Damper Windings Performance Evaluation in Large Hydro Electrical Generators

A. Merkhouf, A. Aguiar, M. Chaaban, C.Hudon
Research Institute of Hydro Quebec (IREQ)
1800 Lionel-Boulet, Varennes (Québec) J3X 1S1, Canada
merkhouf.arezki@ireq.ca

***Abstract*— the predictions of the induced current in the damper windings with acceptable accuracy are the key parameters for temperature-rise calculations damper windings for any considered up-rate of existing large hydro electrical machines. The measurement of the damper bar current is in most of case impossible because of the inaccessibility of these windings; where all the bars are imbedded in the pole face. In this paper, the induced currents in the damper windings of large hydro electrical generator are computed based on the finite element method at different conditions. The computed damper currents and corresponding Joule losses were used as input to the developed thermal model to evaluate the damper bar windings thermal capability at higher load. The obtained result such as flux density in the air gap, induced damper bar current and corresponding temperature will be discussed and compared with the available test data.**

***Index Terms*— damper bar windings, hydro-generator, slot ripple frequencies and eddy currents.**

I. Introduction

The computation of the induced currents in various damper bar winding is a fairly complex problem in electrical machine in operation, especially with fractional slot machines which is almost always the case with large hydro electrical machines. The frequencies, magnitude of these currents and their distribution, are significantly affected by the following parameters:

- The number of bars per pole; the distribution of these bars across the pole face; the bar permeances, determined primarily by the dimension of the slots above the bars. And the connection of the amortisseur winding between poles, or the lack of such connection
- The shape of the air gap (ratio of maximum to minimum air gap, pole face geometry, second pole face radius, etc..); number of slots, slot pitch and slot dimensions in the stator core; the amplitude and frequencies of the armature reaction mmf waves.

A number of other designs variables are not listed above, which my have a second order effect but their interactions are not necessarily negligible. The temperature computation of the damper winding during rated operation or during any asymmetrical fault requires an accurate prediction of the induced current distribution in the damper circuits. The damper current distribution for steady-state operation has been traditionally calculated with d- and q-axis synchronous machine equivalent circuits [1]. The accuracy of the solution for the bar currents is, however, limited by the accuracy with which the d- and q-axis circuit parameters can be determined. Due to the advent of powerful computing workstations, the analysis of synchronous machines has now become feasible for performing simulations studies using electromagnetic transient finite element analysis (FEA) including actual stator and rotor winding topology. The finite element analysis was already used to compute the eddy current in the damper winding during starting [2]. The simulation of unbalanced operation condition of an electrical machine but specifically for the design of the damper bars of single-phase synchronous generators was also reported in [3], this work was extended in [4] to evaluate damper bar performance during starting large salient pole synchronous machines; however the damper bar temperature in this last case [4] were computed only based on adiabatic heating without considering any heat transfer in air gap and in the pole face area. Recently additional losses in the damper bars were also computed analytically and numerically [5] but without any test validation or any consideration for the thermal capability of the damper bars.

In this present paper, electromagnetic finite element analyses were carried out in order to compute the induced currents in the damper windings at different operating conditions and higher ratings (0 %, 71 %, 100 % and at 120 %). The obtained currents were then used to evaluate the damper bar thermal capability. More details about the thermal model and associated assumptions will be given in the final paper. The computed damper bar temperature were compared to the measured test data at different operating conditions.

II. Mathematical modeling and basic assumptions

The mathematical formulation of electromagnetic transient finite-element model of synchronous machines including the external circuits and rotor motion has been previously described in many references since recent years such as in [4] and [5]. The present work is an application of these many developed FEA methods over the years for the evaluation of the damper bar winding performance of existing large hydroelectric generator at different operating conditions. The different carried analyses were performed based on two-dimensional finite element code, where the generator load is represented by external impedance. The studied generator has the following rating: 122.6 MVA, 13.8 kV, 504 slots, 60 poles and 6 damper bars per pole, and has a fractional slots windings. Since the number slots per pole per phase is 2+4/5 slots per pole per phase. Therefore, a fifth pole model is required for modeling the winding pattern. In order to compute the eddy current distribution in the damper accurately, very fine mesh in the damper bars is required where more than 500,000 elements were used in total in this considered study. The mesh density distribution for studied generator is shown in

Fig. 1. A very small time step of few microseconds was chosen during this simulation. The use of very fine time steps gives the possibility to capture practically all the existing harmonics involved in this study.

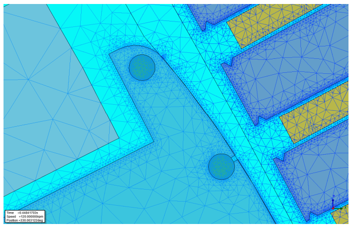

Figure 1. Mesh density distribution in the generator

The heat conduction in the stator and in the rotor is analyzed by solving numerically the Fourier partial differential equation:

$$\left(K_x\frac{\partial^2 T}{\partial X^2}+K_y\frac{\partial^2 T}{\partial Y^2}+K_z\frac{\partial^2 T}{\partial Z^2}\right)+Q=\rho C\frac{\partial T}{\partial \tau} \qquad (1)$$

