TOPMOTORS FACT SHEET No. 28

Motor Systems Tool (MST)

The five key aspects of system optimisation

1. Adapting the system correctly to the demand
2. Optimising the running hours
3. Using modern, efficient components
4. Operating the system based on load – no throttling or bypassing
5. Monitoring and interpreting energy consumption

Free download: www.topmotors.ch/tools

Objective and target group

The Topmotors Fact Sheet No. 28 focuses on the systematic analysis of efficient industrial motor driven systems using the new version of the Motor Systems Tool (MST). The MST allows technically interested people (users, planners, installers, energy consultants, etc.) to coordinate motor driven systems including their respective power output and level of efficiency, and to show the result as a diagram. It features a comprehensive database of standard motors, applications (ventilators, pumps, etc.) as well as transmissions in the form of gears and belts. Thanks to the content stored in the database, complex motor driven systems can be represented in detail using only a small amount of data input. The tool immediately shows any changes made to the motor system and calculates how these changes affect individual components, the total system efficiency, energy consumption as well as the resulting energy costs. The MST can be used to specify up to 12 different duty points in order to simulate different operating states over the course of a year as realistically as possible.

Basics

Electric motor driven systems account for half of the global electricity consumption. An ideal overall level of efficiency can only be achieved when all of a motor system's components are perfectly coordinated. This means that a system's components are specifically adapted to the duty point and the demand of the process.

The most important components of a motor driven unit are as follows (see Fig. 2: Motor driven unit):

- the electric motor
- the frequency converter
- the mechanical elements (gears, belts, brake, coupling, throttle, etc.)
- the powered work machine (pump, ventilator, compressor, conveyor belt, lift, process machine, etc.)

The MST is an important tool for correctly scaling all of these elements and taking into account all relevant operating states, because it applies systemic analysis methods to calculate the losses of the individual components and

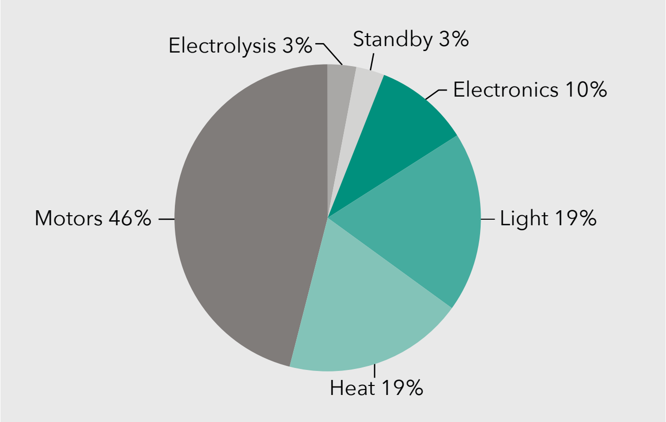

Figure 1: Share of global electricity demand by end use. Source: Paul Waide & Conrad U. Brunner, et al., IEA Energy Efficiency Series, Working Paper, 2011

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automatically show the total system efficiency – a quick and easy way to determine a system's annual energy consumption using selected duty points.

Efficiency of the individual components

Motors

In accordance with the updated IEC 60034-30-1 standard published in 2014, the efficiency levels of electric motors at nominal capacity are divided into four efficiency classes:

- IE4 Super Premium Efficiency
- IE3 Premium Efficiency
- IE2 High Efficiency (formerly Eff1)
- IE1 Standard Efficiency (formerly Eff2)

The total efficiency level is the product of all individual efficiency levels. That is why it is important for each component to present good efficiency and be run in the correct duty point.

Frequency converters

The efficiency level of frequency converters running at nominal capacity at 100% torque and 100% speed is relatively high. The exact figures of an converters level of efficiency depend on how it is set up. Efficiency is further influenced by factors such as pulse frequency and duty point. It is reasonable to estimate that the losses of the frequency converter are similar to those of the motor. For further information on frequency converters, please refer to the Topmotors Fact Sheet No. 25: Frequency Converters (www.topmotors.ch/merkblaetter).

Gears

The efficiency levels of gears vary depending on their mechanical structure. As a result, it is virtually impossible to make valid generalisations about their efficiency. This is where the Motor Systems Tool comes in handy: It uses gear data such as design, torque and speed to determine the respective efficiency level of worm gears, bevel gears and helical gears and to reliably calculate all occurring forces and losses.

