Final report

1.1 Project details

Project title	Power Pack WIND – Hybrid installationsgenerator til havvindmøller
Project identification (program abbrev. and file)	j.nr. 64017-05141
Name of the programme which has funded the project	EUDP-17
Project managing company/institution (name and address)	Zülau A/S, Lysholt Allé 12 7430 Ikast
Project partners	MBM Ikast Elektro
CVR (central business register)	16246204
Date for submission	22.4.2020

1.2 Short description of project objective and results

Projektets formal var at opbygge en hybrid generatorenhed, der kan forsyne havvindmøller med energi i perioder, hvor de er off grid. Det vil være i installationsfasen og i driftsfasen, i perioder, hvor møllen er under service, eller hvor parken er ramt af kabelbrud/forsyningssvigt. I et samarbejde med Ørsted A/S, der er Danmarks største projektvirksomhed på vindmølleområdet, og som besidder langt størstedelen af Danmarks vindkapacitet, har projektet udviklet et anlæg, som er designet til at fungere som permanent installation i en vindmølle, og som kan fungere som forsyningsenhed og backupenhed i hele møllens levetid.

The project's aim was to build a hybrid generator unit that can supply offshore wind turbines with energy during periods when they are off grid. It will be in the installation phase and during the operation phase during periods when the turbine is under service or when the park is affected by cable break/supply failure. In cooperation with Ørsted A/S, Denmark's largest wind turbine project company, which holds the vast majority of Denmark's wind capacity, the project has developed a unit that is designed to function as a permanent installation in a wind turbine and which can act as a supply unit and backup unit throughout the life of the turbine.

1.3 Executive summary

The project has been carried out by a wide range of companies. Some have been involved throughout the project and others have participated with special skills

where it has been purposeful. Ørsted has served as a partner throughout the project, and throughout the project the company has made a team available for sparring. Ørsted has been aware of the challenge of the energy supply for wind turbines for a number of years, and it was therefore natural to involve Ørsted already in the design phase. The objective of developing a permanent installation to be able to supply the turbine with energy throughout its lifetime was thus confirmed as early as the start of the project. In this way, the project's results would be in line with the industry's current focus point, and at the same time it was possible to make use of the data Ørsted already had in this area.

The project's main unit is a generator capable of providing a significant amount of energy to a wind turbine. Charging can be carried out using a diesel engine in cooperation with an electric motor. The diesel engine is switched off once the battery pack has reached a satisfactory level. From here, a battery pack and the electric motor with the generator can supply the energy-intensive units of the turbine with voltage to the extent they need it. Since the unit is mounted on the turbine even before it is sent out to sea, it will be able to supply the turbine with energy during both the installation phase and during the life of the turbine.

The generator system has been sized according to the space to be taken in relation to the relatively modest clearance area found in the wind turbine tower. Here the products are not the same and the sizing we have worked on in the project has been a Siemens turbine. However, we believe that the final solution can be converted to other major brands (e.g. Vestas) without significant impact on the selected component composition.

The project has had two key phases that have been dominant over the lifetime of the project:

1. The construction phase. In developing the unit there is a great deal of preparation in terms of getting to know the energy needs of a wind turbine. Important for knowledge are the so-called peak areas, i.e. situations where the mill requires the most energy. In order to gain this knowledge, a number of data collections from specific mill sites were reviewed and incorporated into a requirements specification for the supply unit. The key task was then to put together a balance of components that could solve the task. Each component (engine units, inverters, etc.) was measured and weighed against the specification, and assessed/tested in relation to their interaction. In this way, the generator system is a unit in which all elements are dimensioned for mutual considerations. The components were purchased from suppliers in Denmark and northern Europe.

   The last and most costly part of the construction phase was to develop the electronic control system, which can ensure optimal interaction between engines, battery pack, etc. and respond to the measurements of energy needs that are required from the mill. About 25% of the total budget of the project was spent on this one task, because this was a development from scratch. No one has worked on this task's solution before, and since much of the task is about programming, we had to connect two experts in programming closely to the project.

   Especially in the area of software programming, complexity gradually increased as we continued to develop and sought the data that came from Ør-

sted. We could see early on that a significantly more complicated test phase than we had first assumed had to be carried out and it required control. Both as an electrical control unit between the subcomponents, but also as a data collection unit and supplier of data from the test phase (simulated operation phase).

