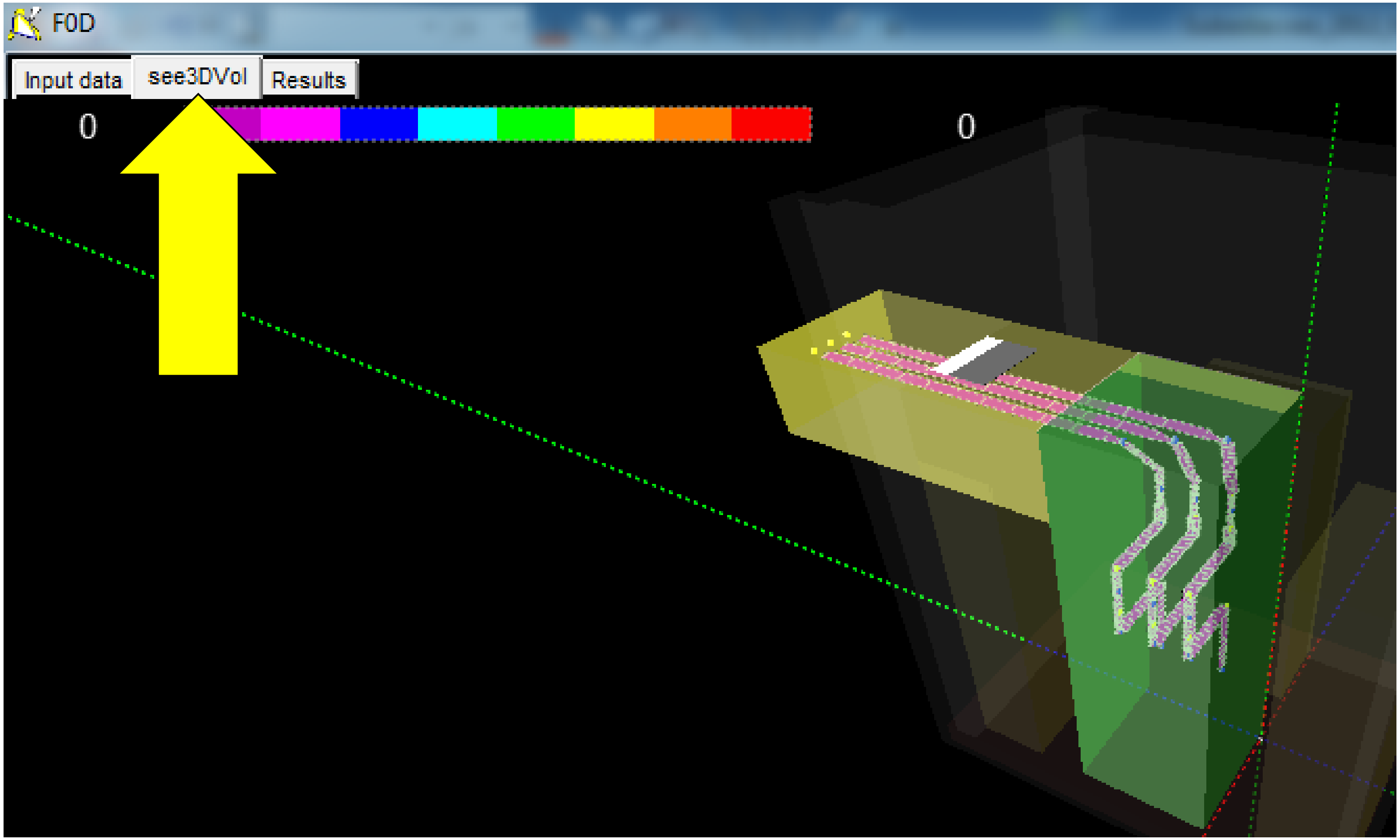
- After inserting all the input data, if you click the Results tab a calculation will be done



- In the next pages, for each type of test, you may see the typical results. Some of the cases are validated by actual tests done in testing laboratories. For more details read the articles in http://www.cognitor.com.br/en_download.htm with a special attention to the one at http://www.cognitor.com.br/Validation_Simulations_English.pdf

