SUBSTATIONS, ELECTRIC PANELS, SWITCHGEAR AND BUSWAYS: SOME "TRICKS" TO IMPROVE YOUR PROJECT

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1. SEVERAL RESOURCES LITTLE USED

There are good opportunities to optimize the design that allow for considerable cost savings by increasing normal and short circuit current carrying capabilities. These techniques are even useful for refurbishing old equipment, allowing you to postpone investments in new equipment.

Often the manufacturer realizes the opportunity to make improvements but hesitates when thinks that will have to repeat the expensive high-power laboratory tests. However, there is something new: users and buyers of equipment are increasingly accepting to replace expensive laboratory tests by extrapolation studies of test results. These studies are prepared to verify, based on the test report of an equipment already tested, whether or not another equipment not tested would be approved in the same tests. More and more companies are accepting these studies to avoid lab tests. IEC documents such as the still little known IEC62271-307 show the parameters to consider in these studies.

Today it is proven that almost all major tests (except for circuit breaker and fuse breaking tests) can advantageously be replaced by simulations that yield information even more complete than actual tests. Regulations are beginning to emerge in countries to accept simulations in place of tests like temperature rise, internal arc and short-time current withstand (short-circuit electrodynamic forces).

The striking fact is that test simulations cost less than 20% of the real laboratory test, not including transportation and other costs.

Some examples of using these optimizations are below. These are techniques that do not require investments and just need creativity and good knowledge of engineering concepts:

- Create or increase the ventilation area to achieve the same temperature rises but using higher currents.
- Paint or coat buses to improve heat dissipation
- Improve electrical contacts to decrease unwanted heat generation and extend service life.
- Direct airflow to warmer points reducing temperature rises
- Modify some-part materials to reduce magnetic induction heating effects
- Modify geometries to reduce magnetic, electrical fields, and short circuit electrodynamic forces (and can increase bearable short circuit levels)
- Modify design to improve or increase the ability to support internal arcs.
- Use simple devices to reduce electric fields and thus use shorter phase-to-ground and phase-to-phase distances (more compact equipment)

2. THE TECHNIQUES AND "TRICKS" TO IMPROVE THE DESIGN

The key-points are the requirements for temperature rise, electrodynamic forces supportability, internal arc overpressures and dielectric distances. All these ones have to do with the geometries, construction details and materials used. To understand them read IEC 62271-307. I, the author of this article, participated directly in the creation of this document being a full member of the IEC Working Group which prepared it.

Temperature rise: The reference parameter is the temperature rise of conductive and insulating parts that cannot be exceeded. If you exceed the limits specified in the technical standards, the equipment ages prematurely. For example, the allowable temperature rise limit for a silver-plated connection on a copper busbar is 75 K. For a bare, uncoated copper connection, this limit is 50K. The freely downloadable article at this link has interesting details about low voltage switchgear http://www.cognitor.com.br//TemperatureRise_IEC61439Mistery.pdf

Applying a permanent overload such that the temperature rise is only 6.5 degrees above these limits will result in a life loss of about 2/3. If we extrapolate this concept to life, it means getting two to three contacts and connections, rather than one, in the period. To understand the details, see pages 101 to 116 of the complete free book at http://www.cognitor.com.br/Book_SE_SW_2013_ENG.pdf . This book is a unique publication for designers of equipment for substations.

Electrodynamic forces: The smaller the phase distances and the greater the distance between busbar supports, the greater the efforts. Too many curves increase efforts.

Internal arc overpressures: The smaller the internal volumes and the smaller and slower the overpressure relief areas the greater the overpressures. Higher and longer short circuit currents have more severe effects on the overpressure to be supported by the walls.

We will use as examples the four models shown in Figures 1 to 4. Some of their features are:

Figure 1 - The first model corresponds to a low voltage panel widely used all over the world. It is composed of busbar and an input circuit breaker. Typical values of rated voltage rated current and short-term withstand current for this type are 380 V - 3200 A and 65 kA. In this analysis, nominal currents in the range of 2000 - 3000 A will be considered depending on whether or not ventilation is provided. This type of project generally has very close busbars which means high electrodynamic stresses during short circuits. The market is increasingly demanding that this type of equipment be able to support internal arcs.

Figure 2 - This is a 3-compartment air insulated medium voltage (AIS) switchgear (cables, circuit breaker and bars). Typical values of rated voltage rated current and short-term withstand current are 15kV - 1250 A and 31,5 kA. Internal arc rating is most often required, and it is often a fully enclosed panel with no ventilation openings.