Belts

Transmission belts also differ significantly in terms of structure, shape and material composition. This results in a wide variety of different belt types with different levels of efficiency. Once again, the Motor Systems Tool is here to help: Its database contains a large number of belt types and variants. This allows the user to retrieve all the required values for power output, efficiency and losses from the database using only a small amount of data input.

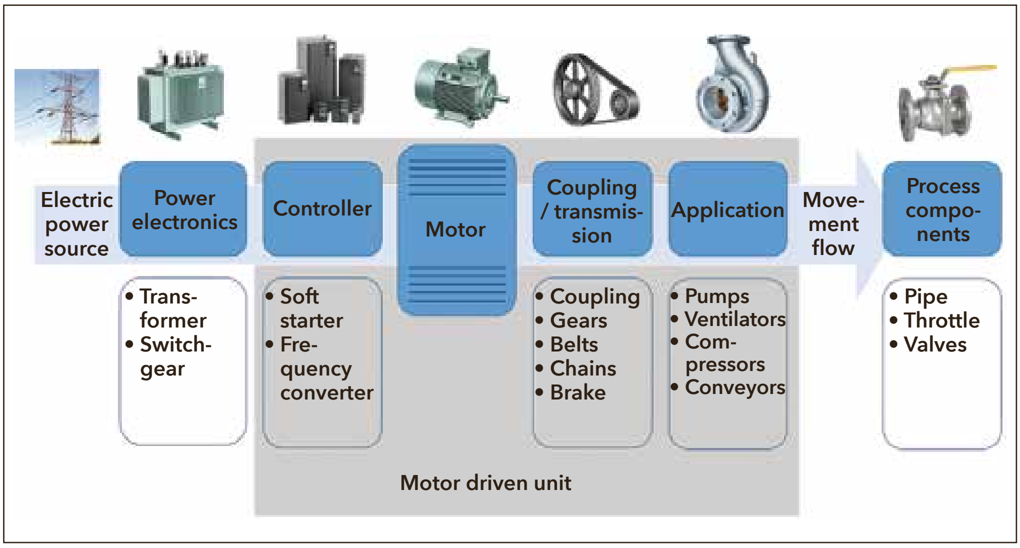


Figure 2: Motor driven unit

Motor Systems Tool

The Danish Technological Institute (www.dti.dk) published the Motor Systems Tool in 2011. It is the only free, manufacturer-independent software tool on the market that systematically gathers and analyses data on electric motor driven systems. Ever since the tool's launch, its database has continued to expand. In addition to the existing English and Danish versions, a German and a French language version of the software have also become available since 2017.

Not only has the number of language versions significantly increased, but the product databases have also been adapted to the updated IEC standards (IEC 60034-30-1 and IEC 61800-9-2) and considerably expanded to also include new motor technologies like permanent magnet and synchronous reluctance. The current version of the MST contains the following components including the respective data:

Motor

- Standard induction motor
- Permanent magnet motor
- Synchronous reluctance motor
- IEC-61800-9-2 reference motor
- Connection method
  - Direct On Line
  - Soft starter
  - Frequency converter

Transmission

- Belts
  - V-belt
  - Cogged V-belt
  - V-ribbed belt
  - Toothed belt
  - Flat belt
- Gears
  - Worm gear
  - Bevel gear
  - Helical gear

Application (work machine)

- Ventilator
- Water pump
- Hydraulic pump
- Air compressor
- Cooling compressor
- Other applications

The Motor Systems Tool can calculate all the relevant parameters such as power input and output, torque and speed at four selectable duty points in the drive system:

- P1 – Motor Input Power
- P2 – Motor Shaft Power
- P3 – Load Input Power
- P4 – Load Output Power

The MST is suitable for all use cases of motor driven units. Below, the path from input to output is illustrated using the example of a ventilation system. A comprehensive instruction manual for the MST is available at:
www.motorsystems.org/motor-systems-tool

Application example: Ventilation system

This application example illustrates the optimisation of an existing ventilation system that conveys the same pressure and the same volume of air both before and after the optimisation.
The unit used in this example is a system with a variable volumetric flow rate. However, this case study only shows the system optimisation with regard to one single duty point: the maximum duty point.

In addition to the ventilator, this motor driven system comprises a transmission, a motor and a frequency converter for load control.

