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ELECTRIC PANELS DESIGN using LESS MATERIALS: approved in the tests (temperature rise, internal arc, short circuit forces, dielectric).

By Eng. Sergio Feitoza Costa, M.Sc. C.V: https://www.cognitor.com.br/Curriculum.html

Things I helped to do: https://www.cognitor.com.br/HelpedToDo.pdf

This is part 1 of 7 of this training prepared by Sergio Feitoza Costa, to help electrical panel / switchgear designers who work in companies that do not provide regular training to their teams. **It covers the following topics:**

- Main design principles to develop safer & lower-cost products.
- Temperature rise test defines the weight of the electric panel / switchgear.
- Short circuit electrodynamical forces define the types and number of insulators
- Internal arc tests define the safety of people and installations about explosions and fires
- How can IEC TR 62271-307 help designers to understand what is really important?

ELECTRIC PANELS FREE-TRAINING for DESIGNERS & DEVELOPERS

May,6	**ELECTRIC PANELS DESIGN WITH LESS MATERIALS:** how to be approved in the tests (temperature rise, internal arc, short circuit forces, dielectric tests). Example.
May, 13	**HOW TO INNOVATE USING IEC_62271-307** for M.V. switchgear. How to explain to your buyers that this document could be used also for low voltage switchgear.
May,20	**INTERNAL ARC TESTS on MV & LV:** design techniques to safer and cheaper solutions. An example of approved solution
May,27	**SHORT CIRCUIT ELECTRODYNAMIC FORCES & STRESSES.** An example of complex calculations to save insulators
June, 3	**WHY SAVING COPPER, ALUMINUM & INSULATORS IS GOOD FOR CLIMATE CHANGE?** How big buyers can use this to improve their environmental image? Examples of BID specifications.
June, 10	**TETRA_AXIAL CONDUCTORS:** a concept for switchgear with lower impedance.
June, 17	**DANGEROUS PROXIMITY OF DISTRIBUTION GRIDS IN URBAN AREAS: AN IEC TECHNICAL STANDARD IS MISSING TO REDUCE RISKS TO PEOPLE**

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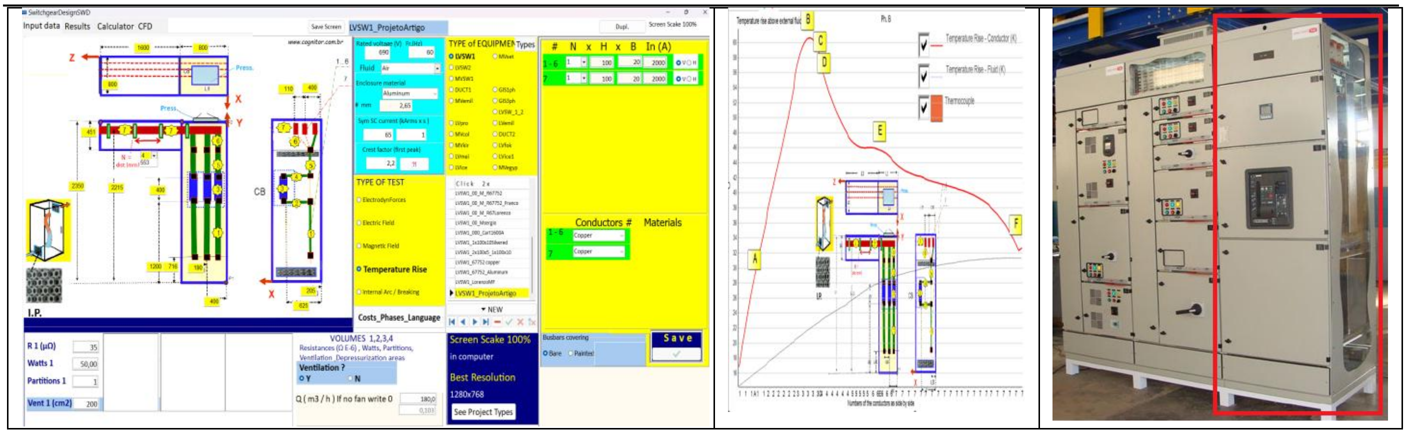
Figure 1 – Reference example for the calculations.



