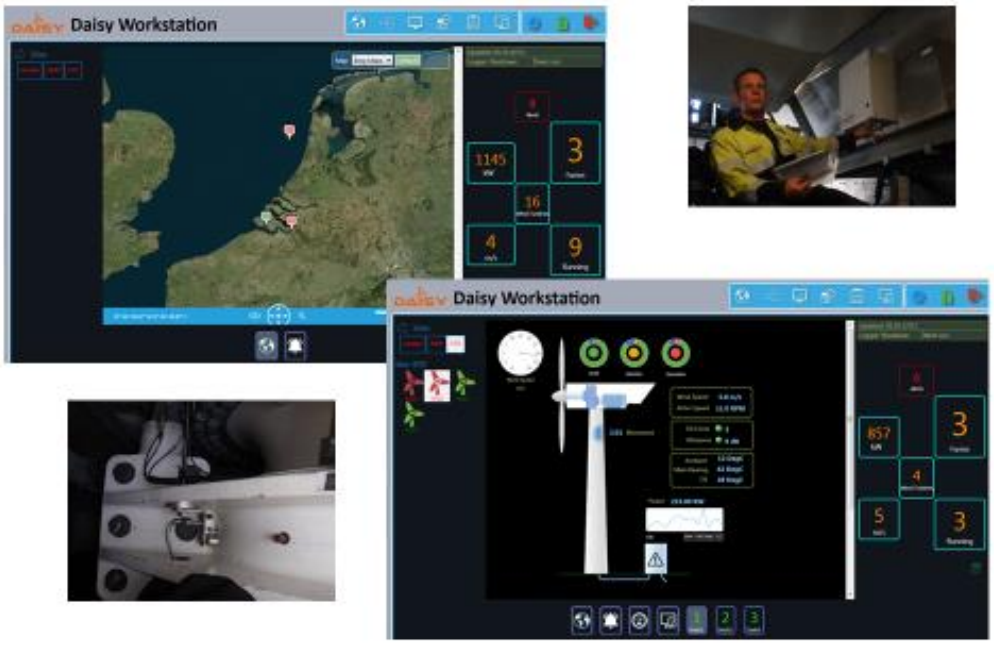
END REPORT

DAISY4OFFSHORE – TKI WIND OP ZEE

Project number: TEW0214006



September 2017

Project data

a. Project number: TEW0214006

b. Project title: DAISY4OFFSHORE - DYNAMIC ASSET INFORMATION SYSTEM FOR OFF SHORE WIND FARM OPTIMISATION

c. Lead partner (penvoerder): Delta Infra BV

d. Project partners (medeaanvragers): Technische Universiteit Eindhoven, Van Kempen Engineering & Consultancy B.V., ECN, Oliveira B.V. (acquired by IJssel Group, Zwolle in May 2016), IMS International B.V. en DI-WCM

e. Project period: Sep 2014 – Jun 2017

Abbreviations

AMP	Anna Maria Polder
CAMPI	Coordinated Advanced Maintenance and Logistics planning for the Process Industries
CAMPIONE	Condition-Based Maintenance for the Process Industry – Open Network Environment
CBM	Condition Based Maintenance
DAISY	Dynamic Asset Information System
OEM	Original Equipment Manufacturer
OWF	Offshore Wind Farms
PDCA	Plan Do Check Act
RDS-PP	Reference Designation System for Power Plants
RUG	Rijksuniversiteit Groningen
TiU	Tilburg University
TUe	Technische Universiteit Eindhoven
WCM	World Class Maintenance
WCWM	World Class Wind Turbine Maintenance

Rijksdienst voor Ondernemend Nederland

DAISY™ 4OFFSHORE

TKI WIND OP ZEE

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Summary

Poor operational performance, lack of transparency and unpredictable maintenance costs were the drivers for the DAISY (Dynamic Asset Information System) consortium to develop technologies that could contribute to the introduction of independent Condition Based (predictive) Maintenance (CBM) in the wind energy sector.
The DAISY consortium was set up within the frame of the Dutch World Class Maintenance (WCM) initiative, had some experience with on-shore parks and worked together in the DAISY4OFFSHORE project to achieve the following goals:

- to develop an independent Dynamic Asset Information System for Wind Turbines, based on the technologies developed within the frame of the WCM initiative;
- to analyse, validate and optimize the system on a real wind park;
- and to quantify the benefits for owners of offshore wind parks.

As a first step the condition monitoring technologies and asset management technologies were further developed towards a fully independent system that can interface with various types and brands of wind turbines. This led to an integrated solution, connected with a central control room at Delta.
Degradation and Operations & Maintenance (O&M) models were connected to the DAISY solution to contribute to the goal of achieving better wind turbine/park performance at lower costs.

Testing of the DAISY solution was done on on-shore and off-shore wind parks, providing the ultimate validation platform. This opportunity arose when Eneco offered the unique opportunity to test DAISY on the off-shore wind park Amalia, instead of analysing the off-shore effects based on a paper exercise.
It was concluded that the DAISY solution can significantly reduce maintenance costs (25%) and simultaneously boost the performance of wind parks (15%). A challenge remains to connect the output of the DAISY solution with the off-shore logistics. Off-shore logistics is rather complex and dynamic and the responsiveness in off-shore logistics is not in line yet with the maintenance directives resulting from the DAISY solution. As a result, potential benefits from condition based and predictive maintenance are often taken away by delay in the off-shore logistics process.
It is expected that this can be improved when off-shore operations will be intensified because of new parks that are planned in the North Sea area and when cooperation is set up between various parks with respect to maintenance and servicing.