Before system

Ventilator

Measurements showed that at a total pressure increase of Δp_t: 2200 Pa , the ventilator (with backward-curved vanes) has a conveying capacity q_v of 4.0 m^3/s. This information is used to calculate the pneumatic performance (P4):
$P4 = q_v \bullet \Delta p_t = 8{,}8$ kW.

The diagram shows that for this duty point, the ventilator has an efficiency level of 84%. The figure also reveals that the ventilator rotates at around 1840 rpm in order to supply the measured volume of air at the defined pressure.
This information is later entered into the MST and taken into account during the calculations.

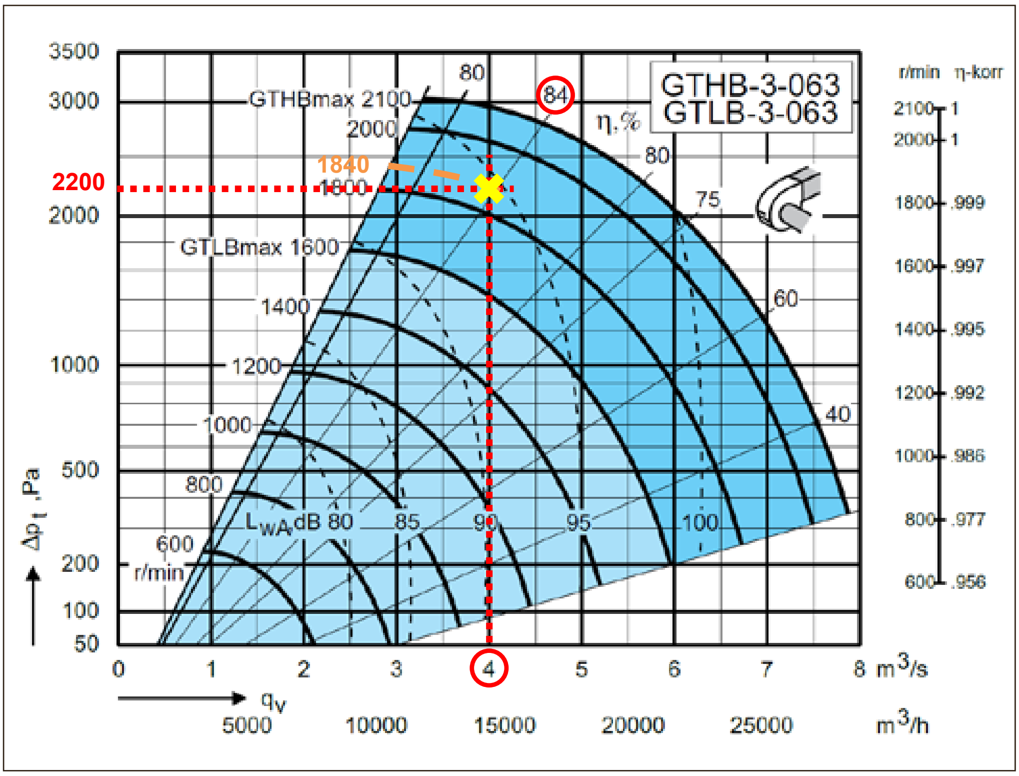


Figure 3: Operational graph of the 'Centrimaster GT3' ventilator
https://oelandonline.dk/docs/Arkiv/GTLB_3_630_teknData_EN.pdf

Once the Motor Systems Tool is started, the start screen appears, showing the three components of the motor driven system. In this example, you are guided step by step through the process of creating a motor driven system.

