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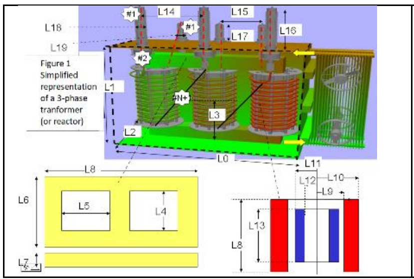
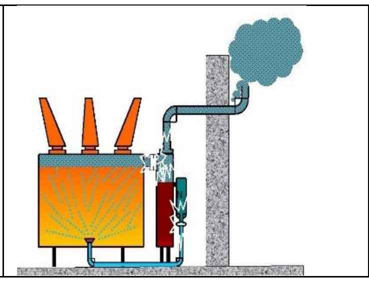
AVOIDING EXPLOSIONS & FIRES in POWER TRANSFORMERS & REACTORS

Why the only worldwide technical standard with a test for internal arc faults and depressurization systems, the Brazilian NBR_8222 (2005) - Protection systems by depressurization ………. was canceled in 2014 ?

Complete text suggestion for a new IEC standard

https://www.cognitor.com.br/transformersfiresexplosions.pdf Author: **Sergio Feitoza Costa (Cognitor – Consultancy, R&D, Training)**





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- Forces & stresses, temperature rise & overpressures of internal arc.: https://www.cognitor.com.br/PowerTranformersReactorsCalculation.pdf
- Explosion & Fires - power transformers: https://www.cognitor.com.br/transformersfiresexplosions.pdf

1. INTRODUCTION

On June, 2022 , when I was inserting one of my technical posts of the book "180 posts for the Electric Power Industry" http://www.cognitor.com.br/180posts.pdf I saw a post from someone about fires in power transformers and the serious economical and image consequences. Weeks ago, I saw another post about tests of short circuit in power transformers. The focus was about electrodynamical forces.

The first thing to mention is that IEC standards, at least up to 2008, do not have any kind of high-power test focused on what happens when a transformer has an internal fault which causes an arc inside and, frequently, an explosion which reach the neighbor transformers. I learned about this around 2003 to 2005 when I had a frequent contact with a manufacturer of protection system by depressurization, drainage and agitation of insulating oil for transformers and power reactors. That manufacturer tested the system successfully using the test of the Brazilian standard NBR8222.

This "internal arc test for transformers" is completely different from the " external short circuit tests of IEC power transformers standard" . In the IEC test the objective is to check if the equipment can support a certain number of external short circuits, like 9, with acceptable changes in inductance. Due to the size of power transformers and the high costs of transportation and short circuit test there is a reasonable opening in the standard for replacing the short-circuit test by calculations. I never saw a validation of these calculations (article below). The fact is that, as written in the articles of my colleagues from Kema (links below) some 20% of the tested transformers fail in the first short circuit test. Most frequently they do not fail due to gross design errors but, instead, due to details difficult to check in the big, enclosed volume with so many components. Read the article [1] "Short-circuit test experience of power- and distribution transformers" by Rene Smeets, R. Bruil, K. van der Linden. DNV GL KEMA Laboratories .

I see designers and experienced users of switchgear and busways in doubt of using simulations of temperature rise tests, internal arc and short circuit forces. They are well validated in ref. [5,6] and important Cigrè brochures like :

- CIGRE 602 (2014) – "Tools for the Simulation of The Effects of the Internal Arc in T&D Switchgear" ,
- CIGRE 740 (2018) "Contemporary Solutions for Low-Cost Substations and
- CIGRE 830 (2021) –"Simulations for Temperature Rise Calculation".

I am coauthor of these brochures. In the brochure 602 it is referred the document " Proposal for IEC Guidelines for the use of simulations and calculations to replace some tests specified in international standards" that I prepared many years ago and sent to IEC . It did not become an IEC work item because, for this, it is necessary to have the support of the big world-wide manufacturers. Only they have the strength to create new work items in the IEC.