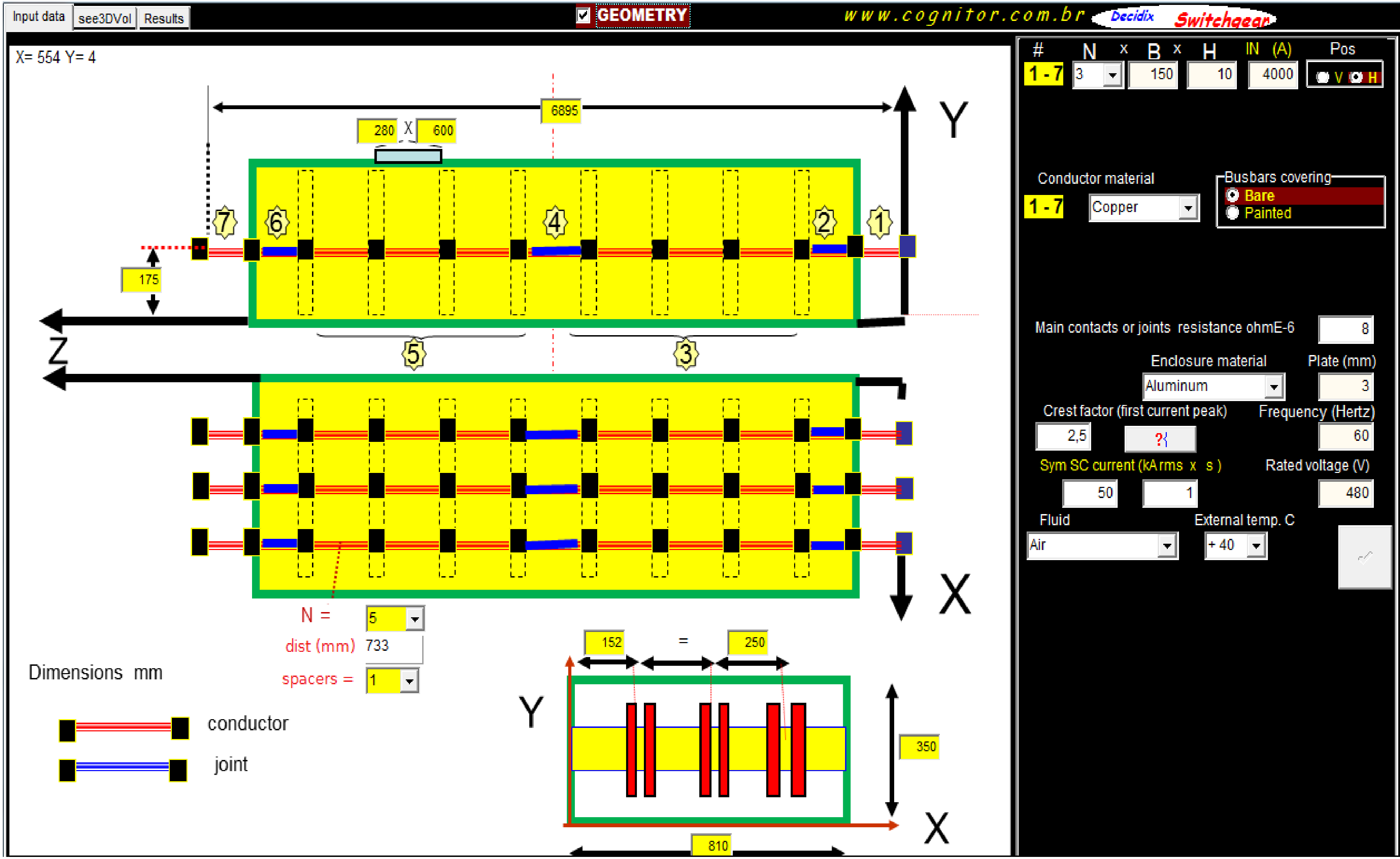
RESULTS VISUALIZATION

- A very common error is to input in the GEOMETRY dimensions which are not coherent. With this objective I created the TAB **See 3Dvol** .
- If you click on it a 3D visualization will appear.
- If this figure is “strange” check the dimensions. If an error message comes due to inconsistent dimensions go again to the GEOMETRY screen and check them.



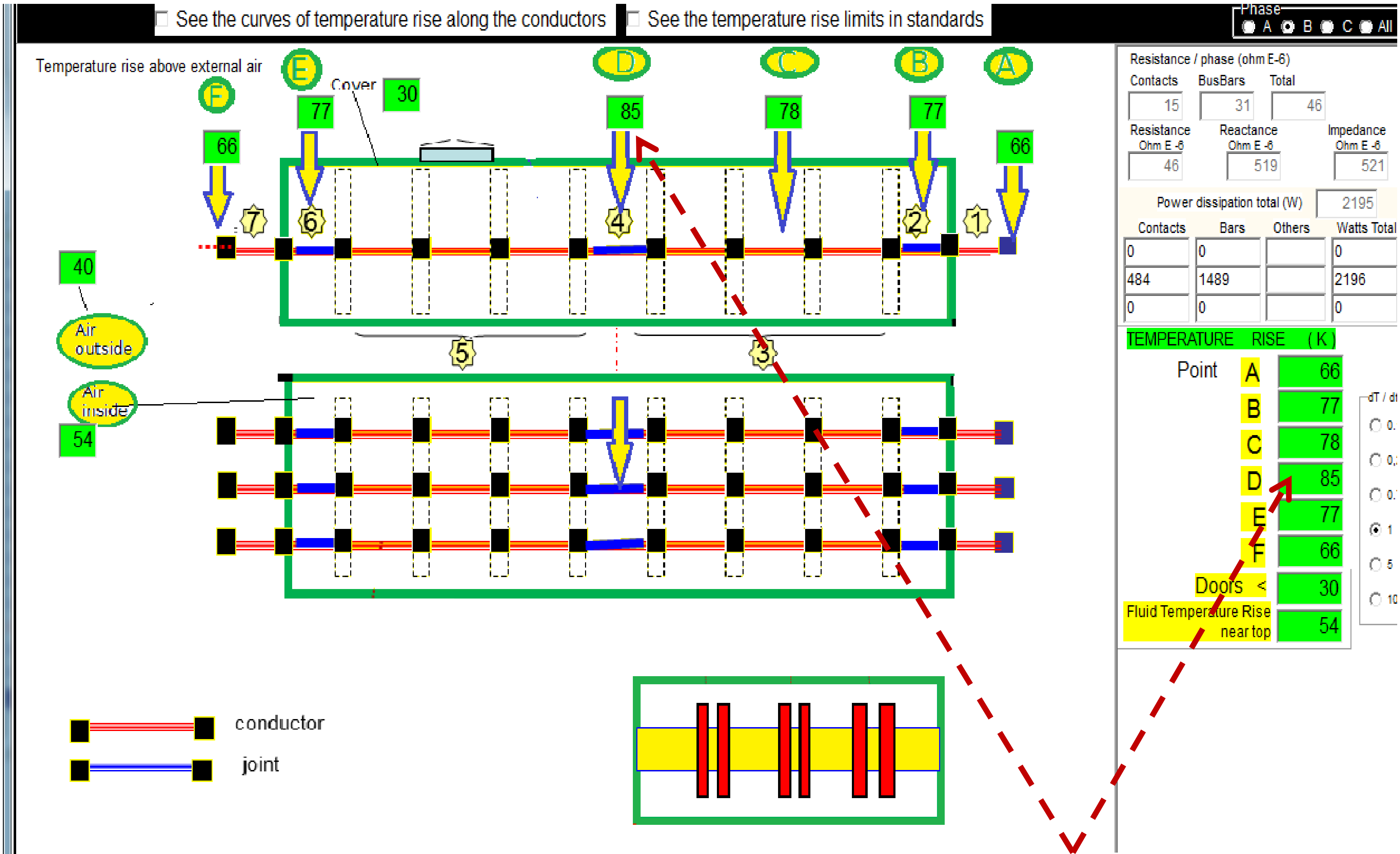
RESULTS VISUALIZATION - TEMPERATURE RISE TEST

BUSWAY (validated case BusWay_3x150x10_CU_R_67131)



RESULTS VISUALIZATION - TEMPERATURE RISE TEST

BUSWAY (validated case BusWay_3x150x10_CU_R_67131)



