REPORT **150/2024**

http://www.cognitor.com.br/TR_150_ENG_ValidationSwitchgearDesignSWD.pdf

Training, Installation & **Validation** of **Testing**

Simulations of high-power tests with

Software ***SwitchgearDesign_*** *2024*

Predict results of tests and modify your design to prevent failures in the laboratory (temperature rise, internal arc overpressures, short time and crest current tests, electro dynamical forces / stresses & more)

Sergio Feitoza Costa

Reference standards:

- **IEC 61439-1/2** - Low-voltage switchgear and controlgear assemblies
- **IEC 62271-200** and others in the series (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.
- **IEC TR 62271-307**: High-voltage switchgear and controlgear - Part 307: Guidance for the extension of validity of type tests of AC metal-enclosed switchgear &controlgear for rated voltages > 1 kV & < 52 kV

THINGS I HELPED TO DO along my professional life: https://www.cognitor.com.br/HelpedToDo.pdf

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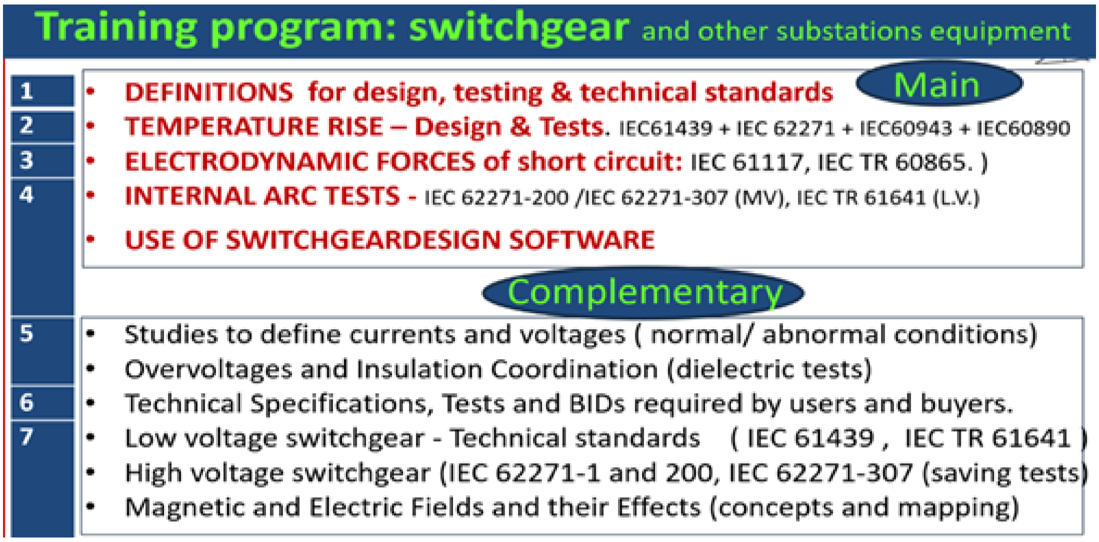
Revisions	Date	Pages	Description
0	July, 30, 2024 (70 years old)	-	First version
1	February 10, 2025		Small changes

1. FIRST, THE TRAINING PROGRAM

Frequently, the clients of our work come with the vision of having in hands the software SwitchgearDesign and knowing how to use it for daily design activities. SwitchgearDesign was developed for easy use. It is based on my 25 years of experience in high-power testing, in writing IEC standards and important Cigrè documents. I also have 23+ years of experience helping manufacturers and certificators to develop and check substation equipment. I do calculations, the equipment is tested and approved and that knowledge feeds back into the software code to make it better. However, the most important part of the consultancy work is the training, unique in the World. There you will learn or review the concepts behind each of the high power / high voltage tests. Understanding these concepts means to be well above the average designers knowledge. Learning this your mind will be more open for challenging tasks like developing innovations and new solutions. So, please start reading this training program. You may choose the points that, along thee training, will be given more emphasis and points that are not of your immediate interest.
The training program is in section 4 of this document https://www.cognitor.com.br/trainingENG.pdf



2. WHAT IS *SwitchgearDesign* AND WHY IT HELPS TO DEVELOP A DESIGN FASTER.

I was lucky to work at CEPEL, the only large test laboratory complex in South America, for 25 years, from 1977. It was from the design of the labs to construction, operation and general management of 14 labs (high power, high voltage, Ex, EMC, materials, etc..). I learned a lot about design, testing, substations equipment and technical standards.

When I left CEPEL, I thought that helping manufacturers of panels, busbars and other substation components with product development and testing, would be an easy task. I soon realized that testing knowledge was not enough to provide high-level support. High-power testing can cost more than USD10,000.00 per day, if you do not fail.

I realized that I needed a tool that could translate design variables as input in reliable results of the more expensive tests. Initially, I used CFD tools. However, they were difficult to learn and use. For two years, I had in hands one of the best software programs in the world at that time, CFDesign. I did not find support to answer my technical questions. The license cost was and still is high. At that time, the CFD developers were very good at equations and numerical methods but knew little about solving substation equipment design problems.

So, I decided to stop representing the CFD software manufacturer and started creating my SwitchgearDesign, which is easy to use and enable to adjust designs to be approved in the laboratory tests. I had already prepared the short-circuit electrodynamic stresses section since the time of the Cepel 300 kArms laboratory project. I learned a lot as an assistant of my friend Dr George Zabludowski, the mentor of the high-power CEPEL's labs.

Just starting to develop SwitchgearDesign, I was called to calculate internal arcing and temperature rise in medium-voltage and high-current 50 kA busducts, for Brazilian oil platforms such as P54 and P56. I had then a real challenge and motivation to complete the software. I have been improving and validating it for the past 20 years based on the test results, after the design review I do for switchgear manufacturers.

The most common work I do is to receive the project drawings, fit them into one of the SwitchgearDesign models I have designed for this purpose and simulate the tests. If something shows that the product will not pass the test, I redefine the project data so that it passes the tests. It costs less than a lab day and avoids the disappointment of not passing and having to repeat the tests. I have been training many people in doing this, all over the world.

Figures 1 and 2 show a typical "input data" screen, the "results" screens for temperature rise, internal arc and short-circuit forces tests. Figure 3 shows typical models for medium and low voltage panels and busbars. The YouTube link for a 4 minutes video showing the basic operations of the software is below.

Figure 1- Typical data entry screen for one of the models

Figure 2 – Results Screen

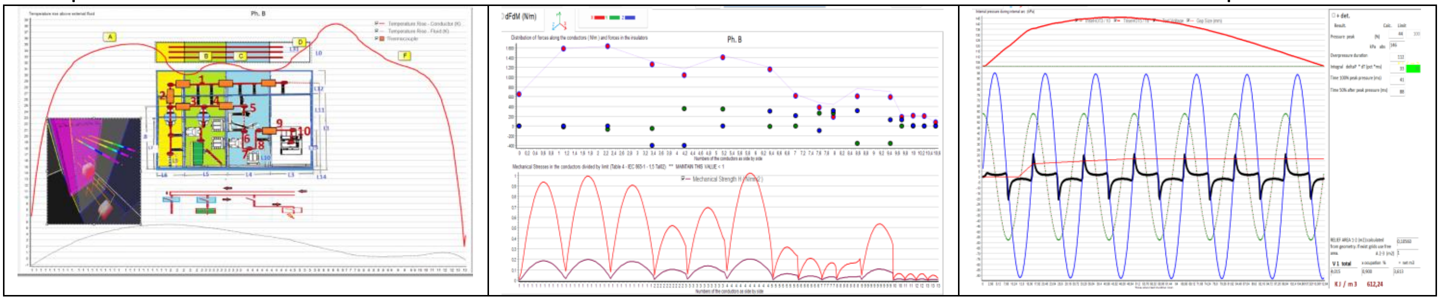
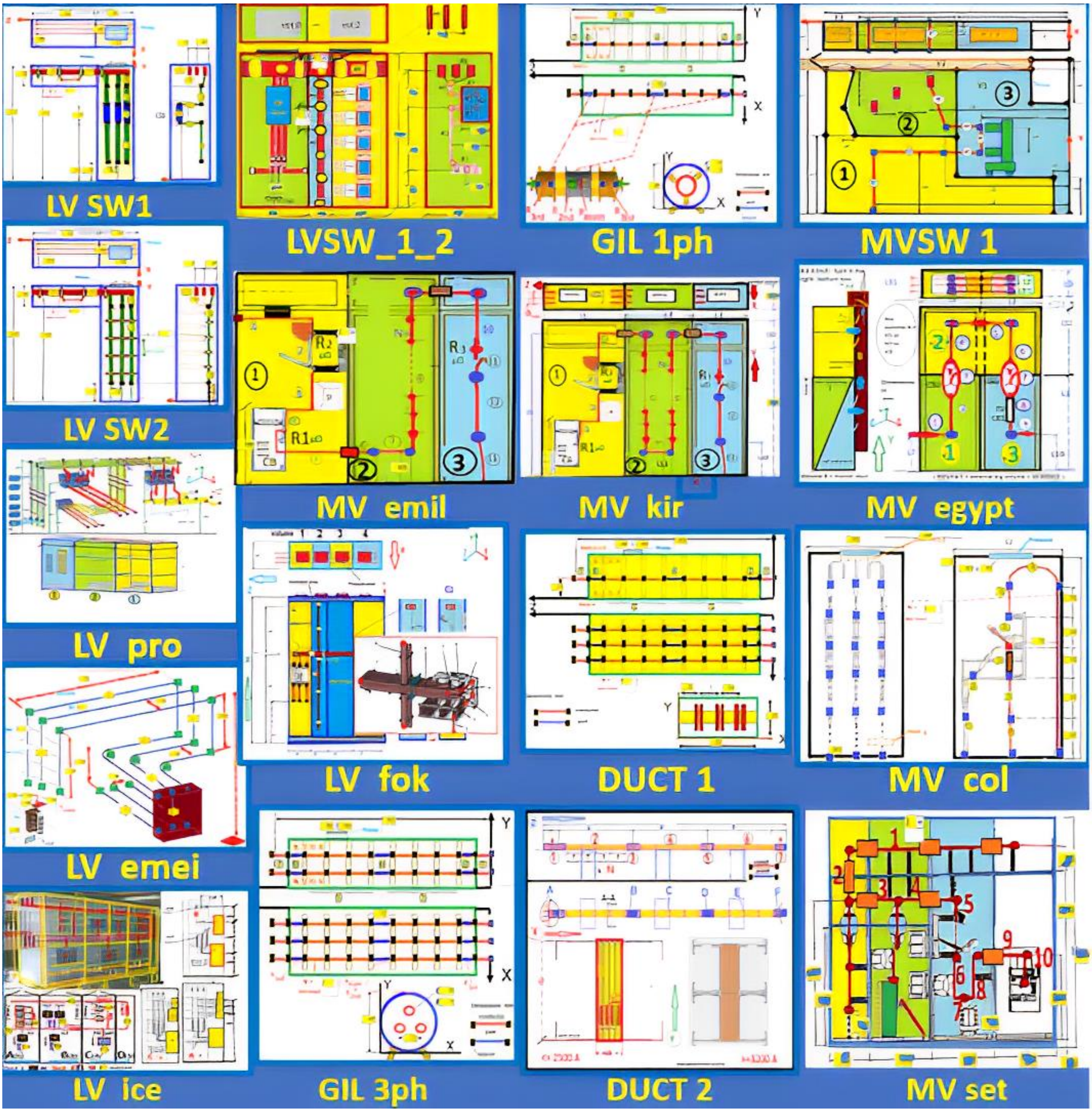


Figure 3 – Typical design models



VIDEO YOUTUBE SHOWING THE SOFTWARE SCREENS

Short video (4 minutes): https://youtu.be/ydYUU-BzhUA

Complete video (50 min): https://www.youtube.com/watch?v=3expB4wHiCM

3. CONTENTS OF THIS REPORT.

This report is an update of the previous reports TR 71 (2014) and TR 74 (2015) whose links are in the References and in my "free downloads area". There you may find complete technical articles written to be useful to designers and developers of equipment for substations, especially electric panels and busbar systems. I use this material in the trainings I apply for equipment manufacturers, certificators and testing laboratories people. You may read details about the service of "Design Review + Training + software " in the link in the end of this article. It includes also installation instructions and more.

Within the material related to test and simulations listed in the REFERENCES section , you may find links to the free books "Switchgear, busways & isolators and substations & lines equipment", "180 posts for the electric power industry, authored by me. They are the base for the training.

This report is intended to help users of the SwitchgearDesign software to understand that simulation results are very near the results obtained in real tests. It helps also to verify that they are using the tool correctly, by comparing test simulations against real laboratory tests. The software tool was developed to allow developers to simulate expensive laboratory tests such as temperature rise tests, short-time current tests (electrodynamic forces) and internal arc tests. The test reports used for validations may be read in the previous validation reports 71 and 74.

The software is focused in solving problems of the daily life. It was developed based on a large experience in the design, operation, and management of large testing laboratories, coordinating IEC standards and participating in CIGRÉ working groups (CV in first page). These documents are of special interest of this report:

- Cigrè Brochure 602 (2014) Tools for the Simulation of … the Internal Arc in T&D Switchgear,
- Cigrè Brochure 740 (2018) Contemporary design of low-cost substations in developing countries
- Cigrè Brochure 830 (2021) Simulations for Temperature Rise Calculation.
- IEC technical standard IEC62271-307 (2015) and IEC 60282-2 (1990)

There is no IEC standard focused in providing guidelines for the use of testing simulations. So, I prepared the **"Guidelines for the use of simulations and calculations to replace some tests specified in international standards "** which is referred in CIGRÈ Brochure 602.

Using simulations of high-power electrical testing is a realistic solution increasingly well accepted. To replace tests by calculations or simulations is not a new idea. It is applied for decades in technical standards such as IEC62271-307 (Extension of the Validity of Test Reports), IEC 60076 - Power Transformers (short tests), IEC 61439 (low voltage switchgear) and the previous IEC 60439.

Each time more equipment buyers accept to replace some tests by testing simulations. A suggested reading is the article "EXPLAINING IEC 62271-307 – EXTENSION OF THE VALIDITY OF TYPE TESTS TO AVOID TESTS REPETITIONS . There you can understand the relevant design variables considered in SwitchgearDesign testing simulations. I am coauthor of this IEC document and of the Cigrè brochures mentioned above.

4. ABOUT TESTS AND TESTING SIMULATIONS.

Laboratory type testing, as specified in product standards, is the most used way to verify if a certain product attends the technical standard specification. High power tests as the internal arc tests, temperature rise test and short time withstand current test are onerous and time consuming. There are relatively few laboratories in the World with capacity to do them. The costs of tests are a real barrier to small-size manufacturers to develop innovations.

Testing simulation techniques can predict results of several type tests. Frequently they enable to obtain much more complete information than the ones obtained in a real laboratory testing. Simulations are used in situations like:

(a) To avoid switchgear tests in equipment with characteristics near to another one already tested
(b) To avoid duplication of testing on product certification processes, when small changes are done to an already certified product.
(c) To replace SF6 by air in internal arc tests.(Focus of the CIGRÈ brochure 602)
(d) To support IEC 62271-307 analysis for the extension of the validity of test reports.

Testing simulation to extrapolate the results of an already done laboratory test to other, with similarities, untested equipment can be done in an easier or more complex way depending on the type of test.

<u>Temperature rise tests:</u> the simulation to replace a test is relatively simple to validate. You need only to compare the results of simulations with measurements of temperature rise shown in th e reports of laboratory tests.

<u>Internal arcs tests</u> : what can be checked are the effects of the overpressures arising during the arc and the risks to persons in the neighborhood. The curve overpressure x time is the decisive agent for the good or bad test result. IEC´s standard 62271-200 specifies this measurement as optional.

<u>Short time withstand current, and peak withstand current tests</u> : the objective is to verify the supportability to the effects of electro dynamical forces on insulators and conductors occurring during a short circuit without arc. To calculate the forces and stresses is not a so complex task but to measure them is very difficult and onerous. Nevertheless, the calculation methods are used for many decades and well accepted in the technical world including IEC 61117: Method for Assessing the short-circuit withstand strength of partially type-tested assemblies (PTTA). There is no known way to do validation of simulations electrodynamic forces against laboratory test reports. By the same reason the IEC 61439 and IEC 62271-307 documents also reference IEC 61117.

”Guidelines for Simulations” informed above, details all the steps and conditions for validating testing simulations. It is considered that a model or method is acceptable when it produces validated simulation results within acceptable tolerances if compared with the real test results and this can be demonstrated in a transparent way to the users. The reproducibility of the calculation method is the key point.

3.1 – Temperature rise test (concept)

The equipment is installed in a place free of air drafts. The rated current is applied for a time sufficient to have the temperature stabilization of the measured points. The measured temperature rise should not go beyond certain limits specified in the technical standard. The results are influenced by the current flowing, the type of materials, the contact resistances, the temperature of the fluid, the geometry of the conductors, net internal volume of the enclosure and the existence of partitions and ventilation openings. The contact resistance and ventilation areas are key factors in the results. For the test to be reproducible it is necessary to measure not only the total resistance per phase but also the higher resistance like a switch, circuit breaker key or fuse as seen from its terminals. Most testing labs measure only the total resistance per phase because the IEC standard to do highlight the partial values.

3.2- Short-time withstand current and peak withstand current tests (concept)

These tests are made for checking the effect of the forces and high temperatures applied to the isolators and conductors during a short circuit. It is possible to calculate the mechanical forces acting on insulators (compression, tension and bending) and the mechanical stresses on the bus bar conductors using the expressions presented in previous reports 71 and 74 (References).

