# EuP Lot 30:
# Electric Motors and Drives

## *Task 3: Consumer Behaviour and Local Infrastructure*

*ENER/C3/413-2010*

*Final*

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# Table of Contents

# 3 Consumer Behaviour and Local Infrastructure

Consumer behaviour can – in part – be influenced by product-design but overall it is a very relevant input for the assessment of the environmental impact and the Life Cycle Costs of a product. One aim is to identify barriers and restrictions to possible eco-design measures, due to social, cultural or infra-structural factors. A second aim is to quantify relevant user-parameters that influence the environmental impact during product-life and that are different from the Standard test conditions as described in Subtask 1.2.

## 3.1 Real Life Efficiency

### 3.1.1 Real life energy considerations of induction motors

**Actual efficiency compared to catalogue efficiency**

The nominal efficiency represents the average value of a representative sample of manufactured motors for each product category. The actual motor full load efficiency can deviate from the nominal efficiency due to both manufacturing variation and testing uncertainty.

Evidence from independent verification is that motors do meet the claimed efficiencies. Because of the high material cost of making more efficient motors, established manufacturers are able to consistently produce motors that just exceed the MEPS.

**Repair of failed motors**

When induction motor windings fail, they will be removed and replaced with new windings. This process typically loses 0.5-2.0% in efficiency, although in some cases it is possible to have no additional losses, and even to reduce losses to less than those of the original machine. For large motors >55kW the average decrease in efficiency may be less than this.[i]

For maintenance personnel, the need to quickly get the plant working again means that the fastest option will usually be chosen. A motor can typically be repaired in less than 24 hours, and it can be certain that it will fit and work properly. Sourcing a new motor of the right specification may take longer, and there is a small risk of minor additional works for it to operate satisfactorily. The cost of unscheduled plant downtime will usually be much greater than those from the slightly reduced efficiency of an older motor compared to a new one. Hence motor repair is an important business.

For larger motors, the value of the motor makes repair increasingly attractive. The typical threshold for replacing rather than repair is 5-40kW. Across all users, the threshold for replace or repair is considered to be an average of 10kW[ii].

For specialist motors where replacements may be hard to source, then it will still be sensible to repair much smaller sizes.

Best practice in motor repair is given in an ANSI repair guide[iii].

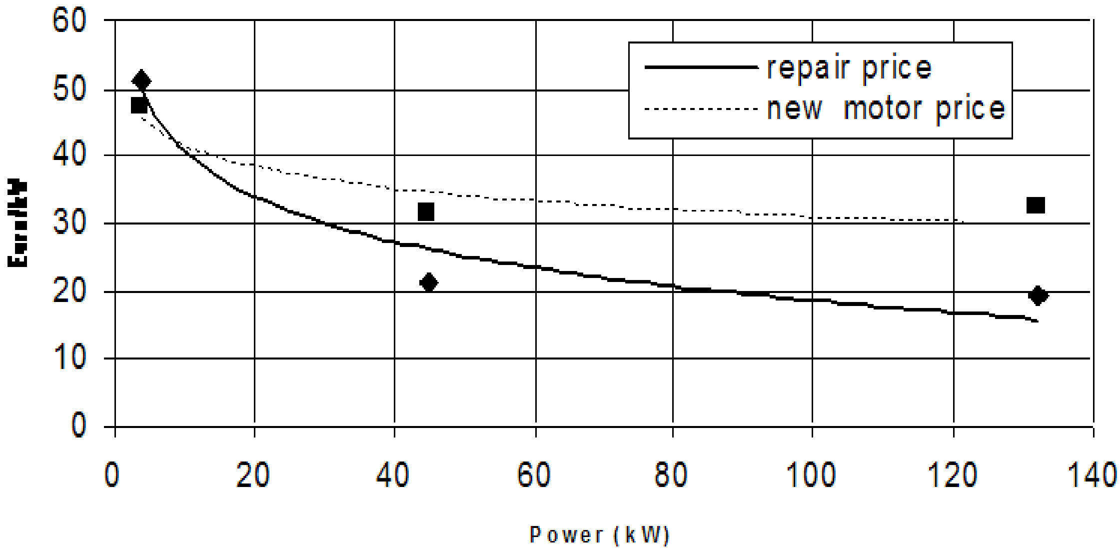


**Figure 1 Motor repair : replace costs**[iv]

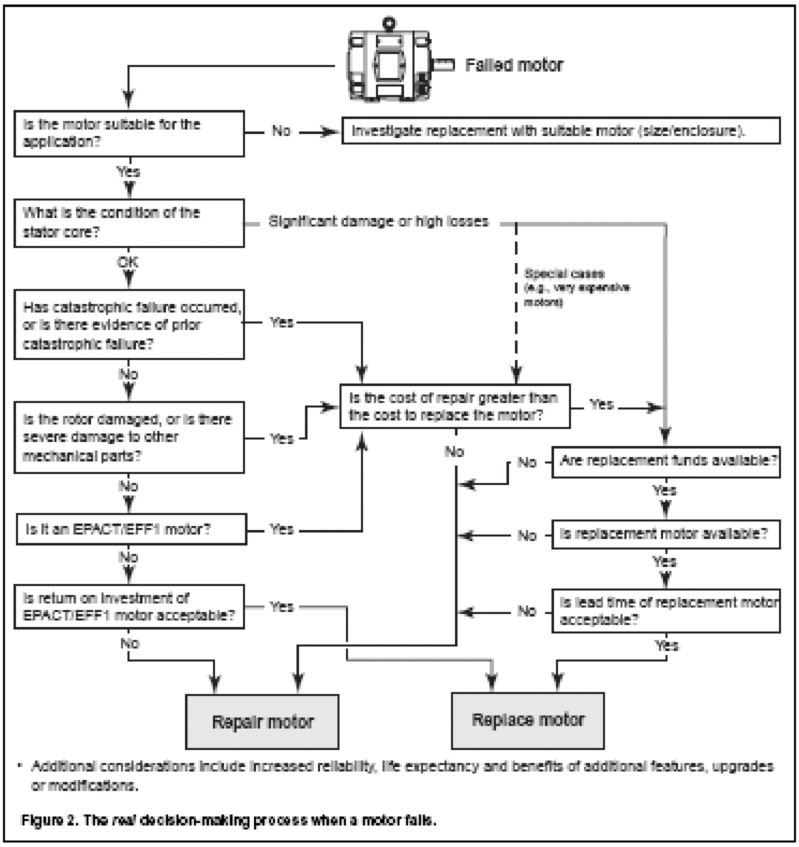


**Figure 2 Motor repair : replacement chart**[v]

## Stocks of old motors

Many sites have stocks of older “salvaged” motors, and there is a natural tendency to use these “free” motors rather than purchase new motors.

If the MEPS and hence price for new motors are set too high, there is a risk that use of salvaged motors will increase.

**Deterioration with time**

It is unusual for efficiency to decrease significantly over time. The exception is the build up of dirt on the body of the motor, fan or fan guard, which will effect cooling. Seal losses will decrease over the first 10's of hours operation.

**Part load efficiency**

Historically, induction motors have been optimised for operation at 75% load, as this is close to the 60% loading[vi1] where they will on average spend most of their running time. In practice, this means that the efficiency is close to its peak from 50-100% load.

The shape of the efficiency vs load curve is a function of the ratio of iron to copper losses, and so is a parameter that can be controlled by the designer.

Sometimes, and for short periods, motors can be operated above 100% load. Over this point, a slight decrease in efficiency is observed. Typically, a service factor of 1.20 (this represents a 20% overload) is permitted, although prolonged operation at this power will decrease lifetime. Where there is adequate cooling, prolonged operation at higher loads is permitted, for example the motors used on some axial fans. Motors on some industrial packaged screw compressors are also used in their service zone during normal operation.

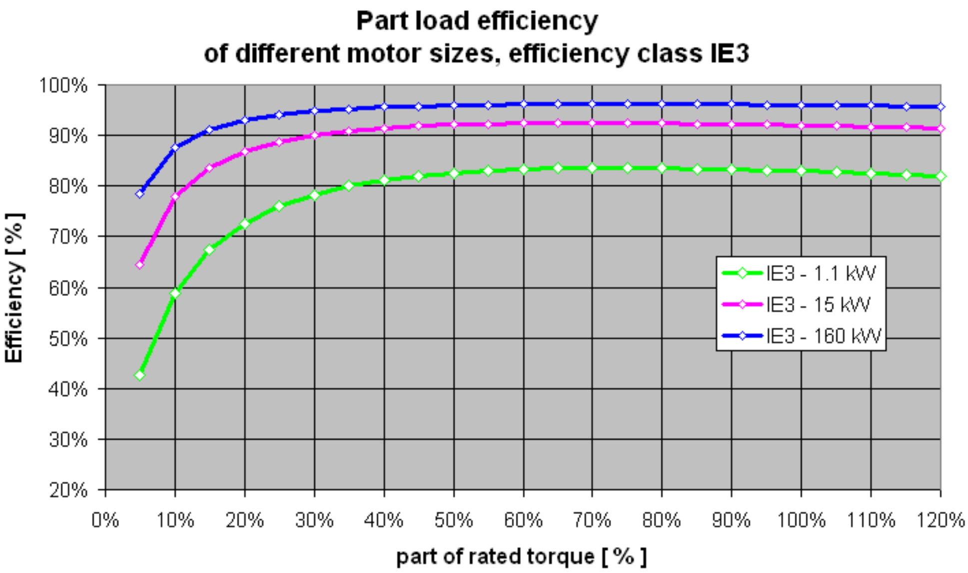


**Figure 3 Motor Efficiency vs. Load (CAPIEL)**

The figure above also shows how modern high efficiency motors have flat efficiency profiles, with smaller motors being almost flat in the 40-100% load range, and medium to large motors flat between 30-100% load. Above 100%, there will only be a gradual decrease in efficiency.

