Final report – ACTION project

1. Project details

Project title	ACTIve frOnt-eNds for smart electrical drives (ACTION)
File no.	64020-1096
Name of the funding scheme	EUDP
Project managing company / institution	Danfoss Drives A/S
CVR number (central business register)	19883876
Project partners	DTU Electrical Engineering/ DTU WIND, Bornholms Spildevand A/S, TREFOR El-Net Øst A/S
Submission date	16 August 2024

2. Summary

Project summary:

Electrical motors consume about half of the world's annual electrical energy. Motors controlling low-dynamic, non-time-critical processes, like those in sewage and heat pumps, fans, and compressors, can be flexible in their energy consumption without affecting their primary functions. These motors are typically connected directly to the electrical grid or use passive power electronic converters, which limits their controllability and regenerative power capabilities.

The ACTION project has achieved significant milestones by developing, implementing, and showcasing active front-end (AFE) converters for water pump applications, enhancing their flexibility. Additionally, the project demonstrated remote controllability for conventional diode-rectifier + inverter drives. While conventional drives can optimize energy efficiency with IoT platforms and prepare for aggregation, AFE drives offer more. They enable precise active power regulation and influence current and voltage waveforms, thereby enhancing power quality and serving as intelligent distributed sensors. Notably, the project showcased highly accurate frequency measurement capabilities. Fig. 1. below indicates frequency measurements collected from the IoT gateway and platform with regards to the high-quality frequency measurements from the AFE.

Fig. 1. Validation of frequency measurements from the Danfoss AFE, which abide to the highest

These advancements were showcased at PowerLabDK (Smart Converter Lab) at the Technical University of Denmark and in a real-world case study on Bornholm Island. In summary, the project yielded a new smart AFE drive product and an IoT platform capable of controlling both conventional and AFE motor drives, where both technologies are currently being commercialized.

The purpose of the project *(max 350 characters incl. spacing):*

The ACTION project addressed the challenge of inefficient energy use by electrical motors and unlocking the flexibility from them. It developed and demonstrated new AFE converters and new IoT platform to harness their flexibility, improving efficiency, power quality at grid connection and enabling real-time grid optimization of aggregated portfolio.

Results, conclusions and perspective *(max 1500 characters incl. spacing):*

Most Important Results:

- *We have created an AFE drive product and a smart IoT platform for remote control of both conventional and AFE motor drives.*
- *Improved power quality has been developed by allowing AFEs to actively regulate current and voltage waveforms at the grid connection point.*
- *Remote IoT control of active power (conventional drives) and reactive power (AFE drives) has been demonstrated in Bornholm Island and in PowerLab. Experimentally it has been demonstrated on 6 real world pumps systems and on 2 back to back motors in PowerLab*
- *Smart aggregated control of conventional and AFE drives has been demonstrated in simulation.*
- *Up to 10% efficiency improvements on individual wastewater pumps in Ronne have been demonstrated when utilizing smart IoT driven control of the drives. See Fig. 2, as also reported in the article published in IECON 2024.*

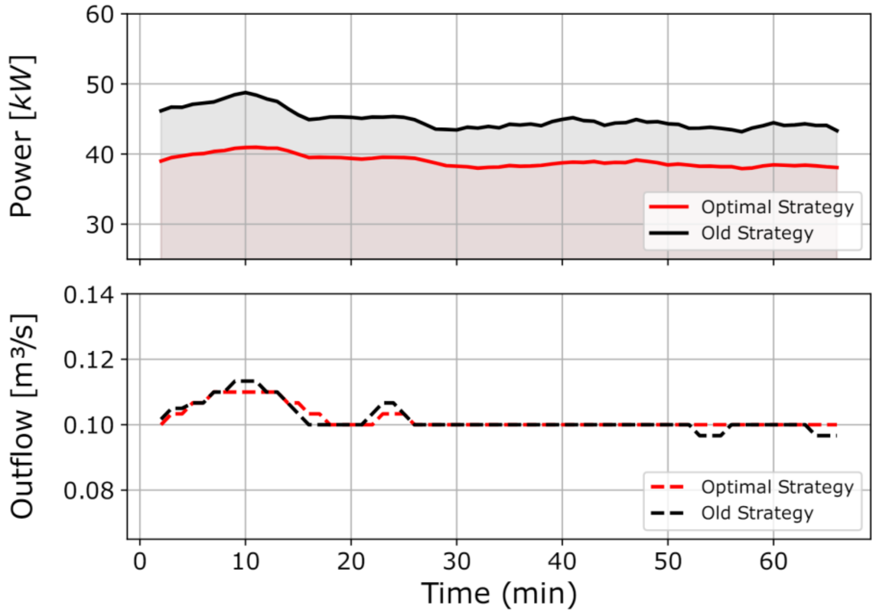

Fig. 2. Comparison of the optimal versus the conventional control strategy when prioritizing the most efficient pump. The bottom panel shows that the outflow of the optimal control strategy is comparable between the two strategies, whereas the power consumption is reduced (above panel).

Future Use of Results:

- *Grid operators, equipment owners and commercial aggregators will be able to use both the IoT platform technology and AFE technology to optimize grid load management, grid frequency stability, reduce infrastructure costs, and improve overall grid stability.*

Expected Effects:

- *Enhanced energy efficiency in industrial and municipal motor applications, leading to significant energy savings.*
- *Improved power quality and grid stability through more precise control of energy consumption and distribution.*
- *Reduced operational costs for grid operators by avoiding costly infrastructure upgrades.*
- *Increased revenue opportunities for end-consumers through participation in emerging flexibility markets.*
- *Increased sales of Danfoss Drives.*

3. Project objectives

Objective of the Project:

The ACTION project aimed to develop cost-competitive active front end (AFE) grid-connected electrical drives and demonstrate new methods for grid-friendly control of these converters in applications such as pumps, fans, and compressors. The goal was to unlock the untapped consumption flexibility of these motors in the smart grid, facilitating their integration into smart energy systems with sector coupling capabilities.

