CIGRÉ INTERNATIONAL TECHNICAL COLLOQUIUM
SEPTEMBER 12 th-13th, 2007
RIO DE JANEIRO - BRAZIL

CFD, IEC STANDARDS AND TESTING LABORATORIES: JOINING THE PIECES FOR HIGHER QUALITY HV EQUIPMENT.

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Summary: *Electricity users are each time more exigent, on the need that the equipment they use has a test certificate or report. Tests are expensive and usually the manufacturer, before arriving to an approved design, need to repeat test some times. Simulation techniques which include CFD ("computational fluid dynamics") are useful as a virtual laboratory in the equipment design stage. Better simulations means less testing costs. IEC Standards are used all over the World and are the basis for national standards. Within certain limits, simulation techniques can be used to extrapolate the results of an already done laboratory test to other similar, but not equal, equipment. This paper show examples of these possibilities and present, for discussion, an objective strategy on "To establish some rules to enable simulation techniques to be used as an auxiliary tool for the verification of some testing requirements in IEC standards"*

Keywords: CFD, Equipment, Testing, Arcs, Temperatures, Short-circuit, Ampacities, Switchgear

1. INTRODUCTION

To better understand some ideas which are proposed in the text to follow it is useful to inform that the author's basic experience is on high power testing, IEC work management and electrical equipment and substations design.

High power and high voltage testing laboratories are within the main tools a country has to achieve a high electricity quality. Electricity users are each time more exigent, on the need that the equipment they use has a test certificate or report. Such documents are used to demonstrate that the product was type tested according to a recognized technical standard like the IEC -International Electrotechnical Commission ones.

Type tests are done in qualified testing laboratories and usually the manufacturer, before arriving to an approved design, need to repeat tests 2 or 3 times. In 2007 there are relatively

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few laboratories all over the World. The clear trend is to have each time less laboratories owned by the few companies which understood that this activity can be an interesting business from the financial point of view. All over the World, we can count these ones without needing to use all the fingers of just one hand.

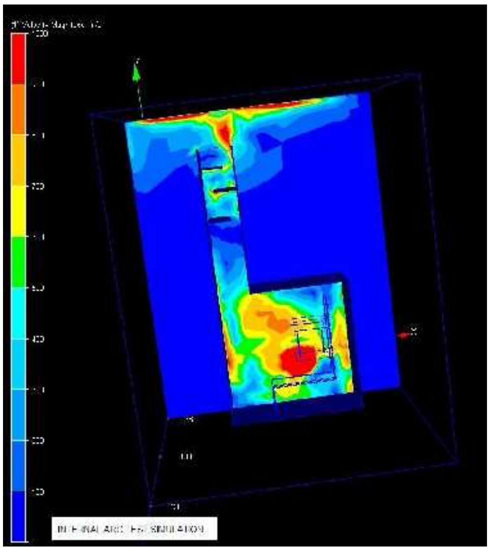
Laboratory tests, specially the high power ones, are expensive because the laboratories installations require investments in the order of magnitude of US$ 50 million. Many of the existing laboratories are “company dedicated ones” and do not focus on selling services to have a high occupancy to optimize the return on the investment done. This create situations where there is a long waiting list and a manufacturer shall wait one year to have its equipment tested and the test installation is occupied just 1/3 of the year hours.

We can give an idea on testing costs using metal-enclosed switchgear used on 15 to 36.2 kV systems. To do only a part of them, comprising the "Temperature Rise Tests", the ” Short-Time Current Withstand Tests" and " Pressure Relief during Internal Arc Tests", we arrive to more than U$D15000,00. Adding transportation costs and few test repetitions we go well beyond U$D20000, 00. This is the value if all the tests are successful in the first trial (a rare fact on the first of a series). The uncertainties about succeeding put many manufacturers out of the market.

Supposing that a certain type of equipment design was successfully tested it is a common fact that the equipment purchaser request the manufacturer to test another design if the geometrical is similar but different from the tested one. This occurs mainly when there are not written calculation methods available to do the extrapolations.

Simulation techniques and tools, including the CFD ("computational fluid dynamics") ones, used by experienced designers, are useful as a virtual testing laboratory. Temperature rise and arcing energy pressure relief are good examples of possible test simulations (Figures 1 and 2).