The fact is that, on the contrary of power transformers, switchgear and busways are very easy equipment to identify small design or construction errors. So, many designers and users, accept calculations in large power transformers, to replace tests, but do not accept calculations in easy items. The reason is simple. In the case of transformers , the opening for calculations is written in an IEC standard. So, the responsibility is not theirs. More than this, if it fails in the future, no one will be able to validate whether the calculations were right or wrong. That's why I have always advocated the creation of the IEC standard with rules for the use of test simulations, referred in Brochure Cigrè 740. It is not for showing how to do calculations . It is to show how to validate them within a certain error.

Coming back to the Brazilian standard NBR8222, around 2005 I proposed the revision of a Brazilian Standard on this matter to include a test to demonstrate that the protection by the depressurization system really works. The standard was created, the “internal arc short circuit test” was included. I know that after that, tests were done in the protection system, in the Brazilian labs, and confirmed that the system works.

Actually, at that time, I managed within the Brazilian Standards Association (ABNT) the revision of these 4 standards

● NBR 13231 - Protection against fire in conventional electrical substations, attended and not attended, of transmission systems.
● NBR 8222 - Protection systems by depressurization, drainage and agitation of insulating oil for transformers and power reactors.
● NBR 8674 - Systems with nebulized water for power transformers and reactors.
● NBR 12232 - Systems with CO2, by total flooding for transformers and power reactors containing insulating oil.

Just after this I stopped to work with this theme. I still applied trainings about for some years before stopping. Now, I am not updated about what happened after this. However, I included in my testing simulation software SwitchgearDesign a module to simulate tests of internal arc overpressures, short circuit forces and temperature rise. Recently, as no manufacturer asked me about such kind of calculations, I removed the module. Calculations and simulations are a good thing when they are well validated as in Refs. [5 to 8] below. Here this was not possible.

The next figure and the one at the end, show the calculation model. If anyone is interested take a look in my older article “ Power transformers & reactors: calculations of electromechanical forces & stresses, temperature rise and overpressures of internal arc. It is in the link https://www.cognitor.com.br/PowerTranformersReactorsCalculation.pdf

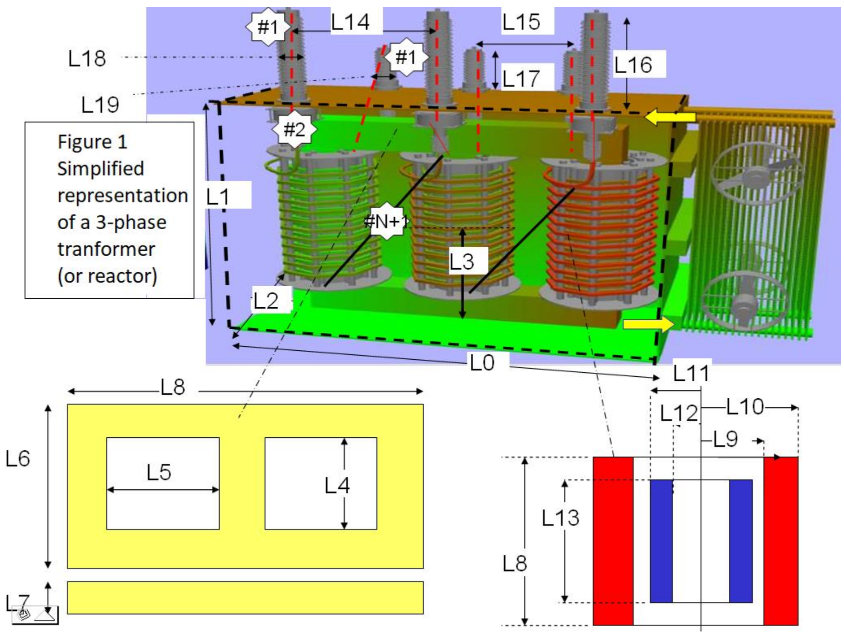

Figure 1 Simplified representation of a 3-phase tranformer (or reactor)

Also check this article about a fire of high impact in Brazil, during 2020 http://www.cognitor.com.br/AmapaENG.pdf

2. WHY THE ONLY WORLDWIDE TECHNICAL STANDARD ABOUT INTERNAL ARC SHORT CIRCUITS AND DEPRESSURIZATION SYSTEMS NBR 8222 (2005) WAS CANCELLED IN 2008 ?