1. Introduction

In 2007 The Netherlands embraced the ambition 'World Class Maintenance' resulting in a Dutch Institute World Class Maintenance (DI-WCM) and a community of around 300 companies, educational and knowledge institutes that joined forces in an innovation programme to 'create sustainable business together' (ref. WCM Masterplan). For The Netherlands maintenance is identified as the industrial key to increase the competitiveness of asset owners, OEMs and services providers and create new business and export expertise.

Within the frame of the World Class Maintenance (WCM) initiative the World Class Wind Turbine Maintenance (WCWM) project was performed by a consortium of 24 companies, including among others DI-WCM, ECN and TNO, and Delta as prime contractor. The main deliverables of the project were realised in March 2014.

The project was initiated by a group of asset owners (Delta, Eneco, Zeeuwind, Deltawind) and wind turbine Operations & Maintenance (O&M) specialists that were not satisfied with the current level of performance of wind turbines and OEMs providing maintenance services. The main underlying problems were: (i) poor true availability and output of turbines, (ii) poor service by OEMs, (iii) lack of transparency by OEMs with respect to data on true performance, technical status and maintenance activities carried out (data were not provided or were somehow processed) and (iv) lack of an integrated approach to proactively and continuously improve the operations and maintenance of wind turbine parks. At the same time asset owners had to pay high prices for service contracts and insurance, in order to ensure that all risks that may hurt the business case are covered. Though all Dutch experts agree that a huge O&M cost reduction can be achieved, whilst improving performance, safety, output and balance sheet value, the current non-optimum situation and business case is still viable for asset owners because of the subsidies for development of new parks and on the wind energy price.

During the project, the project team developed various technology components that would contribute to a long term goal to set up a control room that would provide asset owners full transparency and data to optimise O&M of wind parks. Since DAISY is an independent solution on top of systems provided by wind turbine OEMs, the goal has always been to develop a solution based on a state of the art system, but at a low cost, with the capability to optimize the O&M for various asset owners for various types of wind turbines and parks, permitting wind energy to become self-sustainable and independent of subsidies.

The DAISY4OFFSHORE project was started to further develop the various DIASY technology components, as well as strengthen these with the latest developments from knowledge institutes ECN and TUe. Furthermore, the project was meant to come to an integrated solution and validate the solution on real wind parks on and offshore.

2. Objectives

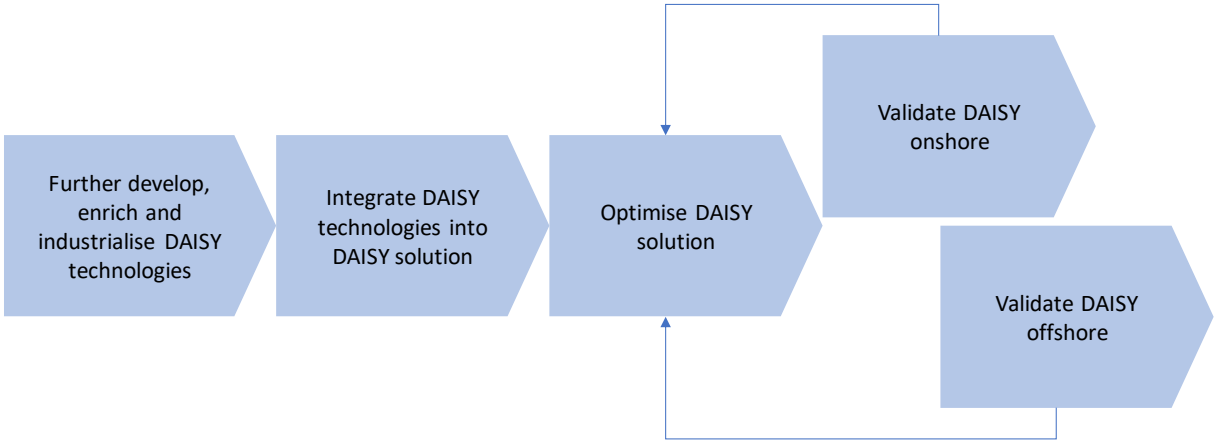
The main objectives of the project were: (i) to develop an independent Dynamic Asset Information System for Wind Turbines, based on the technologies developed within the frame of the WCM initiative, (ii) to analyse, validate and optimize the system on a real wind park, and (iii) to identify the benefits for owners of offshore wind parks.

In order to achieve this, the following sub-objectives were defined:

- Industrialize the various technology components of DAISY, w.r.t. cost, standardization, predictability, availability, maintainability, safety, manufacturing, integration, self-testing features, obsolescence management, etc.
- Asses the options to integrate latest technology from knowledge institutes ECN and TUe.
- Develop decision support modules that support O&M decision making
- Validate, analyze and optimize DAISY on multiple turbines and at wind park level, onshore and offshore