They consist in doing a 3D simplified model of the equipment and to associate to the model the components materials and the boundary conditions like temperature, wind speed, power injection and others. The key point is that it is possible to visualize temperatures and air flows which would need hundreds of thermocouples or sensors in a real laboratory test.



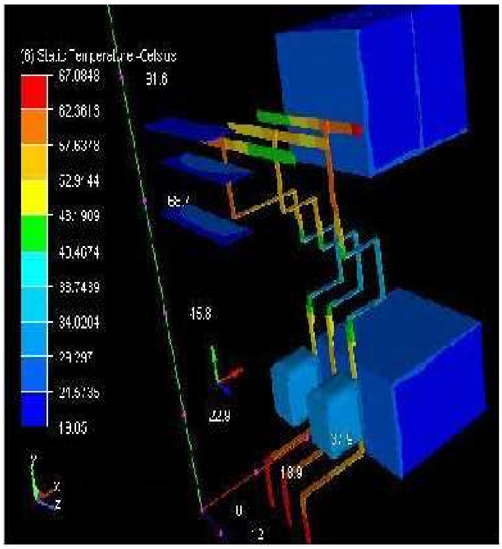


Figure 1 – Internal arc simulation **Figure 2 – Temperature rise simulation**

The example of the “internal arc test in metal-enclosed switchgear” is interesting to explain the possibilities of such simulations and it will be described in more details in Section 2. Most of the manufacturers have arrived to approved designs by the “trial and repeat” method because some needed calculations like “where the hot particles will arrive” was practically impossible to do in the past. Nowadays, with simulations techniques, it is possible at least to know the effect of each parameter involved reducing the number of trials before succeeding.

Our objective, in this case, is to provide guidelines on how to enable that simulation tools are used to extrapolate the results of an already done laboratory test to other in a similar, but not equal, equipment (for example the tested equipment have dimensions 1,0 x 1,2 x 2,0 m and the untested one is 1,0 x 1,3 x 2,1 m)

IEC Standards are used all over the World and are the basis for national standards. IEC standards are the possible compromise which can be achieved at a certain moment by manufacturers, users and laboratories. It is impossible to attend simultaneously all the interests and sometimes some small words and sentences which are clear to the IEC Working Group participants elaborating the standard are not clear or even perceived by the big number of the standard users all over the World. This is not good but sometimes is the only possible way to enable that, in a next revision, the subject will be included in the standard in details. The problem is when the next revision of the standard occurs more than 10 years after. Some examples are showed in Section 2.

If it is considered useful to have some link between simulation techniques and testing, the proper way to disseminate the idea and to trace guidelines is through IEC standards. A strategy for this will be proposed

So, the **objectives of this paper** are
a) To show examples of simulation techniques applications that could be used as an auxiliary tool to support some IEC standards application.

b) To present a suggestion for a strategy, to be discussed within Cigrè, on how "To establish some rules to enable simulation techniques to be used as an auxiliary tool for the verification of some testing requirements in IEC standards"

In no part of this text the idea is to propose to replace tests by simulations. The proposal is to start to consider and study how some simulation techniques can be used in parallel to type tests to make the life easier.

3. REFERENCE SITUATIONS TO FACILITATE THE UNDERSTANDING

To facilitate the understanding of the proposal I describe in 3.1 and 3.2 two specific situations related to high power testing on high voltage equipment. For each one there is a small description of what can be simulated, the possibility of applying simulation techniques on extrapolating testing results and also, using the opportunity, some relevant points which are not quite clear for many standard users but can be better explored through simulations.

3.1) INTERNAL ARC TEST ON METAL-ENCLOSED SWITCHGEAR ACCORDING TO IEC 62271-200 (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 62271-2 specify internal arc tests to support the use of classifications (IAC) given to metal-enclosed switchgear and related to provide safety to persons near the equipment if an internal high power electric arc occur. The arc increases the pressure inside and this can even open the doors, make a hole and eject hot gasses and materials which expose people outside to a risk of life.

There are two design objectives. The first one – to avoid that doors open - is easy to calculate. To obtain the maximum pressures inside and to provide adequate means to avoid opening do not require complex calculation tools. The second one is related to the fact that the metal-enclosed switchgear need to have pressure relief window, usually in the top, in order to avoid that the internal pressure goes beyond certain values. When the internal pressure exceeds a certain value these windows open and the hot gasses flow outside. These gasses reflect on the ceiling and external walls and can not go back to the body of a person outside which would be injured. The distance the hot particles can reach can be estimated only by simulation techniques or repeating trials in expensive high power tests.