Where $\boldsymbol{K_x}$, K_y, $\boldsymbol{K_z}$,are the thermal conductivity coefficients in x, y and z directions, $\boldsymbol{T}$ is the temperature, $\boldsymbol{X}$, $\boldsymbol{Y}$, $\boldsymbol{Z}$ are the spatial coordinates, $\boldsymbol{Q}$ is the heat source, $\boldsymbol{\rho}$ is the density, $\boldsymbol{C}$ the thermal capacity and $\boldsymbol{\tau}$ is the time.The heat losses in the damper bars are introduced as volumetric heat source (W/m^3). They are evaluated by integrating the RI^2 loss resulting from the induced current harmonics in these bars and their AC resistance at the prevailing frequencies

III. SITE TEMPERATURE MEASUREMENT

Special site tests were performed to determine the pole face and the damper bars temperature during different operating condition (0%, 71 %, 100 % and 120 %). Even if in some cases temperature could vary from on pole to the next, on the generator tested here only one pole was instrumented with several thermistors, there were connected to a data logger to store data during various operating conditions. The data were stored in data logger for more than 10 Hours.

IV. RESULTS AND DISCUSSION

During this carried study, electromagnetic simulations were carried out at rated conditions (123.1 MVA, 0.9 p.f., and an excitation current of 739 A), at 146 MVA and no-load rated voltage. Fig. 2 shows the corresponding induced damper current waveform at 100 % load, where the presence of higher harmonics can be easily observed, such as the slot ripple frequencies of 1008 Hz. The presence of higher harmonics in the damper current windings will certainly leads to the increase of the there corresponding temperature. The temperature distribution in the damper bars are function of load but also function of the fluid dynamics phenomena and corresponding heat transfer coefficient in the air gap and the pole face area. Figure 3 shows the measured temperature on different damper bars at different load (rated voltage no-load, 71 %, 100 % and at 120 %). It can be observed that from this figure 4 that the damper temperature are load dependent and also not uniformly distributed across the pole face area. In this particular case it was not possible to measure the damper bar current because of the inaccessibility of the damper windings (all damper windings are embedded in the pole face). The comparison between measured and computed temperature at different rated condition are summarized in table 1 where it can be observed that the model predictions are in general in a good agreement with the test data. More details will be given in the extend paper.

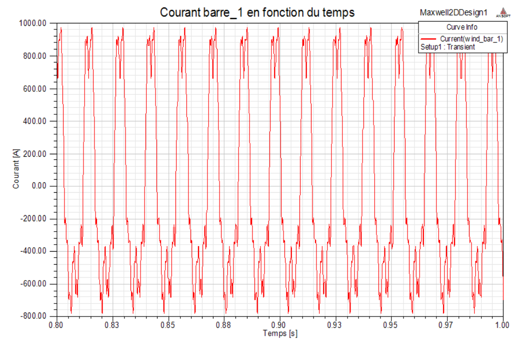

Figure 2. Damper bar current spectrum at 100 % load

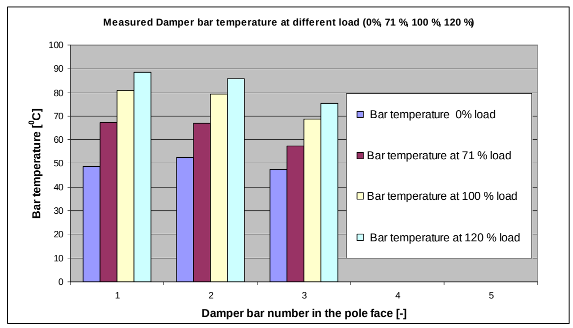

Figure 3. Measured damper bar temperature at different operating conditions

Table 1: Comparison between measured and computed damper bar temperature

Power level	**146.55 MVA**		**123.08 MVA**		*0 MVA*	
	Calc.	Meas.	Calc.	Meas.	Calc.	*Meas.*
T-damper #1	80.0	--	68.9	--	39.0	--
T-damper #2	83.6	88.6	74.8	80.8	43.9	*48.8*
T-damper #3	87.4	85.9	78.6	79.3	48.6	*52.5*
T-damper #4	80.0	80.0	71.1	73.8	48.4	*51.4*
T-damper #5	71.8	75.3	63.5	68.8	43.7	*47.5*
T-damper #6	*69.9*	--	*61.2*	--	*38.9*	--

REFERENCES

[1] H. Vögele, M. Xuan, J. Simond, “Modelling of a Single-Phase Generator Equipped With a Damper Winding Having Solid Lateral Bars”, Vol. 3, pp. 266-271, Proceedings ICEM 1998.

[2] A. Kladas and A. Razek, “Eddy current currents modeling in synchronous machines during starting accounting for the nature of damper en connections”, IEEE Trans. Magn., Vol. 24, pp. 186-186, 1988

[3] K. Weeber, Design of Amortisseur Windings of Single-Phase Synchronous Generators Using Time-Stepping Finite Element Simulations, Proceedings ICEM, 1998.

[4] H. Karmaker and C. Mi, “Improving the starting performance of large salient- pole synchronous machines”, IEEE Trans. Magn., Vol.40, N°4, 2004.

[5] G. Samek, Tlugand and A. Schwervy “Additional Losses in the Damper Winding of Large Hydro-generators at Open-Circuit and Load Conditions”, IEEE Trans. Magn. Vol. 40 N°4, 2010