Thermal Design of VSD Dry-Type Transformer

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Summary Design of variable speed drive (VSD) dry-type transformers requires accurate electromagnetic and thermal modelling of the transformer. The models should be able to explain the behaviour of the transformer under normal and short circuit conditions. If not appropriately taken into consideration, load losses can generate local overheating in the transformer and hence cause the transformer failure due to increased winding temperature. A thermal network model to be used with a finite element model of the unit is described. This method is shown to deliver a good compromise between time-consuming simulations and a semi-empirical thermal model for reliable designs of complex dry-type VSD transformers.

1 Introduction

Variable speed drives are used to control the speed of rotation of electronic motors in many industrial applications. These are pumps, ventilators, compressors, belt conveyors, rolling mills, paper machines and an innumerable amount of different machines used in manufacturing and other industries. ABB Dry Type Converter Transformers have an extensive experience with VSD transformers since more than 20 years. Especially the harmonic frequencies content in the transformer current increases the mechanical, dielectrical and thermal stresses. Therefore the transformers must be specially designed for this duty, fulfilling the IEC [3] requirements and beyond.

2 Electromagnetic Simulation of VSD-Transformers

Analytic formulations for the losses in the windings which are governed by skin and proximity effects are limited because of the complex arrangement of the windings in typical VSD transformers. As a result, the use of computational electromagnetic is vital in order to predict these losses at the normal operating conditions. In this paper, we consider the case of a 12-pulse transformer consisting of the two secondary low voltage (LV) windings.

3 Thermal Network Model

The main focus of this work relies on the thermal model to be used with the losses computed by the electromagnetic simulations [4] and predict local overheating of the windings. The model proposed uses physics-based formulation of mass, energy and momentum balance equations which enables a large validity range of the method in opposite to purely empirical models.

3.1 Physics-based Thermal Model

The physics of the thermal model is described in three basic structures. The simplified generic structures show to be very efficient for modelling and simulating advanced thermal systems [1,2,5].

3.1.1. Solid Structure

The winding losses from the electromagnetic simulation (ohmic and eddy-current) are applied in the solid structure. In this structure, the conductors and insulation material are described. The energy balance is stated as follows

$$0 = P_k - \dot{Q}_{cond}\,, \tag{1}$$

where P_k are the transformer losses and $\dot{Q}_{cond}$ is the (axial and radial) heat diffusion inside the windings.

3.1.2. Surface Structure

The surface structure is used to map the interface between a solid potential and a fluid potential. The energy balance equation is stated as follows:

$$0 = \dot{Q}_{cond} - \dot{Q}_{conv} - \dot{Q}_{rad}\,, \tag{2}$$

where $\dot{Q}_{conv}, \dot{Q}_{rad}$ are convective and radiation heat transfer, respectively.

3.1.3. Fluid Structure

The fluid structure is used to map the cooling duct between winding blocks.

$$0 = \dot{Q}_{conv} + \dot{m}_{in} \cdot \left(h_{in} + \frac{v_{in}^2}{2} + g z_{in} \right) - \cdots \tag{3}$$

$$\cdots - \dot{m}_{out} \cdot \left(h_{out} + \frac{v_{out}^2}{2} + g z_{out} \right)$$

where $\dot{m}_{in}$, $\dot{m}_{out}$ are the inlet and mass flow rate of the cooling medium inside the transformer cooling duct, respectively. h_{in} and h_{out} are the inlet and outlet enthalpy of the cooling medium, respectively. v_{in} and v_{out} are the inlet and outlet velocity of the cooling medium, respectively.

The non-linear algebraic system of equations described in the structures is represented in Eq. 4 and is solved by a standard algebraic equations solver.

$$F(x) = 0, \qquad (4)$$

where x is the vector of temperatures of all structures of the transformer model.
Figure 1 shows an overview of the thermal model. The solid structures are connected with each other via heat conduction axially. The solid and surface structures are connected radially via conduction. The surface structures are connected to each other via radiation resistance. The connection between a surface and a fluid is done by convective resistance. Both the convective and the radiation resistance are non-linear, temperature dependent resistances.