3. Approach

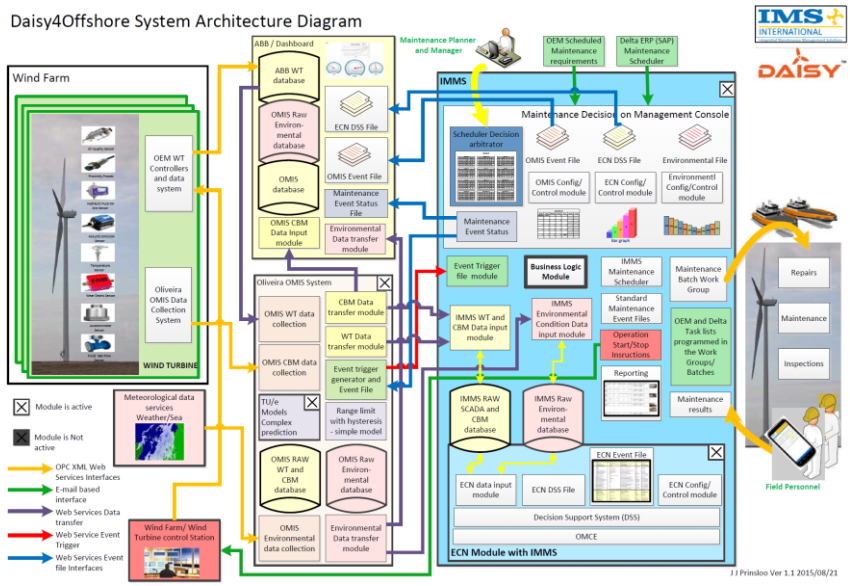
From a technical point of view, the project was carried according to the approach shown below.



Project approach

Besides the technical activities, the project also included project management and knowledge dissemination activities.

As a first step the DAISY technology components were further developed and industrialised to assure a good performance during real operations. During this step also an assessment was performed on technologies developed by ECN regarding options to integrate these into the DAISY solution.
A new architectural (IT) design was made for DAISY to facilitate the integration and communication between the various technology components of the different project partners. Moreover, this architecture allows easy and parametric integration and expansion regarding the introduction of predictive models.



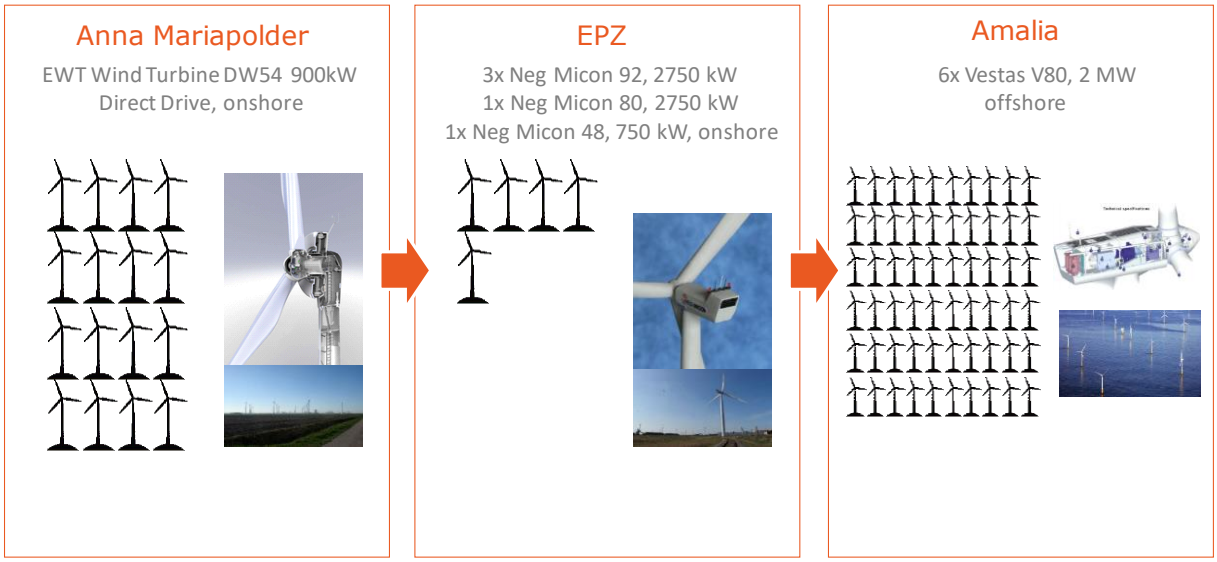
DAISY4OFFSHORE System Architecture

ECN developed a solution for wind farm load monitoring as a stand-alone system, not linked to other systems used to monitor a wind farm. During the project an assessment was made to integrate this technology with DAISY. However, it was concluded, that the technology was not mature enough and as a result the solution was considered too expensive, considering the goal of achieving a truly low cost solution.
ECN also developed an O&M optimisation software module that can be used to support asset management decisions and optimised routing of servicing ships. This solution was connected to DAISY.
TUe was involved for the development of the predictive maintenance algorithms, driven by operational, maintenance, environmental and condition monitoring data.

Integration of the various DAISY components, was established based on the new architecture and communication protocols based on OPC connections, web services and event files. Finally, DAISY back-end components were installed at various servers in Delta's data center and connected to an overall dashboard developed by Delta.

Validation of the DAISY solution was fully performed based on pilots with onshore (AMP, EPZ) and one offshore wind park (Amalia), replacing the original alternative based on a paper analysis. During the beginning of the project, data from the OLAZ park was also used for optimisation purposes. Small scale experiments onshore already started in 2015, but full scale pilots on onshore parks took approximately 1,5 years and the validation exercise took about a year offshore.

Onshore wind parks used for validation



Wind parks introduced during the DAISY4OFFSHORE project for validation purposes

Condition monitoring

The CMS part of DAISY consists of a broad sensor set, communication and data processing unit (V-bridge) and backend software for data processing and analysis (UpTimeAnalist).
The design of Autonomous vBridge was developed from a design that depended heavily on having a very fast and stable network connection with a server, to what is essential a standalone unit, capable of collecting high resolution sensor data, perform FFT transformations within the local processing unit, store these readings for an extended period of time. The unit is truly web based, with M2M communication via 4G as our stand means of communication directly with a cloud based Azure environment.
The sensor set consists of dedicated DAISY sensors, but also sensors placed by the wind turbine OEM are readout by the vBridge.

