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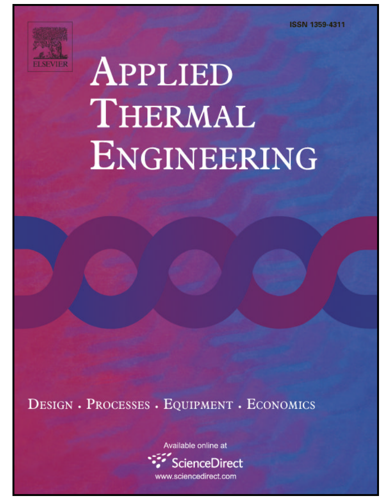

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Numerical investigation of oil flow and temperature distributions for ON transformer windings

Xiang Zhang[1], Zhongdong Wang[1]*, Qiang Liu[1], Paul Jarman[2], Massimo Negro[3]

***Abstract*—In this paper, numerical investigation of oil flow distribution and temperature distribution is performed for a disc-type transformer winding in an oil natural (ON) cooling mode. First, dimensional analysis is carried out based on the governing differential equations with the Boussinesq approximation, and *Re*, *Ri* and *Pr* are found to be the governing dimensionless parameters in determining flow and temperature distribution. Then a CFD case study is performed on a winding model as the benchmark for this study, in which reverse flow and hot-plumes are observed. After the case study, CFD parametric sweeps of *Re* and *Ri* are executed. It is found that the minimum value of the hot-spot factor, which characterizes the thermal performance of the transformer winding, is achieved in a relatively small and fixed range of *Ri* (from 0.4 to 0.6) regardless of the values of *Re* and *Pr* in their practical ranges. Consequently, the relationship of an invariable minimum hot-spot factor with a small fixed range of *Ri* makes the optimization of the transformer operational regime possible. Finally, a new CFD case study is performed to confirm the shifting of an uncontrolled operational regime to a quasi-optimal one by changing *Ri* from 1.46 in the benchmark case to 0.6 in the new case.**

***Keywords*—Disc-type transformer, Dimensional analysis, CFD, hot-spot factor, optimal operational regime**

NOMENCLATURE

c_p	Oil specific heat at constant pressure ($J/(kg\cdot K)$)
c_{pp}	Paper specific heat at constant pressure ($J/(kg\cdot K)$)
c_{pc}	Copper specific heat at constant pressure ($J/(kg\cdot K)$)
D_h	Hydraulic diameter at the pass inlet ($2\times W_{inn}$) (m)
Δx	The thickness of the paper insulation (m)
g	Gravitational acceleration (m/s^2)
g_{ave}	Average temperature gradient (T_{aw}-(T_{to}+T_{bo})/2) (K)
Gr	The Grashof number ($g\beta(T_{aw}-(T_{to}+T_{bo})/2)D_h^3/\nu^2$)
Gr/Re^2	The ratio of Gr to Re^2 ($g\beta(T_{aw}-(T_{to}+T_{bo})/2)D_h/u_m^2$)
h	Heat transfer coefficient of the winding ($W/(m^2\cdot K)$)
H	The hot-spot factor ((T_{hs}-T_{to})/(T_{aw}-(T_{bo}+T_{to})/2))
k	Oil thermal conductivity ($W/(m\cdot K)$)
k_p	Paper thermal conductivity ($W/(m\cdot K)$)
k_c	Copper thermal conductivity ($W/(m\cdot K)$)
Nu	The Nusselt number ($h\cdot D_h/k$)
p	Static pressure (Pa)
p_{to}	Top oil static pressure (Pa)
Pr	The Prandtl number ($\mu\times c_p/k$)
q''	Heat flux at the hot-spot (W/m^2)
r	Coordinate in radial direction
Ra	The Rayleigh number ($Gr\cdot Pr$)
Re	The Reynolds number ($u_m\times\rho\times D_h/\mu$)
Ri	The Richardson number (Gr/Re^2)
T	Temperature (K)
T^*	Dimensionless temperature ($\frac{T-T_{to}}{T_{aw}-(T_{to}+T_{bo})/2}$)
$T^*_{\max disc}$	Dimensionless maximum temperature of a disc ($\frac{T_{disc\max}-T_{to}}{T_{aw}-(T_{to}+T_{bo})/2}$)
ΔT	Temperature gradient across the paper insulation (K)
T_{aw}	Average winding temperature (K)
T_{bo}	Oil temperature at the bottom of the winding (K)
T_{bulk}	Bulk oil temperature surrounding the hot-spot (K)
T_{hs}	The hot-spot temperature in the disc (K)
T^*_{hs}	Dimensionless highest temperature in fluid domain
T'_{hs}	The hot-spot temperature in the fluid domain (K)
T_{to}	Oil temperature at the top of the winding (K)
u_m	Average oil velocity at the winding inlet (m/s)
u_r	Radial velocity component (m/s)
u_z	Axial velocity component (m/s)
W_{inn}	Inner vertical duct width (m)
W_{out}	Outer vertical duct width (m)
Δx	The thickness of the paper insulation (m)
z	Coordinate in axial direction
β	Oil volumetric thermal expansion coefficient ($1/K$)
ρ	Oil density (kg/m^3)
ρ_{to}	Top oil density (kg/m^3)
ρ_p	Paper density (kg/m^3)
ρ_c	Copper density (kg/m^3)
μ	Dynamic viscosity ($Pa\cdot s$)
ν	Kinematic viscosity (m^2/s)

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1. Introduction

Power transformers connect electric power networks of different voltage levels and convert electric power efficiently.