Assessment of Efficiency of Low Voltage, Three Phase Motors

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Introduction

Three-phase, low-voltage squirrel cage induction motors are the most commonly used electric motors in industry. They can be found from a few hundred watts up to several megawatts. The induction motors are characterised by data provided by the manufacturer at rated speed, power, voltage, current, power factor and efficiency. In the past, the efficiency value was of minor importance. Nowadays, with the growing emphasis on energy conservation the efficiency value has become very important and even dominant for applications in industry. Efficiency data by manufacturers are measured or calculated according to certain standards. The main differences between these standards are discussed in this paper, as well as the process of making accurate measurements. Knowing the real efficiency at rated and partial load, instead of the fictional IEC efficiency, allows choosing the motor that has the highest efficiency in the actual process where it is used. Annual energy savings of up to 50% of the purchase cost can be achieved. Some practical examples of energy saving using variable speed drives are also given.

Efficiency standards

Worldwide, there exist several standards for testing electric machinery. For induction motors, the three most important ones are IEEE Standard 112 [1], JEC 37 (Japan) and IEC 34-2 [2]. At this instant, a new IEC standard, the IEC 61972, is under development [3]. In most European countries, the standards are harmonised to IEC 34-2.

The efficiency value obtained from the different testing standards can differ by several percent, as will be shown by the measurement results. This seems in contradiction with the theoretically simple definition of the efficiency:

$$\eta = \frac{\text{power out}}{\text{power in}} = 1 - \frac{\text{overall losses}}{\text{power in}} \tag{1}$$

The second form allows the correction to a specified ambient and reference motor temperature, by correcting the individual loss components.

The first four loss components are stator and rotor copper losses (P_{stator} and P_{rotor}), iron losses (P_{Fe}), and friction and windage losses ($P_{fr,w}$).

P_{Fe} and $P_{fr,w}$ are determined by a no-load test, the copper losses are calculated based on stator resistance, slip and input power measurements under load. The values of the copper losses are corrected to the reference motor temperature.

Additional load losses have been the subject of numerous studies. In fact, these are all the losses that are not covered by the above mentioned loss components and therefore, they may be expressed as:

$$P_{addit} = \left(P_{in} - P_{out}\right) - \left(P_{Fe} + P_{stator} + P_{rotor} + P_{fr,w}\right) \tag{2}$$

The main difference between the standards emerges from the way in which the fifth loss component, the additional load losses, is treated.

Since a direct measurement of the additional load losses requires the rotor to be removed, the only correct and practical method is to measure both input and output power, and to calculate the difference between the overall loss and the four known loss components, using (2). This is the method used in IEEE standard 112 - Method B. The resulting values are linearised and corrected for zero additional losses at zero load.

Historically the torque measurement required by this method was difficult, and therefore the IEC 34.2 standard assumes a standard value for the additional load losses at rated load of 0.5% of the input power, proportional to the current squared at lower load levels. The new proposed IEC 61972 standard gives two possibilities for the assessment of the additional load losses. The first one is a determination by means of the measured output power, as in the IEEE 112-B; the second one attributes a fixed amount to every machine of the same rated power.

The Japanese JEC standard 37 completely neglects the additional load losses.

Measurements

Eighteen induction motors of 11, 55 and 75 kW were tested, in a program in collaboration with Laborelec, the Belgian national laboratory for electricity. The motor manufacturers were ABB, ACEC, Brook-Hansen, Leroy-Somer, Samco, Siemens and WEG.

Efficiency was measured according to IEEE 112-B and IEC 34.2 standards, and compared with the European catalogue value, normally based on the IEC standard. Although some manufacturers' values are reasonably accurate, others overestimate the efficiency by 3 to 4%. Measured additional load losses vary from 1.5 to 2.3 %

of input power for the 11 kW motors tested (7 motors), from 0.4 to 3.0% for the 55 kW motors (6 motors) and from 0.9 to 2.7% for the 75 kW motors (5 motors). Values in the same range were found for some other motors tested in other power ratings. Similar values can be found in [4] and other references.

Given the achievable measurement accuracy, differences in efficiency of less than 0.5 % are not necessarily reliable. Therefore, it is proposed to use a standardised list of values, as used in the NEMA nameplate labelling standard MG1-12.542.

Furthermore, a difference in partial load efficiency, at 50 and 75 % load, of up to 5 % was found for motors with a difference in rated load efficiency of only 1 %. As motors are usually overdimensioned, the partial load efficiency is often even more important than the rated load efficiency, and should be mentioned as well.

Given the relatively low purchase and high energy cost, differences in efficiency of a few percent can lead to very high annual savings compared with the purchase cost, even up to 50%.

Measurement problems

The biggest problem in making accurate efficiency measurements of grid connected motors in a laboratory situation is properly setting up and aligning the motor, torque transducer and load. A very high accuracy is required in current, voltage, power, torque and speed measurement.

When measuring frequency converter drives, EMC becomes a problem. Proper cable connections and earthing schemes are needed, as well as shielding the measurement equipment. A major issue is measuring the distorted voltages and currents at input or output of the PWM frequency converter. Power analysers like the Voltech PM3000A allow high frequency measurements – incorporating the fast voltage variations – while synchronising the measurements with the much lower basic frequency.

In industrial environments, torque measurements can be performed using strain gauges. Applying these strain gauges obviously requires a drive stand still, which can be a problem for the industrial process. Contactless data transmission can be analogue or digital, but may be sensitive to EMC.

Additional load losses in the IEC 60034-2 and the new IEC 61972 standard

In the proposed new IEC standard, the additional load losses are either measured in a procedure similar to the IEEE method, or taken as a certain percentage of input power. For this second option, the only difference with the existing IEC 34.2 is that this percentage depends on the motor size, e.g. 1.9% of input power for the

55 kW motors. This may be a better average value than the 0.5 % of IEC 34.2, but this is entirely irrelevant, as indicated by the (real) example in Table 1.