DAISY4OFFSHORE installed at Amalia

TUe performed research on the requirements that the quality and format data should meet in order to be useful for the DAISY solution. Warning and alarm algorithms have been developed and implemented in statistical software R. These algorithms have been adapted to the specific data formats and protocols of the various consortium partners. A first version was developed based on onshore data and later on the algorithms were developed based on data of the Amalia wind park. In

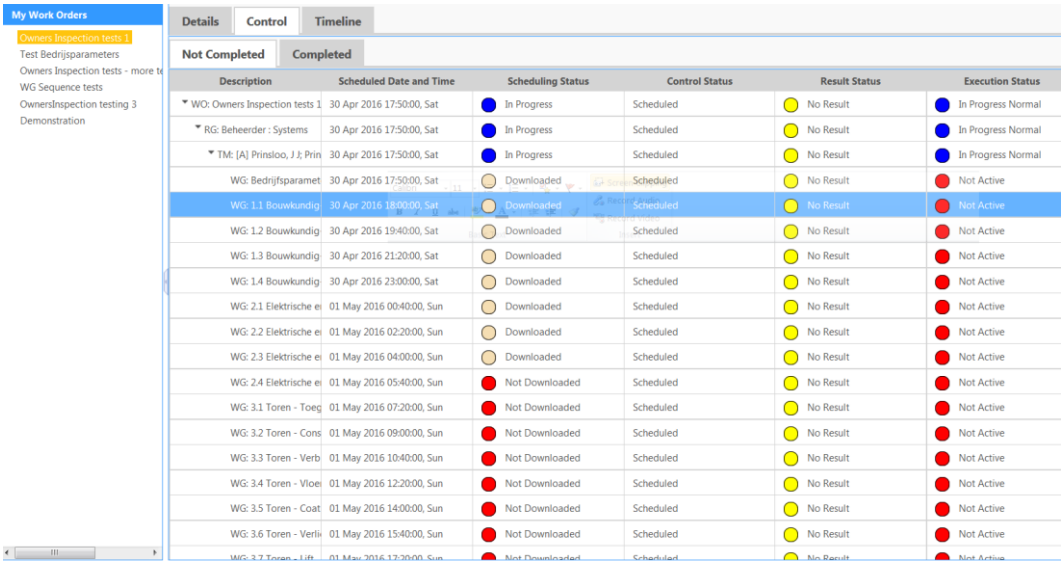
addition, there is a health index for the effective monitoring of the system state developed based on the power output. These indices were created specifically for OLAZ, AMP and Amalia data.

Regarding prognostics and predictions, a method has been developed to predict the remaining lifetime of components based on the cumulative number of warnings (in terms of a corrected calendar time). Since large data sets are required for multiple years to develop accurate predictive maintenance algorithms, real wind turbine data was used and enriched by conclusions based on Philips Healthcare data available at TUe. Finally, specific data analyses were performed on incident data sets of OLAZ, EPZ, AMP and Eneco.

Asset management

The asset and maintenance management part of DAISY was further developed during the project, particularly by IMS, Delta and KEC, with various asset owners of the wind parks available for guidance.

A completely new IT architecture was designed to facilitate the integration and communication between the various technology components of the different project partners. The new design allows all relevant data to be captured, synchronized and analyzed, resulting in alerts of pre-defined actions, automatically connected to management dashboards. The architecture allows easy and parametric integration and expansion regarding the introduction of predictive models. This is relevant, since every new turbine or park may have it specific characteristics that need to be taken into account.
The maintenance management solution was turned into an asset management solution, supporting the complete lifecycle. The system was designed such that the asset manager complies with the larger part of the ISO55000 standard automatically. Particularly the PDCA-loop is automated facilitating optimization based on technical data, management data and data captured by field engineers. Reporting was also automated and as requested by asset owners the DAISY solution now also supports the wind turbine RDS-PP architecture.
Since the output of the asset management solution is connected to Delta's control tower, the solution now also supports the real time tracking of activities and compliance against desirable results.
The asset management system was fully populated with plans and procedures for all onshore and offshore parks. During this exercise expertise of Delta was used to optimize the plans and procedures beyond the prescriptions of the OEM and such that the maintenance procedures can also be used by the field engineers to capture data suitable for predictive maintenance.