Nevertheless it should be noted that all international MEPS are based on efficiency at 100% load, but this does not reflect the average load. This is a discrepancy that might be considered later in the

[1] A figure similar to this is cited by various authorities. For example SAFE refer to an average of 59-63% on a survey of 75 motors in Switzerland, (submission to this study), and ABB in their submission agreed this value is reasonable.

study when reviewing policy options. The SEAD motor competition rules are suggesting a load weighted scheme that takes account of this issue, and is used in evaluating the energy losses of motors in Task 5 of this study. This is particularly pertinent given the growth of the VSD market.

**Motor over-sizing**

For various reasons the motor may be deliberately over-sized:

- Lower running temperature to offer increased reliability
- Higher starting torque
- Ability to cope with future increases in load
- Ability to operate under adverse electrical or environmental conditions
- Gives additional margin for the system designer

But it is much more usual for the designer to err on the generous side, with the others in the procurement chain perhaps offering an additional margin of safety.

Manufacturers are aware of this impact, and so induction motors are commonly designed with a flat efficiency between 50-100%, often peaking at around the 75% load point. For induction motors, providing the load is at least 50%, then the efficiency is close to the rated efficiency. But below this point, the efficiency declines quickly.

However, since larger motors are inherently more efficient than smaller motors, over-sizing by one or two power ratings could yield a higher efficiency.

Packaged equipment is much more likely to run at close to full load, as the designer will know much more closely the load conditions.

**Load Profiles**

Many motors will operate at different loads at different times. The overall energy performance then depends on the time spent at each load, and the efficiency of the motor at this load.

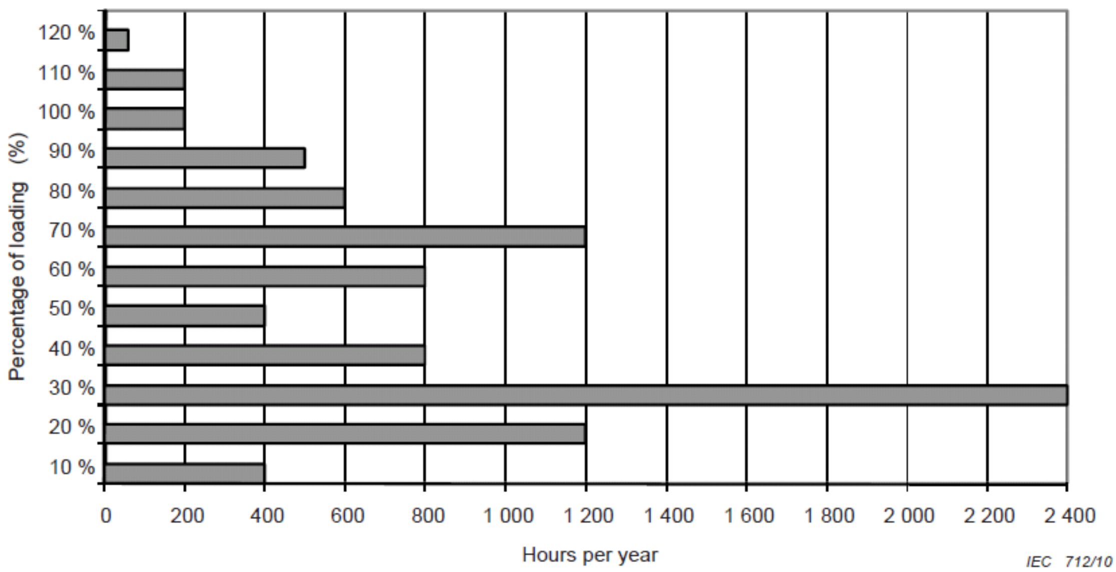


**Figure 4 Example of a load factor graph**[vii]

### 3.1.2 Dosage of auxiliary inputs during use

Motors require low amounts of auxiliary inputs during use, which are:

- Periodic lubrication with grease, for larger motors only
- When motors are repaired, all metal components can be recycled.
- For induction motors, it is assumed that all induction motors ≥7.5kW have bearings replaced two times during their lifetime. It is also assumed that all motors < 7.5kW are recycled when they fail.
- Brushed motors may need replacement brushes. For example, the brushes on older washing machines and some power tools.

### 3.1.3 Real Life energy considerations of Soft Starters

**Soft Starters**

Soft Starters enable motors to be started in a gradual way such that inrush current and any starting torque "shock" are reduced to safe levels. Modern soft starters are very sophisticated, but do not offer the variable speed control of a VSD. They are particularly popular in applications such as:

- Where there is only a weak supply.
- Where the load cannot withstand a sudden torque change, such as a conveyor.
- Where the system cannot withstand a sudden change in speed, such as a pump system where water hammer is a danger.
- Where a smooth ramp up and/or down is required.

However, VSDs are preferred for applications requiring very frequent cycling.

**Soft Starters - Internal losses**

Their internal losses relate almost entirely to the voltage drop across the internal thyristors used for power control. In addition there will be some power used by the display, other electronics, and the cooling fan where fitted.

There will be a reduction in peak KVA demand at start up, but the motor will take longer to run up to operating speed, and so the energy saving (if any) is only small. A typical ramp up time is 5 – 15 seconds. The energy losses are calculated as (Loss/cycle x ramp up time x No starts pa) + (On-time x quiescent loss).

**Soft starters and system efficiency**

In addition, they have several aspects that effect system efficiency:

**Voltage balancing:** Out of balance phase voltage reduces motor efficiency dramatically. A soft starter can be used to balance voltages and hence reduce motor losses.

**Bypass mode:** Once up to speed, the thyristors can be bypassed by a contactor to reduce thyristor losses. If this is not done, there will be continuous internal losses.

**Table 1 Allowable number of starts per hour for different size induction motors**[viii]

| kW | 2-pole | | 4-pole | | 6-pole | |
|---|---|---|---|---|---|---|
| | Max Starts/hr | Minimum off time (sec) | Max Starts/hr | Minimum off time (sec) | Max Starts/hr | Minimum off time (sec) |
| **1** | 15 | 75 | 30 | 38 | 34 | 33 |
| **5** | 8.1 | 83 | 16.3 | 42 | 18.4 | 37 |
| **10** | 6.2 | 92 | 12.5 | 46 | 14.2 | 41 |
| **15** | 5.4 | 100 | 10.7 | 46 | 12.1 | 44 |
| **20** | 4.8 | 100 | 9.6 | 55 | 10.9 | 48 |
| **50** | 3.4 | 145 | 6.8 | 72 | 7.7 | 64 |
| **75** | 2.9 | 180 | 5.8 | 90 | 6.6 | 79 |
| **100** | 2.6 | 220 | 5.2 | 110 | 5.9 | 97 |
| **200** | 2 | 600 | 4 | 300 | 4.8 | 268 |
| **250** | 1.8 | 1000 | 3.7 | 500 | 4.2 | 440 |

**Load detection:** Motors can be switched off when no load is detected for a set period of time. This reduces system energy consumption, for example, with escalators.

**Voltage optimisation:** For induction motors operating at low load, the soft-starter can reduce the output voltage to give a small energy saving. A threshold of 40%-50% load factor is typical of the load point above which no savings will be achieved, but is motor specific. (An alternative that is beneficial below about 40% load is running the motor permanently in star connection.)