1. DESIGN PRINCIPLES TO DEVELOP SAFER & LOWER-COST PRODUCTS.

To develop lower-cost products is good for profits and much beyond this, helps to save materials of the Planet. Saving materials like copper, aluminium & insulators is beneficial for mitigating climate change because minimize the need for new raw materials. These savings reduce greenhouse gas emissions. The best moment for savings and innovations is the design phase. Designs that use less materials are a great opportunity for small and medium-sized manufacturers, since "old designs" predominate in the global sales of large international manufacturers. The big manufacturers do not focus on improvements that take them out of their comfort zone of decades of consolidated sales. As they coordinate the preparation of IEC/IEEE standards, they do not include in the standards phrases that encourage more efficient projects that use less materials. Designers that reach this vision tends to be well-positioned in the work market. I suggest to readers, when they have some free time, to read this article [Ref [1]) with innovative concepts and ideas. If you like them, please share and practice them https://www.cognitor.com.br/certificate.pdf .

A good reading to open the vision of designers for lower-cost products is this book that I helped to write as coauthor in 2018. It is the Cigrè Brochure 602 (2018) entitled "Contemporary design of low-cost substations in developing countries."

To facilitate the understanding on how to develop safer and lower-cost products, I will use a simplified didactic example of low-voltage panel project as in Figure 1. It is a circuit breaker (CB) column with a normal current of 2000A. It uses 1x100x20mm bare copper bars (without coating), a 180m3/hr fan with a lower and an upper ventilation opening, each 20x10=200cm2. The CB has a power dissipation of 3 x 35µΩ x $(2000)^2$= 420 W (Watts = $3xRxI^2$). Using CBs with higher power dissipation make electric panels to heat more and to use more materials. In these articles [Ref [6]) I explain why https://www.cognitor.com.br/LVcircuitBreakerDevelopment.pdf
and https://www.cognitor.com.br/DevelopingCircuitBreakers.pdf

Under these conditions, during the temperature rise test, the panel reaches the **60K temperature rise limit for bare connections** [Ref. 4,5] in IEC62271-1. When you optimize the design to pass in the test near the limits specified in the technical standard you are reaching the lower cost design because use the minimum necessary weight of busbars.

In this article I show 3 "easy" ways to optimize the design to use less materials. In Table 1 I do the comparisons between these alternatives. The parameter for comparing the projects is the kG/MVA indicator explained in Reference [1,2]. The reader should have in mind that, for each alternative it will be possible to pass more current than the original 2000A attending the same 60K temperature rise limit. That's why the kg/MVA indicator is good. The didactic objective is to use the same original weight but for transmitting considerably more current (lower kg. /MVA transmitted). This design concept can be easily applied with tools like the software SwitchgearDesign. You simply change the types of bars and recalculate the results in few minutes as shown in videos more ahead in this text.

The optimization ways considered here are:
(a) maintain the weight of bars but using 2x100x10 mm instead of 1x100x20mm per phase
(b) to change the brand of the circuit breaker to another one with 50% of the original power dissipation
(c) to increase in 50% the air passage area of ventilation openings.

Other possible optimization ways like the use of metal foams, changes in IP degree, use of coaxial configurations and changing copper by aluminium are more complex and are not presented here. In the test simulations necessary to do the comparisons we use the software SwitchgearDesign to simulate the performance in the tests [Ref. 18].

2. "TEMPERATURE RISE TEST" DEFINES THE WEIGHT OF THE ELECTRIC PANEL / SWITCHGEAR.

