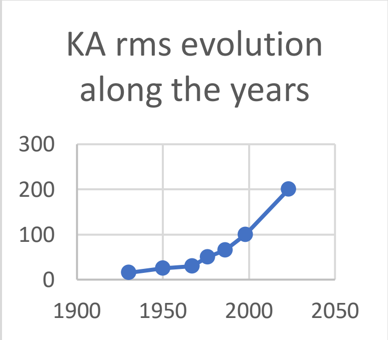
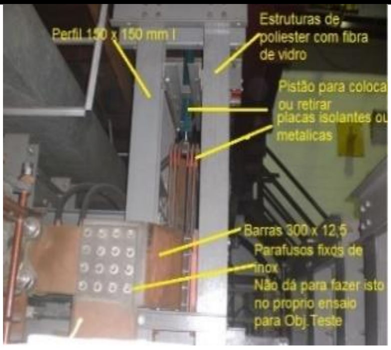
COGNITOR Consultancy, R&D and Training Ltd

SHORT CIRCUIT CURRENTS FORCES: what MHD propulsion systems have in common with switchgear, electric panels & busways.

YouTube 8 min. video - effects of forces https://www.youtube.com/watch?v=CRPopRlyjPc





- ARTICLE in English: https://www.cognitor.com.br/ElectrodynamicForces.pdf

1. SHORT CIRCUIT FORCES AND THEIR INCREASING IMPORTANCE IN THE COST OF SWITCHGEAR

The magnitude of short circuit currents continuously grow in the last decades as in the chart above. 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. Internal arcs trend to become more dangerous (lower volumes = higher overpressures).

Likewise, the electrodynamic forces acting on busbars and supports, proportional to the square of the currents and the inverse of the distances between busbars, will grow much more. This is the context in which this article is inserted. It will be increasingly important to create more optimized solutions to avoid the effects of short circuit stresses. We will show some techniques later.

For example, by the end of the 70's , when I was younger and we designed the CEPEL's High Current Testing Lab in Brazil, we were looking decades ahead and dimensioned it for reaching 300kArms /750kAcr (and 50kA continuous). We are arriving to these short circuit levels in 2024, some 40 years later.

<u>In next sections we will show how to calculate forces and mechanical stresses as well as describe the relevant design parameters.</u> For whom wants to go deeper in the theme I suggest reading IEC TR 62271-307 in the part related to short circuit thermal and electrodynamic stresses. Calculations include determining electromagnetic forces between conductors and the mechanical stress that can cause damage to insulators and bend busbars.

The calculation methods used in the SwitchgearDesign software, developed by me, are based in the following documents:

- IEC 61117, Method for assessing the short-circuit withstand strength of partially type-tested assemblies (PTTA)
- IEC 60865-1, Short-circuit currents – Calculation of effects – Part 1: Definitions and calculation methods.
- IEC TR 60865-2, Short-circuit currents – Calculation of effects – Part 2: Examples of calculation.
- M.Sc. Thesis by Sergio Feitoza Costa -M.Sc. Thesis - 1979: Electromechanical stresses in electrical equipment, especially switchgear created to support the design of CEPEL's High Power and High Current Test laboratories.
- IEC TR 62271-307 - 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. Read my article "IEC 62271-307 – Extension of the validity of type tests to avoid tests repetitions" in this link https://www.cognitor.com.br/IEC62271307ENG.pdf