The distance between the test and the real use:

The tests well represent what may occur in the case of an internal arc. The cotton pieces which are installed to simulate the outside person's skin enable to clearly identify if the equipment attend the standard requirements.

Example of points where the IEC standard is not clear enough to users and could be improved:

One situation which may occur and it is not explicit is the case of a metal-enclosed switchgear having capacitors filled with oil inside. In case of an internal arc involving also oil the consequences would be much worst than not having oil. I do not know about tests already done with metal-enclosed switchgear including oil capacitors but I know cases of such use.

Possibility of simulations in the design stage

The internal pressures are easy to determine considering the arc currents and the air or even air plus oil volumes involved. It is possible to estimate where the hot particles and gasses will arrive after the opening of the pressure relief window. With this simulation the manufacturer can choose between different design alternatives and flows.

Possibilities to extrapolate the results of an already done laboratory test to other untested equipment similar, but not equal

If the geometric dimensions of the untested metal-enclosed switchgear and distances to the ceiling and walls are within a range of around minus or plus 30%, if compared to the tested one, reasonable simulations can be done as an extrapolation.

3.2) TEMPERATURE RISE TEST AND HOT-SPOTS ON POWER TRANSFORMERS ACCORDING TO IEC 60076

There are several IEC standards covering the different aspects of power transformers specification and testing. These standards were published before 1993. In the last 20 years there were technological changes in materials and design techniques. An example is that, in the past, transformers tanks were much more resistant to the overpressures originated by arcs inside the transformer tanks. It is interesting that these aspects are not covered by IEC standards although transformers explosions and fires have hard consequences and are not a rare fact. The Brazilian technical standard ABNT NBR 8222 / 2005 show guidelines for a test related to the consequences of internal arc in the transformer with oil.

In the two next paragraphs there are two aspects of the standards IEC 60076 which have a direct link with simulations and testing within the scope of this paper.

Temperatures and ageing in power transformers

IEC 60076-2:1993 – Part 2 include requirements about temperature-rise limits and the related type test. The test method for the temperature-rise test consists in measuring two parameters. The first one is the average temperature rise of the windings above the oil (which is above the external air temperature). This average temperature rise is calculated by knowing the winding cold resistance without current and the hot one after passing the rated power and temperatures stabilization. The second parameter is the temperature of the top of the oil considered to be the highest inside the transformer. The ideal but not possible test procedure would be to put thermocouples or something equivalent in the hottest points usually unknown in advance.

Using the example of a 55°C class transformer the fundament is that, for the limit condition of an external air temperature of 40°C, the maximum temperature in any point of the winding in contact with the oil shall not exceed 40°C + 55°C + 10°C = 105°C. Above this 105°C ageing and oil decomposition start (table VI in IEC 60943).

Although not written in the standard, the 10°C seems to be an estimative of the maximum value above the average temperature of the windings that may be found in any part of the winding. Possibly this value was obtained, more than 20 years ago, based on the existing experience of the transformers manufacturers. Measuring systems and simulations in the 80's where less accessible than nowadays.

Within the length of a transformer winding there are points with temperatures higher and lower than the average value measured in the test. If we find in some part of this transformer a 15°C difference instead of 10°C this could not be detected through the average temperature measurement. It is not necessarily true that the top oil temperature is the highest anywhere in the transformer.

If the fact described in the previous paragraph happens this means that a test approved transformer may have inside, in winding parts in contact with oil, temperatures higher than 105°C (oil decomposition). In the Annex B (informative) of IEC 60076-2:– Part 2 it is defined a "hot-spot factor" assumed to be from 1,1 in distribution transformers to 1,3 in medium size power transformers or even higher in larger transformers. This seems to confirm the possibilities of temperatures higher than 105°C.

The question is: Are we sure that the 10°C difference found more than 20 years ago is still valid? If not this could be the reason for some recent failures in big transformers and reactors with reasons not yet clarified? With simulations techniques it would be possible to advance very fast in this respect.