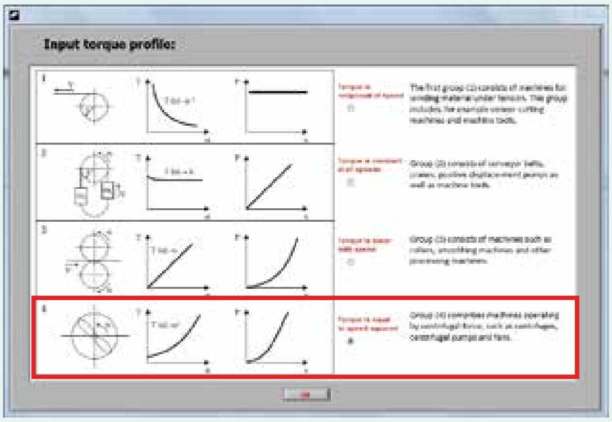
Step 1: Load

Step 2: Transmission

Step 3: Motor & Frequency converter

Step 1: Input torque profile

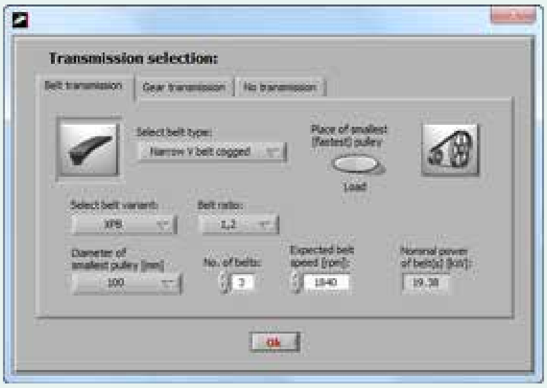
First, the load type is selected. This example featuring a ventilation system is an application with a quadratic characteristic curve according to the 'Load profile 4: Torque is equal to speed squared'.



Step 2: Transmission selection

This example uses a belt transmission system. Please set the transmission as shown in the diagram and confirm your data input by clicking the 'OK' button.

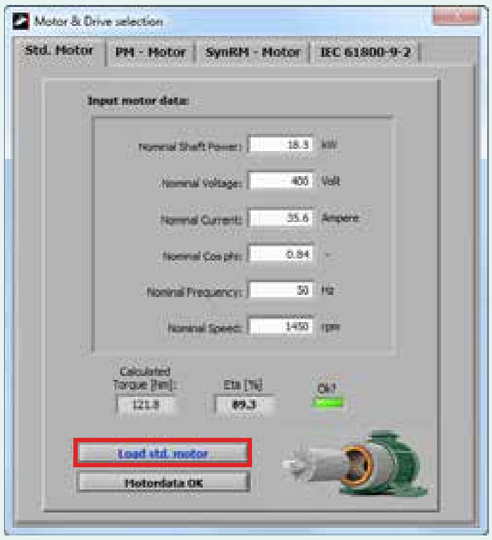
PS: 'Expected belt speed [rpm]: 1840' refers to the speed (according to the diagram) of the ventilator.



Step 3: Motor & Frequency converter

The current example uses a motor with a ratingplate that is no longer legible. We only know that it is an 18.5-kW asynchronous motor with four poles. Due to the fact that all other information is missing, we will assume this is an IE1 motor.

Click on the button that says, 'Load std. motor' to select the respective motor from the database.

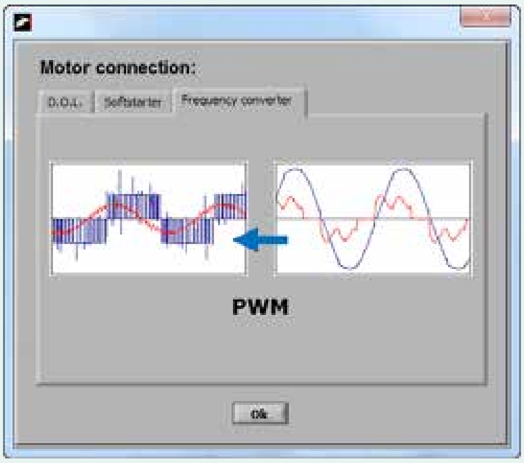


Step 3.1: Motor connection

Once the selected motor type has been confirmed by clicking ‘Motordata OK’, a window appears, showing the different motor connection methods that are available. Here you can choose between the following three connection methods:

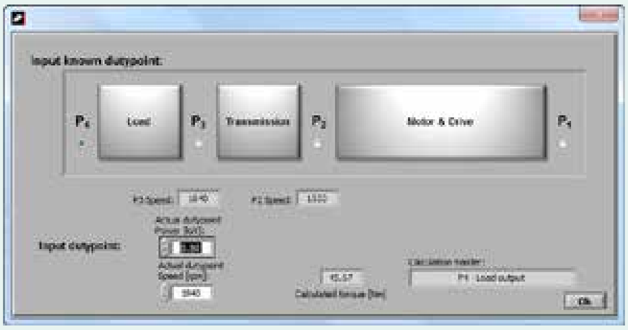
1. Direct On Line (D.O.L.)
2. Soft starter
3. Frequency converter

The system featured in this example has a variable volumetric flow rate due to a frequency converter.