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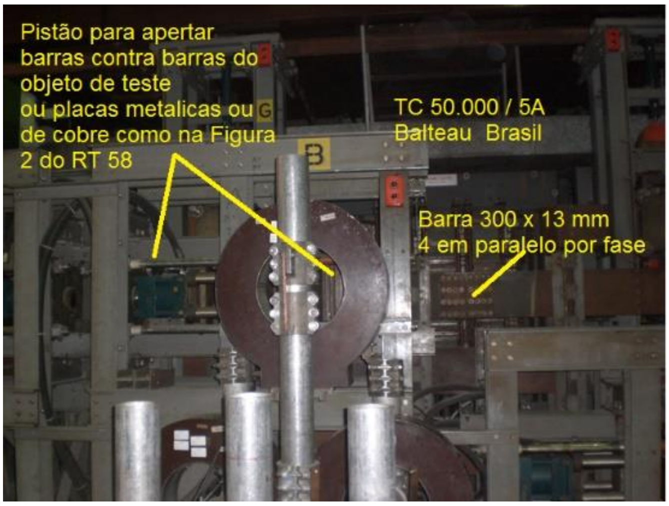
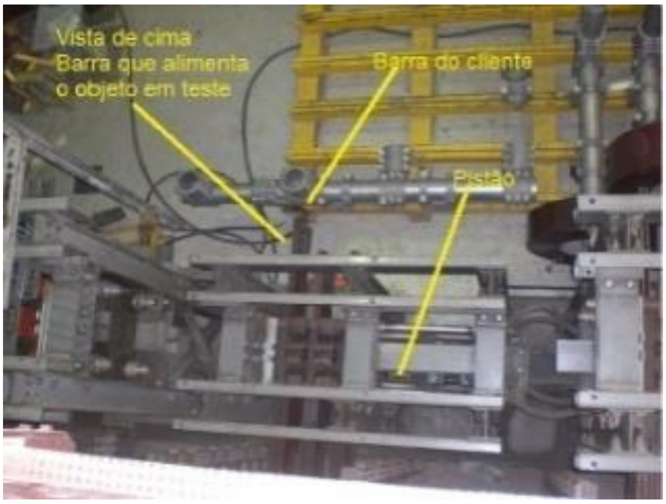
A good way to start understanding what is relevant to calculate short circuit forces is to look for the performance criteria regarding thermal and electrodynamic short-circuit stresses of Table 5 of IEC 62271-307. I, Sergio Feitoza Costa, am co-author of this IEC document published in 2015.

Item	Design parameter	Acceptance criterion	Condition	Criteria attended?
(1)	(2)	(3)	(4)	
1	Centre distance between phases	≥		
2	Electro-dynamic forces due to current path	≤	The conductors have the same physical arrangement.	
3	Mechanical strength of insulating conductor supports	≥		
4	Length of unsupported sections of conductors	≤		
5	Cross-section of conductors	≥	Connections of the conductors are scaled and have the same or greater clamping force and contact area.	
6	Material of conductors	same		
7	Temperature class of insulating material in contact with conductors	≥		
8	Mechanical strength of the enclosure /partitions/ bushings	≥		
9	Contacts of removable part	same	Consider complete design of contact sub-assembly and the fixing / mounting of the removable part.	





2. THE CALCULATION OF ELECTRODYNAMICS FORCES IN SWITCHGEAR AND OTHER BUSBARS

The concepts on how to calculate electrodynamic forces and stresses which occur during short circuits are a must in the design of switchgear, busbar systems and even complete substations arrangements. The objective is to determine forces and their consequences to design the structures, size of the busbar conductors, number of insulators and supports, etc. Also very important are the minimum cross sections of grounding busbars,

If you do calculations on a medium voltage or low voltage switchgear at short circuit levels higher than, let's say 31,5 kA you may get forces in the range of tons. This is because the forces are approximately proportional to the square of the values of crest currents and inversely proportional to the distance between phases.

The shape of the short circuit currents can be understood in the next figure.

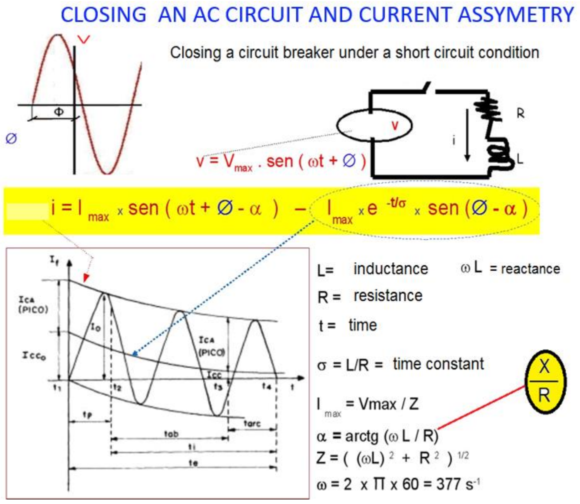
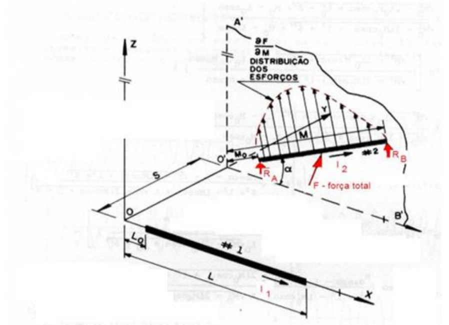


Figure 1 – Forces created in two neighbor conductors circulated by short circuit conductors.

F = Fx (x) + Fy (y) + Fz (z)

dF/dm = dFx/dm (x) + dFy/dm (y)+ dFz/dm (z)



The equations to calculate forces and stresses in two neighbor conductors circulated by short circuit currents are like the ones showed in Figure 1, extracted from my 1979 M.Sc. Thesis.

