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Dynamic Improving Energy Efficiency in Automotive Electrical Equipment

Sadeq Mohammed Ameen Saeed

Electrical and Electronics Engineering, University of Garmian Faculty of Seince

sadeq.amen@garmian.edu.krd , **https://orcid.org/0009-0000-7605-9947**

Smko Hussein M.Murad

Electrical and Electronics Engineering, Garmian polytechnic University

smko.hussein@gpu.edu.iq, **https://orcid.org/0009-0003-5724-4196**

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Abstract

This paper examines the advancements in energy efficiency for three-phase squirrel cage induction motors (SCIM), the leading segment in the electric motor market. It highlights the development of SCIMs that meet IE4efficiency standards using standard frame sizes and aluminum rotor cages, emphasizing the historical use of copper for achieving IE3 standards and reducing rotor inertia. Additionally, the paper discusses other IE4 class motors such as Line Start Permanent Magnet (LSPM) motors with interior rare-earth permanent magnets and auxiliary cages for starting, as well as Variable Reluctance Synchronous Motors (VRSM) and Switched Reluctance Motors (SRM). The SCIM IE4 motor, with its cost-effective aluminum cage, is particularly suitable for large-scale industrial use due to its production costs, starting torque, and synchronization capabilities. The article also explores the potential market growth for LSPMs if their capabilities are enhanced to meet IE5 standards. Furthermore, it discusses the impact of national and regional standards on motor frame sizes and the challenges faced by manufacturers in reducing losses to improve efficiency. Through a comprehensive analysis of materials, design optimizations, and cutting-edge manufacturing techniques, the article provides insights into achieving higher efficiency in electric motors.

Keywords: Reluctance motors, Squirrel cage induction motors, Variable reluctance synchronous motors, Commutator switches.

1. Introduction

While a lot of work has been done to improve the efficiency of vehicle technology Enhancing the energy efficiency of automobile HVAC and cooling systems, which undergo manufacturing procedures and are put together in auto assembly plants, should also be a major priority. Because they satisfy a variety of consumer mobility needs, Automobiles play a vital role in our economy. Many efforts have been made to increase their efficiency and overall environmental performance since, despite their great value to their owners, they are also noticeable consumers of materials and energy.

Reducing the overall quantity of energy needed to produce products and services is the goal of energy efficiency, which is defined as the ratio of useful energy outputs to inputs. Glass making furnaces, Among the energy-intensive procedures utilized in The automotive industry includes hot water supplies, ventilation boilers, foundries, milling and cutting, degreasing, electroplating, drying, and polishing g.Heating to melt metal and plastic substrates is one of the operations that uses the most energy in the automotive industry [1]. Energy conservation can help businesses cut their energy costs by 30%, increase the lifespan of their machinery and equipment, and minimize maintenance downtime.

(high-intensity-discharge) lamps, help save energy by substituting inefficient conventional bulbs. In the end, efficient electric motors will take the place of combustion engines, as is already the case with hybrid and electric vehicles.

- **The Importance of Energy Efficiency in Electric automotive**

Because they transform fuel energy—such as electricity, gasoline, or diesel—into kinetic energy—the energy of motion—cars are able to move. Efficiency quantifies the amount of fuel energy that is transformed into kinetic energy to start the tires. Since some energy is always lost when producing heat, no machine can be 100% efficient. Cars' physical restrictions mean that energy will be lost to rolling resistance from tires and wind resistance. But in general, the higher the efficiency, the less energy we need to power our car. To put it another way, efficiency is the ability to complete the same task while using less energy. [2]

This has significant ramifications for the transition to a low-carbon future. By increasing efficiency, we are lowering our energy use and increasing the likelihood that renewable energy sources will take over our electrical system. It indicates that we're producing what environmentalist Amory Lovins would refer to as a "megawatt," or doing more with less.

- **Several areas of vehicle power management hold promise for important technical advancements: Battery Technology:**

As the foundation of electric and hybrid cars, developments in battery technology have the potential to completely transform the range, energy density, and charging times of these vehicles. Research suggests that there is promise for batteries in the future that are lighter, last longer, and charge faster, citing solid-state, lithium-sulfur, and other cutting-edge chemistries .