The "temperature rise test" is used to verify if the working temperatures of a switchgear and its components are lower than the values that would produce a faster aging of materials. There are also other verifications as the temperatures reached by enclosures that could be touched and hurt the hand of persons like operators or lay people.
For the test, the electric panel is mounted as in normal use. You apply the test current, wait for temperature stabilization and measure the temperatures in some key points. The equipment pass on the test if the temperature rise in the key points are lower than the limits specified in the technical standard. The values of these limits are the key for materials savings. Depending on the materials and coatings used, higher or lower temperatures are permitted in the connections or contacts. The limits are specified in the technical standards tables like the one IEC62271-1 , from which I show here a small part

Table 3.1 (extracted from Table 14 of IEC 62271-1 (2017)) – Some limits of temperature rise for various parts, materials and dielectrics of high-voltage switchgear and controlgear

Nature of the part, of the material and of the dielectric	Maximum value	
	Temperature °C	Temperature rise at ambient temperature not exceeding 40°C K
Connections, bolted or the equivalent		
Bare-copper or bare-copper alloy or bare-aluminium		
alloy	100	60
- in OG	115	75
- in NOG	100	60
- in Oil		
Silver-coated or nickel-coated	115	75
- in OG	115	75
- in NOG	100	60
- in Oil		
Tin-coated	105	65
- in OG	105	65
- in NOG	100	60
- in Oil		
Terminals for the connection to external conductors by screws or bolts (refer to points 8 and 14)		

Attention: Be careful with the confusing and poorly written IEC 61439 table. It induces to errors like in the Ref. [4,5]. The table in IEC62271-1 is very good and clear.

The best world document I know to understand the principles is IEC TR 60943:1998 - Guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals. The document is intended for guidance in estimating the permissible values for temperature and temperature rise of component parts of electrical equipment carrying current under steady state conditions.

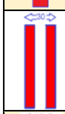
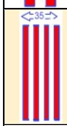
The table from IEC62271-307 for the extension of the validity of test reports enables us to understand the key design factors for temperature rise tests.

The "Temperature Rise Test" determines the conductor weight of materials used in the products design because, if the limits that you cannot go above are lower, you need to use more conductor material to reach the limit. If the limits are higher, you can use less material to pass the test with the same current.
For switchgear of any voltage (IEC61439, IEC 61271) the connections between busbars and to other components, such as circuit breakers and disconnectors, are typically the "hot spots" to pass the temperature rise test. The main factor affecting the temperature rises are the local resistances.

In this 5-minute video I present a resume of the concepts explained in detail in the (not-free) 2-days presential training [16,17]. https://www.youtube.com/watch?v=R28GXw1V9ZY

For whom want to go deeper read this guide: https://www.cognitor.com.br/TemperatureRiseGuide.pdf
Reference [3] is the free book "TEMPERATURE RISE LIMITS used in I E C / IEEE S W I T C H G E A R STANDARDS". Read it in https://www.cognitor.com.br/TemperatureRiseLimits.pdf .

Table 1 - COMPARING PROJECTS ALTERNATIVES WITH THE SAME COPPER WEIGHT. Using testing simulations with SwitchgearDesign for a temperature-rise in the hot-spot equal to 60K
Original design with CB column at 2000 A with 1x100x20mm bare copper bars (without coating), a 180m3/hr fan forcing air through ventilation opening, each with 20x10= 200cm2. CB power dissipation of 420 W.
The more economic alternatives are the ones with lower kg. /MVA

	Design alternative.	Current to reach 60K (Amperes)	Weight kg	Kg/MVA
	Original design with a solid copper bar 1 x 100 x 20 mm per phase	2000 A	220	**136** (100%)
	Alternative with a solid copper bar 2 x 100 x 10 mm (instead of 1x100x20)	2360 A	220	**115** (85%)
	Alternative with a solid copper bar 4x 100 x 5 mm (instead of 1x100x20)	2800 A	202	**97** (71%)
	Changing brand of the circuit breaker to another one with 50% of the original power dissipation (210 W instead of 420W) Original bars	2400 A	22	**113** (83%)
	Increasing in 50% the air passage area of ventilation openings. (300cm2 instead of 200cm2) Original bars	2100 A	22	**129** (94%)