The forces must remain below the limits specified by the manufacturer of the insulator otherwise, it can be destroyed. The mechanical stresses in the conductors must remain below certain limits dictated by the materials otherwise the bars will suffer a permanent and visible deflection.

The results are affected by the short circuit current, the materials, and the geometry of the conductors, distances between phases and the types of insulators.

3.3 – Internal arc tests and overpressures (concept)

The idea is to create an arc along a certain time duration. The consequences of the overpressures are observed. The requirements for passing in the test like are the evidence that the doors will not open, that hot gases expelled out through the pressure relief parties should not burn cotton indicators placed near the accessible parts that simulate the skin of a person in the vicinity. Holes on the outer walls, caused by the arc. are not allowed. Issues to consider and assessment methods are in IEC 62271-200 (medium voltage - Ref. 12) or IEC TR 61641 (low voltage - Ref. 21).

For air, insulated switchgear the main cause of failures during tests is the burning of the horizontal cotton indicators due to reflections of the hot gases in the ceiling. Because the flow of hot gasses cannot be simulated well, all the assessments are made based on the overpressure curves values.

The main factors that influence the results are the voltage, current, net internal volume, relief area and time of operation of the pressure relief devices. Ventilation openings, good in temperature rise tests are an example of a potential way for the exit of the hot gases, burning cotton indicators.

3.4 – Validation of a simulation method against laboratory tests and tolerances.

Validation is 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. The method is 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 like these examples.

Table 1 – Tolerances between test results and simulation results

Type of test	Parameter to compare	Typical values of acceptable tolerance
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	Electrodynamic forces and mechanical stresses	5% to 15%

5. VALIDATION OF SIMULATION RESULTS FOR SOME SwitchgearDesign MODELS.

The main models available in SwitchgearDesign are like in the figure to follow. They cover more than some 90% of the situations I have seen in the electric industry.

In the next pages we will compare the tests results and simulation results for some of these models.

When the SwitchgearDesign user have doubts it is using the tool correctly can calculate one or more of these examples to be sure is doing the right things and typing the correct values.

Remember that there are many variables, and a wrong typed number can have a big influence in the simulation results.

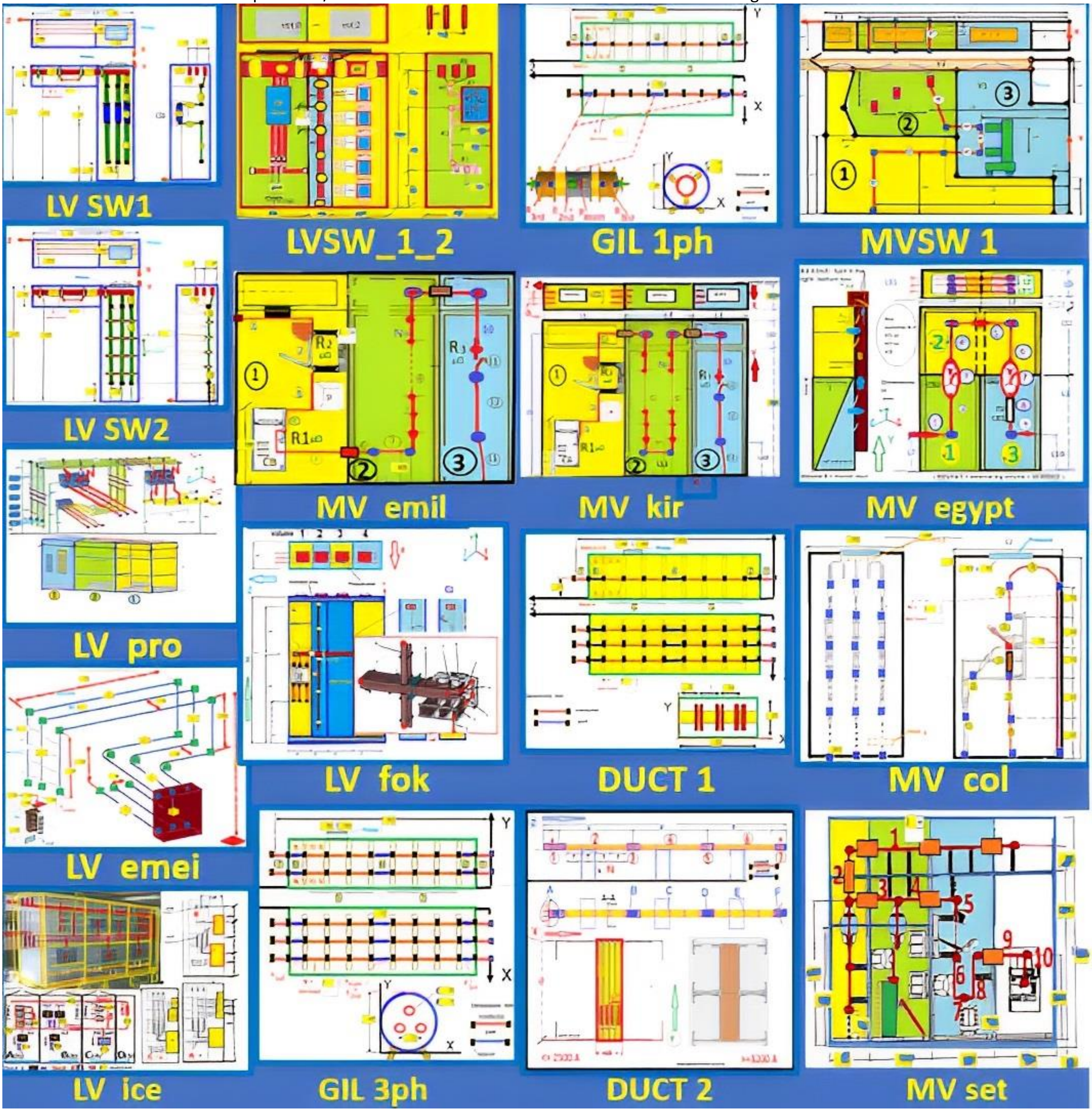
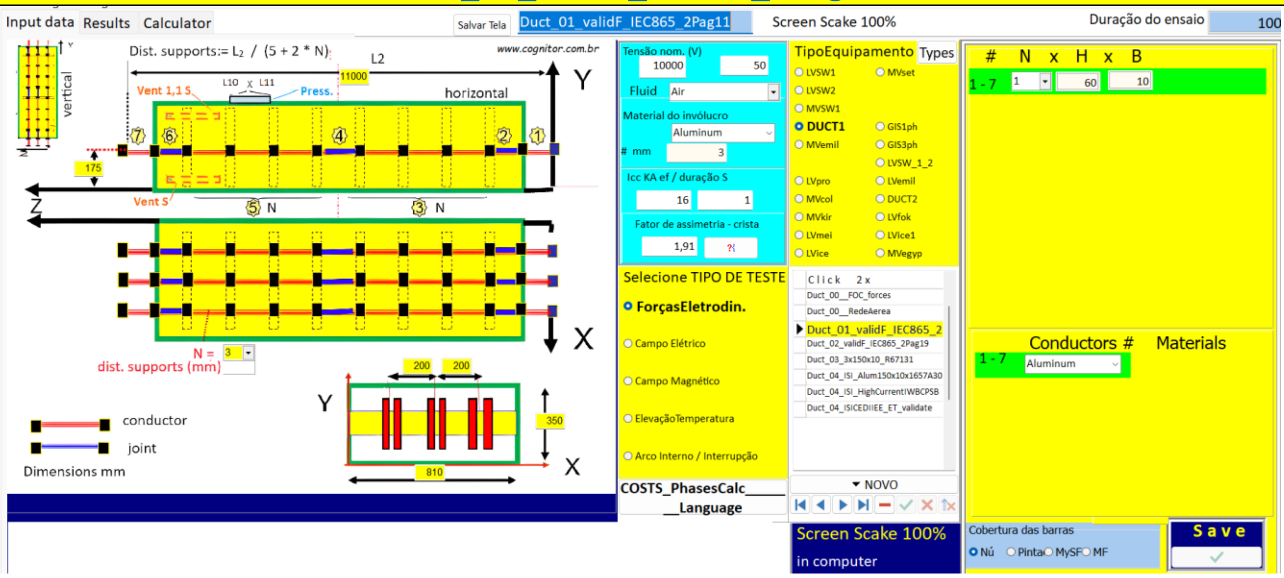
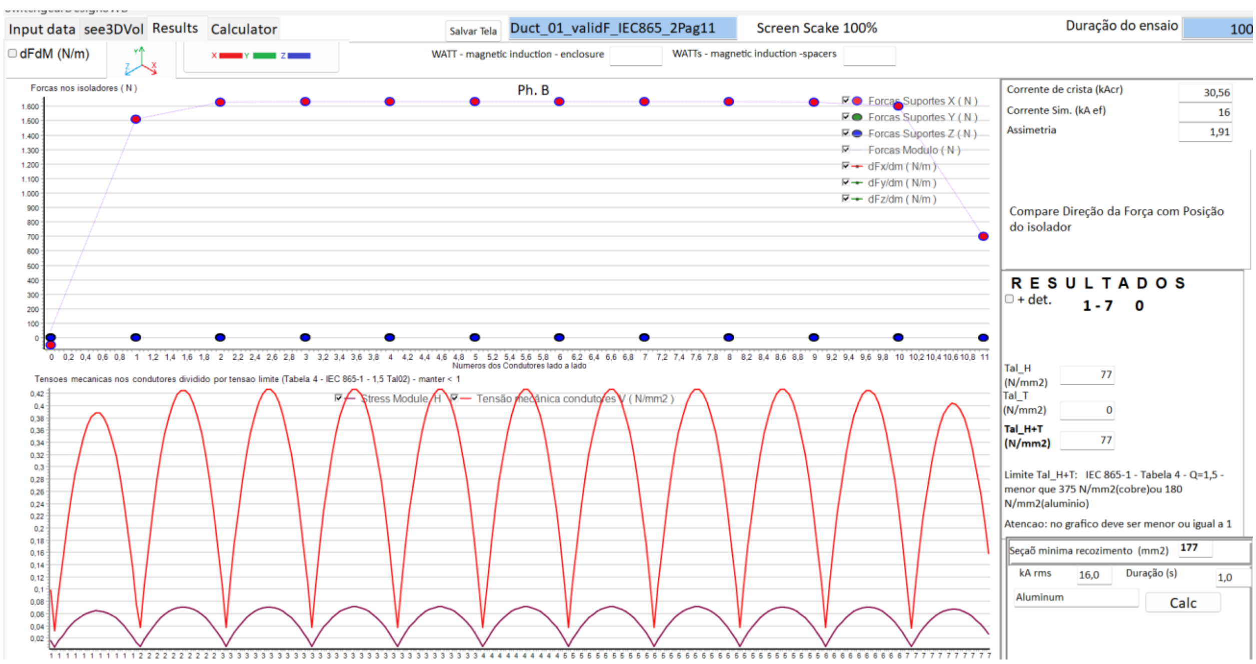

LV SW1
LVSW_1_2
GIL 1ph
MVSW 1
LV SW2
MV emil
MV kir
MV egypt
LV pro
LV fok
DUCT 1
MV col
LV emei
LV ice
GIL 3ph
DUCT 2
MV set

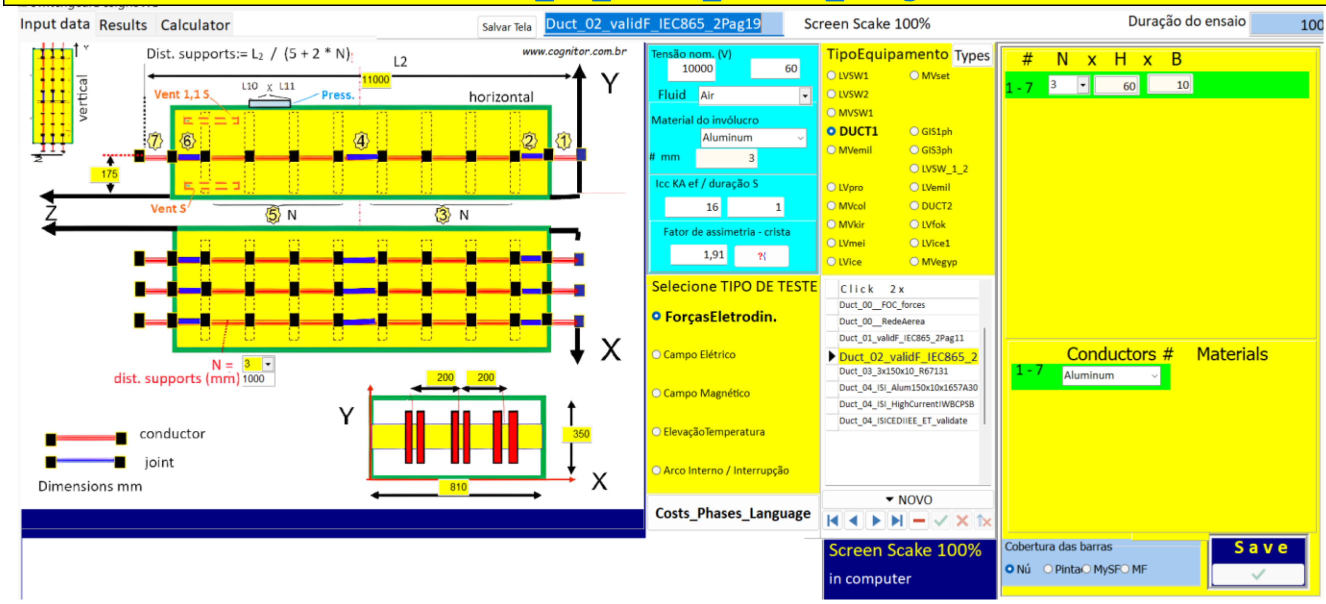
Figure 1 – Duct1 – Short-time withstand current, and peak withstand current Duct_01_validF_IEC865_2Pag11

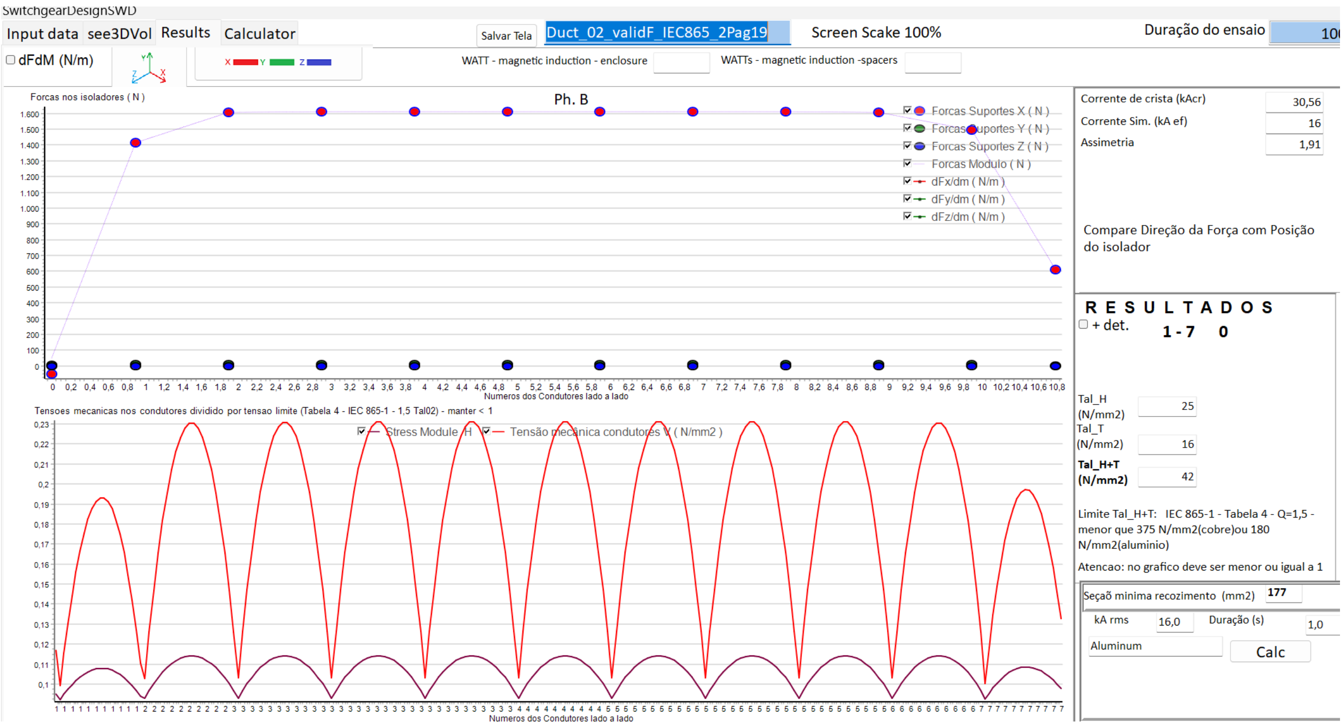




Parameter	Result in IEC standard	Simulation results	Difference
Max. Mechanical Stress σH (N/mm2)	73,3	76,0	3,5 %
Max. Mechanical Stress σT (N/mm2)	Do not apply	Do not apply	-
Total Max. Mechanical Stress σH + σT (N/mm2)	73,3	76,0	3,5 %
Max Force in the insulator in phase BB (central) in compression or tension (N)	Do not calculated	3	-
Max Force in the insulator in phase BB (central) in) flexure (N)	1606	1611	0,3 %

