TECHNICAL NOTES

Turning losses into gains

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Abstract: WEG explains how reducing efficiency losses is key to achieving IE4 class efficiency with induction motors

Introduction

Standard induction motors use about 30 per cent of all the electricity generated in the world. Armed with that statistic, it is not hard to realise why increasing efficiency is a crucial R&D strategy among manufacturers. Regulations continue to drive the search for efficiency. In the EU, the Ecodesign directive has been in force since 2011. The 640/2009 regulations mandated that from June 2011 motors within its scope had to meet at least the efficiency level IE2, soon to be strengthened (January 2015 / 2017) to IE3 unless controlled by a variable speed drive. And with further studies presently being conducted as part of the revision of the Ecodesign Regulations, the requirement for currently legislated motors to meet the IE4 efficiency level is also set to come into force in the foreseeable future.

Even without those regulations, the demand from users is a constant search for efficiency, driven by the twin challenges of the climate change debate and volatile and escalating energy prices. So what are the motor manufacturers doing to reduce losses in induction electric motors in order to meet the level of efficiency required by IE4?

The key to designing a more efficient motor is to understand where the losses occur. When compared to IE3 motors, those that reach IE4 will need to reduce their losses by between 10 to 24 per cent. Which raises the question of how to achieve this?

Looking for losses

Knowledge is king and knowing exactly where the losses are located is the key to any plan to reduce them. For example the losses for a WEG, IE4, W22, 30kW, 4-pole induction motor are 43.7 per cent for Joule losses in the stator windings, 26.7 per cent for iron losses, 20.4 per cent for Joule losses in the rotor, 3.53 per cent for mechanical losses 0.67 per cent for harmonics and a further 4.91 per cent for additional losses. This makes it apparent that particularly for this type of motor, reducing the Joule and iron losses is of prime importance. However, the work to reduce each particular loss will increase the cost of the motor.

In other situations, starting current, starting torque or power factor can be affected. So, the challenge is to reduce losses with a minimum cost increase and general motor performance improvement, not only in terms of efficiency, but also noise, vibration, temperature rise, starting current and torque, and power factor.

Joule losses in the stator winding

Top of the list when it comes to losses is usually the Joule losses in the stator winding. To reduce these it is essential to reduce the resistance of the winding. There are two main ways that this can be achieved – either enlarging the wire diameter or increasing the stator length, with several alternatives.

When it comes to enlarging the wire diameters this can be done at the same time as maintaining or decreasing the number of turns. The disadvantage with maintaining the number of turns is that it would require improvements in the winding manufacturing process because with the fill factor higher it is difficult to insert the windings into the stator slots.

If a complete new stator lamination design is necessary, stator slots can be enlarged. The price to be paid is a narrower stator tooth or stator core that will increase magnetic flux density in these regions, increasing magnetic losses. If the number of turns is decreased it does away with manufacturing concerns but the magnetic flux will increase and, therefore, the iron losses. If the stator length and the wire diameter are both increased, reducing the number of turns and keeping the original stator slot size it would reduce losses, but increase the cost with conductors and steel lamination.

By simply enlarging the stator length, the cost of conductors and steel lamination is increased. The stator resistance becomes higher, increasing Joule losses, but it is compensated by the reduction of iron losses due to the magnetic flux density reduction. The performance characteristics of the motor remain the same because the magnetic flux was not modified.

Enlarging the stator length has another positive consequence. The area for heat transfer from stator surface to the frame becomes larger and hence the temperature rise decreases, which means less energy is required for ventilation.

Joule losses in the rotor

Joule losses in the rotor are not only a matter of rotor bars conductivity. Shape of rotor bars and short-circuit rings is also relevant, although several shapes are already well established among manufacturers and in the related technical literature. The question is not how to design properly the rotor cage but how to fabricate it free from many interferences of the manufacturing process. In order to reduce Joule losses of cast aluminum rotor cage, simulation software should be used to analyze the quality of rotor slots and short-circuit rings filling and its correlation to the cast aluminum process parameters.

Another important aspect to be considered to reduce Joule losses in the rotor is related to the conductivity of the rotor bars and short-circuit rings, specifically the advantages and disadvantages of using cast copper or aluminum. In 2011, WEG conducted a study [3] to ascertain the feasibility of manufacturing squirrel cage low voltage induction motors using cast copper as a substitute for the traditional aluminum, as an alternative to increase efficiency and reduce costs. A case study accomplished with a 15 kW 4-pole IE3 motor showed that, in order for the use of a die cast copper cage, rather than the traditional die cast aluminum cage, to become economically advantageous in industrial three phase induction motors, the quotation (price/kg) of the copper must be no greater than 1.1 times the quotation of the aluminum.

Mechanical Losses

Good ventilation is key to reducing the mechanical losses, particularly for two pole motors. Because of its high efficiency an IE4 motor has inherently less demand for heating removal, so the ventilating system can be optimised in order to reduce mechanical losses and consequently acoustic noise. The geometry of the fins is also important. There is a good relationship between the height of fins and width between two adjacent fins. They have to be designed in order to provide the best thermal dissipation.

Consideration should also be given to positioning the terminal box so as not to interfere with the air flow and the design of the end shields, which should have fins to remove the heating generated by the bearing's friction. When designing the fan and end cover consideration must not only be given to efficiency, but also noise.

Iron losses

A major cause of inefficiency comes from iron losses. On the face of it using higher quality, silicon steel lamination (usually thinner lamination) than those currently used would appear to be the answer. However as with most improvements it is a question of costs against efficiency gained.

Reducing magnetic flux density is another possible solution but again, lamination costs increase by increasing the amount of magnetic material. However, some initiatives can be taken without adding cost.

The problems, however, come when software is used to calculate the iron losses. These usually consider the magnetic saturation (BH) curve of the steel lamination material obtained from the Epstein Frame Test. The difficulty is that this procedure is not accurate because the magnetic flux behaviour in an Epstein Frame Test sample is different from what really happens when a motor is run.

To evaluate the steel lamination properties properly, a three-phase electromagnetic device was developed at WEG that generates a magnetic flux that really represents the magnetic flux of an electric motor. It can evaluate the magnetic losses generated in the stator, taking into account the lamination's geometry and the magnetic field rotating component. Unlike the traditional Coil Ring test, this allows evaluation of the total magnetic losses taking place in the stator, which comprises those generated in the yoke and in the teeth.

Future path

To reach IE4 efficiency, motor designers and manufacturers have an abundance of choice. Each step down the path to improve efficiency has an effect on the motor's performance, cost and ease of manipulation, so care must be taken to understand the required parameters before embarking on any change.

Induction motors, when properly designed and manufactured, can reach IE4 efficiency levels.