By curiosity I went to the site of ABNT and did not find any reference. Then I went to the site of an institution that sell ABNT technical standards and found in this link that it was cancelled in 2014 ABNT NBR 8222 Execução de sistemas de prevenção

Don't ask me why it was canceled. I also do not know the reason and do not have time to check. Anyway, for whom is interested in the 2005 text just go to section 4 and you will find it but improved by me when writing this article. I have now an experience that I did not have at that time, about calculating the overpressures. If you know how to calculate the overpressures you can created reduced models with a much lower volume of oil and arc current. The idea is to do the test in a way that you can extinguish the fire if the equipment fails in the test. Simple like this and based in the same principles of brochure CIGRE 602 mentioned above. I am coauthor of this brochure about high currents internal arcs.

In another article about a major fire in transformers, in 2020 in Brazil (link above) I asked the Brazilian regulators (ANEEL/ONS) what are the current rules for fire prevention and protection systems in substations? I also asked if there are ABNT standards that cover this, as there were until 2014? Unfortunately, I didn't get any answer to explain here.

In the next section I explain the contents and objective of that NBR 8222.

3. THE OBJECTIVES of the standard and the INTERNAL ARC TEST of NBR 8222 (2005)

The objective of the standard is to show specific requirements for prevention against explosions and fires by avoiding overpressures resulting from internal electric arcs in power transformers and reactors. The general requirements for installation projects were in the standard NBR 13231.

This type of system does not eliminate the convenience of installing traditional devices to prevent the spread of fire, such as: drained and protected concrete bases, non-combustible barriers and fire walls, mobile extinguishing devices. Applies to oil-filled transformers, autotransformers, reactors and oil-filled parts (changers, bushing and cable boxes).

The goal is to avoid the explosion of the transformer or reactor and consequently the fires. The prevention systems in the Standard seek to prevent the internal overpressure resulting from the internal electrical arc from reaching values greater than the withstand of the protected equipment. The principle may involve, among others, depressurizing the internal parts, conveying the gases produced to a place where they can burn safely, without affecting nearby people and equipment, and creating a flow of gases to cool the oil and to eliminate explosive gases. .

Proof of the efficiency of the protection method must be done through type tests. These tests are to verify the ability of the prevention system to prevent explosion and fire under internal arc conditions. For the purposes of this Standard, the tests are being studied and the purpose of the text is to explain the principles and performance criteria to allow manufacturers and users to establish, mutually agreed conditions for the test. With experience gained, it should be possible, in future revisions of this Standard, to specify a complete type test.

The test consists of simulating in a high-power laboratory a certain number, e.g. three of short circuits and arcs inside a transformer tank or reactor, to verify how the prevention system installed in the equipment to be protected would behave. It starts applying current values and durations compatible with what would happen in a real situation (see table 1). As the arc energies influence the process, it can be established that the applications will be made with 25%, 50% and 100% of the maximum arc current. The arc initiation must be done by thin fusible wires. The performance of the system shall be verified taking into account the following criteria:

a) non-breaking of the protected parts.
b) the operation of the devices in a time shorter than those that would guarantee non-rupture due to overpressures.
c) non-occurrence of explosions or fire or oil spillage.

4. COMPLETE TEXT SUGGESTION FOR A NEW IEC STANDARD

Here is the complete suggestion. It is based on the (cancelled) NBR 8222 but with important improvements in the fundaments, to avoid the possibility of dangerous situations during tests, for example the need to extinguish fire in big oil volumes. The parts **highlighted in red marked as " SFC: … new text …"** are the modifications proposed by Sergio Feitoza Costa in June 2022. Sergio ed the 2005 revision and is author of a good part of this text, specially and of the internal arc test.

To download this text in a better formatted way, go to this link
http://www.cognitor.com.br/suggestionnewiecstandardtransformersfiresandexplosions.pdf

To better understand the context read the article https://www.cognitor.com.br/transformersfiresexplosions.pdf

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Here is the complete suggestion for a new IEC standard. It is based on the (cancelled) Brazilian standard NBR 8222. **The parts highlighted in red** " are modifications proposed by Sergio Feitoza Costa in June,2022? Sergio coordinated the 2005 revision and is author of a good part of this text and of the internal arc test.
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Proposed Standard (2022) : Execution of explosion and fire prevention systems, to avoid overpressures resulting from internal electric arcs in power transformers and reactors

Summary

Introduction

When reading this standard, the NBR 13231 is considered the main standard of the set of standards NBR 8222 (depressurization systems), NBR 12232 (nebulized water systems) and NBR 8674 (CO2 systems) . The specific aspects of each type of system are covered in each document which include:

- the general and specific aspects of the preparation of installation projects;
- general aspects of the design, installation, maintenance and testing of the systems.

