"Easy" program for electric motor systems efficiency in Switzerland

Rita Werle, Conrad U. Brunner, Rolf Tieben

Swiss Agency for Efficient Energy Use

Abstract

Industrial electric motor systems represent by far the largest share of industrial electricity use. The equipment is in general too old, inefficient, oversized and not adapted to load. Industrial firms often do not have the capacity and the in-house knowledge for a systematic improvement of the energy efficiency of their rolling stock. In order to lower the barrier of time- and cost-intensive preliminary analyses preceding the retrofit of motor systems a subsidy program was developed. The incentive program is based on earlier developments of an audit method for companies with many hundreds and thousands of rotating machines. The primary goal of the method is to identify effectively the potentially most cost-efficient energy savings.

The Swiss financial incentive program Easy (Efficiency for Electric Motor Systems www.topmotors.ch/easy) was launched on 1 November 2010 by the Swiss Agency for Efficient Energy Use (S.A.F.E.). The goal of the program is retrofitting existing motor systems in mid-size industrial and infrastructure plants and large buildings with an annual electricity consumption between 10 and 50 GWh. The program has a budget of CHF 1 million from public funding and runs until 31 October 2014.

So far 4142 electric motors have been assessed in detail and 104 motors have been measured on site. Some efficiency measures (motor / pump replacement through more efficient and / or smaller equipment, installing frequency converter, better transmission, better control system for compressors, etc.) have already been implemented, with more expected to be carried out by 31 October 2014.

The results show, that from the 4142 motors 56% are already older than their operating life expectancy. The oldest motor has been running for 64 years. The median of motors' output power is 5 kW (half of the motor population is below 5 kW output power). Only 20% of motors are equipped with a frequency converter.

For the 104 motors measured, median output power is 24 kW and the median load factor is 61%.

Lessons learned confirm on the one hand, that the process with the necessary preliminary assessments is long and tiresome. It requires human and financial resources and know-how, which are often lacking in the factories. On the other hand, the approval of the management and committed energy managers are a must for a successful implementation.

The way forward foresees a continued implementation of the program beyond 2014, complemented by an education and training program for energy managers and technicians.

Introduction

S.A.F.E. made an analysis involving 25 Swiss industrial plants which shows that motor systems are responsible for 87.8% of total electricity consumption. The analysis made it clear that programs focusing on industrial motor systems are necessary.

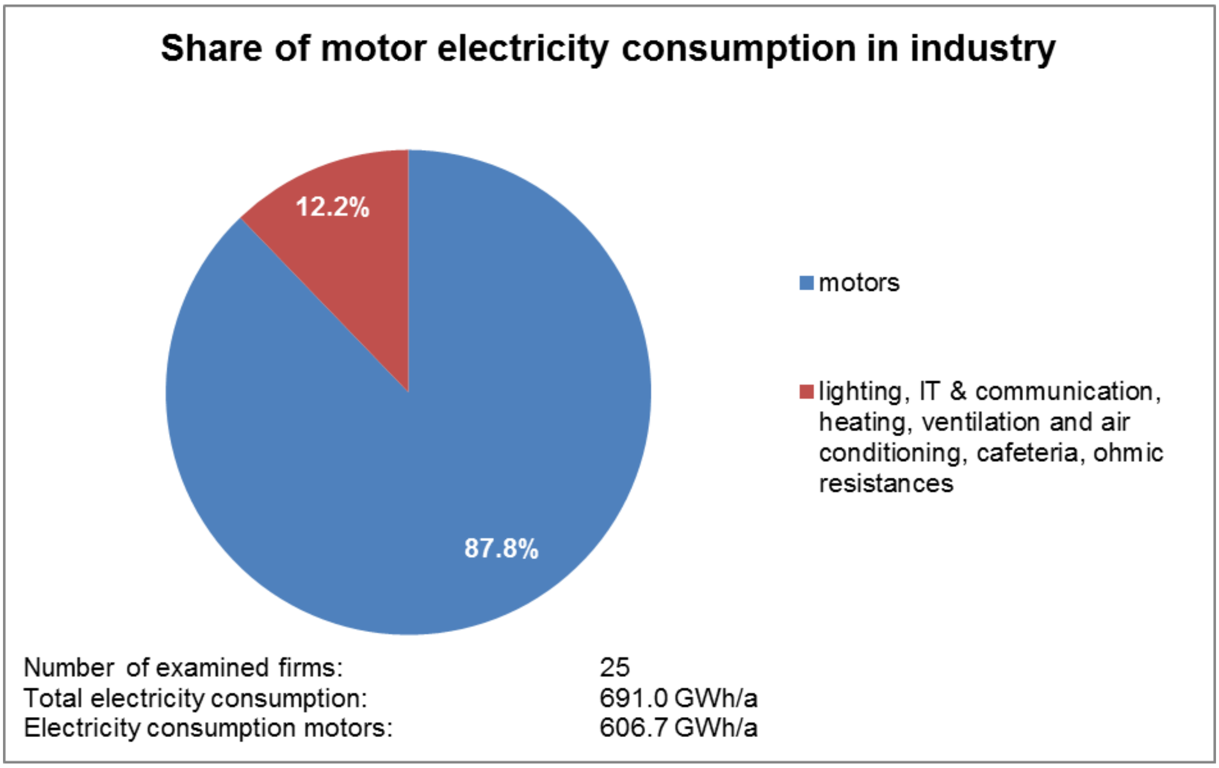

Figure 1 Motor systems are responsible for 87.8% of industrial electricity consumption

S.A.F.E. 2013

Overview of the program

Easy was launched by S.A.F.E. on 1 November 2010 and will end on 31 October 2014. The program has a total budget of 1 million CHF which S.A.F.E. won through a public tender. The tender is held annually, supervised by the Swiss Federal Office of Energy (Swiss government) [1]. The financing is secured through an additional fee on the tariff for the transport of electricity through the transmission grid.