What we do is to calculate for each one conductor, the forces produced in it by all the other conductors of the switchgear busbar system. To do this we consider the instantaneous values in each of the phases with the corresponding phase angles. These forces depend on the currents, asymmetries, phase angles, geometry, distances, materials used, etc.…. Inside a switchgear there are dozens of conductors, each one influencing the other.

So, to calculate the forces in conductors and in the supports and insulators it is necessary to use a computer program like SwitchgearDesign, in which you just enter with the values of currents, distances and asymmetry factor (Figure 2).

$$\frac{\partial F_x}{\partial m} = (\mu_0 I_1 I_2/4\pi) \cdot sen^2\alpha \cdot m \left\{ \left[1/\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2}\; \left(\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2}+L_0-m\cos\alpha\right)\right] - \left[1/\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}\; \left(\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}+L-m\cos\alpha\right)\right] \right\} \quad (3.1)$$

$$\frac{\partial F_y}{\partial m} = -(\mu_0 I_1 I_2/4\pi) \cdot \cos\alpha \cdot S \left\{ \left[1/\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2}\; \left(\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2}+L_0-m\cos\alpha\right)\right] - \left[1/\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}\; \left(\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}+L-m\cos\alpha\right)\right] \right\} \quad (3.2)$$

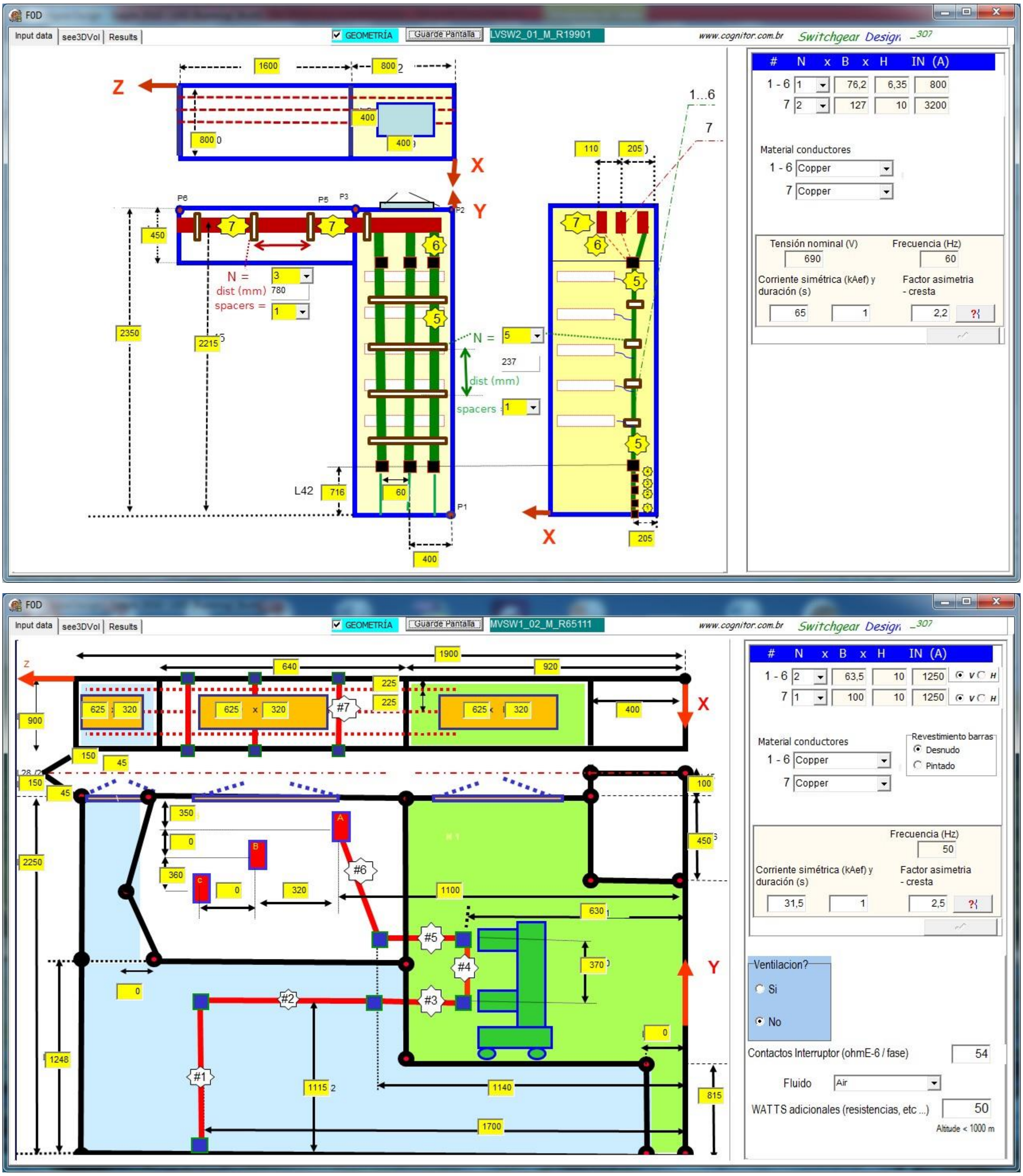
$$\frac{\partial F_z}{\partial m} = -(\mu_0 I_1 I_2/4\pi) \cdot \cos\alpha \cdot sen\alpha \cdot m \left\{ \left[1/\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2} \cdot \left(\sqrt{m^2-2L_0\cos\alpha\, m+L_0^2+S^2}+L_0-m\cos\alpha\right)\right] - \left[1/\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2} \cdot \left(\sqrt{m^2-2L\cos\alpha\, m+L^2+S^2}+L-m\cos\alpha\right)\right] \right\} \quad (3.3)$$