1 Objective

This Standard sets the specific minimum requirements required for the design, installation, maintenance and testing of fixed automatic explosion and fire prevention systems to avoid overpressures resulting from internal electrical arcs in power transformers and reactors. The general requirements for the preparation of installation projects are described in NBR 13231.

This type of system does not eliminate the convenience of installing traditional devices to prevent the spread of fire, such as: drained and protected concrete bases, non-combustible barriers and fire walls, as well as mobile extinguishing devices.
This type of system applies to all types of oil-immersed transformers, autotransformers, reactors and also their individual oil-containing parts, such as on-load tap-changers and bushing and cable boxes.

The objective of this type of system is to avoid the explosion of the transformer or reactor and, consequently, the fires that can occur when there is a failure and an electrical arc inside the protected transformer or reactor.

The start of an electrical arc usually results from a breakdown in the insulation. This can be caused, among other reasons, by overloads, switching or atmospheric surges, gradual deterioration of insulation, low oil level, humidity, acidity in the oil, etc. Such an electric arc generally involves high electric currents. The contact of the electric arc with the insulating oil produces a considerable amount of self-igniting and explosive gases. The formation of gases within the closed volume of the protected equipment causes the pressure to grow very quickly. If there is no device that relieves the internal pressure before it exceeds the value supported by the tank, it will break.

The rate of increase of the internal pressure in the tank, depending on the currents involved, is in the range of 0.05 bar to 1 bar per millisecond. Current transformers and reactors, in turn, support overpressure values of the order of magnitude from 1 bar to 2 bar. If these values are exceeded, the tank, bushings or on-load tap-changer may rupture. If this rupture occurs, the explosive gases that have formed inside the protected equipment will come into contact with the oxygen in the air, starting the fire. At the same time, the surface temperature of the oil tank quickly reaches the oil flash point, and the transformer oil ignites.

It should be noted that the total interruption times of protection systems involving circuit breakers are in the order of magnitude from 50 ms to 80 ms, which is not enough to eliminate the arc before high overpressures have already occurred.

In generation installations, the situation is more severe as the inertia of the generator can feed the electric arc for 1 s and 2 s when it is not protected by a circuit breaker. This situation is the worst-case scenario to prevent an explosion in the transformer tank.

The prevention systems dealt with in this Standard seek to prevent the internal overpressure resulting from the internal electric arc from reaching values greater than the withstand of the protected equipment.

The principle may involve, among others, depressurizing the internal parts, conveying the gases produced to a place where they can burn safely, without affecting nearby people and equipment, and creating a flow of gases to cool the oil and to eliminate explosive gases.

2 Normative references

The standards listed below contain provisions which, when cited in this text, constitute prescriptions for this Standard. The editions indicated were in effect at the time of this publication. As every standard is subject to revision, those who enter into agreements based on this standard are recommended to check the suitability of using the most recent editions of the standards cited below. ABNT has information on the rules in force at a given moment.

NBR 13231:2005 - Protection against fire in electrical generation, transmission and distribution substations

3 Definitions, symbols and abbreviations.

The definitions, symbols and abbreviations adopted in this Standard are those described in section 3 of NBR 13231.

4 General requirements.

4.1 Aspects relevant to dimensioning and to avoid risks during the tests

In the design, installation and operation of the prevention system, all types of short circuits that may occur inside the transformer tank or other protected equipment must be taken into account. Table 1 shows typical values of short-circuit currents that could occur inside transformers where there was an internal fault, and an electrical arc was created. These values can be used as a reference for carrying out tests to verify the ability of the prevention system to prevent explosion and fire, prescribed in this Standard.