To achieve this, the project required parallel development of the AFE hardware and a smart IoT platform. In this context, IoT platform prototype ready for testing has been developed prior to AFE hardware, and hence it was tested on conventional drives for a year before carrying out tests on the AFE drives.

Developed and demonstrated energy technology:

- *Developed AFE converter prototypes: Created hardware prototype of cost-competitive AFE grid-connected electrical drive with essential software features as well.*
- *Local grid-support services: Implemented grid-monitoring and local reactive current and frequency support based on local grid measurements and drive flexibility.*
- *Aggregated control services: Developed communication protocols to collect data from distributed AFEs and send it to a centralized IoT platform. Real-time optimization algorithms were implemented to improve energy efficiency and aggregation concept was developed to coordinate flexibility reserves among multiple drives and other flexible assets.*
- *Smart AFE product: Integrated local services into a new Smart AFE product.*
- *Demonstration: Successfully demonstrated the technologies in both laboratory settings and real-world environments, specifically at PowerLabDK and a pump station on Bornholm island.*

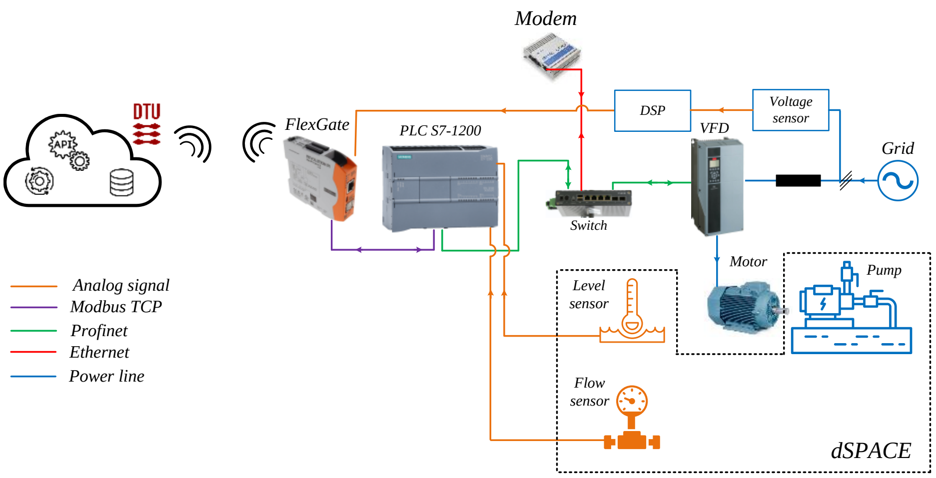

Fig. 3. Block diagram of the platform used at DTU to develop real-time IoT driven control.

Breakdown of achievements per WP.

WP0: Project Execution

Identified and prepared the pump station for AFE installation, and Knudsnæs for temporary test with standard Drive w/o AFE.

Conducted grid service workshops to prepare for field test activities.

WP1: Development and Integration of AFE Drives

Design and Component Procurement: Finalized the design and ordered necessary mechanical, magnetic, and PCB components for the drive.

Integration Testing: Conducted comprehensive integration testing of both hardware and software components.

Drive Testing: Built and tested multiple drives for internal validation, covering performance, thermal characteristics, EMC protection, and safety.

User Interface Development: Developed user interfaces and validated communication protocols for the installation.

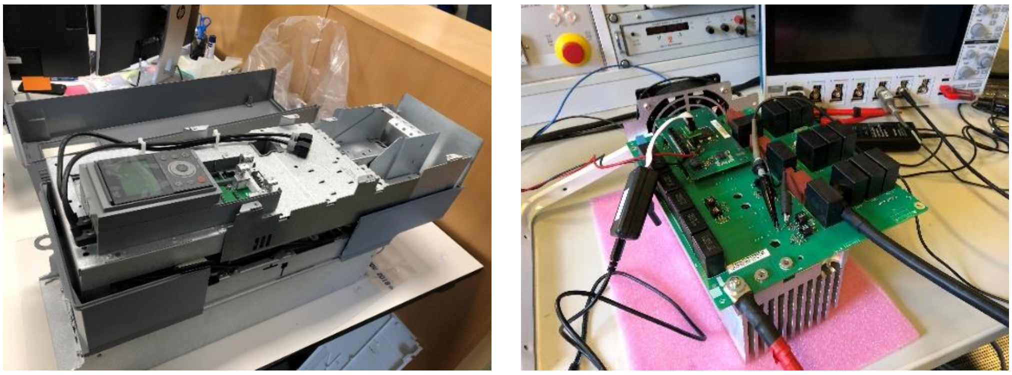

Fig. 4. New AFE hardware during development process.

Installation and Operation: Built, tested, and installed the AFE Drive at the Rønne Pump Station (see Fig. 5.). The drive has been operational for several month.

