EuP Lot 30:
Electric Motors and Drives

Task 4: Technical analysis existing products

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Anibal De Almeida

Hugh Falkner

João Fong

ISR – University of Coimbra

ATKINS

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4 Introduction

This section entails a general technical analysis of current products, as defined in section 1, and provides general inputs for the definition of the BaseCases. The BaseCases need to be representative of the whole spectrum of products for each category as defined in subtask 1.1, both in terms of design features and size. This is necessary so that the outputs from the EcoReport tool for single products can be extended to be representative of the entire range of sizes and styles of that sub-type. The BaseCase is the reference point for further improvements, and should therefore ideally represent the average new EU product.

For the purpose of this study, the following BaseCases for motors will be analysed, divided into three major categories according to output power:

For **Small motors** in the power range of 120 W to 750 W, two BaseCases will be considered:

- BaseCase 1 – 1-Phase Induction Motor (IM), 370 W, IE1
- BaseCase 2 – 3-Phase Induction Motor (IM), 370 W, IE1

Medium motors in the power range of 0.75 kW to 375 kW

- BaseCase 3 –1-Phase IM, 1,1 kW – IE2
- BaseCase 4 – 3-Phase IM, 1,1 kW – IE2
- BaseCase 5 – 3-Phase IM, 11 kW – IE2
- BaseCase 6 – 3-Phase IM, 110 kW – IE2

Large motors in the power range above 375 kW, up to 1000 kW.

BaseCase 7 – 3-Phase IM, 560 kW LV, IE2
BaseCase 8 – 3-Phase IM 560 kW MV (6600V), IE2

The efficiency levels for all of the above motors are based on IEC 60034-30-1 standard.

All of the BaseCase motors are 4-pole motors.

Two additional BaseCases will also be considered for submersible motors. Submersible Motors are a separable part of the Multistage submersible borehole pumps considered in Lot29. The analysis of these is within LOT30 so that the analysis is done on the same basis as other motors, but the results of this analysis will be highly relevant to LOT29.

Motor Controllers
For the analysis of Variable Speed Drives (VSDs) one additional BaseCase will be considered for all of the above motor powers, when coupled with a VSD.

Three BaseCases will also be considered, on a first approach, for Soft-Starters coupled to 1.1 kW, 11kW and 110 kW motors for the evaluation of the environmental impact of such equipment.

4.1 Production Phase

The material composition of electric motor BaseCases is presented in the following Bill-of-Materials (BoMs).

The material fractions of motors are derived from data provided from CEMEP[1] for this and the previous Lot 11 study. For Soft-Starters, the material fractions were provided by CAPIEL.

Small Motors

Table 4-1 shows the material fractions used in a single-phase induction motor of 370 W (BaseCase 1) and a three-phase induction motor of the same output power (BaseCase 2), both of IE1 efficiency levels.

Table 4-1 Bill-of-Materials for Small Motors, Basecases (370 W IE1)
Source: CEMEP

Materials	Number of Phases	
	1-Phase	**3-Phases**
Electrical steel (kg/kW)	12,5	10,5
Other steel (kg/kW)	3,0	2,1
Cast iron (kg/kW)	0- 3,5	0-3,0
Aluminium (kg/kW)	4,0	3,6
Copper (kg/kW)	2,3	1,9
Insulation material (kg/kW)	0,06	0,06
Packing material (kg/kW)	2,0	2,0
Impregnation resin (kg/kW)	0,4	0,4
Paint (kg/kW)	0,12	0,12

Medium Motors

Table 4-2 shows the material fractions of three IE2, four poles, three-phase induction motors of 1,1 kW, 11 kW and 110kW.

Table 4-2 Bill-of-Materials for Medium Motors, Basecases

Materials	Motor Rated Power		
	1,1 kW	**11 kW**	**110 kW**
Electrical steel (kg/kW)	8	4,8	3,6
Other steel (kg/kW)	1,6	1	0,7
Cast iron (kg/kW)	2,5 (0,0 - 5,0)	1 (0,0 - 2,0)	3
Aluminium (kg/kW)	0,5 - 4,0	0,25 - 1,8	0,2
Copper (kg/kW)	1,9	0,9	0,6
Insulation material (kg/kW)	0,05	0,02	0,01
Packing material (kg/kW)	1	0,9	0,5
Impregnation resin (kg/kW)	0,3	0,1	0,05
Paint (kg/kW)	0,1	0,05	0,01

Large Motors

[1] CEMEP - Comité Européen de Constructeurs de Machines Electriques et d'Electronique de Puissance (European Committee of Manufacturers of Electrical Machines and Power Electronics).

