Energy efficiency of motor driven systems

Michael Björkman, Technical Director, Marketing

Vacon Plc

Vaasa, Finland

Abstract:

The upcoming standard on the energy efficiency requirements of variable speed driven machines is presented together with some data from the existing CD version.

One of the recurring themes in the discussions today is energy efficiency – the drive to do more with less. The climate change and CO_2 emissions debate is one obvious driver for this discussion, as is the continually increasing price of energy. This debate has been ongoing for some years and some effects of it can be seen. Looking at the trend of energy used per unit of GDP produce, it can be seen that in the more industrialized countries the ratio is not increasing, meaning that they get more out of a unit of energy than do poorer and developing countries. Partly this can be explained with the (today) higher cost of energy efficient technologies. The disregard of life cycle cost calculations is also a probable cause – investments and operations funding are handled differently. These attitudes are slowly changing – also in the developed world.

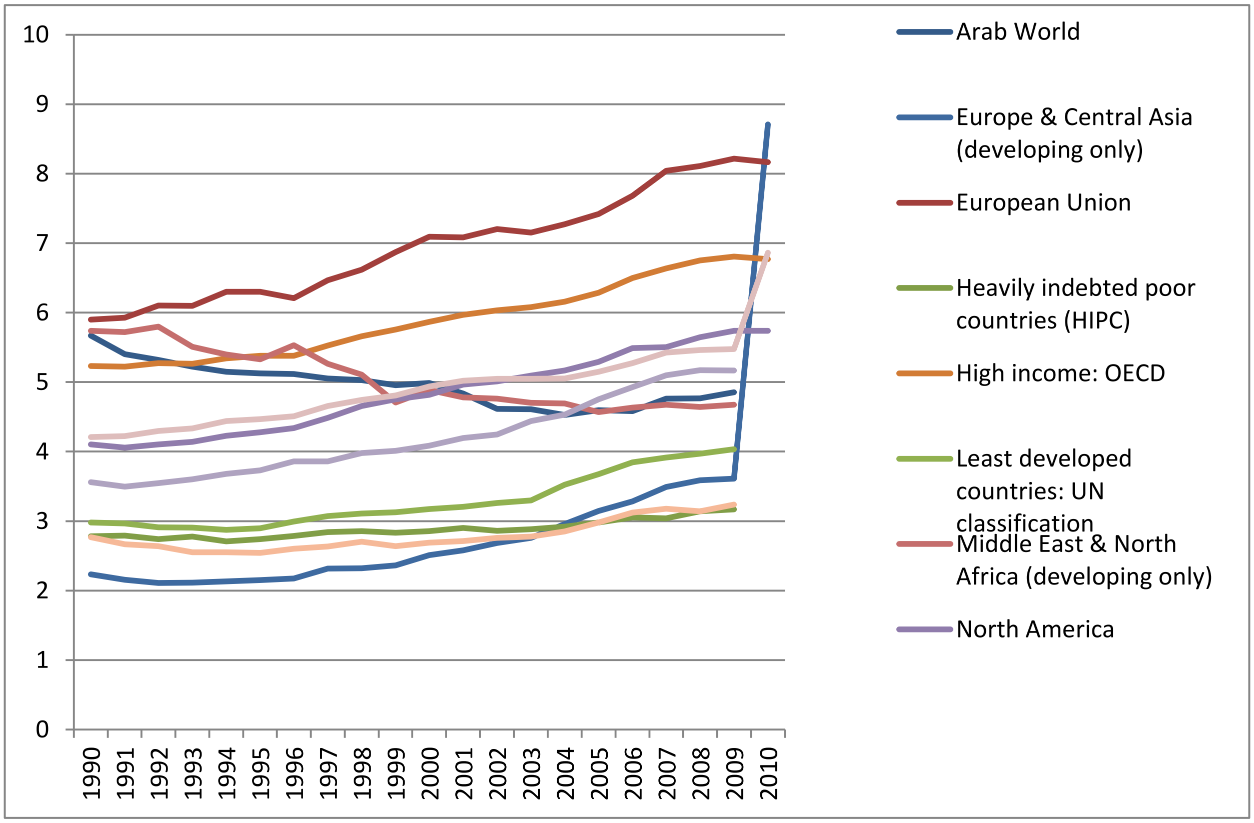

Figure 1. Energy used per unit of GDP /1/

In Europe we have had the Ecodesign Directive in force since 2009. The first lot of products covered includes electric motors – as formalized in regulation 640/2009, which requires that motors for sale in the EU have to be of at least class IE2, later IE3, unless controlled by a drive, in which case they can be IE2. A second round is now in progress, with the goal of getting motor driven systems, amongst others, within the scope of the Directive.