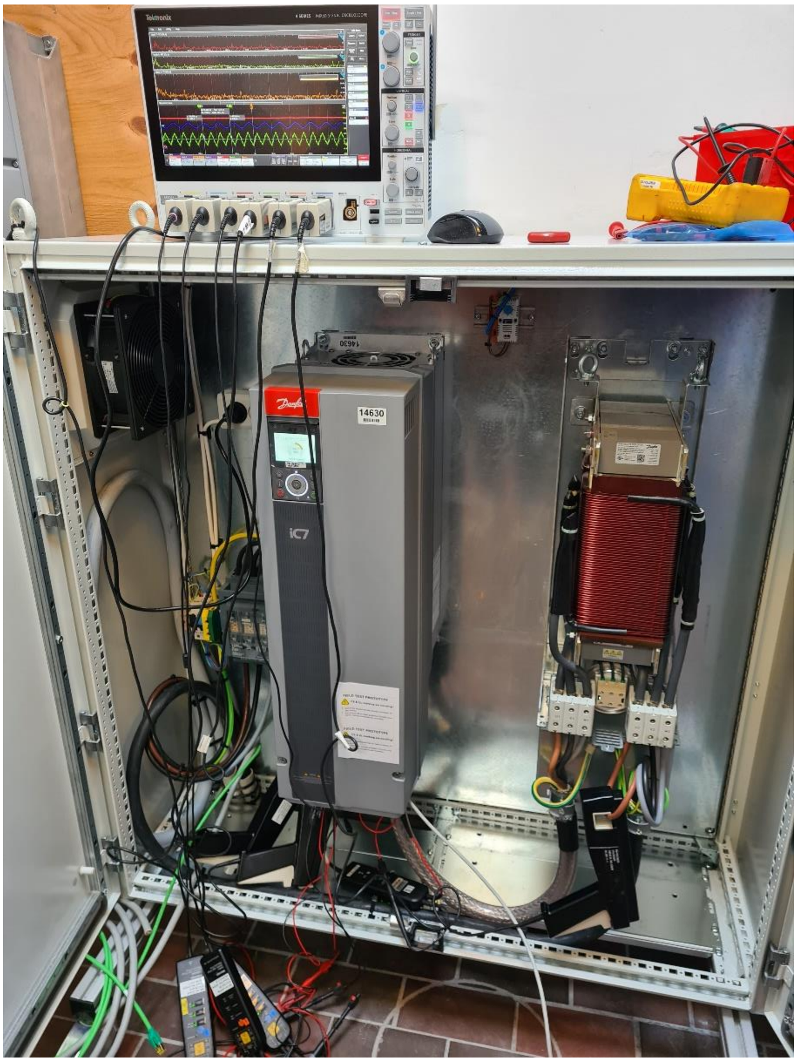

Fig. 5. AFE prototype installed at Rønne Wastewater pump station, with power quality test being carried out.

Fig.6. Wastewater pumps to which both conventional drives and iC7 prototype have been connected. Right hand side of the figure indicates wastewater tanks at the Ronne pump station.

WP2 & WP3: Grid Support Functions and Efficiency Optimization

Grid Support Implementation: Implemented grid support functions and efficiency optimization in existing FC202 drives at the pump station.

Data Collection and Analysis: Collected and analyzed data to develop a digital twin of the station, enabling smart control implementation.

Efficiency Improvements: Found that station efficiency could be improved by 5-10% and estimated both short- and long-term flexibility.

Cloud Data Streaming: Streamed relevant data to the cloud for market-level aggregation. A small replica of the iC7 drive has also been built in DTU (see Fig. 7). However, since this replica has not been equipped with AFE, only basic software functions and data connectivity have been tested.

Fig. 7. Small scale iC7 demo setup at DTU.

Control Functionality Testing: Successfully tested remote reactive power control for AFEs and active power control on conventional drives. For example, Fig. 8, shown below demonstrates testing of AFE functionalities within the Smart Converter lab at DTU.

Edge Controller Development: Developed a smart IoT-connected edge controller that optimizes the energy efficiency of the pumps and communicates bidirectionally with the PLC.

Aggregation Method Demonstration: Demonstrated the method for aggregating wastewater pumps and batteries in the context of providing FCR-D up and down services.

PowerLabDK experimental test setup:

The PowerLab setup includes multiple programmable Danfoss AFEs, primarily using the earlier FC302 operating system. These AFEs were used in most tests during the project, and with the dSPACE control platform, we tested various control codes that are also compatible with the newer iC7 AFEs. Danfoss has since donated a back-to-back iC7 converter setup to DTU, configured with a passive front end, allowing our team to become familiar with the iC7 operating system.

Testing at DTU was conducted with both the older FC302 AFEs and the iC7 drives in passive front-end configuration. The iC7 AFE was installed on Bornholm and tested remotely from DTU.

Regarding grid connections, PowerLab is connected to the DK2 grid (Eastern Denmark) and has access to grid simulators. When AFEs were connected to the regular grid, it was to the DK2 system. When using grid emulators, we could simulate events from either DK1 or DK2. It's important to note that the Bornholm grid system is part of the DK2 grid.

The tests we carried out included both internal controls of the AFEs (such as internal voltage, current, and power control loops) and external IoT-driven controls (sending externally calculated references via the cloud to the converter to compensate for unbalance, harmonics, or to improve system efficiency).

