International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Estimation of Pressure and Temperature Rise Due to Internal Arc Generation in Switchgears

Tanaya Vijay Muneshwar[1], Chinmayee Abhay Phadke[2], Atharva Nilesh Pandit[3], Aaditya Vaijnath Aravat[4]

[1,2,3,4]Student, Department of Mechanical Engineering, K. K. Wagh Institute of Engineering and Research, Nashik.

Abstract

The switchgears are vital component in energy system which protects, regulates and isolates the electrical transmission line by making or breaking the high voltage circuit with the use of circuit breakers. During the operation of switchgear internal arc is a failure criterion which is a result of a short circuit current. To quench this arc, the internal arc chamber is used which encapsulates the energy generated and protects the further transmission system and appliances. The gas insulated switchgears used for medium voltage application are enclosed inside the metal chambers and thus design of these chambers becomes crucial as they handle high pressures and temperatures. This fact is also exacerbated by the condition that metal chambers are prone to sudden increase in pressure due to internal arc phenomenon. The type testing process used for validating the design of chamber against internal arc is time consuming, costly and thus shall be performed with no margin of error. The paper aims to establish the standardized approach to calculate the instantaneous pressure and temperature rise inside the gas tank of switchgear which are otherwise impossible to approximate given the short timeframe in which internal arc occurs by using the approaches discussed in the CIGRE committee reports.

Keywords: Switchgears, Internal arc, CIGRE, Pressure, Gas chamber.

Introduction

Switchgears are the important components of the power system regulating, protecting and controlling the electrical circuits to which they are connected. The main switching action inside the switchgear is obtained by the use of circuit breakers. These circuit breakers are housed inside gas chambers and insulating medium is provided in the chamber which in most of the cases is either air or the SF_6 gas. This study is limited for the SF_6 gas insulated switchgears. SF_6 gas insulated switchgears(GIS) are prone to the structural failure due to generation of internal arc emanating from the short circuit current which is created when the current inside the switchgears flow from the unintended path. Study of this failure becomes critical especially when the GIS are used for the higher voltages and current ratings i.e. for medium and high voltages (1KV -66KV). The energy generated during the internal arc fault at such voltage and current ratings is of massive amount and the chamber housing the switchgear component should be robust enough to contain this energy till it is being vent out via exhaust mechanism. The chamber shouldn’t fail structurally as it can cause mishaps and accidents resulting in damage of life and property. Therefore the design of these chambers is of paramount importance.

Validating the design of this chamber is not an easy task as the simulation of the short circuit current is difficult to achieve practically. Even though the tests are available where actual short circuit is generated and the strength of chamber is tested, these tests are cost and time intensive and thus are not always feasible to do. The only way remains of the virtual analysis of the chamber by creation of a CAD model and simulating the pressure and temperature rise and thereby ascertaining the behavior of the chamber for increased pressure. These pressures and temperature rise can't be instrumented and measured by available devices in the market as rise of pressure due to arc generation is for an infinitesimal period say 1/1.5 seconds and due to practical difficulties in achieving the short circuit condition. Thus there should be a way to calculate the maximum value of pressure and temperature rise inside the chamber during internal arc fault.

There are several methods to do this. These methods are discussed by the CIGRE committee conference proceedings. This paper aims to provide the feasible way of calculating the pressure and temperature rise by resorting to the basic method approach discussed in CIGRE committee reports.

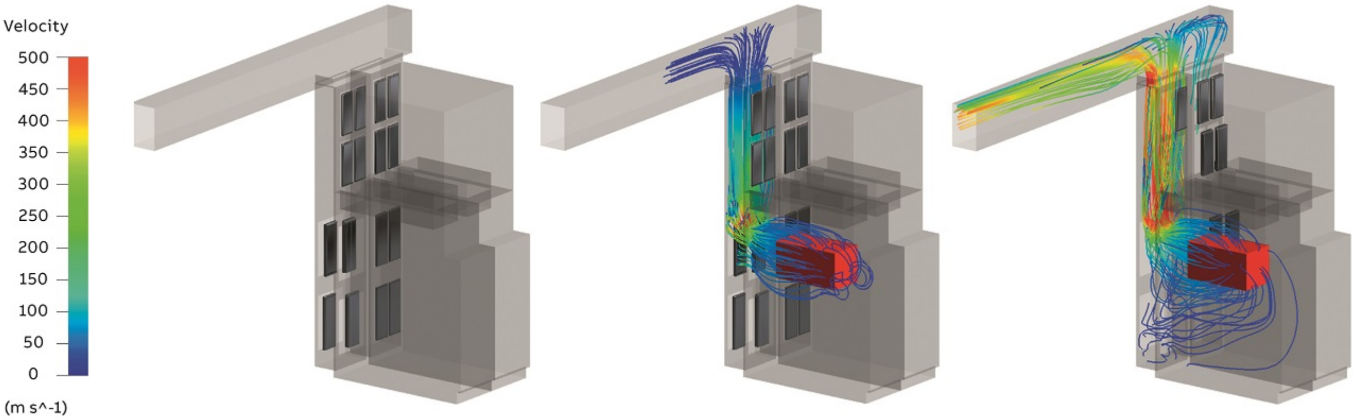

Figure 1 - Generation of internal arc in chamber of switchgears [5]

