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TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

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inside

Rotating electrical machines –
Part 31: Selection of energy-efficient motors including variable speed applications – Application guide

Machines électriques tournantes –
Partie 31: Choix des moteurs éconergétiques incluant les applications à vitesse variable – Guide d'application

IEC/TS 60034-31:2010

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ROTATING ELECTRICAL MACHINES –

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FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60034-31, which is a technical specification, has been prepared by IEC technical committee 2: Rotating machinery.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
2/1575/DTS	2/1594/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 60034 series, published under the general title *Rotating electrical machines,* can be found on the IEC website.

NOTE A table of cross-references of all IEC TC 2 publications can be found in the IEC TC 2 dashboard on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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INTRODUCTION

The present technical specification gives technical guidelines for the application of energy-efficient motors in constant-speed and variable speed applications. It does not cover aspects of a purely commercial nature.

Standards developed by IEC technical committee 2 do not deal with methods of how to obtain a high efficiency but with tests to verify the guaranteed value. IEC 60034-2-1 is the most important standard for this purpose.

For approximately 15 years regional agreements were negotiated in many areas of the world regarding efficiency classes of three-phase, cage-induction motors with outputs up to about 200 kW maximum, as motors of this size are installed in high quantities and are for the most part produced in series production. The design of these motors is often driven by the market demand for low investment cost, hence energy efficiency was not a top priority.

In IEC 60034-30, IE efficiency classes for single-speed cage-induction motors have been defined and test procedures specified:

IE1	Standard efficiency
IE2	High efficiency
IE3	Premium efficiency
IE4	Super-premium efficiency

Determination of efficiency for motors powered by a frequency converter will be included in IEC standard 60034-2-3.

However, for motors rated 1 MW and above, which are usually custom made, a high efficiency has always been one of the most important design goals. The full-load efficiency of these machines typically ranges between 95 % and 98 %. Efficiency is usually part of the purchase contract and is penalized if the guaranteed values are not met. Therefore, these higher ratings are of secondary importance when assigning efficiency classes.

With permission from the National Electrical Manufacturers Association (NEMA), some parts of this TS are based on NEMA MG 10, *Energy Management Guide For Selection and Use of Fixed Frequency Medium AC Squirrel-Cage Polyphase Induction Motors*.

ROTATING ELECTRICAL MACHINES –

Part 31: Selection of energy-efficient motors including variable speed applications – Application guide

1 Scope

This part of IEC 60034 provides a guideline of technical aspects for the application of energy-efficient, three-phase, electric motors. It not only applies to motor manufacturers, OEMs (original equipment manufacturers), end users, regulators and legislators but to all other interested parties.

This technical specification is applicable to all electrical machines covered by IEC 60034-30. Most of the information however is also relevant for cage-induction machines with output powers exceeding 375 kW.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-30, *Rotating electrical machines – Part 30: Efficiency classes of single-speed three-phase, cage induction motors (IE-code)*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60034-1 and in IEC 60034-30 apply.

