Potential energy savings through legislative development

-A closer look at EU Ecodesign requirements for electric motors

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Abstract
One of the legislative regulations aiming at reduced energy consumption in the European Union, is (EC) 640/2009 that imposes requirements of the efficiency of electric motors sold in the Union. This study aimed at examining the effectiveness of these legislative requirements. To illustrate the opportunities of reducing energy consumption by the introduction of more efficient motors, an efficiency measurement of electric motors that drive the fuel feed system in a cogeneration plant in Nybro was intended to be carried out. This was to enable a comparison between the efficiency of existing motors with motors which comply with the efficiency levels in (EC) 640/2009 and to calculate how much the energy consumption would decrease in this energy system if more efficient motors were introduced. The planed measurements could not be carried out to give a reliable result because the plant suffer from the same problem as many other industries in the EU, which is that the motors in this energy system are oversized and operate at low loads. Oversized motors do not operate at their rated efficiency and therefore a comparison of existing motors and motors that comply with the efficiency requirements in (EC) 640/2009 fails to give a correct result, since they would not operate at their rated efficiency if they were installed in this energy system due to the efficiency drop at low loads. Instead the load factor was determined with the Input Power Estimation Method that showed that all motors were operated far below their rated power, thus making this an inefficient energy system. This is a common problem, and an impediment for the directive to achieve its full potential energy savings because the efficiency of motors drops substantially if they are operated below their rated power. The results show that guidelines to avoid motor misapplications is just as important as raising the efficiency of electric motors. In the studied case higher energy savings can be achieved by replacing the tested motors to smaller motors instead of introducing new motors of the same size with a higher efficiency.

Keywords
Motor downsizing
Motor efficiency
Ecodesign Directive
Energy consumption

Thanks
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1. Introduction

Energy consumption is increasing around the world while our ability to create energy with existing methods is decreasing. The majority of the produced energy is generated using finite resources [1]. The use of these raw materials leads to a strain on the environment. Reduced energy use decreases the extraction of raw materials and reduces the environmental impact. An optimized use of energy saves our resources and economy and reduces the levels of greenhouse gases in the atmosphere and other negative environmental effects that energy production causes [2].

The EU believes that energy conservation is an important aspect of a sustainable development. One of the EU 2020 objectives states that energy efficiency within the Union shall increase by 20% [3]. The EU is trying to reduce and streamline energy utilization across all sectors of society with the aim of reducing greenhouse gas emissions and secure the energy supply in the Union. Industries consumes about 40% of all electricity generated worldwide [1] and this sector is deemed to have significant improvement opportunities through technical and operational changes [2] which is why the EU is trying to govern the development of this sector with economic and administrative instruments. There are 4 directives from the EU which aims to increase energy efficiency in the Union in order to strengthen the EU's economy and ensuring energy access in the EU as well as reduce greenhouse gas emissions.


1.1 Ecodesign Directive

The Ecodesign Directive covers the products that are the most energy-intensive and accounts for a significant part of the EU's energy consumption. The development of these products is considered to require guidance by law since their use causes a significant environmental impact. The development of the remaining products on the market is controlled in other ways such as eco-labelling, consumer information, financial assistance, and other voluntary initiatives.

If the directive is implemented successfully the intended effect of the overall use of electric energy in the EU will decrease by 17% by 2020 and this will save the EU 120 billion € per year. 12 product groups are covered by the Ecodesign Directive, these products consume 80% of the electrical energy in the EU [4]. Electric motors are the group that consumes the most energy and also where the greatest energy savings can be
made. Electric motors consume about 70% of the total electricity consumption when they are used in production processes in the industry sector today [5]. Because such a large share of the energy demand within industries today depends on the operation of electric motors, even small improvements in these systems lead to a large reduction in total energy consumption. The EU imposed the Commission Regulation (EC) no 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors as part of the efforts to reduce energy use in this energy-intensive sector. The regulation is a part of the Ecodesign Directive and aims to reduce the environmental impact of these products throughout their whole life cycle.

An electric motor's highest environmental impact and cost during its lifecycle occurs during the use phase [6] which is why the regulation has focused on increasing the efficiency during the motor's operation. To establish standards for motor efficiency is regarded as an effective method to reduce energy consumption. The introduction of more efficient motors is expected to reduce energy consumption by 25-30% in this sector [5]. (EC) 640/2009 regulation is supposed to save the EU 135-139 TWH per year after 2020, which will reduce CO2 emissions by 63 Mt per year. This will be achieved by raising efficiency requirements on motors that are sold and used in the EU. The requirements for the motors minimum efficiency shall be increased in three steps.