Power Conversion and delivery: Because vehicles incorporate a variety of different voltage domains, there is a significant emphasis on effective energy supply, voltage control, and DC/DC or AC/DC conversion. Innovations in this field can lead to reduced losses and improved power distribution plans. Harvesting Energy: Technologies that can capture and reuse energy to improve a vehicle's efficiency, such solar panels built into the body of the car and regenerative braking, are gaining popularity

Wireless Charging: As EV infrastructure grows, wireless charging technologies hold great promise for offering EV charging solutions that are convenient and flexible. Thermal Management: Effectively controlling heat is essential for improving system longevity and performance, especially in high-power uses, such as rapid charging. Active research is being conducted in fields including innovative materials and cooling techniques. Intelligent Power Management Systems: By combining artificial intelligence (AI) and machine learning, future cars may be able to make decisions about power distribution in real time depending on driving circumstances, passenger demands, and other dynamic considerations..[3].

European Eco Design regulation proposal for electric motors

The EU environmental policies facilitate the sustainable use of resources, by correlating it with the entire product life cycle. The EcoDesign directive has an integrated life cycle evolution, thus its first objective is energy efficiency of energy related products.

The most important EcoDesign PO in the EU are:

• POLA (1st January 2018) states that no single-phase motor should have a lower efficiency level than IE2, or MEPS of IE2, if its rated output is greater than or equivalent to 0.12 kW;;

• POlb, January 1, 2018 The IE2 efficiency level must be met by three-phase motors with rated outputs between 0.12 kW and 0.75 kW.;

POlc (1st January 2018) Three phase LV and MV motors with a rated output of (>375 kW to 1000 kW) shall not

be inefficient compared to the IE3 efficiency level; • PO2 (January 1, 2022) eliminates the IE2 + VSD substitute for the IE3 motor purchase requirement; all motors utilizing an output power of at least 0.75 kW must adhere to the IE3 standard; • PO3 (1st January 2018) Include explosion proof and brake motors;

• PO4 (1st January 2018) Mandatory information Requirements for motors and VSDs;

• PO5 (1st January 2018) VSDs to meet IE1 performance at MEPS;

PO6a (1st January 2022) increasing the MEPS for medium-sized induction motors (≥0.75 kW to 375 kW) from IE3 to IE4;

PO6b (1st January 2022) Raising of MEPS for large induction (>375 kW-1000 kW) motorsmotors from IE3 to IE4 [13, 14].

Regarding the PO1, because of the current global situation, in the case of medium and large sized electrical machines all the countries should introduce MEPS at IE2, and then the motors must comply with IE3 efficiency standard.

The MV large sized motors operate at a nominal voltage between 1 kV and 6.6 kV. They are produced for an individual site, with detailed features and efficiency, with direct consideration of the local power supply characteristics (impedance and short circuit properties). The LV large sized motors have higher efficiency than the

MV devices, because:

- They have a higher cross sectional area of the copper wires;
- Alow control of the partial discharges and a medium cost of the insulation system;
- Smaller winding overhangs are thermally and mechanically advantageous;
- Easier cooling of the device.
- In the case of small sized motors, the regulations refer only to the induction motors(three-phase and single-phase), includes motors with shaded poles. The limited operating hours of mechanically commutated machines serve as justification for their regulation.

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- In the case of PO2 the elimination of the IE2+VSD alternative leads to a single option of a general use of the IE3 motors. From the economical point of view, the IE3 machines have a much lower price than an IE2 motor with a VSD circuits. It was noticed that an IE3 electrical machine is more efficient than the IE2 motor, when connected directly to the power line and have additional reduced load losses, when is linked with a VSD control[4,5]

Because brake motors frequently start and stop, which increases starting losses, their inclusion in energy efficiency rules makes sense.

According to PO4, the current criteria for product information should be expanded to cover all motors with an enlarged power range of 0.12 kW. and 1 MW and have comprehensive and detailed technical information about the motor on the rating plate.

