RETROFITTING of IEC 62271 & IEC61439 products

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RETROFITTING: low-cost techniques for more efficient substations equipment

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1. ABOUT RETROFITTING.

I write articles with the aim of helping colleagues who work in the design, testing, certification, and specification of equipment for low to high voltage substations (LV, MV, HV). So, sharing this information is free and welcome.
This article is about techniques for retrofitting substation equipment. More than postponing investments, using sound concepts and creativity, you can even get a more efficient product than the original. Retrofitting is like renovating your old car instead of buying a new car. We need a performance indicator to allow for serious comparisons. I use the weight of the equipment divided by the transmitted power (kG/MVA).

Many electrical equipment that has been in operation for 15-30 years can be used longer and perform better by making relatively simple modifications. The reason is that, before these difficult years now, it was common to design and market over dimensioned equipment. Sometimes it was due to a vision that the system would grow and sometimes it was simply because of an excessive specification. As energy consumption and power grids grow fast, the levels of rated and short-circuit currents grow as well and thus parts of the installation may become insufficient or without an acceptable safety margin. Remember that when an equipment is originally tested it is new and stronger.

Switchgear, controlgear and switchboards are good examples to show what is possible to do with retrofitting. Replacing an old item in an industrial facility with hundreds of control cables is a difficult task. The biggest problem is not the value of the investment in the new equipment, but the great work and lost production time necessary for the replacement, for example of cables by optical fibres.

Here we will focus on relatively simple reforms that do not involve a long time of execution and downtime. The idea is to show, by testing simulations, the positive effects of:

- Creating or increasing the ventilation area using higher currents but maintaining or reducing previous temperature rises.
- Painting or coating busbars to improve heat dissipation capability
- Improving connections or contacts to decrease heat generation and increase service life.
- Directing the air flow to hotter spots reducing temperature rises
- Modify the design to improve or increase the ability to support internal arcs.
- Reducing the number of supports and insulators (remember high buildings)
- Modify materials to reduce the effects of magnetic induction heating

• Modify design parameters to reduce short-circuit magnetic, electrical, and electrodynamic forces and be able to increase short-circuit levels

These techniques require low investment, if using creativity and good knowledge of engineering calculations you use testing simulations instead of expensive laboratory tests. The design parameters that must be considered are related to temperature rises, electrodynamic stresses, internal arcs, and dielectric distances. They all have to do with the geometries and materials used. The relevant design parameters are detailed in IEC 62271-307 [4] of which I am the honour of being co-author.

With regard to temperature rise the key aspects are the rise limits of conductive and insulating parts that cannot be exceeded. If the limits specified in the technical standards are exceeded, the equipment ages prematurely. For example, the allowable temperature rise limit for a silvered connection on a copper busbar is 75K.

For a bare bolted copper connection, this limit 60 K. In the past, the limit on bare connections was 50K and has been increased to 60K, in IEC62271-1. Recently I wrote an article asking if the 75K value for silvered connections could be increased to 85K. This would mean a much lower weight of conductor materials (lower kg/MVA). Read these articles to understand the benefits of reducing temperature rise. If you manage this well the other things are easy to do.
http://www.cognitor.com.br/bareconnections.pdf
http://www.cognitor.com.br/silvered.pdf

Remember that using a permanent overload on the busbar such that the temperature rise is only 6.5 K above these limits, there will be a loss of useful life on the order of 2/3. If we extrapolate this concept to the useful life, this means acquiring 2 to 2 pieces of equipment, instead of one, in a given period of time. To understand the details, see pages 101 to 116 of my free book [4]. To explain the retrofitting concepts, I will use the models in Figures 1 to 4.

Figure 1 corresponds to a LV switchgear with a busbar and a circuit breaker. The typical value of rated voltage and current and short-time withstand current ratings are 380 V – 3200 A and 65 kArms. Here I consider rated currents in the range of 2000-3000 A with and without ventilation. This design has busbars very close together, which means high electrodynamic forces during short circuits. The market increasingly asks for this type of equipment to be able to withstand internal arcs.

The second model (Figure 2) corresponds to a medium voltage panel. It consists of 3 compartments (cables, circuit breaker and bars). Typical ratings are 15kV – 1250A and 40kA. Internal arc rating is required and may be a fully enclosed panel with no ventilation openings.

