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# Protection of oil-filled Transformer against Explosion: Numerical Simulations on a 200 MVA Transformer

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**Abstract — Oil filled transformer explosions and their prevention are a complex industrial issue. Experimental tests showed that when an electrical fault occurs in a transformer, it generates dynamic pressure waves that propagate in the oil. Reflections of these waves on the walls build up high static pressure which transformer tanks can not withstand. Besides, a numerical tool was developed to simulate the phenomena highlighted during the tests and mainly the pressure wave propagation. It is based on a compressible two-phase flow modelling where viscous flow, electromagnetic, thermal and gravity effects are taken into account. The equations are solved using a finite volume method allowing computing complex 3D transformer geometries. Simulations of the consequence of an electrical arc occurring in a 200 MVA transformer geometry show that the static pressure increase can be prevented by a quick oil evacuation triggered by the first dynamic pressure peak generated by the electrical arc.**

*Index Terms* — **Pressure effects, protection, simulation, transformer**

## I. Nomenclature

| | | | |
|---|---|---|---|
| $\alpha\rho_1$ | Gas partial mass | $\rho$ | Mixture density |
| $\rho\vec{u}$ | Mixture momentum | $\vec{u}$ | Mixture velocity |
| $E$ | Mixture total energy | $\varepsilon$ | Mixt internal energy |
| $P$ | Mixture pressure | $\alpha$ | Gas volume fraction |
| $\Phi_g^{u,E}$ | Gravity terms | $\Phi_\mu^{u,E}$ | Viscosity terms |
| $\Phi_T^E$ | Mixture Fourier's law | $\dot{E}$ | Arc energy transfer |
| $u,v,w$ | Velocity components | $x,y,z$ | Spatial coordinates |
| $\partial\cdot/\partial\cdot$ | Partial derivative | $div(\cdot)$ | Spatial divergence |
| $\otimes$ | Tensor product | $\nabla$ | Spatial gradient |
| $\Delta t$ | Time step | $\lambda_i$ | Eigenvalue $i^{th}$ wave |
| $\Omega_i$ | Volume of cell *i* | $V(i)$ | Neighbours to cell *i* |
| $\vec{n}$ | Normal to cell edge | $l$ | Cell edge length |
| $\phi_i$ | Variable at cell *i* | $\phi_{ij}$ | Variable at cell edge |
| $\phi^n$ | Variable at time *n* | $\phi^{n+1}$ | Variable at time *n+1* |

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## II. Introduction

PRIVATISATION of electricity companies leads to an electricity market that becomes more and more competitive. To limit costs, companies often reduce the investments by using aging equipments and by overloading the power transformers. Oil-filled transformer explosions are then more and more frequent and they result in dangerous fires, very expensive damages and possible environmental pollution. For all these reasons, transformer explosions and their prevention are becoming a critical industrial issue.

Fig. 1. Transformer tank rupture (extracted from [1])

Explosions were found to occur when the transformer oil loses its dielectric properties (because of age, design errors, oil pollution, overloading, lack of maintenance…) leading to the occurrence of an electrical arc inside the transformer tank. This paper starts with a short review of various experiments that explains the physical phenomena leading to the tank explosions. Various models from the literature are then presented, all of them are based on a incompressible approach which supposes that the pressure is uniform inside the tank (contrarily to what is exhibited during the tests). A numerical tool was thus developed to describe unsteady non uniform pressure phenomena following the arc ignition. This simulation tool deals with 2 phase flows, unsteady compressible, viscous flow, electromagnetic forces, thermal and gravity effects and a 3D modeling. In the last section, simulations are performed on an industrial 200 MVA transformer geometry to evaluate a strategy based on a quick oil evacuation to prevent transformer explosions.

## III. Background

Several studies, experimental or computational, have been performed to understand the explosion process in order to establish strategies to prevent it.

### *A. Experimental tests*

#### *1) SEBK*

An interesting test campaign was performed during the SEBK project. The first phase of this work [2] analyzed transformer oil vaporization, cracking and oil vapor explosion. Tests such as igniting a spark which could deliver up to 2 kJ in a small chamber (1-2 liters) showed the generation of highly flammable gas such as hydrogen and acetylene. Complementary tests showed that the amount of gas released is a very important parameter for the explosion load, an implication of this is that one very important risk reduction measure will be to minimise the amount of energy released in the electrical arc. The last phase of the project [3] was to simulate large scale transformer explosions. On that purpose, hydrogen gas was released in a transformer room ($50m^3$) and oil transformer was sprayed in the room to represent gases from cracking of oil. This mixture was supposed to represent the gases generated by the cracking of oil and is ignited in the transformer room leading to a strong explosion, flames and overpressures up to 1.5 bar. Moreover, several systems based on spraying different mixtures (powder, water…) were tested in order to mitigate the effect of the explosion. Their effects were found to be relatively limited.