Scope, goal

The scope of the program is retrofitting existing motor systems in industrial plants, infrastructure systems and large buildings, consuming more than 10 GWh/a of electricity. Since there is a minimum management cost associated with each participating factory and the possible savings are dependent on the total electricity consumption of participating factories, S.A.F.E. decided that participants should consume at least 10 GWh/a so that the program management costs would not be higher than the possible savings.

Four steps

Firms entering the program go through a standardized four-step audit process (Motor-Check), with the first three steps being preliminary analyses and the last being the implementation of efficiency measures.

For each step, a tool was developed by S.A.F.E. to help find the motor systems promising the highest savings in a systematic manner. (Reference to these tools is made in the section "Case study: meat processing plant"[1].)

Subsidy

The subsidy is based on the total costs of each step. A subsidy is given for all four steps, with a higher percentage for the preliminary analyses. The rationale behind this is that these analyses are

[1] Further reading: [2]

necessary to be able to retrofit motor systems and since they are time-consuming and cost-intensive, they constitute the main barrier for efficiency improvements. The goal of the program is to help firms overcome this barrier.

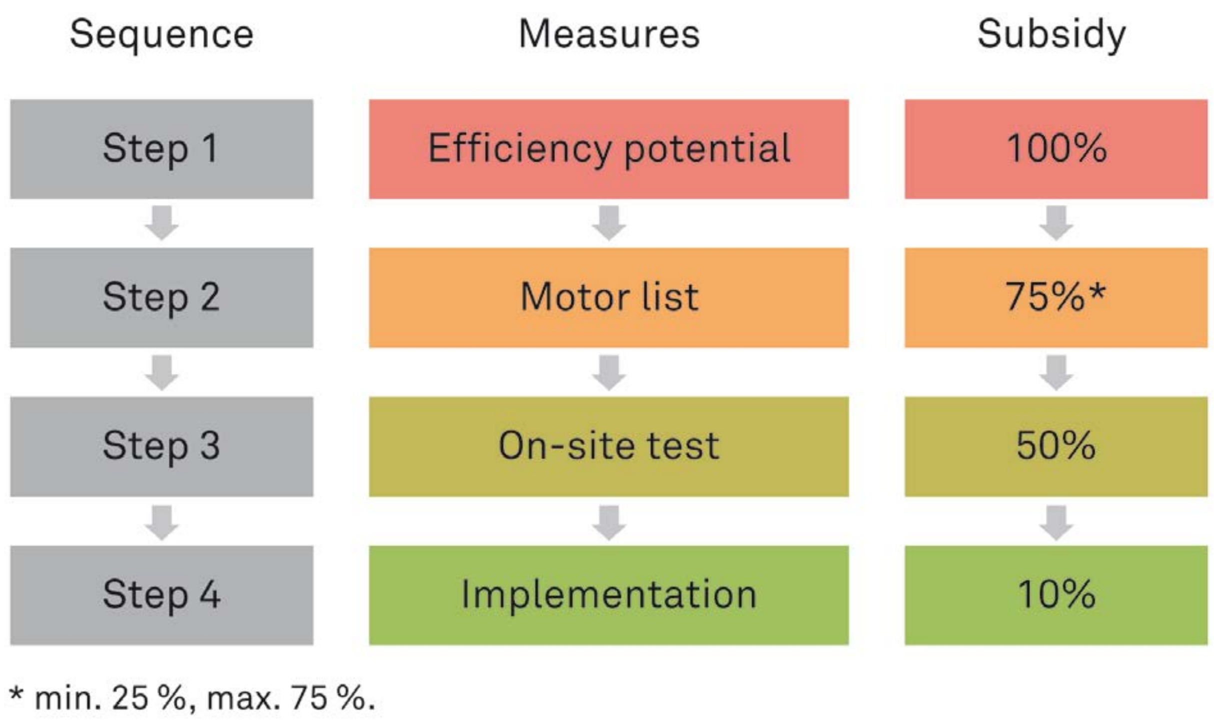

Figure 2 **Easy four-step process and respective share of subsidy**

S.A.F.E. 2013

For steps 1 - 3, the costs for both internal work (e.g. the necessary time for putting together the motor list) and external services (e.g. on-site tests by consulting engineers) borne by the firms are taken into account. For step 4, the subsidy is given for all types of measures and their attributed costs aimed at improving the complete motor system efficiency (e.g. improved operation and part load control, improved transmission and gears, advanced driven application, planning, installation) - thus not only for motor replacement.

Results

In the following sections, the results of analyzing 4142 motors from the motor lists of 18 industrial plants and infrastructure systems are shown.