3.2 Symbols

η_n is the nominal efficiency, %

η_N is the rated efficiency, %

f_N is the rated frequency, Hz

n_N is the rated speed, min^{-1}

P_N is the rated output power, kW

T_N is the rated output torque, Nm

U_N is the rated voltage, V

4 General

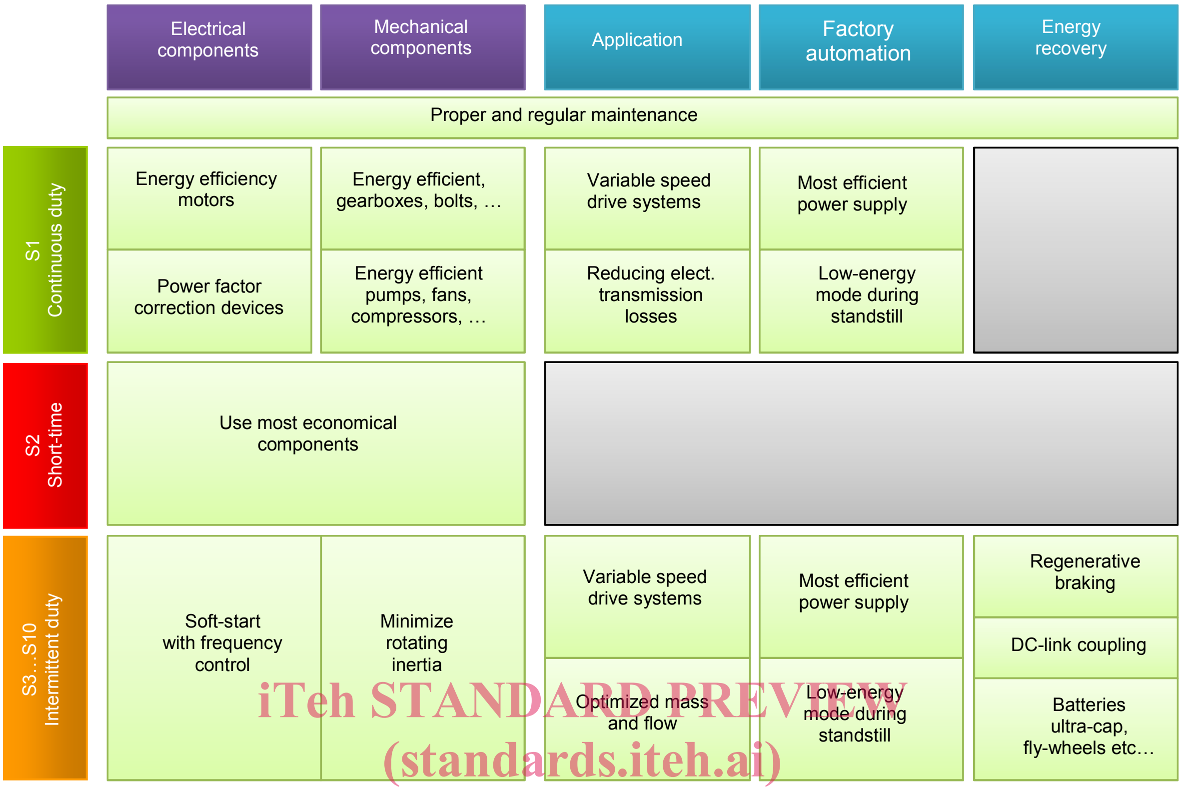

Figure 1 – Overview of different areas for savings of electrical energy with drive systems

Energy can be saved in different areas of electrical drive systems depending on the duty type (continuous or intermittent).

In continuous duty applications, improved efficiency of the electrical motor is beneficial. An improved power factor (frequency converter, synchronous motor) can help reduce I^2R losses in cables. Mechanical optimizations (gearbox, belts, pumps, fans, etc.) may lead to much greater savings than improvements of the electrical motor.

The application should also be regarded as well because, in many cases, the main part of the energy saving can be obtained by managing the application load from the system point of view. For that purpose, a demand-oriented speed control is often helpful.

Proper maintenance is usually beneficial. Many industrial plants have a high energy consumption within the low voltage control circuits (typically 24 V power supply). Therefore, high-efficiency low-voltage power supplies should be used. If possible, the factory should also be shut down during long standstill periods (weekends, holidays).