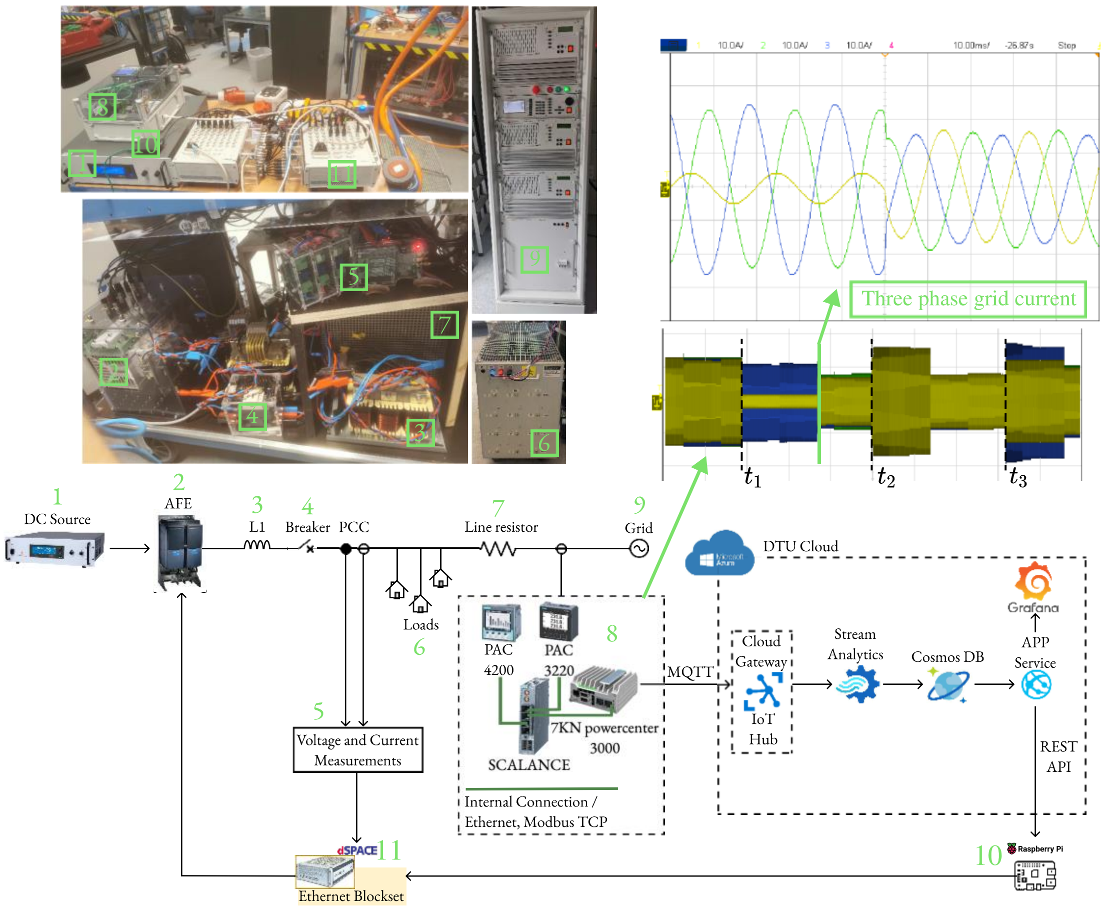

Fig. 8. Setup for testing unbalance compensation of AFE within the PowerLab environment and associated experimental results.

PowerLabDK simulation case study:

Despite demonstrating the technology on individual pumps and motors, testing the developed technology experimentally on a large number of hardware pumps and motors across different sites would not be practically or economically feasible. Each individual unit would require the installation of an expensive gateway, along with ongoing operational costs, such as internet subscriptions and SIM cards, to ensure connectivity and control. These costs would quickly escalate, making widespread deployment prohibitively expensive, especially in the early stages of technology adoption.

Therefore, to address the need for understanding the technology's scalability and performance across multiple units, we conducted extensive simulations in PowerLab. These simulations allowed us to model and evaluate the aggregation concept across many motors (see Fig. 9 below). While these tests were not performed on physical hardware, the simulations were designed to closely mimic real-world conditions, providing us with valuable insights into the technology's potential to scale effectively.

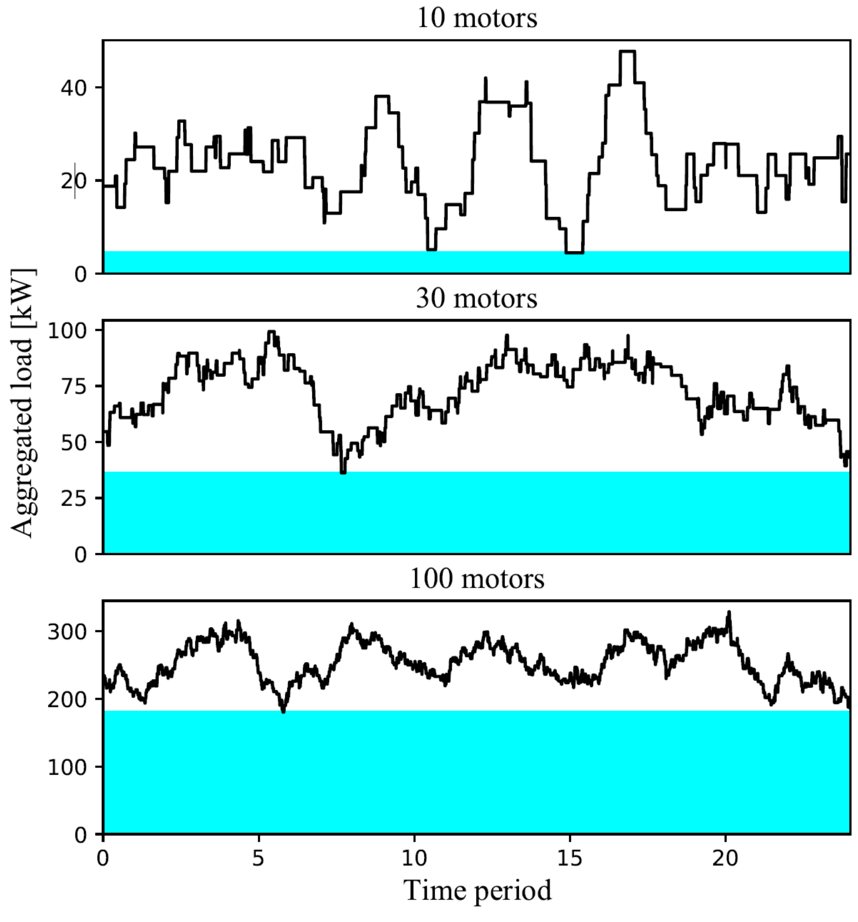

Fig. 9. Aggregated flexibility increases, as the number of small AFE motors increases.

In general, the simulated results from PowerLab offer a good foundation for understanding the benefits of the AFEs when applied to multiple units. Although we did not test numerous physical motors, the simulation outcomes suggest that the more AFEs we aggregate, the greater value we can produce. This approach allowed us to validate the technology's potential in a cost-effective manner, without the need for extensive and expensive hardware deployment.