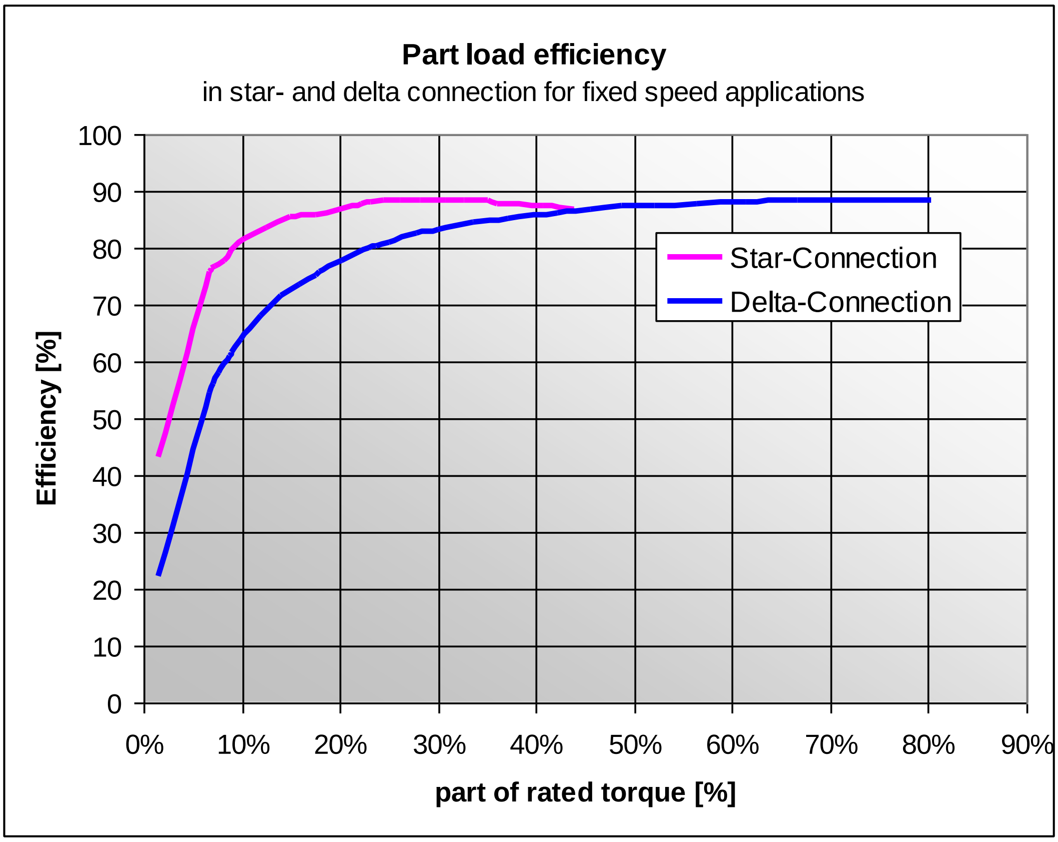


**Figure 5 Energy savings by connecting low loaded motors in star**

Factors where flex reduction might be more attractive, based on the iron losses being larger, include:

- Lower load.
- High supply voltage.
- Lower efficiency motor.
- Higher pole motor.

### 3.1.4 Real life energy considerations of VSDs.

**Variable Speed Drives**

The analysis here focuses on the PWM VSD, which currently dominates sales. Many of these can also be programmed to control other types of motor, which makes it much easier for the user to install and commission.

**Energy Savings by the use of VSDs**

VSDs can save large amounts of energy in many applications, especially some fan and pump systems. These savings are frequently many times larger than the savings from using a more efficient motor, but because the savings are so application dependent, it is hard to regulate for their use. However, the Extended Product Approach is an attempt to do just this, currently described best in the Europump draft Extended Product Approach description (see annex) The application of VSDs and how to estimate savings is described in IEC 60034-31: 2011, [vii] and many other commercial marketing publications.

**VSD – Control Strategies**

There are two core control strategies when using a VSD:

Passive – where the speed is set on commissioning and rarely changed.

Active – where the speed is dynamically adjusted according to a feedback signal, (which would only rarely be speed itself.) VSDs mean that motor speed can be rapidly adjusted to follow fast changing load conditions.

The VSD will also give additional losses in ancillaries such as any filters or cooling devices that may be required. Although small, if energy savings are the objective of fitting a VSD, the system savings should considerably exceed the additional losses incurred when using a VSD.

It is noted that for pump and fan applications, where the energy savings are largest and response times not demanding, and where low speed operation is unusual, simple control systems are adequate. For high speed servo positioning systems and similar, more advanced controls are required. In some cases, cascade or voltage depression control strategies are appropriate.

**VSDs – Internal power loss**

From test work to date by the Study team, it is thought that above 10kVA, VSD internal losses are very similar. Below 10kVA, there is more variation between designs. This is thought to be due primarily to differences in the power transistors selected. Lower loss transistors will be more costly, but also give the benefit of requiring a smaller heatsink and hence more compact package. VSD volume is an important marketing factor, with compactness particularly important for cabinets containing control gear for many motors. Lower heat loss also reduces, or completely removes, the need for forced ventilation. It also improves the critical capacitor lifetime.

Technically the biggest opportunity for saving is through the use of very low loss power devices, such as Gallium Nitride.

Other losses include the display, other electronics, chokes, input bridge and fan (where used).

At low loads, the efficiency of the VSD decreases. At the time of writing this report, no scheme for giving an “efficiency index” based on losses over a typical load profile has been suggested, but work is being undertaken by various organisations that will influence this. These include:

- BC Hydro (Pierre Angers)
- Caltech (Andrew Baghurst)
- IEA EMSA (Task C)
- SEAD Motor competition

This load profile will give an Energy Efficiency Index (EEI) that is similar to that adopted for the Circulators (Lot 11 study), and will consider a representative selection of torque and speed points, weighted by typical times at those points.

There are several detailed considerations to take account of, including type and length of the motor cable, mains side filter specification and switching frequency. It is of note that the switching frequency is key in determining the losses in the motor and VSD.

IEC TC22X/123/CD is under development, and publishes target "good practice" efficiencies for the VSD. It is expected that by the time of the 2nd stakeholder meeting a methodology will have been proposed.

It has been suggested by one stakeholder that the cost of a comprehensive test of a motor + drive combination can be 10,000 to 30,000 euros.[ix]

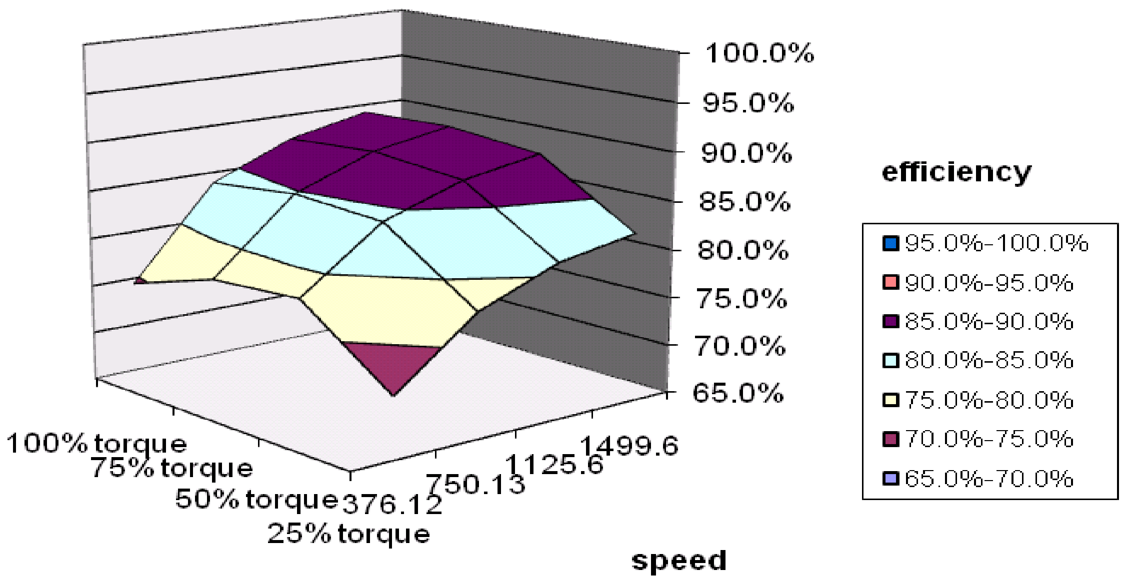


**Figure 6 Example of part load performance of an 11kW induction motor[x]**

If a VSD supplied motor is ever running at full speed, then a bypass contactor can be fitted, in which case the power losses are greatly reduced.

**Voltage balancing**

VSDs synthesise the motor voltage waveform, which will be precisely in phase and balanced, even if the incoming mains supply is not. This can give an additional energy saving advantage.

### *3.1.4.1 VSD Ancillary component losses*

VSD losses comprise various elements which help differentiate performance between different products:

- Switching frequency
- Internal control algorithms
- Filtering
- Rectifier / inverter front end (for energy recovery)

The reason the total losses fall at high load is that the (current and hence torque dependent) losses in each element are at their maximum. At very low load, the fixed losses become more important, and although only small give a very low efficiency simply because the output power with which the losses are compared are so themselves so small.

In addition to the internal losses of the VSD itself, the use of a VSD will create additional losses in ancillary components:

- Additional heating due to harmonic currents in the mains supply cable.
- Additional heating due to harmonic currents in the motor supply cable.
- Heating in any input or output filters used.
- Energy used by any active cooling such as fans or air conditioning.

**VSD and System Efficiency**

The harmonic distortion in the motor waveform due to the inverter compared to the mains, leads to additional motor heating and hence de-rating. IEC60034-2-3 (draft) gives an indication of the change in losses of a motor when controlled by a VSD. Indicatively these are 10-15%.

The energy savings in motor systems due to the use of VSDs are widely acknowledged, shown below in Figure 3.6 as representing 50% of the total optimization potential in the average motor system. (This average energy saving is assumed in this study, but similar but different figures have been shown by different authors, reflecting the difficulty in gaining an overview of the potential on ALL motor systems.) Such variation can be addressed partly by later sensitivity analysis to understand the implications of variations in this figure. It should also be noted that VSDs may also be fitted for control rather than energy saving reasons.