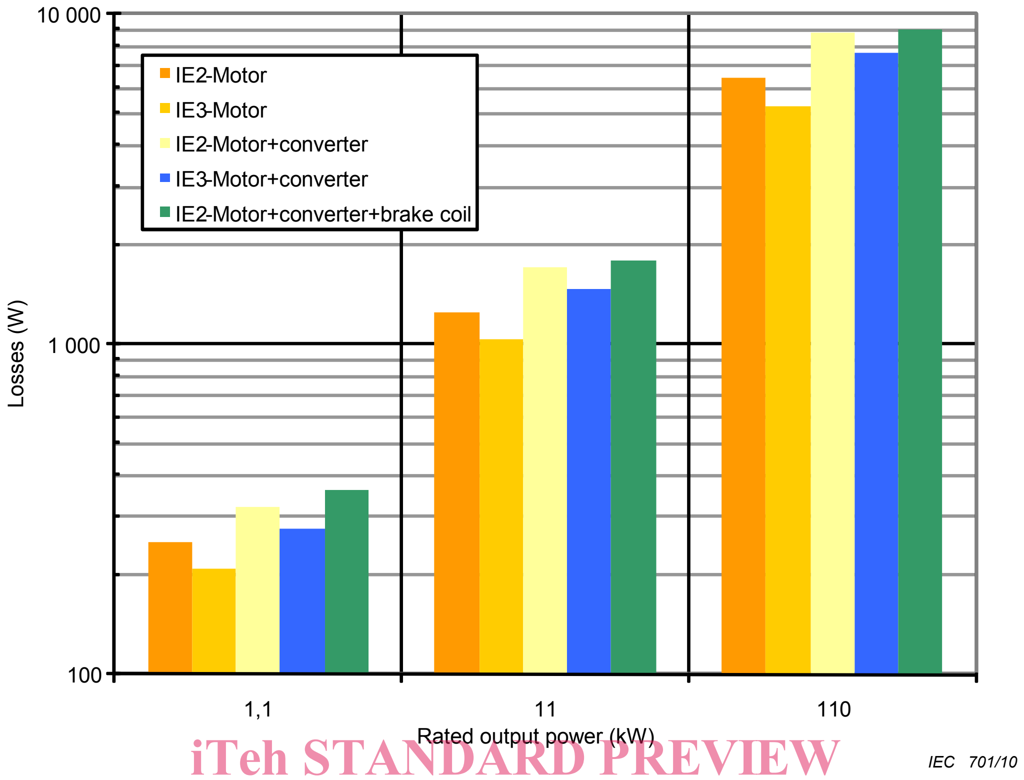

Figure 2 – Typical losses of energy-efficient motors, converters and electro-mechanical brakes

Figure 2 gives an overview of typical losses of energy-efficient motors and typical losses for the power drive system including motors with voltage-source frequency converters with and without brake coils of electro-mechanical motor brakes.

In intermittent duty applications, energy efficient motors are not very effective and may even use more energy due to their increased inertia and start-up currents. For these applications, the energy consumption during the starting phase can be reduced by ramping with a frequency converter. Intermediate energy storage may be beneficial when the operating cycle includes frequent regenerative braking phases (for example hoist drives, lifts, cranes etc.).

5 Efficiency

5.1 General

Motor efficiency is a measure of the effectiveness with which electrical energy is converted to mechanical energy, and is expressed as the ratio of power output to power input:

$$Efficiency = \frac{OutputPower}{InputPower} = \frac{OutputPower}{OutputPower + losses}$$

Motor efficiencies are usually given for rated load, although approximations for 3/4 load and 1/2 load may also be provided.

The efficiency of a motor is primarily a function of load, rated power, and speed, as indicated below.

a) A change in efficiency as a function of load is an inherent characteristic of motors. Operation of the motor at loads substantially different from rated load may result in a change in motor efficiency (see Figure 3).

b) Generally, the full-load efficiency of motors increases with physical size and rated output of motors.

c) For the same power rating, motors with higher speeds generally, but not always, have a higher efficiency at rated load than motors with lower rated speeds. This does not imply, however, that all apparatus should be driven by high-speed motors. Where speed-changing mechanisms, such as pulleys or gears, are required to obtain the necessary lower speed, the additional power losses could reduce the efficiency of the system to a value lower than that provided by a direct drive lower speed motor.