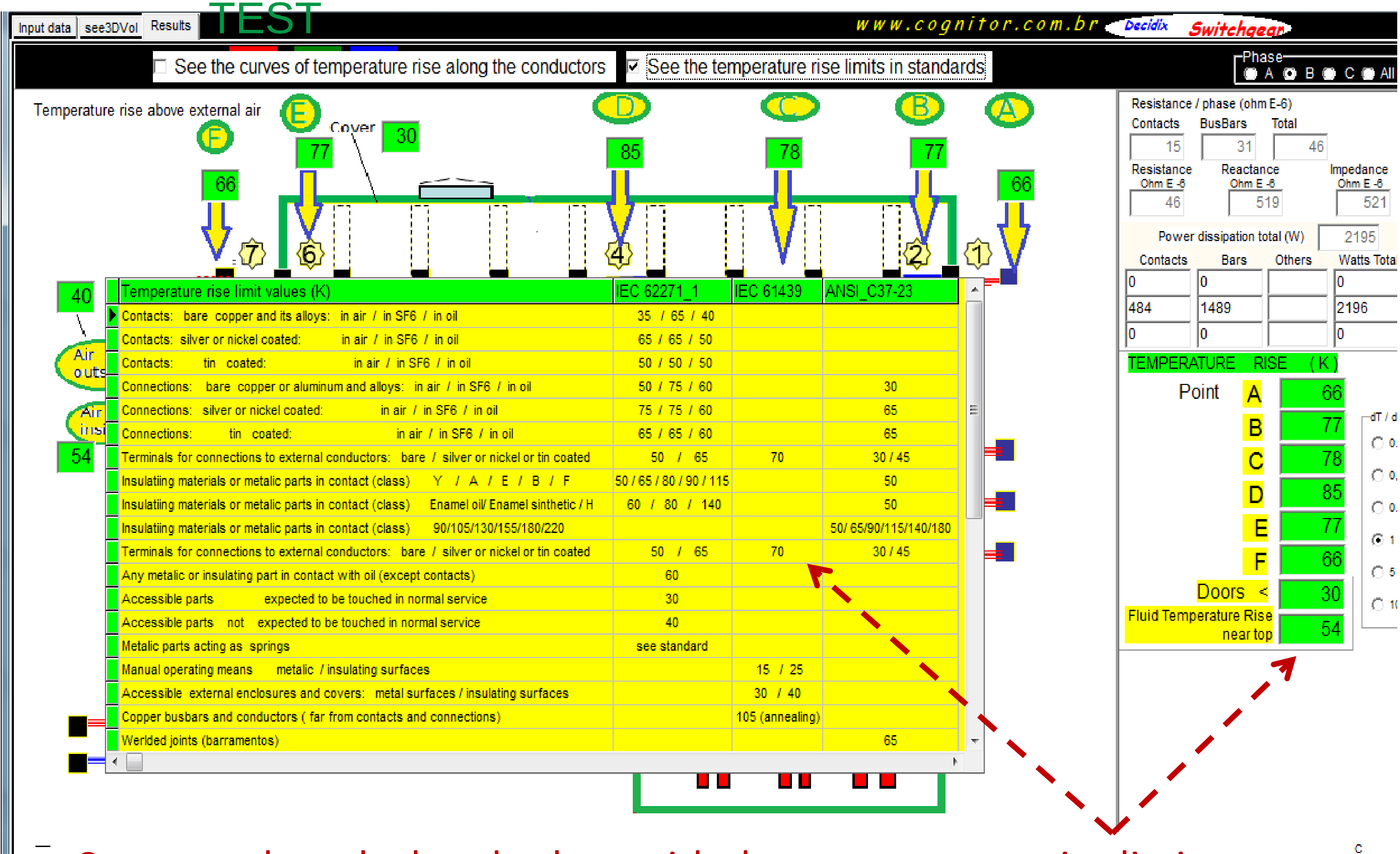
Temperature rise (K) above the temperature of the external air at different points

BUSWAY (validated case BusWay_3x150x10_CU_R_67131)

Point of the measurement at central phase B	Test result (K)	Simulation result (K)
Connection at the start conductor # 2	72,4	73 to 77 (*)
Bus-bar at conductor # 3	84,0	78
Connection at the center conductor # 4	83,5	85
Connection at the end conductor # 7 (short circuit point)	66,6	66
Enclosure side at 50% height	30,2	30
Fluid inside near top	not measured	54
Total resistance per phase = joints + bars (μΩ)	not indicated	15 + 31 = 46
Joints resistance (μΩ)	not indicated	8
Ventilation	No	
Bus bar	Copper 3 x (150x10) mm Horizontal	