Step 3.2: Input known duty point

After clicking the ‘OK’ button, the following window appears: The tool requires a known point in order to calculate all other points. In this case, we know that point P4 has a measured value of 8.8 kW (‘before state’). Furthermore, we know that the required speed of the ventilator is 1840 rpm. All necessary information has now been entered. Once you click the ‘OK’ button, the tool calculates the data.



Without further data input, the MST uses a ventilator efficiency level of 65 % as the base for its calculations. This value can be defined more precisely by clicking ‘Input known duty point’.

Step 4: Input known duty point

In this step, you enter the information about the ventilation system that has been available from the beginning.

- Airflow: 14 400 m^3/h
- Pressure: 2200 Pa
- Recalculated efficiency: 84 %

The before-state of the drive system has now been fully determined.

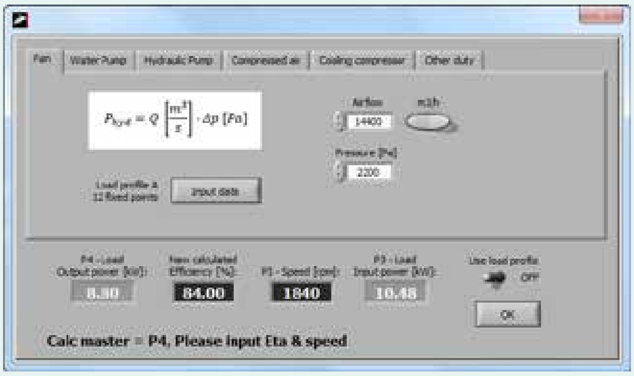
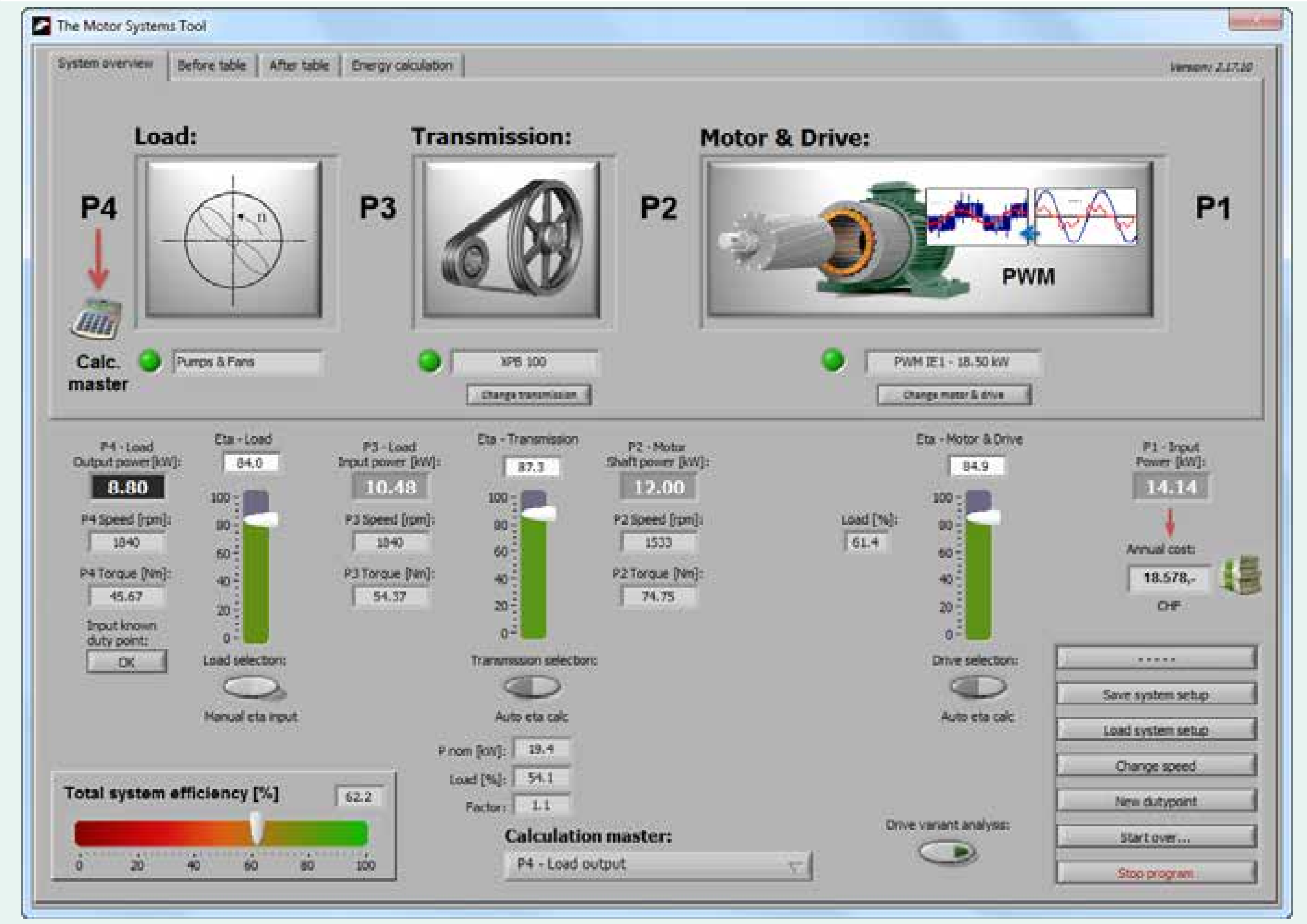