In substations calculations it is frequent to use approximations considering that all the conductors are parallel. This is not good nor necessary. It is better to do a clean calculation like in SwitchgearDesign.

A clean calculation means that all conductors and their geometric positions are considered. So, you do not need to use uncertainty safety factors over dimensioning the system.

Because of using uncertain calculations, to avoid failing in the expensive type tests in testing laboratories, the designer tends to use high "safety" factors. So, at the end, the project become over dimensioned with a higher weight of copper and aluminum and a much higher number of supports and insulators than necessary.

Figure 2 – Input data for calculation of forces and stresses in MV and a LV switchgear **(extracted from** Report 071/2014: Validation Of Software Switchgeardesign_307 For Simulation Of High Power Tests (Temperature Rise, Short Time And Crest Current Tests – Electro Dynamical Forces / Stresses And Overpressures From Internal Arc - download in http://www.cognitor.com.br/TR_071_ENG_ValidationSwitchgear.pdf)



It is impressive to see the number of possibilities of optimizations and reduction of materials in the existing designs of medium voltage and low voltage switchgear. A lot of money and resources are thrown away due to exaggerated projects. In many cases gains of 20 to 30% are easily achievable by a more precise calculation. This occurs not only in the aspect of mechanical forces but also with temperature rise aspects.

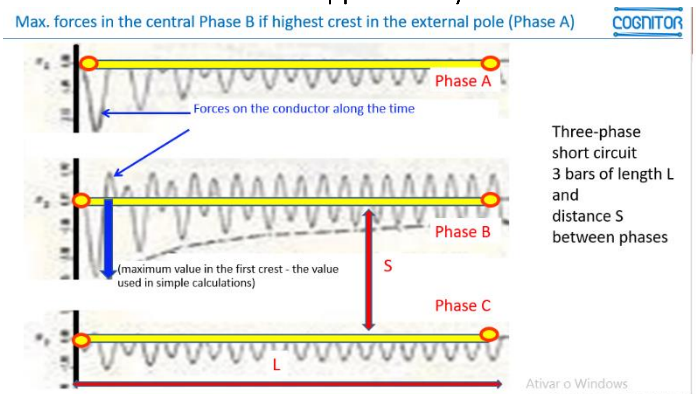
To assess the withstand ability of insulators and conductors the main steps to follow are:

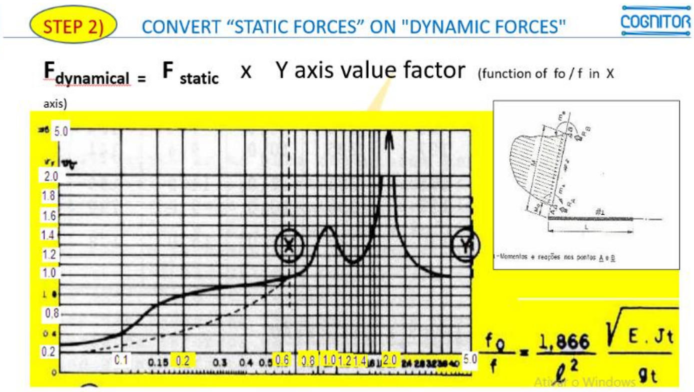
- Calculate the static forces distributions (equations above).
- Convert static forces in "dynamic" forces (figure below)
- Calculate forces on insulators, shear forces and bending moment diagram.
- Calculate mechanical stresses on the conductors = bending moment / resistant moment
- Compare stresses in conductors and forces in insulators with permissible limits.