Table 4-3 shows the material fractions of two IE2, 560 kW, 4-poles, induction motor, one low-voltage and on medium-voltage.

Table 4-3 Bill-of-Materials for Large Motors, Basecases, 560 kW
Source: CEMEP

Materials	Voltage	
	Low Voltage	**Medium Voltage**
Electrical steel (kg/kW)	3,2	3,2
Other steel (kg/kW)	0,4	0,9
Cast iron (kg/kW)	1,8	2,0
Aluminium (kg/kW)	0,1	0,01
Copper (kg/kW)	0,4	0,6
Insulation material (kg/kW)	0,03	0,2
Packing material (kg/kW)	0,1	0,15
Impregnation resin (kg/kW)	0,03	0,03
Paint (kg/kW)	0,02	0,02
Other (plastic terminals, etc.)	0,02	0,03

A motor design is the balance of different parameters. Therefore the material fractions presented here are only an average value. Depending on the motor design and the steps in lamination diameter, the single value of each different material can deviate from the average value by approximately +/- 40 %.

A major factor in the balance of different parameters is the usage of cast iron or aluminium for the motor case. Therefore, these two materials have got a wide range of values. Their average value is used in the analysis of the BaseCase models and BAT.

Submersible Pump Motors

Although these only enjoy a small niche, submersible pump motors are considered here because this data may be useful in support of possible Lot 29 regulations on submersible borehole pumps.

These specialist motors are designed specifically for connection to submersible borehole pumps, and come in several fixed diameters to match the borehole size. There is also a standard NEMA flange to connect the motor to the pump. They use 2 pole induction motors, and may be of greatly varying length depending on the required power.

They are available as interchangeable “off the shelf” products, which means that it might technically be possible to apply measures relating to their environmental performance.

The market was first developed by Franklin motors, with some companies buying from this or other manufacturers, and others building their own. Larger motors may be hand wound, which enables a higher efficiency through tighter windings.

Evidence so far is that the volume produced motors have very similar efficiencies to each other, and that there are few imports from outside Europe.

Figure 1 Examples of Submersible borehole pump motors (Franklin)

Variable Speed Drives

Table 4-4 shows the material fractions of VSD for each of the BaseCase powers considered.

Table 4-4 Bill-of-Materials for VSDs

Materials	Rated Power				
	0,37 kW	1.1 kW	11 kW	110 kW	560 kW
Steel (kg/kW)	-	0,5	0,16	0,05	0,045
Aluminium (kg/kW)	1,3	1	0,22	0,01	0,009
PVC Plastic (kg/kW)	0,4	0,3	0,05	0,03	0,027
PWB (kg/kW)	0,26	0,2	0,03	0,01	0,009
Electronics small (SMD, IC,...) (kg/kW)	0,26	0,2	0,07	0,04	0,036
Electronics big (IGBT, Thyristors,...) (kg/kW)	0,065	0,05	0,02	0,03	0,027

Soft-Starters

Table 4-5 shows the material fractions of VSD for each of the BaseCase powers considered.

Table 4-5 Bill-of-Materials for Soft-Starters
Source: CAPIEL

Materials	Rated Power		
	1.1 kW	**11 kW**	**110 kW**
Steel (kg/kW)	0,020	0,005	0,011
Aluminium (kg/kW)	0,067	0,018	0,023
PVC Plastic (kg/kW)	0,120	0,015	0,015
PWB (kg/kW)	0,053	0,018	0,002
Electronics small (SMD, IC,...) (kg/kW)	0,033	0,009	0,002
Electronics big (IGBT, Thyristors,...) (kg/kW)	0,013	0,003	0,005
Copper (kg/kW)	0,080	0,003	0,010

4.2 Distribution Phase

The average volume of the packaged products for each power level is considered in the analysis of the BaseCase models.

Table 4-6 Average volume of packaged products

Volume (m^3)	Rated Power					
	0,37 kW	**1.1 kW**	**11 kW**	**110 kW**	**560 kW LV**	**560 kW MV**
Motor	0,02	0,02	0,15	1,1	3	6
VSD	-	-	-	-	-	-
Soft-Starter		0,000664	0,000686	0,00594		

4.3 Use Phase

Electric motors convert electrical energy into mechanical energy, therefore, the only energy consumed by the motor is due to the losses during this conversion. The ratio of mechanical output power to electrical input power gives the motor efficiency.

Tables 4-6 to 4-8 show the efficiency levels considered to be the average efficiency levels of the products coming into the market today. For medium motors the IE3 level is considered as it will be the mandatory efficiency level in 2015. The efficiency levels considered are based on IEC 60034-30-1.