Formal flexibility quantification:

Our team at DTU has developed a new data-driven approach for formally assessing the flexibility of pump assets, focusing on optimizing their energy consumption for Frequency Containment Reserve for Disturbances (FCR-D). This method involves collecting and analyzing three months of operational data to understand the pumps' power consumption and outflow behavior. Flexibility is quantified by evaluating the relationship between outflow and power, with a focus on removing outliers and calculating the maximum power increase achievable with 90% confidence, while not modifying the outflow so much that the wastewater tank is overflown. The wastewater tank will overflow if the pumping system does not evacuate the wastewater with sufficient outflow, and the wastewater tank does not have sufficient buffer capacity. Therefore, for flexibility quantification purposes, it is of essence to model the inflow statistics (see Fig. 10) and to have the mapping between outflow and pump power (see Fig. 11). The methodology differentiates between power flexibility (additional power that can be reliably drawn) and energy flexibility (the duration the pumps can deviate from baseline consumption without creating overflows). DTU's IoT controller was integrated into the plant's control system to manage this flexibility dynamically.

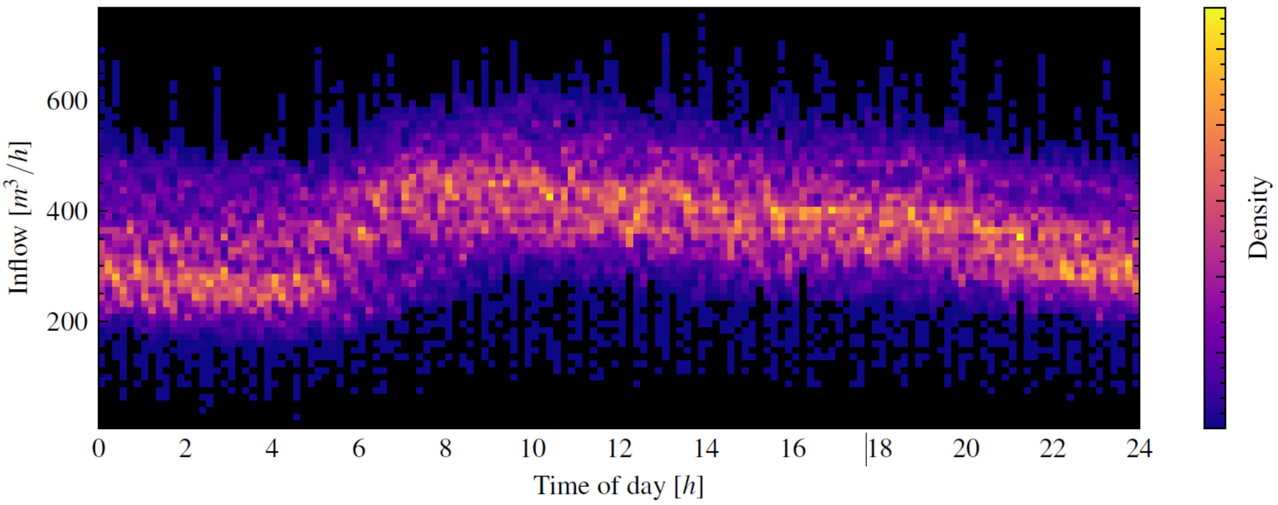

Fig. 10. Historical data-driven analysis of the wastewater inflow pattern for the Ronne wastewater pumping station on days without rain.

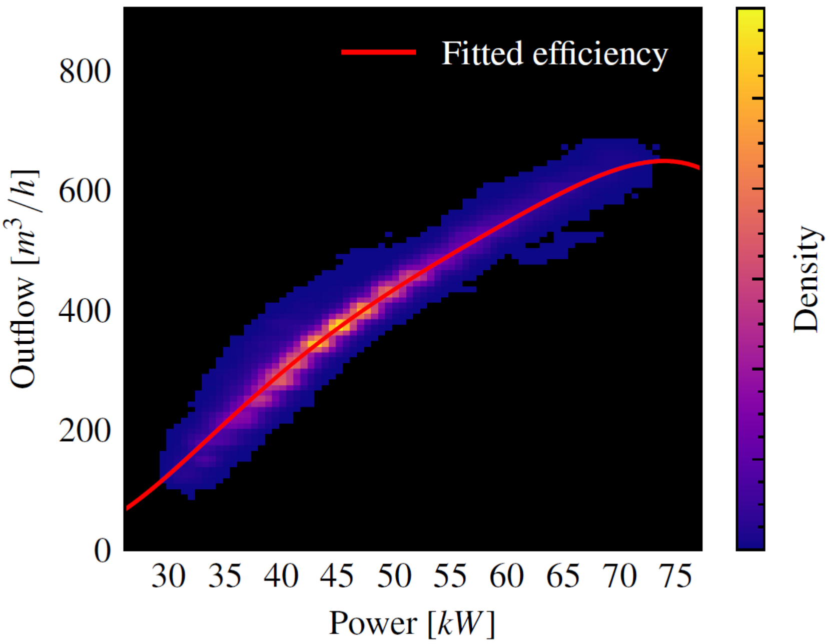

Fig. 11. Data-driven mapping between the pump power and produced outflow.

This approach has also been comprehensively described in one of the publications of the DTU (IECON 2023) and has been informally approved by the TSO in Denmark, Energinet. In essence, the method relies on statistically analyzing how much the power of the assets can be increased or decreased in every hour of the day, and how much would maximum potential increase affect the water levels in the tank. We found out in the project that the guaranteed pump flexibility is, due to the small size of the wastewater tank, only several kWs. Therefore, although the method for prequalifying the assets was working well, the pumps are not planned to be further used commercially on flexibility markets, but the flexibility prequalification will be further developed and potentially applied to other relevant assets.

Flexibility market analysis

Our project revealed that the method we developed for prequalifying and extracting flexibility from assets (described under answer 3) is quite versatile and can be applied to various types of batteries and electrical load assets (such as aerators, heat pumps, electrical boilers, refrigeration systems and others), provided the asset has sufficient flexibility and can be dynamically controlled to meet the necessary limits. Results of ACTION project has created a systematic foundation to analyze the flexibility of different types of assets and to carry out prequalification tests.