S.A.F.E. together with its partners carried out pilot projects for motor systems retrofits in industrial firms before the start of the Easy program in the framework of the program "Topmotors". The results presented in this section of the paper take into account the analyses made under both programs (10 firms under Easy and 8 firms under Topmotors).

Table 1 gives a summary on the assessed firms with details to the number of motors on their motor lists and the motors tested on site.

Table 1 Assessed firms, number of motors on motor list and tested on site

No.	Core business	Electricity consumption	Motors on motor list	Motors tested on-site
		[GWh/a]	[no.]	[no.]
1	Dairy	40.2	294	23
2	Energy solutions	38.4	652	33
3	Waste incineration	38.2	277	14
4	Chocolate	35.4	540	25
5	Dairy	19.7	223	-
6	Chemical industry	16.9	96	-
7	Water supply	15.3	163	-
8	Industrial adhesives	12.4	381	-
9	Plastic material	11.9	10	-
10	Medical products	11.8	186	-
11	Rolled aluminum	11.4	108	-
12	Chalk production	10.0	74	-
13	Bioorganic products	7.8	381	-
14	Meat processing	5.9	42	9
15	Vegetable oils	4.9	208	-
16	Chocolate	3.5	325	-
17	Confectionary	2.8	42	-
18	Yeast production	2.3	140	-
Total		**288.8**	**4142**	**104**

S.A.F.E. 2013

Some firms have not yet finished all steps of the program, therefore their data is not yet available.

The main criteria for taking motors onto the motor list are output power, age and operating hours per year. The eighteen factories for which a motor list is available have a total electricity consumption of 289 GWh per year, their 4142 motors on the motor list consume 196 GWh electricity per year. Thus, motors on the motor list are responsible for about 70% of the total motor systems electricity consumption within a factory.

Table 2 gives an overview on the different characteristics of the 4142 motors assessed.

Table 2 Analysis of 4142 motors, from the motor lists of eighteen firms

Application	Number		Energy consumption		Rated power per motor		Age	Operation	Equipped with VSD	
			total	per motor*	average	maximum	per motor*	per motor*		
	[no.]	[%]	[GWh/a]	[MWh/a]	[kW]	[kW]	[a]	[h/a]	[no.]	[%]
Fans	1044	25%	65.5	63	18	1000	16	5455	311	38%
Pumps	1590	38%	43.2	27	13	315	16	4275	279	34%
Rotating machines	672	16%	29.9	44	35	4050	22	2883	63	8%
Cooling compressors	124	3%	21.5	174	64	450	17	4283	17	2%
Air compressors	109	3%	22.0	202	74	315	15	4064	25	3%
Other	251	6%	8.4	33	25	2870	18	4491	60	7%
Conveyors	352	8%	5.4	15	6	160	19	4232	66	8%
All motors	**4142**	**100%**	**195.9**	**47**	**21**	**4050**	**17**	**4351**	**821**	**20%**

*average

S.A.F.E. 2013

Note: results are shown by application, in descending order according to total energy consumption

The most numerous applications are pumps and fans. Fans are responsible for the highest share within the total energy consumption of all applications. Figure 3 below shows the share of energy consumption for each application.

The energy consumption of compressors per unit (one cooling compressor, one air compressor) is significantly higher than that of other applications.

Annual operation is on average 4351 hours per year.

20% of motors are equipped with variable speed drives (VSDs). The VSDs are mostly used in fan and pump applications because of their "square torque to frequency"[2] characteristics. The average age of motors equipped with a variable speed drive is 11 years, thus lower than the average age of all motors. This suggests that motors which have more recently been put into operation are more likely to be equipped with a VSD.