Table 4-7 Basecase Efficiency – Small motors (0,37 kW) IE1

Motor Efficiency	Number of Phases	
	1-Phase	3-Phases
Small Motor	66	66

Table 4-8 Basecase Efficiency – Medium motors IE2

Motor Efficiency	Motor Rated Power		
	1,1 kW	11 kW	110 kW
Medium Motors	81,4	89,8	94,5

Typically, large motors above 750 kW have customized design for very specific industrial applications and are often produced according to specific requirements of the purchaser. Because of their large power and, in general, of their high number of operating hours, translating into high running costs, particular attention to efficiency is given by purchasers. Therefore, these motors tend to be specified to have high efficiency levels. For this study, it is assumed that the average motor in this power range is of IE2 efficiency level.

Table 4-9 Basecase Efficiency – Large motors (560 kW) IE2

Motor Efficiency	Voltage	
	Low Voltage	Medium Voltage
Large Motors	95,1	96,6

Medium voltage motors avoid the need to have a transformer for voltage reduction, which translates into lower net losses, and also have lower cable losses. Therefore their efficiency is considered to be slightly higher than that of LV motors.

Borehole pump motors

For each borehole size, there is a range of motor sizes that can be accommodated. There is some overlap between ranges, but in general a particular power rating will be made only for a particular diameter borehole.

Power (kW)	Motor diameter (Inches)					Motor IE Ratings		
	4"	6"	8"	10"	12"	IE1	IE2	IE3
0.37	66							
0.55	68							
0.75	70					72.1	77.4	80.7
1.1	74							
1.5	73							
2.2	75							
3	76							
4		78						
5.5		79						
7.5		79						
9.3		81						
11		81						
15		81				88.7	90.3	91.9
18.5		82						
22		83						
30			86					
37			87					
45			87					
55			88					
75			87					
85				85				
93			87					
110			88	86		93.3	94.3	95.2
130			88	88				
150			88	87				
185				88	87			
220					88			
250					88			
300					88			
350					87	94.6	95.6	96.3
400					90			

Figure 2 Efficiencies of typical submersible borehole pump motors (400V supply)

The unusual length to width and the differing cooling mechanism means that these motors are inherently less efficient than conventional induction motors, (figure 3 below). This also shows that the IE scheme curves would not be appropriate, due to the efficiency relative to the IE curves becoming worse with size.

