INCREASING INDUCTION MOTORS EFFICIENCY BY REDUCING ELECTROMAGNETIC LOADS

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Abstract*: The efficiency of any device is a major problem today. The design and construction of high efficiency motors is strongly required from the viewpoint of reducing energy consumption and protecting the environment. This paper deal with the problem of improving efficiency by reducing electrical and magnetic loads of these motors. Using the finite elements method (FEM), the authors will study the influence of these changes on the parameters and characteristics of the initial motor.*

1. INTRODUCTION

Increasing the efficiency of the electrical motors is a continuing and topical problem which is a provocation for designers and manufacturers of electric machines.

But how can it be increased the efficiency of the electric motors? It is possible to improve efficiency by using new materials and technologies, proposing some new constructive solutions (even for conventional motors), or increasing the volume of used active materials. In case of the rotor cage induction motors, in the last twenty years, the active materials have suffered only minor improvements and new design solutions are almost inexistent.

According to [1] all low voltage (<1000 V) rotor cage induction motors, with 2- 6 poles and with rated power between 7.5 - 375 kW must fulfill the minimum conditions imposed by IE-3 standard since 2015, and from 2017, these minimum conditions must be fulfilled of all above electrical motors but with power ranging from 0.75 kW.

Electrical motors which fulfill only IE-2 standard efficiency will be allowed only if they are driven by frequency converters.

According to IE-2 and IE-3 standards, the minimum efficiency in terms of the rated power for rotor cage induction motors with 2-6 poles is shown in Fig. 1.

These measures have been taken because about 70% of electricity consumed in the industrial sector is the energy converted into mechanical energy by electric motors [1].

As an order of magnitude, in 2005, the electrical motors have had 1067 TWh consumption which corresponds to 427 Mt CO2 emissions.

It is estimated that in 2020, the energy consumption of electric motors to reach 1252 TWh, such as a small improvement in the efficiency can lead to very significant reductions in CO2 emissions, and also to the protection of the environment.

The efficiency of an electric motor depends on the quality of the used materials and technology. The problem that occurs is due to the fact that the materials used in the construction of a rotor cage induction motor (electrical circuits, magnetic and insulating materials) have not really been improved in the recent years.

For this reason, the problem of efficiency increasing must be solved not by using new materials, but possibly using new technologies or new constructive solutions, high efficiency motors (with permanent magnets) instead of conventional motors (as induction motor), but mainly by reducing the motor loads (electrical and magnetic), which involves increasing the size at the same rated power. Increasing the size of a motor involves also the increase of the price per power unit, but this is less important than the fact that losses are reduced and in consequence the efficiency is higher.

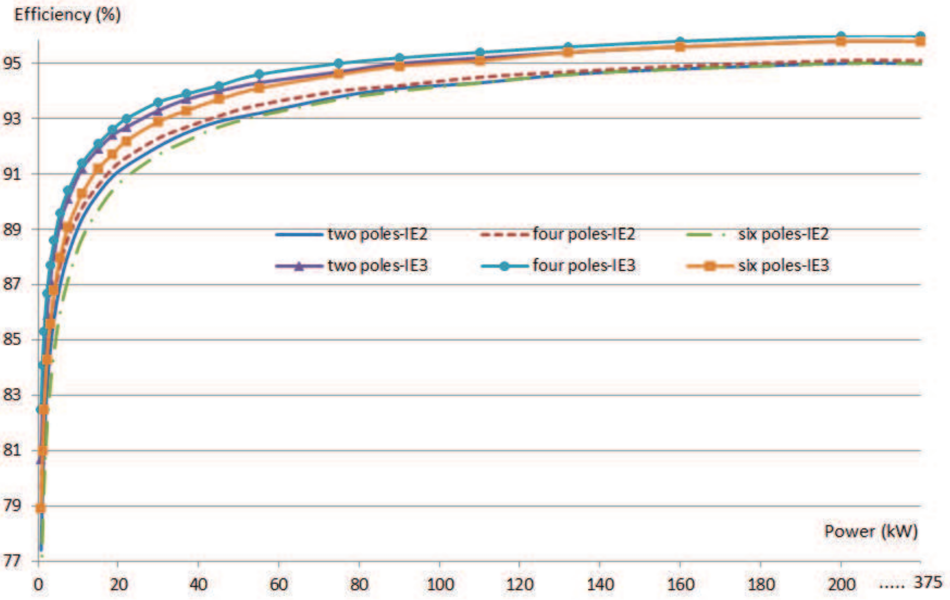

Fig. 1 - Minimum efficiency of rotor cage induction motors, according to IE-2 and IE-3

It is confirmed [2] that an electric motor consumes during its operating life, energy that is 100-200 times greater than its value, so it is more important that the motor be with higher efficiency than be cheaper. It is also important to mention that it is not enough to have a high efficiency motor; it is necessary that the electrical drive reach high efficiency, for this reason it is recommended to use controlled motors with frequency convertor that change proportionally the voltage as well.