The model in Figure 3 corresponds to a 3-phase generator busduct with an external aluminum enclosure. The inner conductors are tubular and can be aluminum or copper. The model in Figure 4 is a conventional 145 kV substation formed by aluminum tubular conductors. The dimensions and materials used can be seen on the right side of each figure. We will demonstrate the improvements by simply changing some design parameters shown in the figures.

Figure 1 – LV switchgear – 480 V – 2000 A – 50kA

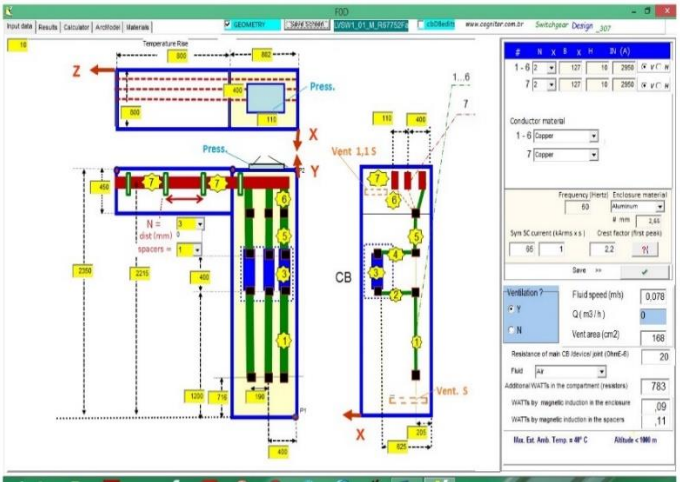

Figure 2 – Medium voltage switchgear 15 kV – 31,5 kA

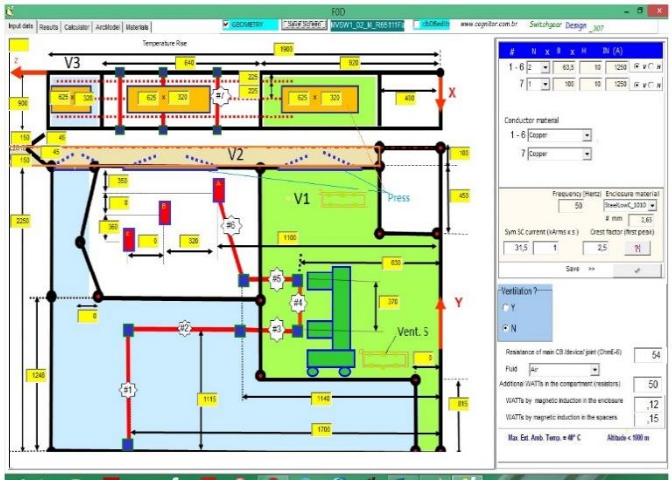

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Figure 3 – Busduct for generator AIS

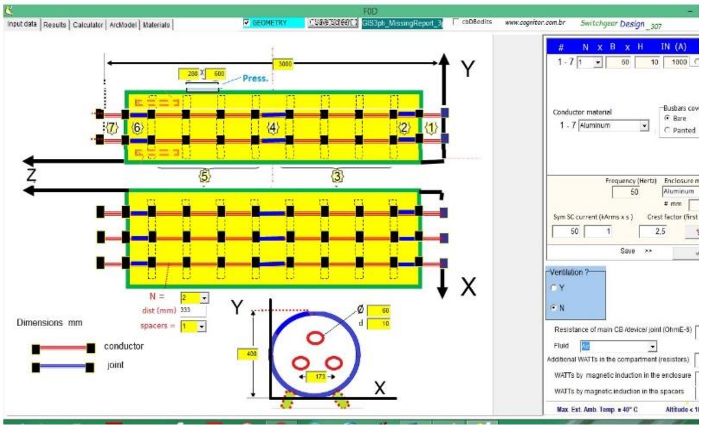
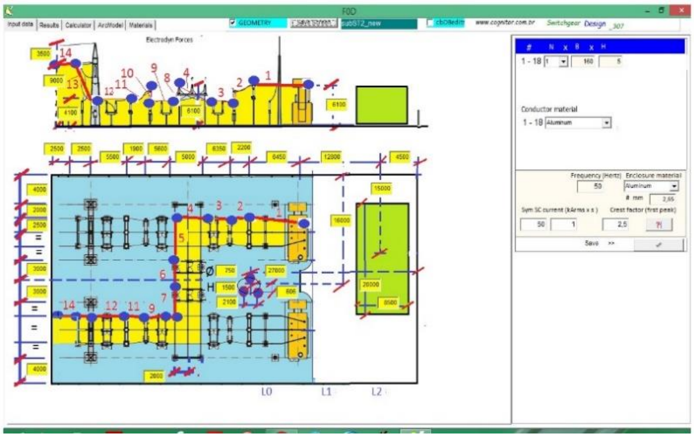