Table 1. IEC 34.2, IEC 61972 and real additional load losses and efficiency

	IEC 34.2		IEC 61972		Real	
Motor	P_{addit} [%]	Eff. [%]	P_{addit} [%]	Eff. [%]	P_{addit} [%]	Eff. [%]
A	0.5	93.0	1.9	91.6	2.5	91.0
B	0.5	92.0	1.9	90.6	0.5	92.0

For example: motor A, labelled as a high-efficiency motor, has a 93 % efficiency according to the old IEC standard or 91.6 % according to the new version. The real efficiency is 91%, because the additional load losses are actually 2.5% for this motor. Motor B of the same power rating has old and new IEC efficiencies of 92% and 90.6% respectively, and a real efficiency of 92%, because the additional load losses are 0.5%. The comparison of both motors according to a method using an assumed or average value for the additional load losses is futile. This comparison would indicate motor A to be the “best”. In fact, motor B is more efficient. Clearly, this method is extremely unfair to the motor manufacturers, and to the customers who want reliable information on motor efficiency. It is not important what fixed or average value of additional load losses is used: it is the difference in additional load losses among motors of the same rating that is relevant.

Determining the additional load losses by means of the measurement of the output power, as in the IEEE method and the first option in the new proposed IEC standard is the only relevant method, since additional load losses can differ significantly between motors of the same rating.

A regrettable example of ignoring the additional load losses can be found in the 1998 IEA Hi-Motors Competition. The 75 kW ABB motor designed for -and winning- the competition states reductions in stator and rotor copper losses, iron losses, and friction and windage losses, but states a “0 W reduction” in additional load losses. The method used was IEC 34.2. The ABB motor’s efficiency is not disputed, but actual measurements have shown that some so-called “high-efficiency” motors – sold at premium price - achieve a high IEC 34.2 efficiency with, however, additional load losses of up to 3%.

Australia

In Australia, the Minimum Energy Performance Standards (MEPS) regulations came into effect on 1 October 2001 [5]. It defines “Minimum Efficiency” and “High Efficiency” requirements, which are the same as the proposed EU eff2 and eff1 standard respectively. All motors must meet the minimum efficiency levels. Labelling as High Efficiency is voluntary.

Australia recognises the difference between both standards, and imposes different minimum efficiencies depending on which standard is used. Figure 1 shows the required efficiency for High Efficiency motors, depending on whether the IEEE or IEC standard is used to determine efficiency. The higher requirements when using the IEC method can be very disadvantageous for manufacturers whose motors have low additional load losses. The requirements will not change for at least 4 years.

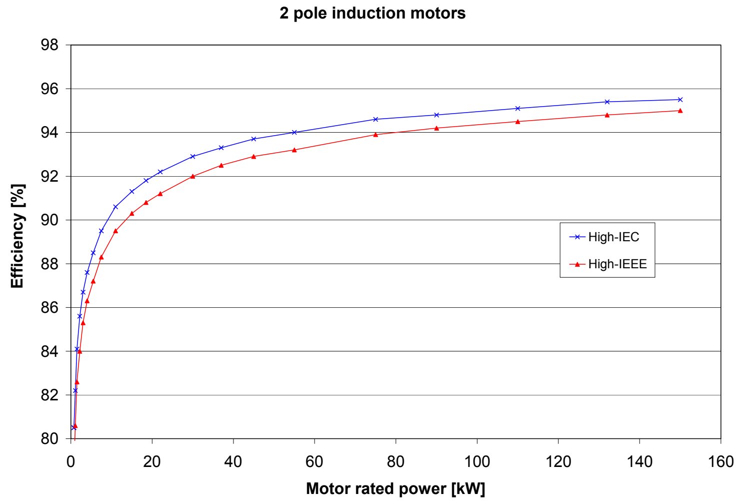

Fig. 1. Requirements for "High Efficiency" motors, Australia

Energy savings with variable speed applications

A variable speed drive, using a standard induction motor and a frequency converter, can lead to annual energy savings of up to 50%, e.g. in pump and ventilator drives, when compared with fixed speed on/off, throttle or bypass systems. At present, no standards are available to determine the efficiency of these drive systems. In this study, the efficiency of a drive is found by dividing the output by the input power. Most converters have efficiencies of 95 to 98%, even at relatively small loads. The average drive efficiency is 2% lower than the grid connected motor efficiency. However, this is less important than the energy saving potential. Some examples of industrial projects where traditional throttle valve or bypass installations were replaced by variable speed drives are given.

- 20 bar – 160 kW pressurizer: 23% savings.
- Circulating water from tower, normally operating without throttling: 24% savings due to more appropriate flow.
- Bypass at high pressure: 13% savings.
- Bypass at lower pressure: 40% savings.
- Several circulating pumps, 55 – 90 kW range: 40 to 46% savings.

Conclusions

The present IEC standard - or any method with fixed allowance for additional load losses as still present in the new IEC standard - does not provide reliable efficiency values. The additional load losses must be measured, and can in no way be replaced by any kind of fixed allowance, as the differences in additional load losses between motors of the same rating are too significant to be ignored. The difference from one motor to another can exceed 2% of input power, far exceeding the measurement error.

The partial load efficiency is just as important as the full load efficiency with respect to energy consumption, as motors are often overdimensioned. A difference in efficiency can have a large impact on the overall energy consumption. Annual energy savings of 50 % of the purchase cost are possible. In industrial processes, variable speed drives can reduce the energy consumption by more than 40 %, especially when fans or pumps are used.

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