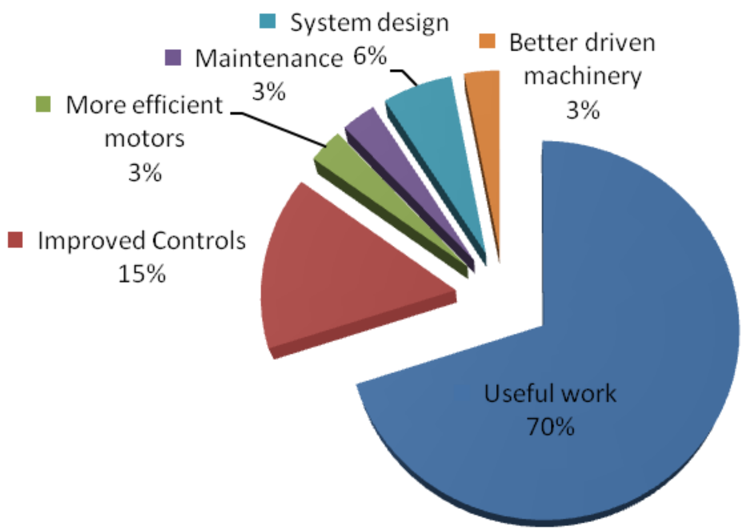


**Figure 7 The importance of better controls (mainly VSDs) in global motor system energy savings.**[xi]

Care will need to be taken to consider the inter-relationships between regulatory changes relating to the motor and those relating to the VSD to check that they are compatible.

### 3.1.5 Other types of motor

We will also be considering the following types of motor in the study. The duty considerations will be similar, although for motors selected on the basis of higher efficiency, they will be biased towards those applications with longer running hours.

- Permanent Magnet motors
- Switched Reluctance drives
- Synchronous motors

- Electronically commutated PM motors
- Shaded pole

While some of these types may be offered as drop-in alternatives to conventional induction motors, their other characteristics may dictate the final selection. Of particular note is the efficiency vs. load profile.

Some types of motors may commonly be used at speeds higher than an induction motor, but there is currently no agreement on what speeds/ loads these motors should be tested at.

Motors with different speed:torque characteristics may allow the control of loads without the use transmission components, representing an additional energy saving.

## 3.2 End of Life behaviour

### 3.2.1 Economical Product Life (=in practice)

Motor lifetime is influenced by many factors including number of operating hours, load factor including possible overloading, frequency of start/stop cycles, power quality and environmental conditions (temperature, vibrations, humidity, chemical pollutions).

75% of induction motors fail due to worn bearings, with stator failure being the other major cause of failure.[xii]

The average life of AC induction motors (including repairs) varies according to the motor power and is shown below.

**Table 2 Average life of induction motors, including repairs[xiii]**

| Power range | Average life (years) |
|---|---|
| 1.0 – 7.5 kW | 12 |
| 7.5 – 75 kW | 15 |
| 75 – 250 kW | 20 |

Further, the life of small motors is assumed to be 10 years, and that of large motors > 250kW 20 years. However, it is noted that with quality maintenance and repair the lifetimes of large motors may be up to twice this.

Surveys of motor stock can give an apparent average age of motor beyond the actual average lifetime of motors used in that plant. This is because the history of motors that have already failed and been replaced will not be known. Figure 8 illustrates this well.[xiv]

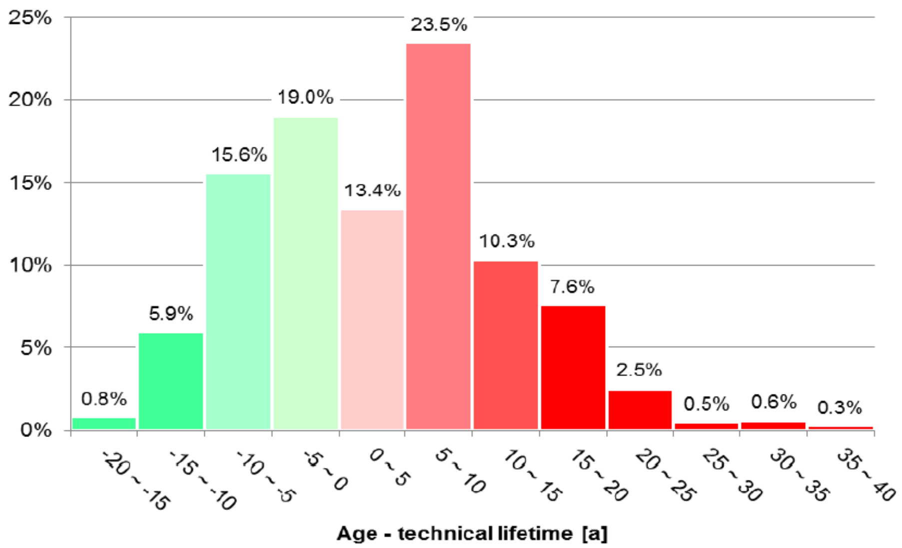


**Figure 8 Deviation of motors lifetimes from average lifetimes**

It is assumed that Permanent Magnet and Switched Reluctance motors of the same rotational speed and load have similar lifetimes.

Universal motors rarely last more than 1,000 hours, due to their commutators and high rotational speeds. Small DC appliance motors will usually be disposed of rather than have brushgear replaced on failure. A maximum life time of 10,000 hours is assumed for these, with an average of 2,000 – 5,000 hours[xv].

#### *3.2.1.1 Hand held portable tools*

Motors used in portable tools for the DIY market will have an average design life of 5 years. The actual life varies widely with the usage, which will rarely be more than a few hours pa.

Similar tools for the professional market may only last 2 years, again depending on the use, dust, dirt and degradation they experience. The average "switch on" time is about 40 hours pa.[xvi]

#### *3.2.1.2 Variable Speed Drive*

For PWM VSDs, the DC-link electrolytic capacitor is the weak point determining the lifetime. The semiconductor output bridge is an important secondary source of failure. Both semiconductor and capacitor lifetime is highly temperature dependent, with heatsinking or forced cooling increasing life. The choice of capacitors with a lower internal resistance reduces self-heating, but there is a cost premium attached to this. Harmonic distortion of the mains supply will lead to additional capacitor ripple current and hence reduce the lifetime, and similarly additional harmonic distortion imposed on the mains by a VSD rectifier will impact other equipment on the supply phase.

Other converter types, such as DC phase angle controllers or matrix converters do not require these capacitors, and so should have a longer lifetime.

A VSD lifetime of 10 years is typical for smaller VSDs, but on larger units where the capacitors and cooling fans will be replaced, this may be extended to 25 years[xvii].

#### 3.2.1.3 *Soft Starters*

A soft starter is less complex and does not have electrolytic capacitors that can dry out. A typical design life may be just 10 years, but the life in practice may be up to 20 years, hence supporting this 15 year average[xviii, xix]. A soft starter would not normally need to be repaired within the lifetime of the motor.

#### 3.2.1.4 *Motors*

On average, a medium to large induction motor will be repaired twice during its life. Small motors will not be repaired unless they are very specialist, (see Fig 1).

Because of the need for speedy response times, most motors will be repaired by local repair shops. Transportation distances are therefore small.

For smaller products, especially integrated packages, the complete product may be returned to the supplier for repair. Alternatively a replacement component may be sent for the User to fit.

For many small products, when the motor fails, then it may be considered easier and more cost effective to replace the entire product.

Suggested repair transportation distances are shown in table 3:

**Table 3 Transportation Distances for motors**

| Motor size range | Repair transportation distance |
|---|---|
| Very small | 0km (Not repaired) |
| Very large | 200km round trip to specialist repairer |
| Small/medium motor | 75km round trip to local repairer |

Small handheld and transportable tools will not be transported for repair, instead the spares will be sent direct to the user.

For critical applications, spare motors will be kept on site to minimize the costs of downtime.

**Table 4 Transportation distance for repair - VSDs**

| VSD size range | Repair transportation distance |
|---|---|
| Small | 0km (Replaced, notrepaired) |
| Medium | 100km trip to specialist repairer |
| Large | Repaired on site |

A similar figure is assumed for Soft Starters. In practice, a soft starter will not need repairing during the lifetime of the motor it is controlling.

***Best practice in facilities dismantling***

Given the high value of the metals content of motors, it is considered that all motors will be dismantled and metal content re-used at end of life.[2]

The growing use of Permanent magnet motors could lead to the disassembly to recover the expensive permanent magnet material, rather than conventional separation techniques.

Transportable and portable power tools are generally exchanged at the end of their life, and the metals reclaimed.

***Second hand market***

Some motors and controls may be refurbished and sold to Developing Countries.

Some second hand products that include motors may be sold within the EU.

***Best Practice in Sustainable Product Use.***

The presumption at this stage is that the net environmental benefit of more efficient motors and the use of motor controllers means that using these products represents Sustainability Best Practice. This assertion will be tested in subsequent tasks.

The exception will be products with very low duties where the additional material content cannot justify the superior product. Many domestic products fall in to this category, for example DIY tools or domestic garage openers.

## 3.3 Local Infra-structure

This identifies and describes the barriers and opportunities relating to the local infra-structure. This includes consideration of energy, water, telecom, installation skills and physical environment.

[2] Siemens is leading the German Government funded More (Motor Recycling) project that is examining in detail the recycling of materials from old motors. The consortium is focusing on permanent magnet materials. It is expected to report 2014.[2] This project is taking various approaches to electric motor recycling: removal of the materials from scrap motors, repair and subsequent reuse of the electric motor or its components, and reuse of the materials and raw materials, and the rare earth metals, following their extraction from pre-sorted and shredded materials. Also being developed are concepts for a recycling-compatible motor design, as well as ecological efficiency analyses and models for material cycles. *This will become an important reference work, but should not be refered to until completion, as without the detailed analysis the results might be misleading.*

### 3.3.1 Electrical

The use of drive systems that reduce energy consumption may lead to a reduction in **supply side electrical infrastructure and losses**. The net effect depends on the balance of increase in losses due to harmonic distortion, and the reduction in power demand.

