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Procedia Engineering 202 (2017) 202–223

Procedia Engineering

www.elsevier.com/locate/procedia

4th International Colloquium "Transformer Research and Asset Management”

A Comparison of Numerical Methods for Modeling Overpressure Effects from Low Impedance Faults in Power Transformers

Jean-Bernard Dastous[a]*, Ewald Taschler[b], Sylvain Bélanger[a], Monther Sari[b]

[a]*Institut de recherche d’Hydro-Québec, 1800 boul. Lionel Boulet, Varennes, Québec, J3X 1S1, Canada*
[b]*Siemens AG Österreich, Transformers Weiz, Elingasse 3, 8160 Weiz, Austria*

Abstract

Low-impedance faults in power equipment may lead to catastrophic tank ruptures, resulting in fires, oil spills and projection of parts, as well as economic losses. Up to recently, the tank for a large power transformer or a shunt reactor was typically designed to withstand vacuum filling, transportation and sometimes earthquakes. Since 2008, Hydro-Quebec has implemented arc-containment requirements in its power transformer and shunt reactor specifications. Tank rupture is a very complex phenomenon to investigate - arc testing is cost-prohibitive and, moreover, random in nature. Therefore, mechanical design of tanks to withstand such events, as well as investigation of such phenomena, must rely primarily on numerical methodologies. In this paper, Hydro-Quebec and SIEMENS present and compare two main classes of numerical methods, as well as some of their possible variations, that may be used to obtain an optimized and safer tank design to withstand overpressure effects from low impedance faults.

Peer-review under responsibility of the organizing committee of ICTRAM 2017.

Keywords: Tank rupture; low impedance faults; overpressure.

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* Corresponding author. Tel.: 450-652-8341; fax: 450-652-8905.
E-mail address: dastous.jean-bernard@ireq.ca

1877-7058
Peer-review under responsibility of the organizing committee of ICTRAM 2017.
10.1016/j.proeng.2017.09.708

1. Introduction

Low-impedance faults in power equipment may lead to catastrophic tank ruptures, resulting in fires, oil spills and projection of parts. Such faults, initiated from a breakdown of the electrical insulation, result in the generation of an electrical arc which vaporizes the surrounding oil. The decomposition of oil leads to the formation of a high temperature and high pressure gas bubble, which expansion results in a rapid pressure rise within the transformer tank.

Since 2008, Hydro-Quebec has implemented arc-containment requirements in its power transformer and shunt reactor specifications; these are detailed in [1]. These requirements specify that such equipment tanks must be able to withstand without opening a low impedance fault of a given amount of energy according to its voltage class, without also projection of parts. Furthermore, it is required that beyond the specified amount of energy, the tank must fail safely by opening only at the cover level in order to minimize oil spills and collateral damage to neighboring structures and equipment. The main design parameter resulting from these requirements is a uniform design pressure that the tank must withstand, which is primarily a function of the amount of energy to be contained and the tank flexibility.

Tank rupture is a very complex phenomenon to investigate - arc testing is cost-prohibitive and, moreover, random in nature. Therefore, mechanical design of tanks to withstand such events, as well as investigation of such phenomena, must rely primarily on numerical methodologies. Towards these ends, there are two main methods that may be used:

- non-linear static finite element analysis ;
- explicit dynamic finite element/finite volume analysis.

The first method is best suited for the mechanical design of tanks, and is currently used by manufacturers in order to comply with the arc containment requirements discussed before, based on a uniform design pressure. The second one is best suited towards investigative purposes, as it permits studying the effect of many parameters, such as the arc position and duration, and the resulting pressure distribution within the tank which is generally not spatially uniform within the tank for some time from the fault initiation to some later time after its termination [1]. Both methods have advantages and limitations, and both rely on a high level of knowledge and expertise in order to be used adequately.

This paper presents the application of these methods in the design and investigation of the fault containment capacity of a 735 kV shunt reactor. A comparison between the results from both methodologies, as well as the effects of different modeling techniques within each, will be presented and discussed.

Nomenclature

C	Volumetric flexibility of the tank, $\Delta V/\Delta P$ (m^3/kPa)
DLF	Dynamic load factor
EM	Young's modulus (GPa)
E	Arc energy of the fault (kJ)
k	Gas quantity generated by kJ of arc energy in oil, $5.8x\ 10^{-4}$ m^3/kJ of arc
P_a	Applied pressure (kPa)
P_f	Pressure to failure (kPa)
P_d	Design pressure (kPa)
P_o	Hydrostatic pressure at the center height of the the main tank due to the oil mass in the tank and conservator (kPa)
SMsh	Submodel, boundary condition from static shell model
SMso	Submodel, boundary condition from static solid model
V	Volume of the tank
V_0	Volume of the tank at P_0