Figure 3 - This model is a three-phase generator busduct that generally has an aluminum outer shell. Internal conductors are generally tubular and can be aluminum or copper.

Figure 4 - The fourth model is a conventional 145 kV substation made up of aluminum tubular conductors.

The dimensions and materials used can be seen on the right side of each figure. We will demonstrate the possibilities of gains by simply changing some design parameters shown in these figures.

Figure 1 – Low voltage panel – 480 V – 2000 A – 50kA

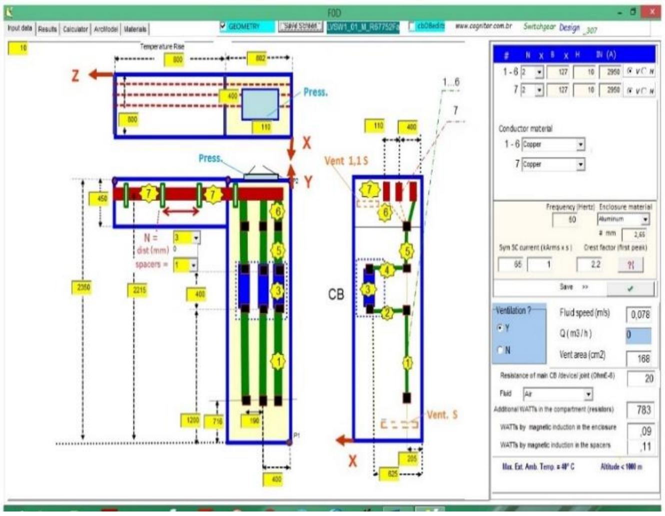


Figure 2 – Medium voltage switchgear 15 kV – 31,5 kA

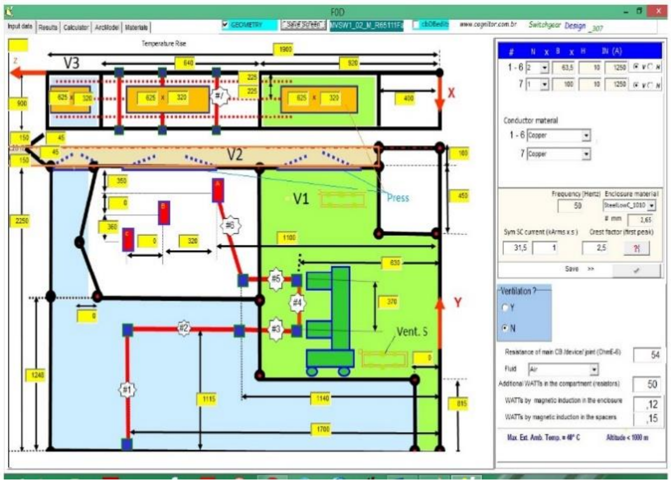


Figure 3 – Generator bus-duct AIS

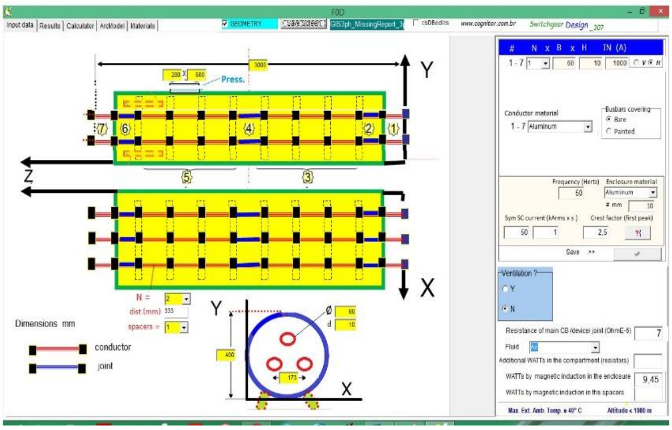
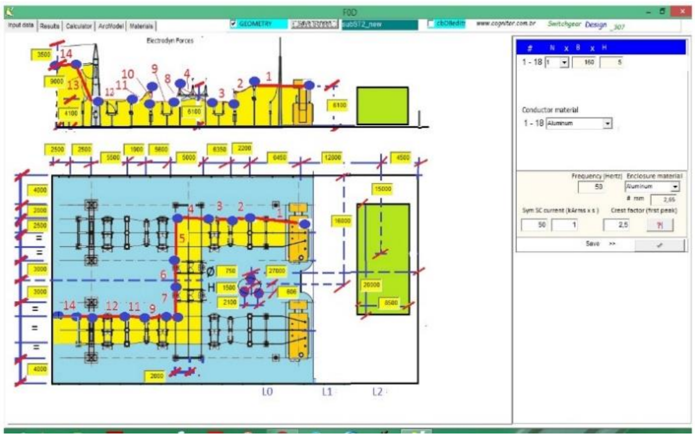