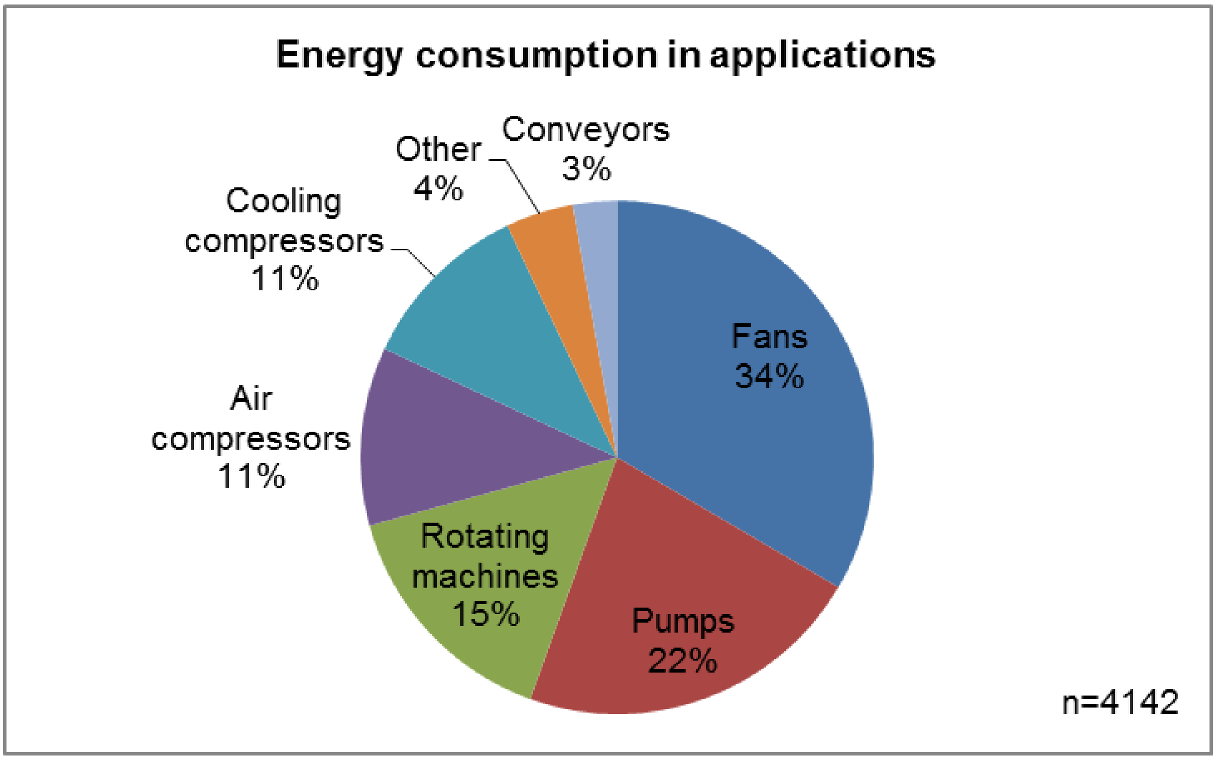

Figure 3 **Share of energy consumption according to application**
S.A.F.E. 2013

[2] In the context of variable frequency drives there are two general types of machines: i.e. conveyors have a constant torque while reducing the frequency; pumps and fans have a square relationship between frequency and torque. This makes the latter applications profit much more from a VFD.

Motors are too old

56% of motors in operation are too old and shown above the red line in Figure 4. These motors are on average 99% too old which means that most motors have been running almost twice as long as their expected lifetime. The oldest motor found has been running since 64 years.

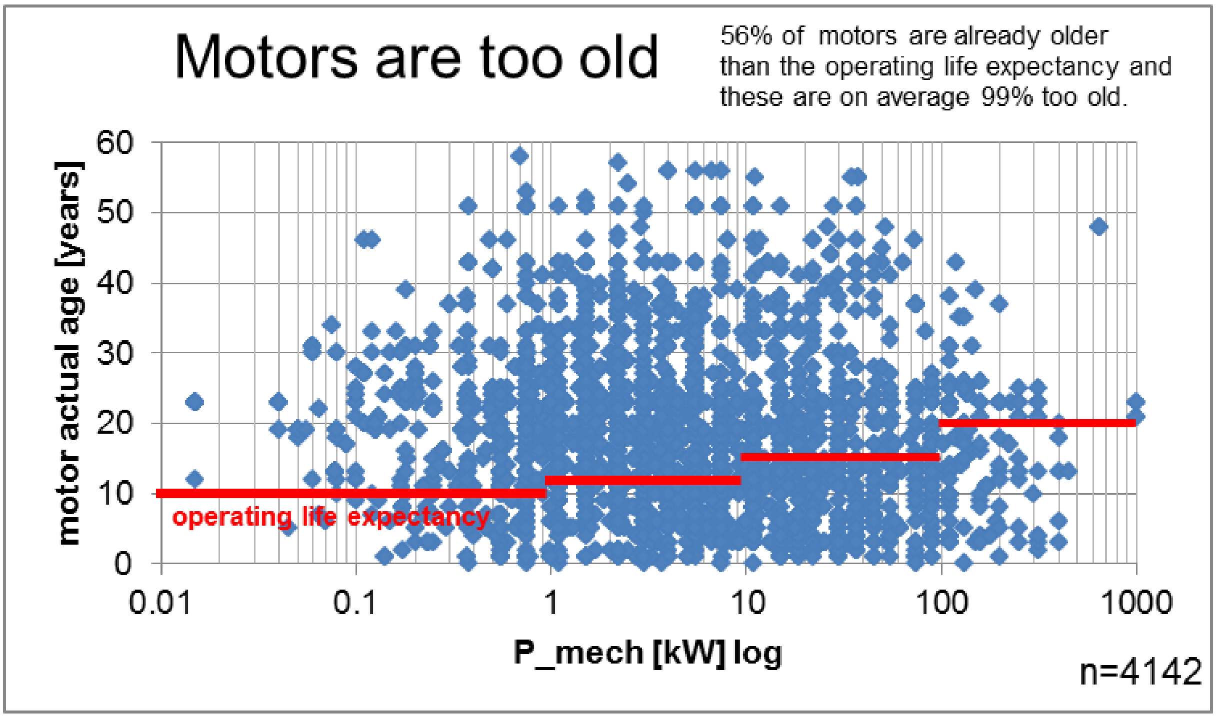

Figure 4 Motor age and expected lifetime

S.A.F.E. 2013. The red line shows the expected lifetime of motors according to [3].