In order to avoid that the market segment of motors with VSD below IE1 standard to increase in Europe, the POS was introduced. Although this sector is small, it would be beneficial to remove the drives that work below IE1 from the market and to use VSD systems with improved losses.

The transition from IE3 to IE4 is in fact similar to that of the IE2 to IE3 and it gives a good meaning of the assumed price for the IE4 motors. IE4 induction motors are already available on the market with a wide power range, although very few producers sell it. Technical changes are also required, especially small sizes of the machines must be used and innovative materials with low power losses must be tested, in order to achieve the IE4 standards [6].

Currently, 68% of motors in use worldwide are large, Nearly 56% of them are older than their expected technological lifespan of 10–20 years, and their average annual load factor is less than 60%.and 80% are not using load control with VFD. The old electrical machines are inefficient (IEO/IE1, fans, pumps and compressors), less reliable and performant and need more maintenance and repair operations. An important problem is that today exist no culture of renewal of the electrical machines in the worldwide industry (Fig. 1) [7].

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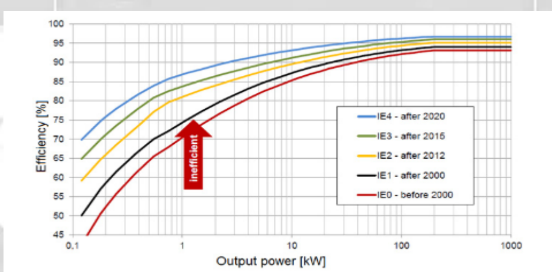


Fig. 1. Motor efficiency standards and the timeline to introduce them in the case of a SCIM with 4 poles

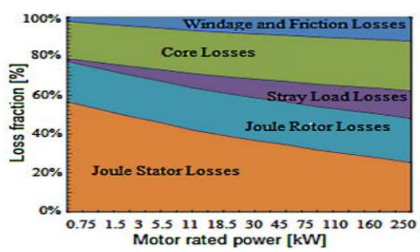
- **Electrical machines that meet the IE4 standard performance**

The three phase SCIM represent the biggest sector of the electrical motor market [2-4, 8]. Some producers succeed to introduce on the market SCIM, which meet the IE4 classification, with standard frame sizes and an aluminum rotor cage, though many manufacturers have previously used copper to meet the IE3 standard or lower the rotor's inertia.

Another type of IE4 class motor is the synchronous LSPM, They feature an extra cage for beginning and a rotor with an internal rare-earth permanent magnet (PM) (NdFeB). Switched Reluctance or Variable Reluctance Motors (VRSM) controlled by the VSD Motors (SRM) are also two types of electrical machines, which are made accordingly with the IE4 standard. The VRSMs have distributed stator winding and SRMs possess concentrated poles in the rotor construction and stator windings.. The SCIM IE4 motor, with aluminum cage and standard frame sizes, is more adequate for the large scale use in industry, especially regarding the production costs and the starting torque and synchronization. The LSPM will gain a place in the worldwide market, only if the producers increase its capabilities, in order to fit the IE5 conditions. The SCIMs and LSPMs are complementary, because IE4 SCIMs own a 5.5–355 kW output power, and LSMs span the power range between 0.55 kW to 7.5 kW. The increase of the active material in high efficiency class SCIMs leads to a higher power density [3, 4, 6].

To increase the market share of high efficiency motors, the manufacturers have to respect the national/regional standards, regarding the output power versus geometrical dimensions. There are an important number of national/regional standards that regulate the frame sizes of the motors: NBR17094, NEMA-MG13, SANS1804, JIS-C-4212, EN50347, etc. Comparatively speaking, the IEC60034-30 standard defines solely the efficiency classes, regardless of dimensional limits. the electrical machine designers have a difficult task in the manufacture of the IE4 devices.

Usually the electrical machine producers tend to reduce all loss components in a motor (Fig. 2).



...(1)

Fig. 2. Loss components in a squirrel cage induction motor versus rated active power.

