CATAPULT
Offshore Renewable Energy

Management of Hydrogen Sulphide (H_2S) Gas in Wind Turbine Sub-Structures: identifying and managing H_2S

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In November 2013, elevated levels of the gas hydrogen sulphide were detected within the foundations of some of the wind turbines at the Teesside offshore wind farm.

This case study presents the approach adopted by EDF-ER as wind farm owner to identify the source of the gas and manage the hazard on an ongoing basis.

This is one in a series of offshore wind operations and maintenance (O&M)-focused case studies, supported by ORE Catapult's O&M Forum and funded by The Crown Estate and the Offshore Wind Programme Board. These studies aim to highlight game-changing O&M projects and share knowledge among the offshore wind O&M community.

Summary of findings

- Chemical reactions can cause high generations of hydrogen sulphide (H_2S), so some form of ventilation is required.
- H_2S permeated into the turbine structure, because cable hang-offs on the 'airtight' platform were found to be leaking.
- A silicon steel reinforced polymer system resistant to extreme levels of H_2S was applied to all affected surfaces.
- The ventilation system in the foundations at Teesside wind farm was not fit for purpose, so forced ventilation before every turbine visit and design improvements to the as-built ventilation system was needed.

Recommendations

- A safe working environment must be a priority and should be addressed in the design phase.
- H_2S is colourless and the distinctive smell can be masked: personal monitoring equipment and fixed monitoring campaigns are recommended.
- Small defects in structures can have significant knock-on effects – testing should be undertaken as part of the windfarm handover process to confirm design intentions have been fulfilled.
- The ongoing management of health and safety hazards can be time consuming and costly: a focused response to the investigation and resolution of the root causes of issues will minimise cost and risk.

Introduction

EDF-ER is a utility company involved in all aspects of energy generation, distribution and retail. As part of its UK electricity generation portfolio, EDF-ER own and operate the Teesside offshore wind farm.

Owner Operator:	EDF-ER
Wind Farm:	Teesside
Capacity:	62.1MW
Number of Turbines:	27
Wind Turbine Capacity:	2.3MW
Full Commission Date:	October 2013
OEM Warranty Handover:	October 2013

Figure 1: Teeside offshore wind farm key facts and figures

In October 2013, this wind farm was handed over from the construction to the operational phase and the operations team identified unexpected levels of hydrogen sulphide (H_2S), an odourless, flammable and toxic gas, within the transition piece of some of the wind turbines. This case study presents the findings of an investigation into the source of the gas and the methodology designed and implemented for management of the hazard.

H_2S is a toxic gas that at certain concentrations can be fatal, as explained in Infobox 1. It often results from the bacterial breakdown of organic matter in the absence of oxygen and, due to the fact that it is heavier than air, it tends to collect in low-lying and poorly ventilated areas.

Infobox 1: What is Hydrogen Sulphide?

Hydrogen sulphide (H_2S) is a colourless gas with the characteristic smell of rotten eggs. It is denser, and therefore heavier, than air. The gas is poisonous, corrosive, flammable and explosive at certain concentrations.

H_2S is both an irritant and a chemical asphyxiant which affects both the respiratory and the central nervous systems. Low concentrations irritate the nose, throat and eyes while high concentrations can cause nausea, sickness and even death. The lethal dose for humans is 600 parts per million (ppm) for 30 minutes or 800ppm for five minutes.

The Health and Safety Executive (HSE) has set the following Workplace Exposure Limits (WEL) for H_2S in EH40:

- *5ppm for eight hours Long Term Exposure Limit*
- *10ppm for 15 minute Short Term Exposure Limit*

H_2S is subject to the requirements of the COSHH Regulations.

All wind turbines at the Teesside offshore wind farm have a monopile foundation design with free-standing cables inside the monopile. Installation methods varied depending on the ground conditions, with some of these monopiles being drilled while the others were piled. Furthermore, a Tekmar seal solution has been implemented on all of the foundations to prevent water ingress to within the transition piece at the cable entry point.