Table 3 Expected motor lifetime

Output power	Expected lifetime (years)
below 1 kW	10
1 kW - 10 kW	12
10 kW - 100 kW	15
100 kW - 1000 kW	20

Source: [3]

Output power

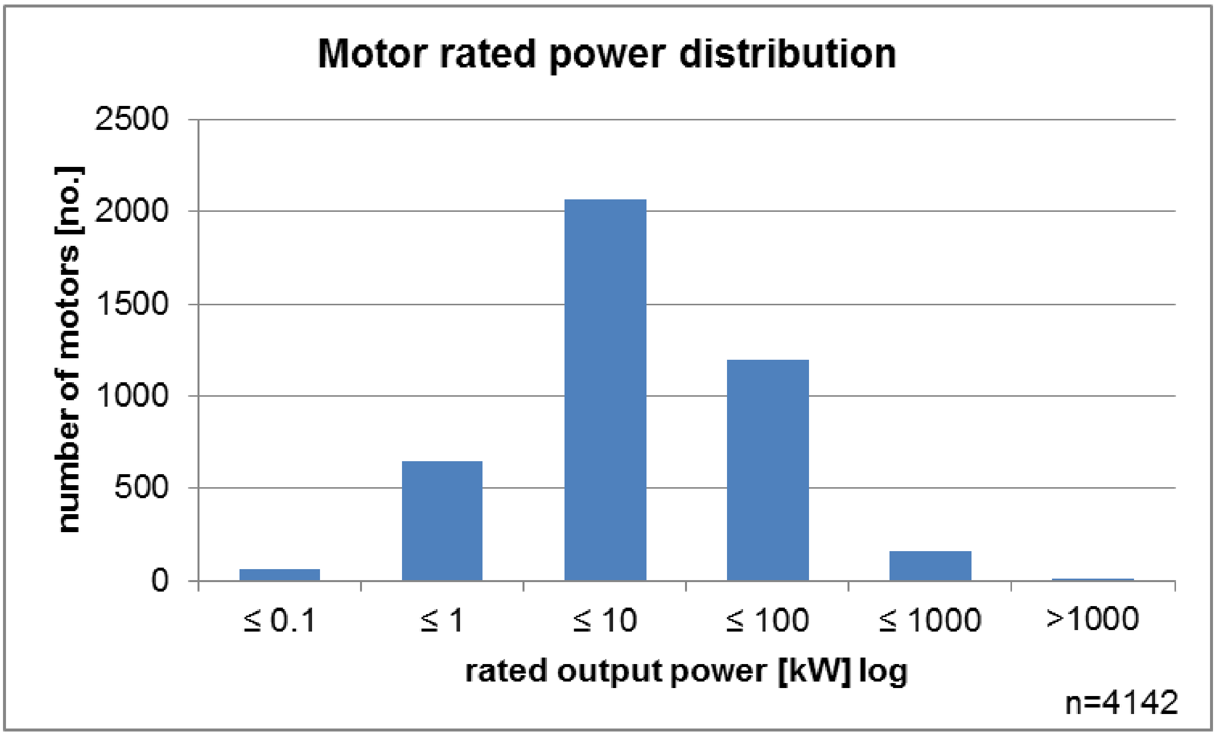

Figure 5 **Motor output power**

S.A.F.E. 2013

67% of motors have an output power below 10 kW. The median is 5 kW which means that half of the motors assessed have an output power below 5 kW, and half above. The average output power of motors is 21 kW.

S.A.F.E. observed in these industrial applications that conveyors, pumps and fans tend to have smaller output power (on average below 20 kW), while compressors (for cooling and compressed air) have a larger output power (on average above 60 kW). The high number of fans and pumps affects the average output power of all motors.

The application with the highest output power is a 4050 kW motor used in a turbine test facility.

Load factor

This section presents the results of 104 on-site measurements.