- June 2011: All motors must meet the efficiency level IE2.
- January 2015: All motors sold in the EU and has a power rating of between 7,5-375 kW shall comply with efficiency level IE3. If the motors are equipped with a variable speed drive they shall comply with efficiency level IE2.
- January 2017: All motors sold in the EU and has a rated output of between 0.75-375 kW shall comply with efficiency level IE3. If the motors are equipped with a variable speed drive they shall comply with efficiency level IE2.

1.2 Case study
To examine how the requirements for more efficient motors in regulation (EC) no 640/2009 can lower the energy consumption in an industrial facility a case study of working electric motors in the cogeneration plant in Nybro was performed. The cogeneration plant consists of three boilers with a capacity of 45 MW. Each year, around 200 000 m$^3$ of biofuel is incinerated to generate 150 000 MWh heat and 20 000 MWh of electricity. An efficiency measurement of electric motors with power ratings between 1.5-30 kW was planned with the objective to highlight how the regulation can affect the internal energy consumption of this plant.

It’s important to divide the energy system in different sections when performing an energy audit to highlight areas of concern and identify efficiency opportunities. This survey is delimited to the cogeneration plants fuel feed system. The reason that this system was considered suitable to study in this survey is that it’s easy to adjust the production during the measurements so that the motors are working at full load during measurement sessions and the system is powered by motors of many different sizes. The chosen electric motors power the screws, conveyers, elevators and hydraulic feeders that transport the fuel to one of the plants boilers. The fuel can be transported through three different routes before reaching the boiler and each of these alternatives was planned to be reviewed and compared.
An overview of the plants fuel feed system is shown in Annex 1.

1.3 Efficiency upgrade
The theoretical efficiency rise between existing motors and motors that comply with (EC) no 640/2009 efficiency requirements IE3 are displayed in table 1.

Table 1.

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>POWER RATING (KW)</th>
<th>THEORETICAL EFFICIENCY (%)</th>
<th>EFFICIENCY REQUIREMENT (EC) 640/2009, IE3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belt conveyor</td>
<td>1,5</td>
<td>80,2</td>
<td>85,3</td>
</tr>
<tr>
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<td>81</td>
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<tr>
<td>Elevator</td>
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<td>87,7</td>
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<td>Screw conveyor</td>
<td>4</td>
<td>84,2</td>
<td>88,6</td>
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<tr>
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<td>84,2</td>
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<tr>
<td>Belt conveyor</td>
<td>4</td>
<td>87,4</td>
<td>88,6</td>
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<tr>
<td>Screw conveyor</td>
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</tr>
<tr>
<td>Belt conveyor</td>
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<td>89</td>
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<td>Belt conveyor</td>
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<tr>
<td>Screw conveyor</td>
<td>7,5</td>
<td>87</td>
<td>90,4</td>
</tr>
<tr>
<td>Hydraulic press</td>
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<td>87</td>
<td>90,4</td>
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<td>Screw conveyor</td>
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<td>91,4</td>
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<td>Hydraulic press</td>
<td>30</td>
<td>91,5</td>
<td>93,6</td>
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</table>

1.4 Objective
The purpose of this survey is to provide measurements and evaluations that show how much the energy consumption and efficiency changes with the introduction of more efficient motors according to (EC) no 640/2009.

2. Assessment of motor efficiency

IEC 60034-2-1 *Rotating electrical machines – Part 2-1: Standard methods for determining losses and efficiency from tests* is the standard that describes the test method that shall be used to measure the efficiency of electric motors. The method is not applicable to determine the efficiency of motors in operation where it is not possible to take the motors out of service and perform the measurements required by this standard. In many cases there are no prerequisites to perform the measurements that
require the motors to be taken out of service which has led to the development of simplified methods that can be used to determine the efficiency of motors in service [7]. The disadvantage of surveys that are carried out without measuring all the motors parameters is that assumptions has to be made about the motors performance based on values that are not actually measured and much of the accuracy depends on how well these data match the motors current performance. The positive aspect of these measurements is that the motors actual operating conditions are determined and the measurements are inexpensive and relatively simple to conduct.