SFC: Doing an internal arc test of a protection system, in a big oil volume, bring obvious risks of fires and explosions. If the tested protection system fails, we will see the same consequences that occurs in substations. So, the oil volumes used in the test shall be within a fire controllable range. As an initial reference let's consider that this is the oil volume of a 10 MVA power transformer. Let's also consider that the test is performed in an open area with resources similar to the substation area where transformers are installed.

The new fact, which did not exist in the original 2005 version of NBR 8222, is that it is now demonstrated in Ref [1], the Brochure Cigrè 602 / 2014, and other references, that testing simulations can be used to predict the overpressures occurring in a closed volume, submitted to an arc , and containing a certain volume of fluid like air or SF6.

For oil volumes the concepts applies because , as in Ref[3], IEC TR62271-307(2015), the same design parameters apply, except for the density, latent heat and other physical properties of the oil.

As the overpressure depend directly on the oil volume, arc current and area and speed of the depressurization openings, it is possible to calculate a smaller oil volume and smaller arc current that will produce the same overpressure. For the protection device this is the main point which will define the performance.

In resume, it is possible and easy to calculate and create a reduced model with a lower volume and current, but using the complete depressurization protection system, and submitted to the same overpressure

Regarding the reference values for the arc currents that may occur, it must be considered that the ABNT and IEC standards on transformers deal only with external short circuits and provide for tests with various short circuit applications with values of currents equivalent to 25 times the value of the rated current with a duration of 0.25 s to 2.0 s.

For short circuits originating outside the transformer, the current is limited by the impedance of the transformer. In the case of an internal short circuit, the transformer impedance may not be limiting. The values in table 1 indicate the orders of magnitude of currents and durations in internal arc situations.

Table 1 - Orders of magnitude of typical maximum short-circuit currents for internal arcs in transformers and power reactors

Transformer power range MVA	~~Voltage range in the highest lowest voltage winding kV~~	Order of magnitude of short-circuit currents kA rms symmetrical	Order of magnitude of short-circuit current duration s
Up to 10 MVA	~~1 a 15~~	5	1 a 2
10 to 50 MVA	~~SFC: Under consideration (Reduced size models)~~	SFC: Under consideration (Reduced currents and volumes with same overpressure)	SFC: Under consideration
> 50 MVA	~~SFC: Under consideration (Reduced size models)~~	SFC: Under consideration (Reduced currents and volumes with same overpressure)	SFC: Under consideration

4.2 Operating principles and typical components

These systems seek to prevent the internal overpressure resulting from the internal electric arc from reaching values greater than the supportability of the protected equipment. The principle may involve, in addition to depressurizing internal volumes, driving the produced gases to a place where they can burn safely and creating a flow of gases to cool the oil and to eliminate explosive gases.

One of the existing configurations consists of having, in one of the oil inlets of the protected equipment, a device activated directly and only by the internal overpressure in the tank. This device must be fast enough so that, when an internal arc occurs with a duration and magnitude of the orders of magnitude indicated in table 1, it relieves the overpressure before it reaches the values supported by the protected equipment.

The order of magnitude of the time required for the device to operate and for the depressurization process to begin is 10 ms. The total depressurization process should not take more than 50 ms. These values must be proven in the tests prescribed in this Standard.

An example of a device with these characteristics is the one that uses depressurization chambers and a rupture disk. These systems must have high operating speeds and can be specified and calibrated to operate when a pre-set pressure is reached.

In a typical system, after the rupture of the device that initiates the depressurization, the oil and gases formed by the arc are ejected through an appropriate duct until reaching a lower collecting reservoir, in the case of larger volumes of oil, or an oil and gas separation tank, in the case of intermediate volumes. In this second case, there may be another pipe coming out of the tank, taking only the gases to be burned in a safe place. This type of system may have additional parts, such as:

a) air insulating shutter to prevent flammable gases from coming into contact with oxygen in the air.

b) obturator in the path between the conservator and the tank, to prevent the volume of oil in the conservator from going down.

c) auxiliary system for injection of neutral gas, after depressurization, to cool the oil and to push the explosive gases to the outside of the tank.

d) fire detectors.