The determining parameters for the design are:

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

Aspects of resonance and types of short circuit shall be considered properly to arrive to the final values of forces and in the assessment of the supportability.

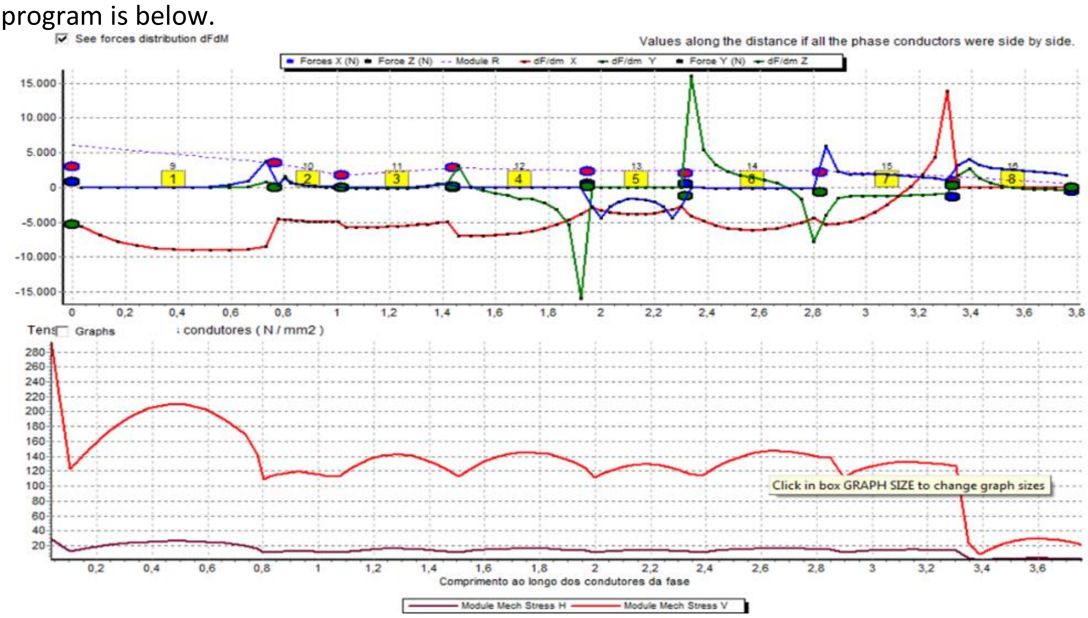




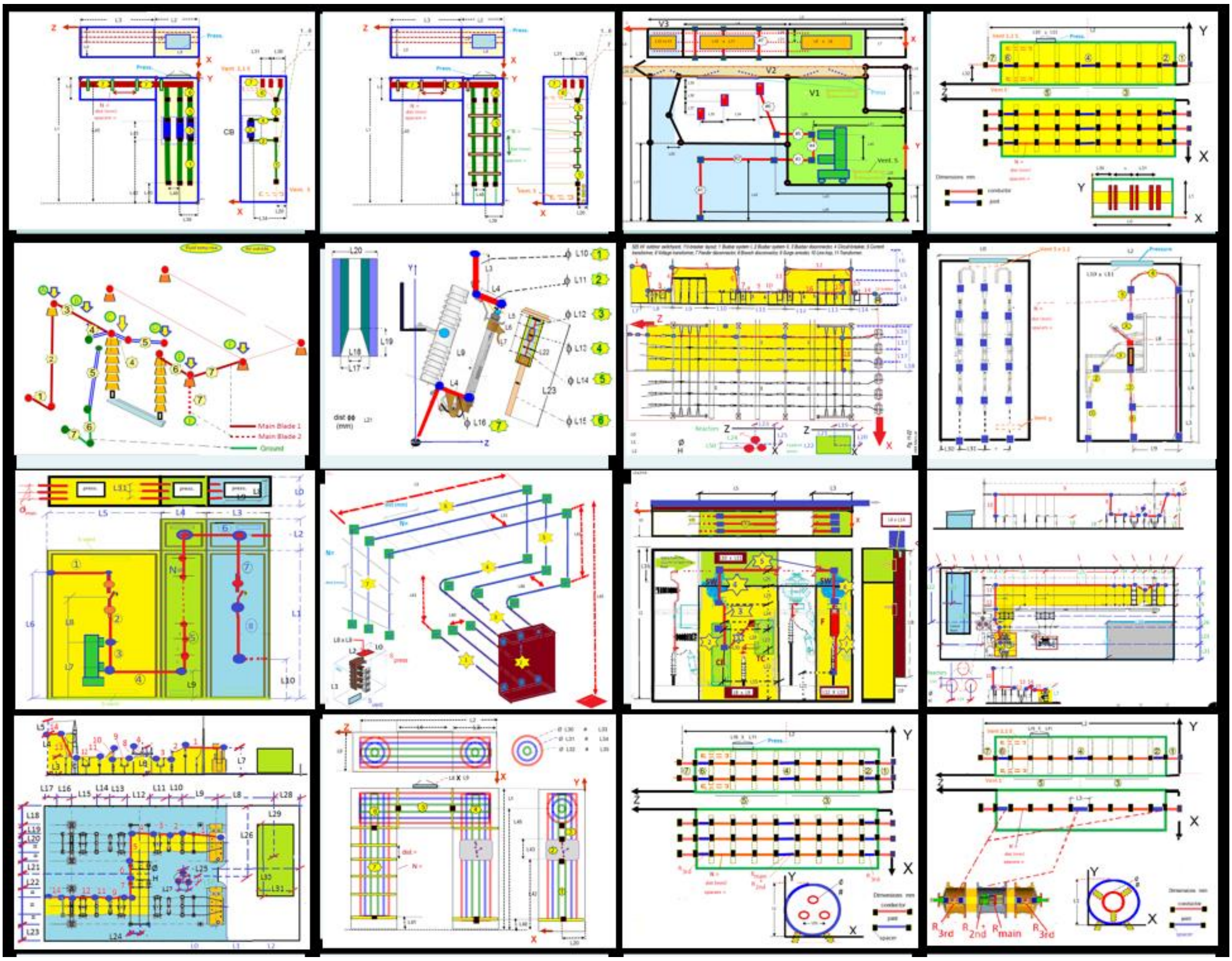
3. SIMULATING SHORT TIME CURRENT AND CREST TESTS (TYPICAL RESULTS)