The use of controlled starting can greatly reduce the peak power demand seen during motor start-up. Even just changing from DOL to star delta starting can reduce the peak to just 1/3 of its original value, and with soft starter or VSD control the peak can be less. The distribution network will see reduced power demand on transformers, cables and other transmission components. This reduces the losses in these components. Where there are local capacity constraints, it may also offset the need for additional equipment.

Controlling the sequence of motor starting will spread the peak starting current of each motor, so reducing overall capacity requirements.

Improved power factor of motors, in particular through the use of VSDs, reduces the current in the cables from the distribution board to the motor. This reduces heating loss, and also reduces wear on any switchgear.

Conversely, if peak output of the motor is not reduced, then the additional harmonic load can require a stronger power supply. Even if the standby power consumption of a VSD is only low, large reactive capacitor charging currents can impose additional losses on the electrical supply.

**Electrical power quality** will also have an impact on motor losses:

**Voltage imbalance.** A 3.5% voltage imbalance will give an increase in motor losses of approximately 20%.[xx] As previously stated, a controller can re-balance the voltage phases.

**Harmonic distortion.** In addition, VSDs and other motor controls will impose a line-bourne distortion that will in turn impact other users. The use of filters to mitigate this effect is essential.

**Voltage level.** Motors must be designed for safe use over the entire voltage range. Low loaded induction motors will be most efficient at low voltage, and high loaded motors most efficient at high voltage. When loads right below 40% frequently occur and if the process requirements no other possibilities permit, additional measures to control the effective motor voltage should be considered. Efficient technical solutions are flux control by VSDs, voltage suppression by soft-starters or re-wiring to star connection in case of fixed speed applications, (figure 9).

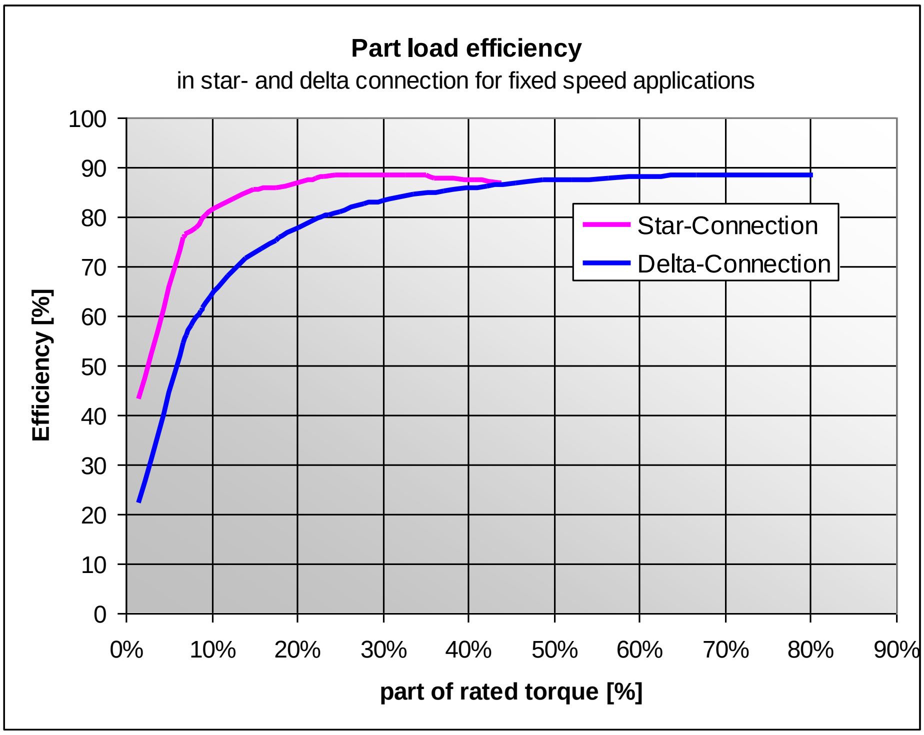


**Figure 9. Connection in star at low load**

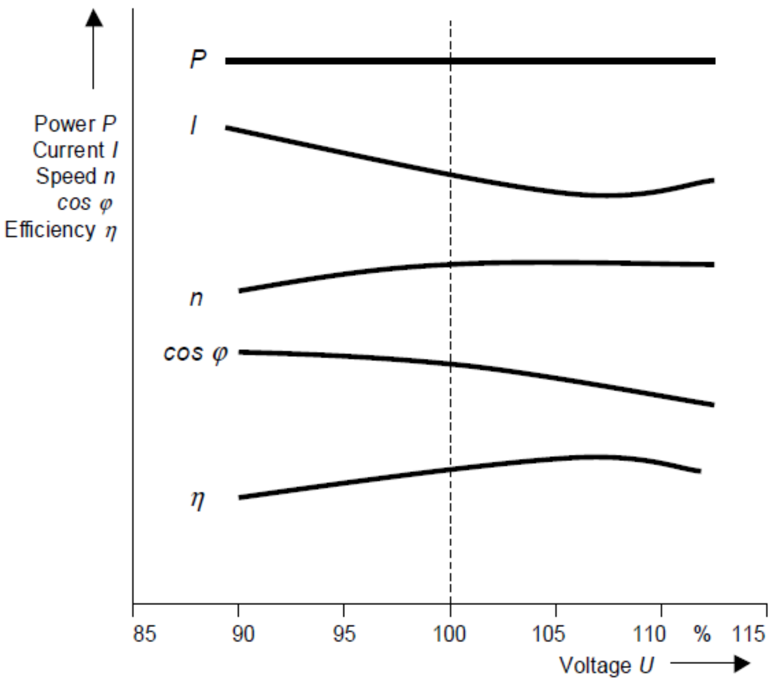


**Figure 10 The impact of motor performance as a function of supply voltage, when subject to full load.**[xxi]

### 3.3.2 Physical Environment

**Controllers:** Electronic controllers should be kept clear of dust and high temperatures, and isolated from any source of vibration. This can be hard to achieve in some applications without costly cubicles, filters and even air conditioning.

**Motors:** Higher ambient temperatures will give higher losses, principally through higher conductor resistance.

### 3.3.3 Appliances / Equipment in which motors are fitted

Products that include new types of motors may need minor re-design to accommodate different size or shaped motors. The shaft height and diameter are key parameters. The motor length and fixing hole pattern and diameter are also important.

Similarly, small differences in electrical or mechanical characteristics may require product re-design and re-certification. Parameters include starting torque, holding torque, inrush current, speed variation with load, duty cycle or operating temperature range.

## 3.4 Summary

Changes in the design of motors and use of controls has many impacts on the usage and hence duty patterns of motors. Of particular importance to this study are the following:

- Motors operate at an average load of 60%. Part load performance is therefore very important, and will vary between different types of motors. As previously noted, modern high efficiency motors will have a fairly even efficiency between 40-110%.
- Some types of motor can work at very high speeds or low torques, enabling system savings through the omission of transmissions and their losses.
- All controllers have internal energy losses, but when fitted in the right application the system energy savings they enable is much greater. Care must be taken that any regulations applying to products do not adversely impact possible system savings.
- Correct motor system design and programming of VSDs is essential in order to maximize system performance and minimize motor losses.
- VSDs increase the losses in induction motors, and so care must be taken that any regulations do not simply lead to the shifting of losses from the VSD to the motor or vice versa.
- As motors become more efficient they become more expensive, so encouraging their repair rather than replacement with more efficient types.
- Motors are almost exclusively recycled, but research is in place to look at better ways to reclaim valuable materials, in particular permanent magnets.
- The transformation from the process requirements into a certain system structure and control strategy and thus in a resulting load profile decides mainly about the energy consumption of the application. Care must be taken that users and system designers are aware of their possibilities and responsibilities.

# EXTENDED PRODUCT APPROACH FOR PUMPS

## A Europump Guide

8 April 2013

**Draft version**

***Draft version***

*This working document for a future Europump guide on the Extended Product Approach is prepared by a subcommittee of the Europump Standards Commission. It has not been presented or discussed in the Europump Standards Commission or the joint working group for EuP/ErP and currently does not reflect the position of Europump.*



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## Foreword

This working document  is prepared by a subcommittee of the Europump Standards Commission which consists of the following members:

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The working document will serve as a communication tool towards the European Commission during the legal process concerning the ecodesign requirements based on the extended product approach (EPA) for pumps. At a later stage this working document will be elaborated into a Europump guide, as an aid  for pump manufacturers and users to ensure compliance with the future regulation on the extended product approach (EPA) for pumps.

## Table of Contents

# 1 Introduction

Europump's answer to the ecodesign directive for pumps is based on three pillars as shown in Figure 11. The Product Approach focuses on the efficiency of the pump alone. The Extended Product Approach is focused on the extended product (pump, PDS, controls) and the System Approach focuses on optimising the pumping system. The purpose of this guide is to describe the methodology for future implementing measures (i.e labelling, legislation etc.) for extended pump products (EPs).