Ability to withstand short circuit (thermal and dynamical effects)

IEC 60076-5:1976 – Part 5 include requirements for power transformers to sustain without damage the effects of external short circuits. It includes calculation procedures used to demonstrate the thermal ability of a power transformer to withstand overcurrents and both the special test and the theoretical evaluation method used to demonstrate the ability to withstand the dynamic effects of the short circuit forces. Experienced equipment designers know that, in the case of the dynamical forces, such calculations are far from being considered exact and can be checked only by testing. If we would test we would not need to calculate.

As the cost of transporting transformers to a high power laboratory is even bigger than the expensive tests these calculations are the possible compromise and are usually accepted. The calculation is useful only in the case of a future justice demand. Even in this case nobody would assure that the calculation is right or wrong because there is no recognized correct calculation.

The distance between the test and the real life:

The tests, in the two cases above, well represent the real life. We can not say that the method to analyze the results of temperature rise tests in transformers is safe from the point of view of premature ageing.

Example of points where the relevant IEC standard is not clear enough to users and could be improved:

For the temperature-rise issue it is necessary to bring the information in the Annex B of IEC 60076-2:– Part 2 to the main text and with objective requirements (and not informative). Simulations can help to do this much faster.

Concerning to demonstrate the ability to withstand the dynamic effects of the short circuit forces there is nothing to do and simulations will not bring new facts.

Possibility of simulations in the design stage

For temperature-rise it is relatively easy to do the simulations but data to compare with is rare.

Possibilities to extrapolate the results of an already done laboratory test to other untested equipment similar, but not equal

If the geometric dimensions of the untested transformer is within a range of around minus or plus 40%, if compared to the tested one, reasonable simulations can be done as an extrapolation.

4. SUGESTION FOR A STRATEGY, TO BE DISCUSSED WITHIN CIGRE, ON HOW "TO ESTABLISH SOME RULES TO ENABLE SIMULATION TECHNIQUES TO BE USED AS AN AUXILIARY TOOL FOR THE VERIFICATION OF SOME TESTING REQUIREMENTS IN IEC STANDARDS"

As I am not sure about the format to present the proposal for CIGRE new work I will do it as I was I used to do when I was coordinating the IEC Technical Committee TC 32 - Fuses.

The proposal for new work is to create a Working Group within IEC TC17 or TC32 involving both and also TC 14 (eventually other Technical Committees in a more advanced stage) **with the following task**:

“To establish some rules to enable simulation techniques to be used as an auxiliary tool for the verification of some testing requirements in IEC standards"

It will be necessary to compare simulation results with known, reliable and published results. At least in the initial stage of the work the Working Group will use as a reference, calculation examples found in the Publication IEC/TR 60943 Guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals.

The main tasks for the Working Group are:

Task 1) To define two test-cases of temperature-rise in electrical contacts (preferably using existing examples in IEC60943). The published results are to be used as a reference for comparison with the results obtained through simulations in existing tools. The test-cases should have results confirmed by official test reports. The idea is that such test-cases may serve in the future as the “calibration” when using a tool for simulation.

Task 2) To define one test-case of temperature-rise calculations in power transformers to be compared with calculations made by simulations in existing tools. The case should have data confirmed by official test reports. The objective is to find the temperatures of some known points located in the winding and in contact with oil. The top oil temperature shall also be calculated. The rated power of the transformer shall preferably be equal or higher than 10 MVA

Task 3) To list some additional test-cases which may be considered useful for future verification of some testing requirements in IEC standards. Examples of these are the calculation of overpressures inside metal-enclosed switchgear filled by air or inside transformer tanks during an internal arc. Another example is to obtain the time-current characteristics of expulsion and current limiting fuses

Task 4) To create a list of input data and output results to be used in simulations which may permit comparison between simulations in different tools. An example of this is the input and output data used in task 1 and 2 above.

4. CONCLUSIONS

Although simulation tools are still quite unknown to the average electrical engineer and designer they are used for a long time by mechanical engineers. These are the tools which made possible to design the wings of airplanes, equipment based on plasma, gas turbines and fuel cells.

There is a clear space for their use in the electrical sector all over the World. Nevertheless, to do this in an organized way requires some basic technical standardization.

A proposal to advance in this direction and to create a link between simulation tools, IEC standards and testing laboratories is presented above to CIGRE.