Precise positioning on the high seas

GNSS  The requirements for the positioning and arrangement of offshore wind turbines are becoming more and more demanding. This applies both to determining positions as precisely as possible at sea and the configuration of all turbines in a wind farm. With the help of redundant Global Navigation Satellite Systems (GNSS) reference stations, service providers at wind farm facilities can clearly and repeatedly position and navigate their vessels for installation, relocation and maintenance work, write Jürgen Rüffer and Michael Schulz, managing directors at Allsat GmbH, Hanover, and Dr Gerhard Wübben, managing director at Geo++ GmbH, Garbsen.

In 2013, Hanover-based Allsat GmbH was commissioned for the first time by Vattenfall to supply and install a Global Navigation Satellite Systems (GNSS) reference station for the construction of the DanTysk wind farm and to operate it during the construction phase.

The purpose of such a reference station is to supply all contractors for the construction and connection of an offshore wind farm with high-precision GNSS corrections in real time. This enables all contract partners using a geodetic GNSS receiver to position themselves at any time, and repeatedly if necessary, with an accuracy of <2cm. On the one hand, the position of a ship can be determined very accurately in real time, and on the other, the turbines can be precisely aligned and other components such as the cables can be measured accurately and retrieved. All hydrographic surveys can be located homogeneously and precisely in the same reference system.

In order to guarantee this, new GNSS corrections must be generated and distributed every second from the precise location of the GNSS reference station antenna. Since the typical distribution of corrections on land via mobile communication at sea is only possible in exceptional cases, 70cm UHF radio systems are used there.

The platform Fino3 was chosen as the location for the reference station for construction of DanTysk, as it is close to the area of the planned wind farm. With the permitted transmission power for 70cm radio, a range of 25km could be safely expected. However, the furthest areas of the wind farm were up to 30km away, which meant that a precise positioning in the centimetre range could not be guaranteed.
As an existing and permanently inhabited site with internet connectivity, Fino3 was considered suitable in this first project to provide a GNSS reference station for the construction of an offshore wind farm with low risk and high availability.

The equipment of a GNSS reference station consists of the following components: a weatherproof GNSS antenna; a separate GNSS receiver with a cable connection between antenna and receiver; a power supply; an internet connection with router for external monitoring of this equipment; and a radio modem with a suitable antenna for the dissemination of GNSS corrections. In addition, a web interface to provide information to users and operators should be available if possible.

In order to ensure the continuous operation of the system, individual components are designed with in-built redundancy and coupled together in such a way that if one component fails, another one can take over seamlessly. In the case of DanTysk, these were the GNSS antenna and the GNSS receiver, the radio modem and the power supply.

With this equipment it has been possible to guarantee continuous operation for about two years in all wind farm installations supported by Allsat. Although some of the system components might fail during that time, the in-built redundancy ensured that work could continue, avoiding expensive maintenance on site and construction downtime.

Since GNSS corrections often have manufacturer-specific characteristics, Allsat suggested the distribution of standardised corrections in RTCM-3 format. In addition, an English language procedural instruction for the users with recommendations was created, which enabled suitable processing of GNSS corrections for GNSS receivers of different types and ages.

A special feature of GNSS reference station operation is the requirement for interference-free reception of the very weak GNSS signals from a distance of more than 20,000km. This would have been possible at each of the sites under consideration (twice on Fino3 as well as on a transformer platform and in the port of Hvide Sande) only at their respective highest points. However, this was ruled out because of...
the installation risks associated with heavy antennas and their connections. Therefore, a provisional antenna installation is chosen at the outset and, after 24 hours of operation, a fault analysis can be undertaken to ensure that the antenna location is suitable.

In addition, the redundant reference station was equipped in such a way that it was able to use the GNSS corrections generated by its own receiving modem for independent permanent positioning for monitoring. Thus, the purpose of the entire system could be checked at any time and the results made available in real time via the web interface.

On the wind farm Horns Rev 3, where Allsat also worked, the redundant reference station was operated as a monitoring station in the port of Hvide Sande, approximately 40km from the wind park.

In order to check the full functionality of the reference stations, a measurement trip to the wind farm area was carried out at the beginning of a project. Using two GNSS receivers from different manufacturers, a one-day test drive around the boundaries of the wind farm with permanent positioning of the route was verified.