It is not possible to identify exactly to position of the thermocouple

RESULTS VISUALIZATION - TEMPERATURE RISE TEST

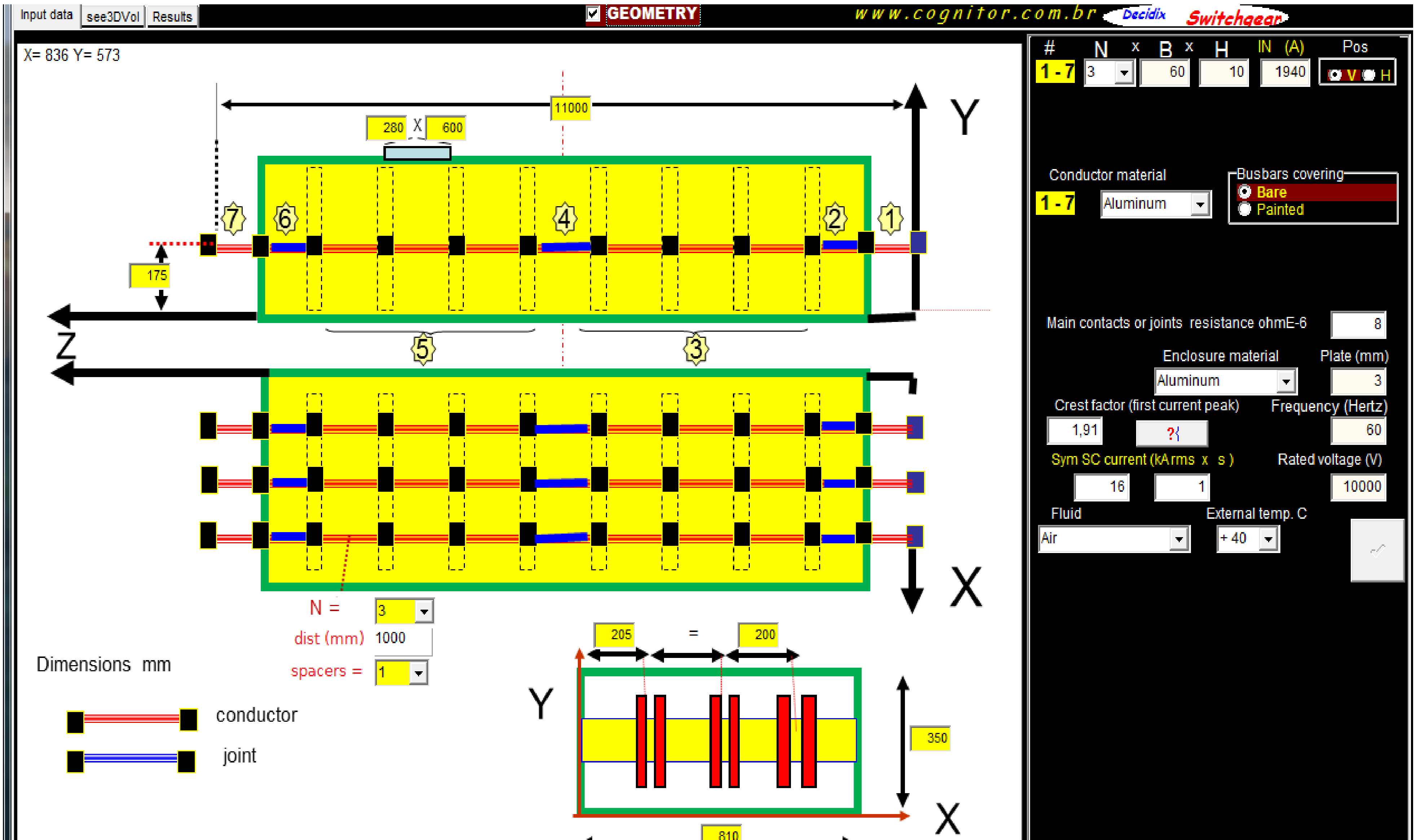


Temperature rise limit values (K)	IEC 62271_1	IEC 61439	ANSI_C37-23
Contacts: bare copper and its alloys: in air / in SF6 / in oil	35 / 65 / 40		
Contacts: silver or nickel coated: in air / in SF6 / in oil	65 / 65 / 50		
Contacts: tin coated: in air / in SF6 / in oil	50 / 50 / 50		
Connections: bare copper or aluminum and alloys: in air / in SF6 / in oil	50 / 75 / 60		30
Connections: silver or nickel coated: in air / in SF6 / in oil	75 / 75 / 60		65
Connections: tin coated: in air / in SF6 / in oil	65 / 65 / 60		65
Terminals for connections to external conductors: bare / silver or nickel or tin coated	50 / 65	70	30 / 45
Insulatiing materials or metalic parts in contact (class) Y / A / E / B / F	50 / 65 / 80 / 90 / 115		50
Insulatiing materials or metalic parts in contact (class) Enamel oil/ Enamel sinthetic / H	60 / 80 / 140		50
Insulatiing materials or metalic parts in contact (class) 90/105/130/155/180/220			50/ 65/90/115/140/180
Terminals for connections to external conductors: bare / silver or nickel or tin coated	50 / 65	70	30 / 45
Any metalic or insulating part in contact with oil (except contacts)	60		
Accessible parts expected to be touched in normal service	30		
Accessible parts not expected to be touched in normal service	40		
Metalic parts acting as springs	see standard		
Manual operating means metalic / insulating surfaces		15 / 25	
Accessible external enclosures and covers: metal surfaces / insulating surfaces		30 / 40	
Copper busbars and conductors (far from contacts and connections)		105 (annealing)	
Werlded joints (barramentos)			65

Compare the calculated values with the temperature rise limits specified in the technical standards

RESULTS VISUALIZATION - SHORT TIME CURRENT TEST

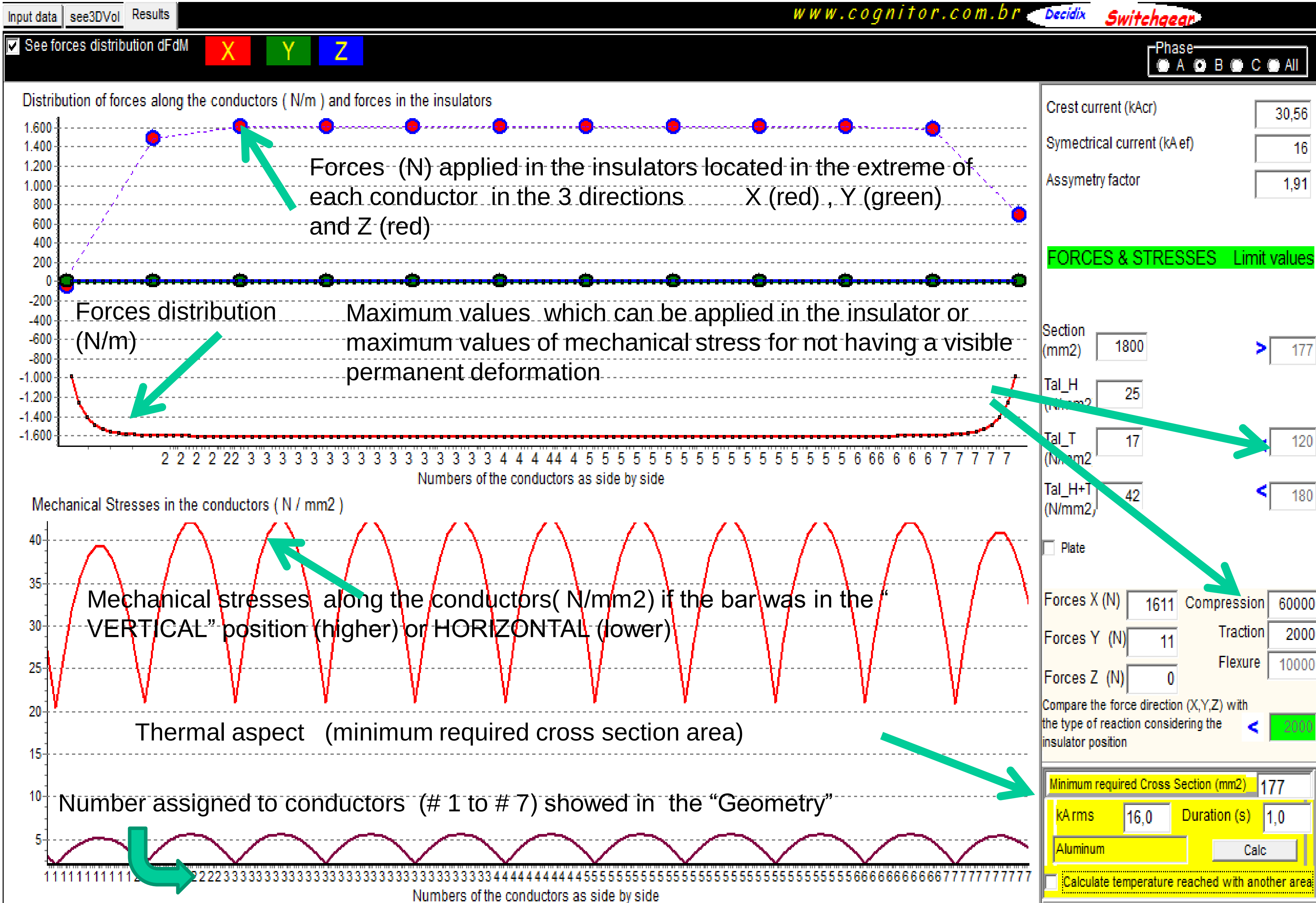
BUSWAY (validated case BusWay_3x60x10_Al_IEC865_2)