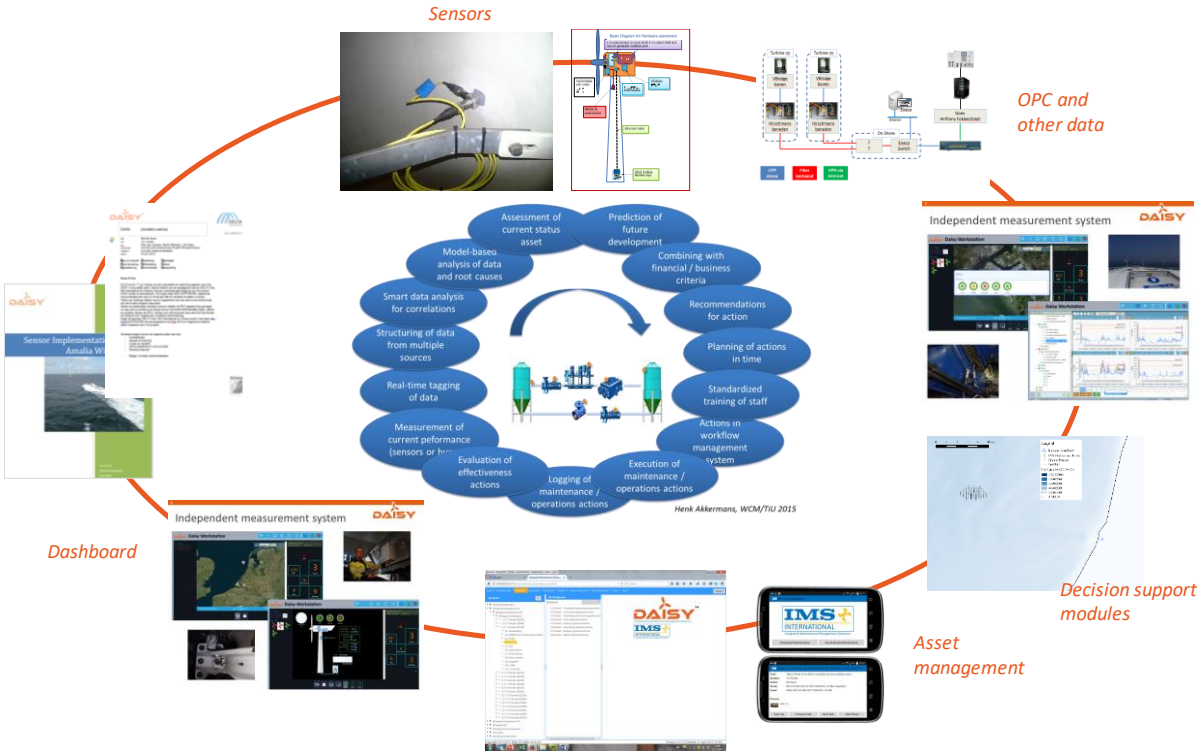
Real time monitoring of work performed by field engineers

The offshore aspect in the project was new to the industrial partners of DAISY. However, ECN has a lot of experience in this area. In order to support the asset manager using the DAISY solution, ECN developed and implemented a short term decision tool (now called ECN DespatchTM) for planning maintenance of offshore wind farms (OWF). The sub-objective of this tool was to reduce O&M costs and/or increase the availability. The aim was to connect the standalone ECN DespatchTM tool with the overall DAISY solution.

The ECN DespatchTM tool identifies the best prioritization and allocation of resources to maintenance activities for any given day, considering the constraints of weather and resources (of technicians and vessels) to meet the performance objectives (e.g. lowest energy loss, lowest cost, etc.) of the wind farm operator. The tool was developed using data and advice from Eneco (Amalia), particularly from their operations of Princess Amalia Wind Park .

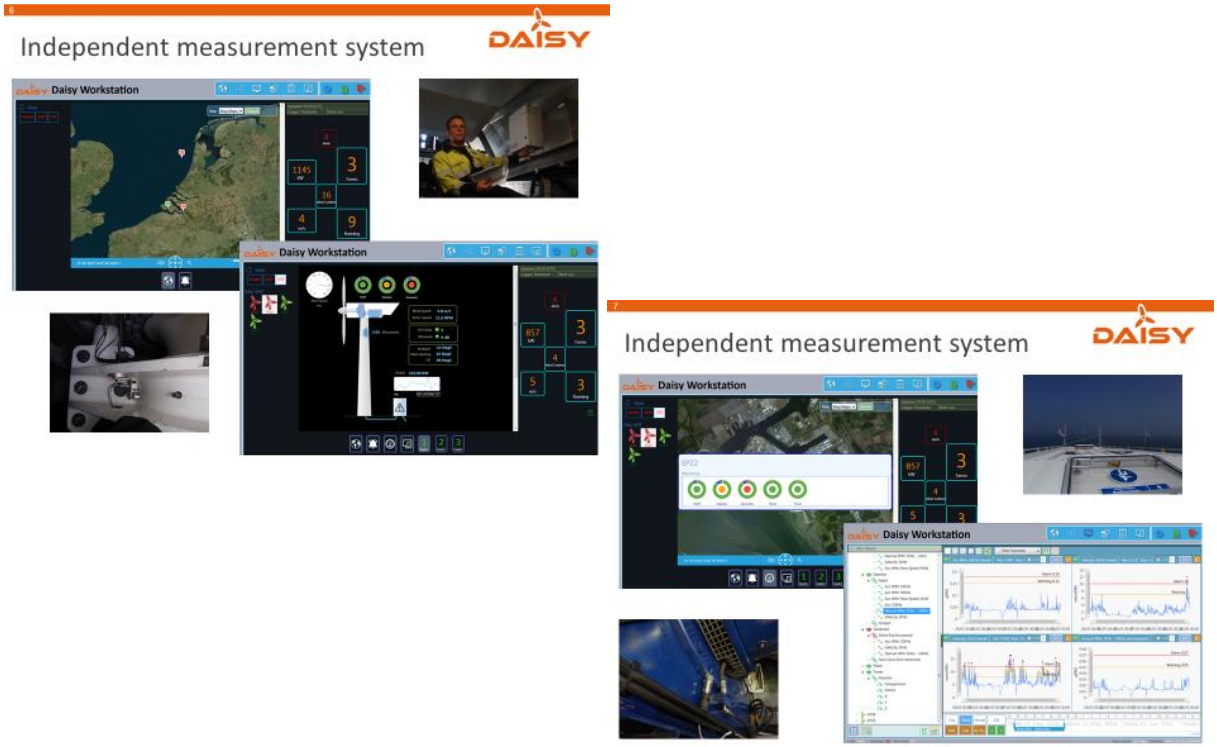
Data management and dashboard

The ultimate goal was of the project was to provide asset owners or asset managers from the Delta company all data needed to optimize O&M through a management dashboard in a control room. In order to achieve this Delta designed and implemented a big data center with servers supporting the various technical components of DAISY.
Delta also ensured that the data loop could be closed, i.e. all data was collected, analyzed and transferred into actions geared towards better performance at lower cost.