Figure 4 – Substation 145 kV



2. CREATE OR INCREASE THE VENTILATION AREA TO ACHIEVE HIGHER CURRENTS AT SAME TEMPERATURE RISE.

This is a simpler design change to implement with a few days' downtime. It does not involve dismantling internal parts such as busbars and control wiring. Look the LV panel in Figure 1. It has 2x127x10 copper bars without ventilation openings and without covering the bars with paint or thermoplastic material. The rated current 2000 A produce a temperature rise 72K at the critical point. It is therefore slightly below the limit to pass the test (silver connection 75 K). This connection is close to the main circuit breaker. The circuit breaker CB is the main heat source having 20 µΩ of resistance per phase, as seen from the terminals. In addition to this CB there are additional 780 W power dissipation in other internal components.

Imagine that, keeping all the internal components, we simply opened a ventilation opening on the order of 17X10 cm (170 cm2) at the top and bottom of the column. In this opening, we would place a simple shutter to allow the free area for air entry to be reduced a little. We wouldn't put in complicated air filters that would block most of the air passage and eliminate the gains made from the work of implanting the opening. This is not a new panel where all issues associated with the IP grade need to be addressed.

The results are in Table 1. Note that to obtain the same performance in terms of temperature rise, a 30% higher current (2600 A) could be used simply because of the opening, without forced ventilation. If we included, in addition to the opening, a 180 m3/h exhauster, we could pass 47% more current (2950 A) at the same temperature rise. Demonstrating this through laboratory tests would be costly, but with well-done test simulations, the most promising solution can be studied for each specific case.

Table 1 - Adding a free ventilation area with / without forced ventilation (limit 75 K in the connection - see Figure 5)

Construction and gains	Original panel without ventilation opening	Modified to include a small 170 cm^2 vent opening (Without forced ventilation)	Modified to include a small 170 cm^2 vent opening (With forced ventilation - exhauster 180 m^3/h)
• Current • Gain	2000 A	2600 A (+ 30 %)	2950 A (+ 47 %)
Temperature rises in connection	72 K	72 K	73 K

3. PAINTING OR COATING BUSBARS TO IMPROVE HEAT DISSIPATION CAPABILITY

This is not a simple change to make as it would imply dismantling the busbars and, therefore, stopping the equipment much longer than the 3 days mentioned in the previous section. However, it can be interesting in some situations of LV and MV installations. Table 2 shows the impacts for the same situation as in Figure 1. For bar painting, the gain is higher than 10%. If we add this benefit to that of ventilation, we can reach very significant current increase values.

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

Construction and gains	Original panel without painting	Modified without vent opening but painted	Modified with 170 cm2 and bars painted
• Current • Gain	2000 A	2200 A (+ 10-14 %)	3100 A (+ 55 %)
Temperature rises in connection	72 K	72 K	73 K

4. IMPROVE ELECTRICAL CONNECTIOS / CONTACTS TO DECREASE HEAT AND INCREASE SERVICE LIFE.

The electrical contacts of the switching device, in the case of circuit breakers or switches, and the power dissipation, in the case of fuses, are the factor with the greatest impact on the internal working temperatures. I strongly recommend to designers to read the details of IEC6043, IEC60890 and IEC62271-307. In my trainings I put a strong focus on this. Depending on the situation, it can be a simple or complex design change in terms of downtime for its implementation.