The rotor cage of SCIMs could be made of copper, instead of aluminum, because the material permits a higher power density to get the same machine efficiency and greater efficiency for the same power density. The copper cage rotor is utilized to reduce the rotor's moment of inertia since, when a higher efficiency class is desired, the aluminum cage's moment of inertia increases. Comparing aluminum and copper cages reveals that the former reduces motor losses by 15–18%, which can be translated into a 2-4% boost in overall efficiency. [6, 7].

The shaft height and the distance between the center lines of the fixing holes are represented by the letter and number that indicate the frame sizes. A larger frame size is more suitable than a greater shaft-height design and lowers total losses for a given rated power..

The iron losses in SCIMs are important and represent almost 20% of the total losses. Although there are made considerable improvements to produce electrical steels with lower thickness, better interlaminar insulation and first magnetization curves and higher electrical resistivity, the amorphous materials became a better choice, to made the magnetic core of the motors, because they have bigger magnetic permeability, lower energy losses and thickness. Unfortunately, there are met also some difficulties: amorphous material is only produced in thin strip ribbons, it has a high hardness, it is difficult to stamp and assemble stacks, the insulation layer is very thin, less than 1 µm, the maximum flux density is 1.6 T, the cut edges are not insulated and it is very difficult to obtain a superior packing factor [9, 10, 6-8].

To achieve the IE4 efficiency level, the stator and rotor design must be optimized. This will result in a better torque-speed curve and a reduction in stray losses, Joule rotor losses, and stator losses. By using unconventional cutting technologies like water jet and electro-erosion techniques, the magnetic losses can be further reduced. However, at present moment, these techniques are not very suitable for mass producing electrical equipment because they are costly and slow. [10-12].

The synchronous technology determines a reduction with 20% of the rotor losses in SCIMs and the impact of this method is very important in the increasing of the motor efficiency. The utilization of the rare earth permanent magnets or hard magnetic ferrites can increase also the efficiency of the motors, but the price of the rare earth like neodymium and dysprosium is very high [8].

Four-pole, double-cage, 15 kW motor

The major dimensions of the 15 kW, 4-pole motor are displayed in Table 1, and the weights and costs of the active materials, losses, and performance are displayed in Figure 3. Both designs operate similarly and in line with what is anticipated from a similar-sized commercial Al motor, and they have the same rated efficiency (92.1%). Both designs are compatible with commercial buildings made by both large and small businesses. The Cu motors provide a size advantage (diameter/stack length) and shed about 11% of their weight. Because Compared to the Al cage, the Cu rotor cage weighs twice as much. the comparison reveals a notable loss between around 18% and 37% in the stator and rotor slot area (rotor bar), respectivelyIn both circumstances, the motor with a copper cage saves 8 to 10 euros on active material costs (excluding die-casting costs). The overall copper weight of the Cu motor (rotor cage and stator winding) is around 13% more than that of the Al motor (stator winding).

Tables 1 Characteristics of a 15 kW, four-pole, double cage motor

η= 92.1% (IE3)	AL	Cu
Stack length (mm)	225	215
Outer stator diameter(mm)	225	245
N. of turns x phase	78	78
Wire size (mm2)	7.90	5.60
Stator slot area (mm2)	228	182
Rotor slot area (mm2)	83	65

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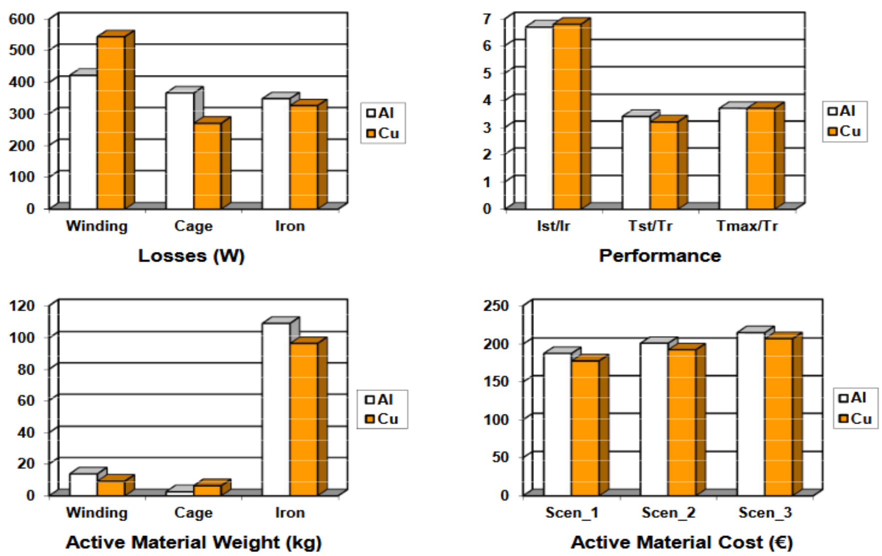

