Final report

1.1 Project details

Project title	Improved Wind Turbine Efficiency using Synchronized Sensors
Project identification (program abbrev. and file)	64012--0134
Name of the programme which has funded the project	EUDP
Project managing company/institution (name and address)	DELTA, Venlighedsvej 4, 2970 Hørsholm, Denmark
Project partners	DELTA, DTU Wind Energy, Siemens Wind Power, CIM A/S, GRAS A/S
CVR (central business register)	12275110
Date for submission	3 Oct. 2016

1.2 Short description of project objective and results

English Version

To improve the efficiency of wind turbine and wind turbine farms using synchronized sensors on wind turbines, their wings, and in wind fields. The technology is used in development, test, modeling, and active control of both wind turbines and wind turbine farms, thus optimizing their efficiency, life span, durability, and noise emissions while lowering production costs and increasing reliability.

The project succeeded in production and field test of synchronized sensors in close cooperation with key wind turbine industrial partners who continue to explore future applications of the products.

Dansk Version

Formålet var at demonstrere muligheden for forbedret effektivitet af vindmøller og vindfarme, ved brug af synkroniserede sensorer på vindmøller, deres vinger, samt i vindfeltet. Teknologien bruges i udvikling, modellering, test og aktiv styring af både vindmøller og vind farme, og benyttes til at optimere deres virkningsgrad, levetid, holdbarhed, og støjemissioner, med reducerede produktionsomkostninger og forbedret effektivitet.

Projektet lykkedes at fremstille synkroniserede sensorer og afprøve dem i feltet, i nært samarbejde med nøgle partnere fra vind industrien, som vil fortsat udforske fremtidige anvendelser af produkterne.

Projektet holdt sig inden for budget og opnåede de tekniske milestones trods to forsinkelser pga. af bemandingsmæssige udfordringer. Den tekniske kvalitet af de udviklede produkter var yderst tilfredsstillende og afprøvning i laboratorie og felt var vellykket. Projektet har løbende dissemineret information omkring projektet via en aktiv blog, samt foredrag, seminarer og artikler.

1.3 Executive summary

The project succeeded in producing 19 high-quality SyncBoards which demonstrated low cost, high portability and low battery consumption. Also developed and calibrated was a 5 pitot tube inflow sensor which demonstrated a modern down-sized design. Coupled with the SyncBoard it provides better capabilities in instrumenting wind turbine parks and sub-systems, for example using blade mounted in-flow sensors whose data are precisely synchronized to GPS, hence enabling system analysis and control.

Project progress was actively communicated throughout the project via the web site, seminars, and personal contacts to key industrial players. These activities continue after the end of the project.

1.4 Project objectives

As a demonstration project, the objectives were very tangible: To produce and test demonstrator units of SyncBoard and In-Flow sensors and demonstrate their viability for wind turbine applications.
The project overcame multiple significant challenges: The very aggressive goals for low battery consumption, small size, and robustness, required optimization of all circuitry and associated embedded firmware. The retirement of a key engineer in the middle of the project, resulted in significant delays before a suitable replacement was found and brought the project back on track in terms technically, but with two extensions of the project plan. The final produced demonstrator SyncBoards were successively field tested on a turbine wing in December 2015, which subjected the board to very poor GPS receiver conditions as well as high g forces due to the high rotational forces and misty, humid weather. The board performed acceptably under these harsh conditions. With the production of multiple prototypes, it became possible to perform both laboratory testing with partners who benchmarked the board against "off-the-shelf" solutions, solutions which were up to 10 times as heavy, expensive, and power consuming. These tests were very successful. Finally, a field test of five boards was performed on a wind turbine site and successfully synchronized data acquisition over hundreds of meters. Thus, in spite of significant technical and staffing challenges, the end result was successful, with very few deployment issues with the demonstrator units.   The above field tests are documented on the project website https://nanosync.wordpress.com/

The in-flow sensor developed in parallel succeeded in producing a fully functional, calibrated demonstrator suitable for turbine wing mounting. This documented in greater detail in the following link:

https://nanosync.files.wordpress.com/2016/06/uweinflow_v1.pdf

1.5 Project results and dissemination of results

DELTA: SyncBoard

As project manager, DELTA also was the primary developer of the SyncBoard which is a GPS synchronized data acquisition card with four microphone channels sampling at 48 kS/s and 8 analog channels at 1 kS/s. All A/D converters provide 24-bit data acquisition and sample simultaneously locked to the GPS clock. Precision clock hold-over circuitry was provided to keep high stability during GPS clock dropout, and provide "gentle" re-synchronization when GPS lock again is achieved.

The board includes a configurable breakout board permitting powering and interfacing to the most common transducers such as microphones, accelerometers, strain gages, wind sensors, thermocouples etc. The acquired data is precision time stamped and stored on a local 32 GByte flash card. Low Power Bluetooth provides for status indication of the board, and was demonstrated in practice with the board mounted on a wind turbine blade and subjected to 12 g forces during rotation while maintaining acceptable synchronization.