The new lots are as follows

- ENER Lot 27: Uninterruptible power supplies (UPS)
- ENER Lot 28: Pumps (extended product approach including motors, VSD and controls, where appropriate) for private and public waste water (including all stages including buildings, networks and treatment facilities) and for fluids with high solid content
- ENER Lot 29: Pumps (extended product approach including motors, VSD and controls, where appropriate) for private and public swimming pools, ponds, fountains and aquariums, as well as clean water pumps larger than those regulated under Lot 11
- ENER Lot 30: Products in motor systems outside the scope of the Regulation 640/2009 on electric motors, such as special purpose inverter duty motors (asynchronous servo motors), permanent magnet motors, motors cooled by their load (fans), including motors and products under Article 1, Points 2(b), (c) and (d) and including drives, such as soft starters, torque or variable speed drives (VSD) from 200W – 1000kW. The study should also cover motors in the scope of the Regulation 640/2009 from 750kW – 1000kW.
- ENER Lot 31: Products in motor systems outside of the scope of Lot 30 and the Regulation 640/2009 on electric motors, in particular compressors, including small compressors, and their possible drives.

Standard induction motors use about 30 % of all the electricity generated in the world, hence the efficiency of the motors and the systems they drive is crucial when energy savings are considered. The saving potential of motors and motor driven systems is by far the highest within the various lots considered.

The motor is a simple case in terms of efficiency - you divide the output power by the input power and get the efficiency. This seemingly simple definition has caused a lot of headaches for the standardization community, when it has tried to develop a common, standardized method of measuring the efficiency. The main problem is the fact that the efficiency of electric motors is relatively high (depending on size and speed 85 – 95 %) – this means that in order to get a meaningful number for the efficiency you have to compare two large numbers of the same size (but of different characteristics) with each other in a repeatable and reliable fashion - and this places severe requirements on the measuring instrumentation and its precision. The defined way on how to measure the efficiency is set out in IEC 60034-2-1. This is, however, valid only for motors connected directly to the mains.

Improving the energy efficiency of motors involves the use of more and better materials (more copper, better quality iron) => this does have an upfront cost implication.

However, the improved efficiency pays back this increased initial cost over the lifetime of the motor. The total cost of ownership of a motor over its lifetime is to 95 % defined by the losses in the motor, purchase price is about 2,5 % as is maintenance.

One key element in the savings is the use of variable speed drives to control the motors. VSDs are typically used in processes where the output must be controlled under changing requirements – if there are no such constraints the motor can run at full power continuously – in which case the optimization problem of the driven machine still remains – i.e. choice of the optimum machine for the given task (defining impeller size, fan blade angles etc)

Normally changes in output always mean changes in the power required to drive the system, theoretically the required power and hence energy is reduced when the output is reduced. The details on how much are defined by the type of application.

The challenge then becomes one of being able to define the best and most efficient way of controlling a process. This is an extremely complex undertaking, requiring knowledge of all components in the system – the source, the grid, the basic drive module (BDM), the motor, the driven machine and finally the process it is driving. The process of defining standards and specify how to apply them in this area has been started by a mandate (M/470) from the European Commission to Cenelec on the subject of the efficiency of motor driven systems. Work has started in TC22X WG6. Cooperation has been intensive with both TC2, the motors standardization committee as well as with the pump manufacturers as well as committees responsible for other types of driven machines.

The basic approach is the so called extended product approach – where the drive/controller, motor and driven machine are considered as one unit. An Energy Efficiency Index (EEI) is calculated for each application – built up of various components with different characteristics. Basically an EEI = 1 defines the theoretical efficiency limit of a given system – the higher the EEI the more inefficient the driven system = the less efficiently the components of the driven system are used. There are obvious challenges with this approach from a standardization point of view, given the wide range of products available on the market– how can we bring together the various bits and pieces in a logical and repeatable manner, so the required efficiency indices can be calculated?