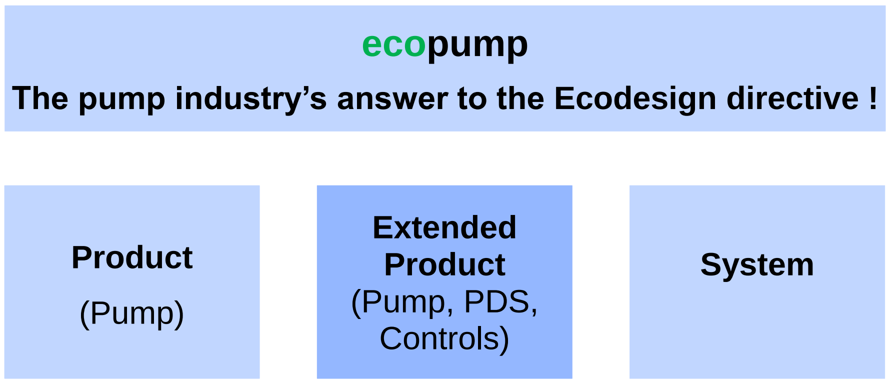


**Figure 11 Europump Ecopump initiative**

Figure 12 shows the difference between a Product Approach and an Extended Product Approach. Implementing measures based on a Product Approach take only the efficiency of the product into account, whereas the Extended Product Approach via the load profile and control method curve also takes the reductions in pump head into account.

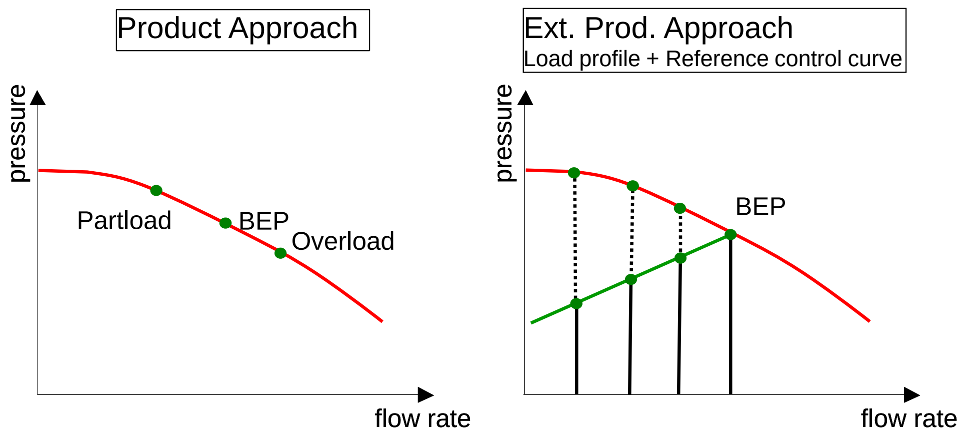


**Figure 12 Difference between a Product Approach and an Extended Product Approach**

## 1.1 Pumps in scope

The Extended Product Approach (EPA) has already been applied for circulators and forms the basis for the ecodesign requirement for these products today [1].

Figure 13 shows the road map for ecodesign requirements for pumps.

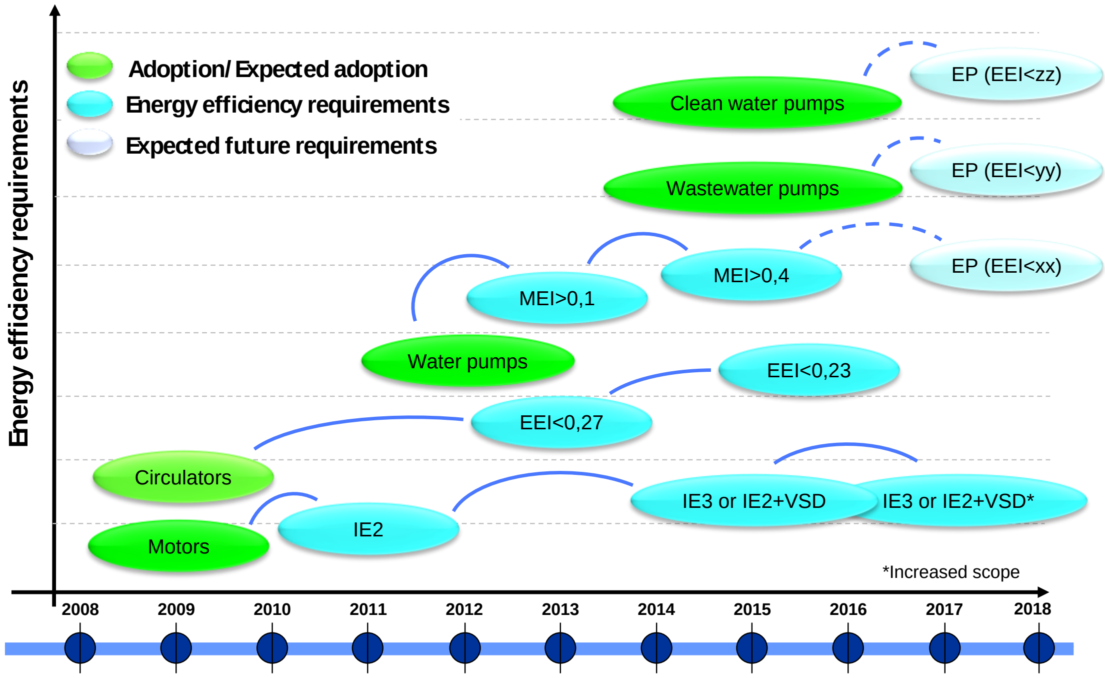


**Figure 13 Road map for energy efficiency regulation on pumps in EU**

Ecodesign requirements based on extended products (EPs) are expected to be introduced during the next 5 years and the requirements will be based on an Energy Efficiency Index (EEI) as for circulators. The following pump products are expected to be targeted:

- Water pumps as defined [2]
- Booster systems (directly or indirectly)
- Wastewater pumps as defined in (to be determined)…up to 150 kW?
- Clean water pumps as defined in (to be determined)…up to 150 kW?

## 1.2 Energy savings

The main driver for the Extended Product Approach is the huge energy saving potential. Europump estimates that a marked transformation based on the EPA for water pumps in the scope of Commission Regulation 547/2012 only will lead to energy savings of 35 TWh per year, which is approximately ten times greater than the saving in 2020 achieved by the current regulation for water pumps.

## 2 Extended Product Approach for pumps

It is important to distinguish between the *Extended Product Approach (EPA)* and the *Extended Product (EP)*.

- **Extended Product Approach (EPA)**: a methodology to calculate the Energy Efficiency Index (EEI) of an Extended Product (EP), which incorporates load profiles and control method.
- **Extended Product (EP)**: consists of physical components

The EPA is a methodology or procedure which can be used to qualify an extended product for a certain efficiency level, whereas the EP is the actual product. This is shown graphically in Figure 14.

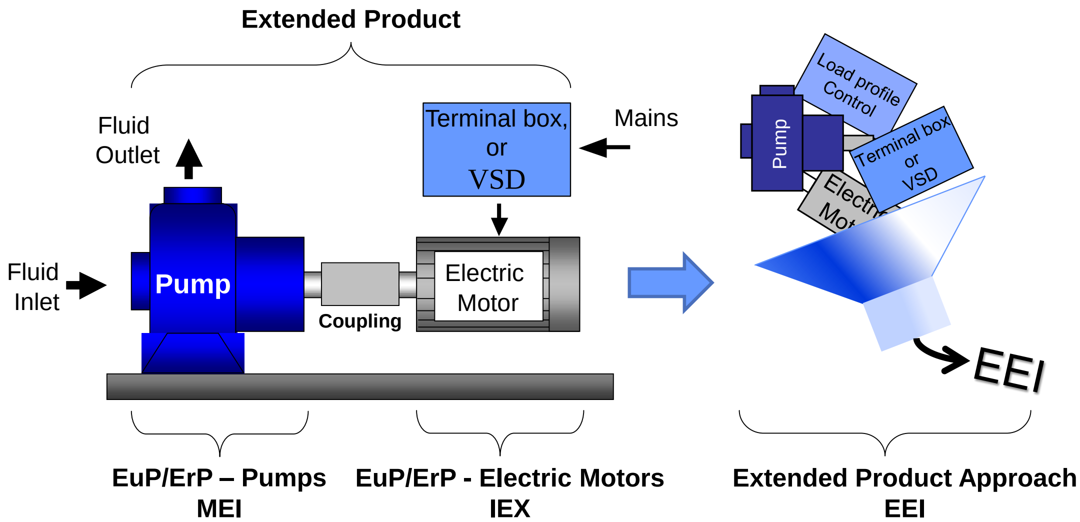


**Figure 14 Definition of Extended Product Approach**

Extended pump products are placed on the market as integrated units i.e. a pump, a motor with or without VSD which is supplied by one manufacturer as a complete unit. They are also placed on the market as separated units i.e. where the pump, motor and VSD are separate products supplied by one or more manufacturers. The EPA must be able to handle both integrated and separated extended pump products.

This leads to the following general definition for an extended pump product

| |
|---|
| *Extended pump product means a pump driven by an electric motor with or without a variable speed drive (VSD)* |

This definition is valid for all extended pump products in the scope, including circulators. The speed control is based on a system feedback which can come from sensors in the system or in the pump or from sensorless feedback transmitted by the motor.

# 3 Load Profiles and reference control curves

Extended pump products are used in a variety of applications with different load profiles and control methods. For the purpose of the EPA methodology these load profiles and control methods are grouped into the following:

- Closed loop systems or open loop systems
- Constant flow systems or variable flow systems

When combined they cover all applications in the scope.