Figure 3 illustrates the Tekmar seal and also shows the compartments within the transition piece. As part of this foundation design, it was anticipated that sea water would enter into the monopile area and below the lower working platform, known as the moonpool. In order to mitigate the corrosive impacts of sea water on the internal surfaces of the foundation structure, cathodic protection was implemented with sacrificial anodes attached to the internal surface of the moonpool. However, a complex reaction can occur between sulphur-containing microbes found in the sea and the cathodic protection system, which creates H_2S gas as a by-product.

To avoid H_2S rising up throughout the internal compartments of the transition piece, the foundation design included an airtight platform

A ventilation system was designed to allow passive removal of any H_2S: a ventilation pipe was installed that connected the moonpool compartment to the open environment above sea level so gasses could passively escape the moonpool.

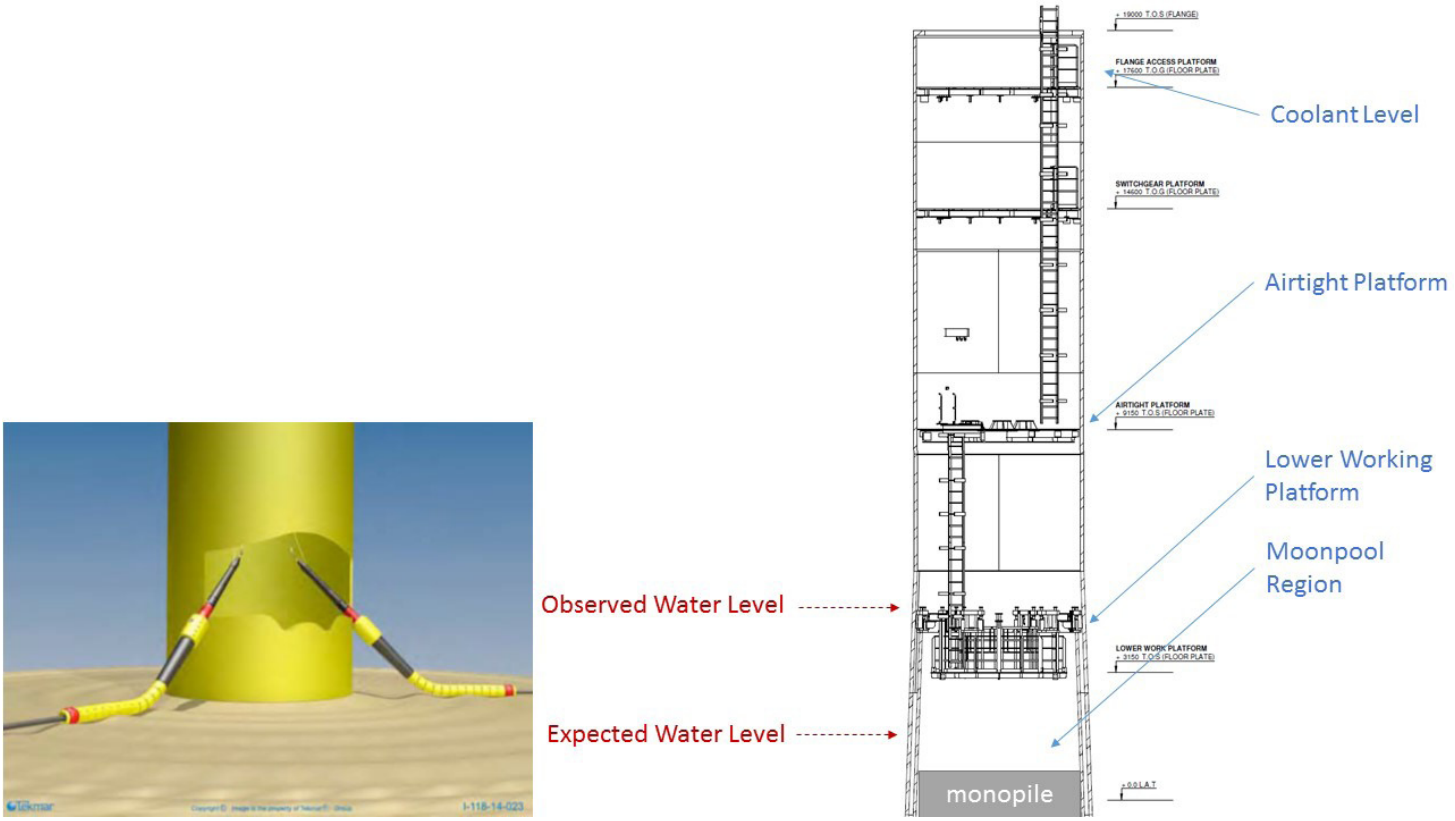

Figure 3: Tekmar seal design for cable entry and the compartments within the transition piece

The challenge

Following a challenging construction phase that involved the original foundation and principal contractor having to be replaced to complete construction, the Teesside offshore wind farm was handed over to EDF-ER's operations team in October 2013. There were immediate indicators of the presence of H_2S including the characteristic smell of rotten eggs.

Given the potential significant health and safety risk of exposure to H_2S, it was the responsibility of EDF-ER as the site operator to act quickly to identify the leak source of the toxic gas and implement a solution that would ensure the safety of all personnel on site.

The challenge was further complicated by a structural integrity issue with the turbine, identified by the turbine manufacturer. This required a visit to all turbines to carry out maintenance activity resulting in a high level of personnel activity offshore.

