European Association for the
Development of Renewable Energies,
Environment and Power Quality

International Conference on Renewable Energies and Power Quality (ICREPQ'09)

Valencia (Spain), 15th to 17th April, 2009

Finite Element Analysis of Electrical Machines Used in Two-Frequency Indirect Temperature Rise Tests

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Abstract. Heat runs of large asynchronous machines (AM) are hardly ever conducted under load but with synthetic approaches, such as the two-frequency method. In its classical variant, the AM's stator is fed by two series-connected synchronous machines (SM) with different frequencies, for instance 50 and 40 Hz. While the 50 Hz voltage determines the AM's flux, the 40 Hz source causes an AM stator current close to its rated value. Together, voltage and current yield approximately full load losses in the AM without mechanical loading. For designing the amortisseurs of the synchronous generators, damper losses were calculated using the Finite Element method. Additionally, calculated full load AM losses were compared against their respective values for the two-frequency method.

Key words

Two-frequency method, temperature rise tests, asynchronous machine, synchronous machine, Finite Element method.

1. Introduction

Direct evaluation of induction motor efficiency using dynamometer tests or torque measurement, cf. [1], is hardly ever performed for machines of more than several 100 kW. The reasons for that are well known: (i) absence of a suitable load, (ii) impossibility of coupling vertical machines to a mechanical load in the test field, (iii) large efforts in terms of energy and time. Therefore, several methods for generating rated load losses without access to a mechanically coupled load have been devised. Besides the two-frequency method, described 1921 by Ytterberg (according to [2]), several other approaches are known from literature, for instance [3]. For the fact that each of these methods runs the machine under very special conditions, an analytical treatment is usually rather cumbersome.

The rationale behind the investigations described in this paper is the design of a test field capable of testing asynchronous machines in excess of 10 MW. This test field will be located in a factory for electrical machines presently being built near Weiz, Austria (Fig. 1). The dampers of two synchronous generators destined to act as sources in future two-frequency test runs were analysed with regard to the expected amortisseur currents.

Fig. 1. View of the new manufacturing plant for electrical machines, September 2008.

2. Two-Frequency Method

The principle of the two-frequency method is depicted in Fig. 2. Two voltage supplies of different frequency are connected in series to drive an induction motor. The main source U_1 exhibits rated frequency f_1, the auxiliary source has a lower frequency f_2, about 60 to 95 % of f_1 and its magnitude ranges from 5 to 25 % of U_1. In practice, U_2 and f_2 are adjusted such that the induction motor is driven with rated rms values of both voltage and current. With no mechanical load coupled, the induction machine oscillates between speeds determined by f_1 and f_2 thus acting alternately as motor and as generator. In order to reduce negative effects on the mains, two motor-generator sets are employed for the independent sources SM_1 and SM_2.

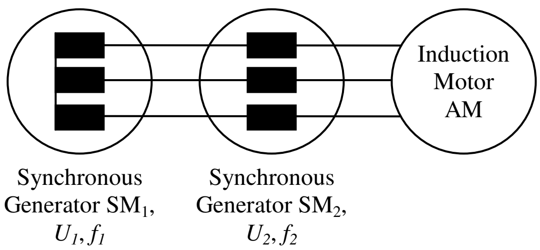
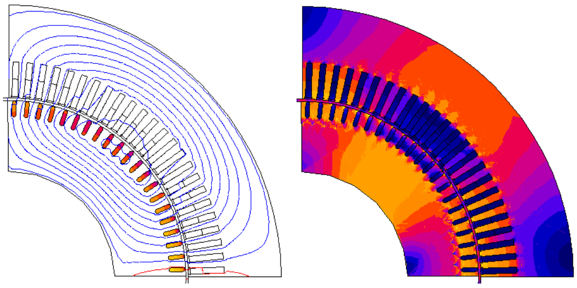


Fig. 2. Schematics of the two-frequency method comprising two synchronous generators.

3. Finite Element Simulations

A. Asynchronous Machine

In the case of the asynchronous machine (AM), the main emphasis lay on torque pulsations, the comparison of iron losses and the estimation of currents in the rotor cage. The cross section of the model under consideration can be seen in Fig. 3.



a) b)

Fig. 3. Induction motor, current density in the cage (a) and magnetic flux density (b).