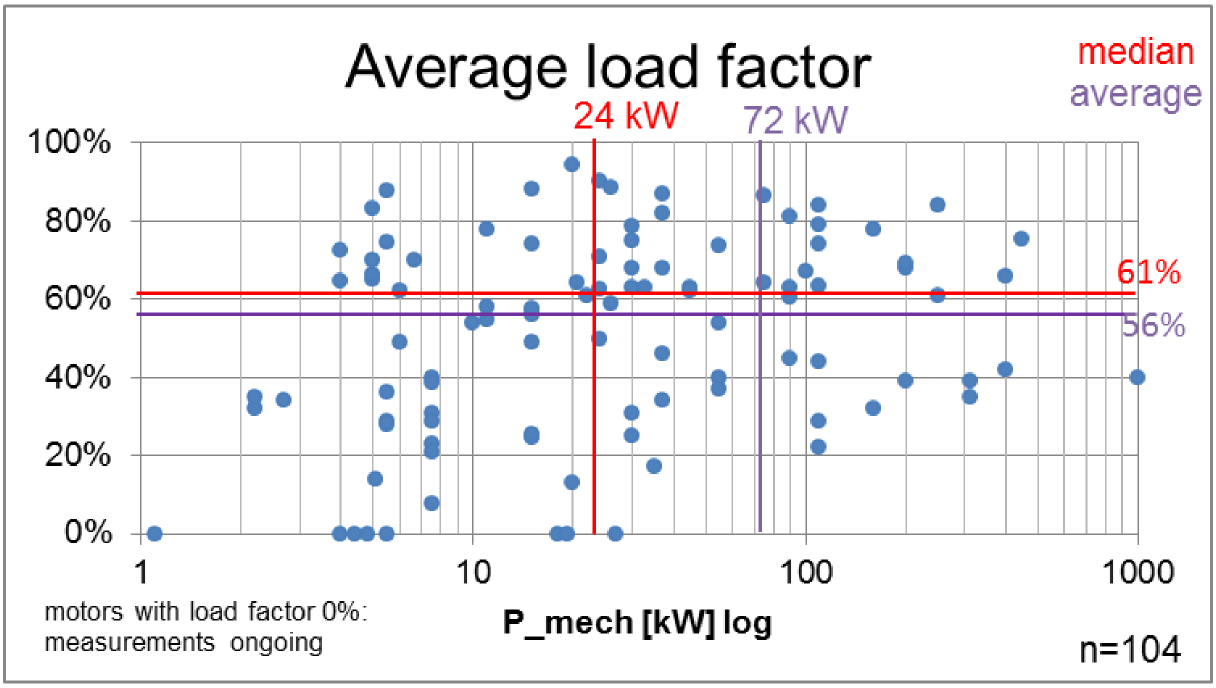

Figure 6 **Load factor of motors measured**

S.A.F.E. 2013

Note: The load factor of motors currently being measured (8 motors) is shown at 0% and not taken into consideration for the calculation of median and average load factors.

The electric input of motors is measured on site in order to observe their starting condition, continuous operation and - if necessary - changing load situations. Figure 6 shows that the average size of motors chosen for measurements is 72 kW while the median is 24 kW (half of the motors tested have an output power below 24 kW). These measurements are a prerequisite to analyze the necessary output size of the motor and to calculate the average load factor. The annual load factor is calculated from the electricity used, the output power of the motor and the measured load factor. The median annual load factor of the motors is 61%. This means that half of these motors have an annual load factor below 61%. 39 motors have an annual load factor below 50% which suggests that they are heavily oversized.

Figure 7 shows an example of an on-site input measurement of a 55 kW motor with 90% efficiency (at full load) driving a blower during start and nominal operation. The results show an average electric input of 22.5 kW (corresponding to a load factor of 38.5%) with a partial load efficiency of 88%. It also shows that the machine has no higher load requirement during the starting phase and runs fairly constantly during operation. The analysis suggests that an IE3 motor of 30 kW output with 93.6% efficiency would be sufficient. Together with other mechanical improvements (lower air volume and speed, better transmission with synchronous belt) a 15 kW motor with a 2 year payback is recommended as a replacement.

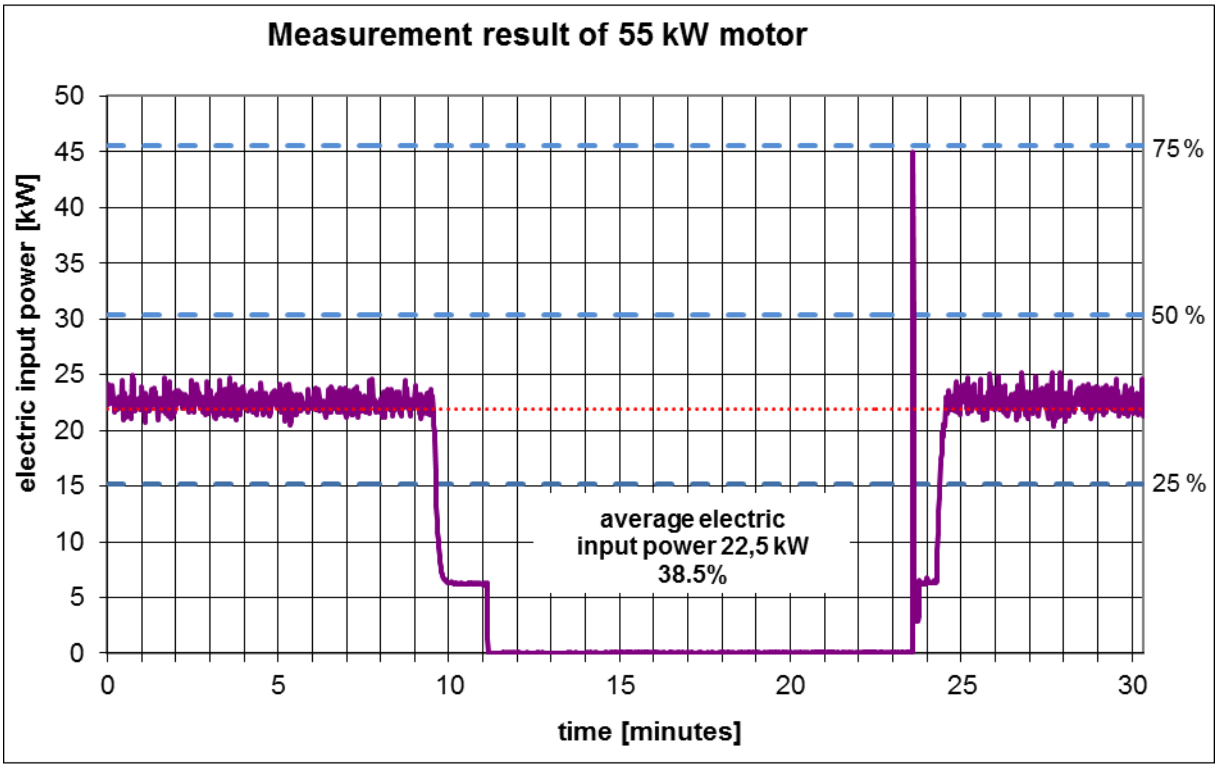

Figure 7 On-site measurement of the electric input (55 kW output)