Changing a circuit breaker from a withdrawable type to a fixed type can mean a large reduction in dissipated power. Changing the circuit breaker brand can also have a positive impact but great care must be taken in the interruption aspects. A circuit breaker approved in one type of panel may perform poorly in another type of panel because the geometries and distances are different.

In Figure 2 we show a typical MV panel. Table 3 shows the currents that could be applied to obtain the same temperature rise if the circuit breaker originally had 54 µΩ of resistance per phase, seen from the terminals, and was replaced by another one with 40 µΩ of resistance per phase.

Table 3 - Current gain by changing the type of circuit breaker (extractable / fixed or changing manufacturer - Figure 6)

Construction and gains	Original panel with a circuit breaker **54 µΩ per phase**	Modified panel with a circuit breaker **40 µΩ per phase**
• Current • Gain	**1250 A**	**1400 A** (+ 12 %)
Temperature rises in connection	72 K	73 K

5. DIRECT AIR FLOW TO HOTTEST SPOTS REDUCING TEMPERATURE RISES

Directing airflow to certain connections as well as placing local heat sinks at connections to circuit breakers, switches or fuses can yield considerable performance gains, around 10%. Due to the space required, explanations will not be detailed here. Write to my e-mail if you need info.

6. CREATE / INCREASE THE VENTILATION AREA TO ACHIEVE HIGHER CURRENTS AT SAME TEMPERATURE RISE.

Use ceilings and areas near to the floor made of metal foam to, without affecting IP grade, improve airflow with noticeable gains in rated current. Read details in this article https://www.cognitor.com.br/switchgearmetalfoam.pdf

7. MODIFY MATERIALS TO REDUCE MAGNETIC INDUCTION EFFECTS.

In panels and busbars with currents higher than some 3000 A, attention should be paid to the materials that are used in the enclosure and in the metallic spacers of the busbars. If magnetic materials such as carbon steel are used instead of non-magnetic materials such as aluminum and certain types of stainless steel, induction heating effects can be very pronounced increasing the internal temperature of the air.

In Figure 3, there is a 3-phase, air-insulated generator busduct carrying high currents. In order to show the effects in a didactic way, we present in Table 4 an estimate of temperature rises that would be obtained if the casing was made of aluminum or if it was made of carbon steel. In the case of the carbon steel casing, the effects of magnetic induction are much greater, and this heats the casing and consequently the internal air. It is for this same reason that spacers

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composed of metallic materials used in LV busbars must be given special attention. As they are very close to the bars, they are subjected to very high magnetic fields. If non-magnetic material is not used, for higher currents, eddy currents will arise that cause heating of the air inside the panel.

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

Construction and gains	Panel with steel enclosure	Panel with aluminum enclosure
3-phase current	1000 A	1000 A
Temperature rises in the connection	72 K	38 K
Temperature rises of internal air	31K	16 K
Power dissipation in enclosure by magnetic induction	306 W	9,5 W

8. MODIFY DESIGN PARAMETERS TO REDUCE MAGNETIC FIELDS AND SHORT-CIRCUIT ELECTRODYNAMIC FORCES, TO INCREASE SHORT TIME AND CREST WITHSTAND CURRENT

Electric and magnetic fields cause important impacts on design aspects such as the electrodynamic forces acting on busbars and their supports as well as on the dielectric distances . Figure 4 is an example of a substation arrangement. Gains in values of electric and magnetic fields can be obtained with changes in positions and dielectric distances. Figure 7 shows the mapping of the magnetic field in the substation.