Calculation of temperature and pressure rise:

Considering a three phase switchgear system with rated voltage of 33kV and rated current of 2500A and short circuit current rating of 31.5kA (a general rating of medium voltage (MV) switchgears). The pressure and temperature rise is due to the conversion of electrical energy produced into the heat energy which in turn heats up the gas inside the chamber and increases its pressure and temperature. Thus first step is to calculate electrical energy generated during the internal arc fault.
To sustain the short circuit current of 31.5kA, the short circuit drops up to 2.7kV.

Thus the electrical energy produced is given as

$$(W_{el}) = (u_R.i_R+u_S i_S+u_T i_T)\Delta t[1] \ldots..(1)$$

Where, Δt is time after which the pressure relief flaps will open and $u_x$and i_x are the individual phase voltages and currents.
The values of u_R, u_S, $u_T$can be calculated by using following formulae:

$$u_R = u_{Rm} \sin(\omega t)$$
$$u_s = u_{Sm} \sin(\omega t + 2\pi/3)$$
$$u_T = u_{Tm} \sin(\omega t + 4\pi/3)$$

And the values of i_R, i_S,$i_T$can be calculated by using following formulae:

$$i_R = i_{Rm} \sin(\omega t - \phi)$$
$$i_s = i_{Sm} \sin(\omega t + 2\pi/3 - \phi)$$
$$i_T = i_{Tm} \sin(\omega t + 4\pi/3 - \phi)$$

Where ϕ is the power factor, ω is the angular velocity of AC and t is the time between generation of arc and the opening of pressure relief systems.
Substituting above vales in equation (1), one can ascertain the total amount of electrical energy being generated inside the chamber.
The heat generated as a result of this arc energy is given as,

$$\Delta Q = K_p \times Wel \text{ [1]} \quad \ldots..(2)$$

Where, K_p(thermal transfer coefficient) = 0.4[1]
The temperature rise in chamber is given by the formula:

$$\text{Temperature rise } (\Delta T_1) = \frac{\Delta Q}{m1 \times Cv1} \text{ [1]} \quad \ldots..(3)$$

Where, m_1 is mass of air inside the chamber, $\Delta Q1$is the heat generated obtained from the equation (2). The volume of chamber and density of gas (ρ)will be known.Due to presence of various electrical equipment inside the chambers the volume is effectively reduced. The reduction factor for MV switchgear below 1250A is 0.8 and for above 1250A, it is 0.7.

Hence, one can calculate the resulting mass of air (m_1) accordingly. Substituting all the available values in equation (3), the temperature rise is obtained.
The pressure rise inside the chamber is given as:

$$\text{Pressure rise } (\Delta P_1) = \frac{(K1 - 1) \times m1 \times Cv1 \times T1}{V1} \text{ [1]} \quad \ldots..(4)$$

Where, K_1 is adiabatic index of gas, $Cv1$is specific heat capacity of gas at constant volume.
Substituting all the available values in equation (4), the pressure rise is obtained.
This will be the maximum gauge pressure obtained for the chamber at event of an internal arc generation.

Thus this pressure and temperature values can then be used to simulate the condition of tank at an event of short circuit using the analysis software.

Figure 2 - Event of an internal arc fault

Conclusion

1. The primary objective of this paper was to specify the feasible method of calculating the pressures and temperatures generated at an event of internal arc as they are impossible to approximate experimentally.
2. Calculations and results are based on the basic method approach given by the CIGRE committee report and thus possess a strong technical background.
3. These values obtained can then be used to simulate the arc generation condition and the chamber could be thoroughly analyzed for the failure and unwanted conditions and accordingly design changes could be made.
4. Physical tests being capital and time intensive, the designers often tend to bypass them but require operating conditions for simulating the results which could be provided by this method.
5. This method will reduce the time required for validating the design of chamber and could enhance the safety of design if suitable factor of safety is considered for the values obtained. \

References

1. WGA3.24, rev 11.1 January 26, 2014, "Tools for simulation of effects of the Internal arc in transmission and distribution of switchgears."
2. Kunio Matsushita, Yoshihiko Matsuura, "Study for the Performance of High-Speed Switchgear for Protection on In-House Generation System" Journal paper by Shikoku Research Institute.
3. Prof. Chennakeshava R., "A Review on Switchgears Analysis and Common Challenges Observed in Switchgear" International Journal of Engineering & Research Technology (Vol. 10 Issue 03 March 2021)
4. Sunil S. Rao, "Switchgear protection and Power systems." 11th Edition. Chapter 15a, 15b.
5. https://new.abb.com/news/detail/24207/mitigating-internal-arc-impact
6. https://www.crtsgroup.com/en/internal-arc-20ka-certification-on-our-mv-atr-switchgear/