COGNITOR

RESULTS VISUALIZATION - SHORT TIME CURRENT TEST

BUSWAY (validated case BusWay_3x60x10_Al_IEC865_2)



RESULTS VISUALIZATION - SHORT TIME CURRENT TEST

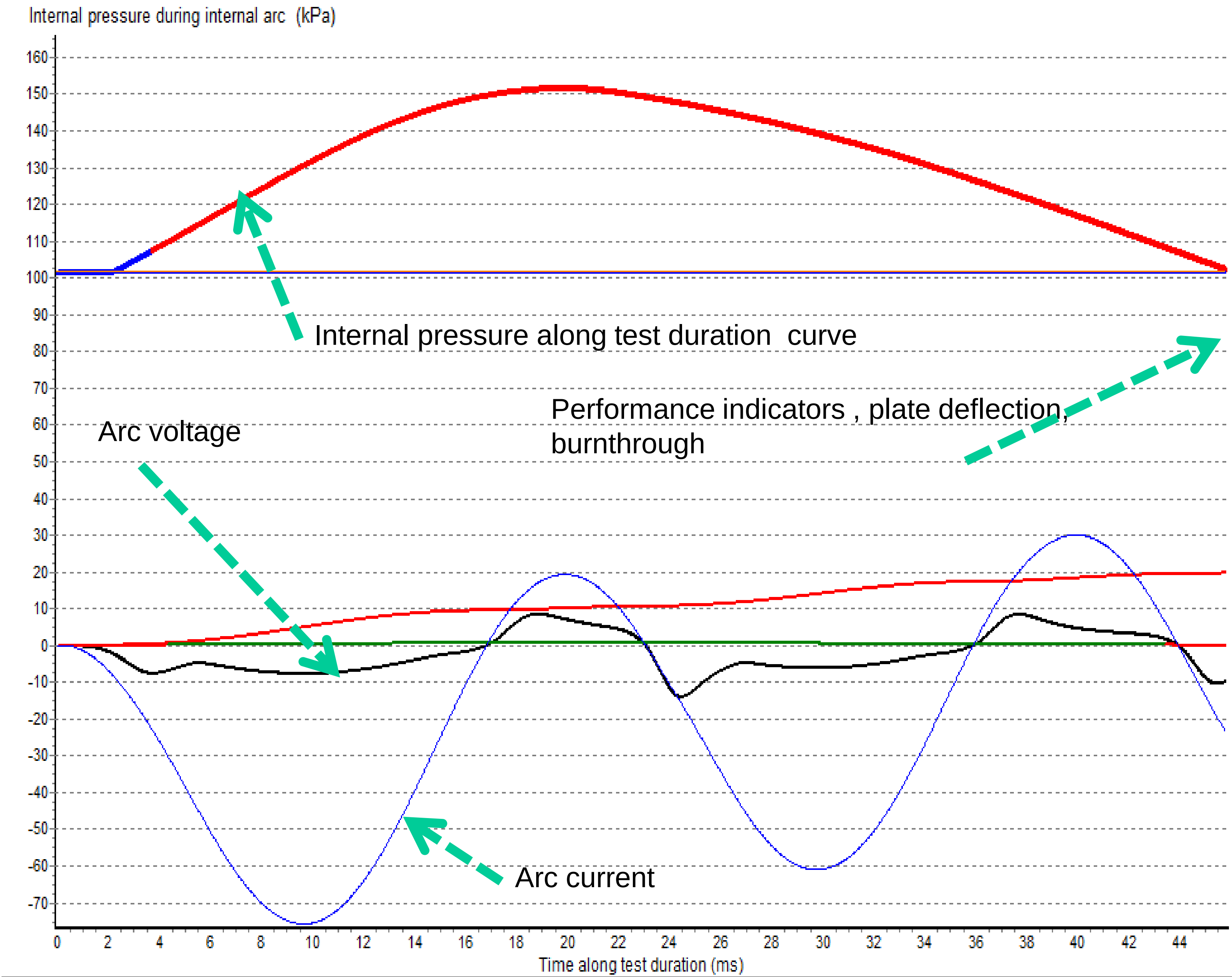
BUSWAY (validated case BusWay_3x60x10_Al_IEC865_2)

The “Test result” is the calculation presented in. IEC 60865-2 (1994) – pages 19 to 27

Parameter	Test result	Simulation result
Max. Mechanical stress σH (N/mm2)	24,7	25
Max. Mechanical stress σT (N/mm2)	16,1	17
Total max. mechanical stress σH + σT (N/mm2)	40,8	42
Max. Force on the insulator in compression or tension (N)	-	11
Max. Force on the insulator in flexion (N)	1606	1611

RESULTS VISUALIZATION - INTERNAL ARC TEST

Medium voltage switchgear (validated case MP1_CB31IArc_valid_ROZV050U



RESULTS		Calculated	Limit
Pressure peak	(%)	50	80
	kPa	152	
Overpressure duration		46	
Integral deltaP * dT * E+3		26	30
Time 100% peak pressure (ms)		20	
Time 50% after peak pressure (ms)		36	
Minimum plate no burnthrough (mm)		1,14	
Burnthrough % of plate thickness		43	
Mx. deflection / deformation (mm)		0,71	
Arc current - pressurized (A rms)		38300	

Checked if switchgear inductance considered

Arcing time (ms)	44
Arc voltage (V)	585
Arc Speed (m/s)	39
RELIEF AREA (m2): this area is calculated as the product of the dimensions showed in the geometry. If there are grids ireducing the area consider it in the geometry	0,248