2. The second main phase of the project has been the test phase, which has been carried out alongside with the development of the electrical control. The construction of a test phase contains a multitude of specification requirements. On the one hand, the subcomponents had to be tested individually and interrelatedly, and on the other hand a number of data simulation tests had to be run in relation to specific turbine sites. Early in the project, the ambition was to run a long key phase in a turbine tower, but we had to recognize that our development continued at the same time as we tested, and it was especially the management part of the development that was expanded. Furthermore, Ørsted was able to provide data and test simulations that were retrieved directly from specific turbine sites that we could test against, and thus we could achieve much the same test results from our own test platform without having to go to a test mill. That we did not get up in the mill was clearly outweighed by the fact that a longer time on the ground gave us time to continue the development, and the end result was bettered.

The test runs spanned over several months, where we reviewed all the specifications with the engines turned on, and where we continuously extracted data in relation to the energy exchange that the plant constantly varied – based on the simulation plans. Tests were carried out to everyone's satisfaction and the facility was ready in March 2020. A single test in December 2019 had to be run twice when the data capture failed. This resulted in additional costs in the form of reprogramming up against an amended specification, and since we failed to find the lost data from this subtest, it had to be repeated and thus implemented with optimal data yield.

Photo: Test/demonstration m. Ørsted.

The project was carried out with the participation of the three parties Zülau, Ikast Elektro and MBM. Permanent partners were Ørsted, T. Montage (project management and mechanics) and KCI (software), and we have had a consultant connected to the project with a focus on safety and working environment, which are key parts of the plant's ability to be used.

Early in the project, the possibilities for patent application were explored, and here we have in cooperation with the company Tropa designed news investigation and a patent application, which is currently under evaluation.

1.4 Project objectives

A wind turbine is dependent on energy for the entire lifetime. The installation period for an offshore wind farm is a hugely energy intensive phase, which is now solved by diesel. The turbines are not yet complete and able to produce power, but in the long period between the towers being erected until the turbines are ready for production and connected to the electricity grid, there are a number of functions that require energy. Lights in the turbines (for aircraft safety), measuring equipment and safety equipment, dehumidification equipment, mounting tools, hoisting equipment, etc. must be operational from the day the tower is raised, and from here it can easily take a year for the mill to be operational and the sea cables for the grid to be towed. The solution today is diesel generators, which consume 1000 litres of diesel per week, for every single offshore wind turbine. This is an energy over-guarding that is only relevant for a few weeks during the period, but since these periods are unpredictable, the generator must provide what is necessary at all times.

This is not only a burden on the energy accounts of offshore wind turbines – it is also a significant cost for the individual offshore wind turbine. In addition to pure diesel consumption, diesel generators have a number of consequential costs: they have to be refilled and they need to be serviced. This means that crews must be allocated during the installation phase only to service the installation's energy supply, and when travelling (as at Anholt) 111 offshore wind turbines, the task is absolutely significant.

With the project, we wanted to develop, in cooperation with our partners, a hybrid and turbine-specific power pack that reduces energy consumption by 75%. The hybrid generator was defined very early in the project cycle as a permanent installation that can supply the turbine with energy throughout its lifetime during periods when there is no supply. It may be during crashes, cable breaks or service where the basic functions of the mill must be kept functional.

1.5 Project results and dissemination of results

The project has developed a hybrid power generator consisting of three elements: a generator unit, a battery pack and a diesel tank.