The approach adopted

Upon becoming aware of the potential hazard, there was an immediate implementation of zero tolerance on H_2S.

All staff, including EDF-ER and the turbine manufacturer's technicians, were equipped with personal H_2S monitors, as illustrated in Figure 4, and instructed that any activity on a turbine was to be stopped and all personnel to transfer off the turbine if levels of H_2S exceeded 1ppm.

This threshold is lower than the accepted safe level of 5ppm long term exposure level. EDF-ER decided to implement a conservative level to ensure safety while the scale of the issue remained unknown and an investigation was being carried out.

Figure 4: a personal H_2S monitor

Following this immediate response, the EDF-ER operations team designed a plan to investigate the issue and roll out a long term solution. In late November 2013, a one-week full site safety stand down was agreed to permit sufficient time to carry out a full investigation.

Investigating the Gas

During the week of downtime, all turbines were inspected using a combination of personal and fixed H_2S monitors. It was found that H_2S was building up and leaking from the moonpool through the airtight platform.

A leak detection spray was deployed on the airtight platform to identify the source of any leaks. This essentially coats the area to be investigated in a soapy solution so escaping gas can be spotted when air is blown into the moonpool through the ventilation system. It was clear that gas was escaping through the cable hang-offs on the airtight platform, as Figure 5 shows:

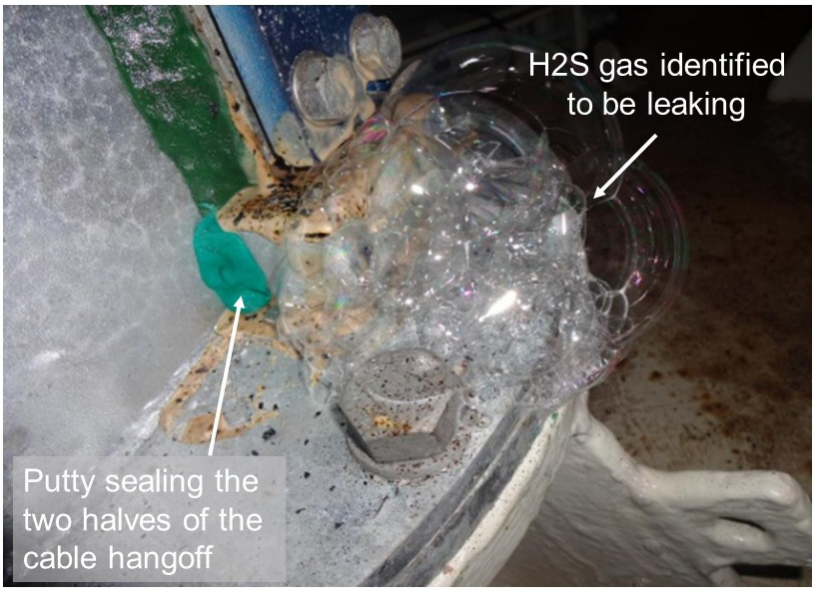

Figure 5: Leak detection spray used to identify leaks in the cable hang-offs on the airtight platform

The investigation concluded that the modular design of the hang-off structure was flawed. The hang-off consists of two steel structures with a sealant between any surface interfaces and the EDF-ER operations team found that the sealant between the two was incorrectly applied, causing leaks in the system.