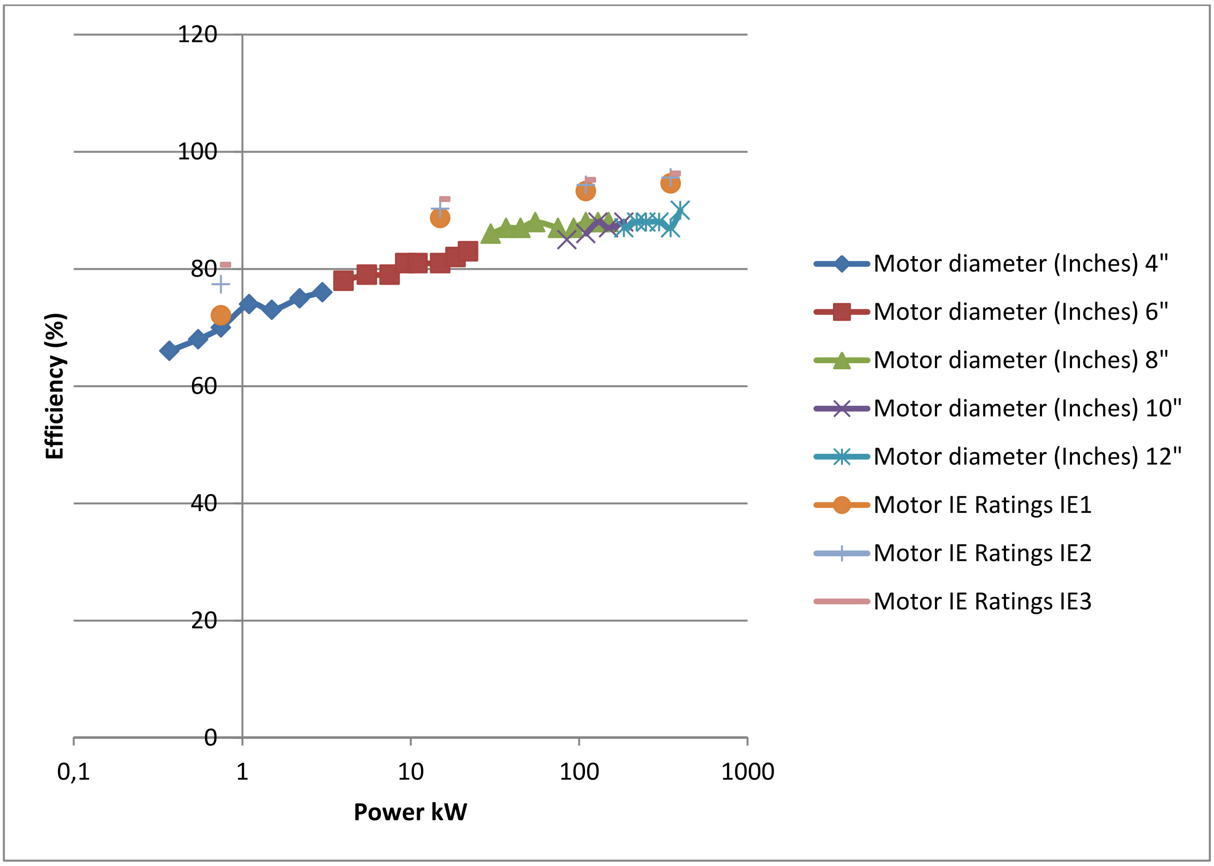

Figure 3 Efficiency of submersible borehole pump motors compared with the IE scheme values for conventional induction motors

Variable Speed Drives

Losses in VSDs occur within their control circuits (motor control, network connection, Input/Output (I/Os), logic controllers etc.), particularly in the output-switches (30-50%).

VSD losses are mainly influenced by the switching frequency and the output current (which is function of output power and load).

Table 4-10 Loss distribution for low-voltage VSDs [1]

	Typical percent of losses for passive front-end converters	**Factors affecting these losses**
Switching losses (output stage)	30 to 50	Motor-current and switching-frequency.
Line-rectifier	20 to 25	losses Line-current (nearly proportional to motor power).
Forward losses (output stage)	15 to 20	Motor current.
Internal control circuit	5 to 20	Nearly constant.

Losses (microcontroller, internal power supply, display, keyboard, buscommunication, digital and analogue ins/outs…)		
Switching losses (line-side converter / active front-end only)	-	Line-current and switching-frequency (nearly proportional to motor power).
Compound losses (line-side converter / active front-end only)	-	Line-current (nearly proportional to motor power).

The full load efficiency of a VSD is typically around 96%, decreasing with partial load.

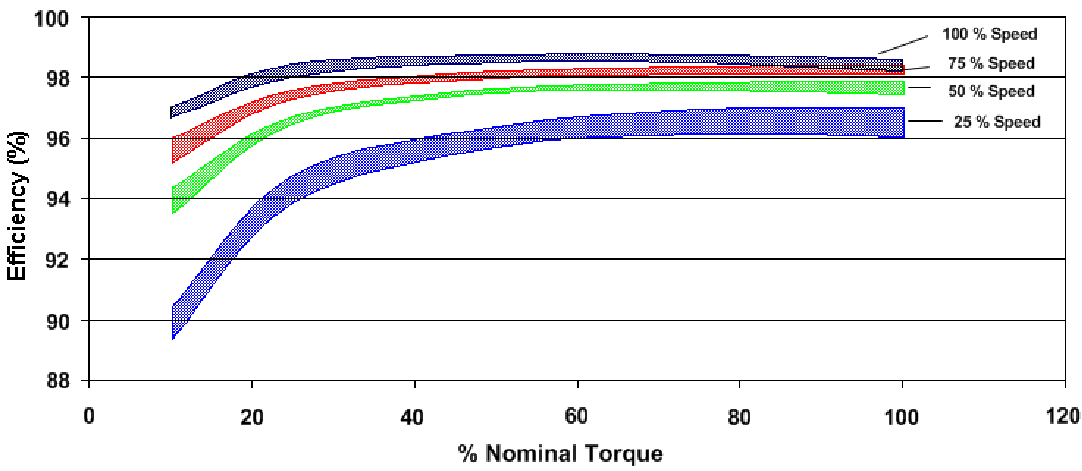

Figure 4-4 37 kW VSD efficiency [2]

Five basecases are considered for motor+VSD based on the motor powers for the motor alone Basecases.

Table 4-11 Losses relative to the apparent VSD output power (BaseCase Powers) [3]

%	Size	Speed		0%			50%		90%
VSD	kW	Torque	25%	50%	100%	25%	50%	100%	50%	100%
Very small	0.37		14.77%	14.82%	15.29%	14.87%	15.02%	15.82%	15.37%	16.84%
Small	1.1		6.86%	7.13%	7.82%	6.93%	7.33%	8.40%	7.68%	9.51%
Medium	11		2.39%	2.68%	3.61%	2.46%	2.87%	4.23%	3.20%	5.43%
Large	110		1.24%	1.48%	2.27%	1.32%	1.68%	2.91%	2.02%	4.11%
Very Large	560		1.15%	1.40%	2.22%	1.22%	1.60%	2.86%	1.93%	4.08%

Soft Starters

The estimation of the soft-starter’s power consumption is presented in the next table, for each of the power ranges considered, including electronic, possible auxiliaries and fans.