#### *2) CEPEL and SERGI*

Beside the SEBK experimental study, where the different phenomena that lead to a transformer explosion were studied separately, a complete experimental study was performed by CEPEL, the Brazilian independent High Voltage Laboratory and SERGI Holding [4].

##### *a) Test configuration*

These experiments consisted of arcing tests in 3 industrial size oil-immersed transformers (up to 5.3 m long) with their internal equipments (windings, cables…) and equipped with various sensors (pressure, temperature, acceleration…). Their large dimensions enabled the detailed study of the pressure non uniform distribution inside the tank. Furthermore, since transformer explosions are very dangerous and uncontrollable, a transformer protection had to be installed during the experimental tests. This one, shown in green in Figure 2, is based on the direct mechanical response of a Depressurization Set (DS) to the tank inner pressure induced by electrical faults.

All the details about the conclusions of the tests can be found in [4] and are summarized in the next paragraphs

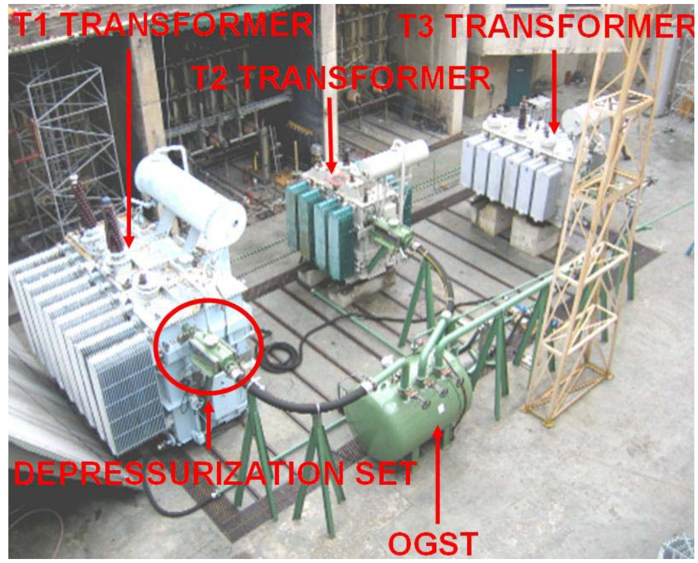


Fig. 2. CEPEL tests configuration

##### *b) First main conclusion: the vaporisation saturation process*

When an electrical arc is ignited inside the transformer oil, it vaporizes almost instantaneously a significant gas volume. The generated gas volume was found to be a logarithmic function of the arc energy, which seems to be in accordance with the vaporization process and especially with the saturation of the vaporization for high energy arcs.

Indeed, after the arc has vaporized the surrounding oil and created a gas bubble, it stays in that volume using its energy to crack the oil vapor rather than continuing directly vaporizing the oil: this results in a smoother vaporization process. The first stage of vaporization process is almost instantaneous and because of the oil inertia, the gas is very quickly pressurized, generating one high pressure peak.

##### *c) Second main conclusion: the pressure wave propagation*

In figure 6, experimental pressure profiles are displayed. Each curve shows the pressure evolution near each sensor respectively located in positions A (at the opposite side of the arc, close to the protection), B (relatively close to the arc) and C (where the arc is ignited).

The displacement of the shock wave in the tank can thus be easily followed. The arc ignition located in C causes a high-pressure peak. The pressure waves propagate leading to a second delayed lower peak in B, ending in A. For each sensor, the other pressure peaks (smaller than the main peak) are due to wave reflections off the walls. It has thus been experimentally shown that pressure increase is not spatially uniform in the tank, and that the pressure waves propagate at a finite speed.

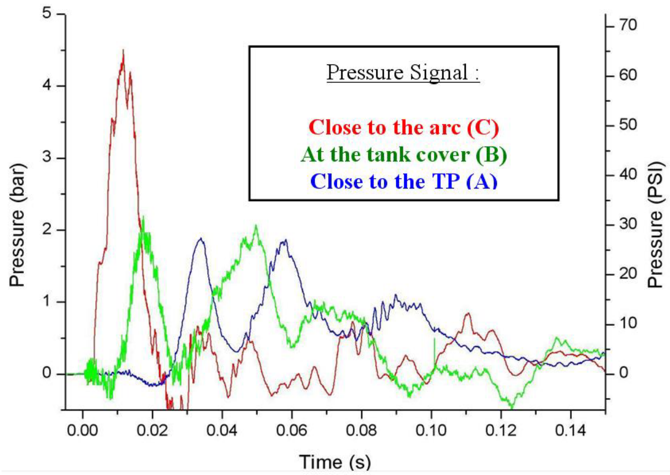


Fig. 3. Pressure profiles at different locations

*d) Third main conclusion: Tank withstand to high dynamic pressure*

The static withstand limit of transformer tanks is usually around 2.2 bars (abs.). In other words, if the tank is submitted to uniform and stabilized pressure (hereafter called *static pressure*) over 2.2 bars then the tank ruptures (see for instance [4] or [5]).