Proposed solutions

Two solutions to apply an improved seal around the cable hang-off were appraised, a rubber seal and a protective and reinforcing coating.

The use of a rubber seal would have required disconnection of the cables, whereas the protective coating could be applied in-situ and was found to be a longer term solution. As such, it was decided that the protective coating would be used.

A silicon steel reinforced polymer system resistant to extreme levels of H_2S was applied to all affected surfaces.

Initially, the surface areas of the affected hang-offs were prepared by using a wire brush to completely remove any grease. Belzona 1831 (Super UW Metal) was applied incorporating reinforcing sheet around the flange edges before leaving to cure.

Figure 6: Protective coating used to seal the hang-offs

Finally, two coats of Belzona 5831 (ST Barrier) were applied to all the repaired areas to complete the application. One of the coated hang-offs is pictured in Figure 7:

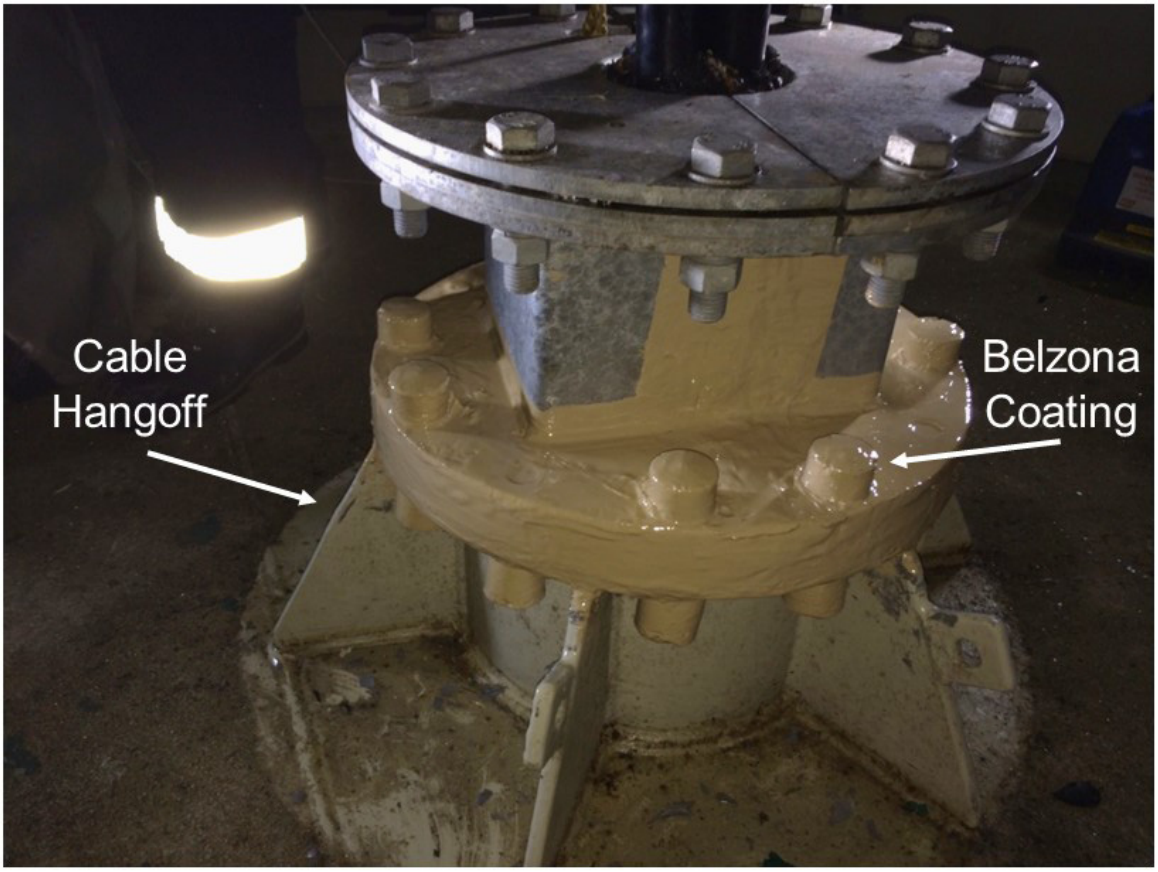

Figure 6: A cable hang-off on the airtight platform after application of the Belzona protective coating

Forced Ventilation on an Ongoing Basis

Between the week of stand-down to investigate the issue in November 2013 and the completion of the protective solution in April 2014, there were ongoing maintenance tasks that required personnel to enter the transition piece.