Figure 4 shows the result of the motor driven system's before-state.



It is clear that the individual efficiency values of load, transmission and motor & converter range from 84.0 % to 87.3 %, yet the total efficiency level of the overall system is significantly lower, presenting at just 62.2 %.

The total system efficiency is the product of the individual efficiency levels:

$\eta_{System} = \eta_{Load} \bullet \eta_{Transmission} \bullet \eta_{Motor\ \&\ FC}$

$\eta_{System} = 84.0\,\% \bullet 87.3\,\% \bullet 84.9\,\% = 62.2\,\%$

The Motor Systems Tool now allows you to change components or duty points. The effect of these changes on power output, efficiency and speed are displayed immediately.

The tool calculates the 'Annual costs' of electricity and also allows the user to compare and contrast different variants and optimisation setups. By clicking on the money icon, the user can individually adjust the annual running hours, kWh price as well as the currency.

After system

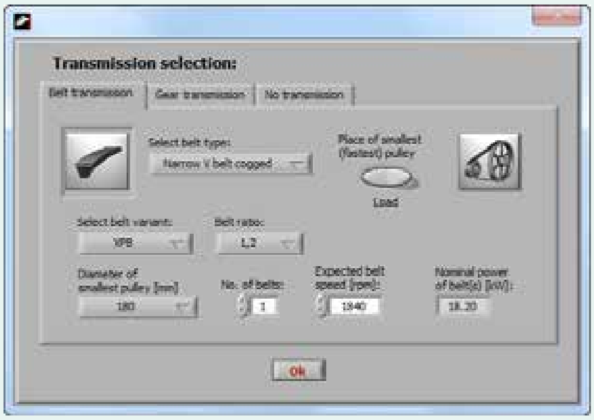
Upon closer inspection of the diagram showing the present motor driven system, it becomes apparent that the transmission (belt) operates at a relatively poor level of efficiency of 87.3 %. This is due to the fact that the belt pulleys have small diameters of 100 mm and 120 mm, which means that the belt is strongly curved (small radius). This strong bending causes proportionally high losses.

At 84.9 %, the efficiency of the motor & converter in the current configuration is also relatively low. This is because a) the system uses an outdated IE1 motor with comparatively poor efficiency, and b) the load factor of 61.4 % is not ideal. An electric motor's effective level of efficiency drops as the load decreases. Motors with a permanent load factor of less than 60 % are, according to the definition of Topmotors, oversized and result in unnecessary costs.

Therefore, in order to improve the total efficiency, the tool suggests two ways to optimise the system.

Adjusting the transmission

The current belt pulleys are replaced with larger pulleys (larger diameters) while maintaining the same belt ratio (1:1.2). This reduces the flexural losses and also allows for the transmission of greater forces. If you select a new 180-mm pulley to replace the transmission's current 100-mm pulley, you will notice that in the new configuration, one belt alone can transmit almost as much force as the previous three belts. Reducing the number of belts has further advantages. Apart from the flexural losses, other losses also occur when the belt is pressed into and released from the pulley. Having fewer belts significantly reduces these losses.