Table 4-12 Soft-Starters – Power consumption
Source: CAPIEL

Description	Power Range corresponding to basecase	Basecase Size (kW)	Power (running) W
Soft Starter - Small	0.25 - 7.5kW	1,1	5
Soft Starter - Medium	7.5 - 75kW	11	10
Soft Starter - Large	75 - 750kW	110	30

Soft-Starter losses, for 2-phase and 3-phase controlled soft-starters, typical cycle time and number of cycles per hour are presented in the next table.

Table 4-13 Typical operating parameters for soft-starters
Source: CAPIEL

Description	Power Range corresponding to basecase	Basecase Size (kW)	Loss/cycle W	Cycle time secs	No. starts /hour
Soft Starter - Small	0.25 - 7.5kW	1,1	2-phase: 1,3 3-phase: 1,9	90	40
Soft Starter - Medium	7.5 - 75kW	11	2-phase: 8,6 3-phase: 12,9	180	20
Soft Starter - Large	75 - 750kW	110	2-phase: 52,4 3-phase: 78,7	900	4

4.4 Motor system electricity use

The efficiency of a motor driven process depends upon several factors which may include:

- Motor efficiency
- Motor speed controls
- Power supply quality
- System oversizing
- Distribution network
- Mechanical transmission
- Maintenance practices
- Load management and cycling
- Efficiency of the end-use device (e.g. fan, pump, etc.)

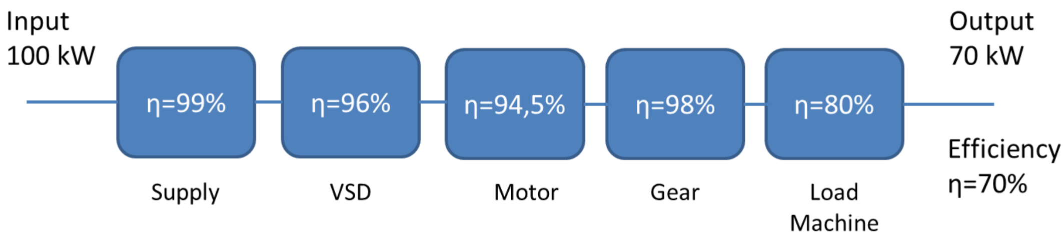

Figure 4-5 Motor system efficiency

It must be emphasised that the design of the process itself can also influence to a large extent the global efficiency of the system (units produced/kWh).

A number of important but often overlooked factors which may affect the overall motor system efficiency include: power supply quality (high-quality power supply), careful attention to harmonics, system oversizing (proper equipment sizing), the distribution network that feeds the motor (attention to power factor and distribution losses), the transmission and mechanical components (optimised transmission systems), maintenance practices (careful maintenance of the entire drivepower system) and the match between the load and the motor (good load management practice).

4.4.1 Power Supply Quality

Electric motors, and in particular induction motors, are designed to operate with optimal performance, when fed by symmetrical 3-phase sinusoidal waveforms with the nominal voltage value. Deviations from these ideal conditions may cause significant deterioration of the motor efficiency and lifetime. Such deviations include:

Voltage Unbalance

Voltage unbalance wastes energy: it leads to high current unbalance which in turn leads to high losses. A phase unbalance of just 2% can increase losses by 25%. Additionally, long operation under unbalanced voltage can damage or destroy a motor (that is why many designers include phase unbalance and phase failure protection in motor starters). Another negative consequence of unbalance is the reduction of the motor torque.