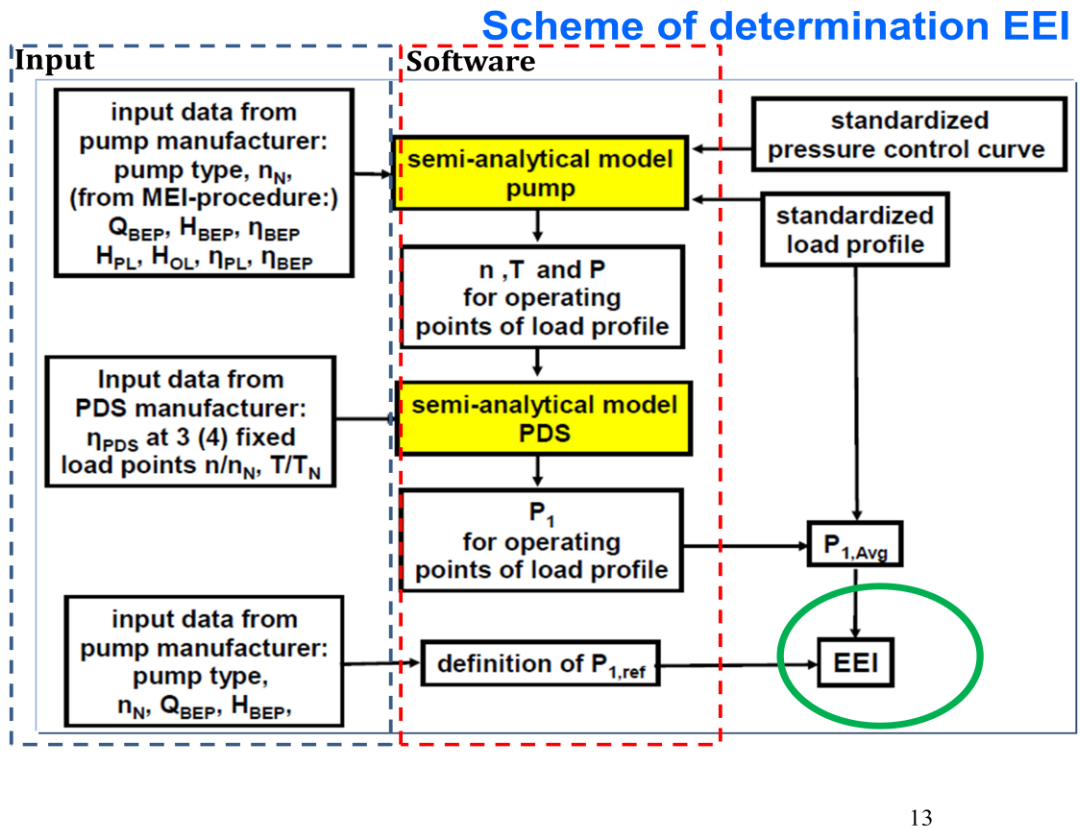

Figure 2: Determination of EEI /2/

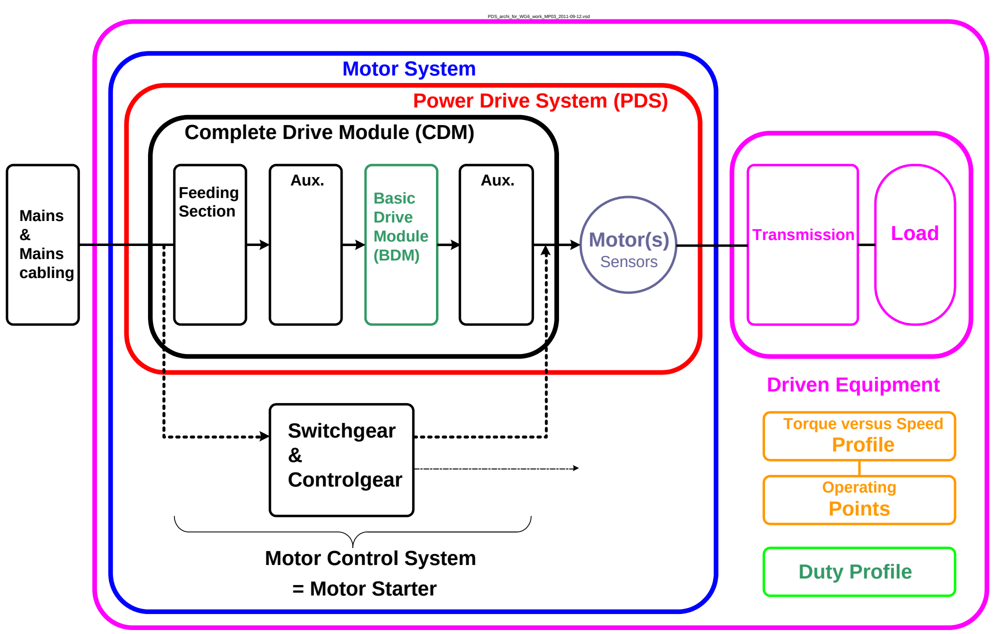

Figure 3. Scope of efficiency standardization /2/

The first challenge is to be able to define the efficiency of the parts of the power drive system (PDS). The motor efficiency in direct on line applications is already clear, but using the same motor on a drive will increase its losses, decreasing its efficiency. The question is then by how much – and this turns out to be a simple question with a difficult answer. The answer depends on multiple parameters –basic drive module (BDM) design, the choice of semiconductors, the switching speed and frequency, to a lesser extent the modulation pattern as well as on the details of the motor construction. The use of various types of filters between drive and motor also change the efficiency values. These issues are addressed in the standard EN 50xxx – 2 -at this time this document is in the process of being commented on, as a CD (Committee draft). The document defines the so- called semi- analytical (SAM). The document is not yet final and will most probably change, but the main definitions regarding measurements and definitions are presented. The final goal of the standard is to be able to present the motor and the drive as well as the characteristics of the driven machine as semi-analytical models for calculating the EEI for any given system. WG6 focuses on the SAM of the PDS, the SAMs of the driven machines are the responsibility of the various other standardization committees. The final standard should be available by the end of 2014 – very fast as standardization work goes.

Changing the load in the case of PDS can mean different things – the motor can run at full speed but at half rated torque = half rated power or full torque at half speed = also half rated power, but the difference in torque and speed between these two points stress the drive system components in different ways. Full torque basically corresponds to rated current – this means that the motor losses are about constant over speed, so the motor efficiency decreases as the speed drops. Running at full speed at lower loads corresponds to the normal part load regime for direct on line motors – the efficiency is about constant, even increasing slightly at about 75 % load and drops rapidly below 25 % load. From the point of view of the BDM (the drive) full current means that the output IGBT bridge is fully loaded, basically generating constant losses, the input bridge load and its losses then depend on the power being drawn by the load. Conversely, at lower currents the IGBT bridge load and losses decreases and the input bridge load and power decrease with the power being drawn by the load.