DAISY4OFFSHORE closed data loop

Dashboard were designed, implemented and validated at various management levels, allowing technicians to go into detail when required, e.g. in case of an alarm triggered by a sensor.



Various DAISY4OFFSHORE dashboards

Deviations from the project plan (all did not affect planning or total budget)[1]

- As described above during the project a major opportunity arise, i.e. to validate DAISY on a real offshore park. After having this discussed with RVO /TKI WoZ it was decided to introduce this validation exercise instead of the initially planned paper analysis exercise. All could be completed within the original budget.
- During the project Oliveira B.V. went bankrupt, but was acquired by IJssel Group, Zwolle in May 2016. IJssel was approved by the team and RVO as new partners and took over all activities, without planning or budget consequences.
- Delta was more heavily involved in the development activities and offshore validation opportunity at Amalia. Also development from other partners (particularly related to the offshore validation opportunity) took more hours. As a result more hours were spent than originally planned (approved by RVO).
- The final “beschikking ”applicable to the project is dated 12th April 2017, TEW021706AM6U.

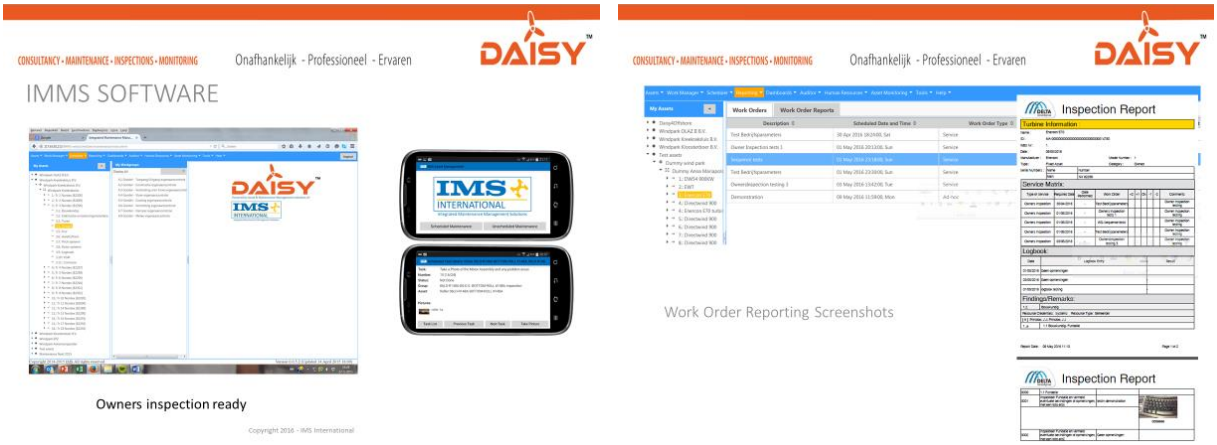
[1] Resulting in updated “beschikkingen” from RVO on 9th May 2016, 14th November 2016 and finally on12 April 2017

4. Project results

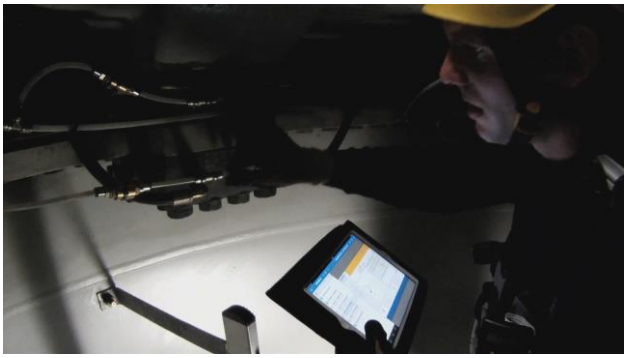
The DAISY4OFFSHORE project resulted in mature and industrialised components regarding condition monitoring and analysis. The various components were used operationally on different wind parks and also developed such that these can be for offshore conditions.

DAISY4OFFSHORE components installed

The asset management part of DAISY was matured and industrialised and operationally used on a daily basis by Delta for all onshore parks. Moreover, the system was implemented for Amalia supporting the asset owner inspections and creating management dashboards.
The system provides planning, monitoring and reporting of maintenance activities, supports field engineers and facilitates data capturing by the field engineers that can be fed into predictive models.