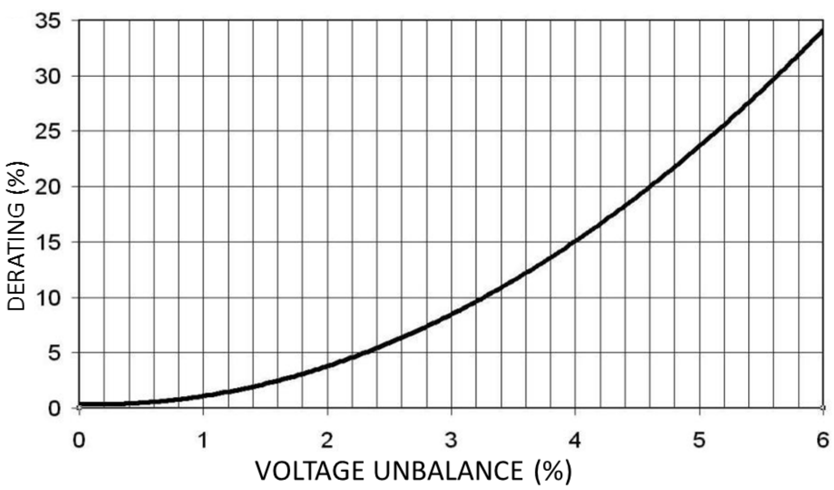

Figure 4-6 Effect of voltage unbalance on motor rating

VSD´s can accept a voltage unbalance of typically up to 3% without remark-able decrease of efficiency, while the connected motor will still run with balanced voltage**.**

Undervoltage or Overvoltage

When the motor is running at or nearly full load, voltage fluctuations exceeding 10% can decrease motor efficiency, power factor and lifetime.

Harmonics

Under ideal operating conditions, utilities supply pure sinusoidal waveforms (50 Hz frequency in Europe). However there are some loads, namely VSDs and other power electronic devices, arc furnaces, saturated magnetic cores (transformers, reactors), TVs and computers that cause voltage distortion. The resulting distorted waveform contains a series of sine waves with frequencies that are multiples of the fundamental 50 Hz frequency, the so called harmonics.

Harmonics increase the motor losses and noise; reduce torque, and cause torque pulsation and overheating. Vibration and heat can shorten the motor life, by damaging bearings and insulation. Harmonics can cause malfunctions in electronic equipment, including computers, induce errors in electric meters (one study sponsored by Electric Power Research Institute (EPRI) found measurement errors ranging from +5,9% to -0,8% in meters subjected to harmonics from VSDs), produce radio frequency static and destroy power system components.

4.4.2 Distribution Network

There are substantial losses through the distribution network from the substation to the loads. These losses can be reduced by proper selection and operation of efficient transformers, by correctly sizing the distribution cables and by correcting the power factor. In large industries it is also common to use a high distribution voltage to reduce the losses.

Transformers

Distribution transformers normally operate above 95% efficiency, unless they are old or are operating at very light load. Old, inefficient transformers should be replaced by new models that are more efficient. It is more efficient to run only one transformer at full load than to run two transformers at light load.

Cable Sizing

The currents supplied to the motors in any given installation will produce losses (of the I^2R type) in the distribution cables and transformers of the consumer. Correct sizing of the cables will not only allow a cost-effective minimisation of those losses, but also helps to decrease the voltage drop between the transformer and the motor. The use of the standard national codes for sizing conductors leads to cable sizes that prevent overheating and allow adequate starting current to the motors, but can be far from being an energy efficient design. Ideally the cables should be sized not only taking into consideration the national codes, but also considering the life-cycle cost.

In general, in new installations it is cost-effective to install a larger cable than that required by code, if the larger cable can be installed without increasing the size of the conduit, the motors operate at or near full load, and the system operate a large number of hours per year.

Power Factor Compensation

A poor power factor means higher losses in the cables and transformers, reduced available capacity of transformers, circuit breakers, and cables, and higher voltage drops.

In the case of motors, the power factor is maximum at full load, and it decreases with the load.

As discussed in section 3.3 an oversized motor will significantly drop the power factor. Thus, a properly sized motor will improve the power factor. Low power factor can be corrected by using capacitors connected to the motor or at the distribution transformer. Reactive power compensation not only reduces the losses in the network but also allows full use of the power capacity of the power system components. Additionally, the voltage fluctuations are reduced, thus helping the motor to operate closer to the voltage for which it was designed.

4.4.3 Motor oversizing

Studies on the use of electric motors in the European countries highlighted that the average motors working load is far below the rated motor power. The average load factor among all surveyed sectors (foods, paper, chemicals, ceramics, foundries and steel, tertiary sector) was estimated to range from 41% for small size motors (below 4 kW) to 51% for motors above 500 kW. In some sectors (foods, tertiary) the average working load is even lower, with a minimum of 24% for smaller motors.

The reasons why designers tend to oversize the motors are usually due to the aim of improving:

- the system reliability
- the starting torque
- the ability to accommodate increasing power requirements
- the allowance for higher load fluctuations
- the operation under adverse conditions (like voltage unbalance or undervoltage)
- the inventory of spare motors

The general practice of motors over sizing is a confirmation that the energy performances - minimum losses in motors and supply lines - are often overlooked in the industry. The machinery manufacturers, who are responsible for choosing the motor in the first place, as well as the users who should influence the buying phase or the replacement of broken down motors, should consider that the design criteria leading to over sizing may have strong consequences on the energy bill. Since motors are designed to withstand short periods of overload, there is no reason to oversize a motor just because the maximum required power is over (e.g 10-15%) the rated power of the motor, during some of the operation time.