Regarding the size of the flexibility market, Energinet published an excellent document towards the end of our project that quantifies the market size and details the specific products and systems contributing to each flexibility category. You can access the document here: https://en.energinet.dk/media/gieparrh/outlook-for-ancillary-services-2023-2040.pdf. An interesting finding from there is that there is no yet wastewater pumps and aerators that have been commercially operated and therefore we could state that we created new value from the ACTION project.

It is also important to note that as the market size increases, more assets will be entering the flexibility market, leading to a gradual decrease in market prices throughout 2024. Specifically for electrolysis technology, it is still not yet widely adopted, so its impact on prices is currently minimal.

WP4: Test Site Preparation and Prototype Installation

Site Selection: Selected the largest pump station on Bornholm as the test site.

Site Preparation: Prepared the site for AFE installation, facilitating data transmission to the DTU cloud and enabling SCADA override for frequency control services.

Prototype Installation: Installed the first prototype AFE in the pump station, ensuring it was operational and integrated with the existing systems.

4. Project implementation

Project Evolution:

The ACTION project evolved through a series of technical and two commercial milestones aimed at developing and demonstrating cost-effective active front end (AFE) grid-connected electrical drives with advanced grid-friendly control capabilities. The project's timeline was structured into four main years of activity:

Year 1: Initial Setup and Site Examination

M1: Tour / examination of Bornholm test sites (including substations and smart meter locations) was completed. ✅

Year 2: Development of Local and Aggregated Control Functions

M2: AFE individual local intelligence and control functions were specified, developed, and programmed. ✅

M3: AFE SCADA-based aggregated control functions were specified, developed, and programmed. Here, it must be noted that the remote-control capabilities were not integrated within SCADA, but an external IoT-based platform and gateway has been developed, but with the exactly the same end functionality as originally envisioned. Therefore, this milestone can also be considered completed. ✅

Year 3: Hardware and Field Tests

M4: AFE hardware / SCADA was made ready for roll-out. Similarly, as in M3, IoT platform has been developed instead of SCADA platform, but developed functionalities were as originally envisioned. ✅

M5: PowerLabDK / Bornholm field tests were completed; and key value services were demonstrated. Before the end of the project, we managed to demonstrate. ✅

Year 4: Market Readiness

CM1: Smart AFE drive was made ready for customer field test, and application areas are being expanded. ✅

CM2: AFE SCADA platform was prepared for aggregator use in the flexibility market. Commercial aggregators are relying on parts of the technology developed within the project and the rest of the platform will soon be ready for market launch. ✅

In summary, we can conclude that we have successfully completed all the milestones that have been originally envisioned.

Throughout the project, we managed the risks that we already anticipated during the application stage, while also navigating unforeseen challenges that arose during the execution. At the project's start, we identified potential risks such as inadequate grid load information, difficulties in accurately quantifying available flexibility, and concerns regarding increased wear and tear in AFE converters. To mitigate the first risk, we proactively engaged in data collection efforts, and developed a dedicate the IoT gateway device, which was connected to the PLC of the plant (see Fig. 12). This action effectively entirely mitigated the anticipated risk within the particular case study in Rønne, because PLC turned out to collect sufficient information to improve the energy efficiency of the pump and to control it in a way that is suitable for active power aggregation (Fig. 13. indicates the concept for asset aggregation). On the other hand, for reactive power control of AFEs, we have been able to control it remotely using the same platform, but for the reference to make sense (i.e. to compensate the reactive power in a way that minimize reactive power at the point of common coupling), we have also connected NeoGrid's smart grid meter to the platform.

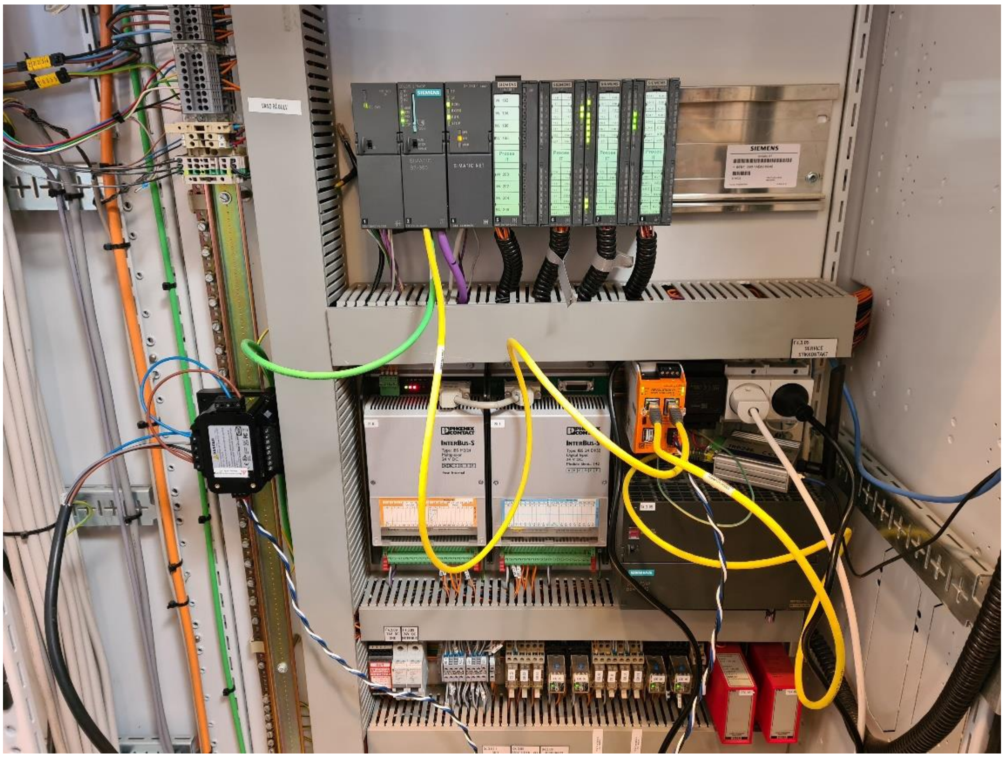

Fig. 12. IoT gateway connected to the PLC of the Rønne wastewater pumping station.