The board is battery operated and has so low power consumption that it can also be powered by a small solar panel. Thus the board is autonomous, and requires no centralized control or cabling to provide extremely high quality synchronization. This has profound implications for instrumenting both turbines and their individual subsystems, but also for instrumenting an entire wind farm "as a system" including the electrical grid. The system is also "infinitely scalable", because each device is fully independent, and therefore there is no upper limit to the number of devices that can be used in the instrumentation system.

During the project development the potential applications generated growing enthusiasm and multiple researchers found unexpected ways of applying the technology. With synchronized data, it becomes easier to validate computational models of airflow, structural, and electrical systems behavior, as well as understand causal relations between these systems. During the project we have actively discussed these concepts with the wind turbine research community which has responded positively in the seeing the new perspectives in both research and development as well as better control of wind turbine farms and smart grids in their entirety.

Another profound consequence of the autonomous, scalable architecture was pointed out by the research community: The opportunity for "serendipitous research". Because all data in the future can be "nanosynchronized", there is a significant opportunity for data mining the results, and search for new research insights, and searching for causal relationships. It is the precision time stamping of the data that makes it much more valuable providing opportunities of "a ha" discoveries in the future. Classic data may be stored with fairly coarse time stamps, and there is no guarantee that the actual A/D converters sampling point in time is known accurately with the respect to the time stamp applied by the computer acquiring the data. Thus accuracies may typically be around one second. With SyncBoard technology, the time stamp is applied at the A/D converter, and since the system knows its internal delay, absolute time accuracy of well below one microsecond becomes possible between SyncBoards, independent of location. This opens up for research of wind flow at a more granular level, structural analysis such as blade bending, and tower sway, gear and power converter behavior, as well as electrical transient transmission within a wind farm as well as on the connected grid.

In addition, our on-going contact with major instrument manufacturers throughout the entire project, not only gave feedback to the project, and more important, showed the instrumentation industry that much smaller, less expensive and energy efficient devices where indeed possible. Especially on the last project seminar on May 26, 2016, users of the demonstrator units strongly pointed out how they enabled multiple applications in the energy industry that previously were not realistically possible.

DTU Wind Energy: In-Flow Sensor

The InFlow Sensor developed by DTU Wind Energy succeeded in a building fully functional calibrated demonstrator. In addition, the project built prototypes of energy harvesting devices using a miniature wind turbine for blade mounting on a full size wind turbine. Since the initial development of the SyncBoard was delayed, DTU Wind Energy used off-the-shelf hardware for their synchronized data acquisition, and this created a benchmark against which the SyncBoard was tested. In virtually all aspects the SyncBoard outperformed the off-the-shelf solution on precision of synchronization, analog characteristics, size, weight, power consumption and cost.

The summary of results is shown in the following presentations.

https://nanosync.files.wordpress.com/2016/06/uweinflow_v1.pdf

In addition, the project participants at DTU Wind Energy were effective evangelists in spreading the news of the developed prototypes to the large research communicate at DTU Wind Energy, and there continues to be an on-going interest in new projects and applications based on the technology.

Helge Aagard Madsen’s presentation on acoustic applications is available here:
https://nanosync.files.wordpress.com/2016/06/madsen-isromac_final_v1.pdf

Siemens Wind Power

As one of the largest wind turbine manufacturers Siemens Wind Power played a key role as a significant sparring partner for the project goals and sensor specifications. With access to virtually all ranges of data acquisition products, Siemens could critically asses the project’s ambitious goals and at the public project seminar on May 26, 2016 described a number of significant applications not previously possible. This is described in greater detail on the nanosync website:

https://nanosync.files.wordpress.com/2016/06/26051620nanosync_trh_reduced.pdf

In addition, Siemens provided the opportunity to test five SyncBoards at the Flø Wind Turbine site, where measurements were made in parallel using three different systems: Brüel & Kjær Wind Turbine test system, DELTA’s Wind Turbine System based on National Instruments hardware, and the five autonomous SyncBoards developed by this EUDP project.

SyncBoards were placed at distances of approximately 100, 200, 300, 400 and 500 meters from the Wind Turbine, and the sound from starting pistol was used to demonstrate the synchronization of the SyncBoards. In addition, the dynamic range and lack of noise and spurious signals in this field test was clearly demonstrated.

The field test is described in greater detail here:
https://nanosync.wordpress.com/2016/07/01/successful-field-test/

CIM A/S: Applications test and benchmarking

As a supplier of test and control systems to the wind turbine industry, CIM has significant experience in supplying GPS synchronized test and control systems. Based on this experience, CIM provided benchmark tests against the SyncBoard and found excellent performance, in a much smaller, less expensive form factor. CIM also provided strong input regarding the need for real time data wireless data transmission in a next generation board.

To be able to successfully deploy SyncBoards, CIM requires fully commercialized implementation of the Demonstrator built by this project.

GRAS A/S: Precision Microphones

As a supplier of precision instrumentation microphone's GRAS provided a valuable role in the project as a sparring partner, and supplier of microphones used for test applications. GRAS also supplies array microphones where the phase synchronization of the microphones in critical for accurate noise source localization. Using SyncBoards the size of these arrays, can in in principle be increased, thus providing better accuracy at lower frequencies.