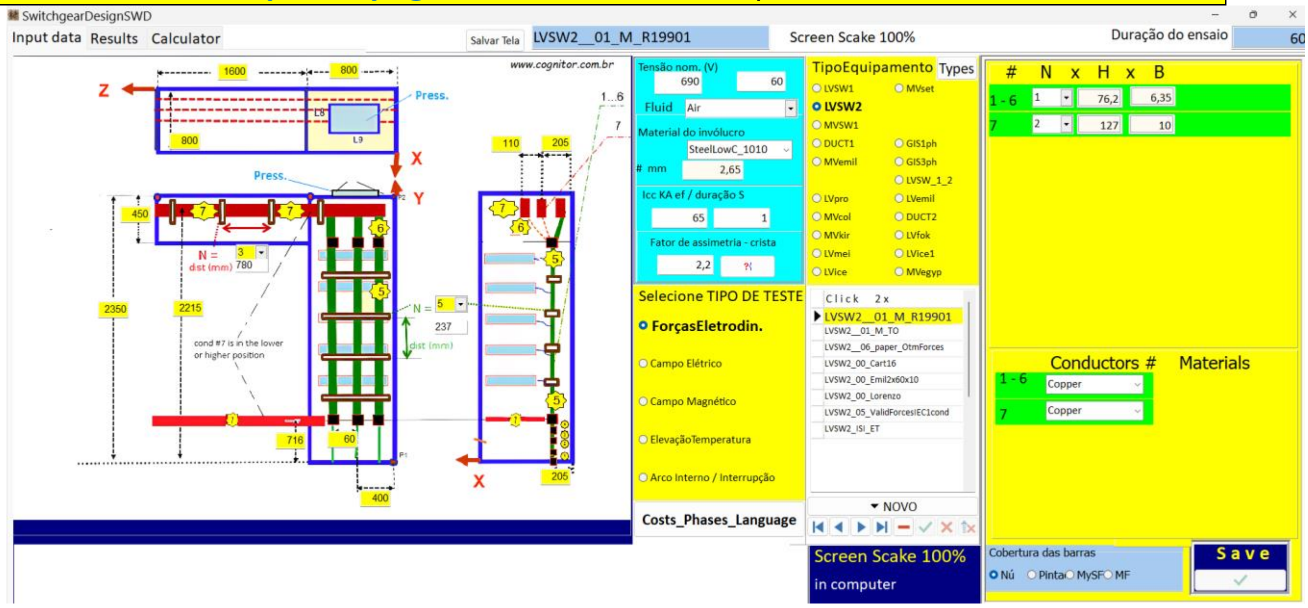
Figure 2 – Duct1 – Short-time withstand current, and peak withstand current – Duct_02_validF_IEC865_2Pag19

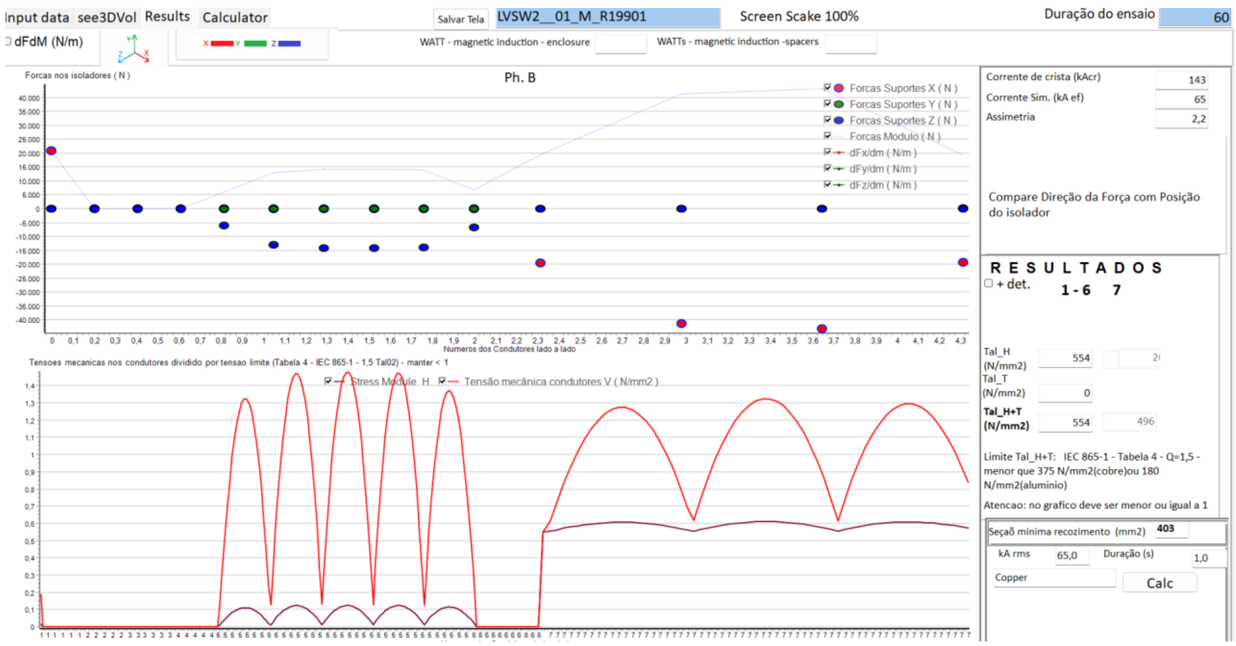




Parameter	Result in IEC standard	Simulation results	Difference
Max. Mechanical Stress σH (N/mm2)	24,7	25,0	1,2 %
Max. Mechanical Stress σT (N/mm2)	16,1	17,0	0,6 %
Total Max. Mechanical Stress σH + σT (N/mm2)	40,8	42,0	0,5 %
Max Force in the insulator in phase BB (central) in compression or tension (N)	Not calculated	11	-
Max Force in the insulator in phase BB (central) in) flexure (N)	1606	1611	0,3 %

Figure 3 – LVSW2 – **Short-time withstand current, and peak withstand current - Example 2 - pages 19-27** - Test report 19901/9-C

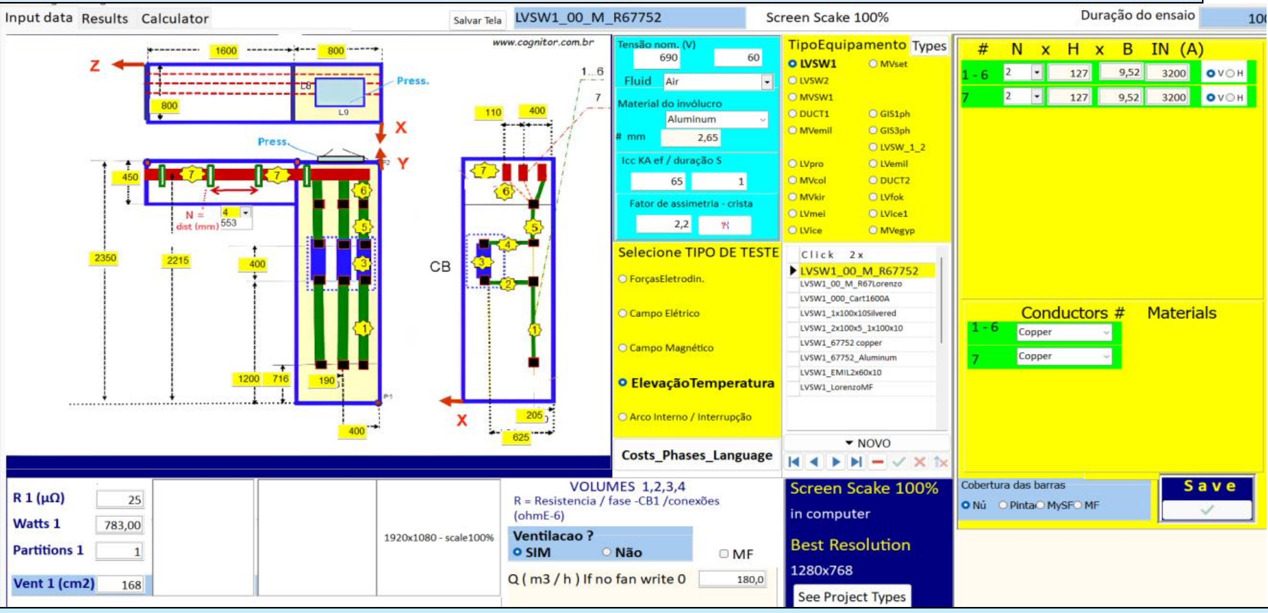




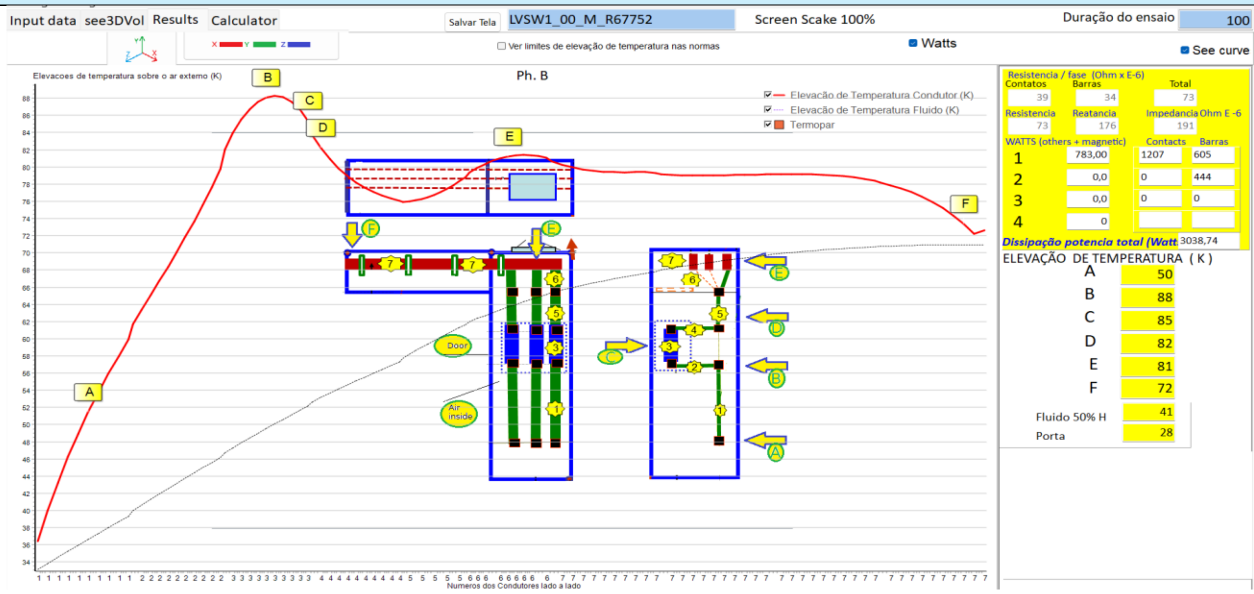
Parameter	Result in IEC standard	Simulation results	Difference
Max. Mechanical Stress σH (N/mm2)	Visual inspection	550 (*)	-
Max. Mechanical Stress σT (N/mm2)	Visual inspection	Not applicable	-
Total Max. Mechanical Stress σH + σT (N/mm2)	Visual inspection	550 (*)	-
Max Force in the insulator in phase BB (central) in compression or tension (N)	Visual inspection	14180 (*)	-
Max Force in the insulator in phase BB (central) in) flexure (N)	Visual inspection	Not applicable	-

(*) Values of interest are in conductors 1-6 - less resistant. Perceive that the limit usually used is 375 N / mm 2 = 1.5 x 250 N / mm2, but in this case passed the test and the value was 550 N / mm2 = 2.2 x 250 N / mm2

Figure 4 – LVSW1 – Temperature rise test - In laboratory - Test report 67752



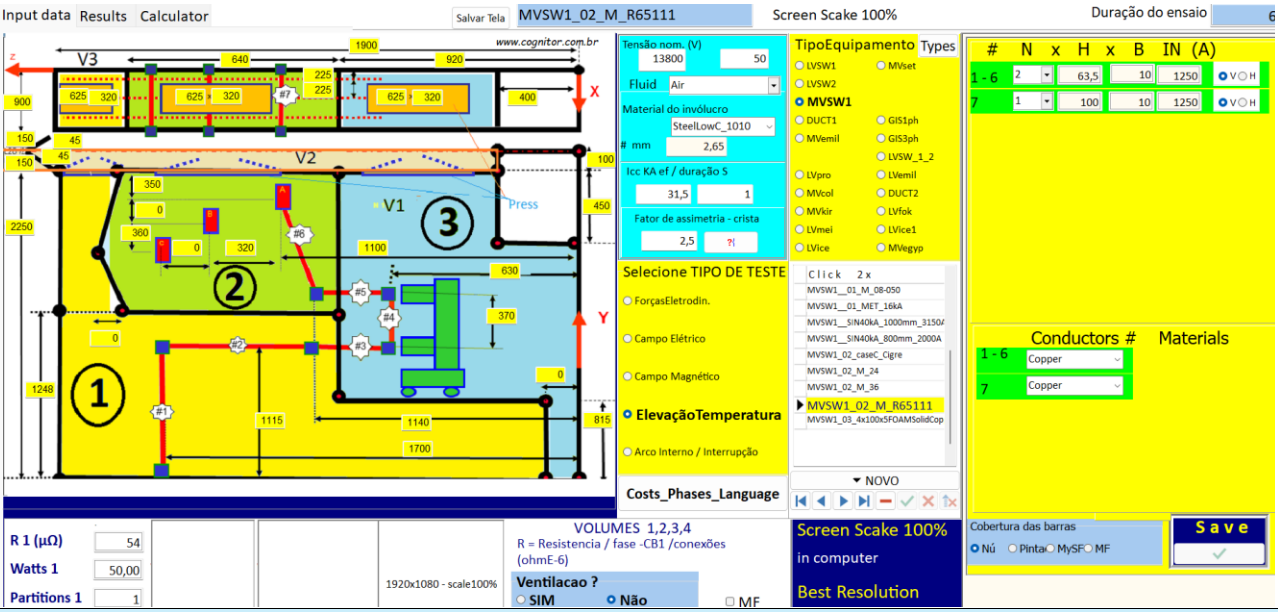
Bare bus bar -- With ventilation openings – 180 m3/h air flux corresponding to an average air speed of 0,078 m/s = 180 / (0,8x0,8) , effective area for the air input 168 cm2 Additional thermal load 783 W (to be added to bus bar resistances and connections and contacts) .... Circuit breaker resistance as seen from the terminals – 25 µΩ per phase (768 W)



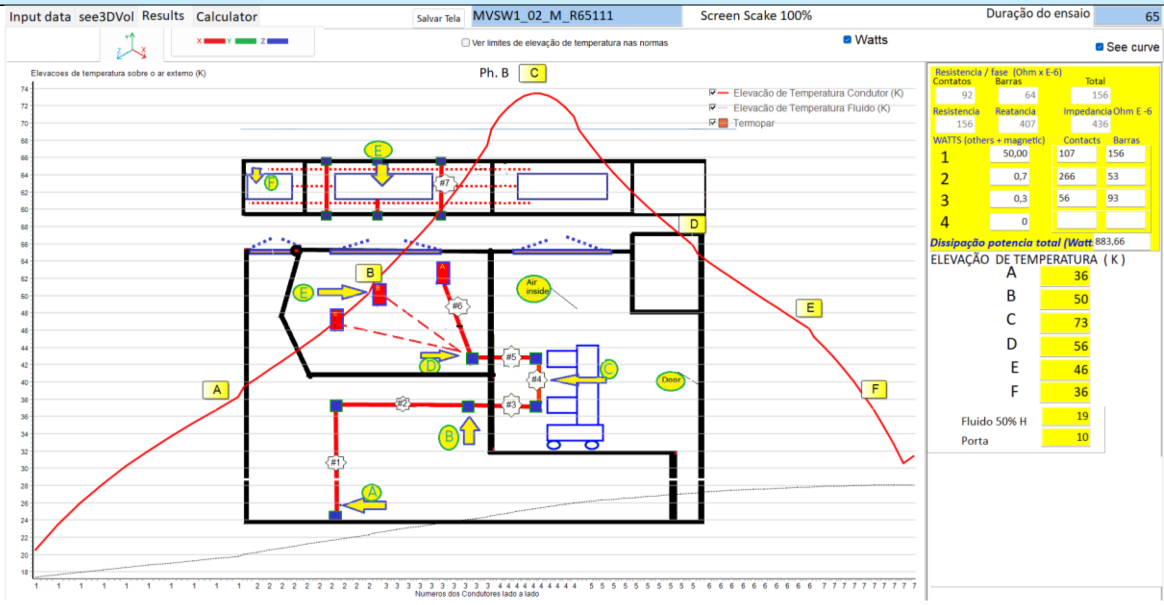
Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external conductors	53	53	< 5 %
B – C – D – connection between bars and circuit breaker (**)	78 to 89	<=88	< 5 %
E – Connection between the horizontal and vertical bars	76	85	< 8 %
F – Short circuit point	46 (***)	76	Thermocouple?
Door	8 (*)	<9	< 12,5%
Internal air	32 (*)	36 al 70	(*)

(*) The position where it was measured in the test is not indicated - no pictures - and the value can change greatly with position. In the simulation, the bottom has 36K and ceiling is 70 K. For the average height is about 50K. (**) Critical point in testing (***) possibly the thermocouple was not properly secured. See temperature point E - same bar

Figure 5 – **MVSW1 –** **Temperature rise test in laboratory** **- Test report 65111**