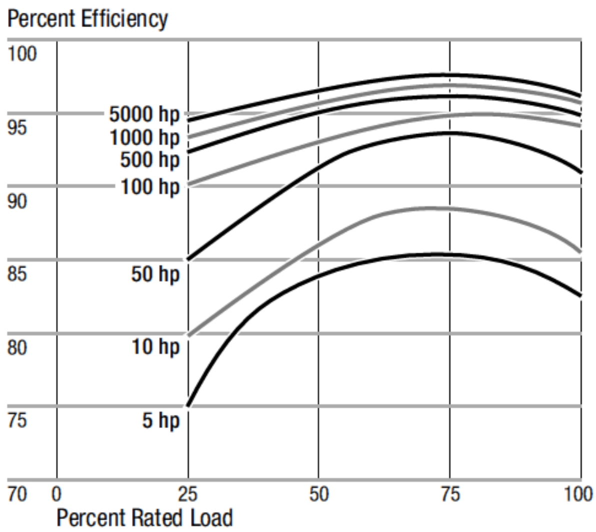

Figure 4-7 Motor Efficiency vs. Load [4]

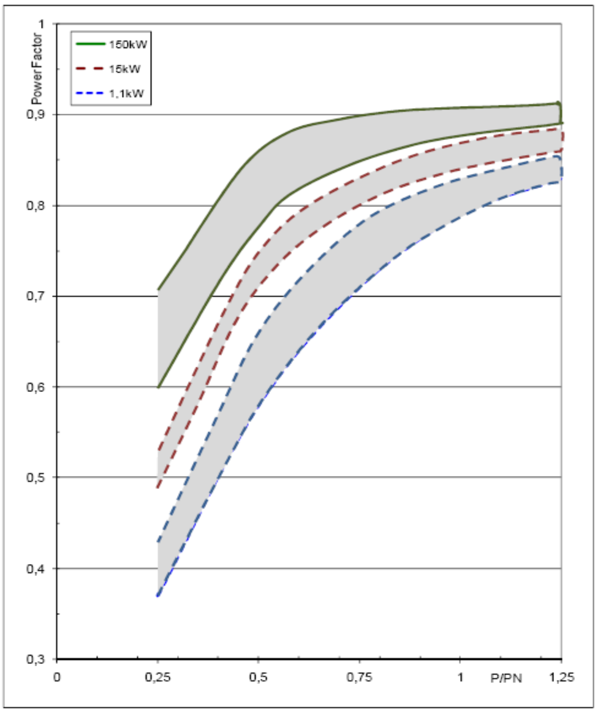

Figure 4-8 Power Factor vs. Load

Whenever a motor has a working point far below 100% of rated power, its efficiency and power factor decrease as well as the capital cost increases.

In most motors the efficiency is almost constant from 75% to full load, but it drops significantly below 50% of full load. This effect is more evident for small motors. Figure 4-7 shows the efficiency vs. load factor of different power electric motors

The comparison of the efficiency characteristics between standard and energy-efficient motors (EEM) shows that even the benefits of using EEM's may be wasted if the load factor is abnormally low.

The adverse effect of the reduction of power factor due to over sizing is often neglected. Figure 19 shows the power factor vs. load factor of electric motors.

Unless the reactive power is compensated for each motor, the additional line losses due to over sizing may, in some cases, be a key factor for the proper motor selection.

4.4.4 Transmission System

The transmission system transfers the mechanical power from the motor to the final end-use. The choice of transmission is dependent upon many factors, namely: the desired speed ratio, motor power, layout of the shafts, type of mechanical load, etc. The most important kind of transmission types available include: direct shaft couplings, gearboxes, chains and belts.

Belts

Most motors are connected to their loads through a transmission system, very frequently through a belt. About one third of the motor transmissions in industry uses belts. Belts allow flexibility in the positioning of the motor in relation to the load. Additionally, belts can also increase or decrease the speeds using pulleys of suitable diameters.

There are several types of belts namely: V-belts, cogged V-belts, synchronous belts and flat belts. While V-belts are the cheapest and are the most common type, other types can offer greater efficiency Table 1.