Use of GNSS equipment after the installation
The equipment used is usually left on the wind farm at the end of a project or – if required in a subsequent project – uninstalled and reinstalled elsewhere. However, no project manager at a new site wants to run the risk that a technical system used in a rough environment for more than two years could fail on a new installation. The equipment has fulfilled its original requirements and has been fully depreciated. Despite this and its relatively low cost, however, it could still prove useful.

The potential benefit will be explained below using two scenarios.

A permanent precise positioning system for the North Sea
A precise positioning service, such as the satellite positioning services of the German national surveying authorities (SAPOS) operated on land and in the immediate vicinity of the coast, provides such a service within the area enclosed by the GNSS reference stations. For many years, a permanently available repetition accuracy for positioning with GNSS in the order of <2m horizontally and <3cm vertically has been possible.

Major components of such a positioning service are suitable geodetic GNSS receivers and antennas, which can now receive signals from the GLONASS, Galileo and BeiDou systems in addition to GPS satellite signals, and use them for the joint calculation of a receiver position. For this purpose, the locations of the GNSS reference stations should normally be no more than 100km apart and their data should be delivered to a central software via IP communication in real time. There the GNSS data are processed in real time for area correction models.

This results in an individual set of real-time corrections for each location in the enclosed area, which can correct the system-related errors from the satellite signals (especially the atmospheric errors) and provide highly accurate positions. Today, in an area the size of the North Sea, even greater distances between GNSS reference stations for a comprehensive network can provide satisfactory performance.

Although there are already services that send near-real-time GNSS corrections via satellites (e.g., Omnistar, Veripos, Atlas), these are services with manufacturer-proprietary and encrypted formats that cannot be decrypted by every type of receiver. They activate with a user license from the respective provider/GNSS manufacturer, thus making a broad application difficult.

The advantages of the service proposed here are the lower costs for users, the homogeneity and accuracy of the coordinates (uniform reference system) as well as the possibilities of online support for users.

There are three essential things to consider for such a service:

- The user must have a GNSS receiver that receives the same (but not necessarily all) satellite signals as the surrounding reference stations;
- In the area under consideration (here: North Sea) a sufficient number of GNSS reference stations are permanently operated and connected to a central computer via the internet (at very low data rates). For this purpose, 15 to 20 stations at sea and the same number on land are sufficient, but they should exist on the coasts of the neighbouring countries and their data should be normally freely accessible;
- There should be at least one two-way communication between the central computer and each individual reference station and at least one one-way.
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communication between the central computer and each user.

If it is possible to set up two-way communication in the working area (e.g., through a regional WAN or a regional mobile radio), online support for users would be possible from a service centre. Under these few conditions, the temporary failure of one or even several GNSS reference stations in the network has almost no impact on the accuracy of positioning.

There are three main reasons for the absence of such services in the North Sea:

- So far, there have been too few users in the North Sea to make the operation of such a service economically viable;
- The desirable two-way communication is only available in the immediate vicinity of the coast;
- The operation of such a supra-national service fails due to the lack of flexibility of national regulatory authorities.

However, the first two points have been changing fast for some time now, mainly because the North Sea and other offshore regions have become more important for wind energy developments.

The third point requires a common understanding among wind farm operators of the economic benefits of a GNSS correction service.

The following aspects need to be adapted for this:

- The GNSS reference stations for the construction of a wind farm should continue to operate permanently and deliver their data via the internet to the central location of a service provider;
- In the main areas of use (e.g., wind farms) local two-way communication facilities should be installed to provide regions with a comprehensive service;
- A service provider should be retained to manage the system and its users so that governments do not need to finance the operation. GNSS services can be funded by users and operators through relatively low user fees.

None of these should pose an insurmountable problem in an age of increasing digitalisation of economies and public administrations.

Benefits of the system

Such a system would mean that users would no longer have to worry about correct coordinates and data storage, as this would be provided by the GNSS correction service. Furthermore, only in the extreme case of a massive failure of multiple GNSS reference stations or the internet would there be significant disruption to operations. If this were to happen, however, each individual reference station would be able to broadcast its GNSS corrections across a limited area with a radius of 20–30km with the same accuracy.