In this type of system, after depressurization, a process for cooling the oil is started. The cooling system is activated by one of the signals coming from the electrical protection system in addition to one of the signals from the devices that initiate depressurization, such as rupture discs. When both signals are registered, the cylinder valve of a neutral gas such as nitrogen is activated, and the gas is injected into the equipment or its protected part. The neutral gas flow will act to cool the medium as well to press the explosive gases to the outside, creating a safe internal atmosphere.

The explosion and fire prevention system can be backed up by a “drain and agitation” type fire extinguishing system by neutral gas flow. In this case, the backup system must be activated by two signals, the first coming from one of the fire detectors and the second from one of the electrical protections of the transformer.

The injection of neutral gas should cause the oil to agitate the protected part, reducing the surface temperature below the flash point and then extinguishing the fire in less than 5 min. Cool heated parts and prevent any restart of combustion.

As a reference, the pressure of the neutral gas cylinder is in the range of 150 bar to 200 bar. If so, the cylinder must be provided with a leak-proof actuator (less than 0.25% loss per year). This cylinder must be capable of providing a gas injection for at least 45 min, time considered sufficient to cool the heated parts and to prevent combustion from restarting.

When existing, fire detectors must be vibration-proof, with the operating temperature in the range of 135ºC to 150ºC. Fire detectors should be located on the tank cover, on the on-load tap-changer and near the bushings.

4.3 Remote control

The system must be monitored from a control room. The system must be provided with a control box that allows:

a) put the system in the “out of order” position when maintenance work is required.

b) operate the system in both “automatic” and “manual” modes.

c) check the performance of each signal (rupture discs opening, transformer circuit breaker opening, shutter valve, fire detectors);

d) verify the normal operation of the control box by a lamp test.

4.4 General operating conditions

The electrical distances between system parts and energized parts must not be less than those specified in NBR 13231.

5 Specific requirements

Systems used in large transformers may include accessories or additional parts such as:

a) prevention of explosions and fires in oil bushings.

b) prevention of explosions and fires in oiled cable boxes.

c) electrical continuity monitoring with associated alarms.

d) autonomous dry battery with associated low charge alarms.

e) audible warning.

f) heaters of the control system

g) manual neutral gas injection valve.

6 Tests

The proof of the efficiency of the protection method must be done, when foreseen in this Standard, through tests.

6.1 Type tests

6.1.1 Test to verify the ability of the prevention system to prevent explosion and fire under internal arc conditions

The range of transformers cover from units with a relatively small volume of oil to large volumes and powers. For the test to be feasible in the laboratory, it is necessary that the volume of oil in the transformer or device that simulates it has a value limited to making the consequences of the fire controllable in the event of failure of the protection device. We are assuming that it corresponds to the oil volume of a 10 MVA – 138/13.8 kV transformer. An old transformer tank can be used in the test. Due to the volumes of oil involved, the laboratory must have the means so that, in case of failure of the equipment under test, the consequences of an eventual fire are controllable.

There is currently not enough experience to fully define the conditions for this laboratory test. For the purposes of this Standard, the following text is to explain the principles and performance criteria that allow manufacturers and users to establish conditions for the test.

The “ideal” test consists of applying, in a high-power laboratory, a certain number, for example three, of short circuits and arcs inside a transformer or reactor tank, to verify how the explosion and fire prevention system would behave. installed on the equipment to be protected.

A current of value and duration compatible with those that would occur in a real situation must be applied (see table 1). As the arc energies can influence the process, it can be established that the applications will be made with 25%, 50% and 100% of the maximum arc current. ~~Durations should be chosen so that, where possible, a constant I 2 x T value applies.~~

Care must be taken that the current flows for the entire duration specified for the test. There must be no “arc extinction” of the current in any of the phases through which the current must flow. These auto-extinctions can occur due to the high dielectric capacity of the oil or due to the use of current sources with insufficient power. In the case of eventual arc auto-extinctions these must not occur for more than 20% of the total duration specified for the test.

The arc initiation must be done by thin fusible wires with a cross section of the order of 1.5 mm2. The circuit must be calibrated to verify that, during the application of the arc, the current will remain sinusoidal. The fusible wire must be placed in positions previously discussed between the manufacturer, the purchaser and the laboratory.

The performance of the system in the test shall be based on the following criteria:

a) non-breaking of the protected parts;

b) the operation of the devices in a time shorter than those that would guarantee the non-rupture due to overpressures;

c) non-occurrence of explosions or fire or oil spillage.