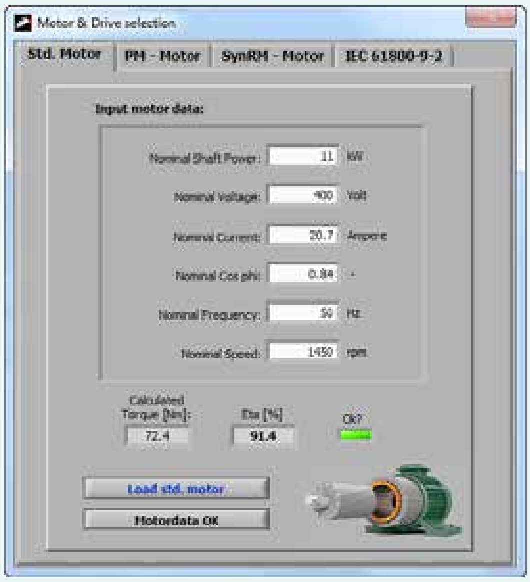


Adjusting the motor & frequency converter

The current IE1 motor is replaced with a more efficient IE3 motor. The new IE3 motor runs at a generally higher efficiency of now 91.4 % (before: 84.9 %); the motor also allows for constantly higher efficiency values in partial-load, thereby improving the system's total efficiency in every duty point.

In order to improve the new motor's load factor, the motor size should be adapted to perfectly match the new requirements.

The new transmission leads to a decrease in the necessary demand in point 'P2 – Motor Shaft Power' from initially 12 kW to now 10.84 kW. That means in the new configuration an 11 kW motor (i.e. with a mechanically induced power output of 11 kW at the shaft) is sufficient to permanently run the motor driven system in a safe manner.