In the event of an unexpected failure of an individual contractual partner in the wind farm operation, any new service provider could access data relating to work already carried out because survey information is homogeneous, valid for an entire region and can be accurately retrieved.

Using the example of a local positioning service for the construction of the fixed Fehmarnbelt crossing (Fehmarnbelt Positioning System, FBPS), the multiple benefits of a GNSS reference network can be demonstrated.

The owner of the Fehmarnbelt fixed link project, the Danish company Femern AS, decided to install a high-precision (1cm accuracy) and uniform coordinate and real-time positioning system for this major project at the outset when the exploration phase began in the mid-2000s. High system availability was a top priority to ensure centimetre-accurate navigation and positioning of expensive plant.

Since projects of this size involve the coordinated use of many different service providers, a service based on international standards should be provided. The use of international standards for GNSS corrections, mobile and radio communications and coordinate (reference) systems enable any user to work with commercially available geodetic GNSS receivers in the same coordinate reference with comparable high accuracy.

This service ran smoothly from its commissioning in 2009 until its temporary shutdown in 2016 due to obstacles caused by lawsuits pending in Germany. It is scheduled to resume in 2021 with the start of construction on the Danish side. Mostly, this can be achieved with the components installed in 2008.

Other possible applications relating to the permanent installation of GNSS reference stations include performance monitoring.

Monitoring the stability of offshore wind energy plants

The monitoring of wind turbines is typically in the hands of manufacturers. But wind farm operators are also interested in monitoring to minimise downtime and potentially extend the operating lives of plant. Any risk to efficient operation should be identified as early as possible and suitable countermeasures taken.
Today, a large number of different sensors are already in use on wind turbines, but GNSS sensors are not yet among them. Information for efficient operation, such as the azimuth system for optimal alignment of the nacelle and high-frequency vibrations of the nacelle, is recorded by sensors that only allow relative measurements.

Apart from a few pilot studies using geodetic GNSS receivers, there is little experience so far with low-cost GNSS sensors that can record the deflections and oscillations of a wind energy system with sufficient accuracy and frequency.

Today, low-cost single-frequency receivers are able to detect such movements in three position components with scanning frequencies ≤10 Hz and with an accuracy in the centimetre range. However, there are some boundary conditions that must be taken into account which have not yet been satisfactorily solved.

The suitable mounting of GNSS antennas – preferably near the nacelle – can minimise disturbance to GNSS signals. When the rotor is in operation, GNSS signals are regularly and continuously interrupted and deflected. This cannot be avoided so far with today’s technologies.

However, these interferences should be minimised to be able to use low-cost single-frequency receivers (factor 10 to 100 compared with geodetic receivers) which are sensitive to such interferences and make reliable positioning more difficult. Furthermore, it is not yet possible to test new systems in pilot projects because plant manufacturers are not prepared to approve research like this while components are still operating under a manufacturer’s warranty.

The monitoring of an individual plant is not attractive due to cost, notably the installation and operation of a geodetic GNSS reference station. However, there are now more economical approaches and some aspects relating to use of a geodetic GNSS reference station on a wind farm are relevant here:

- The reference station on an offshore wind farm fulfils various functions. It is primarily used for the construction and operation of a wind farm and for coordination during the installation of turbines, both above and below the water;
- The installation also provides data to a large-scale GNSS reference network for multiple and numerically unlimited positioning and surveying tasks;
- The system provides high-precision corrections for single-frequency receivers around the wind farm. Receivers can be installed on some or all turbines and permanently describe the movement behaviour of the nacelle in three dimensions.

During periods of high winds and waves in the North Sea, data can provide valuable information about the real behaviour and economic operation of a wind energy plant over long periods without a major maintenance commitment. This is likely to prove of particular interest for the floating plants that are increasingly being discussed.

**Summary and outlook**

Based on experience of precise positioning by means of GNSS reference stations on the high seas, some possibilities of this technology are outlined, which are currently only used to a small extent. The technologies described here are up-to-the-minute and can be installed and used in modular form and scaled.

In this paper only a few of the currently conceivable processes of georeferencing and digitalisation at sea are discussed. The provision of a GNSS reference network on a commercial basis can provide a much broader benefit than the examples described here.

**Literature/References**