In addition to continuing the strict zero tolerance policy on H2S, EDF-ER also implemented a temporary forced ventilation before every turbine visit. Initially, a local fan, as pictured in Figure 8, was applied at one end of the ventilation system, but this was slow to act and each turbine required 24 hours to prepare it for a visit:

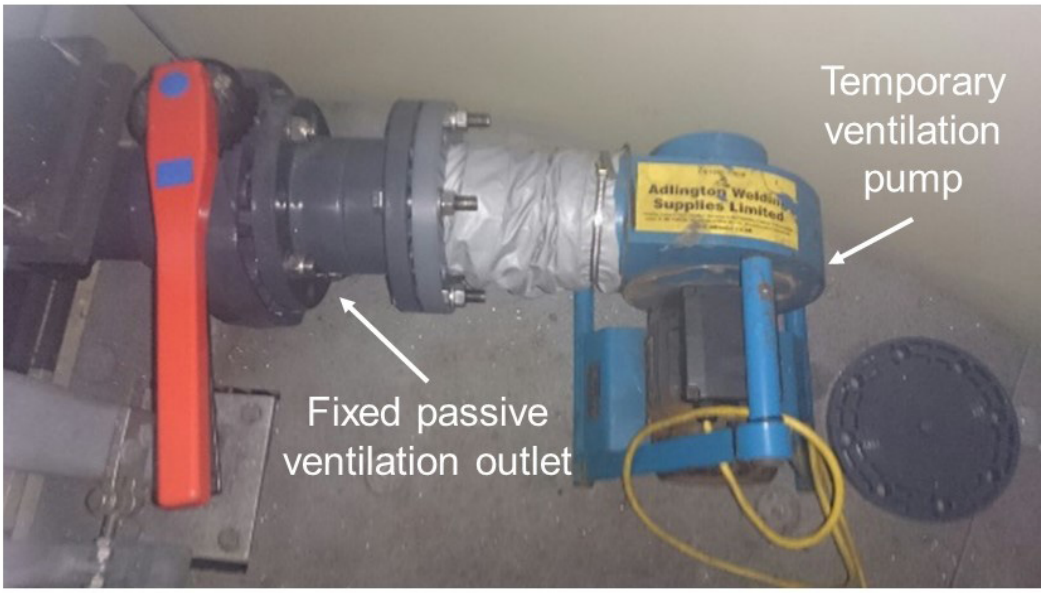

Figure 8: The fan used to force ventilation, which was applied 24 hours in advance of each turbine visit

The Results

Monitoring levels of H_2S

Following the confirmation of H_2S at Teesside offshore wind farm, a specialist engineering firm was sub-contracted to implement and record a monitoring campaign of the toxic gas.

Data collected recently from WTG13, which had a non-drilled monopile with string anodes and a Tekmar seal, is presented in Figure 9.

A fixed H_2S monitor was located in the moonpool area which is below the airtight platform within the transition piece. This chart shows how the concentration of H_2S varies over a period of one week.

The results from 19 January 2016 indicate that forced ventilation is clearly very effective at reducing levels of H_2S, however across the subsequent six days, the concentration steadily builds up to a hazardous level.