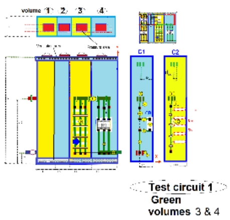
When all the parameters are properly considered, and a calculation is done using SwitchgearDesign the results obtained are presented as below. The upper curve shows the forces acting in insulators and supports of the busbars. The lower curve shows the mechanical stresses which will be applied in the busbars tending to bend them. With the training it is easy to the designer to check if these values are acceptable for a successful type test after.

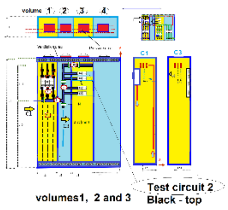
The training program is below.

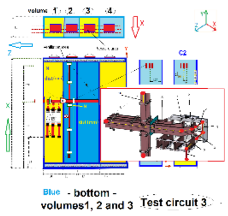


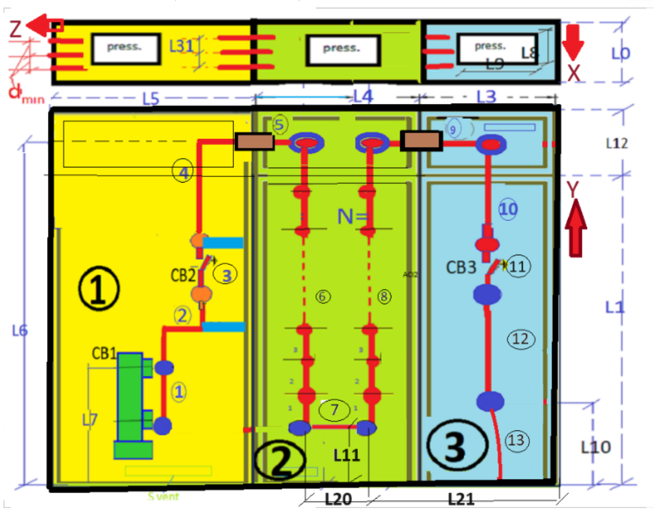
Here are some of the other possibilities of different switchgear systems calculated by SwitchgearDesign.