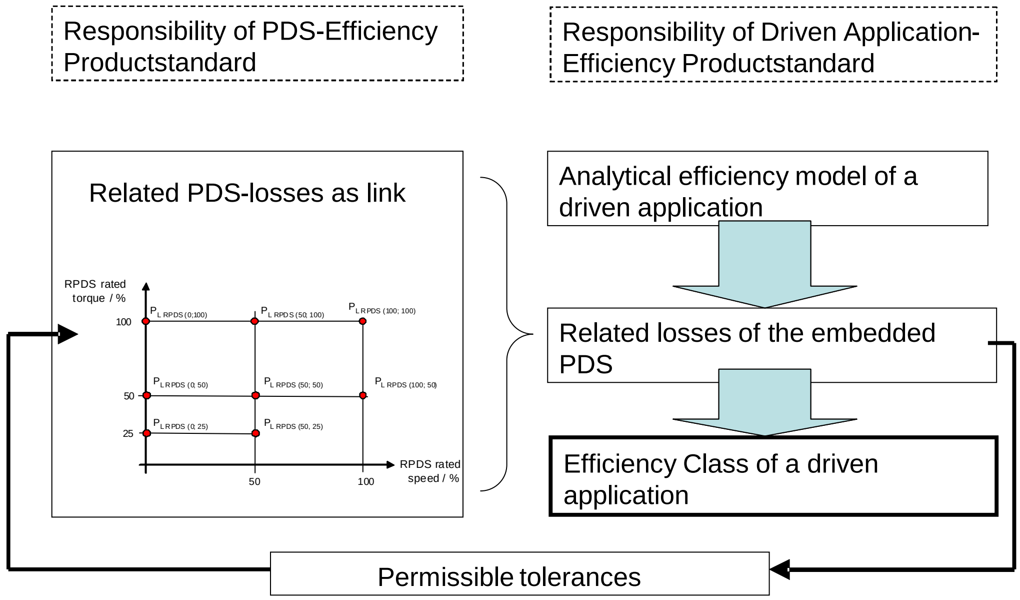

Figure 4: Scope of new standard /2/

The goal of the standard is to enable system designers and manufacturers of the driven equipment to give some reference values to the final customers, values describing the energy efficiency of how his process is controlled. The efficiency of a PDS is already high – the efficiency of the process control is achieved by using the PDS, not by the exact details of the PDS.

The basic PDM consists of two different parts – often manufactured by different companies – i.e. the drive itself, the BDM, and the motor. The losses of these two parts are interdependent – the details of how they work under different conditions will define the total system losses. These losses cannot usually be inferred from data published, they have to be explicitly given. As the manufacturers of the parts differ (even if they are divisions of the same company, the areas of interest still differ) it is in practice impossible to publish losses of all drive/motor combinations. Therefore the approach has been to define both a reference motor and a reference BDM – so the manufacturers of one can use the data of the other in order to publish data for their own product.

The area where the PDM can operate has been simplified in that only 8 points, where the losses are determined, have been defined. The losses for intermediate points can be found using linear interpolation. The (0;0) point can be added as a measure of the stand by losses of the system.

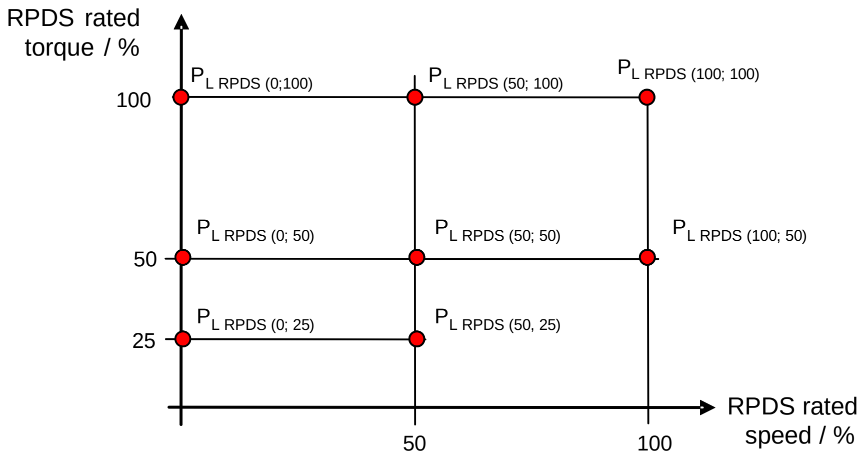

Figure 5: Data points for a PDS /2/

For a pump the data would be used as follows:

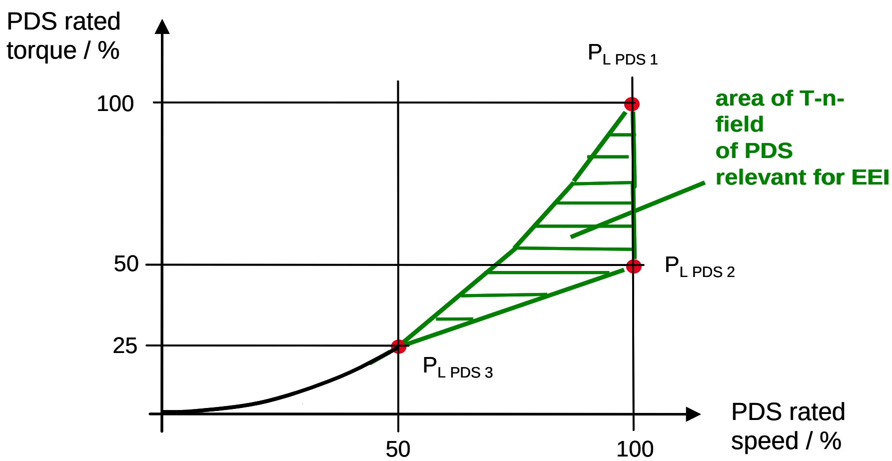

Figure 6:Data points for a pump /2/

i.e. only the losses in the area of relevance for a pump would be used. A constant torque load, such as a compressor would use a much larger operation area.