During the arcing tests performed by Cepel and SERGI, the sensors measured pressure peaks up to 14 bars (abs.) and no tank rupture was noticed. In fact, thanks to the protection operation and as showed in fig 3, the tank was submitted to localised pressure peaks for a very short period of time (hereafter called *dynamic pressure*) and the tank could withstand these high dynamic pressure peaks. The energy of the dynamic pressure was absorbed without rupture of the tank thanks to its elasticity. The tests thus showed that if the oil evacuation out of the tank is activated within milliseconds by the first dynamic pressure peak before static pressure increases, the explosion can be prevented.

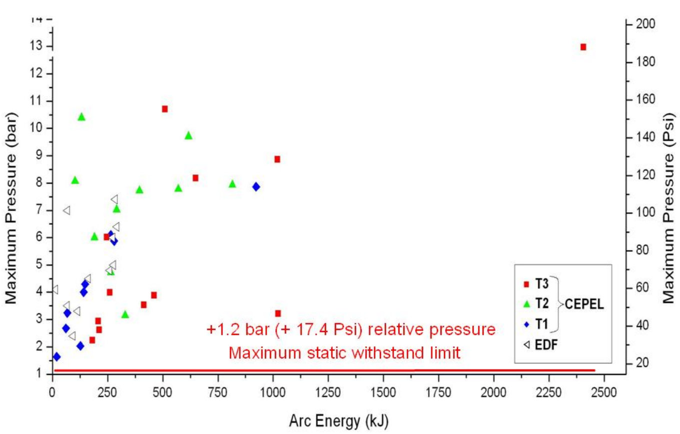


Fig. 4. Max. relative pressure measured for each test vs arc energy

*3) Others*

An interesting test campaign on explosions of small size transformers was performed by Hydro Quebec and briefly presented in [1] but unfortunately no detailed paper was found.

*B. Simulations*

Since live tests performed on real scale transformers are expensive and might be dangerous, an alternative is to study transformer explosions using computational simulations. Several transformer explosion simulation tools have been developed over the last decades. The first models [6] considered the pressure uniform in the tank (0D model) and the tank oil incompressible. The authors compute the amplitude of the pressure peak induced by an arc in a gas blanket located in the top of the tank considering a semi empirical energy conservation equation. The study detailed in [7] is based on similar hypotheses and considers that the tank expansion has to absorb the volume of the gas generated by the arc. Both works concluded that the best way to avoid an explosion is to give place to oil in order to absorb the oil expansion due to the electrical arc. A more elaborated method, detailed in [8] considers a 2D geometry and a potential flow model, using a source singularity to represent the arc. This incompressible and non-viscous model allows computing the deformation of the transformer tank considered as a thin-walled infinite cylinder shell. This model, completed with some empirical laws is also used in [9] to compute the overpressures generated by different arc characteristics for different tank geometry parameters.

The next session details a numerical tool that fully uses the recent progresses made in the field of Computational Fluid Dynamics modeling and in computational capabilities. Indeed, in order to simulate pressure wave propagation inside transformer tanks, a compressible model in a 3D framework is developed.

## IV. Numerical Simulation Tool

Experiments showed that the key phenomena in transformer explosions and their prevention are first, the local pressure increase induced by the vaporization of the oil surrounding the arc and second, the pressure waves propagation. The core of the simulation tool then consists of a set of partial differential equations that govern the fluids dynamic while the other physical phenomena (viscosity, thermal effect, electromagnetic effects…) are modeled via the source terms added in the partial differential equations. Both phases (liquid/gas) are considered compressible. The thermodynamics of the two phases are carefully handled to prevent any theoretical or numerical problems. The modeling is dedicated to flows with interfaces so that both phases share a single pressure and velocity at a given point in the domain. The aim of this tool is to estimate the pressure repartition inside the transformer tank during the first fractions of second after the electrical arc occurrence. The following gives an overview of the tool and all the details can be found in [10].