In addition, GRAS developed specifications for microphones which could operate with much lower power consumption, thus contributing to a long battery life for SyncBoards. GRAS also researched solutions for flush-mounted microphones on wind turbine blades with innovative solutions for removing the high levels of lower frequency noise associated with the high rotational speed.

Results: Economic

A major driver of increased revenue, exports and employment is the success in finding a successful commercial partner. Based on the strong positive feedback we have received from the research and user community, DELTA and DTU Wind Power will continue this process. A much smaller driver of revenue will be the research and commercial projects that the demonstrators developed by the project will enable. This is in the range of 3 to 5 million DKK in the next 3 to 5 years. DELTA has already been asked to bid on some special projects which only can be solved by the nanosync boards. If a manufacturing partner is found, the potential upside revenue is easily 10 times higher.

Dissemination

Licensing of this technology has been discussed in depth with top management of major instrumentation companies, both before the project start, throughout the project and after its conclusion. In some respects, we are getting the feedback that the project is "ahead of its time", but no one is contesting its breakthrough capabilities in terms of price/performance and as an enabling factor for innovation.

The project website,

https://nanosync.wordpress.com/

has been actively visited and continues to drive healthy traffic.

Views/Visitors:

2011: 3719/
2012: 2710/
2013: 1563/ 838
2014: 1215/ 761
2015: 708/ 461
2016: 2030/1275 (pr. 3 Oct 2016)

Two major project seminars have been held during the project and the majority of presentations from these are provided on-line:

Internet of Things IoT 2 Seminar May 26,2016

https://nanosync.wordpress.com/2016/06/09/iot-2-0-seminar-presentations/

where nanosync is presented as a major enabling technology for innovation in Internet of Things devices.

It's about time, a major seminar on Time and Synchronizations was held on December 4, 2013:

https://nanosync.wordpress.com/2013/09/25/nanosync-symposium-december-4-2013/

Two major articles in commercial trade journals related to the project were published in 2016:

Front page article in Elektronik & Data:

https://nanosync.wordpress.com/2016/09/13/nanosync-makes-front-page-news/

and full page article in the Danish Engineering Association paper "Ingeniøren"

https://nanosync.wordpress.com/2016/06/17/nanosync-in-the-press/

Lectures:
In 2014 nanosync was included in the presentations at two differences conferences in the wind turbine industry.

https://nanosync.wordpress.com/2014/05/08/recent-wind-turbine-presenations-by-delta/

1.6 Utilization of project results

DELTA and DTU Wind Energy both expect to use the results and demonstrator boards in current and future projects, both from a research and commercial standpoint. The key individuals in these organizations are actively looking for applications, partners, and commercial opportunities, as well as using the technology in new research applications.

Since many still consider the technology ahead of its time, much of the future planning will be applied to niche applications in the wind turbine, acoustic noise, and power monitoring field. However, we see significant potential in the broad instrumentation market, and are constantly monitoring the market and potential partners for breakthroughs of this nature. The project manager, Carsten Thomsen, was directly involved in the invention of the PXIbus technology in 1997 which today is close to a 1 billion USD market. The PXIbus has many of the same timing capabilities as the SyncBoard, and he sees some parallels to how the technology can evolve. In addition, the technology to make this possible has been shrunk over the past 15 years, going from a large 19 inch rack mounted system to a single board the size of a smartphone. This vision was outlined in this blog entry in 2011:

https://nanosync.wordpress.com/2011/03/07/downsizing-sensors-the-key-to-the-future/

and the results of this EUDP project clearly indicates that the expected downsizing was indeed realistic and will continue. This in itself creates a platform which at any time may take off as a significant new market.

A major contribution of the project was demonstrating that this downsizing was indeed possible, whereas the core technology is the project is based on well-known ideas. Hence no patent applications have been filed.

The project results have significant consequences for the energy sector. In addition to making the design and operation of wind turbines more efficient, the technology enables analysis of the entire energy system possible, from generation to grid to consumption, by making fully synchronous measurements of the system as a whole possible. Hereby modelling of causality and correlation between stationary and transient phenomena becomes possible.

In the course of this and previous projects, we have seen the dramatic potential energy savings associated with synchronization in traffic and logistics fields, and see it additionally coming to play a longer term significant role in the Internet of Things.

1.7 Project conclusion and perspective

The project has successfully demonstrated a dramatic downsizing and improvement in the cost/performance of synchronized instrumentation and control systems. Practical experiments of the demonstrators developed have shown their value, and discussions large users in the wind turbine section have shown the practical value of such systems, and the savings that they provide.

The project blog,
https://nanosync.wordpress.com/

from before the start of this EUDP project extensively chronicles the development through the years, and documents in detail the technological development and the practical applications, primarily as the driver of a more energy efficient society. Therefore, this blog is an important part of this report, and should be read in its entirety to gain the big picture perspective as well as the practical details on the demonstrators successfully built for this EUDP project.

Annex

Nanosync Project Blog:
https://nanosync.wordpress.com/

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