Vol each column	x ocupation %			= net m3
1,026	0,53	0,53	0,53	0,544

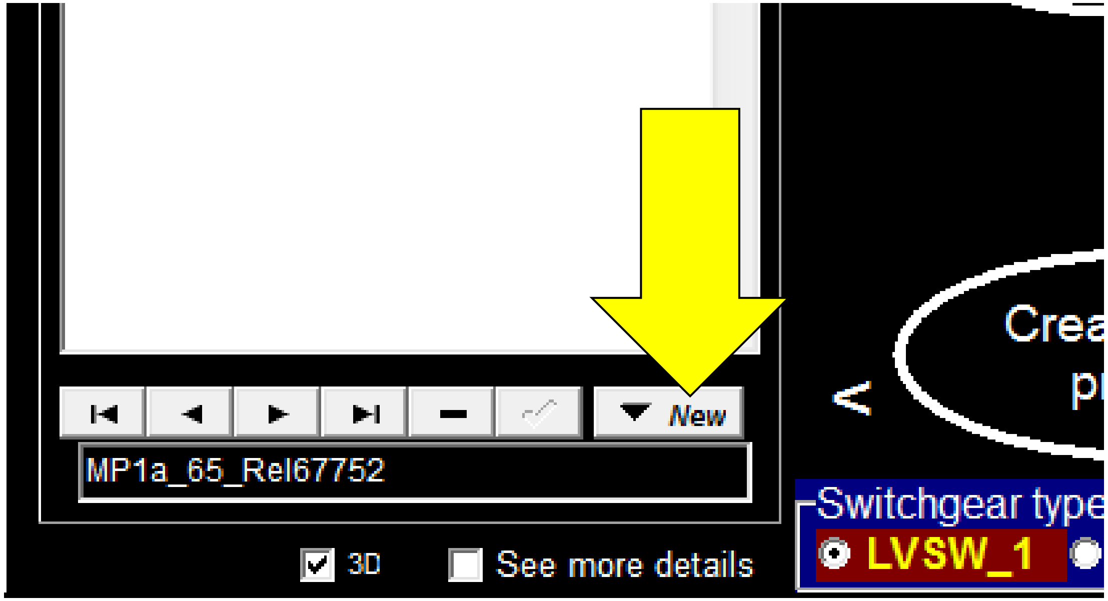
MP1_CB31IArc_valid_ROZV050U

RESULTS VISUALIZATION - INTERNAL ARC TEST

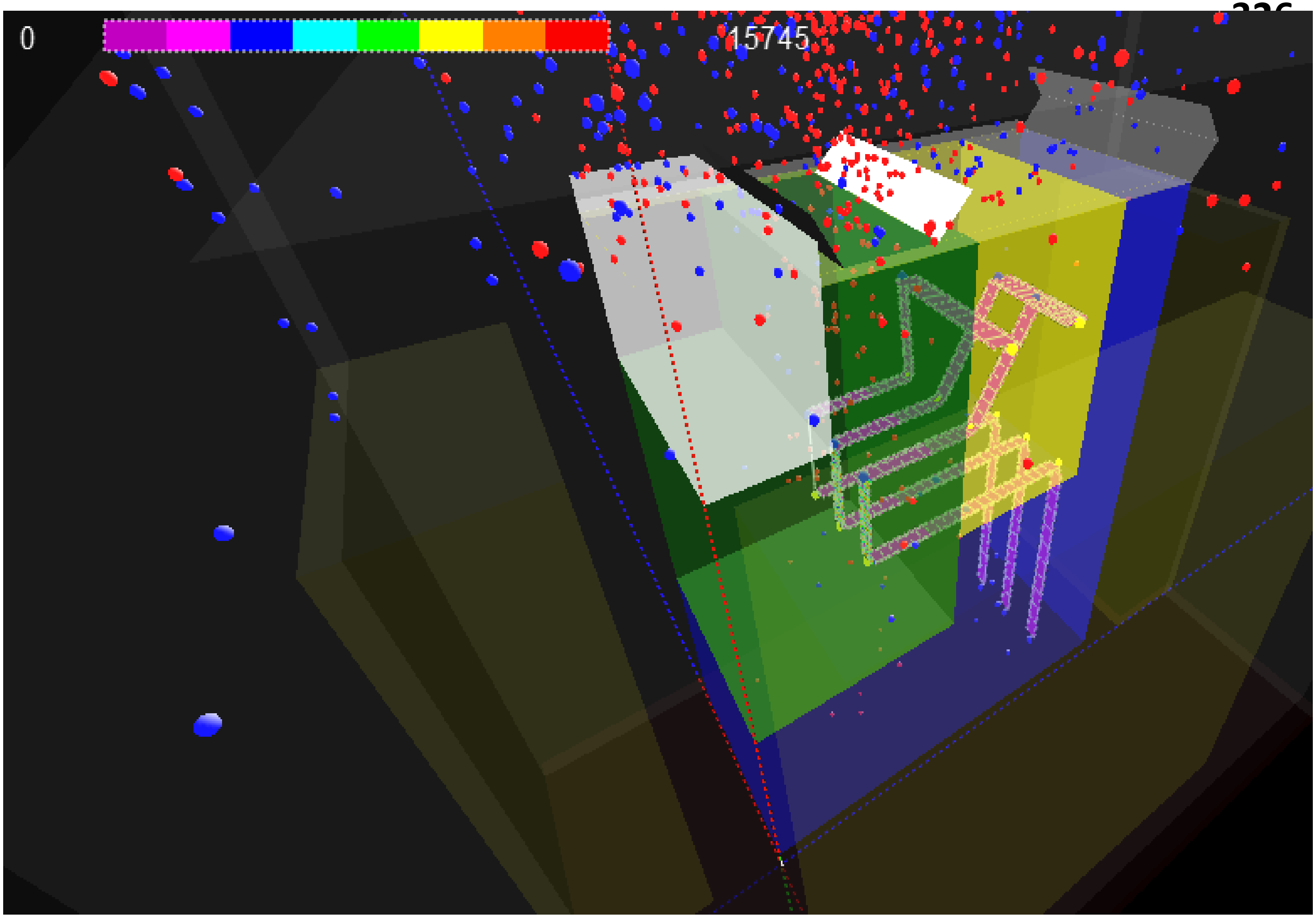
Medium voltage switchgear (validated case MP1_CB31IArc_valid_ROZV050U

Parameters	Test result	Simulation result
Rated voltage (KV)	13,8	
Current kA rms and duration (s) prospective	31,5 – 1s	
Current asymmetry	2,5 crest factor	
Frequency (Hz)	50	
Arc compartment volume (m^3) x occupation factor	1,026 x 0,53 = 0,54	
Pressure relief area in the tested compartment (m^2) . There is a grid reducing the exit area around 80%	0,8 x 0,31 = 0,248	
Arc voltage (V rms)	530	585
Maximum overpressure above 1 bar ΔP (%)	50 to 52	50
Overpressure duration (ms)	42 to 46	46
Integral Pressure curve along the time (bar*s*1000)	-	26
Time to 100% ΔP (ms)	18 to 20	21
Time to 50% ΔP (ms)	24 to 26	36
Ventilation	No	
Absorbers or parts like grids working as absorbers	Yes	