*A. The model*

*1) The governing equations*

The set of equations used to theoretically and numerically describe the phenomena is a model for 3D compressible two-phase flows that is based on a set of partial differential equations (PDE), which governs the hydrodynamic behavior of mixtures. The PDE set is based on a 5 equation model developed in [11] and is given in (1):

$$\begin{cases} \dfrac{\partial \alpha}{\partial t} + \vec{u}.\vec{\nabla}\alpha = 0 \\ \dfrac{\partial \rho}{\partial t} + div(\rho\vec{u}) = 0 \\ \dfrac{\partial \alpha\rho_1}{\partial t} + div(\alpha\rho_1\vec{u}) = 0 \\ \dfrac{\partial \rho\vec{u}}{\partial t} + div\left(\rho\vec{u}\otimes\vec{u} + P\overline{\overline{I}}\right) = \Phi_g^u + \Phi_\mu^u \\ \dfrac{\partial E}{\partial t} + div((E+P)\vec{u}) = \Phi_g^E + \Phi_\mu^E + \Phi_T^E + \dot{E} \end{cases} \quad (1)$$

All the variables are classical and detailed in the nomenclature in section I. One of the most interesting characteristics of the model is its ability to accurately depict the pressure wave propagation inside liquids and gases. Physical effects such as gravity, viscosity, and heat transfers are added in the modeling through the source terms of the system in order to be as close as possible to reality.

#### 2) *Modelling of the source terms*

In (1) the various terms for gravity $\Phi_g^u, \Phi_g^E$, for viscosity, $\Phi_\mu^u, \Phi_\mu^E$, and for heat transfers, $\Phi_T^E$, have the following forms:

$\Phi_g^u = \rho\vec{u}$, $\Phi_g^E = \rho\,\vec{u}.\vec{g}$, $\Phi_\mu^u = div\left(\mu\overline{\overline{\tau}}\right)$, $\Phi_\mu^E = div\left(\mu\overline{\overline{\tau}}.\vec{u}\right)$,

and $\Phi_T^E = \sum_k \alpha_k div\left(K_k\vec{\nabla}T_k\right)$.

$\mu$ is the mixture viscosity defined as $\mu = \alpha\mu_1 + (1-\alpha)\mu_2$ with $\mu_k$ the dynamic viscosity for phase $k$; $K_k$ and $T_k$ are respectively the heat conductivity and the phase temperature for phase $k$.

The viscous mixture stress tensor, $\overline{\overline{\tau}}$, has the following form:

$$\overline{\overline{\tau}} = -\frac{2}{3}div(\vec{u})\overline{\overline{I}} + 2\overline{\overline{D}}$$

where $\overline{\overline{D}}$ is the deformation rate tensor defined as :

$$\overline{\overline{D}} = \frac{1}{2}\left(\overline{\overline{grad}}\;\vec{u} + \overline{\overline{grad}}^{\,t}\;\vec{u}\right), \text{ with } \left[\overline{\overline{grad}}\;\vec{u}\right]_{ij} = \frac{\partial u_i}{\partial x_j}.$$

The term $\dot{E}$ models the energy transfer from the arc to the oil. We assume that the energy transfer is 90% efficient (10% loss due to radiation). This transfer results in a local pressure rise which is governed by the energy source term $\dot{E}$ :

$$\dot{E} = W \times H_\chi(\underline{x}, t)$$

where $W$ is the instantaneous electrical arc power. The mathematical function $(\underline{x}, t) \to H_\chi(\underline{x}, t)$ is the arc test function (1 value in the arc domain and 0 outside).

#### 3) *Equation of state*

Each fluid has its own thermodynamic behavior as it is described by its own Equation of State (EOS). Thus, for completeness and consistency an added thermodynamic closure links the mixture pressure to the total mixture energy. Therefore an EOS exists for the whole mixture to deal with smeared interfaces between oil and gas due to diffusion from the numerical method.

The EOS for the entire mixture is both simple and robust. It only relies on two state parameters: the polytrophic coefficient γ and the stiffness parameter π. Fluid Pressure and internal energy are linked by the EOS given in (2):

$$P = (\gamma - 1)\rho\varepsilon - \gamma\pi \quad (2)$$

### B. *Numerical solving*

A finite volume method is thus adopted to numerically solve the PDE system. The volumes are defined by an unstructured 3D mesh, therefore allowing a precise description of complex geometries such as transformer tanks.