Figure 3 Shows the costs, weights, and performance of a 15 kW, four pole double cage motor.

Two-pole, 22-kW,

double-cage motors with equal performance and the same rated efficiency (92.7%) The Both designs' exterior stator diameters allow for the usage of commercial housings produced by both big and small businesses.; the weight decrease of approximately 8%, the Cu motor has a size advantage (diameter/stack length); The Cu rotor's weight is decreased by around 18% and 32%, respectively, in the stator and rotor slot region (rotor bar). cage is double that of the Al cage. The copper rotor solution is preferable because of the steel weight, even though the Cu motor's entire copper weight (rotor cage plus stator winding)and the Al motor (stator winding) is same... Additionally, in all circumstances, the motor with copper cage can reduce the cost of active materials by around 16 euros (excluding die-casting costs):

Tables 2 – 22 kW, 4 pole double cage motor main dimensions

η= 92.1% (IE3)	AL	Cu
Stack length (mm)	215	205
Outer stator diameter(mm)	290	285
N. of turns x phase	84	84
Wire size (mm^2)	6.36	4.80
Stator slot area (mm^2)	200	164
Rotor slot area (mm^2)	122	83

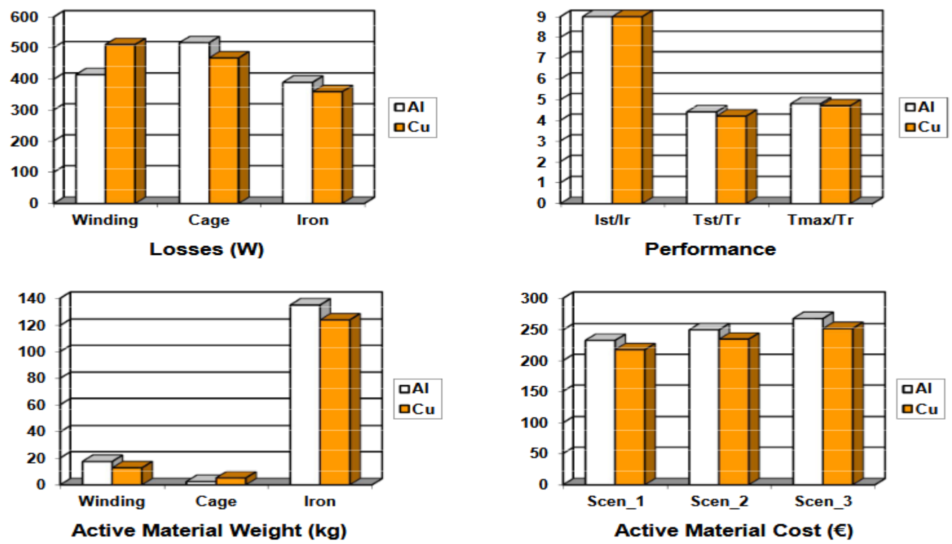

Figure 4 shows the costs, weights, and performance of a 22 kW, two pole double cage motor.

