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Zusammenfassung

Dieses Projekt war der Schweizer Beitrag an das IEA 4E EMSA Programm (www.iea-4e.org/emsa) Task 3 New Industrial Developments and Digitalisation in Motor Systems. Die Digitalisierung ermöglicht eine bessere Zustandsüberwachung und Instandhaltung der elektrischen Antriebssysteme und bringt somit neue Möglichkeiten zur Energieeinsparung, sowie von weniger Störungen bei den Produktionsabläufen in der Industrie. Ziel war es, geeignete gute Beispiele zu erfassen, sowie nebst den positiven Effekten der Digitalisierung auch den Eigenenergieverbrauch der diversen digitalen Technologien und Methoden zu erfassen. Das Projekt lief zwischen September 2021 und April 2024.

In der ersten Schweizer Fallstudie haben die Firmen Hamilton Bonaduz AG und Hamilton Medical AG, die am Standort in Bonaduz medizinische Geräte und Laborausrüstungen herstellen, in Zusammenarbeit mit KAESER ein Druckluftsystem erneuert. Dabei wurde ein adaptive, übergeordnete Steuerung in Kombination mit einer Split-Lösung (ein Mix aus Kompressoren mit und ohne Frequenzumrichter) eingesetzt. Dies führte zu einer elektrischen Energieeinsparung von 16 %.

In der zweiten Schweizer Fallstudie wendet das Unternehmen PRiOT in der Schweiz einen IoT-Sensor an, um verstopfte Luftfilter in Lüftungsanlagen an Serverstandorten frühzeitig zu erkennen, was einen genaueren Zeitpunkt für den Filterwechsel ermöglicht. Die Hauptvorteile liegen in der Einsparung von elektrischer Energie, Ressourcen und Kosten, z. B. durch die Verringerung des Wartungsbedarfs vor Ort, die schnelle Fehlererkennung und das schnelle Eingreifen sowie die Einsparung von Filtermaterial. In einem konkreten Beispiel konnten 20 % der elektrischen Energie eingespart werden.

Was die Analyse des digitalen Energieverbrauchs betrifft, so zeigen die untersuchten Fälle Nettoeinsparungen (ohne digitalen Energieverbrauch) zwischen 5,7 % und 20,4 % (in einigen Fällen in Verbindung mit Hardware-Upgrades sogar noch höher), während der Energieaufwand für die Digitalisierung nie über 1 % lag, sondern eher unbedeutend war. Insgesamt überwiegen die durch die Digitalisierung von Antriebssystemen erzielten Energieeinsparungen bei weitem den zusätzlichen Energieverbrauch, der durch die Digitalisierung entsteht.

Résumé

Ce projet a couvert la contribution suisse au programme IEA 4E EMSA (www.iea-4e.org/emsa) Task 3 New Industrial Developments and Digitalisation in Motor Systems. La numérisation permet une meilleure surveillance de l'état et de l’entretien des systèmes d'entraînement électriques et apporte de nouvelles possibilités d'économie d'énergie ainsi que moins de risques d'arrêts imprévus dans la production industrielle. L'objectif de ce projet était d'identifier des études de cas appropriées (bons exemples) et, en plus des effets positifs de la numérisation, d'identifier la consommation d'énergie des différentes technologies et méthodes numériques. Le projet s'est déroulé de septembre 2021 à avril 2024.

Dans la première étude de cas suisse, les sociétés Hamilton Bonaduz AG et Hamilton Medical AG, qui fabriquent des appareils médicaux et des équipements de laboratoire sur le site de Bonaduz, ont rénové un système d'air comprimé en collaboration avec KAESER. Pour ce faire, une commande adaptative de niveau supérieur a été utilisée en combinaison avec une solution split (un mélange de compresseurs avec et sans convertisseur de fréquence). Cela a permis de réaliser une économie d'énergie électrique de 16 %.

Dans la deuxième étude de cas suisse, la société PRiOT en Suisse applique un capteur IoT pour détecter les filtres à air obstrués dans les systèmes de ventilation des sites de serveurs, ce qui permet

un calendrier plus précis pour le remplacement du filtre. Les principaux avantages sont des économies d'énergie électrique, de ressources et de coûts, telles que la réduction des besoins de maintenance sur site, la détection rapide des défauts et le remplacement rapide du filtre.