#### 1) *Hydrodynamic Numerical Schemes*

The hydrodynamic part of (1) is the most important part of the modelling because the pressure waves are depicted by this part of the equations. The model can be written in the following compact form:

$$\begin{cases} \dfrac{\partial \alpha}{\partial t} + \vec{u}.\vec{\nabla}\alpha = 0 \\ \dfrac{\partial W}{\partial t} + \dfrac{\partial F(W)}{\partial x} + \dfrac{\partial G(W)}{\partial y} + \dfrac{\partial H(W)}{\partial z} = 0 \end{cases} \quad (3)$$

Where :

$W^t = [\rho, \alpha\rho_1, \rho u, \rho v, \rho w, E]$

$F(W) = [\rho u, \alpha\rho_1 u, \rho u^2 + P, \rho uv, \rho uw, (E+P)u]$

$G(W) = [\rho u, \alpha\rho_1 v, \rho uv, \rho v^2 + P, \rho vw, (E+P)v]$

$H(W) = [\rho u, \alpha\rho_1 w, \rho uw, \rho vw, \rho w^2 + P, (E+P)w]$

This model is divided into two parts, one conservative (conservation of mass, momentum and energy), and the other non conservative (advection of the gas volume fraction $\alpha$). In both cases, the Finite Volume Method is used to find the suitable discretisations.

##### a) *Analysis of the PDE*

This PDE system (3) is projected on the local coordinate system linked to the cell edge and solved using the primitive variables: $Y^t = [\alpha, \rho, \alpha\rho_1, u, v, w, P]$. The eigenvalues of the system and their orders of multiplicity are thus:

$$\lambda_1 = \vec{u}\cdot\vec{n} - c\,(1)\;;\;\lambda_2 = \vec{u}\cdot\vec{n}\,(4)\;;\;\lambda_3 = \vec{u}\cdot\vec{n} + c\,(1) \quad (4)$$

It can be shown that $\lambda_1$ and $\lambda_3$ are acoustic waves (typically rarefaction waves and shocks), whereas $\lambda_2$ is a contact discontinuity. The associated Riemann problem is thus very similar to the one associated with Euler equations ([11], [12]).

A more detailed analysis shows that the dimensions of the eigenspace associated with every eigenvalue is equal to the eigenvalue's multiplicity, which means that the PDE system is hyperbolic and can be numerically solved using Riemann solvers and other usual dedicated numerical methods.

*b) Setting of a finite volume scheme for the conservative part*

We then apply a Finite Volume Method (see [11]) onto the system (3) over a cell $\Omega_i$ and a time step $\Delta t$ :

$$\iint_{\Omega_i\,\Delta t} \frac{\partial W}{\partial t} d\Omega dt + \iint_{\Omega_i\,\Delta t} \frac{\partial F(W)}{\partial x} + \frac{\partial G(W)}{\partial y} + \frac{\partial H(W)}{\partial y} d\Omega dt = 0$$

For any given time step all variables are considered as constant on one given cell. The numerical scheme for the conservative part of the hydrodynamic model finally reads:

$$\Omega_i \left(W_i^{n+1} - W_i^n\right) + \Delta t \sum_{j \in V(i)} \Psi\left(W_{ij}^n\right) \vec{n}_{ij} l_{ij} = 0 \qquad (5)$$

$\Psi(W_{ij}).\vec{n}_{ij} = F\left(W_{ij}\right) n_{x_{ij}} + G\left(W_{ij}\right) n_{y_{ij}} + H\left(W_{ij}\right) n_{z_{ij}}$ is the numerical flux at the cell boundary between cell *i* and cell *j*. It has to be evaluated at each cell-boundary.

*c) Setting of a finite volume scheme for the non-conservative part*

The gas volume fraction non conservative advection equation is solved by a robust Godunov numerical scheme:

$$\alpha_i^{n+1} = \alpha_i^n - \frac{\Delta t}{\Omega_i} \sum_{j \in V(i)} \left(\alpha_{ij}^n - \alpha_i^n\right) \vec{u}_{ij}^{\,n} . \vec{n}_{ij}\, l_{ij} \qquad (6)$$

*d) Computation of the flux using Riemann problems solvers*

Equation (5) gives an explicit formula for the computation of the conservative variables at instant *n+1* when knowing them at instant *n*. It just requires the computation of the flux $\Psi(W_{ij}).\vec{n}_{ij}$ which can be done by evaluating the variables at the cells interfaces. To do that, a Riemann problem is solved at every cell boundary using dedicated solvers. The Riemann problem consists of a Partial Differential Equation (PDE) set whose initial conditions are uniform on both sides of an initial single discontinuity. Time evolution of such problems can be described when introducing the wave concept [13]. A Riemann solver that exactly solves the exact Riemann problem has been built for the model we work with. The various state expressions can be deduced from the ones in [12] and are not recalled in the present paper. When dealing with a numerical tool this solver has been associated with a boundary treatment.