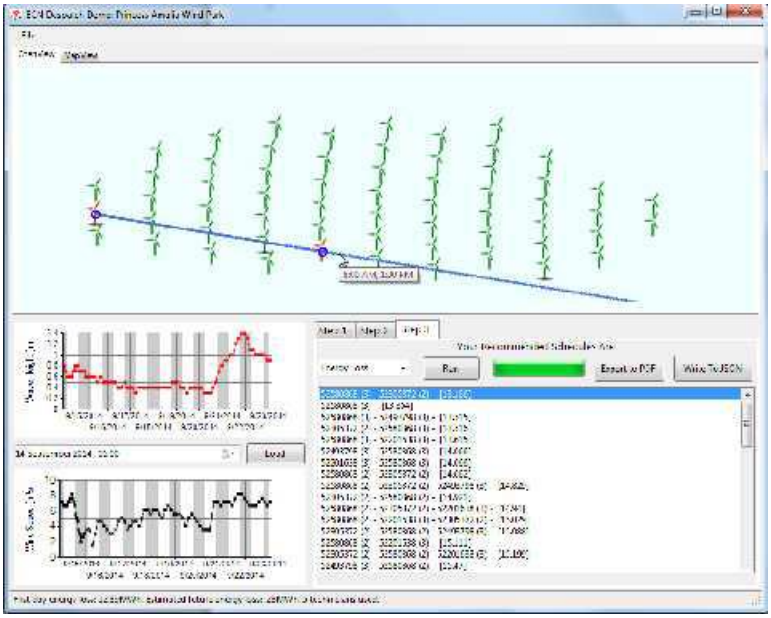


Automatic report generation from the asset management software



Delta Field Engineer using a tablet to collect data

On the backend side algorithms supporting automatic monitoring as input for maintenance planning were developed and implemented and validated on the different parks available during the project. ECN's O&M optimizer is connected to the DAISY solution as a decision support tool to optimize the offshore logistics and various maintenance work orders connected to that.



Maintenance schedule selection for the Amalia wind park

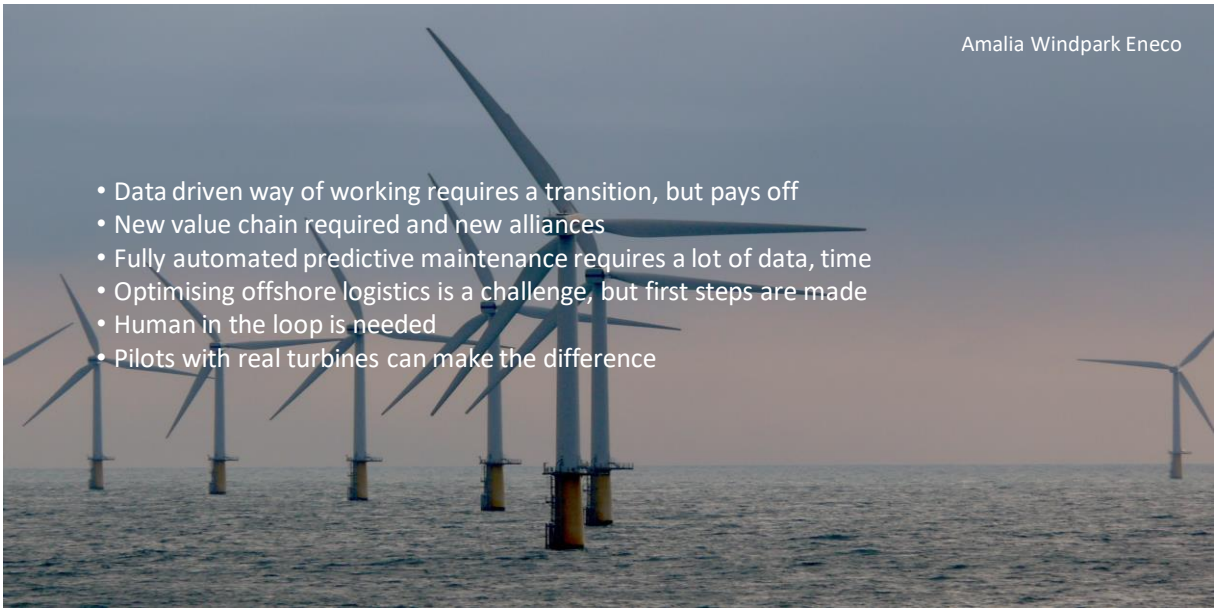
The various DAISY components were integrated into an overall solution for the asset owner and asset manager for independent monitoring, optimising O&M and follow-up of maintenance interventions. Information is available through various dashboards, at different levels of detail, depending on need for analysis.

Various levels of detail in the dashboards at the Delta control room

The DAISY team achieved better performance of wind parks at lower costs. During the project the opportunity was also used to include data from the Kreekrak park. Moreover, also data on the OLAZ wind park was analysed as long as possible. Thereby, the OLAZ park was the park that was monitored for the longest period, thereby offering the opportunity to really quantify the results. This park showed that performance could be increased by 15% and maintenance costs lowered by 25%.

DAISY at onshore wind parks

The validation on the Amalia wind park also showed the potential of an independent system like DAISY. It also showed that the new way of data driven working affects the complete value chain, including the off shore logistics.
Off-shore logistics is rather complex and dynamic and the responsiveness in off-shore logistics is not in line yet with the maintenance directives resulting from the DAISY solution. As a result, potential benefits from condition based and predictive maintenance are often taken away by delay in the off-shore logistics process.



Lessons learned DAISY4OFFSHORE offshore validation

The project also showed that big data sets are required for a long time to make accurate predictive algorithms. From a scientific point of view, these data sets include many incidents, while at the same time in pilots this exactly what the DAISY team wants to prevent for asset owners and asset managers.
Nevertheless, experimenting on real turbines has been extremely valuable to really industrialise DAISY.
To strengthen the project the World Class Maintenance (WCM) foundation has tried to bring in data and experience from other sectors. As an example the link was made with the CAMPI research project on condition monitoring in the process industry, with a lot of attention for rotating equipment (with TUe, TiU and RUG involved). Also within the frame of that project it was concluded that large datasets with incidents are rare. A workaround defined there, i.e. looking at other data sets from other applications, was also applied by TUe, by including data sets (with incidents) from Philips Healthcare.
WCM also connected DAISY with the Smart Industry fieldlab CAMPIONE, to asset its potential for application for rotating equipment in the process industry.