Table 4-14 Comparison of Belt Drive Characteristics [7]

	Typical Efficiency Range (%)	**Suitable for Shock Loads**	**Periodic Mainte-nance Required**	**Change of Pulleys Required**	**Special Features**
V-belts	90-98	Yes	Yes	No	Low first cost.
Cogged-V-belts	95-98	Yes	Yes	No	Easy to retrofit. Reduced slip.
Synchro-nous Belts	97-99	No	No	Yes, with higher cost	Low-medium speed applications. No slip. Noisy.

The V-belt losses are associated with flexing 4 times per cycle, slippage and a small percentage loss due to windage. With wear V-belts stretch and need retensioning. They also smooth with wear, becoming more vulnerable to slip. Thus V-belts need regular maintenance, which is a disadvantage in relation to other non-stretch type belts. Besides, their efficiency will drop if the load is above or below the full load (see Figure 20).

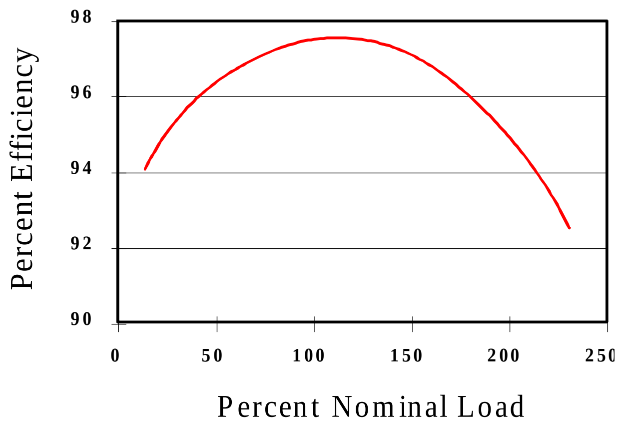

Figure 4-9 Efficiency Curve for a V-belt [8]

The cogged V-belts have lower flexing losses, since less stress is required to bend the belt and so they are typically 1-4 percent more efficient than standard V-belts. They can be used on the same sheaves and pulleys as standard V-belts, last twice and require less frequent adjustments. The efficiency gained with cogged V-belts is larger when small pulleys are used. Cogged V-belts cost 20-30% more than standard V-belts, but their extra cost is recovered over a few thousand operating hours.

The most efficient belt is the synchronous design, with 97-99% efficiency, because it has low flexing losses and no slippage. Synchronous belts have no slippage because they have meshing teeth on the belt and pulleys. Unlike standard V-belts that rely on friction between the belt and the pulley grooves to transmit the torque, synchronous belts are designed for minimum friction between the belt and the pulley. Due to their positive drive, these belts can be used in applications requiring accurate speed control. Synchronous belts stretch very little because of their construction, do not require periodic retensioning and they typically last 4 times longer than standard V-belts. Retrofitting synchronous belts requires installing sprocket pulleys that cost several times the price of the belt. In cases where pulley replacement is not practical or cost effective, cogged V-belts should be considered.

Gears

The selection of efficient gear drives can be a potential for important energy savings. The ratings for gear drives depend on the gear ratio (the ratio of the input shaft speed to the speed of the output shaft) and on the torque required to drive the load.

Today, various types of gear units are used for power transmission together with a motor. Such gear units are, for example, helical, spur, bevel or worm gear units. Other gear unit types with special profiles or a combination of types are also commonly used. Gear units are generally distinguished by coaxial or parallel axes and by those with intersecting axes.

Gear units with parallel and coaxial axes usually reach efficiency levels of up to 98% and beyond in one stage, sometimes even beyond their gear ratio. Gear units with intersecting axes (such as bevel or worm gear units) have efficiency levels of up to 98% in one stage. However, a larger gear ratio in a single stage can be achieved in gear units with intersecting axes, usually at the expense of efficiency. This becomes significant in the case of worm gears with high gear ratio.

The suitable gear unit type shall be selected by the requirements of the application, such as envelope space, noise and special attention given to efficiency at full and part load. In summary, a gear unit interacting with a motor must always be selected in view of the overall application and its requirements.

Chains

Unlike belts, chains typically have been used in low speed and high-torque applications. Like synchronous belts chains do not slip. A well-maintained chain may have an efficiency of about 98%, but wear can decrease this efficiency by a few points.

With the exception of silent chains, chains are noisy. Chains need readjustments and adequate lubrification, which may not be easy to provide. Thus the use of synchronous belts may seem as an attractive alternative to the use of chains.

4.5 End-of-life phase

The EcoReport's default values are used. It is assumed that 5% of the materials go to landfill, 90% of the plastics are incinerated and 10% are recycled and that 95% of the metals and glass is recycled.

4.6 Works Cited

[1] *IEC 60034-31: Guide for the selection and application of energy efficient motors including variable-speed applications,* International Electrotechnical Commission, 2010.

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