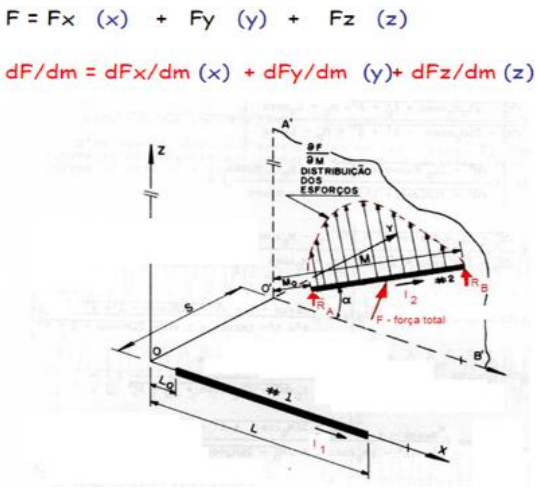
3. SHORT CIRCUIT FORCES (ELECTRODYNAMICAL) DEFINES THE TYPES AND NUMBER OF INSULATORS

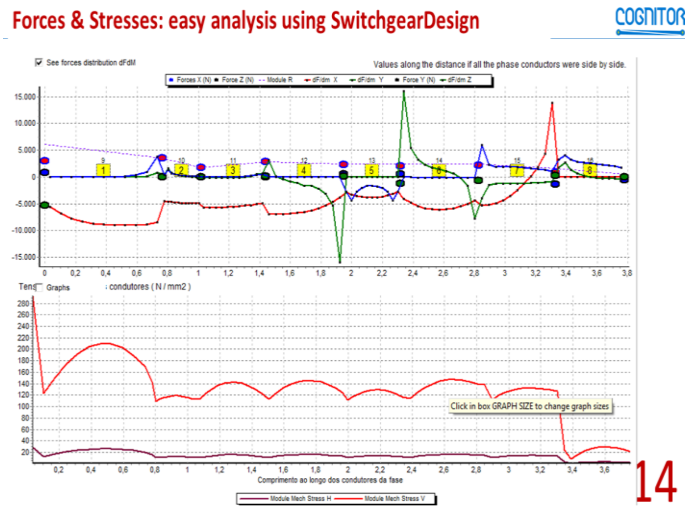
For whom want to understand the details of forces calculations methods the best way is to read my free article “SHORT CIRCUIT CURRENTS FORCES: from switchgear, electric panels & busways to MHD propulsion systems” in this link. It is possibly the more complete (and readable by humans) that you will find in the world-wide technical literature. https://www.cognitor.com.br/ElectrodynamicForces.pdf

In this 8-minute video I present a resume of the concepts that I explain in detail in the (not-free) 2-days presential training [16,17]. https://www.youtube.com/watch?v=CRPopRlyjPc

What happens is that when you circulate an electrical current in the electric conductor #1 it creates a magnetic field around. When this magnetic field touch the neighbour conductor #2, also circulated by a current, a force is produced. The equations to calculate are presented in the article and used in the software SwitchgearDesign to check and sum the contributions of the dozens of conductors inside an electric panel.