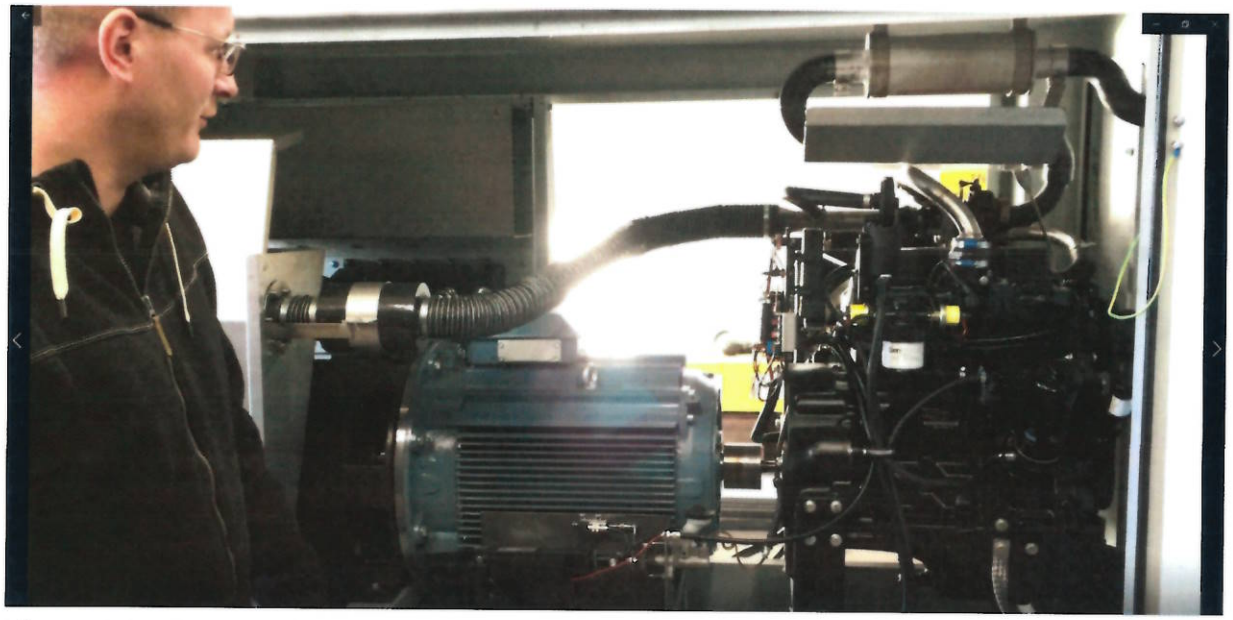
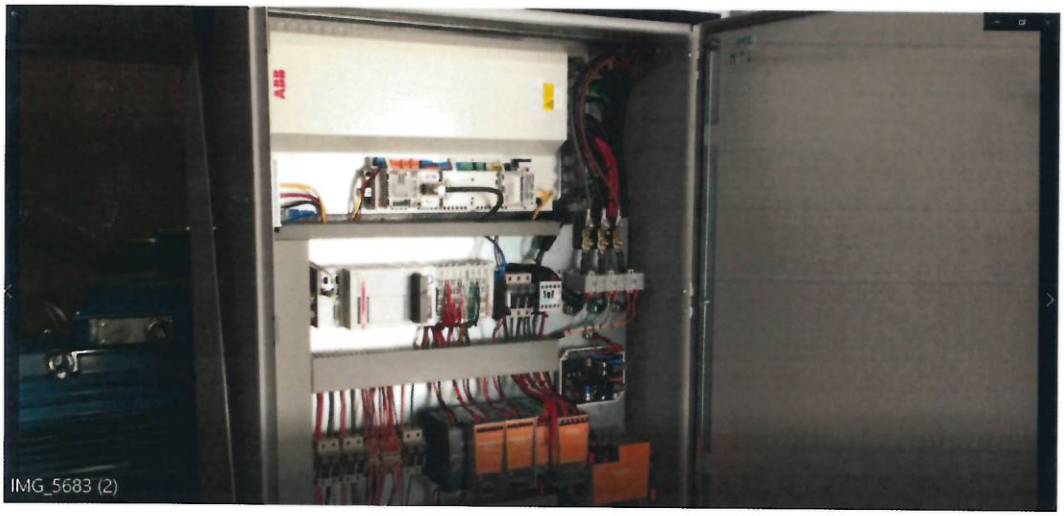


Photo: Diesel engine (right) and electric motor (left)

The generator unit is built from a diesel engine, which is built up to provide the optimal output for the plant. A main engine, which is an electric motor that acts both as a charging unit and as a power output for a 3x690V generator, which is generally controlled from the system's control. This is two-piece so that a control unit is located opposite the engine units as well as the battery pack. The electrical control is stand-alone. The plant can thus be started up completely without external influence.



Picture: The power control of the engine units. Similarly, the control of the battery pack is located above the system.

The advantage of the plant – and this was the main objective of the whole project – is that the diesel engine should not run all the time and that it - when it is running - should only run at its optimum performance (100% load), so that we achieve the optimal use of combustion and the lowest possible diesel consumption. The electric motor feeds the generator and sends voltage to the battery pack when the battery pack needs it. When the battery pack is full, the diesel engine turns off – the charging time is about 3 hours from full discharge to full charge. After that, the time during which the system works from the battery depends on the functions that need energy (wing pitch, curling, dehumidification and other steering, etc. in the turbine).