Changing motor size on the same rated power implies the change of the motor parameters as inductances and windings resistance, and also the motor speed and torque. Some of these changes were analyzed in [3]. In addition, this paper calculates the resistive losses, considering the skin effect in the rotor.

The iron losses of the initial motor and of the motors with size increased will be analyzed comparatively.

The characteristics: torque-slip and current-slip will also be studied comparatively. Finite elements analysis will be used in order to determine these characteristics.

2. INDUCTION MOTOR EFFICIENCY

Like any other device, in case of squirrel cage induction motor, efficiency can be defined as the ratio of mechanical power output, P and electrical power input, P_1,

$$\eta = \frac{P}{P_1} \tag{1}$$

The difference between electrical power input and mechanical power output represents the total motor losses, P_t, and efficiency can be written as:

$$\eta = \frac{P}{P+P_t} \tag{2}$$

The total motor losses include: resistive losses in the motor windings, P_{Cu}, iron losses in the magnetic circuit, P_{Fe}, additional losses, P_{add} and friction and ventilation losses, P_{fv},

$$P_t = P_{Cu} + P_{Fe} + P_{add} + P_{fv} \tag{3}$$

Resistive losses are due to the current flowing in the motor windings; they are proportional to the square of the rms stator phase current, I_1, and to the windings resistance R_1 and $R_2^{'}$.

$$P_{Cu} \sim (R_1 + R_2^{'}) I_1^2 \tag{4}$$

R_1 is the stator phase resistance and $\mathrm{R}_2^{'}$ is the rotor phase resistance referred to the stator.

Iron losses include hysteresis and eddy current losses.

Hysteresis losses depend on frequency, f, the peak magnetic flux density, B, mass of the magnetic circuit, m_{fe}, and a constant material, $1 \leq \alpha \leq 2$,

$$P_h \sim m_{fe} f B^{\alpha} \tag{5}$$

Eddy current losses are proportional to the same quantities but the exponents differ,

$$P_{ec} \sim m_{fe} f^2 B^2 \tag{6}$$

Experimental determination of additional or stray load losses is described in [4], and they depend on the rotor current, I_2, which at his turn is determined in terms of the stator current, I_1 (for which additional losses are computed) and no load current, I_0,

$$P_{add} \sim I_2^2, I_2 = \sqrt{I_1^2 - I_0^2} \tag{7}$$

If additional losses are not determined experimentally, they can be obtained in terms of the input power.

Friction losses depend on the rotor diameter, rotor mass, inner diameter of the bearing and of course depend on the speed and the type of bearing. Ventilation losses depend on the ventilator efficiency for a given power.

In order to improve motor efficiency, losses must be reduced.

Resistive losses can be reduced because the current remains the same (power remains the same) only by reducing the windings resistance.

If all the initial motor dimensions are multiplied by a factor k, it can be demonstrated that the cross section of the new motor will be k^2 times higher and the length will be k times higher. The conductors will also have cross section k^2 times higher and the length will be approximatively k times higher. In conclusion, the new motor will have windings resistance k times lower and resistive losses will be k times lower as well.

Because the surface through which the magnetic flux closes increases k^2 times, and the polar flux remains unchanged (as the supply voltage remains unchanged), the magnetic flux density will be reduced k^2 times.

Mass of the magnetic circuit will be increased k^3 times. Hysteresis losses of the new motor, P_{hn}, will be, in terms of the hysteresis losses of the initial motor, P_h,

$$P_{hn} \sim m_{fen} f B_n^\alpha = k^3 m_{fe} f \left(\frac{B}{k^2}\right)^\alpha = k^{3-2\alpha} P_h \tag{8}$$

The above relation shows that for $\alpha > 1.5$, hysteresis losses of the new motor are reduced.

Eddy current losses of the new motor are:

$$P_{ecn} \sim m_{fen} f^2 B_n^2 = k^3 m_{fe} f^2 \left(\frac{B}{k^2}\right)^2 = \frac{P_{ec}}{k} \tag{9}$$

Friction and ventilation losses of the new motor will increase slightly because the rotor mass and diameter will be larger. But because these losses are much lower than the iron and resistive losses, the total motor losses will be lower.