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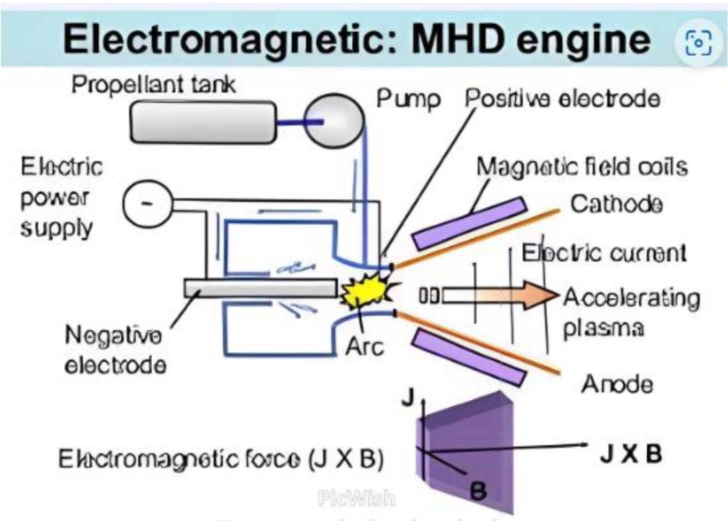
4. TRANSPORTATION PROPULSION USING MAGNETOHYDRODYNAMICS (MHD)

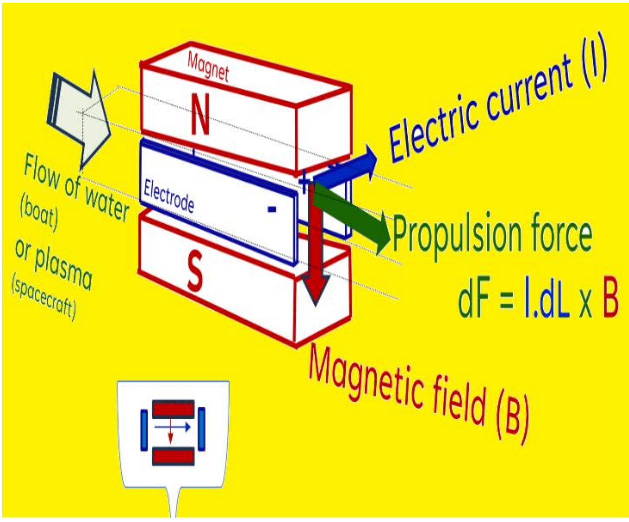
There are modern applications of electrodynamic forces that go far beyond switchgear and substations busbars

As in Wikipedia https://en.wikipedia.org/wiki/Electromagnetic_propulsion#mw-head electromagnetic propulsion (EMP) is the principle of accelerating an object using the interaction between magnetic fields over conductors made of metals, water or plasma. It is the same principle of two electric busbars of a busway circulated by high currents. The current in one of them create a magnetic field that will reach the neighbour conductor creating mechanical (Lorentz) forces.

If you mind that one of the conductors is made of water or even plasma you can use the forces for the propulsion in a system designed to take advantage of the phenomenon. First you use something to create a strong magnetic field. After, a fluid (liquid or gas) is employed as the conductor that will be moved by the forces. It is sometimes named as magnetohydrodynamic drive. In electric motors the forces are used to produce rotational energy

The science of electromagnetic propulsion has application in many different fields. The thought of using magnets for propulsion has been dreamed of since at least 1897 when John Munro published his fictional story "A Trip to Venus".[1] The easier applications are in maglev trains, ships, and submarines. Check the fundaments in the figure.