Martin Blenkers of IJssel, giving a workshop on DAISY in the CAMPIONE Fieldlab

Finally, WCM supported a lot on knowledge dissemination, by organising newsletters, workshops and conferences, providing a good platform for DAISY.
Meanwhile WCM also involved other partners to strengthen the DAISY team and to think about follow-up options, particularly focused on connecting DAISY to offshore logistics optimisation. As a result, the idea of a Smart Industry wind energy fieldlab project was defined (Zephyros).

TUe made (or prepared) a couple of scientific publications:

- Condition-based maintenance at both scheduled and unscheduled opportunities by S. Kalosi, S. Kapodistria, en J.A.C Resing
- Data-driven online monitoring of wind turbines by T. Kenbeek, S. Kapodistria, en A. Di Bucchianico
- Simple, discrete time stochastic models for wind turbine power output for modeling wind park power by D. Bhaumik, D. Crommelin, S. Kapodistria, en B. Zwart
- Wind turbine power modelling by S. Kolumbán, N. Nooraee, en S. Kapodistria

The DIASY team has given various presentations during the course of the project:

- 2016 Studium General Big Data NAP Process Industry Network
- 2017 High Tech Meets Data Science Symposium
- 2017 Smart Maintenance event
- 2016 Workshop on the mathematics of future energy systems
- 2016 9th IMA International Conference on Modelling in Industrial Maintenance and Reliability (London, England)
- 2016 Studium General Big Data NAP Process Industry Network
- 2016 ENBIS Conference (Sheffield, England)
- 2016 Computational Sciences for Future Energy Conference - CSER
- 2017 Workshop on Stochastic Models, Statistics and Their Applications (Berlin, Germany)
- 2016 Smart Industry conference
- 2016 Wind Days
- 2016 Annual Conference, World Class Maintenance
- 2016 Workshops with Hogeschool Zeeland
- 2016 – 2017 Participation of DAISY representatives in various WCM workshops and round tables
- 2017 International Workshop in Sequential Methodologies (Rouen, France)
- 2017 ENBIS Spring Meeting on Predictive Maintenance and Reliability for Big and Complex Data (Aigen-Schlägl, Austria)
- 2017 DAISY demo, CAMPIONE Fieldlab
- 2017 APS INFORMS (Chicago, V.S.)
- 2017 Wind Days

5. Spin off and follow-up potential

As a result from WCM's knowledge dissemination activities, the DAISY concept is also one of the innovations tested within Smart Industry fieldlab CAMPIONE, in order to asset its potential for the process industry.

Kick-off of CAMPIONE by Henk Kamp, Minister of Economic Affairs

Moreover, a new fieldlab is being setup for the wind energy sector to connect the concept op predictive maintenance to offshore logistics optimization. The fieldlab is called Zephyros and the corresponding consortium is growing with partners from the asset management logistics chain. Part of this fieldlab will be dedicated to education to assure that besides future technology also future qualified personnel will be available to work with that technology.

The development of ECN DespatchTM is a valuable step addressed to assist the offshore wind farm managers in daily decision support. However, there are a number of limitations in the existing version of ECN DespatchTM that have been recognized. Recommendations and feedback from potential users would help make invaluable contributions to the design and capabilities of the tool.

TUe will use the insights from DAISY4OFFSHORE in education and in follow-up research. The generated generic research insights are also useful outside of the wind turbine area and will be used in the Smart Manufacturing and Maintenance Research Program of the TU / e Data Science Center Eindhoven.

6. Discussion

The introduction of the DAISY solution has contributed to the awareness that the O&M part is the largest part of the lifecycle of wind parks and that many expected benefits from wind energy, particularly offshore, can be achieved through optimized O&M throughout the complete lifecycle. Awareness also grew regarding the opportunities of feeding data from the O&M part of the lifecycle back to the design of wind turbines and parks.

Finally, independent solutions like DAISY currently put pressure on OEMs to become more transparent and share data with the value chain, eventually leading to better performance at lower cost for the whole sector.

7. Conclusion and recommendations

The DAISY solution has a lot of potential to increase performance of wind parks at lower costs, by optimizing the O&M part of the lifecycle, representing the largest part thereof.

The solution proved to be effective for onshore parks and looks promising for offshore applications. However, with DAISY a new way of working is introduced also requiring a transition of the complete value chain. This takes time to become fully operational. However, the new way of working introduces new opportunities for services and alliances.

Full automation of predictive maintenance, based on sensor, operational, environmental and maintenance data requires a lot of data of large time slots. Therefore, for the midterm the human factor will always be in the loop regarding decision making and solutions like DAISY will provide the best information to support decision making processes.
Most challenging however is the connection of predictive maintenance solutions like DAISY with the offshore logistics processes. Off-shore logistics is rather complex and dynamic and the responsiveness in off-shore logistics is not in line yet with the maintenance directives resulting from the DAISY solution. As a result potential benefits from condition based and predictive maintenance are often taken away by delay in the off-shore logistics process.
It is expected that this can be improved when off-shore operations will be intensified because of new parks that are planned in the North Sea area and when cooperation is set up between various parks with respect to maintenance and servicing.
Having had the opportunity to validate and optimize DAISY on onshore and offshore parks was and is an enormous opportunity and provides the Dutch consortium a strong position internationally.
This is already demonstrated by the interest shown by UK wind park owners in the follow-up fieldlab project Zephyros, that will be focussed on connecting predictive maintenance, optimizing the value chain and new agile offshore logistics concepts.

Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.