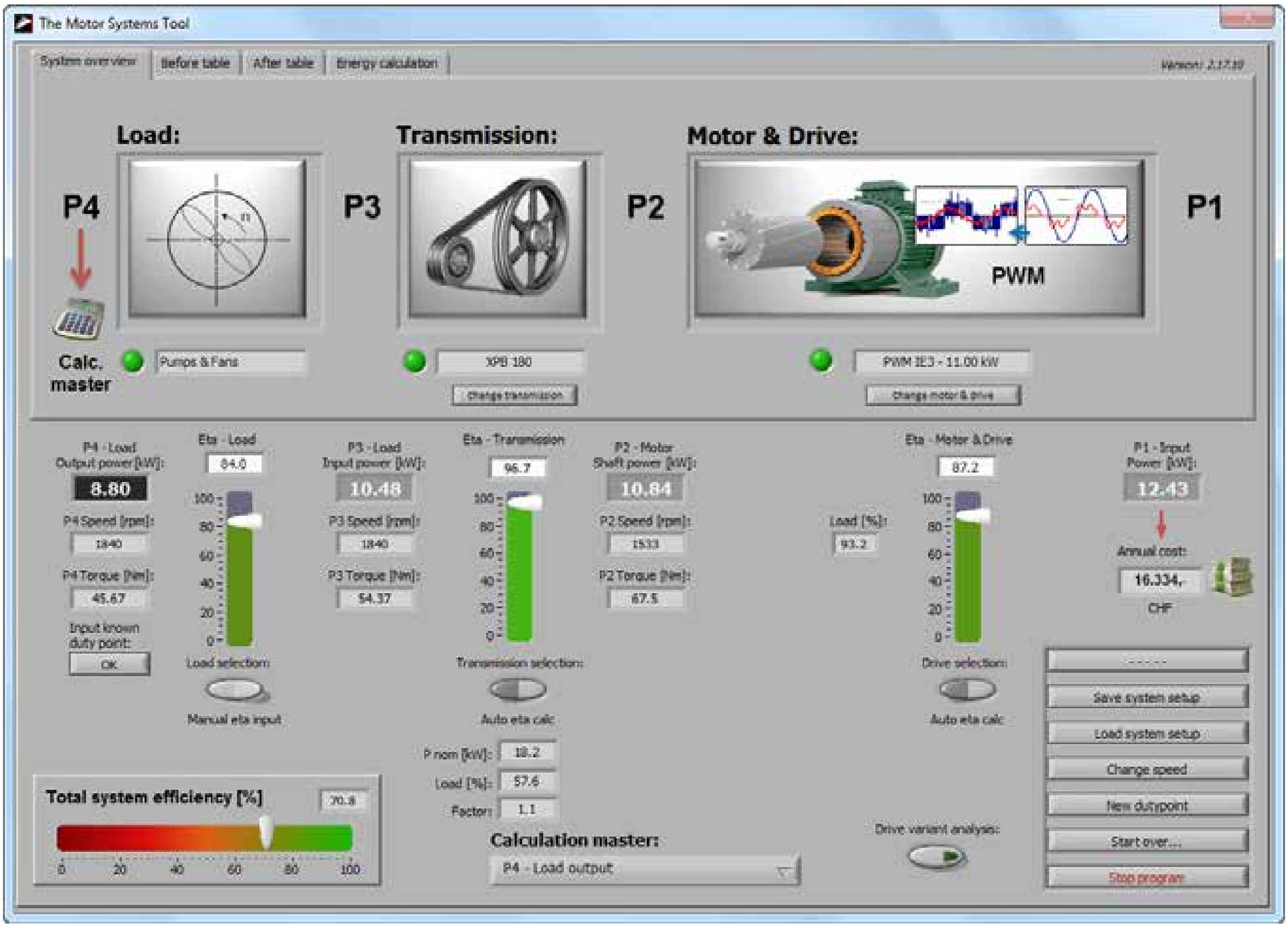


Figure 5: After-state of the drive system

Before/after comparison

		BEFORE	AFTER	DIFFERENCE
Point P4	Power (mech.)	8.80 kW	8.80 kW	–
	Speed	1840 1/min	1840 1/min	–
	Torque	45.67 Nm	45.67 Nm	–
Point P3	Power	10.48 kW	10.48 kW	–
	Speed	1840 1/min	1840 1/min	–
	Torque	54.37 Nm	54.37 Nm	–
Point P2	Power	12.00 kW	10.84 kW	–1.16 kW
	Speed	1533 1/min	1533 1/min	–
	Torque	74.75 Nm	67.50 Nm	–7.25 Nm
Point P1	Power (elect.)	14.14 kW	12.43 kW	–1.71 kW
	Annual cost	18 578 CHF	16 334 CHF	–2 244 CHF (–12 %)
		BEFORE	**AFTER**	**DIFFERENCE**
Efficiency	Load	84.0 %	84 %	–
	Transmission	87.3 %	96.7 %	+9.4 %
	Motor & converter	84.9 %	93.2 %	+8.3 %
Load factor	Motor & converter	61.4 %	70.8 %	+9.4 %

Conclusion

A systematic analysis is the best approach for achieving an increase in the efficiency of electric motor driven systems. Only by using and effectively coordinating efficient components can a good total Efficiency be achieved. As this example has shown, simply adjusting the transmission and using a more efficient motor is a quick and easy way to save 12% in annual energy costs.

An efficient motor driven system is more reliable than an inefficient one. Furthermore, losses in the form of friction or heat always negatively affect a system's lifespan. Individual results of the calculation show the following:

- A strongly bent belt is under greater structural stress than belts with larger bending radii, meaning it also wears out and fatigues more quickly.
- Similarly, losses in the form of heat negatively affect the lifespan of components such as bearings.
- Furthermore, unwanted heat can lead to high follow-up costs in scenarios where rooms, for example in the food industry, have to be permanently cooled to a low temperature, which requires a lot of energy.

These secondary efficiency yields are very difficult to estimate. However, these types of savings are often greater than the amount of electric energy saved in the drive system itself.

Editorial remark

The Motor Systems Tool Fact Sheet was prepared by Impact Energy in the framework of the Topmotors programme which provides information and raises awareness for energy-efficient motor driven systems. It was compiled by Conrad U. Brunner (iE), Petar Klingel (iE) and Rolf Tieben (iE). Copy-editing and graphic presentation: Faktor Journalisten AG.

Standards

- IEC 60034-30-1:2014 Rotating electrical machines – Part 30-1: Efficiency classes of line operated AC motors (IE code).
- IEC 61800-9-2:2017 Adjustable speed electrical power drive systems – Part 9-2: Ecodesign for power drive systems, motor starters, power electronics and their driven applications – Energy efficiency indicators for power drive systems and motor starters.

Additional information

For a detailed instruction manual as well as the video of a webinar featuring the Motor Systems Tool, please visit: www.motorsystems.org/motor-systems-tool