2.1 Adoption of Ontario Hydro Modified Method E
Ontario Hydro Modified Method E (OHME) [7] was to be used in this study as it is not possible to measure the efficiency of the motors according to IEC 60034-2-1 in this plant. Measurements according to the OHME method can be performed without affecting the production at the facility and does not require intrusions on the motors which are why this method was chosen. The method is estimated to have an accuracy of +/- 3-4% and is considered to be one of the most reliable in order to assess the efficiency of motors under operating conditions [7]. The method was developed by Ontario Hydro and is a simplified version of IEEE Standard Test Procedure for Polyphase Induction Motors and Generators test method E1[8] that estimates the average values of the parameters that would require intrusion on the motors to be measured and is not practically possible to perform on motors in operation. The method uses models to calculate the motors output powers as otherwise would it require major intrusion on the motor to measure and the method was developed to estimate the motors efficiency during in-field conditions. The only practical measurement needed to calculate the motors efficiency is the input power which shall be measured with a three-phase wattmeter and the rotor speed of the motors which shall be measured with a tachometer.

2.2 Assessment of load factor by the Input Power Estimation Method
The consumed true power is consistent with motor load [10]. Because of this the Input Power Estimation Method (1) was used to determine motor load factor. This method is considered to be the most reliable in-field method for assessing motor load [11]. The motors consumed true power was measured during one hour at maximum production conditions with a three-phase power quality analyzer (C.A. 8334) set to 20 second measuring interval. The instrument logs the root mean square voltage (Urms) and current (Arms) as well as true power (W), reactive power (VAR), apparent power (VA) and power factor (cos \( \phi \)). The instrument has a measurement accuracy of +/- 1%, when power factor exceeds 0.8 and +/- 1.5% when the power factor is lower than 0.8. The theoretical efficiency was collected from EuroDEEMs database in cases where it was not specified on the motors nameplate. The uncertainty of this method is based on previously stated that the efficiency of the motors drops significantly when they are run under 50% of their rated power, and is not the same as the one that the manufacturer has measured during the tests of the motor. The calculated values in this study thus generate an excess. The error is greater the smaller the motor is and the lower the motor is loaded. It is difficult to assess the surplus and this is avoided but mentioned that it should be taken into account when interpreting the results.

\[
(1) \text{ Load Factor (\%)} = \frac{\text{Input power (kW)} \times \text{Efficiency (Rated)}}{\text{Rated power (kW)}}
\]
Figure 1 displays the load factor of the examined motors. The bars in the diagram represent motor load for the measured motors as a function of % full load on the y-axis. The motors rated power is specified under each bar on the x-axis.

![Figure 1](image.png)

**Figure 1** The Load Factors for the measured motors, indicated by their Rated power

### 3. Results

During the preparations before the measurements a current and voltage control were performed with a clamp-on ammeter to determine which motors have a balanced power supply and therefore were suitable to be used as objects in the investigation. These measurements showed that the motors were operated far below their rated output power even under maximum production conditions because the voltage and current levels were very low. The efficiency requirements in EC 640/2009 are all calculated when the motor is operated at its full capacity because the efficiency is based on the motors rated power, voltage and frequency according to annex II of EC 640/2009. In general motors are designed to be most efficient operating between 75-100% of its rated power [9].

All motors at the studied plant operated far under their optimum capacity and when the motor is loaded under this power the efficiency of the motor is reduced significantly causing the motor to operate under the marked efficiency. Because the efficiency of electric motors decreases when operated under the power they are made for the assessment was made that the results of these measurements could not be used to make an accurate comparison between the existing motors and motors with the efficiency that the regulation requires.

The operating conditions of existing motors makes it impossible to perform an accurate estimation by comparing how much energy consumption had decreased with the
introduction of motors which meet the efficiency classes according to the EC 640 2009 because the motors do not operate at the specified efficiency if they are operated at low loads. In order to make an accurate comparison between the existing motors and new motors complying with the requirements of EC 640/2009 had required the motors to operate at a higher load than they do in this case. The method selected for determining the efficiency of the motors only give accurate estimates when the motors are operated over 50% of its rated power, which also means that the results of the practical measurements had been misleading. In view of these facts the survey had to change focus and it was chosen instead to make power measurements on the motors in order to examine what load the motors operate at during maximum production conditions in this facility.

The efficiency of all motors in the fuel feed system was planned to be determined with the OHME method but because the results from these tests where considered to yield an uninterpretable result it was no longer necessary to measure all the motors in the fuel feed system. In order to investigate the load factor of the motor it was considered more important to single out motor of different sizes rather than measure all the motors in the fuel feed system. The motors sizes became the most important aspect and the motors that where easy to access and control during the measurements were chosen for subjects.

