Applied Thermal Engineering 136 (2018) 541–547

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Experimental determination of the convective heat transfer coefficient for a switchgear busbar system with a use of the data reconciliation method

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HIGHLIGHTS

- Data reconciliation method was applied for heat losses determination.
- Heat transfer coefficient was determined for low-voltage switchgear.
- New expression for heat transfer coefficient for typical busbar system was presented.
- Influence of current on the heat transfer coefficient was assessed.

ARTICLE INFO

Keywords:
Busbar system
Electric switchgear
Heat transfer coefficient
Power loss
Data reconciliation

ABSTRACT

The paper proposes new approach for the determination of the convective heat transfer coefficient for the typical busbar system located in the industrial low-voltage naturally air-cooled electrical switchgear. The correlations for this parameter that are available in the literature are applicable for simple shapes only. This means that they were not designed for the application of the busbar system. In this study, a determination of the convective heat transfer coefficient is mainly based on the experimental values of the busbar and ambient temperatures, and the heat transfer rate dissipated from busbars. The coefficients of the proposed expressions for a Nusselt number were determined in the least square sense from the convective heat transfer coefficients and the measured temperatures to the postulated model. The convective heat transfer coefficients were obtained using the data reconciliation method for two energy balance equations defined at different locations and for the power loss equation for the AC current flow of the considered switchgear. The developed correlations used different than typical fluid temperatures to express the convective heat transfer coefficient to make the approach more practical. The method has been applied for four power levels for both ventilated and hermetic switchgear configurations.

1. Introduction

Switchgears are among the most important parts of systems that deliver and distribute power. As the high current flows through the busbar systems inside the switchgears, heat losses are generated. There is a maximum temperature level acceptable inside the switchgear [1], therefore it must be cooled [2]. There are two possible cooling configurations: ventilated or sealed [3]. The former is mostly cooled by natural convection. In this case, the air flows into the casing at the bottom part. Then it flows around the busbar system and leaves the switchgear in the upper part of the casing. For the hermetic casing, the air internally circulates, transferring the heat from the busbars to the casing walls. As a consequence, the heat is dissipated only through the walls. This causes higher busbar temperatures but simultaneously provides a higher ingress protection (IP) class. Each configuration can be supported by a fan that changes convection type from natural (less effective) to forced (more effective), but this solution is rather rare as it increases the maintenance cost and decreases reliability of the design.

Knowledge about the convective heat transfer coefficient (HTC) inside the switchgear is an important in thermal aspects of the design process. Namely, a value of the convective HTC is required for validation of the proposed switchgear configuration in terms of maximum operating temperature [2]. Furthermore, it is required to predict the thermal behaviour of the switchgear at different operating conditions. For example, the assumption of the convective HTC that is too small at the design process leads to excessive copper use for a switchgear busbar

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https://doi.org/10.1016/j.applthermaleng.2018.03.036
Received 21 October 2016; Received in revised form 18 January 2018; Accepted 10 March 2018

Nomenclature

Latin

a, b	empirical coefficients, –
A	area, m^2
g	gravitational acceleration, m/s^2
h	heat transfer coefficient, W/(m^2 K)
I	current, A
k	thermal conductivity, W/(m K)
l	characteristic dimension, m
Nu	dimensionless Nusselt number, -
Q	heat transfer rate, W
R	electric resistance, Ω
Ra	dimensionless Rayleigh number, -
S	AC/DC correction factor, -
T	temperature, K
w	velocity, m/s

Greek

β	thermal expansion coefficient, 1/K
ε	emissivity, –
ϕ	objective function, –
ν	kinematic viscosity, m^2/s

Subscripts

air	air
bus	busbar
conv	convective
es	casing
in	inlet
inf	surrounding objects
out	outlet
tot	total

structure and, as a result, higher investment cost.

Nowadays many companies involved in switchgear manufacturing have based new designs on the company staff experience and data in the literature. Namely, on the basis of all the successful and failed designs, the convective HTC value, in particular for the busbar application and configuration, can be estimated. Then, the convective HTC is usually implemented into other, simpler models such as heat conduction models, thermal field models and thermal network models [4–6]. Unfortunately, this approach is not sufficient for new designs that may be significantly different from the previous configurations. Therefore, there is a need to develop a relatively simple method/algorithm/relation for the convective HTC that is dedicated to the busbar system application.

Typically there are three methods for the convective HTC determination. The first involves the application of general correlations for dimensionless numbers, which describes heat transfer in terms of natural or forced convection [7]. This approach requires knowledge of the surface temperature of the copper busbar inside the switchgear as well as air temperature and, in the case of forced convection, the velocity vector as well [8]. However, the busbar temperature determination is difficult in practice because of the complex structure of the busbar system. In addition, a character of the air flow can be described only roughly, taking into account the presence or absence of a cooling fan. Moreover, there is doubt about where to measure the air temperature to use it in empirical correlations.

The second method is based on the coupled numerical analysis of the current flow, heat transfer and fluid flow inside the switchgear. It requires preparation of the complex geometrical model and a numerical mesh [3]. Then, for each mesh cell, a set of equations encompassing continuity, momentum, energy and current flow is solved simultaneously. This approach, in theory, does not require data from measurements. However, the method requires a validated model and relatively long computing times [9]. The biggest drawback of this approach is that there is no guarantee that a model successfully validated for one switchgear type and size will produce accurate results for another switchgear design.

The last approach involves temperature measurements of the busbars and surrounding air as well as the total heat flux dissipated from the considered busbars [10]. The temperatures can be measured with the use of thermocouples or contact sensors. The total heat flux can be measured directly by using appropriate sensors or by determining the total power loss by voltage and current measurements for whole electric path inside the switchgear [11,12]. When the temperatures and the total heat fluxes are known, the total HTC value is obtained directly from Newton's law of cooling [7]. In the next step, the convective HTC can be computed based on the radiative HTC value. The latter value can be obtained on the basis of the known emissivity value. The second possibility is to determine the radiative heat flux which is then

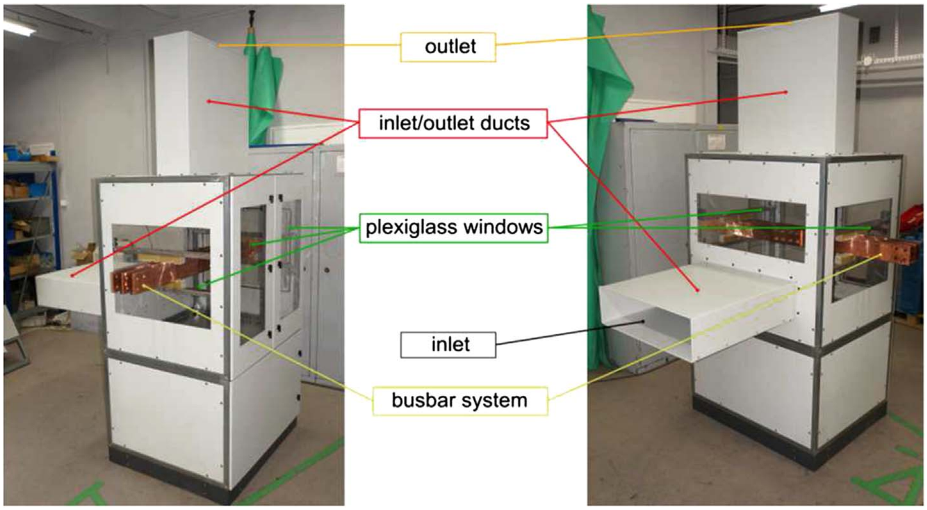

Fig. 1. General views of the switchgear model.