CREATION OF NEW CASES



- This is possible only with the “version distributed in the course” and, is explained in the course
- The fundament is that when a NEW case is created a new line is included in the data base tables exactly equal to the one which was selected before. The only difference is the “name “ of the new case .
- You will just rename it as you wish and change the input data and geometry as you wish



This feature here is under development. It is awaiting a sponsor willing to pay 3 months of work of the developer of software plus 2 days of testing in a high power laboratory to do the results validation. It is a method to identify the impact of the design parameters on the burning of the cotton indicators in internal arc tests. The burning of horizontal indicators is the major cause of failure in testing of internal arc

CASE STUDIES WITH THE USE OF THE SOFTWARE

(PRESENTED IN THE COURSE USING THE SOFTWARE)

SHORT TIME AND CREST WITHSTAND CURRENT

(ELECTRODYNAMICAL STRESS, MECHANICAL STRESS)

- Normal use and explanation about performance indicators
- How to optimize the number of insulators
- How to optimize the type of bars considering also the temperature rise requirements

CASE STUDIES WITH THE USE OF THE SOFTWARE

(PRESENTED IN THE COURSE USING THE SOFTWARE)

TEMPERATURE RISE TESTS.

- Normal use and explanation about performance indicators
- How to optimize the ventilation solution
- How to optimize the type of bus bars
- How to consider the relationship with the internal arc test requirements

CASE STUDIES WITH THE USE OF THE SOFTWARE

(PRESENTED IN THE COURSE USING THE SOFTWARE)

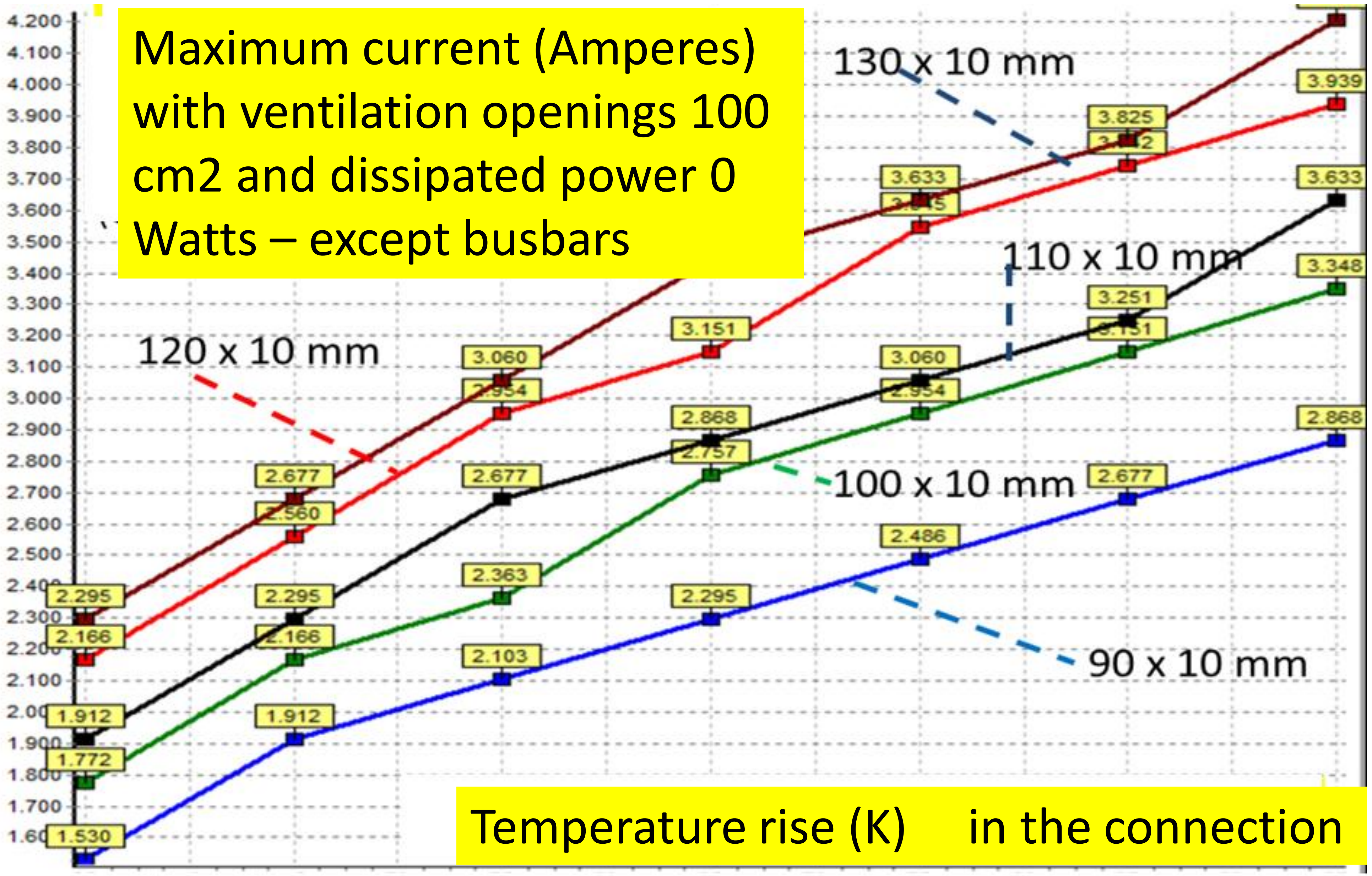
INTERNAL ARC TEST

- Normal use and explanation about performance indicators
- How to optimize the pressure relief device
- How to optimize the plate thickness
- How to consider the burnthrough effects
- How to consider the relationship with the temperature rise test

OPTIMIZED DESIGN (customized versions only)