The operation points for the motor and the drive are then defined in a corresponding manner, enabling a complete evaluation to be made for a given PDS driving a given load under various speed/torque conditions.

The typical relative losses of a PDS (standard CDM and standard motor) are as follows:

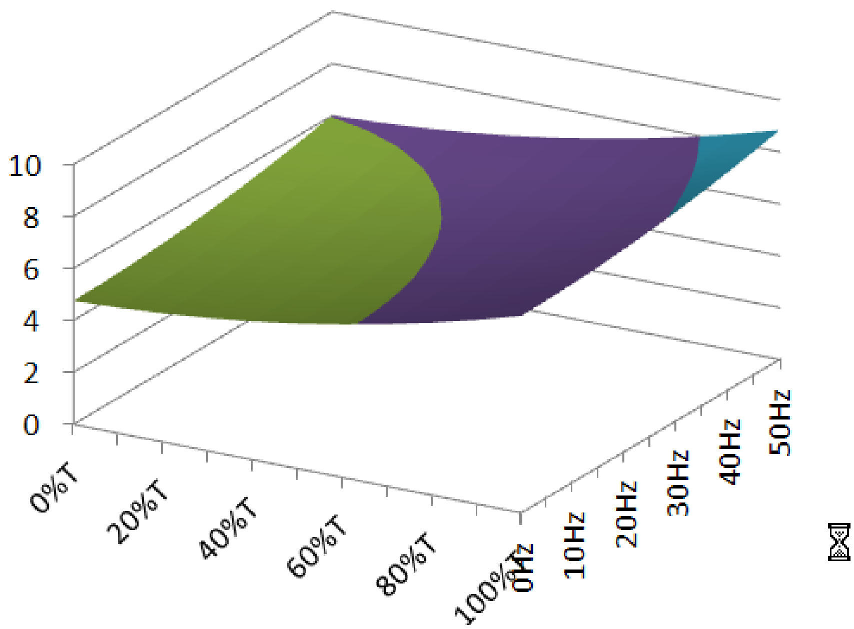

Figure 7: Typical example of the relative power losses presented as versus speed and torque within a PDS /2/

The losses of the CDM are almost constant, whereas the motor losses change more as a function of speed

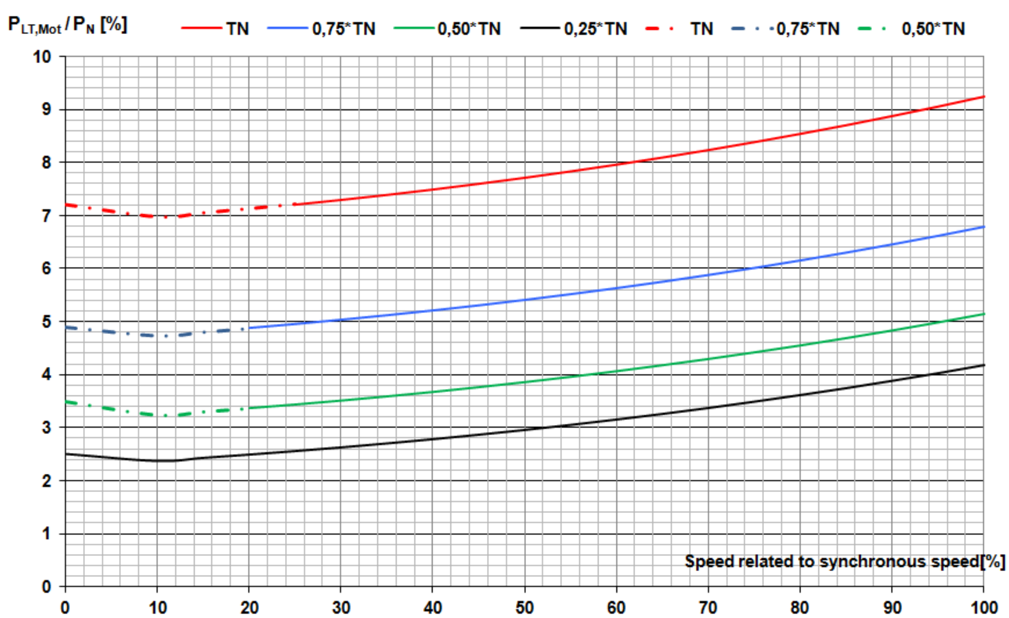

Figure 8: Relative losses of motor versus relative speed, converter operation/2/

The relative power losses of the reference BDM change in the following manner:

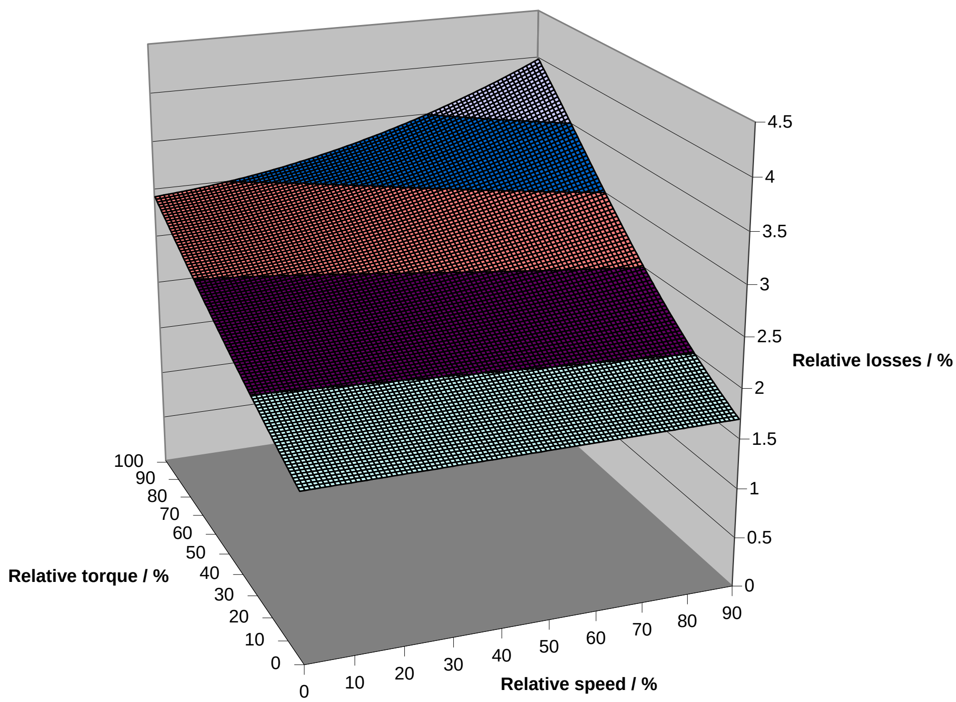

Figure 9 :Relative losses of the 7,5kW reference CDM /2/

For a pump , the pump efficiency at various operating points would typically behave as follows :

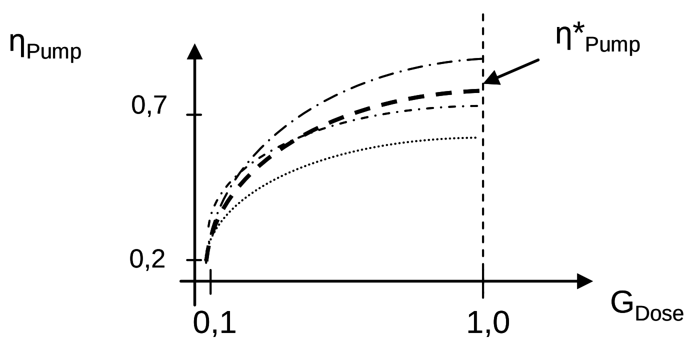

Figure 10: Typical variations of different pump efficiencies for a closed circuit fluid system (e.g. controlled by a throttle)/2/

where G_{dose} is the relative load of the pump G_{dose}=1 means the pump is running at its rated capacity at its optimum point.