BIBLIOGRAPHIC REFERENCES (OF THE STANDARD):

[1] BROCHURE CIGRE 602 / 2014 TOOLS FOR THE SIMULATION OF THE EFFECTS OF THE INTERNAL ARC IN T&D SWITCHGEAR.

[2] "GUIDE" FOR THE USE OF CALCULATIONS AND SIMULATION OF LABORATORY TESTS (referred in the brochure Cigrè 602/2014)”

http://www.cognitor.com.br/GUIDE_Simulations_v0_October2010.pdf

To understand the context read also: http://www.cognitor.com.br/Article_Competitivity_Eng_04102011.pdf

[3] IEC TR 62271-307:2015 : 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

[4] "SIMULATIONS AND CALCULATIONS AS VERIFICATION TOOLS FOR DESIGN AND PERFORMANCE OF HIGH-VOLTAGE EQUIPMENT" - Co-authors: M. Kriegel, X. Zhu, M. Glinkowski, A. Grund, H.K. Kim, P. Robin-Jouan, L. Van der Sluis, R.P.P. Smeets, T. Uchii, H. Digard, D. Yoshida, S. Feitoza Costa

CIGRE WG A3-20 publication A3-210 (2008) - Presented at Congress Cigre - Paris 2008

http://www.cognitor.com.br/Cigre_Paris_A3_210_2008.pdf

[6] SIGNIFICANT PARAMETERS IN INTERNAL ARC SIMULATION AND TESTING,

CIGRE WG A3.24, CIGRE A3 SESSION, 2009 -Co-authors: M. Kriegel, R. Smeets, N. Uzelac, R. Pater, M. Glinkowski, P. Vinson, S. Feitoza Costa, G. Pietsch, E. Dullni, Th. Reiher, L. van der Sluis, D. Yoshida, H.K. Kim, K. Y. Kweon, E. Fjeld,

[7] Report 071/2014: VALIDATION OF SIMULATIONS OF HIGH-POWER TESTS (TEMPERATURE RISE, SHORT TIME AND CREST CURRENT TESTS – ELECTRO DYNAMICAL FORCES / STRESSES AND OVERPRESSURES FROM INTERNAL ARC)

http://www.cognitor.com.br/TR_071_ENG_ValidationSwitchgear.pdf

End of the proposed text for the Standard

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REFERENCES (OF THE ARTICLE)

[1] SHORT-CIRCUIT TEST EXPERIENCE OF POWER- AND DISTRIBUTION TRANSFORMERS
R.P.P. Smeets, R. Bruil, K. van der Linden DNV GL KEMA Laboratories – Netherlands

[2] A "GUIDE" FOR THE USE OF CALCULATIONS AND SIMULATION OF LABORATORY TESTS FOR INCREASING THE COMPETITIVENESS OF THE ELECTRIC INDUSTRY (by Sergio Feitoza Costa)
http://www.cognitor.com.br/Article_Competitivity_Eng_04102011.pdf

[3] POWER TRANSFORMERS & REACTORS: CALCULATIONS OF ELECTROMECHANICAL FORCES & STRESSES, TEMPERATURE RISE AND OVERPRESSURES OF INTERNAL ARC. Method and possibilities of a software focused in developing countries (by Sergio Feitoza Costa)
https://www.cognitor.com.br/PowerTranformersReactorsCalculation.pdf

[4]: M. Waters, "The Short Circuit Strength of Power Transformers"- 1966 - MacDonald & CO Ltd (Gulf House,2 , Portman Street, London, W.1)

[5] 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)
http://www.cognitor.com.br/TR_071_ENG_ValidationSwitchgear.pdf

[6] "VALIDATION OF SIMULATIONS OF ELECTRODYNAMICAL FORCES, TEMPERATURE-RISE AND INTERNAL ARC TESTS IN SWITCHGEAR (& main parts of a code) (2010) . Presented at the CIGRE Technical Seminar "Modeling and Testing of Transmission and Distribution Switchgear" March 24, 2010 Brisbane – Australia
Download: http://www.cognitor.com.br/Validation_Simulations_English.pdf

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