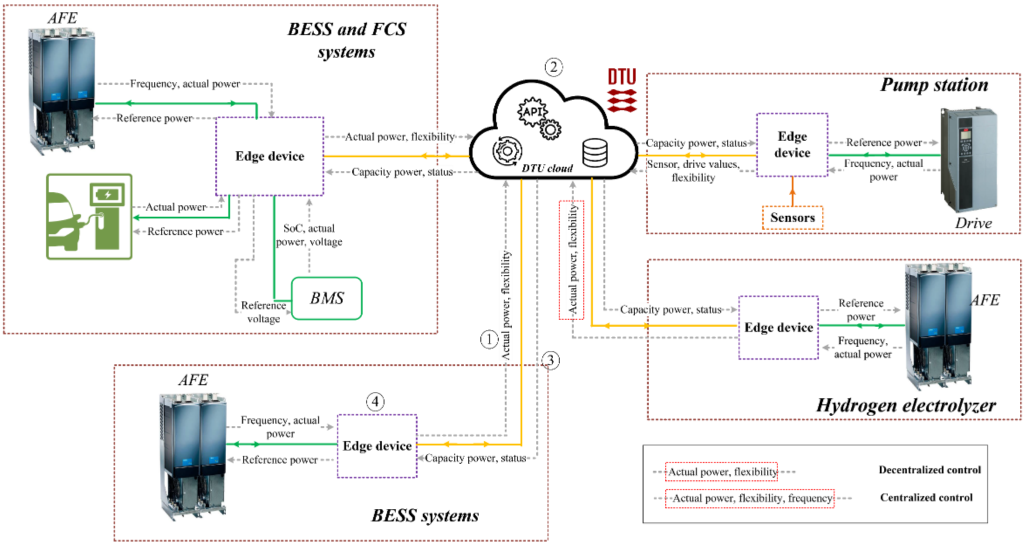

Fig. 13. Flexible energy asset aggregation concept developed during the ACTION project.

When it comes to flexibility quantification, DTU has achieved it through intense research as well as collaborative efforts with stakeholders. These results have been published in several top tier international conference proceeding (i.e. IECON 2022, and IECON 2023). Moreover, we been working on implementing outlier detection approaches to enhance AFE reliability, addressing thermal loading and potential wear and tear issues. These respective results have been published in the top tier international journal (IEEE Transactions on Industrial electronics) Additionally, measures such as equipping AFEs with active damping and harmonic compensation control algorithms, as well as good practices in hardware and filter design. mitigated risks associated with electromagnetic interference.

We have experienced unforeseen technical challenges emerged during the project, particularly during the integration phase of AFE drives at the pump station. We experienced some communication issues, leading to delays in milestone achievements. However, we did carry out prompt action to rectify these issues, and eventually completed the milestones with slight delay.

Unexpected Problems:

While the project implementation largely followed the planned milestones, some unexpected issues arose:

Field Test Delays: The field test at Bornholm was delayed due to milestone M4 not being achieved on time, leading to a request for a project extension.

Technical Challenges: Integration of the AFE drive at the pump station initially faced internal communication issues, causing the drive to trip intermittently. This was resolved with a software patch.

Despite these challenges, the project successfully developed and demonstrated innovative AFE technology, significantly contributing to the future of smart grids and energy management. The smart AFE drive and SCADA platform will soon be ready for market launch, offering new capabilities for grid optimization and flexibility.

5. Project results

The original objective of the project, which aimed to develop highly cost-competitive AFE grid-connected electrical drives and demonstrate new methods for grid-friendly control, was achieved to a significant extent. However, certain obstacles hindered complete attainment of the objectives. Delays in milestone achievement, particularly in integrating AFE drives at the pump station due to communication issues, posed challenges. To mitigate these obstacles, adjustments were made to the project plan, including the implementation of software patches and extensions to project timelines. Despite these challenges, the project successfully developed and demonstrated technological advancements in AFE technology and grid-friendly control systems. The obtained technological results include the successful design, integration, and testing of AFE drives, as well as the development of smart IoT-connected edge controllers for optimizing energy efficiency. Additionally, the project demonstrated the feasibility of aggregating wastewater pumps and batteries for providing grid support services. While some unexpected technical challenges were encountered during the project, such as communication issues during AFE drive integration, the project team effectively addressed these obstacles, ensuring the overall success of the project. The project successfully developed and demonstrated innovative AFE technology. The smart AFE drive, and SCADA platform will soon be market-ready, offering new capabilities for grid optimization and flexibility.

The target group remains as originally envisioned during the project's application stage. The Smart AFE addresses a need for drive customers to install drives easily without concerns about grid quality deterioration. Additionally, the AFE enables customers to participate in future grid performance optimization. The specific value of these settings will be determined during the project and will depend on the evolving flexibility markets.

The project results have been disseminated through various channels to reach diverse audiences. From the BEOF perspective, dissemination efforts have focused on leveraging the project's demonstration sites at Bornholm. This includes publishing in two versions of the wastewater industry magazine as well as exhibited the technology at Bornholm Folkemodet – a renowned event attracting a wide audience particularly in the energy area - at a human library event as well as a Huxi Bach hosted Waste Water event with participation from BEOF, Aalborg University, European Energy, Climate and Energy Spokesperson. 4 Videos from the event created for social media. .