## 3.1 Closed loop variable flow system

**In a closed loop system the purpose of the pumps is to produce enough head to overcome friction losses in the system losses in the system and satisfy the requirement for actuators (valves etc.). A typical closed system is a hydronic a hydronic distribution system of a heating and/or air conditioning system (HVAC-system). The purpose of these pumps purpose of these pumps is to distribute energy from the energy supply (boiler, chiller etc.) to the emission systems emission systems (radiator, coils, air handling units etc.) by circulating a pumped media. The load profile for these profile for these systems is shown in ~**

Table 5.

~

**Table 5 Load profile for closed loop variable flow systems**

| | Flow [%] | Time [%] |
|---|---|---|
| $L_1$ | 100 | 6 |
| $L_2$ | 75 | 15 |
| $L_3$ | 50 | 35 |
| $L_4$ | 25 | 44 |

At part load the pump head can be reduced due to reduction in friction losses in the system. The control method must take that into account. Figure 15 shows the load points from Table 5 and the reference control curve as defined for these systems (green line).

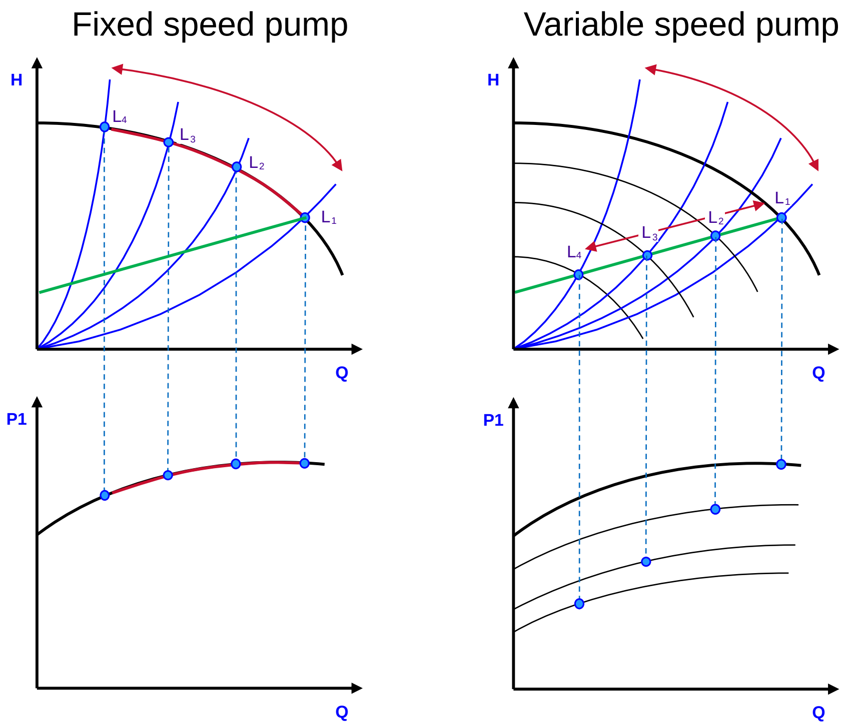


**Figure 15 Load points and control curve for closed loop variable flow systems**

The EEI calculation of all pumps (fixed speed or variable speed) used in closed loop variable flow systems will be evaluated according to this reference control curve and load profile.

## 3.2 Open loop variable flow system

Pumps in open loop variable flow systems must deliver a certain static pressure and, in addition, enough head to overcome friction losses in the system. A typical open loop variable flow system is a water distribution system in cities and buildings. A load profile for these systems is shown in Table 6.

**Table 6 Load profile for open loop variable flow systems**

| | Flow [%] | Time [%] |
|---|---|---|
| $L_1$ | 100 | 1 |
| $L_2$ | 90 | 2 |
| $L_3$ | 80 | 3 |
| $L_4$ | 70 | 4 |
| $L_5$ | 60 | 6 |
| $L_6$ | 50 | 12 |
| $L_7$ | 40 | 19 |
| $L_8$ | 30 | 26 |
| $L_9$ | 20 | 21 |
| $L_{10}$ | 10 | 6 |

At part load the pump head can also be reduced in these systems due to reduction in friction losses and the control method must take that into account. Figure 16 shows the load points from Table 6 and the reference control curve as defined for these systems (green line).

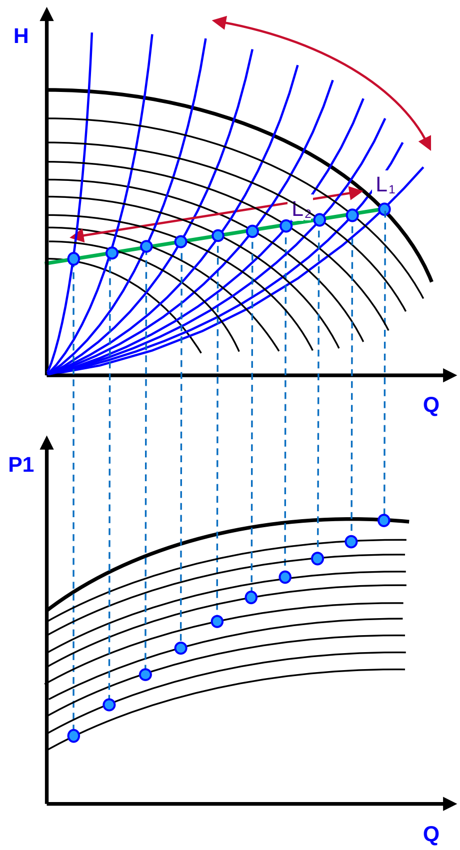


**Figure 16 Load points and control curve for open loop variable flow systems**

The EEI calculation of all pumps (fixed speed or variable speed) used in open loop variable flow systems will be evaluated according to this reference control curve and load profile.

## 3.3 Constant flow system (open and closed loop)

In a constant flow system the pump must overcome a certain static pressure in an open loop system or overcome a certain friction loss in a closed system which is designed to give a certain constant flow. A typical application of an open loop constant flow system is where the purpose of the pump is to move liquid from one reservoir to another. A typical example of a closed loop system could be a boiler feed pump. In a real system the flow is very seldom constant. For example it will vary due to the level of the reservoirs etc. Therefore it makes sense to define a load profile with a load point around the best efficiency point. Such a load profile is shown in Table 7.

Table 7 Load profile for constant flow systems (open and closed loop)

| | Flow [%] | Time [%] |
|---|---|---|
| $L_1$ | 110 | 25 |
| $L_2$ | 100 | 50 |
| $L_3$ | 75 | 25 |

These are the same load points as those used for MEI calculation for water pumps, where a time profile has been added.

Figure 17 shows the load points listed in Table 6. In these systems variable speed is not a benefit and no reference control curve is defined.

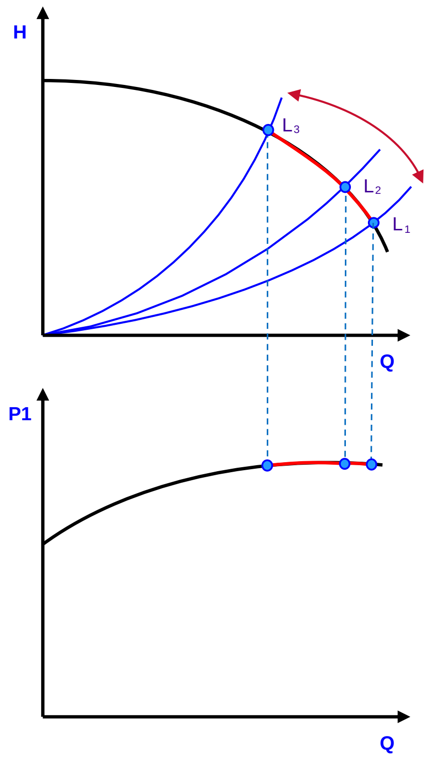


Figure 17 Load points constant flow systems (open and closed loop)

The EEI calculation of all pumps (fixed speed or variable speed) used in constant flow systems (open loop and closed loop) will be evaluated according to this load profile.

## 3.4 Relation between system types and pump types

There is no one-to-one mapping between system types and pump types. Some pump types are used in different systems. Table 8 show the relation between system types and pump types.

**Table 8 System type vs. pump type**

| Pump type | Relation to EuP/ErP | System type | | |
|---|---|---|---|---|
| | | Variable flow | | Constant flow |
| | | Closed loop | Open Loop | Closed and open loop |
| Circulators | Lot 11 | X | | |
| ESCCI | Lot 11 | X | O | O |
| ESOB | Lot 11 | X | X | X |
| ESCC | Lot 11 | X | X | X |
| MS | Lot 11 | O | X | O |
| MSS | Lot 11 | O | O | X |
| Wastewater pumps | Lot 28 | O | O | X |
| Clean water pumps | Lot 29<br>(except Lot 11 pump types) | O | O | X |

For pump types used in more than one system type, more than one EEI value will be calculated. The *product information requirements* must ensure that the EEI is calculated and documented for all the entries in the table marked with an 'X'. Calculation and documentation of an EEI are optional for the entries marked with an 'O' in the table.

The *energy efficiency requirements* must specify that when putting an extended product into service, the energy efficiency requirements (in terms of EEI) for a particular pump type used in a particular system type must be met.