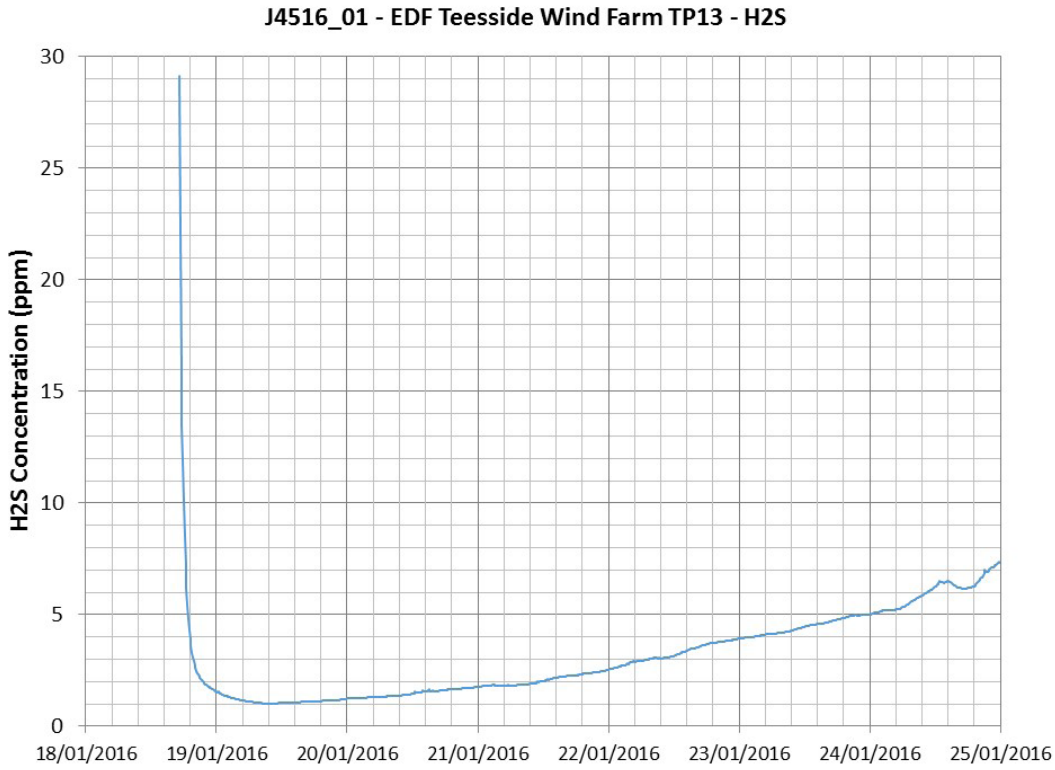

Figure 9: Example of monitored levels of H2S in WTG13 at Teesside offshore wind farm over a one-week period

By analysing similar datasets for the whole farm during the incident, the engineering specialist concluded that a significant volume of H_2S was present, predominantly in foundations without seawater ingression.

Foundation fixed ventilation design flaw

As outlined earlier, the reason for the leak was revealed to be cable hang-offs on the airtight platform, constructed in segments, and suffering from inadequate application of the putty and sealant used to fill imperfections in the steel hang-off design.

In addition, the investigation led by EDF-ER revealed a more fundamental design flaw at the heart of the problem, in that the fixed passive ventilation system was not fit for purpose.

The system included two pipes passing through the airtight platform, one connecting the moonpool to the coolant level of the transition piece to allow fresh air into the moonpool and the other pipe connecting the moonpool to the external atmosphere to allow exhausts to escape. The original design was modified to prevent flow from below the airtight platform returning inside the tower. This was effected by replacing the shut off damper at the outlet connecting to the external atmosphere with a non-return valve, as illustrated in Figure 10.

However, this non-return valve was never installed and air was able to enter the substructure via this pipe. This added to the existing problem of the leaking hang-offs and more H_2S was forced up through the transition piece.