If only the motor diameters are multiplied with k, and the initial length is kept, windings resistance will decrease approximately k^2 times (because the length of the end windings will increase) and also the resistive losses. In this case, the new hysteresis losses are:

$$P_{hn} \sim m_{fen} f B_n^\alpha = k^2 m_{fe} f \left(\frac{B}{k}\right)^\alpha = k^{2-\alpha} P_h \tag{10}$$

Eddy current losses will be:

$$P_{ecn} \sim m_{fen} f^2 B_n^2 = k^2 m_{fe} f^2 \left(\frac{B}{k}\right)^2 = P_{ec} \tag{11}$$

If resistive losses are higher than iron losses, this solution needs to be analyzed.

As conclusion, increasing the size of a motor (at the same rated power), its efficiency increases as well.

The drawback is that the motor characteristics will also be changed.

In the following, the characteristics of the initial motor will be showed comparatively with the characteristics of the increased motors.

It is important to mention that in the design phase the losses require to be determined with high accuracy, this involving a high accuracy for the efficiency determination. Many papers deal with this topic, this paper refer to some of them [5]-[10].

3. CASE STUDY

This study was carried out using an electromagnetic field computation program based on the finite elements method (FEM).

Resistive losses in stator can be calculated analytically with high accuracy (for any current).

Rotor resistive losses can be calculated analytically also with high accuracy, but ignoring skin effect. If skin effect is to be taken in consideration, the analytically calculation of the resistive losses in rotor has a fairly low accuracy. In this case it is preferable that the rotor resistive losses to be calculated by FEM simulations.

Iron losses are calculated by the used program based on the field values, the magnetic material having the losses curve, at 60 Hz, showed in Fig. 2. Iron losses will be recalculated at 50 Hz.

The studied three-phase rotor cage induction motor has the following main data: rated power 0.37 kW, nominal phase voltage 230 V, stator core length 75 mm, inner and outer diameter of the stator 70 mm and 106.5 mm respectively, two pole-pairs, stator slots number 36 and number of turns in a coil 133, the numerical model being shown in Fig. 3.

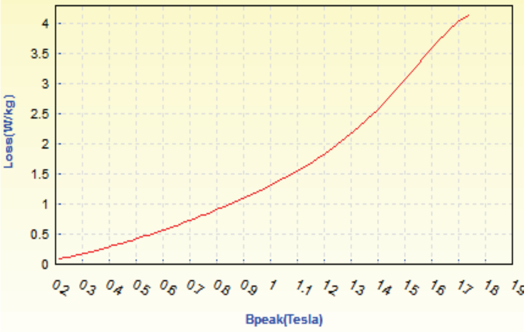

Fig. 2 - Losses curve at 60 Hz, for the magnetic material

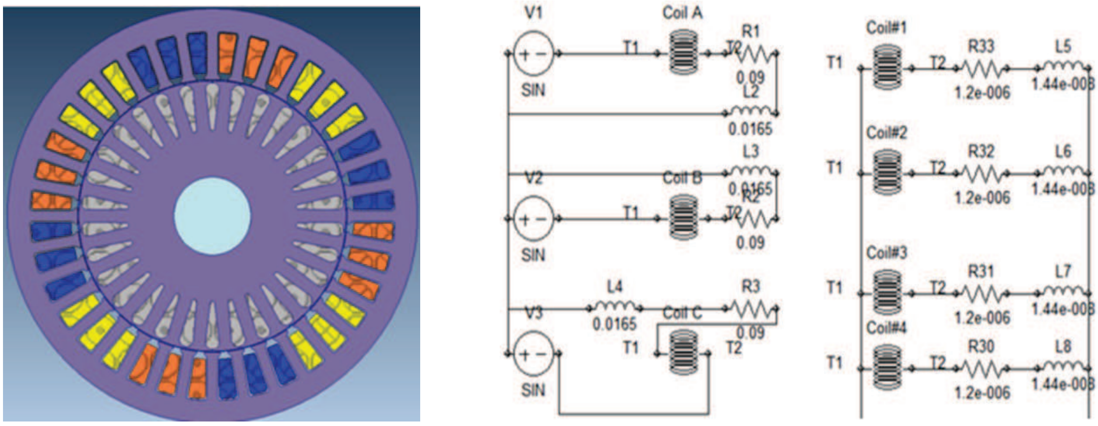

Fig. 3 - Studied motor: a) Numerical model; b) Motor windings

Based on the presented model (denoted initial), other two models were performed: one with size increased by $k = 1.5$ times (denoted with M1); the other where only the diameters were increased by $k = 1.5$ times, but the length being kept (denoted with M2).