4. Discussion and Conclusion

4.1 Oversizing

Oversized motors in industrial processes are a common problem. Electric motors are loaded an average of only around 60% of their rated power in the EU [10]. This problem usually occurs because of the difficulty in determining how much power a motor need to deliver during operation which leads to the selection of a larger motor that gives a safety margin to ensure operational dependability. There are methods to assess how much power a motor needs to be able to deliver [9] but the actual operating conditions is very difficult to predict.

Average motor load should be measured in the early stages after installation to ensure that the motor is correctly dimensioned. An oversized motor is very inefficient and leads to a greater economic cost than a properly applied motor. Only determining average motor load percentage during one occasion which was done in this survey do not provide sufficient evidence to replace the motors but it is the first indicator that more studies are needed to optimize the energy systems [9].

Some motors must be able to deliver high power to manage start-ups and top conditions during operation. If the motors operate at its rated power at any time during operation, even if this only occurs for a short period, it’s properly sized. However, modern electric motors have a higher service factor and can be overloaded between 10-20% at longer times before the motor overheats compared to older motors which allows for reduction of this safety margin.

Oversized motors are rarely needed to ensure the operational dependability and for the majority of the motors installed today the dimensioning is based on erroneous conclusions during the construction planning. As previously mentioned, a motor achieves the highest efficiency if the motor is operated between 75-100% of its rated
power and the aim should be to install a motor that is loaded in that span. Ferreria et al suggest that if a motor is operated between 50-60% of their rated power they should be replaced [10].

4.2 Regulation limitations
Operating conditions in the industry rarely handles constant loads. Motors normally operated in varying loads, which means that current efficiency standards that only calculate efficiency at rated power cannot be used to create the most energy efficient solutions for systems that are driven by electric motors. This have been pointed out, among others, by Vanhooydonck, D et al[12] in 2010.

Regulation (EC) 640/2009 only defines guidelines for the efficiency of a motor and does not specify how the motors shall be used to operate most effectively. The results from this study show that there is also a need for guidelines on how to determine that the motor is correctly dimensioned and operated properly in order to streamline the energy system. The regulation will not give the intended effect if a large proportion of the motors in the industry are oversized.

The energy saving that more efficient motors can achieve is not attained if they are oversized [13] and operated below its optimum load so that the efficiency decreases. Implementing new motors which are approved according to (EC) 640/2009 don't operate with the efficiency that the regulation requires if they are operated far below their rated power. Introducing more efficient motors does not generate the expected efficiency if the motor is over-sized.

ECOFYS report Evaluation of the Energy Labelling Directive [14] points out that in many cases there are opportunities for greater energy savings through influence on system level than through product development. The consumption and efficiency of input energy depends largely on how the energy system is designed because energy losses are larger in the energy system the motor drives compared to the losses that take place inside the motor. One assessment indicates that the introduction of more efficient motors can provide an energy savings of between 4-5% of the operating expenditure but that the correct application of the motors and actions on system level can lead to savings between 20-30% of the operational expenditure for electric motor driven system [15].

ECOFYS report [14] recommends that implementation of the products must be investigated more systematically and the system aspects should be inserted into the directives in order to optimize its effects. The report [14] stresses that the motor is just one part of an energy system and all parts must be examined to be able to optimize and operate the system efficiently. The study [14] suggest introduction of energy performance tests and guidelines that consider the performance from a system perspective.

A more efficient motor does not provide a great energy saving if it’s misapplied. There are currently no developed test standards for assessing the effectiveness of the whole energy system. Some energy system is very complex and cannot be controlled with the help of standards and legislation and the problem that emerged from this study is hard to control but requirements to assess operating conditions on recently installed motors and introducing minimum load requirements can be imposed to address this problem and avoid motor misapplication.
4.3 Conclusion
The regulation has certainly lead the development of electric motors to move forward but the efficiency of these has always been high compared to other operating systems [6] and it is now required guidelines for how these motors shall be applied so that they operate the most efficient and generate the potential energy savings. The regulation focuses on the technological aspects of the product itself but the full potential energy savings may only be achieved if the product is correctly applied. The highest energy savings can be achieved through proper implementation and optimization of all the elements within an energy system and for the energy system in this study a higher energy savings can be achieved by replacing the tested motors to smaller motors instead of introducing new motors of the same size with a higher efficiency.
References


Annex 1.