S.A.F.E. 2013

Typical efficiency improvement measures

Typical efficiency measures which have been implemented at participating firms are:

- Higher-level control system for compressed air and cooling systems
- Reduction of volume, nominal pressure and speed in air ducts and water pipes
- Downsizing of motors based on actual measured requirements
- Improve starting conditions to reduce maximum required torque
- Replacement of old motors with new (down-sized) IE3 motors
- Installation of variable speed drives in motors with variable load conditions
- New, smaller components (e.g. pumps, fans, compressors) for an optimized system
- Better transmission (synchronous belts) or direct drive
- Optimization of operating hours depending on production requirements (e.g. necessary operation during the night, weekend, etc.).

Case study: meat processing plant

A plant producing fresh meat and meat products for Switzerland and the European Union is participating in the Easy program, optimizing its existing motor systems. The company employs 210 people, has an annual sales volume of CHF 150 million and an electrical energy consumption of nearly 6 GWh per year.

Like all the companies taking part in Easy, the plant went through the four-step Motor-Check audit. In a first step, the efficiency potential was estimated with the help of the software tool for efficient motor systems (SOTEA) [4]. It showed a modest 7.2% electricity savings potential, if 44% of motors were to be replaced with more efficient ones. This relatively low potential is due to the fact that most motors were relatively young (compared to the average age of motors found in other plants), being in operation only since 12 years. The second step was building a motor list using the software tool Intelligent Motor List (ILI+) [5]. The motor list contained about 40 motors. In a third step, 13 motors from the motor list were measured on site, efficiency improvements were elaborated, the expected savings were calculated and the best solution was recommended. Now the company is in the process of implementing these recommendations, taking a stepwise approach.

First, a higher-level intelligent control system was installed for the air compressors. In addition, an air-pressure reduction of the entire network was possible once the new control system was in place. The actual pressure reduction exceeded all expectations (from the original 8.3 bar down to 7 bar) and doubled the expected electricity savings. The evaluation of the optimized operation showed total savings of 35 MWh/a. The current energy consumption is 16% lower compared to the original condition.

Figure 8 One air compressor (left) and display of new, higher-level control system (right)

Second, the ventilation system was optimized by installing new IE3 motors controlled by frequency converters.

Third, an intelligent control system is planned to be installed for the cooling compressors. The standstill of the cooling system has an enormous impact on the production and therefore must be carefully planned. Negotiations regarding the implementation of this measure are ongoing between the company and the supplier.

Table 4 summarizes the planned and already implemented measures. The individual measures have different payback times ranging from 1.5 to 7.3 years, while the payback of the total package is only 2.4 years.

Table 4 Summary of optimization measures at meet processing plant

No.	Optimization of	Investment [k CHF]	Savings [MWh/a]	[k CHF/a]	Payback [a]
1	Air compressors	8	35	5	1.5
2	Ventilation system	53	56	7	7.3
3	Cooling compressors	65	308	39	1.7
Total		**126**	**399**	**52**	**2.4**

S.A.F.E. 2013

Lessons learned

Throughout the management and implementation of Easy, S.A.F.E. learned a number of lessons which can be summarized as follow:

1. Plant managers lack resources, meaning both necessary time and engineering know-how to design and optimize electric motor systems in an energy efficient manner.
2. Motor manufacturers and service companies are not pursuing the sale of efficient motors or components. Partly, because this requires changes in their business model (and they have not yet recognized their potential gains in selling energy efficiency) and partly because they lack the necessary knowledge for optimizing systems. The supply of IE3 motors proved to be a challenge, often accompanied with long waiting periods and discouraging comments from the suppliers.
3. Machine builders threaten with early termination of warranty in case they are asked to change one or more components for more efficient ones (instead of the client ordering a whole new machine).
4. The implementation of efficiency measures for motor systems which are involved in the core production process are hindered by fears of a possible production standstill.
5. The costs of on-site measurements and related efficiency improvement engineering and recommendations were on average 1000 - 1500 EUR per motor system in the Easy program. This was higher than anticipated and is independent of motor size, but can be higher for complex systems. This means that only larger machines or machines with many identical small motors can be improved in a cost-effective manner.
6. Some industrial plants participating in the program decided to mandate external engineers to help them order new equipment and negotiate with manufacturers and OEMs for more energy efficient solutions. External efficiency advice is very costly but sometimes necessary.
7. Investments for motor systems as part of a systematic improvement process quickly add up to a few hundred thousand EUR - an investment decision to be taken to the top management level due to its scale. Plant managers do not have a direct contact or any influence on top management, therefore they cannot argue in favor of a positive decision on proposed energy efficiency measures.
8. The economic assessment of investments in industry and the subsequent investment decisions are essentially based on short pay-back periods (below 3 years) instead of life-cycle costs. This means that even if the purchase price of a motor represents only a few percent from its total life cycle cost and the electricity costs during its life cycle make up more than 90% of the life cycle cost (see Figure 9), the purchase price remains the decisive criteria in the investment decision.
9. A "champion" is necessary in all firms to make the retrofit project reality and is willing to make the implementation successful.
10. The time period between the initial contact to a firm and the efficiency measures implemented at the firm is one to three years, thus relatively long.
11. The first positive results of implemented efficiency measures stimulate the implementation of further measures.
12. The fact that 56% of motors run almost twice as long as their expected lifetime points at the lack of a continuous improvement process within the factories.
13. The subsidy helps to open doors but does not bring a remedy to all problems. A subsidy of 10% for the improvement measures in the implementation phase proved to be too low to be able to effectively influence the investment decision of certain firms for more energy efficient solutions.
14. All these factors doubled the costs of the program management (to date), for providing the necessary system optimization know-how to the firms, for the negotiations with manufacturers, machine builders and service companies and for keeping the motivation of the project "champions" in the firms high towards realizing the efficiency measures.