En ce qui concerne l'analyse de la consommation d'énergie numérique, les cas étudiés montrent des économies nettes (hors consommation d'énergie numérique) allant de 5,7 % à 20,4 % (dans certains cas, elles étaient encore plus élevées lorsqu'elles étaient associées à des mises à jour des équipements), tandis que les dépenses énergétiques pour faciliter la numérisation n'ont jamais dépassé 1 %, mais ont été plutôt négligeables. Par conséquent, dans l'ensemble, les économies d'énergie réalisées grâce à la numérisation des systèmes de motorisation dépassent largement la consommation d'énergie supplémentaire résultant du processus de numérisation.

Summary

This project covered the Swiss contribution to the IEA 4E EMSA programme (www.iea-4e.org/emsa) Task 3 New Industrial Developments and Digitalization in Motor Systems. Digitalisation enables better condition monitoring and preventive maintenance of electric motor systems and thus brings new opportunities for energy savings as well as less disruptions of the production processes in industry. The aim of this project was to identify suitable case studies (good examples) and, in addition to the positive effects of digitalisation, to identify the energy consumption of the various digital technologies and methods. The project ran between September 2021 and April 2024.

The first Swiss case study showed that the companies Hamilton Bonaduz AG and Hamilton Medical AG producing medical devices as well as laboratory equipment at the facility in, have revamped a compressed air system in collaboration with KAESER, applying an adaptive air pressure management system in combination with a split solution (a mix of compressors with and without a variable frequency drive). This resulted in an electric energy saving of 16%.

In the second Swiss case study, the company PRiOT in Switzerland applies an IoT sensor to detect clogged air filters in ventilation systems at server sites, allowing a more accurate timing for the exchange of the filter. The main benefits are savings in electric energy, resources and costs, such as the reduction of on-site maintenance needs, quick fault detection and fast intervention, as well as savings in filter material. In a concrete example, 20% of electric energy could be saved.

As for the analysis of digital energy consumption, the studied cases show net savings (excluding digital energy consumption) ranging from 5.7% up to 20.4% (in some cases combined with hardware upgrades even higher), whilst the energy expenditure to facilitate digitalisation never exceeded 1%, but was rather insignificant. Consequently, on an overall level, the energy savings achieved through the digitalisation of motor systems far outweigh the additional energy consumption resulting from the digitalisation process.

Main findings

- **Digitalisation is an enabler to create transparency** in terms of when and how energy is being used. This is a **crucial first step** when it comes to the optimisation of motor systems' operation.
- The potential **savings vary greatly**. In general, they depend largely on whether the **information** obtained through the digital solution **used to implement optimisation measures** and to what extent the motor system was already optimised before the optimization measures.
- **Energy savings are not always the primary driver but rather a side-effect** of the optimisation.
- The energy consumption associated with the digitalisation of motor systems was analysed in five concrete cases and remained always below 1% of total consumption. **The possible savings and other benefits outweighed the additional energy consumption in each case.**

Contents

Abbreviations

AI	Artificial Intelligence
IEA	International Energy Agency
4E	Energy Efficient End-use Equipment
EMSA	Electric Motor Systems Annex
IoT	Internet of Things
VFD	Variable Frequency Drive

1 Introduction

1.1 Background information and current situation

Worldwide, around 53% of electric energy is consumed by electric motor systems. New digital technologies open up novel possibilities for the continuous monitoring of parameters relevant to the energy consumption and maintenance of electric motor systems. In the its 4th programme phase (2019 - 2024), the International Energy Agency 4E Electric Motor Systems Annex (EMSA www.iea-4e.org/emsa/) defined a new focus topic: digitalisation of motor systems. The topic was addressed in EMSA Task 3 New Industrial Developments and Digitalisation in Motor Systems. Throughout this work, EMSA found that there is still significant potential for the spread of digitalisation in industrial motor systems.