Figure 5 – LV switchgear – 480 V – 2000 A – 50kA

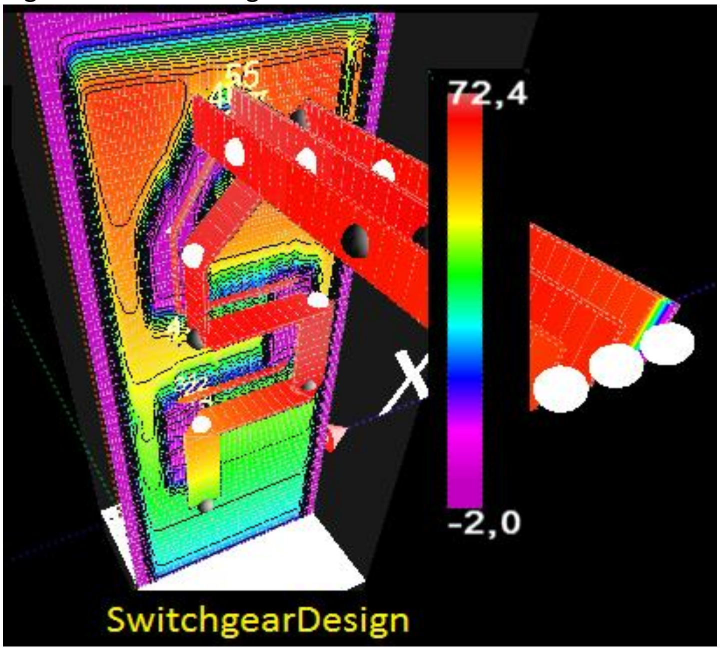
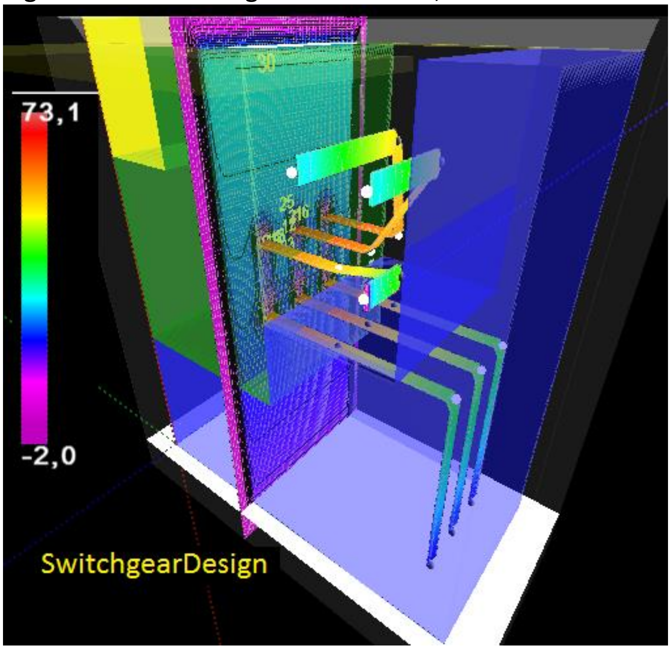


Figure 6 –MV switchgear 15 kV – 31,5 kA



9. IMPROVE OR INCREASE THE ABILITY TO SUPPORT INTERNAL ARC

This topic was detailed in previous articles and in the Brochure Cigré 602 (2014) - Tools for the Simulation of Internal Arc Effects in Transmission and Distribution”. I am co-author of this brochure and also of IEC62271-307 .

These documents show the design parameters and relevant aspects to consider when modifying existing or designing new equipment. In general, these modifications are relatively simple to implement and quick to make. The use of metal foams in the ceiling and top parts enable very interesting solutions. They may serve as heat absorbers during arcs.