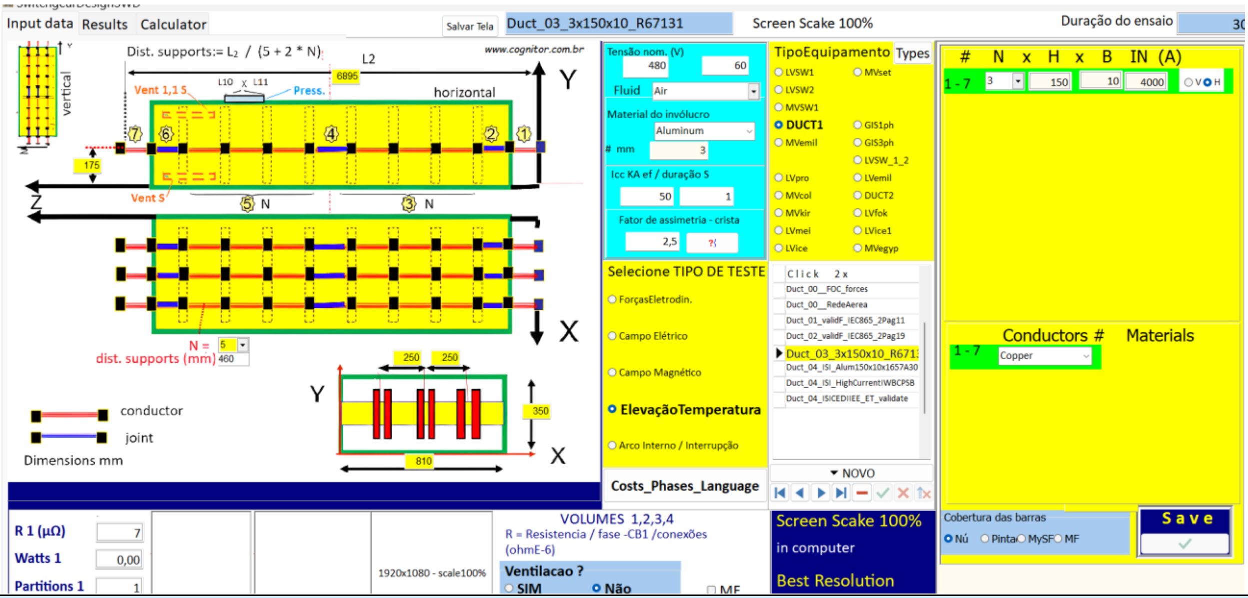
Bare bus bar Without ventilation openings - Circuit breaker resistance from terminals – 54 µΩ per phase



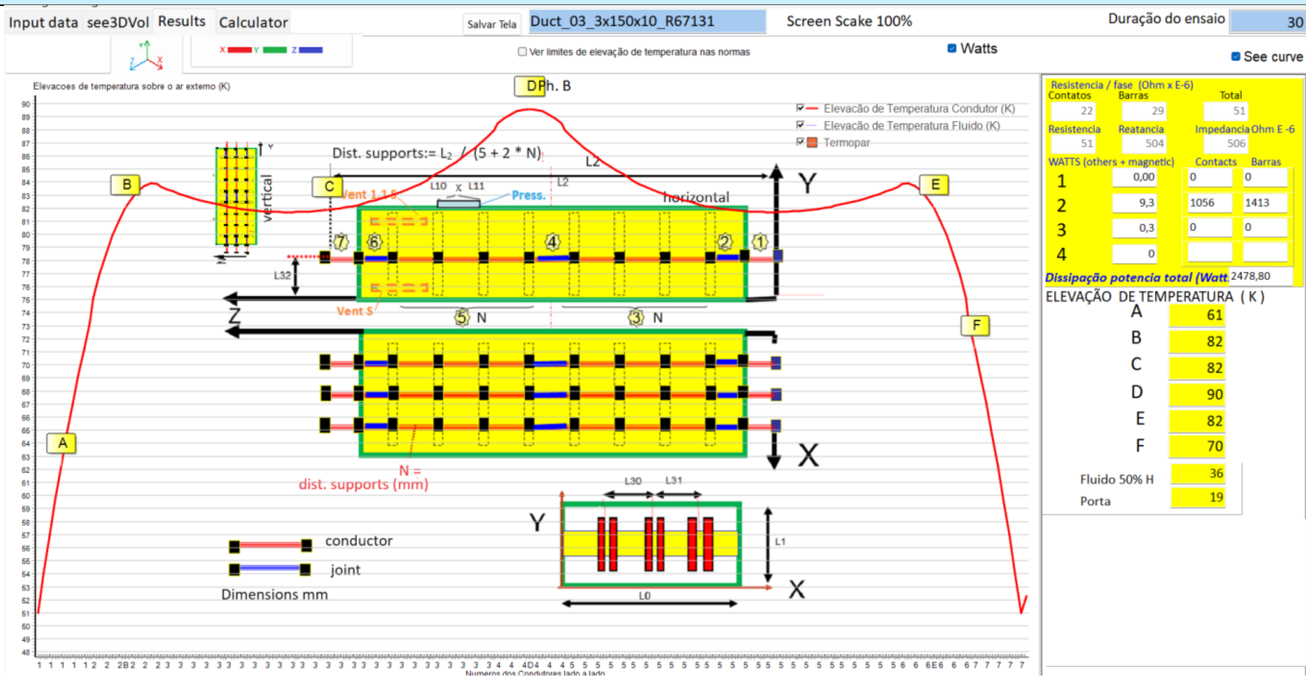
Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external conductors	39	39	< 5 %
B – C – D – connection between bars and circuit breaker (**)	56 al-72	51 al 73	< 5 %
E – Connection between the horizontal and vertical bars	44	45	< 5 %
F – Short circuit point	34	35	< 5 %
Door	12 (*)	11	< 15 %
Internal air	Not measured	13 al 26	(***)

(*) The position where it was measured in the test is not indicated - no pictures - and the value can change greatly with position.
(**) Critical point in testing
(***) in the simulation, the bottom has 13K and ceiling is 26 K. For the average height is about 20K.

Figure 6 - DUCT1 - Temperature rise test - In lab - Test report 67131 Duct_03_3x150x10_R67131



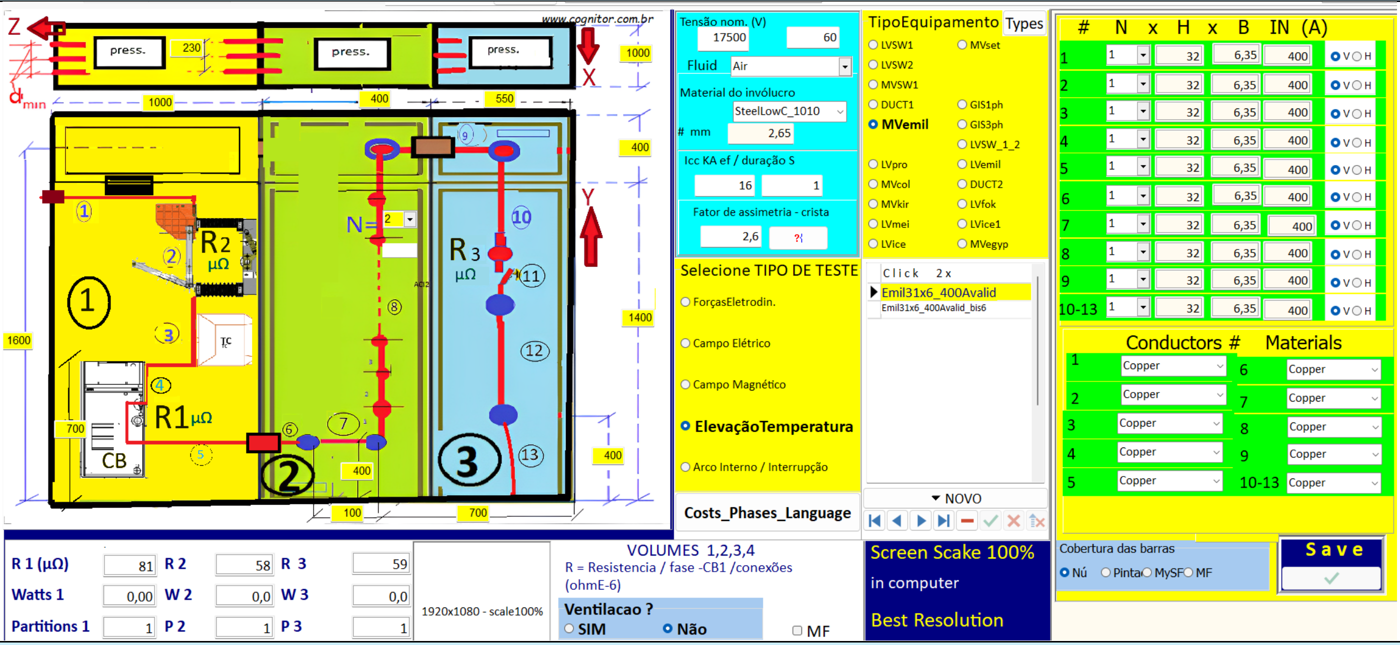
Bare bus bar Without ventilation openings Connection / joint resistance 7 µΩ



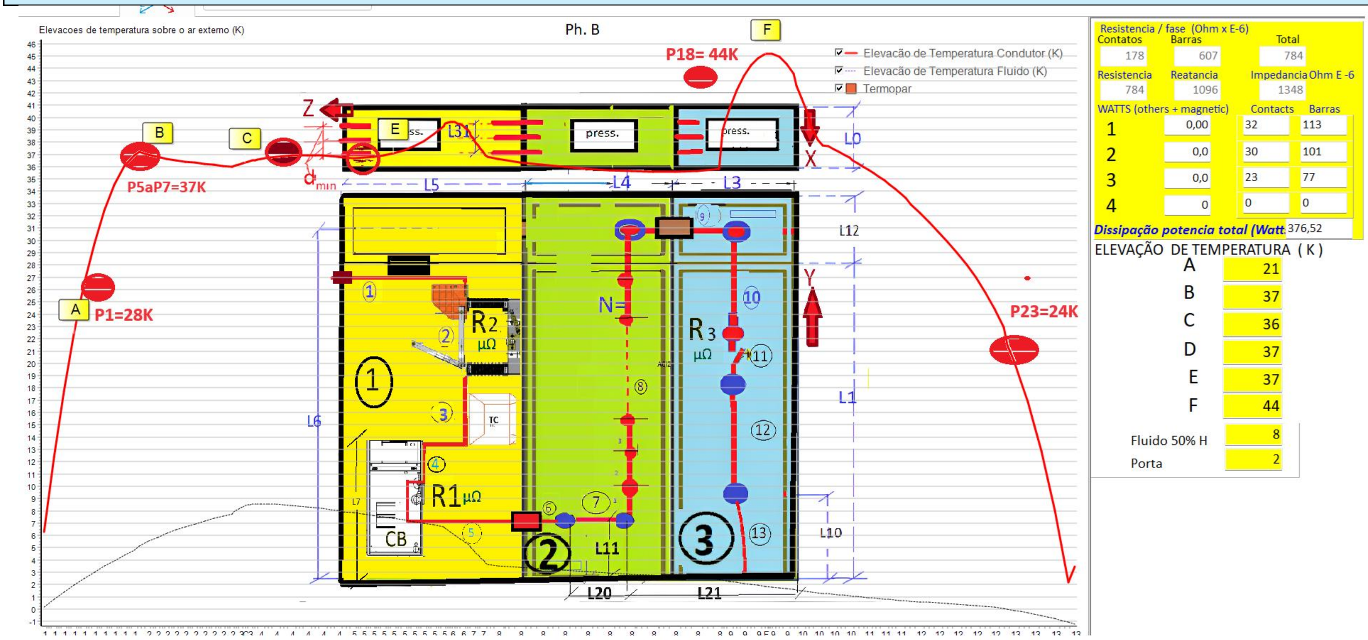
Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for connection to external cond.	72,4	74	< 5 %
B – Conductor # 2	Not measured	88	-
C – Conductor #3	83,9	82	< 5 %
D – Conductor #4 (** connection)	84,5	90	< 7 %
E – Conductor # 6	Not measured	88	-
F – #7 – Short circuit point	66,6	66	< 5 %
Side of the enclosure	30 (*)	19-30	(*)
Internal air (50% H)	Not measured	48	-

(*) The position where it was measured in the test is not indicated - no pictures - and the value can change greatly with position. (From 9 to 51/2 = 25 K) (*) Critical point in testing

Figure 7 – **MVemil - Temperature rise test - Test report 82998 –** 27/07/2021 **- Emil31x6_400Avalid**



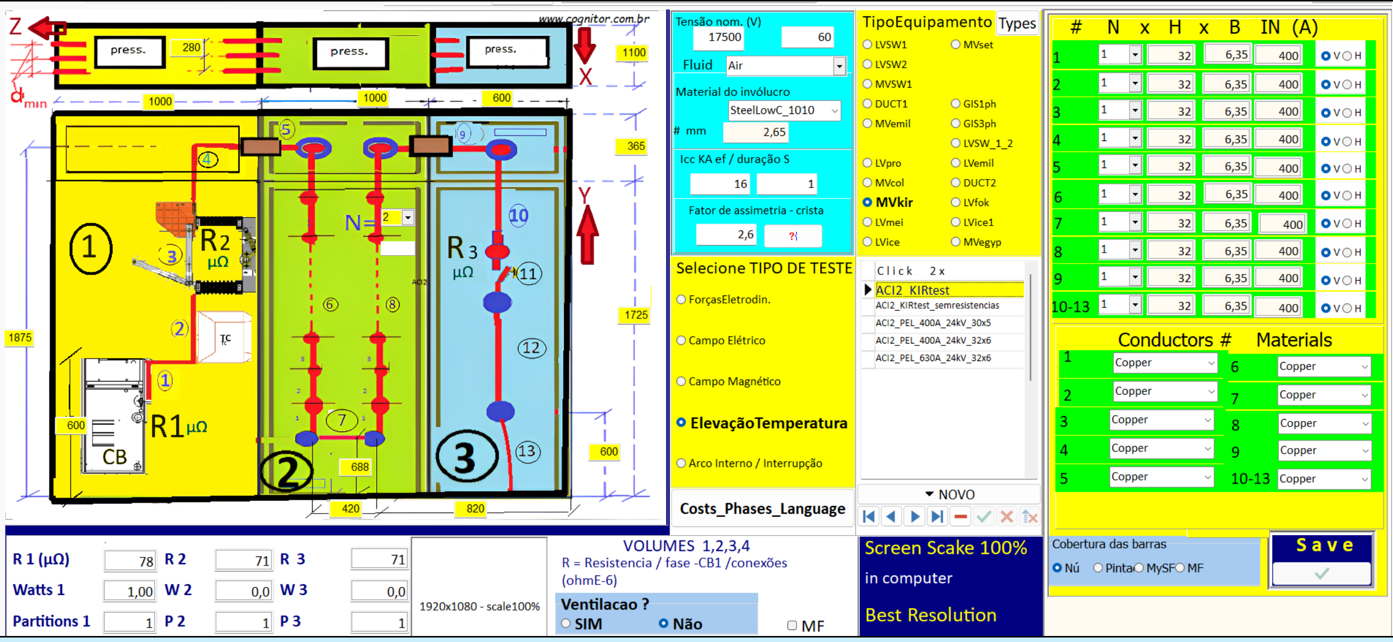
Total resistance per phase measured after test **707 µΩ** - Resistance CB 81 µΩ - Resistance switch 59 µΩ



Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external cond.	28	27 to 29	< 5 %
B – C – D – connection between bars and circuit breaker (**) or switches (see figure above)	37 – 41 - 44	37-43	< 10 %
E – Connection between the horizontal and vertical bars	44	43-46	< 5 %
F – Short circuit point	24	~24	< 5 %
Door	1 a 4	1 to 6	< 15 %
Internal air	Not measured	<5	

Figure 8 – MVkir - Temperature rise test - In lab - Test report ?????– - ACI2_KIRtest

Recent test and design review. Waiting for the testing lab test report to validate this case



Total resistance per phase measured after test 1100 µΩ - Resistance CB 78 µΩ - Resistance switch 71 µΩ