1.2 Purpose of the project

In the framework of the international collaboration amongst four countries (Austria, the Netherlands, Sweden and Switzerland), it was intended that the topic of digitalisation in motor driven systems shall gain worldwide increased attention and be brought forward, through:

- Raising awareness on the energy savings potential
- Showing best practices through case studies and successful policy instruments
- Identifying barriers and potentially ways to overcome these
- Motivate and help industrial facilities to start and/or continue to reap the savings potential offered by the digitalisation of their motor systems through targeted information and case studies as “good examples”
- Closing an information gap also with regard to the energy consumption due to the digitalisation of electric motor systems
- A structured coordination and exchange with international experts and stakeholders.

1.3 Objectives

Goals and research questions:

- Development and publication of two case studies (“good examples”) from Switzerland with regard to New Industrial Developments and Digitalisation in Motor Systems.
- What examples of energy consumption and energy efficiency already exist in the area of digitalisation of motor systems in Switzerland and other countries? How can companies be motivated to push ahead with digitalisation? What are the benefits of digitalisation? How can existing obstacles be overcome?
- How large is the energy consumption associated with the digitalisation of electric motor systems? What are the benefits (e.g. energy efficiency, lower maintenance cost, etc.) and downsides (e.g. higher energy use due to digitalisation) of using digital technologies? Do the benefits outweigh the downsides?

- Participation in the EMSA Task in all activities in order to promote international exchange and to make the best possible use for Switzerland of the knowledge gained in close cooperation with Austria, the Netherlands and Sweden.

2 Procedures and methodology

Since the project is carried out in collaboration with three international partners, there were regular meetings with all project partners every 4 – 8 weeks. These served one the one hand to monitor progress according to the jointly agreed Work Plan**.** On the other hand, to coordinate activities, share information and findings, this way benefitting from synergies and avoiding duplication of effort.

As for the **case studies/good examples**, the following process was followed:

1. Clarification of information to be gathered and shown (according to template)
2. Detailed exchange and understanding with partners involved in the case study
3. On-site visit (where applicable)
4. All countries use the agreed template for the publication of the case studies (according to a proposal put forward by Switzerland)
5. Contacts & data collection in each country and for each case study individually
6. Coordination among project partners when choosing the examples, with the goal of working on a diverse portfolio of examples
7. Circulation of drafts for information
8. Finalise text, layout, publication.

As for estimating the **energy consumption** due to digitalisation of motor systems, the following methodology was used:

- Define a small number (e.g. 1 to 3) of typical setups, identifying:
    a. different digital technologies & applications e.g. sensors, predictive maintenance
    b. related infrastructure (IT-equipment)
    c. related energy consumption
- Once that is done, depending on data availability and quality, this could have been extrapolated to e.g. an installed base of motors in e.g. a factory or an industrial sector, maybe a country (Switzerland). However, data availability did not allow such extrapolation.
- Start analyses on a qualitative basis, proceed only to quantitative if feasible.

The following steps were undertaken:

1. Literature review
2. Data collection from available and reliable sources, based on data availability
3. On-site visits where applicable and suitable
4. Analysis
5. Discussion and quality check with the international project partners

6. Draft report
7. Publication of results.

3 Results and discussion

The identification of two case studies proved to be significantly more challenging and took much longer than anticipated. In total, over 40 organisations had been contacted in search for suitable case studies.

One case study could be identified through existing contacts with the air compressor manufacturer KAESER. At one of their clients, Hamilton Bonaduz AG and Hamilton Medical AG, a medical equipment producing facility, an adaptive air pressure management system with intelligent control and real-time monitoring was applied (see Figure 1). The control system evaluates pressure and humidity sensor feedback for an adaptive compressor control. A hardware upgrade was also made, three compressors were retrofitted of which two are equipped with a Variable Speed Drive (VSD). This split solution, i.e. a mix between air compressors with and without a VSD, was chosen to achieve optimal overall efficiency and flexibility: the compressed air baseload is produced through compressors without VSD and the remaining variable compressed air is produced with compressors with a VSD. The combination of load management of the different compressor units and monitoring of system data allows a reduction of energy used per compressed air volume. In case of the studied company, the compressor energy was reduced significantly; with respect to the baseline an overall saving of 16% has been reached:

- one part is achieved by running the compressed air system at the lowest possible total system pressure (5%),
- one part is thanks to the intelligent control and hence the optimised control of the compressor system (6%),
- and the rest due to the revamping of the compressor units (5%).