Read details in this article https://www.cognitor.com.br/switchgearmetalfoam.pdf

Figure 7 – AIS 3-phase bus duct

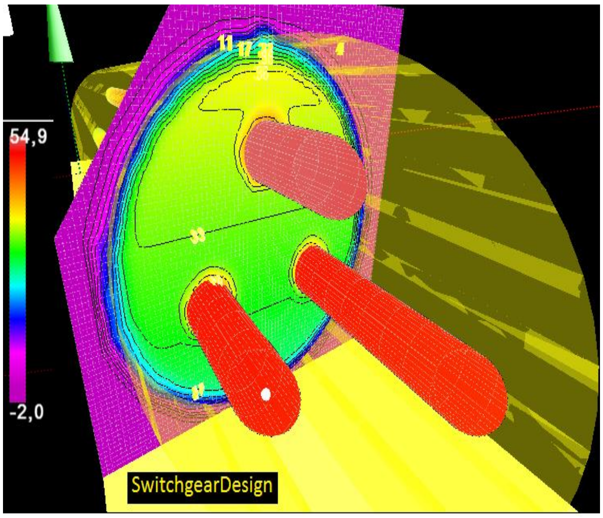
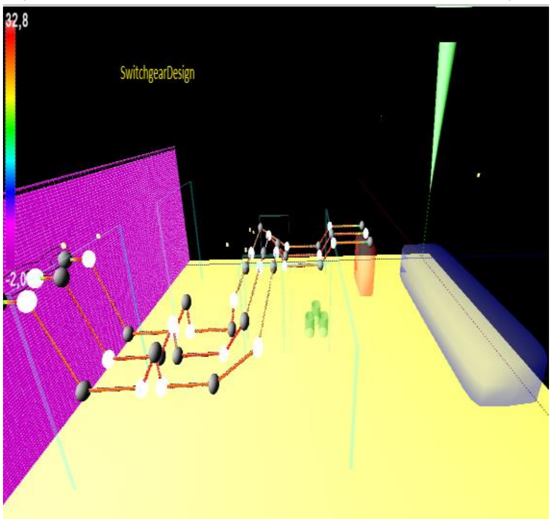


Figure 8 – Substation 145 kV - Magnetic field, electric field (SE, control room, reactors, transformers)



10. FINAL COMMENTS

In these difficult times, it is interesting to be able to offer solutions for the renovation of substation equipment. This is of interest to those who want to postpone new investments. There is an attractive market, especially for small manufacturers. It is better to design new equipment already using these techniques. In the training below I teach how to use these techniques.