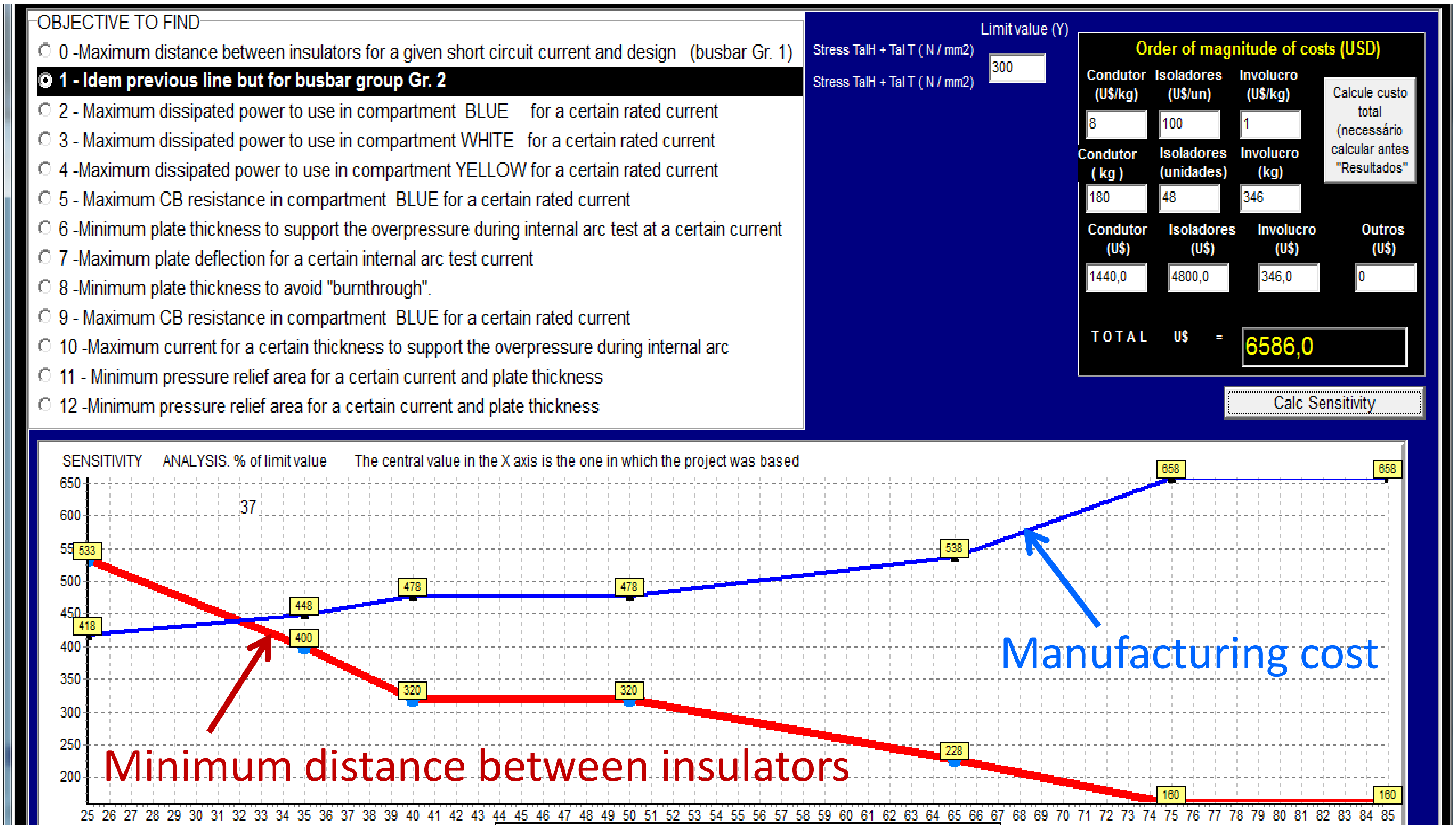
- Maximum distance between insulators x mechanical stress x short circuit current
- Maximum rated current x temperature rise
  - In the internal air
  - In the connection (hot spot)
  - In the doors
  - With or without ventilation openings
  - With or without additional dissipated power (drawers)
  - With variable contact resistances (circuit breakers, switches, fuses)
- Minimum thickness of steel plate with pressure not to break with arc
- Minimum thickness of steel plate without arc holes ("burn-through")
- Minimum area and fast relief of overpressure

OPTIMIZED DESIGN (customized versions only)



OPTIMIZED ECONOMICAL DESIGN

(customized versions only)



Short circuit current(kA)

Thank you very much !

For suggestions and contacts

Sergio Feitoza Costa
Cognitor – Consultancy, R&D and Training
Phone : (55) (21) 2465 3689 or (55) (21) 33934600

Skipe sergiofeitoza1

(we can speak in English, Portuguese, Spanish or French)

E-mail: sergiofeitoza@cognitor.com.br
Site: **http://www.cognitor.com.br**

Livro produzido pela

Câmara Brasileira de Jovens Escritores

Rio de Janeiro – RJ – Brasil

http://www.camarabrasileira.com

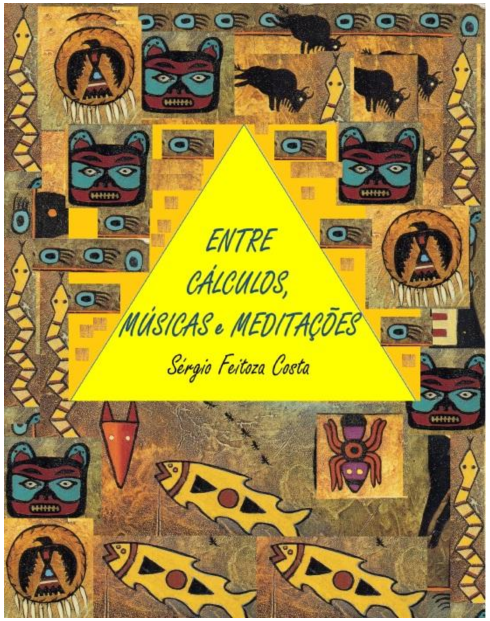
Email: cbje@globo.com

Free download of a non technical book written by Sergio Feitoza Costa

Version in Portuguese

Title: ENTRE CALCULOS, MUSICAS E MEDITAÇÕES

http://www.cognitor.com.br/LivroSergioFeitoza2012.pdf



Version in English

Title: BETWEN SONGS, CALCULATIONS AND MEDITATIONS

http://www.cognitor.com.br/LivroSergioFeitoza2013.pdf

Hear Sergio songs (3rd CD)

http://www.gravadoravirtual.net/sergiofeitoza

For a long time I had been taking the courage to leave, as a “free book”, this text used as reference for two training courses that I have been applying for many years all over the World. Now it is done and I hope that this material can be useful to professionals who did not participate in the courses, to teachers and to electrical engineering students.

I am also making available the software **SwitchgearDesign_307** developed by me for the design of switchgear, busways, isolators and other equipment for substations (part 7 of this book).

The explanation on how to get both is in the first page of the site http://www.cognitor.com.br

There you will find also “free”, my recent non-technical book entitled “Between calculations, songs and meditations” and a link for the songs of my 3rd CD where I sing some of the songs I composed.

ISBN 978 85 413 0239 5
9 788541 302395

Câmara Brasileira de Jovens Escritores
Rio de Janeiro