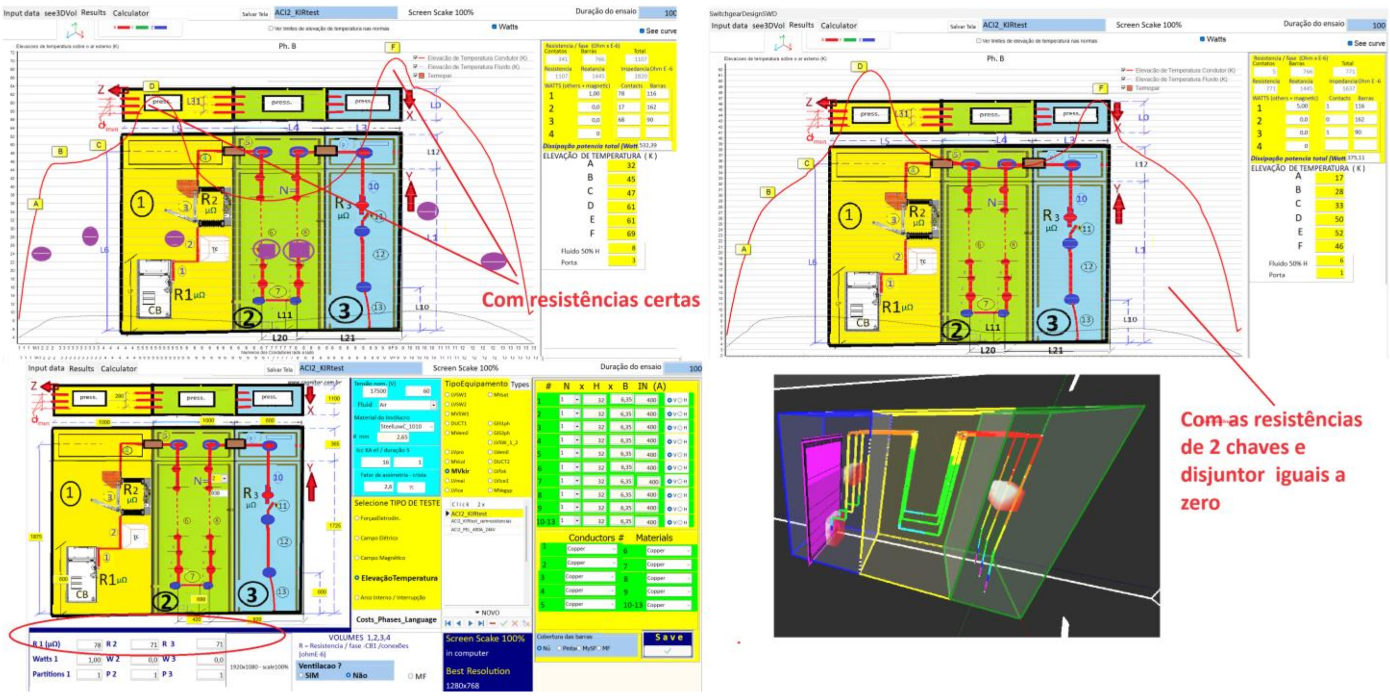
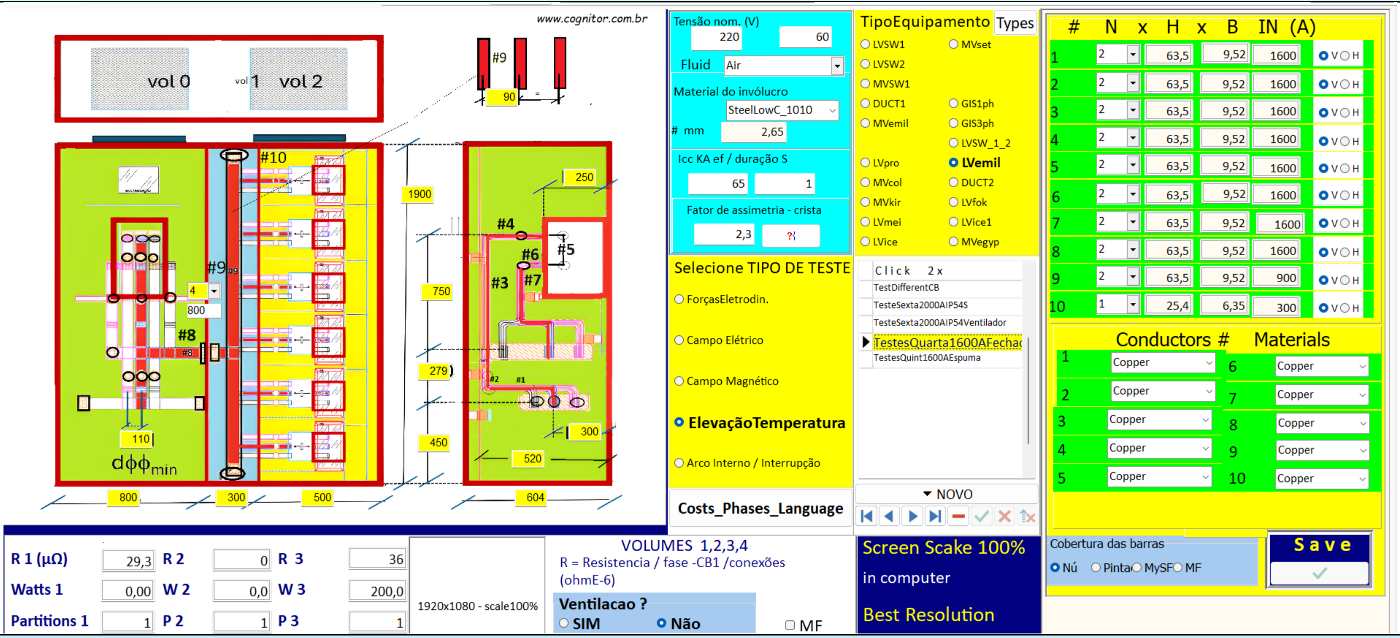
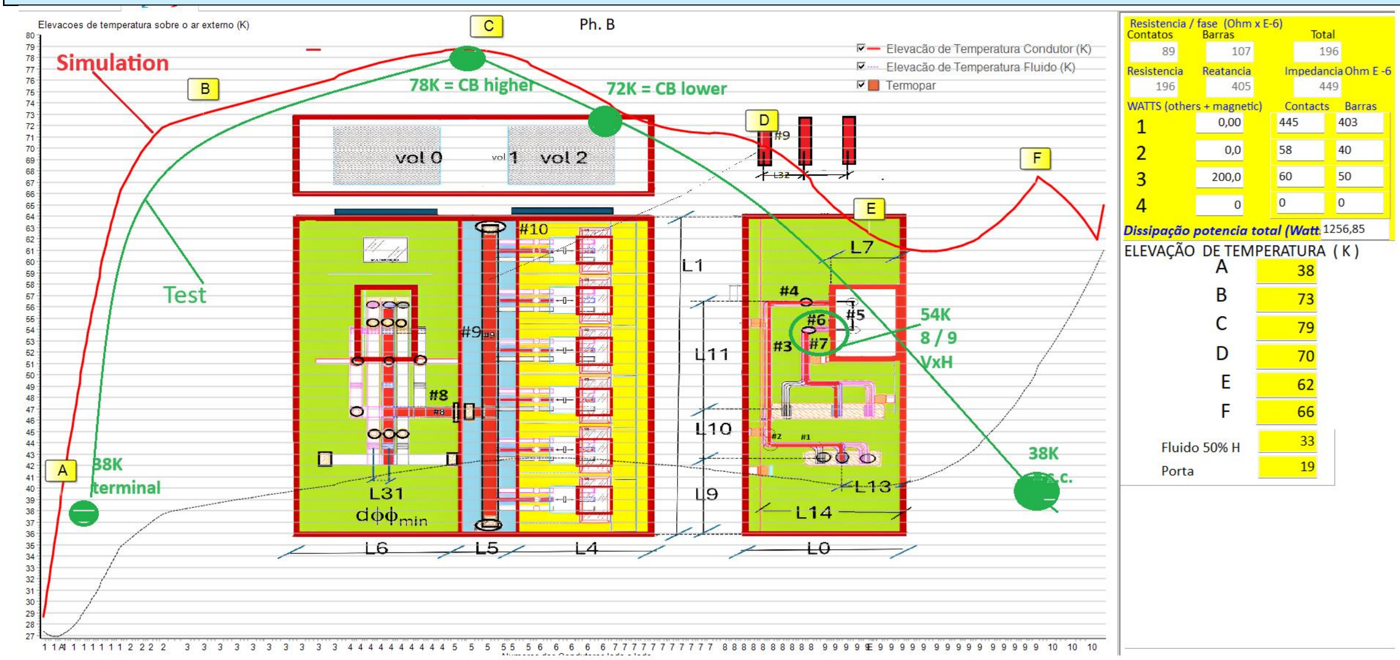


Figure 9 – **LVemil - Temperature rise test - Test report ???? –** 08/05/2024 **- TestesQuarta1600AFechado**



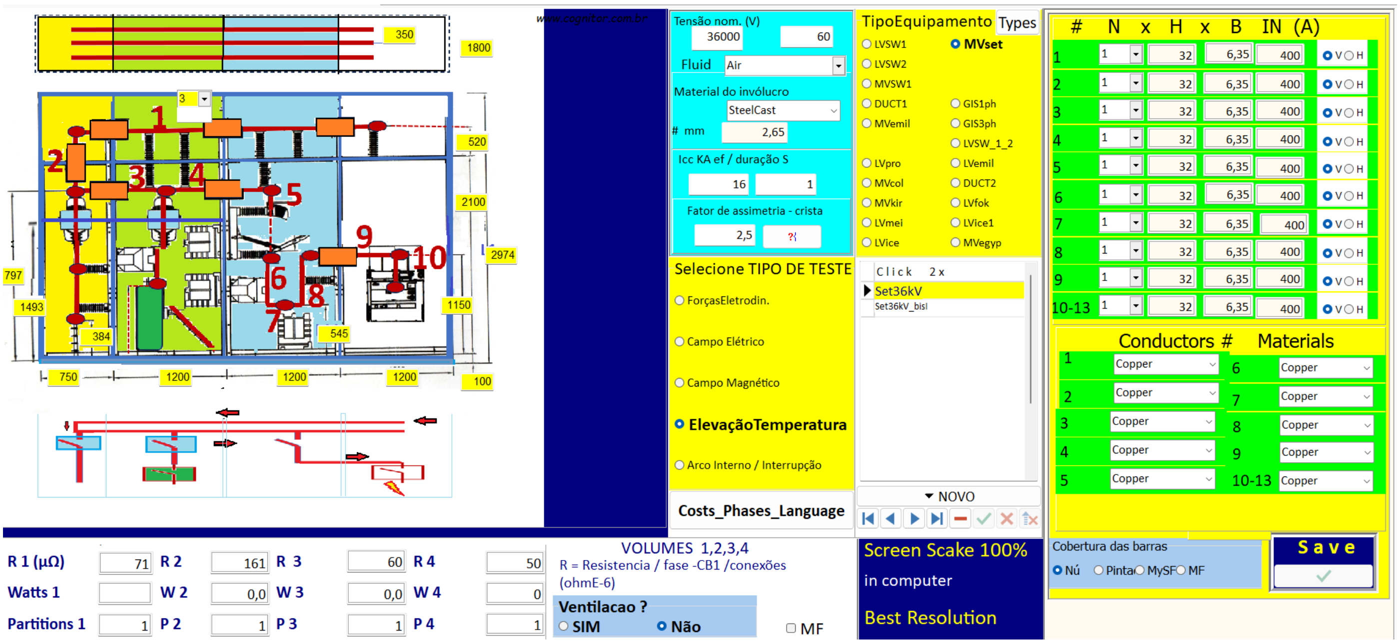
Total resistance per phase measured after test **XXX μΩ** - Main CB 2500 A – Other CBs 5 x 300 A – Resistance and power dissipation not measured TEST 1600 A (approved)

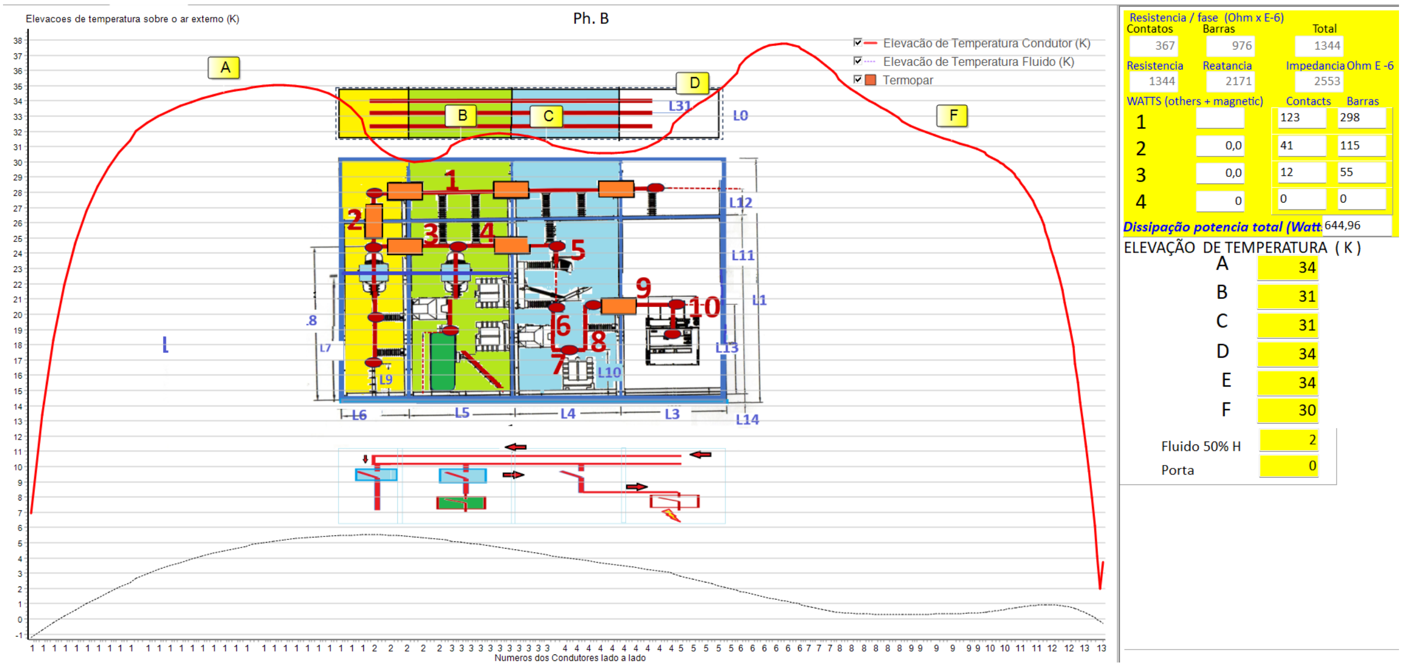


Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external cond.	38	~42	< 5 %
B – C – D – connection between bars and circuit breaker (**) or switches (see figure above)	78	80	< 5 %
E – Connection between the horizontal and vertical bars	54	70	< 20%
F – Short circuit point	38	>60	< 5 %
Door	1 a 4	1 to 6	-----
Internal air (*)	26 to 32K	<42K	-----

(*) Air near main CB 26K .... Air near CB 300A ... 32K
Air near top col.1 = 30K ...... Air near top col.2 ...29K

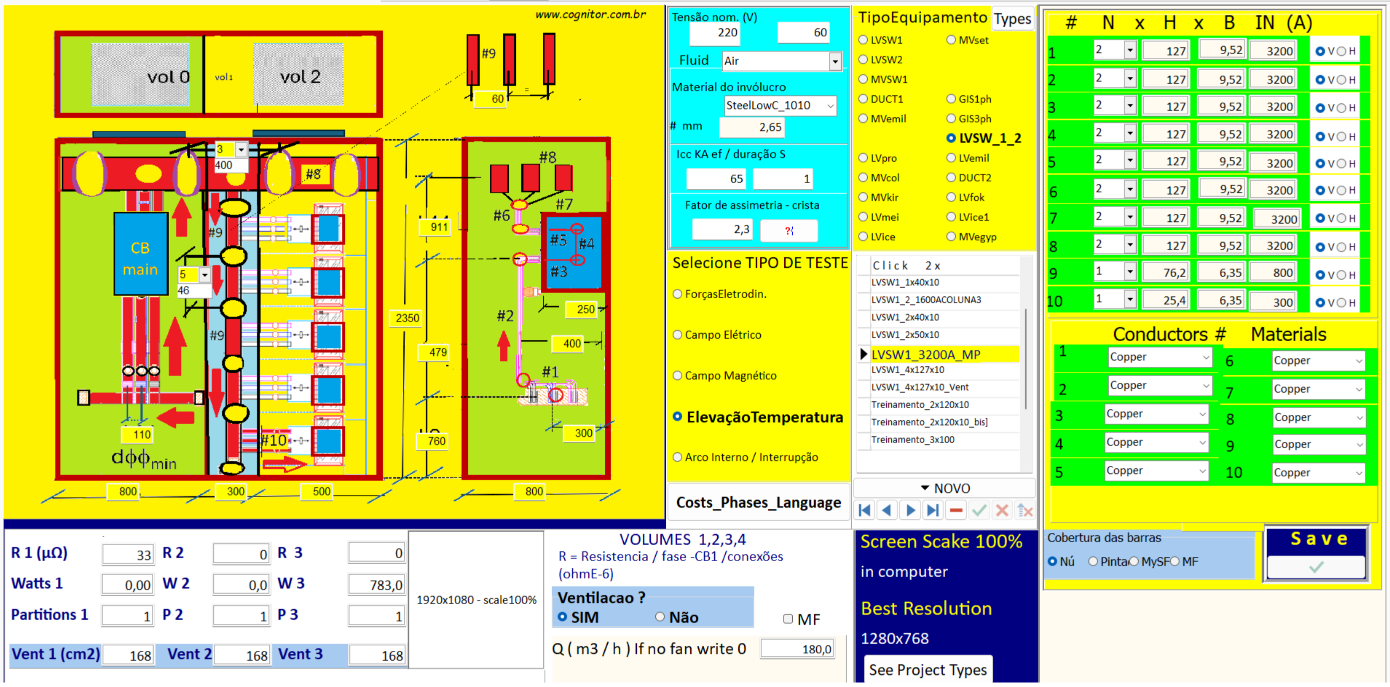
Figure 10 – **MVvset - Temperature rise test - Test report ???? Set36kV**
Total resistance per phase measured after test **XXX µΩ**
Recent test and design review. Waiting for the testing lab test report to validate this case