Time-harmonic analysis was used, the frequency being in terms of the slip, $f=sf_n$. The procedure is described in [11].

Next, it will be presented comparatively (Fig. 3 - 10) the obtained results for the three models of rotor cage induction motors.

4. CONCLUSION

Noticing the manner of iron losses variation for the three motors, it can be concluded that, for slip values corresponding to the normal operation regime, the total iron losses are the lowest for motor M1 and the highest for motor M2. This is understandable because the hysteresis losses are much higher than the eddy current losses.

Regarding resistive losses must specify that they are determined according to the slip (load). But the motors do not have the same slip for the same load. For a fair comparison between resistive losses, the slip corresponding to the same nominal power must be determined for each motor. This will be done in a future work.

It can be also noticed that the size increasing involves the decrease of the starting torque. This is explained by the fact that the rotor resistance is reduced. The motor M2 has the highest maximum torque, followed by the initial motor and then by motor M1.

Motor M1 has the most convenient current-slip characteristic and then the initial and M2 motor.

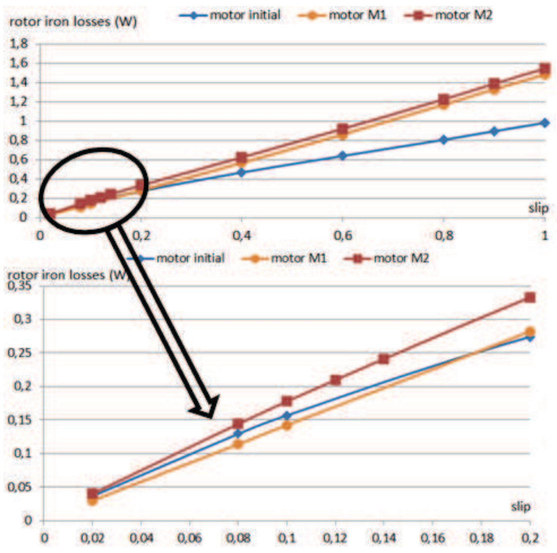

Fig. 3 - Rotor iron losses in terms of slip

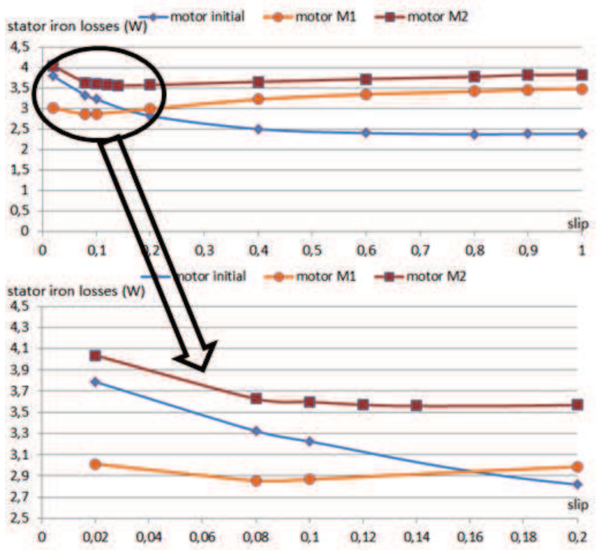

Fig. 4 - Stator iron losses in terms of slip

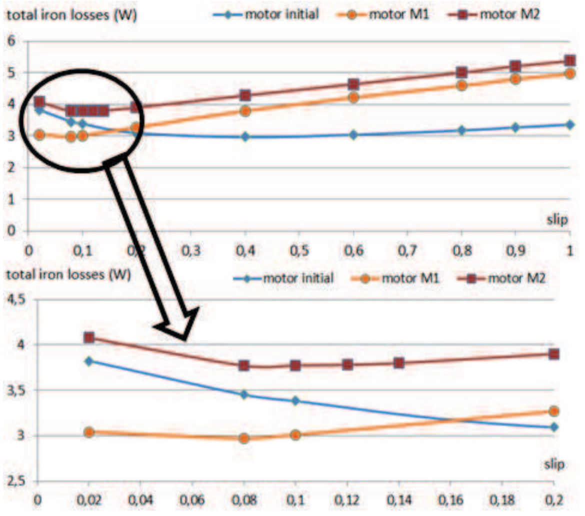

Fig. 5 - Total iron losses in terms of slip

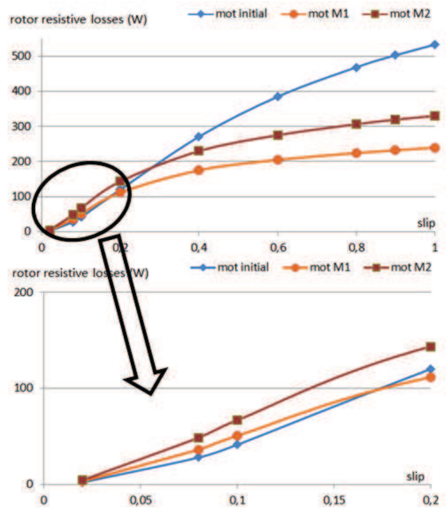

Fig.6 - Rotor resistive losses

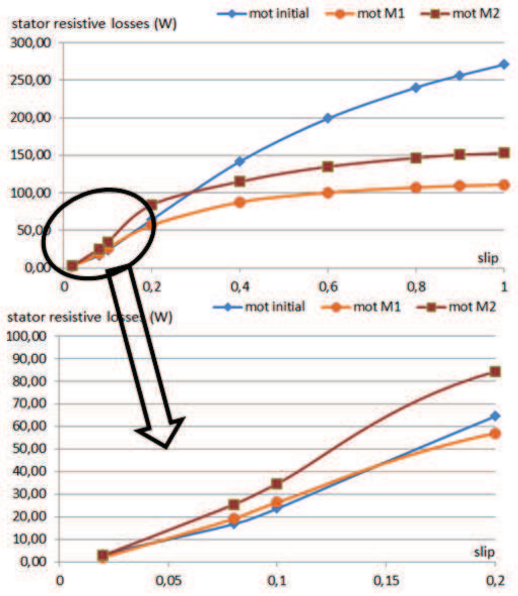

Fig. 7 - Stator resistive losses

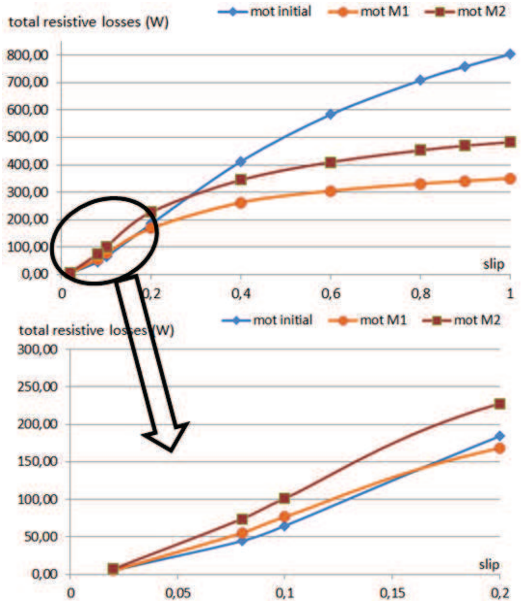

Fig. 8 - Total resistive losses

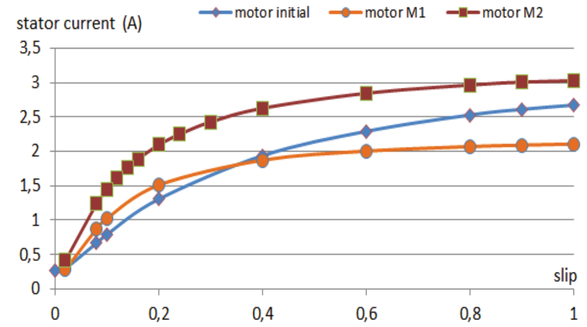

Fig. 9 - Current-slip curve (at rated voltage)

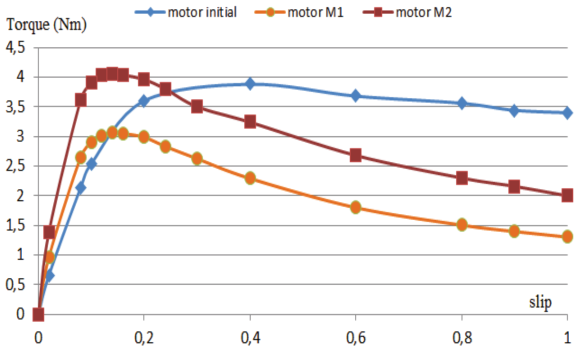

Fig. 10 - Torque-slip curve (at rated voltage)

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