Figure 1 The newly installed air pressure management system of the first good example, SIGMA 4.0 (photograph: Pascal Kienast)

In the second case study, the company PRiOT AG in Switzerland applies an IoT sensor to detect clogged air filters in ventilation systems at server sites, allowing a more accurate timing for the exchange of the filter. The main benefits are savings in electric energy, resources and costs, such as the reduction of on-site maintenance needs, quick fault detection and fast intervention, as well as savings in filter material. In a concrete example, 20% of electric energy could be saved. The implemented measures centre around demand-based filter replacement, optimising the efficiency of the system. This strategy is complemented by a comprehensive integration of digital technologies: smart sensors, Internet of Things (IoT), continuous condition monitoring, data analysis, digital twin, and cloud-based services. These technologies ultimately ensure a more precise and proactive approach to filter replacement based on the actual usage. While this case study is taken from the services sector, the same technology can be applied also for an industrial context.

Figure 2 IoT sensor to be installed at the filter system. (Source: www.priot.ch)

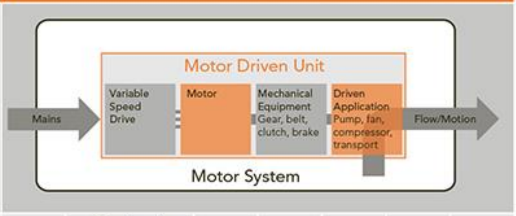
The analysis of the energy consumption of digitalised motor system components has shown the following: the consumption attributable to the digitalisation of motor systems stems from a variety of sources. Notably external network communication i.e., the use of cloud services can add to the total energy consumption when high data volumes and storage requirements are given. However, with regards to limiting factors such as battery life in smart sensors, it is much more common to work with small and compressed data sets that leave a marginal impact even when considering pessimistic values for network energy consumption. As for hardware components attributable to digitalised motor systems, sensors and local data communication or storage devices typically show a low energy consumption. There is a variety of digitalisation concepts, of which smart sensors have negligible energy consumption but some systems may show larger power usage. Generally, infrastructure necessary to facilitate digitalisation of motor systems may already be in place to a large extent – notably in energy intensive companies. This directly limits the additional energy required for further network participants (e.g., scaling of LAN switches). As for typical smart sensors, additional infrastructure for data handling is often not required. With regards to energy intensity, a classification of the type of digitalisation is proposed according to Table 1. The classification distinguishes primary targets of the digitalisation which, based upon the study findings, result in different typical energy consumption. This typically directly correlates with the computational complexity. It is worth noting that the baseline values for the classifications have been chosen arbitrarily considering the cases analysed.

	Smart Sensors/ IoT	**Advanced analytics**	**Adaptive control systems**
Annual energy consumption of digital system	< 10 Wh/a	10 Wh/a -200 kWh/a	> 200 kWh/a
Computational frequency	<<1 Hz	~1Hz	>1 Hz
Number of motors	1	>=1	>2
Primary target of digitalisation	Error Detection, analytics	Error detection, optimisation	Energy savings, emission reduction
Assignable cases from this study	Case 1 Case 2	Case 2 Case 3 Case 4	Case 5

Table 1 Classification of digitalised motor systems

Since the availability of data considering the impact of digital energy consumption in motor systems is currently poor, this project aimed to make a first step through the analysis of concrete cases. The sample size with the cases presented is by no means representative which is a limiting factor for aggregated conclusions.