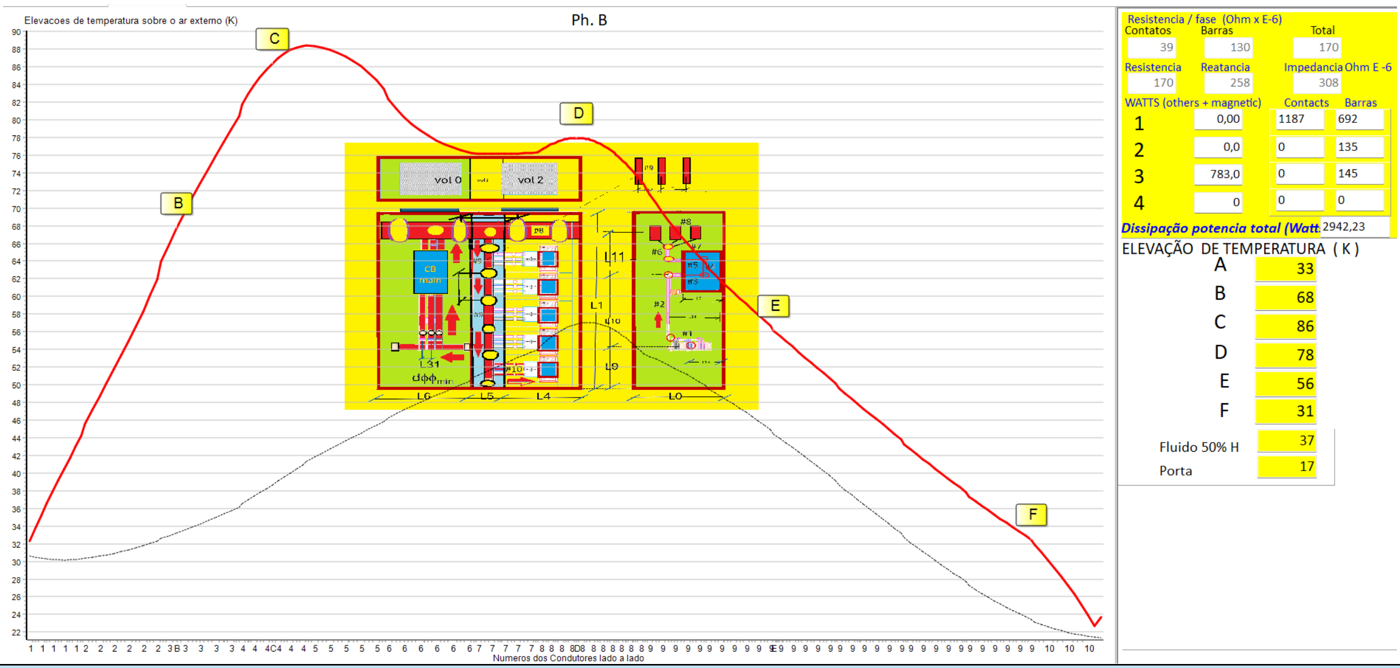




Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external cond.			
B – C – D – connection between bars and circuit breaker (**) or switches (see figure above)			
E – Connection between the horizontal and vertical bars			
F – Short circuit point			
Door			
Internal air (*)			

Figure 11 – LV_SW_1_2- Temperature rise test - Test report ???? LVSW1_3200A_MP

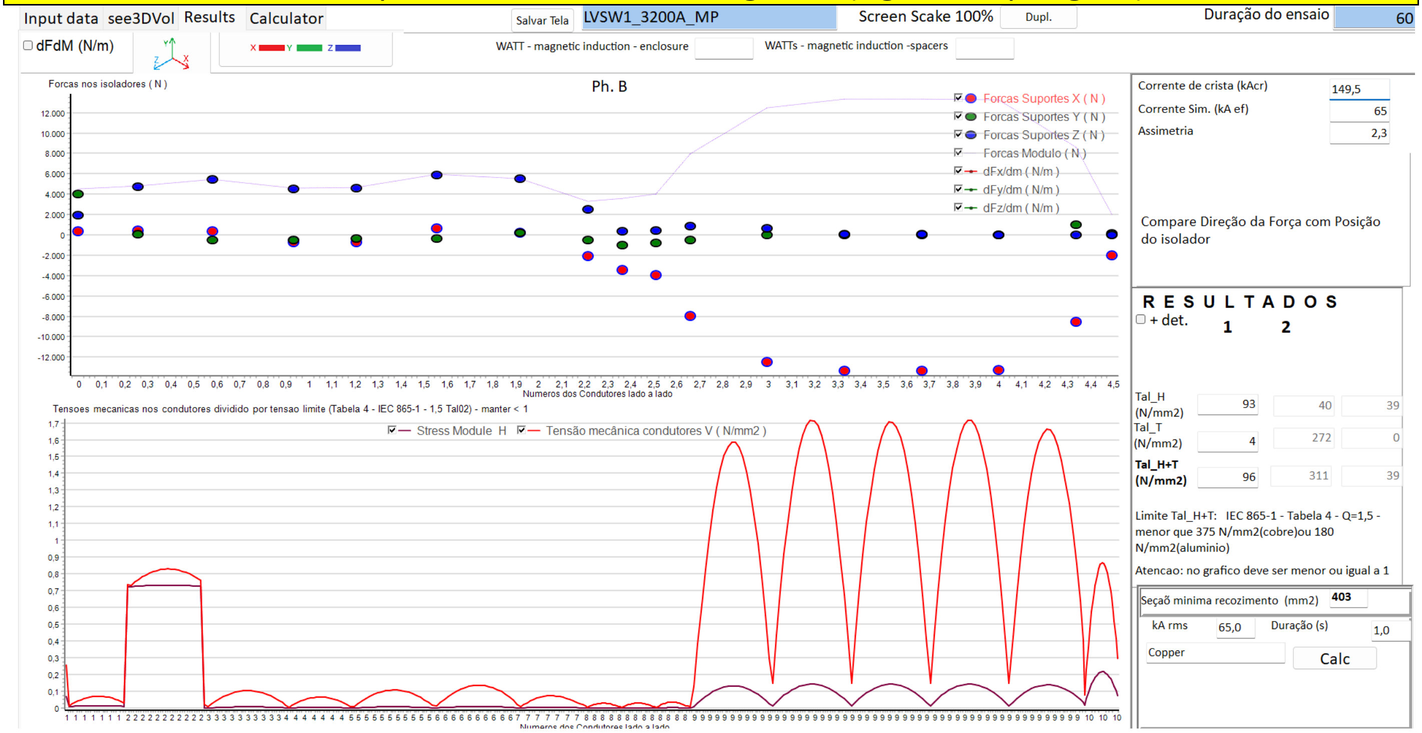




Compare with validated case of Figure 4 – LVSW1 – Temperature rise test - In laboratory - Test report 67752 which is the circuit in the left side of the figure

Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external cond.			
B – C – D – connection between bars and circuit breaker (**) or switches (see figure above)			
E – Connection between the horizontal and vertical bars			
F – Short circuit point			
Door			
Internal air (*)			

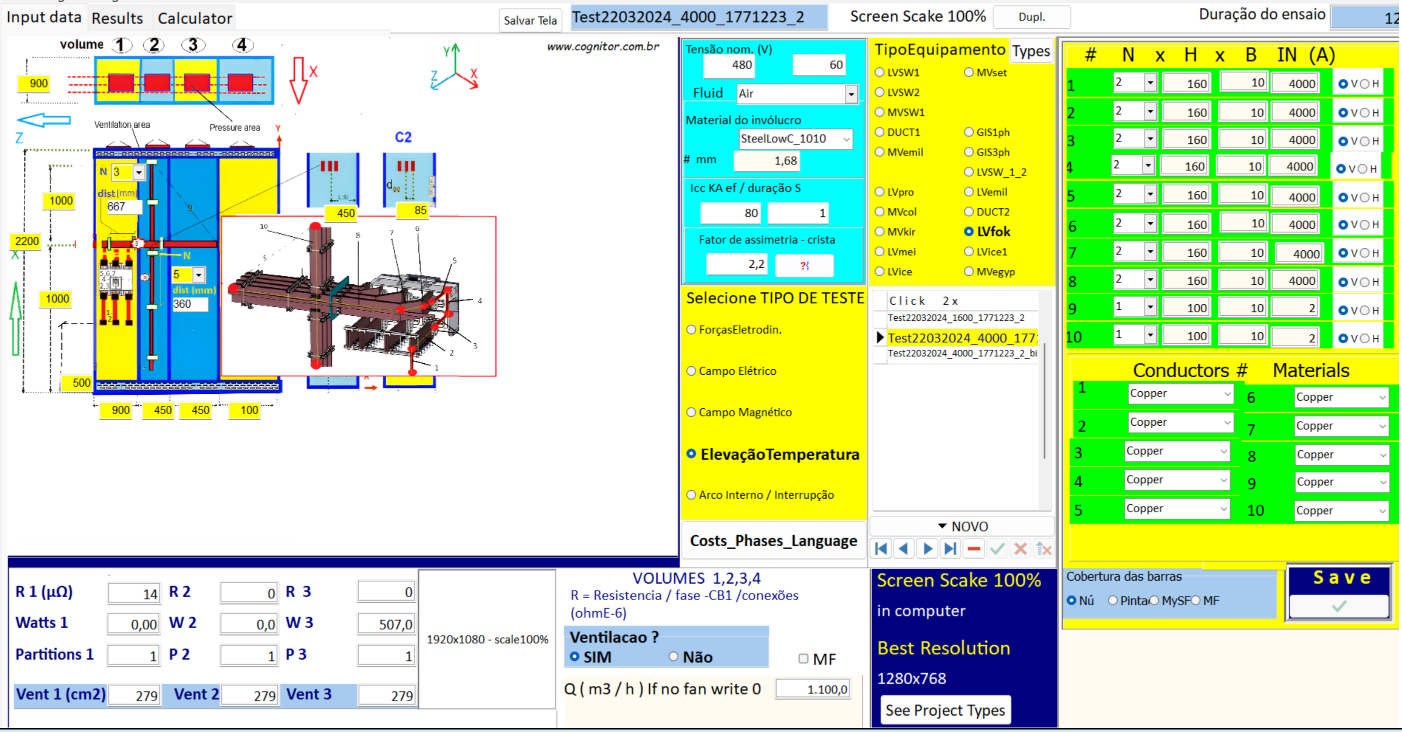
Figure 12 – LVSW_1_2 – **Short-time withstand current, and peak withstand current - Like** Test report 19901/9-C in Figure 3 (right side pf figure)

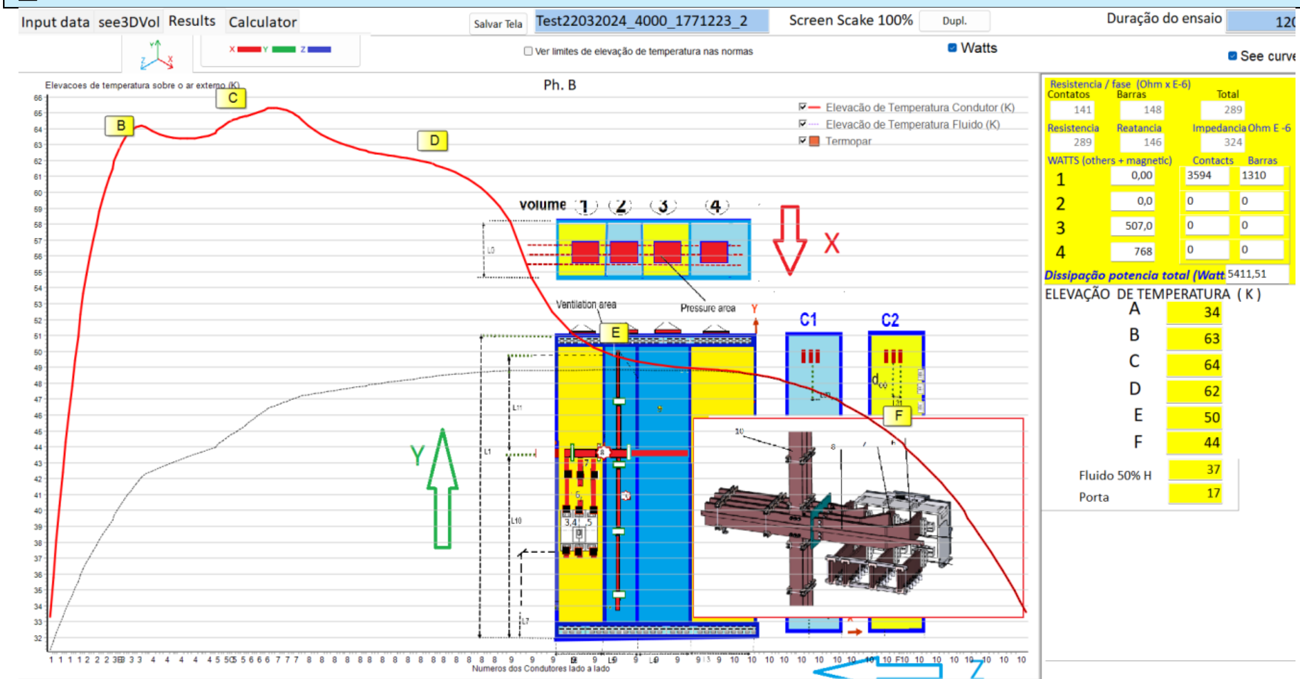


Parameter	Result in IEC standard	Simulation results	Difference
Max. Mechanical Stress σH (N/mm2)			-
Max. Mechanical Stress σT (N/mm2)			-
Total Max. Mechanical Stress σH + σT (N/mm2)			-
Max Force in the insulator in phase BB (central) in compression or tension (N)			-
Max Force in the insulator in phase BB (central) in) flexure (N)			-

Figure 13 – LVfok- Temperature rise test - Test report 1771223-2

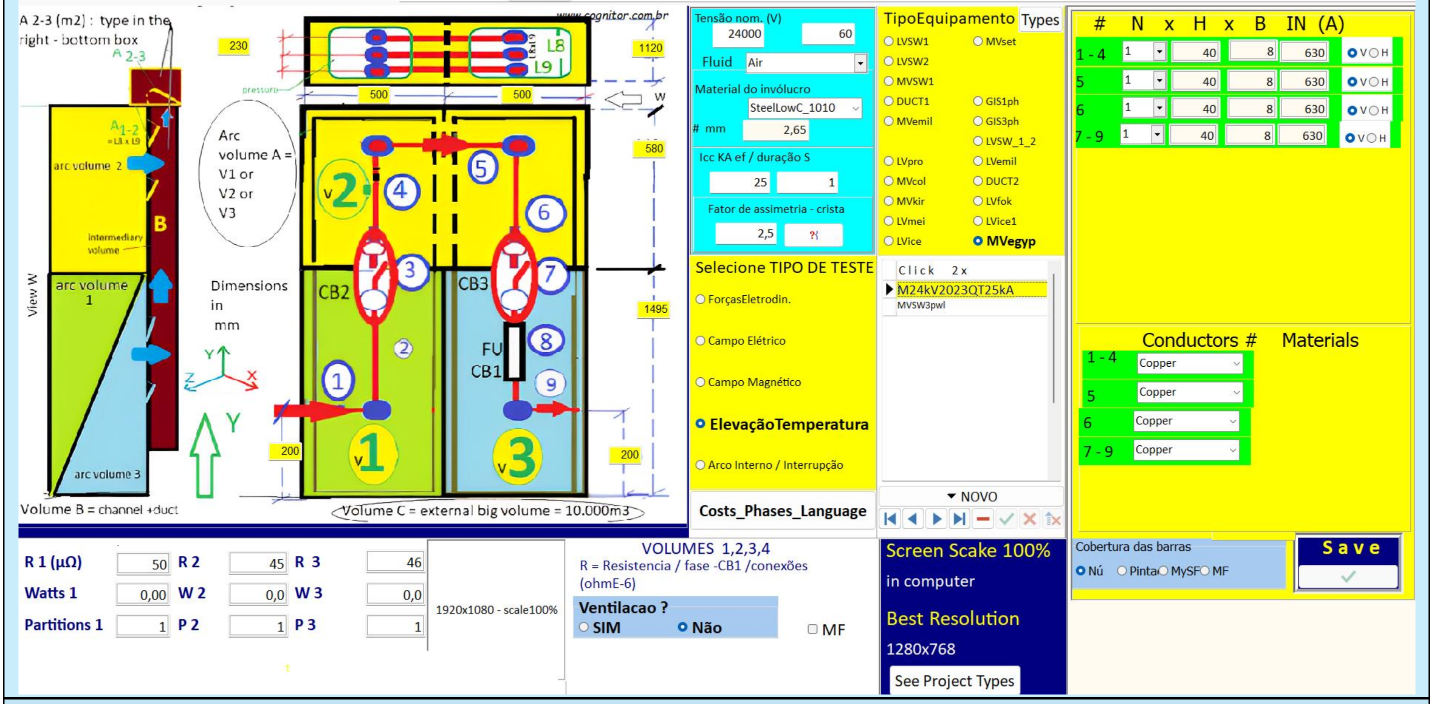
Recent test and design review. Testing lab test report under analysis.