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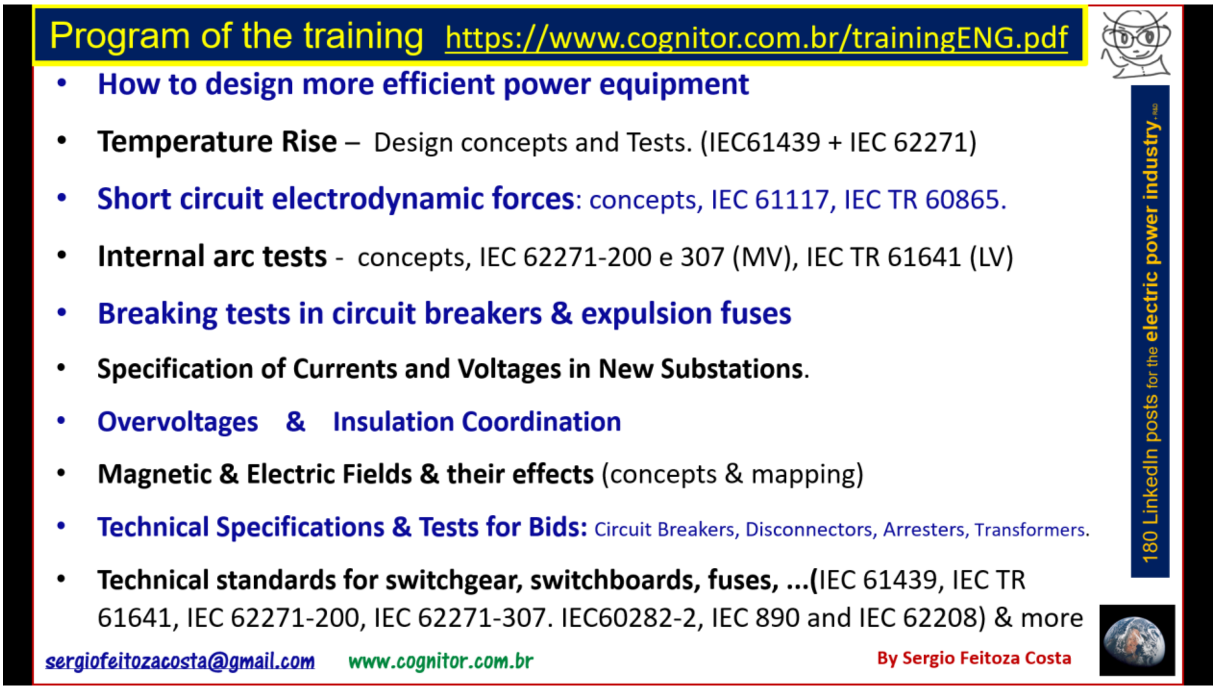
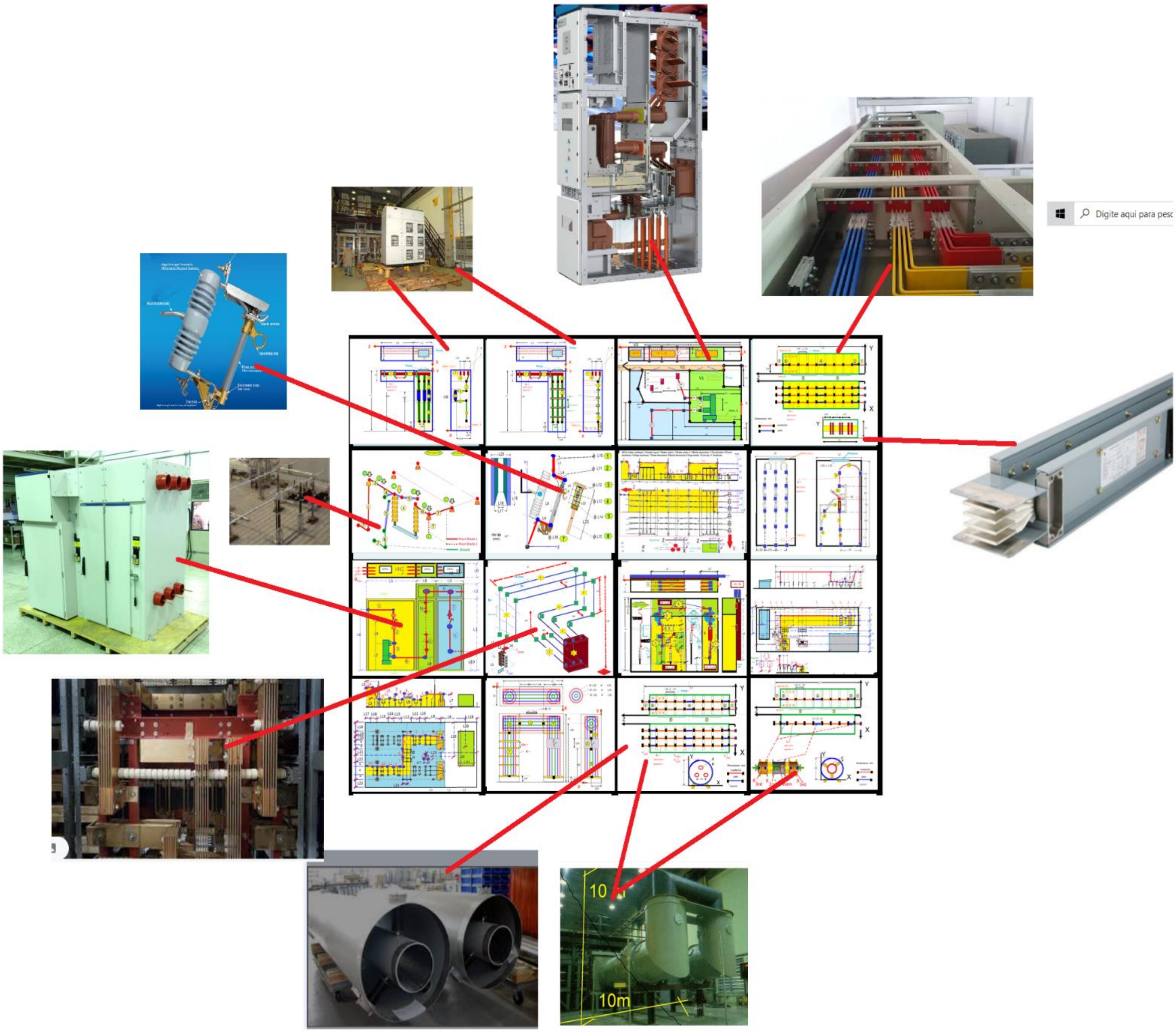
[5] Temperature rise: a guide to learning to design MV switchgear (IEC62271), LV switchboards (IEC 61439)& busways http://www.cognitor.com.br/TemperatureRiseGuide.pd





Some of the possibilities of SwitchgearDesign

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