Conclusion:

Through this article, the importance of improving Three-phase induction motors' energy efficiency (SCIM) and other motors that meet high efficiency standards such as IE4 is highlighted. Several key conclusions can be drawn: Technological developments: The use of rare earth permanent magnet (LSPM) motors, variable reluctance motors (VRSM) and switched reluctance motors (SRM) helps achieve higher energy efficiency. Also, the use of copper in the rotor cage instead of aluminum can reduce total losses by 15-18%, increasing efficiency by 2-4%. Manufacturing challenges: Challenges remain in developing high-efficiency motors due to manufacturing constraints, national and regional standard requirements, and the need to improve rotor and stator design to reduce various losses such as magnetic losses and joule losses. Future innovations: Manufacturers should adopt non-traditional materials and advanced cutting methods such as the use of amorphous materials and advanced technologies such as hydro-electric cutting to reduce losses and increase efficiency, despite current manufacturing challenges. Collaboration and Regulation: Close collaboration between manufacturers and governments is essential to achieve sustainable improvements in energy efficiency and ensure that electric motors comply with regulatory standards and requirements, supporting their widespread adoption in the global market. Environmental and economic impact: Improving the energy efficiency of automotive electrical equipment not only contributes to reducing emissions and improving the environment, but also provides economic benefits by reducing operating costs and increasing the overall efficiency of electric vehicles. Therefore, improving energy efficiency is a vital step towards a more sustainable and less polluting future, and efforts must be ongoing in research and development to keep up with the challenges and achieve the best possible performance of electric motors. When compared to commercial Al motors of the same size, The motors with Al and Cu cages work consistently and rather similarly. When it comes to overall weight and dimensions (diameter/stack length), Cu motors are always better. The combined copper weight of the rotor

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cage and stator winding of the Cu motors is greater than that of the Al motors, regardless of size (in the case of a 22 kW motor, they are comparable).

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تحسين كفاءة الطاقة بشكل ديناميكي في المعدات الكهربائية للسيارات

صادق محمد امين سعيد
الجامعة التقنية كرميان كلية هندسة
وزارة التعليم العالي والبحث العلمي
sadeq.amen@garmian.edu.krd

سمكو حسين محمد مراد
جامعة كرميان كلية العلوم
وزارة التعليم العالي والبحث العلمي
smko.hussein@gpu.edu.iq

الخلاصة

تتناول هذه الورقة البحثية تطورات كفاءة الطاقة في محركات الحث ثلاثية الطور ذات القفص السنجابي(SCIM) وهي الفئة الرائدة في سوق المحركات الكهربائية. وتُسلّط الضوء على تطوير محركات SCIM التي تُلبي معايير كفاءة IE4 باستخدام أحجام إطارات قياسية وأقفاص دوارة من الألومنيوم، مُركّزة على الاستخدام التاريخي للنحاس لتحقيق معايير IE3 وتقليل قصور الدوار. بالإضافة إلى ذلك، تُناقش الورقة محركات IE4 أخرى، مثل محركات المغناطيس الدائم ذات البدء الخطي (LSPM) المزودة بمغناطيسات أرضية نادرة دائمة داخلية وأقفاص مساعدة للبدء، بالإضافة إلى محركات التزامن ذات الممانعة المتغيرة (VRSM) والمحركات التزامنية المُبدّلة .(SRM) يُعدّ محركSCIM IE4 ، بقفصه المصنوع من الألومنيوم بأسعار معقولة، مُناسبًا بشكل خاص للاستخدام الصناعي واسع النطاق نظرًا لتكاليف إنتاجه وعزم بدء تشغيله وقدراته التزامنيّة. كما تستكشف المقالة النمو المُحتمل لسوق محركات LSPM في حال تعزيز قدراتها لتلبية معايير .IE5 علاوةً على ذلك، يناقش المقال تأثير المعايير الوطنية والإقليمية على أحجام أغلفة المحركات والتحديات التي يواجهها المصنعون في تقليل الخسائر لتحسين الكفاءة. من خلال تحليل شامل للمواد، وتحسينات التصميم، وتقنيات التصنيع المتقدمة، يقدم المقال رؤىً ثاقبة لتحقيق كفاءة أعلى في المحركات الكهربائية.

الكلمات الدالة: محركات الممانعة، محركات حثية على شكل قفص سنجاب، المحركات المتزامنة ذات الممانعة المتغيرة، المبدلة المفات.