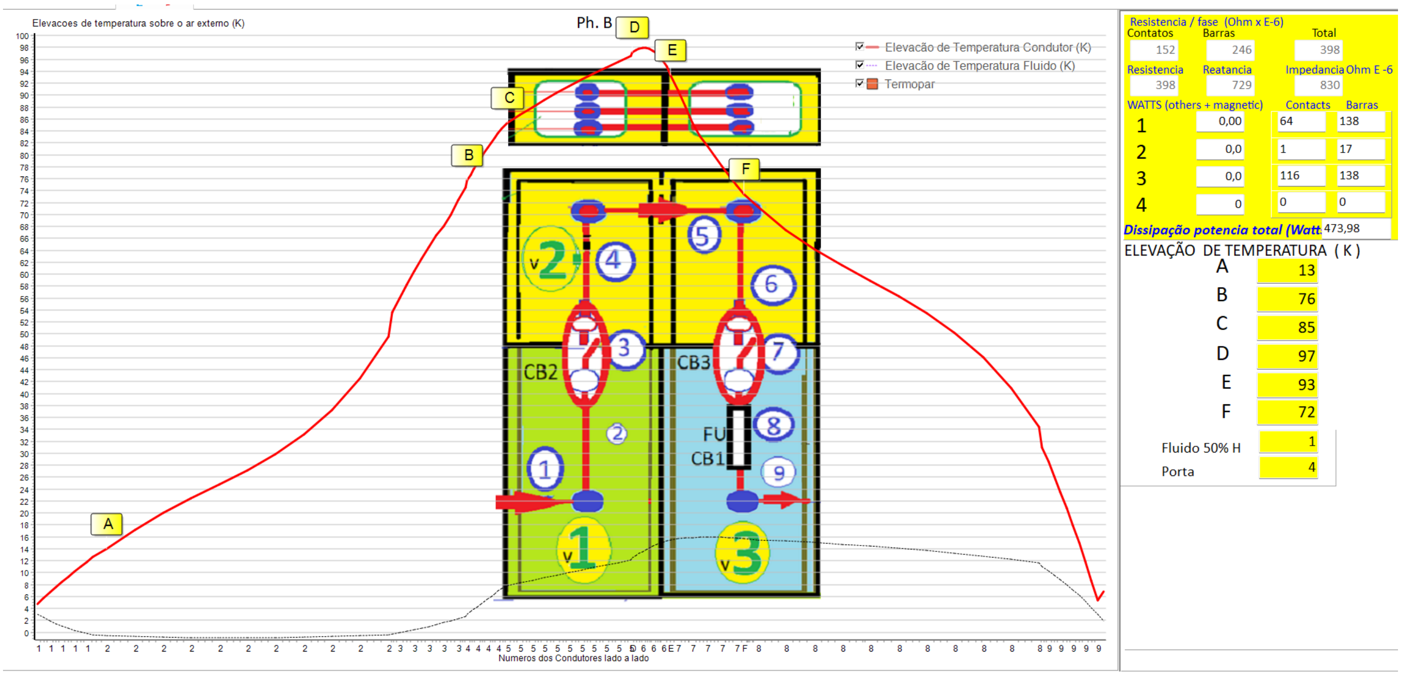




Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external cond.	xxx	xxx	
B – C – D – connection between bars and circuit breaker (**) or switches (see figure above)	xxx	xxx	
E – Connection between the horizontal and vertical bars	xxx	xxx	
F – Short circuit point	xxx	xxx	
Door	xxx	xxx	
Internal air (*)	xxx	xxx	

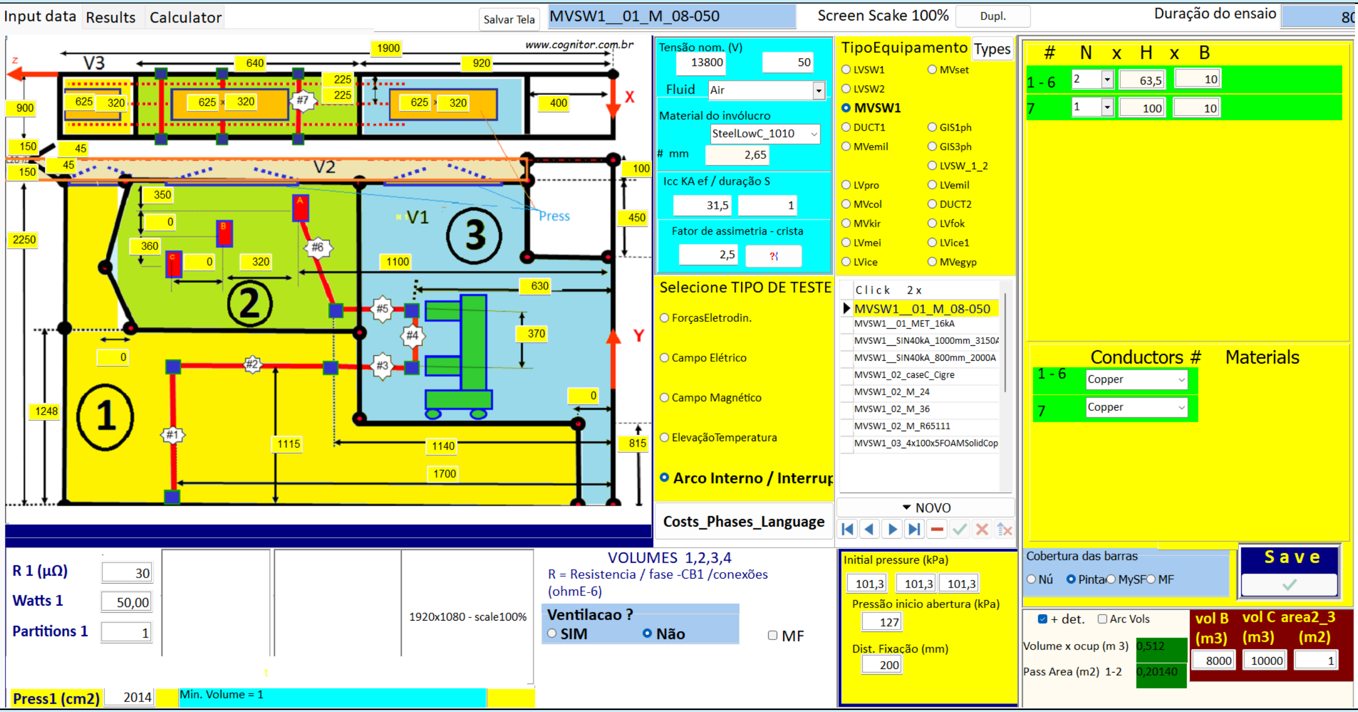
Figure 14 – MVegyp- Temperature rise test - Test report not informed



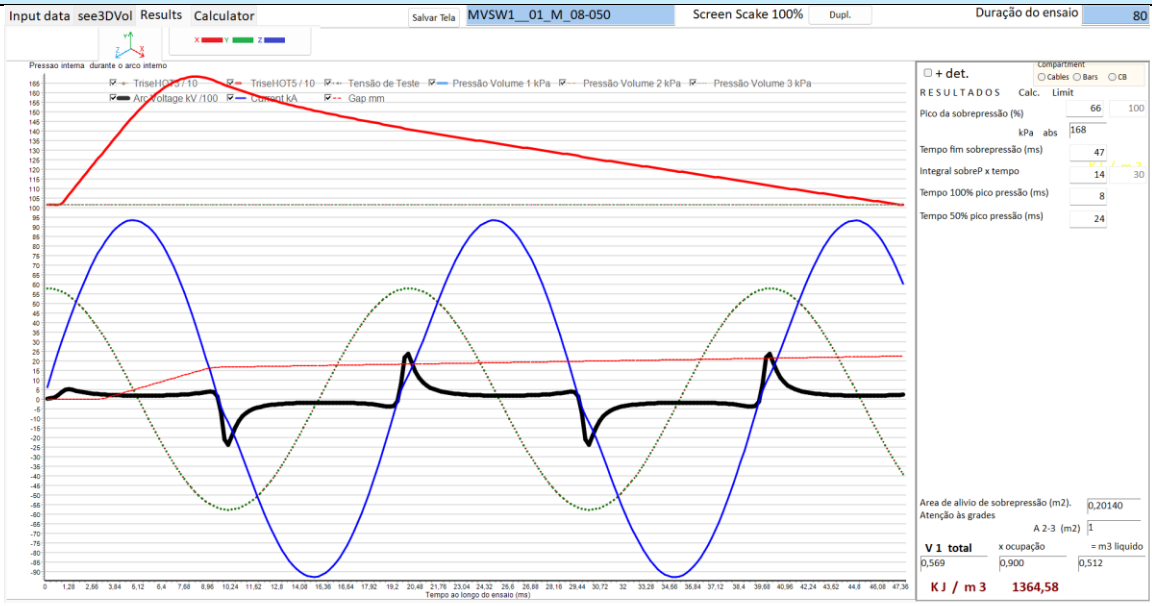


Measuring point	Test temperature rise (K)	Simulation (K)	Difference
A - Terminals for the connection to external cond.			
B – C – D – connection between bars and circuit breaker (**) or switches (see figure above)			
E – Connection between the horizontal and vertical bars			
F – Short circuit point			
Door			
Internal air (*)			

Figure 15 – **MVSW1 – Internal Arc Test -** Test report 08-050 - **MVSW1_01_M_08-050**

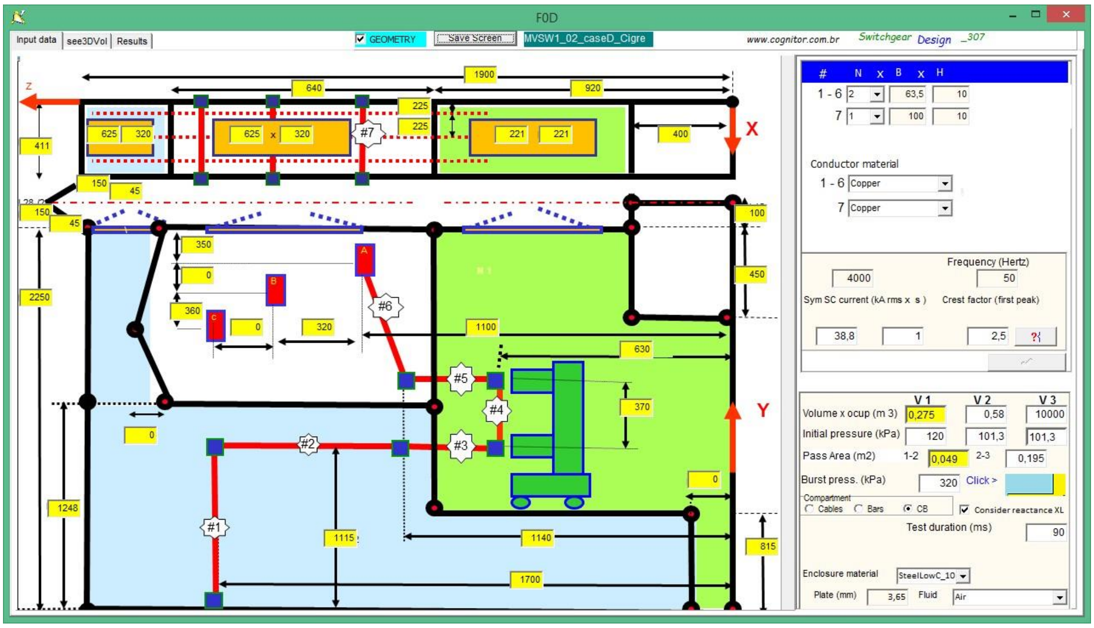


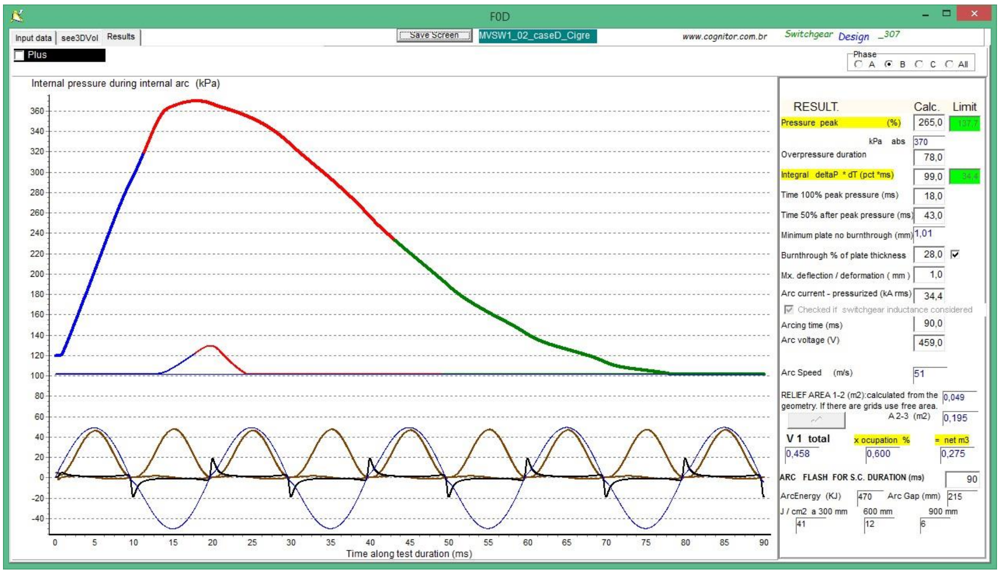
Worst overpressure considering the 3 different arc volumes___



Performance indicators	Obtained in test	Obtained in simulation	Difference
Maximum pressure (kPa) and overpressure above arc volume initial pressure ΔP (%)	160 kPa (58 %)	168 kPa (66%)	< 10%
Overpressure duration (ms)	46	47	< 10%
Integral of the overpressure x time duration curve (bar*s*1000)	-	14	
Duration to reach peak pressure (ms)	~ 15	8	
Duration to return to 50% of the peak pressure (ms)	~ 25 (*)	24	

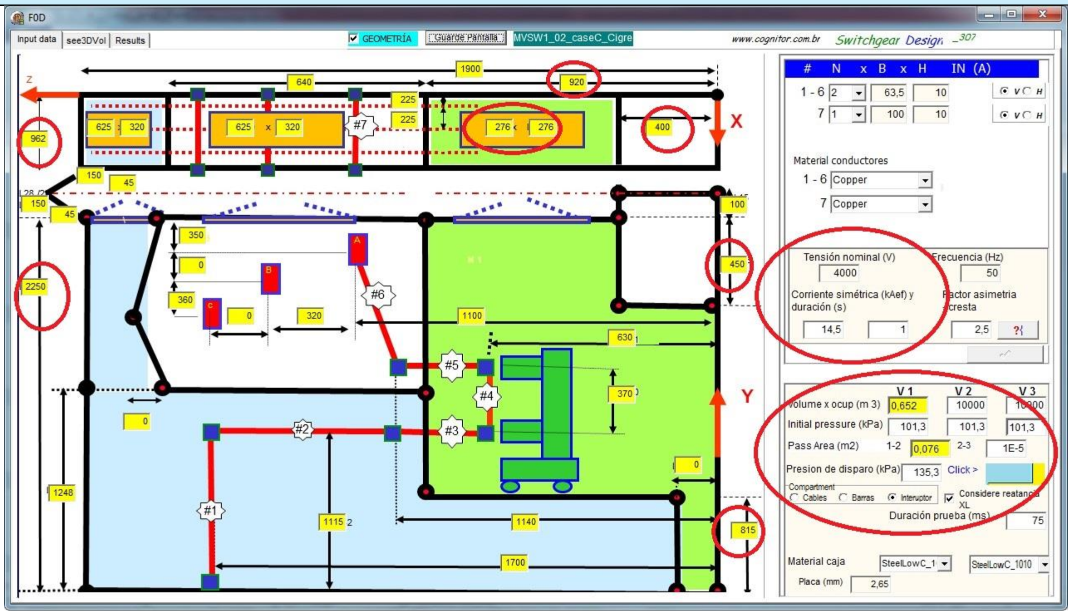
Figure 16 – **MVSW1 – Internal Arc Test – CASE D Brochure Cigrè -** MVSW1_02_caseD_Cigre

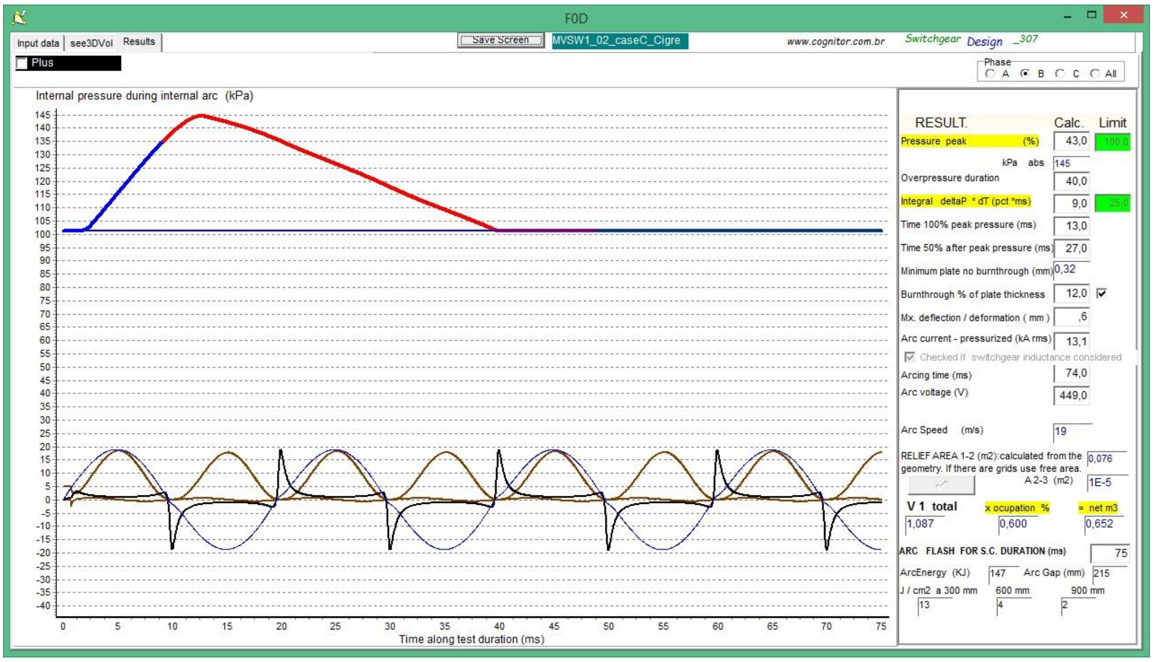




Performance indicators	Obtained in test	Obtained in simulation	Difference
Maximum pressure (kPa) and overpressure above arc volume initial pressure ΔP (%)	353 kPa (volume V1) 138 kPa (V2)	370kPa (V1) 129 kPa (V2)	<15 % (V1) < 10 % (V2)
Overpressure duration (ms)	~ 72	78	< 5 %
Integral of the overpressure x time duration curve (bar*s*1000)	---	99	-
Duration to reach peak pressure (ms)	~ 13	18	
Duration to return to 50% of the peak pressure (ms)	~ 25	43	
Arc voltage (V)	Avg F-T 350 / 250	460	
Arc velocity (m/s)	-	51	