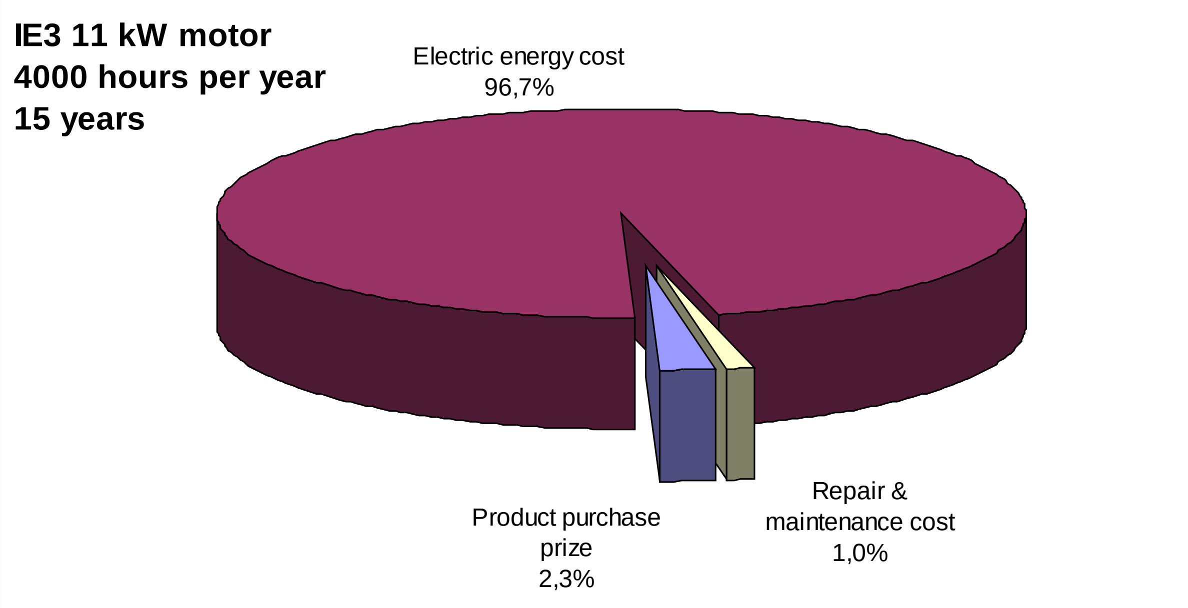

Figure 9 Life cycle cost of a 11 kW IE3 motor.

Source: [6]

Way forward

Through the implementation of Easy, S.A.F.E. realized that it is not enough to bring external know-how to the factories and enterprises, but the know-how needs to be present in-house. Certain structural changes in the hierarchy of the industrial enterprises must support a continuous efficiency improvement process. S.A.F.E. is convinced that these changes could be achieved through the introduction and support of energy management systems and through adequate training.

The Swiss parliament has decided to introduce a voluntary agreement scheme for energy-intensive companies. Companies with an electricity cost share of more than 5% within total costs could enter into efficiency target agreements and have their feed-in tariff payments refunded.

In January 2013, a first continued education program for energy management (Certificate of Advanced Studies) was launched at the University of Geneva. The course received very positive feedbacks and generated much attention. S.A.F.E. is now working in cooperation with the University of Geneva to build up the course in the whole country, targeting plant managers, representatives of manufacturers, importers, OEMs, service companies, consulting engineers and costumer consultants in utilities. The joint program foresees two focus areas: energy management and energy technology. In the latter, a great emphasis will be put on motor systems optimization.

References

[1] www.prokilowatt.ch

[2] Conrad U. Brunner, Rita Werle: *Incentive program for motor systems efficiency in industry - First experiences from Easy in Switzerland.* In the proceedings of EEMODS'11 (Alexandria (VA) USA, 12 - 14 September 2011).

[3] Anibal T. De Almeida et al.: *EUP Lot 11 Motors*, ISR- University of Coimbra, 2008.

[4] http://www.topmotors.ch/Potentialabschaetzung/

[5] http://www.topmotors.ch/Intelligente_Liste/

[6] Brunner. Conrad U., *Global Motor Systems Network: The International Energy Agency 4E EMSA Project*. In: Proceedings of the 6th International Conference EEMODS '09: Energy Efficiency in Motor Driven Systems, Nantes, FRANCE, 14-17 September 2009, EUR 24142 EN/1 - 2010.