The electrodynamic forces acting on busbars and supports, are proportional to the square of the currents and the inverse of the distances between busbars. So, smaller switchgear means higher forces and more insulator supports to reduce risks





The magnitude of short circuit currents continuously grow in the last decades. As there is still an insane desire to make switchgear, switchboards, and panels smaller and smaller this means that our electrical circuits will become increasingly dangerous and unsafe. Also, internal arcs trend to become each time more dangerous (lower volumes = higher overpressures). When you calculate the electrodynamical forces (upper part of the chart) and mechanical stresses (lower part) inside an electric panel you get values like in the left figure that you will compare with the supportability of the insulators to break and the conductors to bend. Take a look in this video to understand. https://www.youtube.com/watch?v=2j8D_N1v0tU

The way to optimize a certain design is long to explain here but basically consists in reducing the number of insulators and checking if the forces and stresses remains below the supportability of insulators (catalogue) and the mechanical strength of the conductors materials. This can be done in minutes looking to the SwitchgearDesign charts like above.

4. INTERNAL ARC TESTS DEFINE THE SAFETY OF PEOPLE AND OPERATORS ABOUT EXPLOSIONS AND FIRES

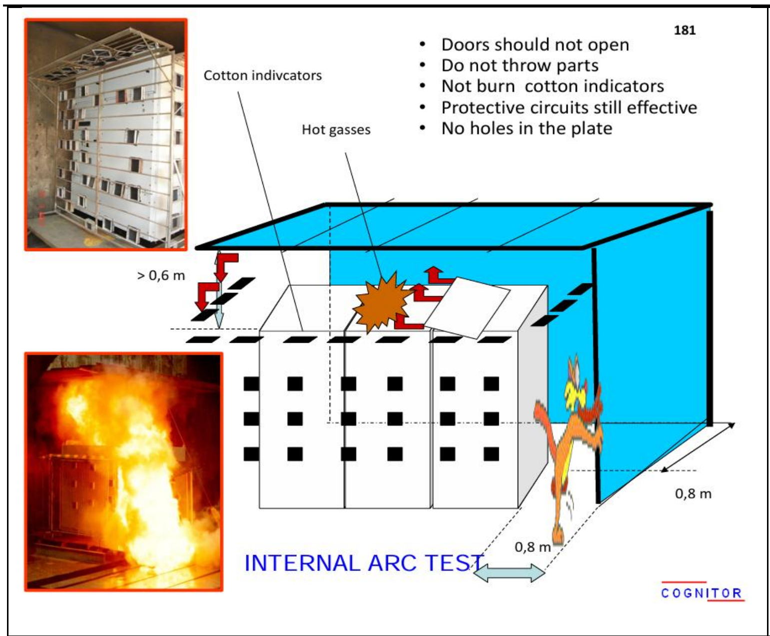
In this 5-minute video I present a resume of the concepts that I explain in detail in the (not-free) 2-days presential training [16,17]. https://www.youtube.com/watch?v=mTpPBkCBAQ8

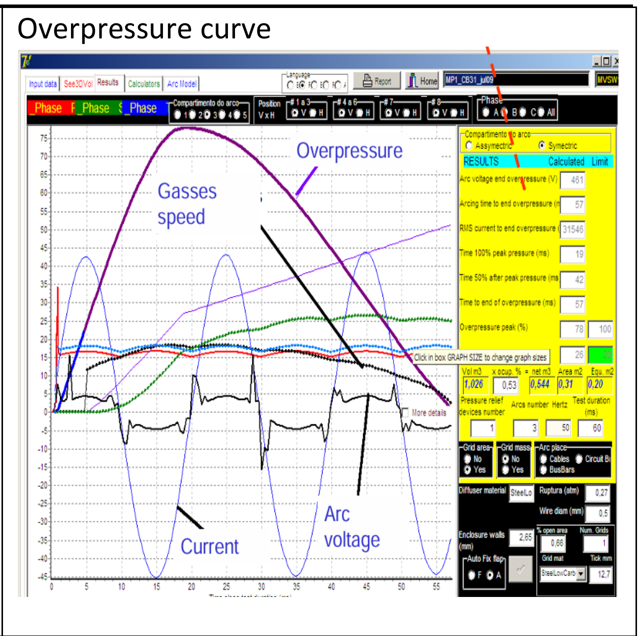
For whom want to understand the details of internal arc calculation methods I suggest start reading this my article https://www.cognitor.com.br/LVinternalArcGuide.pdf . The most complete document for understanding the processes is reference [13] CIGRÈ Brochure 602 (2014). I am coauthor of it.