Figure 4 – Substation 145 kV



3. CREATE OR INCREASE THE VENTILATION AREA TO ACHIEVE THE SAME TEMPERATURE RISE BUT USING HIGHER CURRENTS.

This is simple to implement because it does not imply disassembling internal parts such as busbars and control wiring. For this example, we use the low voltage panel of Figure 1. It has 2x127x10 copper bars with no ventilation openings and no coating of the bars by painting or thermoplastic material. It has a nominal current of 2000 A and, in this current, in the temperature rise test, has a critical point elevation of 72 K. It is therefore slightly below the threshold for being approved in the test (75K in a silvered connection). The circuit breaker, which is the main heat source, has 20 μΩ resistance per phase, viewed from the terminals. In addition to this circuit breaker there is 780 W more power dissipation on other internal components.

Imagine that, keeping all the internal components, we simply opened a vent opening of 17X10 cm (area = 170 cm2) at the top and bottom of the column. In this opening we would put only a simple shutter that allowed the free air intake area to be only slightly reduced. We would not put in complicated air filters that would block most of the air passage and eliminate the gains from creating the openings. Here there are no difficult questions associated with the IP degree.

The results are shown in Table 1. To achieve the same temperature rise, a 30% higher current (2600 A) could be used simply by having the opening without forced ventilation. If we included, in addition to the opening, also a 180 m3 / h exhauster we could pass a 47% higher current (2950 A) maintaining the same temperature rise. It is a considerable and simple gain to realize in the project, without spending almost anything.

Demonstrating this through laboratory testing would be costly but with testing simulations one can study even more alternatives within minutes. Just use creativity added to some inexpensive software like the lightweight SwitchgearDesign https://www.youtube.com/watch?v=l2kROAX5Ajc

Table 1 - Gain by simply adding a ventilation area - with and without forced ventilation - Permissible temperature rise of 75 K at connection (results in Figure 5)

Type of construction, currents and gains	Original switchgear No ventilation opening	Modified With ventilation opening 168 cm² - no forced ventilation	Modified With ventilation opening 168 cm² - with a exhauster 180 m³/h
Current Gain	2000 A	2600 A (+ 30 %)	2950 A (+ 47 %)
Temperature rise in the connection	72 K	72 K	73 K

4. PAINT OR PUT COATING IN THE BUSBAR TO IMPROVE HEAT DISSIPATION CAPACITY

This change is interesting in many low and medium voltage busducts. Table 2 shows the impacts for the same situation as in Figure 1. For bar painting the gain is 20% in the current. If we add to this, the benefit of the ventilation, we can reach very significant current increase values.

Table 2 - Gain by painting or coating the bars (parameter = temperature rise)

Type of construction, currents and gains	Original switchgear No ventilation opening	Modified without ventilation opening but painted bars	Modified with ventilation opening 168 cm² - with a exhauster 180 m³/h and painted bars
Current Gain	2000 A	2200 A (+ 10 %)	3100 A (+ 55 %)
Temperature rise in the connection	72 K	72 K	73 K

5. IMPROVE ELECTRICAL CONTACTS TO REDUCE HEAT GENERATION AND INCREASE LIFE.

Electrical contacts, in the case of circuit breakers or switches, and power dissipation in the case of fuses are the major impact factor on internal temperatures. It can be a simple or complex design change. Switching a circuit breaker from withdrawable type to fixed type can mean a large reduction in dissipated power.

Changing the breaker mark can also have a positive impact, but care must be taken in the interruption aspects. A circuit breaker approved on one panel type may perform poorly on another panel type because the geometries and distances are different.

Figure 2 shows a medium voltage panel without ventilation openings. Table 3 shows the currents that could be applied to obtain the same temperature rise if the circuit breaker originally had 54 µΩ resistance per phase, seen from the terminals, and was replaced by another one with 40 µΩ.