The system is equipped with two cooling fans that can be started up individually or together, depending on the cooling requirement. The exhaust system will be flexible in terms of how the plant is to be used and placed, so that the exhaust gas can be diverted as is optimal in relation to the production environment in the turbine.

Picture: The battery pack is located on top of the engine system.

Throughout the project, the project has been demonstrated in 1:1 contexts with relevant companies. Of course, the most important thing is Ørsted, and here it can be mentioned that our project was mentioned in an internal letter among Ørsted's employees in the context of other priority projects. Other companies in the wind turbine sector, especially Siemens, have been introduced to our project idea and to our plants, but we have wanted to acknowledge the good cooperation we have had with Ørsted, so that the knowledge they entered into the project was treated confidentially in detail.

Other companies outside the wind industry have also overviewed our facilities, and we are seeing more and more applications in other contexts than wind. The project has been very far in the thinking around a spin-off project with a contractor who wanted a new approach to the utilization of solar energy in an off-grid residential environment. We will continue to work on these opportunities in the future.

A video sequence has also been created, which will be posted on Youtube. Here we explain the connections and give a tour around the unit. We await approvals from our patent partner and Ørsted before publishing it. Unfortunately, we are experiencing some delays in these months, as our own employees have been sent home due to a lack of staff. Coronavirus.

The video can be sent to the EUDP Secretariat and several of the images from this report are screen dumps from there, but otherwise it will be published as soon as possible. The demonstration video will also be posted on our website.

We had a desire to make a more official conclusion for all the project's larger and smaller collaborators about 20 companies at our factory in Ikast with demonstration/workshop and barbecue arrangement, but unfortunately we have to wait for this – also due to Coronavirus.

1.6 Utilization of project results

The project is completed in the middle of the danish society's major lock down, caused by Coronavirus/Covid-19. Therefore, the opportunities to exploit the results of the project in the short term are limited and, in the longer term, subject to some uncertainty. This is important to draw attention to in the context of this report. The project was initiated and we invested significantly in the project's implementation during the life of the project with the aim of being able to sell the solution and variants thereof to the wind turbine sector and project holder in the energy sector for many years to come. Today we must note that our company (Zülau) is shut down and employees are sent home. We receive compensation for our employees and for our fixed costs, but the situation is obviously serious and we have expenses that cannot currently be covered, as turnover is only sporadic in these months. We hope that the situation will be improving after the summer holidays and that the second half of 2020 could initiate a real commercialization of the results.

The plant is designed to be installed in a turbine tower, and the dimensioning of engines, battery pack and electrical control is built as a turnkey unit for a wind turbine, but the principles of being able to handle energy in the way we have developed can be transferred to other sectors that we will look into. We have already been in dialogue with (demonstrated) the plant to actors who do not operate daily in the wind industry, and the feedback is promising in relation to a very broad spectrum application. For example, residential complexes, factories and temporary installations, bases, etc., where one or more energy sources (perhaps off-grid) are intended to supply energy, and where both energy production and energy consumption are fluctuating can benefit from a unit that can produce, collect and distribute power. Here, for example, energy production could come from solar panels or a biogas plant, thus contributing to a more efficient use of renewable energy.

The unit is expected to be marketed globally. However, with a starting point here in Denmark. At the time of writing, however, as mentioned above, our company's business base is under pressure from Corona-Virus. We write this as Corona/Covid-19 can have a significant impact on our ability to sell the plant in the short term commercially:

- On the one hand, the flow of goods and trade between countries is currently severely restricted and linked, in particular, to basic goods and proven technical components, for which training and major service functions are not required. –
- Second, the wind turbine sector has significantly reduced its level of activity in terms of development. This also applies to Ørsted, our development partner in the project. Vestas has just today announced the dismissal of 400 employees in Denmark.
- Third, we must expect that an economic downturn following the Corona crisis will have an impact on our ability to dispose of the plant commercially.

There will be markets that will be closed for longer than others and we cannot currently predict which this is, but as soon as a picture starts to emerge, we will be able to re-organize our marketing plan and focus the stakes where there is best access. At the same time, our plant is likely to be interesting in other contexts that do not necessarily concern wind turbines, and we will actively

seek out these opportunities in parallel with the development of the turbine segment.