*2) Boundary Conditions*

The boundary conditions are accounted for by virtual cells neighbouring inner geometry cells located at the limit of the geometry profile. The variables in those virtual cells are set depending on the type of boundary conditions one has imposed (walls, outlet/inlet, etc.). Once those cells are updated, one can solve a Riemann problem at the geometry edges to compute a numerical flux.

*3) Gravity, Viscous and Thermal Effects*

The gravity, viscous and thermal source terms of (1) as well as the arc energy transfer are taken into account by a time splitting scheme, including the contributions of the physical effects considered separately. The numerical time integration scheme is then based on a first order Runge-Kutta time scheme.

*4) Validation*

Comparisons between the experimental test data and the simulation results are in good agreements and validate the model. For instance, fig. 5 displays the comparison of a pressure profile for one test (more details in [5] and [10]).

*Experiments:*

*Simulation:*

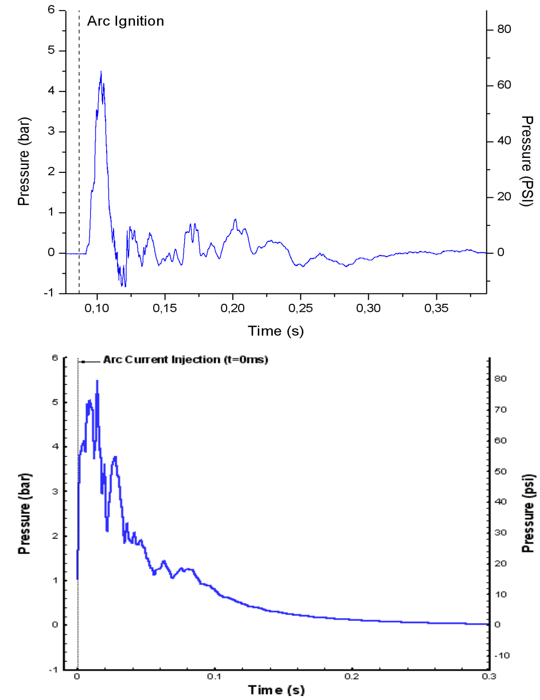


Fig. 5. Experiments / Simulation pressure profiles comparison (close to the arc)

## V. Simulations of a 200 MVA Transformer Explosion and Its Prevention

### *A. Aim of the study*

The present section uses the simulation tool in order to study in details the effects of an electrical arc occurring in a usual 200 MVA transformer. Moreover, it analyses the consequences of using the strategy presented in the first section to prevent transformer tank explosion.

### *B. Configuration*

The 200 MVA transformer is *5.75 m* long, *3.25 m* high and *2.5 m* large and all the equipments of the transformers, such as bushing turrets or windings are taken into account. An electrical arc (*11.5 MJ*-arc generating about *3.4* $m^3$ of gas) ignites near a winding, generating an *11 bar abs* gas bubble.

### *C. Results of the simulations*

Figure 6 shows the simulated evolution of the pressure inside the tank after the occurrence of the gas bubble generated by the arc. On the right side (fig. 6b), the transformer is equipped with the protection presented previously, while on the left side (fig. 6a), the transformer is not protected.