Table 3 - Current gain by switching circuit breaker type (fixed or withdrawable from 54µΩ to 40µΩ - Figure 6)

Type of construction, currents and gains	Original 54 µΩ	Modified to 40 µΩ
Current Gain	1250 A	1400 A (+ 12 %)
Temperature rise in the connection	72 K	73 K

6. DIRECT AIR FLOW TO HOTTEST POINTS REDUCING TEMPERATURE RISE

This action as well as the placement of local heatsinks in the connections to circuit breakers, switches or fuses bring considerable performance gains, but will not be detailed here.

7. MODIFY MATERIALS TO REDUCE MAGNETIC INDUCTION EFFECTS.

For panels and busbars with currents greater than 3000 A, attention should be paid to the materials used in the enclosures and metal busbar spacers. The use of magnetic materials, such as carbon steel, rather than non-magnetic

materials, such as aluminum and some types of stainless steels, produce induction heating effects, which are added to normal rise due to busbar currents circulation.
In Figure 3 there is a three-phase, high-current air-insulated generator bus. Table 4 shows the temperature rise values that would be obtained if the enclosure were made of aluminum or carbon steel. In the case of carbon steel, the effects of magnetic induction are much greater. For this same reason, spacers composed of insulating and metallic materials used in low-voltage switchgear should be given special attention. As they are very close to the bars they are subjected to very high magnetic fields. Without the use of non-magnetic material, eddy currents may occur which increase temperature elevations.

Table 4 - Uses of magnetic or non-magnetic materials in enclosures and spacers (Figure 7)

Type of construction, currents and gains	Carbon steel enclosure	Aluminum enclosure
Current	1000 A	1000 A
Temperature rise in the connection	72 K	38 K
Temperature rise in the internal air	31K	16 K
Power dissipation in enclosure by Magnetic induction	306 W	9,5 W

8. MODIFY GEOMETRY TO REDUCE MAGNETIC FIELDS AND SHORT CIRCUIT FORCES AND MAY INCREASE SUSTAINABLE SHORT LEVELS

Fields cause impacts such as electrodynamic forces (magnetic fields) on buses and their supports as well as dielectric distances and overall dimensions of equipment and entire substations (electric fields). In Figure 4 there is an example of substation arrangement. Various gains can be obtained by changing positions and dielectric distances. Figure 7 shows the magnetic field mapping in the substation. Figure 9 shows an improvement in dielectric capability by a simple construction detail

9. IMPROVE THE ABILITY TO SUPPORT THE OVERPRESSURES OF INTERNAL ARC

In the Recent Cigré 602 Brochure - "Tools for Simulating Internal Arc Effects. This document was published by CIGRÈ International in December 2014. The author of this article, Sergio Feitoza, was one of the co-authors of the brochure that shows the relevant aspects to consider when modifying existing or new equipment designs. In general, these modifications are relatively simple to implement and quick to make.

10. FINAL COMMENTS

The techniques presented here are simple to implement. They only require some creativity and that the designer better know some engineering concepts. Having some simple simulation tool is a must to "test in the factory" rather than in a costly testing laboratory.

Today there are simple test simulation tools like SwitchgearDesign that are little known by equipment manufacturers. They are implementable by quick simple trainings of less than 3 days.

They are inexpensive and can take your business to the next level with real innovations.

The disciplines of a typical training, on these disciplines, can be observed in these links.

https://www.youtube.com/watch?v=l2kROAX5Ajc (presential)

http://www.cognitor.com.br/ChaptersResumePrices2019.html (vídeo lessons)