The stator currents of AM are shown in Fig. 4 where the frequency sweep is easily discerned. Because of the two frequencies in the stator winding, the rotor cage carries substantial currents.

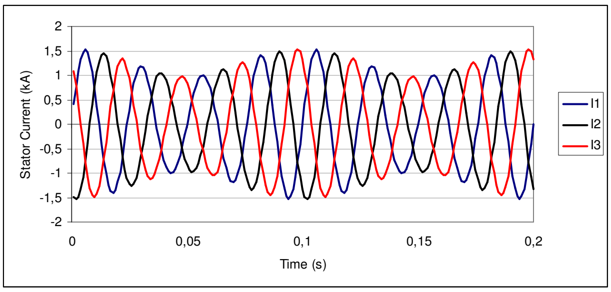


Fig. 4. Stator currents of AM and both SMs.

It can be inferred from the torque oscillations in Fig. 5 that AM alternately works in motoring and in generating mode. The FE-computed iron losses of the two-frequency method compared well against calculated iron losses of the load case.

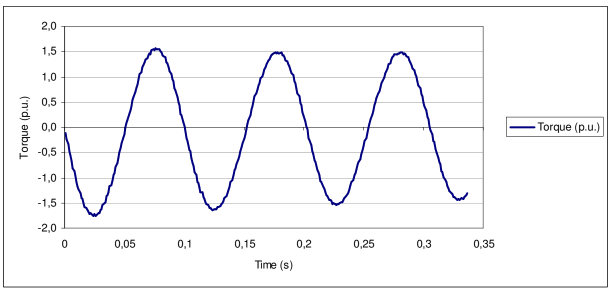
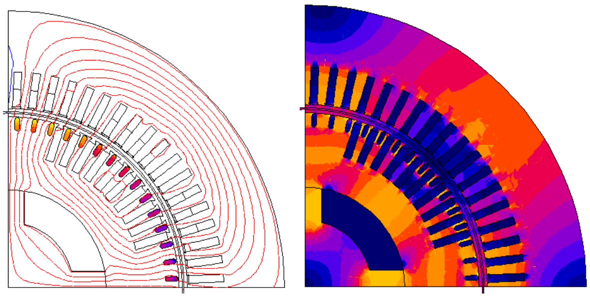


Fig. 5. Torque oscillations of the asynchronous machine.

B. Synchronous Machines

SM_1 with rated frequency f_1 and voltage U_1 supplies the magnetisation current for AM. Additionally, it carries the much bigger load current of AM with frequency f_2 provided by SM_2. Consequently, due to the difference in rotation speed, SM_1 has to compensate the armature reaction of AM's load current in its damper winding. Fig. 6 illustrates the FE-model of SM_1 supplying f_1 carrying massive damper currents due to the load current with f_2.



a) b)

Fig. 6. Synchronous machine SM_1, current density in the damper (a) and magnetic flux density (b).

Fig. 7 delineates torque and speed oscillations of SM_1 during the two-frequency test. Damper losses were calculated to about 0.5 % of rated power, which required an enhanced damper concept.

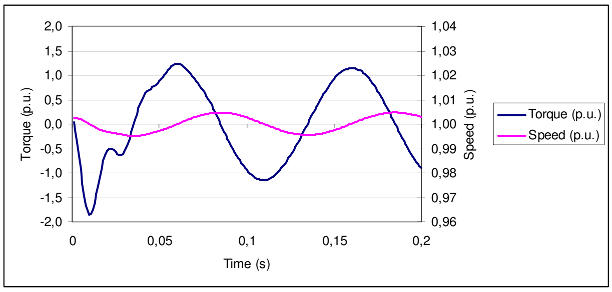


Fig. 7. 'Torque and speed oscillations of the synchronous machine SM_1.

4. Conclusion

The two-frequency method is an indirect temperature rise test. It allows a thermal loading of asynchronous machines similar to the conventional load test, albeit without mechanically coupled load. Besides questions concerning comparability of direct and indirect methods, design issues of the two synchronous machines serving as sources of different frequency had to be clarified. The Finite Element method (Flux2D) yielded answers in terms of losses, torque and speed oscillations as well as support for design decisions.

References

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