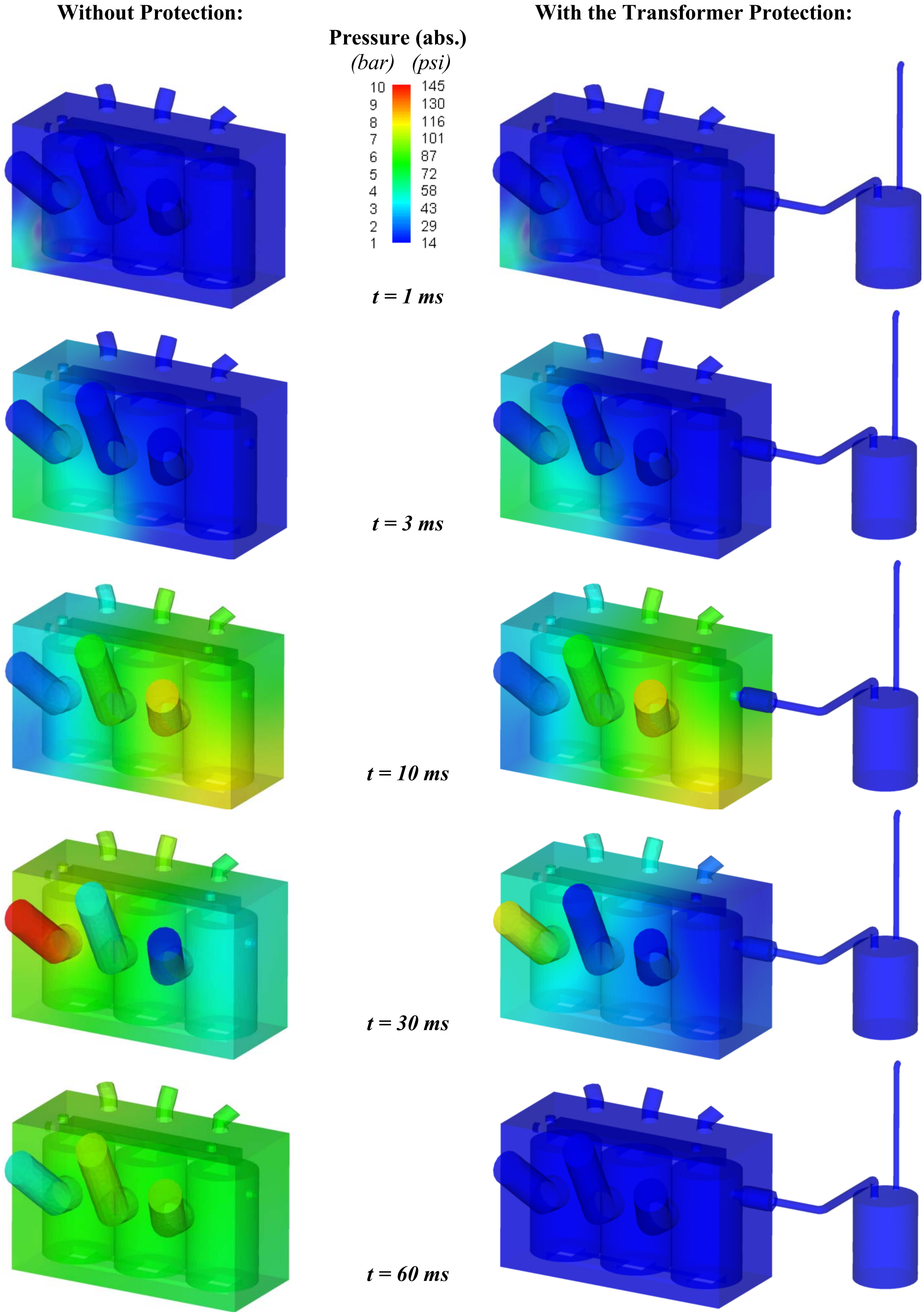


Fig. 6a. Pressure evolution in an unprotected tank

Fig. 6b. Pressure evolution in a transformer tank equipped with a DS

When the transformer is equipped with the protection, the pressurized gas bubble creates pressure waves which propagate throughout the transformer, reflecting and otherwise interacting with the tank structure (fig. 6b). Within *3 ms*, a large pressure peak has reached the entry of the first bushing, as shown in fig. 6b. Then the pressure wave triggers the Depressurization Set activation within about *10 ms* after the gas bubble creation. This induces the rapid evacuation of fluid from the transformer tank (see fig. 7), which thus generates rarefaction waves spreading throughout the transformer. After only *60 ms*, the pressure throughout the transformer stabilize well below dangerous levels, as shown in fig. 6b.

Otherwise, when the tank is not equipped with any protection system, and if it is subjected to a similar low impedance fault, the tank is exposed to very dangerous pressure levels. For instance, *30 ms* after the arc occurrence, the pressure in a bushing reaches more than *10 bars abs* as shown in fig. 6a. Moreover, without the tank protection, the static pressure stabilizes around *6 bars abs* and the transformer would violently explode (as transformer tanks are designed to withstand static pressure up to about *2.2 bars abs*).