As can be seen from these examples, usually the efficiency of the driven machine is crucial in determining the total system energy efficiency. In terms of energy savings (not directly efficiency) an even more important factor is the way the load torque behaves as a function of the speed as well as how much of the time the system operates at different loads.

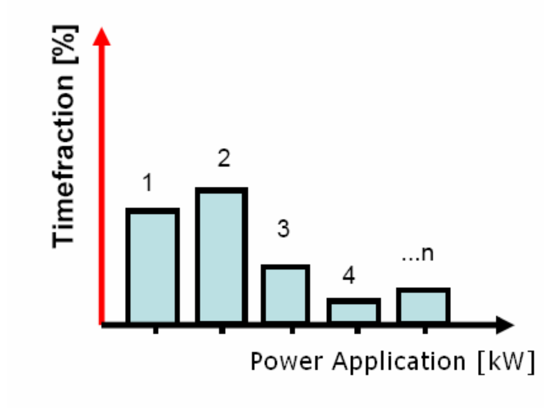

Figure 11: Dwell time curve of an application /2/

If the system operates at rated load all the time no control is required and the best efficiency is achieved by finding the best driven machine for that production rate and using a high efficiency motor and a DOL (direct on line) starter or a soft starter. When the demand fluctuates it is usually energetically more advantageous to change the production speed instead of throttling the production in some manner.

The new standard proposes a classification scheme for the various parts of a PDM in order to assist customers and users in choosing the best system. The various parts have their own classes, for BDM

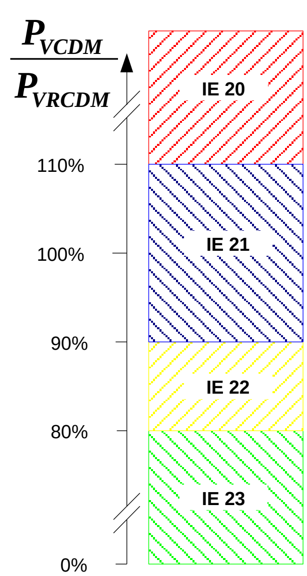

Figure 12: Proposed IExx classes for BDMs/2/

i.e if a specific BDM has losses within ±10% of the losses of the reference converter it is classed as IE 21, if the losses exceed 110 % of the losses of the reference converter it is IE 20, if the losses are between 80%and 90% it is IE 22 and less than 80 % IE23

For the total PDS the following classes are proposed

PDS IE class	PDS losses
IE30	>RPDS losses
IE31	<= RPDS losses
IE32	<= 90% RPDS losses
IE33	<=80% RPDS losses

The motor losses are defined by the normal IE class, as defined by IEC 60034-30, with an added (proposed) digit to specify the added losses caused by the harmonics of the switching voltage pattern.

Increased efficiency = decreased related power losses

Line fed motor	Converter fed motor	Converter CDM	Power Drive system PDS	
	IE10	IE20	IE30	
IE 1	**IE11**	**IE21**	**IE31**	**Reference classes**
IE 2	IE12	IE22	IE32	
IE 3	IE13	IE23	IE33	
IE 4	IE14	IE24	IE34	
IE 5	IE15	IE25	IE35	
IE 6	IE16	IE26	IE36	
IE 7	IE17	IE27	IE37	
IE 8	IE18	IE28	IE38	
IE 9	IE19	IE29	IE39	

Figure 13: Proposed total classification scheme /2/

Note that the table should not be read so that an IE11 converter fed motor plus an IE CDM automatically corresponds to an IE31 PDS – a separate calculation has to be done for each specific case. Also note that the designations 'IE' might still change, as the standard evolves.

For the purpose of loss calculations, the power losses of motor starters according to the product standard EN/IEC 60947-4-1 shall be calculated as 0,5% of the rated motor power.

Soft starters according to the product standard EN/IEC 60947-4-2 are usually bypassed and therefore calculated like motor starters as well.

The goal of the new standard is to help users and designers to choose the optimal motor driven system for each application. Defining a reference PDM, consisting of a reference motor and a reference basic drive module will allow the designer to make a relatively accurate first estimate of the losses involved in controlling his process under various control schemes. He can then do a first, basic choice, on how to control his process after which he can refine his choices concerning motors and BDM or fixed speed control and their characteristics.

References:

1. www.worldbank.org
2. Draft standard TC22X WG6 22X/123/CD