A definite relationship exists between the rated speed (min^{-1}) and the efficiency of a cage-induction motor. That is, the lower the rated speed, the lower is the efficiency, for slip is a measure of the losses in the rotor winding (slip of an induction motor is the difference between synchronous speed and operating speed). Slip, expressed in %, is the difference in speeds divided by the synchronous speed and multiplied by 100. Therefore, Design N cage-induction motors having a slip at full-load of less than 5 % are more efficient than motors having a higher slip and should be used when permitted by the application.

For loads such as pumps, fans and air compressors, it may be possible to make a significant saving in energy by utilizing a multispeed motor or by using a variable speed drive (VSD). However, it should be noted that the efficiency of a multispeed motor at each operating speed is somewhat lower than that of a single-speed motor having a comparable rating. Single-winding (for example Dahlander winding), multispeed motors are generally more efficient than two-winding, multispeed motors.

Motors which operate continuously or for long periods of time provide a significant opportunity for reducing energy consumption. Examples of such applications are processing machinery, air moving equipment, pumps, and many types of industrial equipment.

While many motors are operated continuously, some motors are used for very short periods of time and for a very low total number of hours per year. Examples of such applications are valve motors, dam gate operators, industrial door openers, fire pumps and sewage pumps. In these instances, a change in motor efficiency would not substantially change the total energy cost since very little total energy is involved and may decrease the required performance.

A modest increase of a few percentage points in motor efficiency can represent a rather significant decrease in percentage of motor losses. For example, for the same output, an increase in efficiency from 75 % to 78,9 %, from 85 % to 87,6 %, or from 90 % to 91,8 % represents a 20 % decrease in losses in each case.

As efficiency typically increases with the size of the motor, high-voltage machines with output powers exceeding 1 MW usually have an efficiency above 95 %.

NOTE While an electric motor's output power increases with the square of its diameter the permissible heat dissipation increases almost linearly. Therefore, a higher efficiency is an inevitable precondition for the design of larger motors.

5.2 Motor losses

An electric motor converts electrical energy into mechanical energy and in so doing incurs losses which are generally described as follows:

a) Electrical (stator and rotor) losses (vary with load) – Current flowing through stator and rotor windings produces losses which are proportional to the current squared times the winding resistance (I^2R). Rotor loss increases with slip.

b) Iron (core) loss (essentially independent of load) – This loss is produced mainly in the laminated core of the stator and, to a lesser degree, in the rotor. The magnetic field, essential to the production of torque in the motor, causes hysteresis and eddy current losses.

c) Mechanical (friction and windage) losses (essentially independent of load) – Mechanical losses occur in the bearings, fans, and seals of the motor. These losses are generally small in IP2X, IP4X and IP5X slow-speed motors, but may be appreciable in large, high-speed or totally-enclosed IP6X motors.

d) Additional load losses (stray load losses) – The additional fundamental and high frequency losses in the iron; conductor and circulating current losses in the stator winding; and harmonic losses in the rotor conductors under load. These losses are assumed to be proportional to the torque squared.

Listed below (Table 1) are the motor loss components, with the typical % of the total motor losses they represent, and the design and construction factors which influence their magnitude.

Table 1 – Loss distribution in three-phase, 4-pole, cage-induction electric motors

	Typical % of losses **4-pole motors**	**Factors affecting these losses**
Stator loss	30 to 50	Stator conductor size and material.
Rotor loss	20 to 25	Rotor conductor size and material.
Core loss	20 to 25	Type and quantity of magnetic material.
Additional-load loss	5 to 15	Primarily manufacturing and design methods.
Friction and windage	5 to 10	Selection/design of fan and bearings.

In general, by increasing the active material in the motor, i.e., the type and volume of conductors and magnetic materials, losses can be reduced.

5.3 Additional motor-losses when operated on a frequency converter

Harmonics of voltage and current in a cage-induction motor supplied from a frequency-converter cause additional iron and I^2R winding losses in the stator and the rotor. The total value of these additional losses is essentially independent of load. These additional losses decrease with increasing switching frequency in the converter.