Case studies of digitalisation of Electric Motor Driven Systems (EMDS)



Case	Digital aspects	Before	After	Net savings	Role of digital-isation	Power equipment	Controls: VSD	Controls: Control, sensor, gateway	Motor	Transmission	Application (PFCO)	Piping, other	Heat exchanger, other
1	IOT in air ventilation system in server facilities	Sporadic manual tests of air filter clogging	Detection of clogged air filters in ventilation system for servers	20.4 %	P	–	–	X	–	–	–	S	–
2	Predictive maintenance and vibration diagnostics	Visual motor inspection (or unplanned failure)	Detection of potential motor failures, which could lead to increased motor losses and downtime	n.a.	P	–	–	X	S	–	–	–	–
3	Intelligent control of water treatment facility pump system	Static (set points for) operation of pumps	Adapted set-points (load) and target speeds of pumps, closer to their optimal efficiency	5.7 %	P	–	S	X	–	–	–	–	–
4	Large scale field trial (#202 motors)	Mixture of DOL and VFD operated motors, some systems partly optimised	Improved control/ VFD operation, optimised assets including replacements and/or other optimisations	average: 11.4 %	P	X	X S	X	X	–	X	–	–
5	Intelligent control of air compressor system in large production facility	Set of DOL (on/off) air compressor units	VSD operated compressor units plus sensors and control	15.0 %	A	–	X	X	–	–	X	S	S

EMDS= Electric Motor Driven System; VSD = Variable Speed Drive, PFCO = pump/fan/compressor
cases including hardware upgrades
A= active role: digitalisation has a direct influence on the energy consumption of an EMDS
P= passive role: digitalisation is an enabler for identifying savings (delivers information)
X = components added to the EMDS
S = sensor(s) added to the EMDS

Figure 3 Summary of cases presented

The studied cases show net savings (excluding digital energy consumption) ranging from 5.7% up to 20.4% (in some cases combined with hardware upgrades even higher), whilst the energy expenditure to facilitate digitalisation never exceeded 1% but was rather insignificant for many cases. Consequently, on an overall level, the **energy savings achieved through the digitalisation of motor systems far outweigh the additional energy consumption resulting from the**

digitalisation process. It is important to highlight that the actual benefit of digitalisation is constrained to what type of measures are classified as digitalisation and what is regarded as the baseline. In the cases studied, what was decisive for the savings potential is to what extent systems were already optimised before the measures and to what extent measures could contribute to an optimised system operation.

4 Conclusions

Thanks to the international collaboration, a catalogue of case studies was elaborated, with 8 case studies collected by the project participants (two of which from Switzerland). This served as a broader basis for describing conclusions. During the collection and evaluation of the case studies, we learned the following:

1. **Digitalisation is an enabler to create transparency** in terms of when and how energy is being used. This is a **crucial first step** when it comes to the optimisation of motor systems' operation.
2. The potential **savings vary greatly**. In general, savings depend largely on the following factors:
    a. **Is the information** that is provided through the digital solution **used to implement optimisation measures**? Does this necessitate human intervention and is this intervention being followed through?
    b. **What is the starting point**, i.e. is the motor system already optimised to some level (e.g. use of a VSD)? Typically, higher savings can be achieved if the motor system is not optimised at the outset. In the case studies presented, the highest savings were achieved by simply using as much energy as is really needed. [1]
    c. **Energy savings are not always the primary driver but rather a side-effect** of the optimisation. Non-energy benefits play a more decisive role (e.g. avoiding downtime, decreasing maintenance cost, increasing production efficiency, extending the lifetime of equipment).

The analysis of the additional energy consumption caused by digitalisation has shown that energy savings achieved through the digitalisation of motor systems far outweigh the additional energy consumption resulting from the digitalisation process.

5 Outlook and next steps

Throughout the course of the project two international workshops were held. During the most recent event on 19 September 2023, the need for concrete examples of digitalisation was expressed by the participating experts. The aforementioned catalogue of case studies is a first step for that (see Appendix), in which it was possible to show how digitalisation creates transparency and enables significant energy savings.

The analysis of the energy consumption resulting from the digitalisation process identified further questions for research, such as:

1. What type of digitalisation solution suits best certain motor system setups?
2. What is the range of expected energy savings stemming from the different digitalisation technologies?
3. To what extent does digitalisation unlock additional energy savings?
4. What is the savings potential in certain sectors (energy-intensive, non-energy intensive)?
5. What is the cost-effectiveness of digitalisation and the size of programmes required for its large-scale application?

In the next project phase, focus will shift from digitalisation to demand flexibility in industrial motor systems.