Internal arcing is an extreme event that, although IEC standards state that it is rare, occurs with some frequency. Switchgear technical standards like IEC62271-200 and IEC TR 61641 specify tests to classify (like IAC) products according to their capacity to withstand the effects of overpressure, such as accidents with people and equipment in the vicinity.

The test consists of creating an arc between the phases of the busbars using a thin wire. This wire is there to represent things as diverse as a tool left on the busbars during a circuit de-energization for maintenance or the occurrence of a dielectric discharge that causes a path for a short circuit.

The high temperatures of the arc vaporize the copper and other materials adjacent to the busbars. Small volumes of solid, once vaporized, increase in volume by about 15,000 times. It is as if we had a closed metal box with air at a pressure of 1 bar and, in less than 20 milliseconds, another equal volume of air was injected into it, adding to what was already there. This causes the pressure to suddenly rise from 1 bar to something like 2 bar. In enclosures made of sheets of the order of 2.5 mm, when the internal pressure reaches around 1.2 bar, the depressurization windows begin to open. If they are well dimensioned, an equilibrium condition is reached in which all the copper gas generated can escape and the pressure returns to about 1 bar, as in this figure taken from page 181 of this reference book.
https://www.cognitor.com.br/Book_SE_SW_2013_ENG.pdf (free reading)





The arc, once started at a certain point, moves in the opposite direction to the voltage source. During its duration, three effects occur that cause impacts to the panel and people nearby. **The first effect** is the overpressure caused by the internal creation of gases. This can damage and open the panel doors or cause the walls to deform. The walls are made of sheet metal, and the enclosure is sealed by screws spaced at a certain distance. The mechanical withstand ability of the enclosure increases as the wall thickness increases. If the distance between the screws is smaller, the deformation of the plates between each two adjacent screws will be smaller.

The second effect is what we call "burnthrough". The moving arc can eventually stop at a screw or at an arc barrier. If it stops, the local metal material is melted and vaporized by the very high temperatures. A stopped arc can create a hole through which the hot pressurized gases can flow out of the enclosure.

The third effect is the reaches of hot gases and particles that will be ejected through the pressure relief devices. This is directly related to the values and duration of the overpressure. This effect cannot be reliably simulated.

To evaluate the effects of the arc, we use two “performance indicators” to allow us to estimate whether a given design will be approved. These indicators are the peak value of the overpressure and the integral of the overpressure x time curve. The limits used for the indicators are based on the experience of this consultant in previous tests and calculations. The acceptable limits are values for which there are records of successful tests already carried out. This does not mean that they cannot be exceeded, but rather that there are no results yet showing that they can be exceeded. The smaller the internal volume, the lower the overpressure. The depressurization area is also a key factor. The larger the area, the lower the overpressure.

The way to optimize a certain design is long to explain here but basically consists in defining the area of the depressurization openings and their speed and checking if we remain inside the supportability limits.

5. HOW CAN IEC TR 62271-307 HELP DESIGNERS UNDERSTAND WHAT IS REALLY IMPORTANT?

Here I suggest the readers to just read the article in Reference [19]
IEC TR 62271-307 – Extension of the validity of type tests to avoid tests repetitions. https://www.cognitor.com.br/IEC62271307ENG.pdf

There you have a good explanation about the IEC document tables and how to use them for preparing extension of the validity reports. I am coauthor of IEC TR 62271-307 and helped the IEC working group to write it. I learned a lot there and use this knowledge to do “extension of the validity reports” for many companies all over the World.

5. FINAL COMMENTS

I hope this text can be useful to switchgear designers and developers all over the World.
Please share it for the benefit of more people. Wait for the next training article

-- end of article -- --

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