Figure 5 – Low voltage – 480 V – 2000 A – 50kA

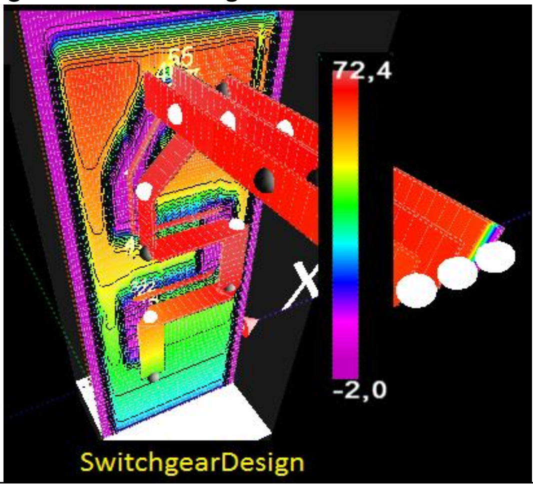


Figure 6 – Medium voltage 15 kV – 31,5 kA

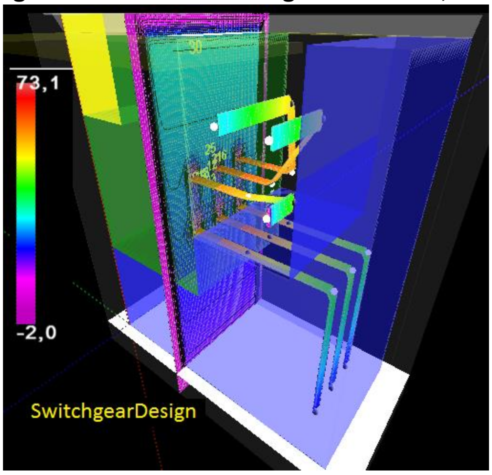


Figure 7 – Generator bus duct

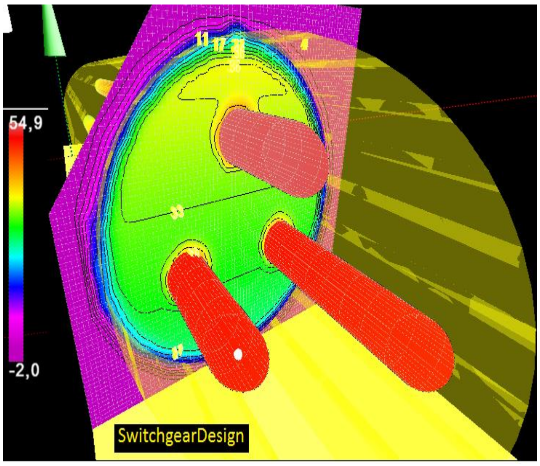


Figure 8 – Substation 145 kV – Magnetic and Electric fields mapping

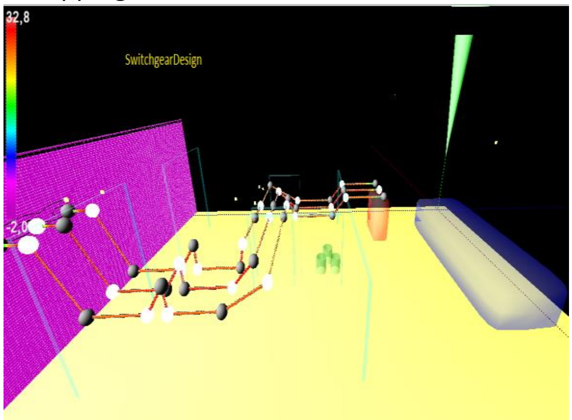
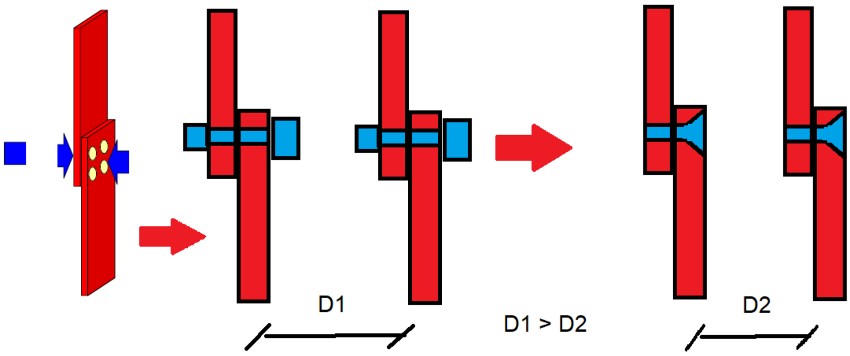


Figure 9 – Reducing dielectric distances with a simple “trick”



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The author of this article is Eng. Sergio Feitoza Costa. Sergio is an electrical engineer, M.Sc. in power systems and director of COGNITOR. It has 35+ years of experience in the design, operation and management of high power, high voltage and other testing laboratories. After leaving activities at CEPEL's testing labs, Sergio gained considerable experience using test simulations to support manufacturers and certification companies in substation equipment projects. He is co-author of several IEC and ABNT standards. Sergio is the author of SwitchgearDesign simulation software and provides consulting services for the development of innovative equipment as well as helping to implement projects from small to large testing labs. Possibly this is the only simulation software made by an engineer with 25 years of experience doing real tests in high power labs.

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