6 National and international cooperation

The international collaboration allowed for a good exchange of research findings among the project partners. These were not limited to case studies and energy consumption, but also evolved around:

a. Technical recommendations for end users for 'digitising' certain motor systems
b. Research on barriers and drivers for digitalisation, organisational, technical, economic barriers
c. Research on policy programmes including capacity building, recommendations for policy makers.

The collaboration allowed a deeper understanding of the subject matter. Project members also delivered valuable feedback to the Swiss research findings, this way contributing to keeping a high quality of the work.

7 Publications

During the course of the project, the project group prepared the following publications:

1. Classification of digitalisation technologies for electric motor driven systems [1]
2. Policy Brief - Digital technologies for motor systems
3. Digitalisation in electric motor systems – Part I: Findings for policy makers (under publication)
4. Digitalisation in electric motor systems – Part II: Technical recommendations for industrial end-users (under publication)
5. Digitalisation in electric motor systems - Part III: Catalogue of case studies
6. Digitalisation in electric motor systems – Part IV: Energy consumption due to the digitalisation of electric motor systems

Figure 4 Digitalisation in electric motor systems - Part III: Catalogue of case studies. BMW case, Austria

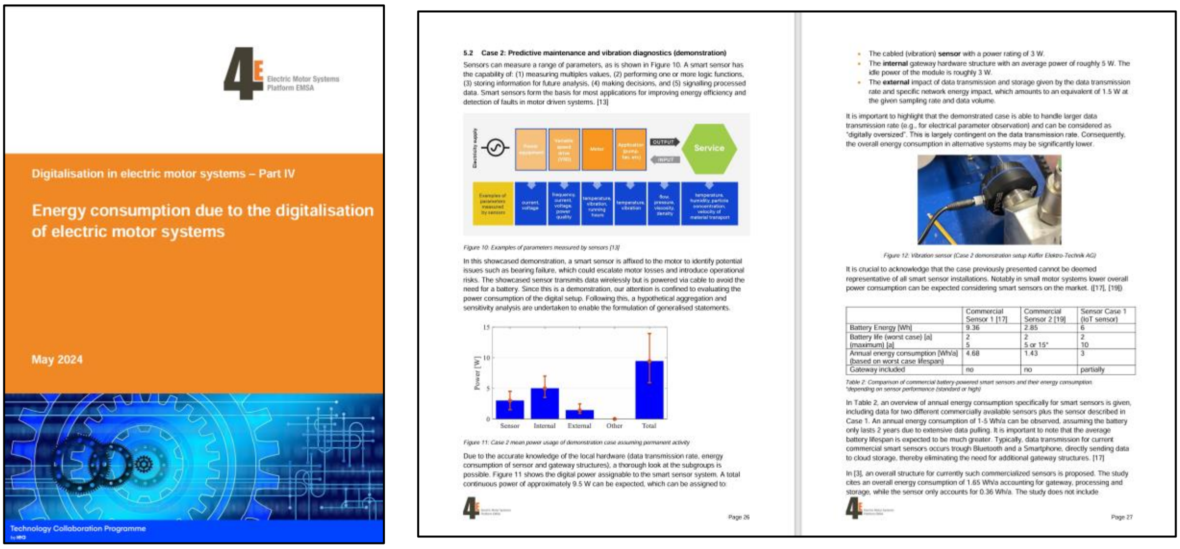


Figure 5 Digitalisation in electric motor systems - Part IV: Energy consumption due to the digitalisation of electric motor systems. Case 2: predictive maintenance and vibration diagnostics.

8 References

[1] Brunner, C.U., Brechbühl, B., Glauser, H., Nipkow, J., Steinemann, U.: Betrieb ohne Nutzen, Swiss Federal Office of Energy SFOE, 2009

[2] Kulterer, K., Dawody, J., van Werkhoven, M., Widerström, G., Classification of digitalisation technologies for electric motor driven systems, IEA 4E EMSA, 2022.

9 Appendix

- Digitalisation in electric motor systems - Part III: Catalogue of case studies
- Digitalisation in electric motor systems – Part IV: Energy consumption due to the digitalisation of electric motor systems