Fig. 14. Dissemination at Folkemødet Bornholm

Several internal workshops have been conducted to evaluate the different services and business models of the AFE Drives for participating companies. Danfoss has promoted new Smart AFE products at trade shows and fairs. Academically, DTU has disseminated scientific findings through publications in several top-tier peer-reviewed journals and conference proceedings. Below is a list of articles published by DTU related to the project*:*

- *D. Gebbran et al., "Cloud and Edge Computing for Smart Management of Power Electronic Converter Fleets: A Key Connective Fabric to Enable the Green Transition," in IEEE Industrial Electronics Magazine, vol. 17, no. 2, pp. 6-19, June 2023, doi: 10.1109/MIE.2022.3211125*
- *M. M. Mardani, R. D. Lazar, N. Mijatovic and T. Dragičević, "Artificial Neural Network-Based Constrained Predictive Real-Time Parameter Adaptation Controller for Grid-Tied VSCs," in IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 11, no. 2, pp. 1507-1517, April 2023, doi: 10.1109/JESTPE.2022.3214342*
- *M. M. Mardani, N. Mijatovic and T. Dragicevic, "Optimal Model Predictive Controller for Grid-Connected Voltage Source Converters," 2022 IEEE 31st International Symposium on Industrial Electronics (ISIE), Anchorage, AK, USA, 2022, pp. 7-11, doi: 10.1109/ISIE51582.2022.9831711.*
- *C. Zhang, M. M. Mardani and T. Dragičević, "Adaptive Multi-Parameter-Tuning for Online Stabilization Control of Grid-Tied VSC: An Artificial Neural Network-Based Method," in IEEE Transactions on Power Delivery, vol. 37, no. 4, pp. 3428-3431, Aug. 2022, doi: 10.1109/TPWRD.2022.3171708.*
- *W. Oppedijk, N. Tiben, D. Gebbran and T. Dragičević, "Flexibility Prediction in Wastewater-Energy Nexus using Machine Learning," IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 2022, pp. 1-6, doi: 10.1109/IECON49645.2022.9968419.*
- *Quattrociocchi, R. K. Subroto, W. M. Oppedijk and T. Dragičević, "Energy Efficiency Optimization of a Wastewater Pumping Station Through IoT and AI: A Real-World Application of Digital Twins," IECON 2023- 49th Annual Conference of the IEEE Industrial Electronics Society, Singapore, Singapore, 2023, pp. 1-6, doi: 10.1109/IECON51785.2023.10312592.*
- *J. Schneider, R. Kurniawan Subroto, W. Meinte Oppedijk and T. Dragičević, "Flexibility Estimation for Wastewater Pumping Stations Participating in Grid Ancillary Services," IECON 2023- 49th Annual Conference of the IEEE Industrial Electronics Society, Singapore, Singapore, 2023, pp. 1-6, doi: 10.1109/IECON51785.2023.10312219.*

6. Utilisation of project results

Danfoss has advanced the Technology Readiness Level (TRL) of the AFE Drive from TRL 3 to TRL 7, successfully demonstrating the Smart AFE Drive in a pump station on Bornholm. The productization and commercialization of AFE Drives will continue, aiming to bring these products to market. Field test activities with selected customers are being expanded to further support commercialization. Due to the grid friendliness, high efficiency, and ease of installation, the market for AFE Drives is expected to grow rapidly and significantly, with plans to expand the portfolio. Competing solutions, such as active or passive line harmonic filters, exist but are often large, inefficient, and lack the intelligent features of AFE Drives.

Regarding energy policy objectives, the ACTION project has successfully developed Smart AFE drive technology, enhancing power system flexibility and supporting renewable energy integration. Over four years, the project produced internal reports, scientific publications, and test platforms, resulting in nearly market-ready Smart AFE drives and SCADA (IoT) platforms. These innovations enable precise control of flexible motors, potentially reducing dependency on fossil fuels and supporting the transition to carbon neutrality. By improving grid flexibility, Smart AFE drives can lower CO2 emissions by reducing the need for ramping up carbon-based power plants. Additionally, they help alleviate grid congestion, create new revenue streams from emerging flexibility markets, and reduce the need for smart meter installations by incorporating advanced measurement and intelligence functions within the drives.

7. Project conclusion and perspective

After extensive research and practical demonstration, the project draws several key conclusions. Firstly, the successful development and demonstration of highly cost-competitive AFE grid-connected electrical drives signifies a significant advancement in energy technology. These drives, coupled with new methods for grid-friendly control, have unlocked untapped consumption flexibility potentials in the smart grid. The project's findings highlight the feasibility and effectiveness of locally installed grid-support services inherent to individual drives, as well as coordinated control services from multiple aggregated drives. This not only enhances grid stability but also facilitates the integration of renewable energy resources, paving the way for a more sustainable energy future.

Moving forward, the developed technology holds immense potential for further innovation and implementation. The next steps for the technology involve scaling up its deployment across various sectors and regions. By leveraging the insights gained from the project, future iterations of AFE drives can be optimized for even greater efficiency, reliability, and grid support capabilities. Additionally, there is a need to explore novel applications and use cases for AFE technology beyond pumps, fans, and compressors. This may include integration into emerging sectors such as electric vehicles, renewable energy systems, and industrial processes, further expanding the impact and reach of the technology.

In perspective, the project results are poised to influence future developments in energy technology and grid management significantly. By demonstrating the viability of AFE drives and grid-friendly control methods, the project sets a precedent for leveraging flexibility in the power system at a lower cost compared to traditional solutions. This paves the way for broader adoption of similar technologies globally, accelerating the transition towards a more resilient, sustainable, and decentralized energy infrastructure. Furthermore, the project's success underscores the importance of collaborative research and innovation in addressing complex energy challenges, fostering partnerships between academia, industry, and government entities to drive meaningful change in the energy sector. Overall, the project's outcomes serve as a catalyst for future advancements in smart grid technology and contribute to shaping a more efficient and sustainable energy landscape for generations to come.

8. Appendices

- Add link to relevant documents, publications, home pages etc.