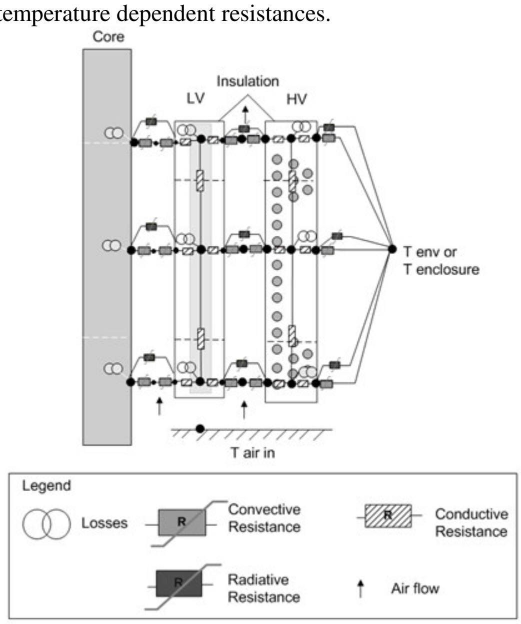

Fig. 1: Network representation of the thermal model with a vertical discretization of 3 structures (In this example: 1 low voltage and 1 high voltage winding package)

3.2 Object-Oriented Structure

Figure 2 shows the object oriented structure of the transformer. The structure of the model is fixed, i.e. one coil, one core and an open number of low voltage (NLV) and high voltage (NHV) winding packages. The geometry is fully parametrized which allows high freedom during design process.

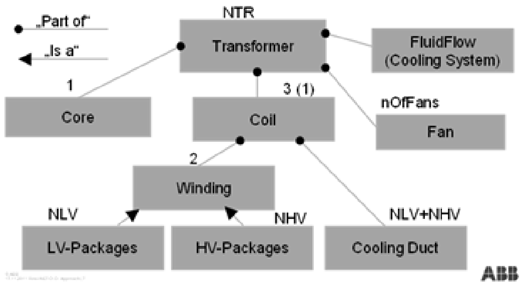

Fig. 2: Object-oriented structure of the sub-models of the transformer thermal model

3.3. Thermal Management of Windings

As part of the design optimization, it is possible to visualize the thermal management of each winding block. The thermal management gives information about the heat transfer by convection at the winding surroundings. The designers are able to choose more effective cooling ducts by comparing thermal characteristic number as the Rayleigh number.

4 Weak Coupling of Electromagnetic Simulation with Thermal Network Model

A weak coupling of the thermal network model is conducted by using the same axial discretization (number of structures in axial direction) of the thermal model and the post-processed losses of the electromagnetic simulation [4]. The losses computed during the electromagnetic simulations are used as input for the thermal model.

5 Conclusion

The method shown in the present work speeds up the design process of complex VSD-transformers. Overheated areas are localized before production of the unit. This method has been proven to be a good compromise between time-consuming simulation and a semi-empirical thermal model for production of complex dry-type transformer designs.

References

1. Bockholt, M *Transient Modelling of a Controllable Low Pressure Accumulator in CO_2 Refrigeration Cycles,* 6th International Modelica Conference, March 3rd-4th, 2008 www.modelica.org
2. Bockholt, M. *Dynamische Optimierung von mobilen CO_2-Klimaanlagen mit innovativen Komponenten* PhD-Thesis, TU-Braunschweig, 2009.
3. IEC 60076-11. *Dry-Type Transformers, CEI/IEC 60076-11:2004.*
4. *MagNET v.7, Infolytica Corporation,* *www.infolytica.com, Last access: 30.09.2011.*
5. Tegethoff, W. *Eine Objekt-orientierte Symulationsplattform für Kälte-,Klima- und Wärmepumpensysteme*. PhD-Thesis, TU-Braunschweig, 1999.