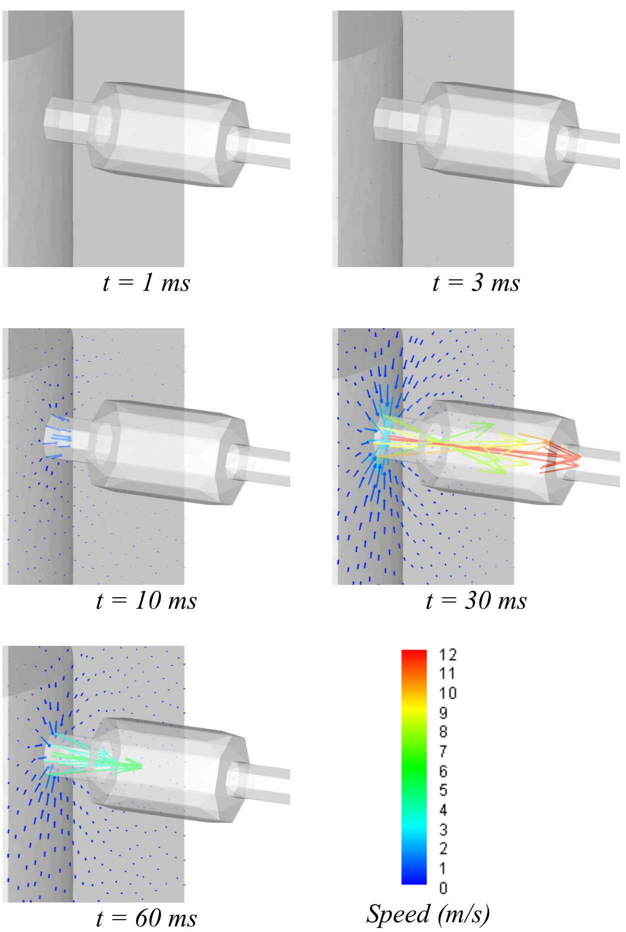


Fig. 7. Speed at the entrance of the Depressurisation Set

## VI. Conclusions

An experimental tests campaign was dedicated to the understanding of transformers explosion induced by electrical arcing. Because transformer explosions are uncontrollable and lead to huge damages, the tests were performed with transformers equipped with an explosion prevention technology that operates at a calibrated pressure level due to dynamic pressure peaks.

The tests showed that when an electrical arc occurs in the tank, the oil surrounding the arc is quickly vaporized and the generated gas is pressurized because the liquid inertia prevents its expansion. The pressure difference between the gas bubbles and the surrounding liquid oil generates pressure waves that propagate within the oil. When the first dynamic pressure peak reaches the protection, it triggers an oil evacuation that quickly depressurizes the tank so that no tank rupture occurs.

During the tests, transformer tanks could withstand such high pressure peaks (up to *14 bars abs.)* during several tens of milliseconds even if the static withstand limit of transformer tanks is around *2.2 bars abs*.

Complementarily, the consequences of arcing inside unprotected transformers can be studied safely using computational simulations. A numerical simulation tool was developed for that purpose. In order to be efficient, it has to deal with liquid and gas and to be able to compute pressure wave propagations. Therefore, a complete modeling for unsteady compressible two phase flows has been adapted and a finite volume method was set to solve the equations on 3D unstructured meshes.

Simulations were then run on a 200 MVA transformer; they highlighted the advantages of using advanced simulation tools:

- First, it gives a deep understanding of what happens during a transformer explosion. The simulation tool confirmed that when an electrical arc occurs insides a transformer tank that is not protected, the dynamic pressure waves generated by the arc propagate through the tank, reflects on the wall and progressively increases the static pressure inside the tank resulting in its rupture.
- Second, the computational tool is efficient to study the operation of explosion prevention strategies such as the ones based on a fast depressurization induced by oil evacuation. Indeed, the results showed that this fast fluid evacuation generates large rarefaction waves that propagate and depressurize the whole tank within milliseconds thus avoiding the static pressure build up that can not be withstood by the tank.

Such strategies based a fast tank depressurization generated by a quick oil evacuation can thus be considered an efficient protection against transformer explosion.

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## VIII. Biographies

**Guillaume Perigaud (M'06)** holds a Diploma of Mechanical Engineering and a MSc degree in Fluid Mechanics and Transfers (Ecole Centrale Nantes, Nantes, France, 2000). He holds a PhD in Mechanics and Heat Transfers (Université de Marseille I, France, 2003). As a IEEE member he is actively involved in the IEEE PES Power Transformer Subcommittee Task Force regarding Transformer Tank Rupture & Mitigation.

**Sébastien Muller** is a SERGI Holding researcher. He holds a Diploma of Mechanical Engineering, and a MSc in Fluid Mechanics (ENSMA, Poitiers, France, 2002). He is Doctor in Fluid Mechanics (Université d'Orléans, France, 2007). He is an NFPA member, currently working on the development of a simulation tool that models the vaporization process due to the arc interaction with the liquid oil.

**Margareta Petrovan Boiarciuc** is a SERGI Holding researcher. She holds a Diploma of Aeronautical Engineering and a MSc degree in Fluid Mechanics (Université d'Orléans, France, 2004). She is Doctor in Fluid Mechanics (Université d'Orléans, France, 2008). She is currently working on the development of a simulation tool that deals with moving meshes.