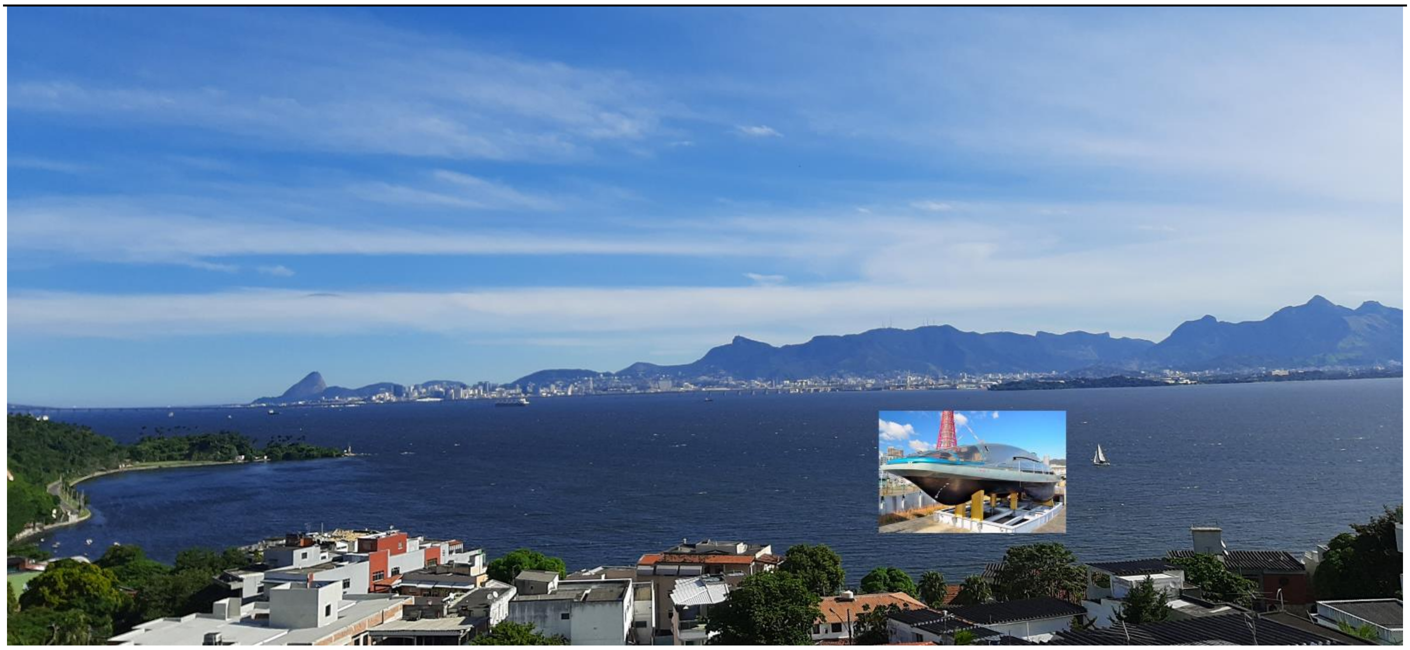




About 20 years ago, while I was the coordinator of an R&D group on energy generation technologies, I became familiar with the concepts of MHD. At the time, I didn't fully comprehend them, but now I do. I believe that creating anything with plasma to enable space travel is a bad idea since I would be unable to test it and verify the simulations. I'm working on a practical use for boat propulsion. The goal is to use solutions that are both fairly priced and environmentally friendly. The researcher needs to be aware that people who are comfortable with less efficient technologies where they have gained money will put up obstacles in the way of pursuing better technical solutions.

Right in front of my window is one example. I can see Rio de Janeiro's beautiful but dirty Guanabara Bay from there. The extensive use of boats, as is done in Istanbul, Turkey, is the obvious solution to speedier transportation and lowering pollution from vehicle transportation.

But in this case, bus operators have consistently resisted the expansion of water transportation. The similar situation occurs throughout Brazil, where there is just no interstate train system for moving people. The bullet train project between Rio and São Paulo failed twenty years ago. I will not attempt to clarify why. There were admirable initiatives for railway transportation more than 200 years ago, but they were abandoned. Who knows what new is emerging in these times of green H2. My book "Renewable Energy + Environmental Education to try to save the Planet" present some ideas.
Read free here https://www.cognitor.com.br/educationfortheplanet.pdf



About MHD R&D, when I read the many articles and documents on the Web, I notice a lack of focus. I see researchers exhibiting electrodynamic force equations that have been issues resolved for over 50 years, as in my 1979 thesis used to design busbars up to 750 kAcr.

> The good focus is not there, but on finding how to produce magnetic fields at a lower cost, with less weight and energy use. Also, how to generate, in small space, the energy used to circulate electric currents in the water under the ship or boat.

When we start studying a concept like MHD we need first to compare the promising solution with the existing conventional alternatives. In the case of the boat propulsion the alternative is a kind of marine motor moved by gas or diesel. In the case of a spacecraft, typically we have fuels like liquid hydrogen (LH2) which will be mixed with liquid oxygen (LO2 or LOX) as an oxidant. These are expensive processes because hydrogen and oxygen remains in a liquid state at a temperature like -183 °C to -253 °C. We need to investigate the aspects of costs under a vision of some decades ahead focusing on benefits to common people and environment.

5. FINAL COMMENTS

The concepts and calculations of electrodynamic forces have been known for many decades, but there is still a lot of room for optimization in the design of switchgear, switchboards, busways, and busbar systems in general.

The potential of magnetohydrodynamics tends to be more explored at this time when the use of green hydrogen is being more explored. It is a good theme for R&D projects and master's or doctoral thesis.

The use of hydrogen is now increasing on the Planet due to environmental issues. This will help bring more attention to the potential of MHD. When we do a simple search on the Web, we see that the number of experimental projects is significant, it is likely that developers are already seeing good medium-term opportunities.

Before starting to "copy-paste" old electrodynamic force equations, researchers need to keep in mind how their research can be useful in improving people's lives in modest real-world situations. This is the key for the success.

END OF THE ARTICLE

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