In conclusion, with our company's reopening, we must of course focus on recovering the basic turnover in order to maintain earnings. It is unlikely to be relevant to start marketing the plant before the last quarter of 2020.

No commercial results have been achieved on the basis of the project yet.

Although the hybrid generator plant will be completed as a project by the end of the first quarter of 2020, the development cooperation with Ørsted will hopefully continue when we get to the other side of the Corona crisis. The commercial exploitation will have to be done in close cooperation with manufacturers (Siemens, Vestas and others) and with project holders such as Ørsted. Today, the plant is designed as a permanent installation in the turbine tower, from which the turbine can fetch energy during the installation phase and during periods when there is no access to power, and this is a huge safety measure especially for large offshore wind turbines that cannot do without power for even relatively short periods of time.

Although the turbines produce power, they rely on energy from the land to operate on their own. The large mechanical components (wings, blades, turret, etc.) as well as electrical control functions must always be supplied to keep the turbine functional – even in windy weather. If there is a cable break or otherwise obstruction in the delivery of energy to the turbine, our plant will in future be prepared to supply the projects and ensure the mill's functions also during the mill's operation/service life.

Our customers thus will be the technical and commercial project developers in the industry, and they are the ones we want to focus on. This will be done nationally and internationally, but there will naturally be an initial focus on further developing the contact network that has been created in the project.

In the course of the project, it has become clear that there are potential far-reaching opportunities for the dissemination of the technology. It can be both on land and at sea. In many places you need energy that is produced locally. It can be temporary installations, platforms, new builds and much more. Here, our plants – or adaptations thereof – will be able to offset fluctuations in energy production, so that one is not dependent on constant diesel combustion. With our hybrid solution, we will be able to control the supply of energy when we have either a reasonably constant consumption pattern or a pattern of consumption where fluctuations are reasonably predictable. Perhaps the system needs to be dimensioned either up or down. It may need to be encapsulated to match a special need for the customer – but we expect that there may be interesting opportunities for spin-off.

We are still awaiting a response to our patent application, which is pending. The patent application has been submitted by Zülau A/S, but we will distribute the proceeds from a later commercialization with our partners. We must be realistic about the current situation: the plant has now reached a stage from which we will be able to commercialize it, but significant further development, as it stands today, will only take place on the basis of specific commercial pro-

jects. We three partners all feel the crisis hard and we will not have the opportunity to invest in new technological opportunities without specific tasks where the customer/customers pay for the development.

We have not yet been invited into specific commercial projects. As soon as this happens (and we hope it can happen in the foreseeable future), it will potentially turn our business around. A single plant delivered to a customer will be a good business for us. 20 installations for a single offshore wind farm will change all our businesses immediately and we will have to change our setup immediately. In this case, we will have to launch two main development tracks:

1. Create a production setup that can handle future major tasks efficiently.

2. Initiate standardization and efficiency of the plant so that the production price of a single plant can be reduced and make us competitive in the future compared to established solutions and potentially future competing products.

This really means that we are in between two extremes: A very difficult situation due to the Corona virus that has hit our basic business and a potential growth adventure with the commercialization of the new hybrid generator system. In addition to traditional barriers to the implementation of new products in trade contexts, today we have to contend with the fact that we do not have employees at work and that we do not know the future we face. A significant upward adjustment of national investments in green conversion will be beneficial for our project, but it takes time for them to be implemented and we, as smaller companies, do not have a significant influence on this.

1.7 Project conclusion and perspective

The project has been completed and we have developed a facility that we believe fully – and more to – meets the goals we set ourselves when the project was launched. We have benefited from the considerable insight we have gained from the project from Ørsted throughout the process, and we hope to see the plant in operation on turbine sites around the world in the coming years. We are challenged in recent months, as the rest of society is, and this will of course have an impact on how quickly we will be able to commercialize the project.

Whether the development from this is a step towards optimization in relation to the wind turbine sector, or whether other sectors will be able to use our plants earlier, it is still too early to predict. As the project's result offers a green solution in general, the environmental purpose of the project can be achieved by several tracks, and we will thus be able to contribute to a reduced CO2 emissions across a wide range. We have been pleased with the cooperation with the Danish Energy Agency and the responsiveness we have met about the acceptance of our project and the implementation over the 2.5 years it lasted.

22.04.2020 Magnus Thulan