# 4 Methodology for calculation of EEI for extended products

The Energy Efficiency Index (EEI) is based on the same methodology as for circulators. Basically it consists of an average power input calculated on a load-time profile divided by a reference power input.

Figure 18 shows how the power in an extended product is defined. $P_1$ is the electrical power input from the grid. $P_2$ is the mechanical power from the motor shaft. $P_{hydr}$ is the hydraulic power produced by the pump.

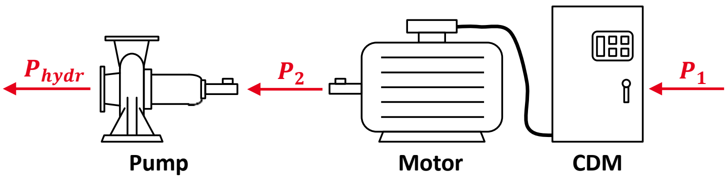


**Figure 18 Definition of *Powers* in an extended pump product. The combined motor and CDM (VSD) is referred to as a Power Drive System (PDS)**

A graphical presentation of the EEI calculation is shown in Figure 19. The left side shows the calculation of average power input i.e. the numerator of the EEI index. The right side shows how to calculate the reference power i.e. the denominator of the EEI index.

$$\boldsymbol{EEI = \frac{P_{1,avg}}{P_{1,ref}}}$$

$$\boldsymbol{P_{1,avg} = \sum_i L_i \; P_{1,i}}$$

$P_{1,100\%}$ $P_{1,75\%}$ $P_{1,50\%}$ $P_{1,25\%}$

$$\boldsymbol{P_{1,ref} = \frac{P_{2,ref}}{\eta_{mot,ref}}}$$

$$P_{2,ref} = \frac{P_{hydr,ref}}{\eta_{pump,ref}}$$

$\eta_{mot,ref}$ from IEC 60034-30

$$P_{hydr,ref} = \rho g H_{100\%} Q_{100\%}$$

$\eta_{pump,ref}$

$H_{100\%}$ $Q_{100\%}$ $n_s$

**Figure 19 Graphical presentation of the EEI calculation**

The power input values $P_{1,I}$ in Figure 19 can be measured, but this is not possible in most cases especially not for separated units. The $P_{1,I}$ values will then be calculated from Semi Analytical Models as described in the next section.

The reference power input based on actual efficiency of the pump as defined in the EC regulation for water pumps [2] and later on for the other pump types in the scope in Lot 28 and Lot 29. Based on actual measurements of the pump, the head and the flow, the best efficiency point (H100%, Q100%) is determined and from that the specific speed (ns) is calculated. Based on the hydraulic power and the efficiency, the reference shaft power $P_{2,ref}$ is calculated, which can via the IEC 600034-30 for motors be converted onto a reference power input. The reference efficiency of the VSD is set to 100% by definition. The actual efficiency of the specific VSD is captured by the power input values $P_{1,l}$ as is the case for pump and motor.

## 4.1 Semi Analytical Models (SAMs)

A methodology for an extended pump product cannot be based on measurement only although this is an option, which can be applied in some cases.

Separated extended pump products are in many cases built on site, which makes a determination of EEI based on measurements of the extended product impossible. Therefore a methodology based on Semi Analytical Models (SAMs) has been developed to overcome this problem [3].

A SAM is a model which is based on measurement combined with physical and empirical knowledge of the product. Based on SAMs of the pump, motor and VSD it is possible to calculate the EEI of the extended product based on a few measurement points (supporting points) of the individual products (pump, motor and VSD).

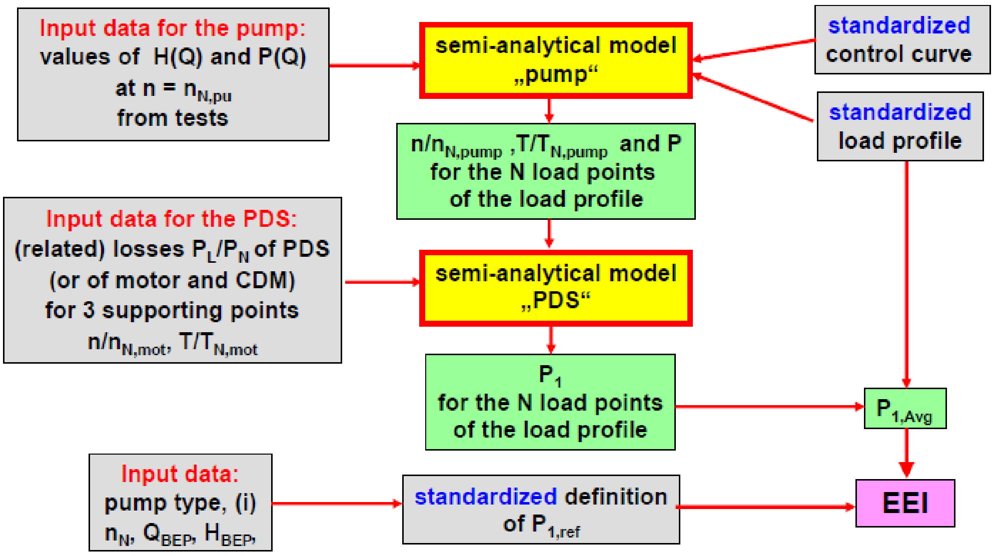


**Figure 20 Flow chart for calculating EEI of an Extended Pump Product**

Based on the SAM for the pumps, the torque and rotational speed at the part load point is calculated.

Based on SAMs of the Power Drive System (PDS) the power losses at these part load point can be calculated and used to determine the power input to the extended product.

The SAM for the PDS is decribed in [4]. Figure 21 shows the eight load points which are defined in this standard. These eight points are chosen to cover all PDS applications.

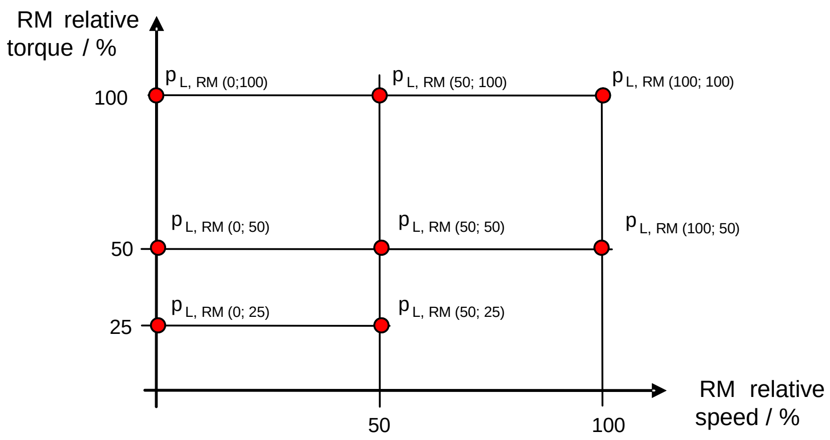


**Figure 21 Related losses of a PDS at different part load points (Source: [4])**

Figure 22 shows the three supporting points for pump applications. All pump applications in the scope will be within the green shaded area.

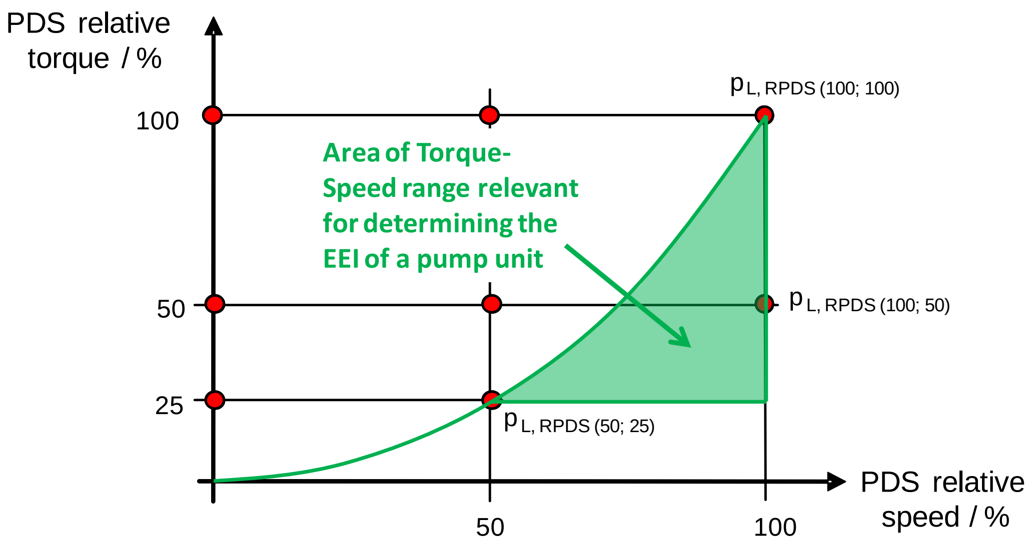


**Figure 22 Three points of related losses and shaded area of interest for pump manufacturers when calculating the EEI (Energy Efficiency Index) of a pump unit (Source: [4])**

The actual losses will be based on interpolation based on these supporting points. Part One of the PDS standard [5] will cover the generic application of the standard for extended products. A specific measurements standard must be written for all products. A draft standard for pumps is already under development.

**Bibliography**

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