Figure 17 – **MVSW1 – Internal Arc Test – CASE C Brochure Cigrè -** MVSW1_02_caseC_Cigre

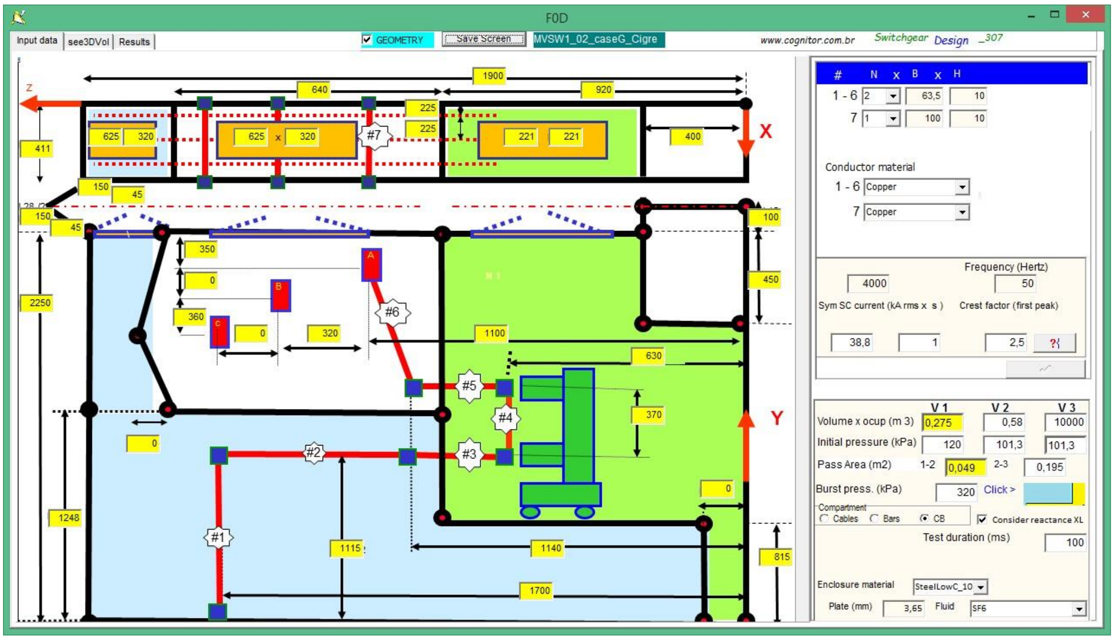


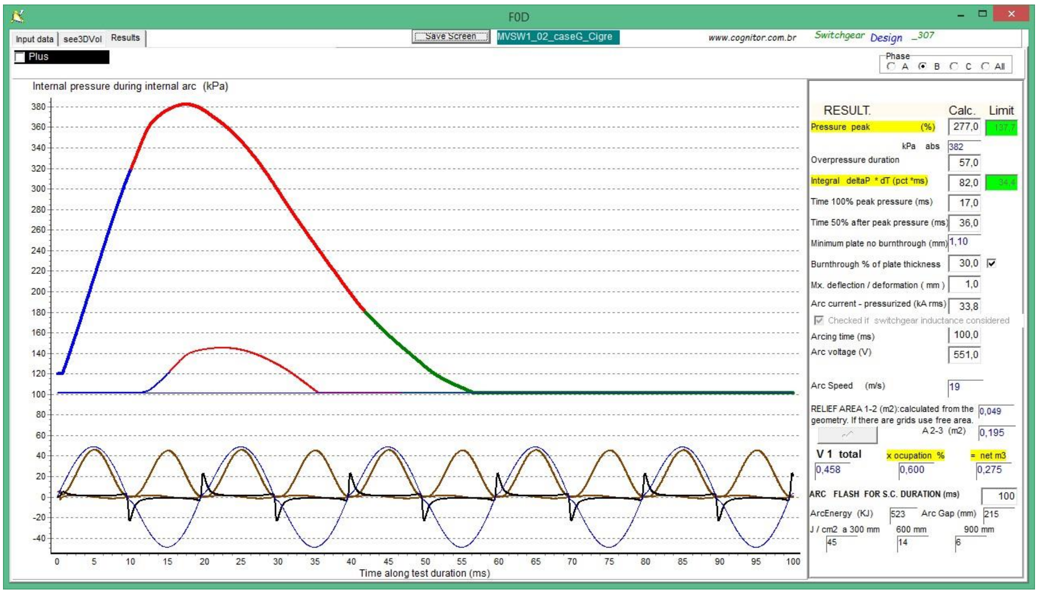


Performance indicators	Obtained in test	Obtained in simulation	Difference
Maximum pressure (kPa) and overpressure above arc volume initial pressure ΔP (%)	138 kPa 2 arcs (*)	145 kPa 3 arcs (*)	< 10%
Overpressure duration (ms)	70	40	
Integral of the overpressure x time duration curve (bar*s*1000)		9	
Duration to reach peak pressure (ms)	20	13	
Duration to return to 50% of the peak pressure (ms)		27	
Arc voltage (V)	400	449	
Arc velocity (m/s)		19	

(*) Note: The calculations shown in Figure 9b were made using a number of arcs equal to 3, which is what is done in the software. In Table Cigrè Brochure in Annex E the number of "arcs was 2. With 3 arcs the calculated pressure is a little larger than with 2 arcs

Figure 18 – **MVSW1 – Internal Arc Test – CASE G Brochure Cigrè -** MVSW1_02_caseG_Cigre SF6





Performance indicators	Obtained in test	Obtained in simulation	Difference
Maximum pressure (kPa) and overpressure above arc volume initial pressure ΔP (%)	330 kPa (V1) 170 kPa (V2)	381 kPa (V1) 145 kPa (V2)	<15 % (V1) <15 % (V2)
Overpressure duration (ms)	~90	57	
Integral of the overpressure x time duration curve (bar*s*1000)	---	82	-
Duration to reach peak pressure (ms)	~ 15	17	
Duration to return to 50% of the peak pressure (ms)	~ 40	36	
Arc voltage (V)	Medio F-T 400	551	
Arc velocity (m/s)	-	51	

6. ABOUT THE TRAINING and INSTRUCTIONS FOR INSTALATION AND USE OF SwitchgearDesign

Read the document "LV / MV Switchgear (IEC 61439, IEC 62271, IEEE) - Training for Design to be approved in the tests with focus on lower-cost products . Using software SwitchgearDesign to understand engineering concepts (Internal arc, temperature rise, short circuit strength, seismic & dielectric tests). https://www.cognitor.com.br/trainingENG.pdf

6. FINAL COMMENTS

The testing laboratories of the future will be small installations with people trained in doing real physical tests and people skilled in testing simulations. I explain in the article " High-Power (Small) Testing Laboratory + R&D Switchgear Development…. " In the link https://www.cognitor.com.br/hplENG.pdf

In the article (sorry in Portuguese - English version to be available soon) **"The lack of testing laboratories is making the Brazilian electrical (substations) equipment industry go back 35 years"** I explain a good opportunity for **international testing labs.** https://www.cognitor.com.br/hplPOR.pdf

Unfortunately, **there is no IEC or IEEE technical document defining the use of testing simulations** to replace tests. I wrote in 2010 the draft text of the standard "Guidelines for The Use of Simulations and Calculations to Replace Some Tests Specified In International Standards ". Link below. This document is referred in the Cigrè Brochure 602.

If I would compare my 25 years doing laboratory tests with the 20 years involved with testing simulations, **I would say that I learned much more with the simulations than with the real tests.** The reason is that simulations are fast and cheap to do. For test you can wait 2 days of mounting to pass a short-circuit current along 1s. Simple like this.

When you do test simulations before going to do the lab real tests the probability of approval is higher than 95%. Never 100% because some things cannot be simulated or validated because the necessary tests to compare would be very expensive. This is the case of the flow of hot gasses that go out of switchgear during AIS internal arc tests.

Additionally, human error may happen during testing on the part of the manufacturer or the testing laboratory. Labs rarely admit their own mistakes; The lab teams of today, all over the World, are smaller, more pressed, with small time to be trained and not well prepared as some decades ago.

I realize how mistaken I was in the past, being the manager of the 14 testing laboratories, to say that all substation's equipment needed to be tested. This is the perspective of whom has not noticed the changes in the World and have halted in time. Due to this thinking some testing laboratories have closed, and some are going straight on the same direction.

Repeating a criticism I often make in my articles, **the standardization institutions (IEC, IEEE) and the knowledge institutions supporting them like Cigrè, have a nice environmental speech but are slow to change their paradigms.**

An example is that using fewer materials and resources from the Earth should be a priority for the electric industry. However, there is no technical standard that says that making products with fewer materials and more efficient is better than just make heavier equipment to pass in, more severe than necessary tests.

For example, **most AIS electrical panels sold worldwide by large international manufacturers could use some 30% less copper and aluminum.** If a single researcher like me know how to do this, their very competent R&D teams knows much better. I witnessed this in many Cigrè and IEC WG meetings. The barrier is that making design changes to achieve lower cost equipment means leaving the comfort zone of selling already tested items. **It is time to IEC and IEE technical standards explicitly allow replacing tests with simulations, as IEC 62271-307 does.**

By the way, CIGRÈ will meet in Paris next August. In Paris, in this moment of Olympic Games, the minds will be more open influenced by good environmental and energy efficiency examples. Cigrè should discuss matters like this, especially with experts from G7 countries that have a poor history of caring for economies or saving materials. A suggested reading is in my free book "Renewable Energy + Environmental Education to Try to Save The Planet"

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[2] **CIGRÈ BROCHURE 830 (2021)** – "SIMULATIONS FOR TEMPERATURE RISE CALCULATION". (Sergio Feitoza Costa is co-author)

[3] **CIGRÈ BROCHURE 740 (2018)** Contemporary design of **low-cost** substations in developing countries. (Sergio Feitoza Costa is co-author)

[4a] **IEC62271-307 (2015) -** High-voltage switchgear and controlgear - Part 307: Guidance for the extension of validity of type tests of AC metal and solid-insulation enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV. (Sergio Feitoza Costa is co-author)

[4b] **ARTICLE "EXPLAINING IEC 62271-307** – EXTENSION OF THE VALIDITY OF TYPE TESTS TO AVOID TESTS REPETITIONS" . https://www.cognitor.com.br/IEC62271307ENG.pdf

[5] **Article "TEMPERATURE RISE LIMITS OF IEC 61439-1** : unclear values distort the LV switchgear market. (May,12, 2023) - http://www.cognitor.com.br/IEC614391Table6.pdf

[6] **IEC TR 60943:1998** - Guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals. (Issued 1st time by IEC Technical Committee TC 32 when Sergio was the chair of IEC TC32)

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[17] **Free book by Sergio "RENEWABLE ENERGY + ENVIRONMENTAL EDUCATION TO TRY TO SAVE THE PLANET"** https://www.cognitor.com.br/educationfortheplanet.pdf

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Things Sergio helped to do http://www.cognitor.com.br/HelpedToDo.pdf

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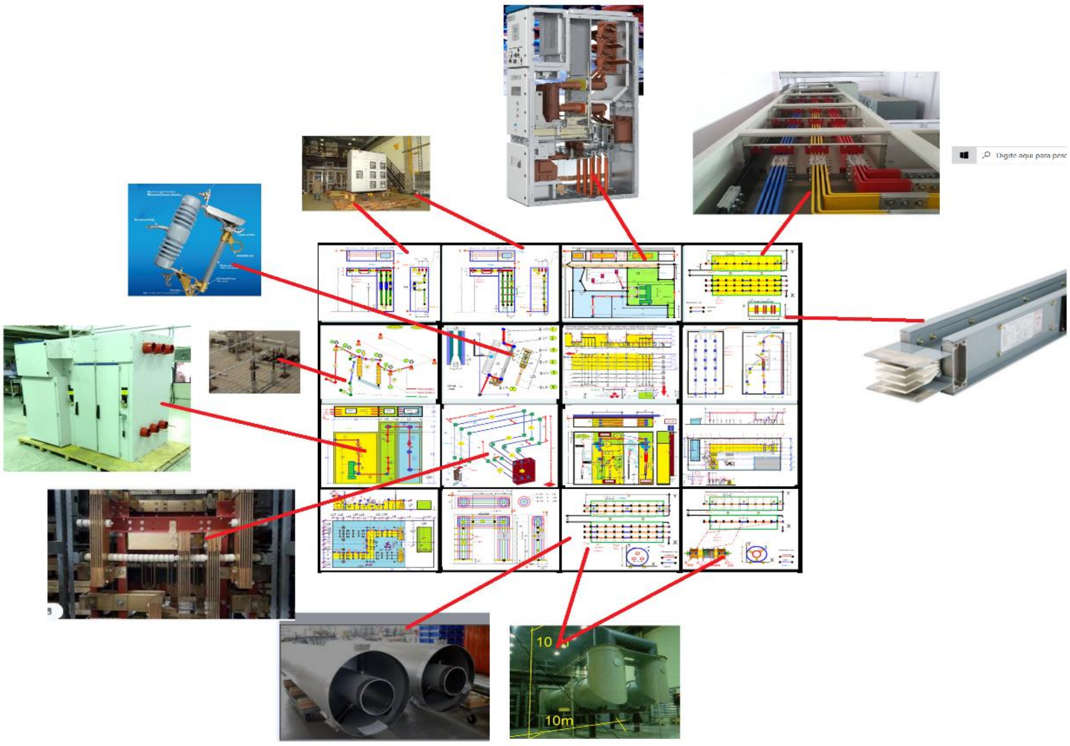
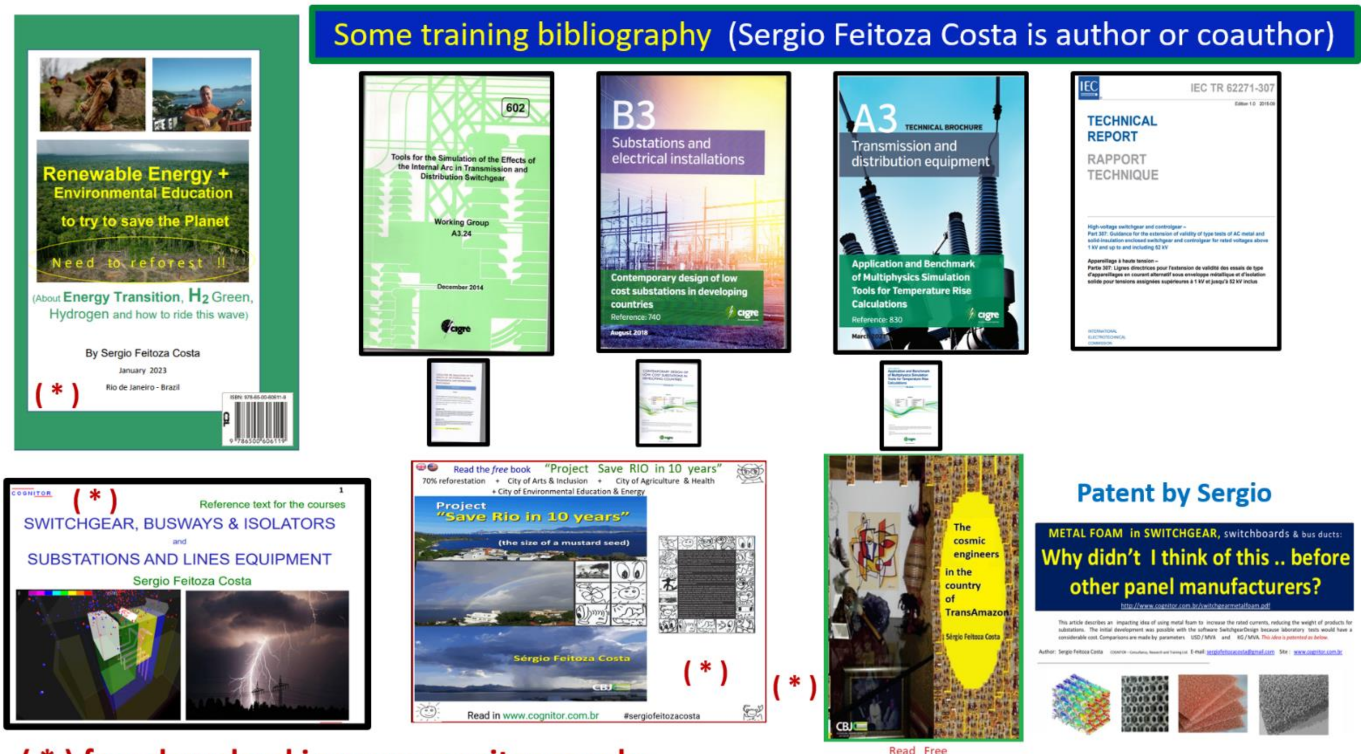
Design Review + Training + software : https://www.cognitor.com.br/proposal.pdf.

Some SwitchgearDesign models





(*) free download in www.cognitor.com.br