In adverse circumstances the additional losses in the motor caused by the frequency converter can increase the total motor losses up to 15 % to 20 % more than when operating on a sinusoidal power supply.

For details see IEC 60034-17 and IEC 60034-25.

5.4 Motors for higher efficiency classes

It is expected that advanced technologies will enable manufacturers to design motors for higher efficiencies than IE3 with mechanical dimensions (flanges, shaft heights etc.) compatible to existing motors of lower efficiency classes (for example EN 50347, NEMA MG1 and other local standards). These motors usually require power electronics (frequency converters) to operate.

Losses in the rotor are almost eliminated when using synchronous motors without a field winding.

In Annex A, this technical specification proposes a super-premium efficiency-class IE4 which is specifically targeted at such motors (although the efficiency class IE4 as such is not limited to specific motors).

Permanent magnet (PMSM) and reluctance (RSM) synchronous motors are already developed and to some extent commercially available. PMSM usually have some inherent reluctance torque and RSM can be PM enforced, thus hybrids are possible.

Depending on the amount of magnet material used, a PMSM can have a higher power factor than an induction motor thus improving efficiency in the distribution network and in the frequency converter. These motors however require a frequency converter and a rotor position sensor (encoder) (unless an encoder-less control algorithm is used in the converter) for proper operation.

A simpler motor control with block commutated voltage of low switching frequency is also commonly used in small size and/or high speed motors ("brushless-DC" or "electronically commutated (EC) motors"). The main disadvantage is the additional losses due to parasitic harmonic voltages and currents. The improvement in efficiency over asynchronous motors is less when compared to the improvement of PWM (pulse-width modulation) controlled permanent magnet or reluctance synchronous motors.

Another synchronous motor design features both permanent magnets and a cage. It can therefore be used for on-line starting (line-start, permanent magnet, synchronous motors "LSPM"). These motors do not necessarily need a frequency converter for operation. However their starting performance is rather poor with torque ripple and noise and considerable restrictions on the permissible load torque and load inertia. They need to be closely matched to the application and cannot be used as general-purpose machines.

NOTE It is envisaged to expand the scope of IEC 60034-30 and amend it with this Annex A (as normative) when more experience with synchronous motors in standard applications becomes available.

5.5 Variations in motor losses

All manufactured products are subject to tolerances associated with materials and manufacturing methods. No two products will perform exactly the same, even though they are of the same design and produced on the same assembly line at the same time.

This is also true for electric motors. Product tolerances in materials, such as steel used for laminations in the stator and rotor cores, will lead to variations in magnetic properties and ultimately affect iron losses and therefore motor efficiency. Using a tested 7,5 kW motor as an example, a 10 % increase in iron loss (300 W to 330 W), which is within the tolerance offered by steel suppliers, would increase total motor losses from 946 W to 976 W and reduce efficiency from 88,8 % (IE2) to 88,5 % (IE1).

Variations also occur as the result of manufacturing process limitations. There is an economic limit to the practical dimensional tolerances on motor parts. Combinations of mating parts contribute to dimensional variations, such as the size of the air gap, which cause variations in additional-load loss and hence motor efficiency.

In addition, uncertainties can be caused by manufacturing processes and testing procedures.

Thus in forecasting the efficiency of a given motor, one can speak of the rated efficiency as defined by the manufacturer (which should be equivalent to the average efficiency of a large population of motors). The rated efficiency should also be above or equal to the required nominal efficiency of the rated efficiency class (in accordance to IEC 60034-30).

The actual efficiency at rated load of any individual motor, when operating at rated voltage and frequency, can be lower than the rated efficiency but not less than rated efficiency minus the tolerance of the efficiency according to IEC 60034-1. This is the level reached when both raw materials and manufacturing processes are at the least favourable end of their specified tolerances.