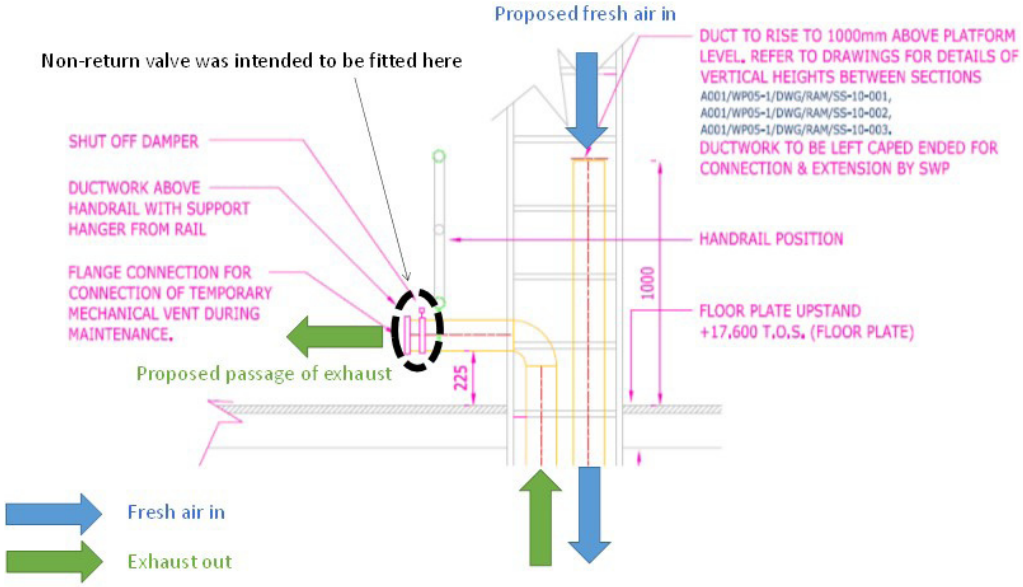

Figure 10: Proposed fixed ventilation system under normal day-to-day operation

H_2S is a by-product of the cathodic protection system, so its presence is inevitable and must be managed. Identification and mending of leaking seals successfully prevents H_2S escaping from the moonpool into the rest of the transition piece: however, ventilation will always be required to reduce H_2S levels below the airtight platform to an acceptable level.

Shortfalls in communication during the handover from construction phase to the operations phase were also to blame for the issues. Method statements, risk assessments and access procedures relating to the ventilation system in the turbine sub-structure were not included in handover information.

Health and Safety as a priority

The identification and management of the H_2S hazard at Teesside offshore wind farm demonstrates EDF-ER's commitment to excellent standards of health and safety.

Despite significant pressure to reach full commissioning of the site, as soon as H_2S was identified on site, EDF-ER implemented a safety-focused week of full site safety stand down. This allowed sufficient time to fully investigate the issue and design a comprehensive plan of action.

Following the week of downtime, EDF-ER also implemented the zero tolerance rule,whereby any indication of H_2S caused activity at that turbine to be cancelled and access to personnel prevented. Furthermore, when a solution to the leak was selected, it was rolled out across all turbines, even those without signs of hazardous levels of H_2S.

Personal safety was ensured by providing all staff with personal monitors, installing fixed monitors across the wind farm and providing additional rescue kits. EDF-ER also notified the Health and Safety Executive (HSE), although the incident did not trigger any formal reporting or statutory action.

Lessons learned

The following key lessons were identified by the EDF-ER team:

- *H_2S as a hazard*

H_2S can be generated in elevated concentrations due to cathodic protection of wind turbine substructures.

The production of H_2S from the cathodic protection system is a significant hazard that must be monitored, understood and mitigated in an effective manner.

- *Leaking airtight platform*

Following a comprehensive examination of the sub-structure, the cable hang-offs on the airtight platform were found to be leaking. Poor application of sealant was identified as the cause of the leaks.

- *Construction (Design and Management) Regulations failed to identify the significance of the risk of H_2S*

The implementation of a ventilation system is evidence that the designers were aware that H_2S is a hazard to be managed.

However, the poorly designed ventilation system did not satisfactorily mitigate the risk.

- *Improved testing and handover management could eliminate this risk*

Improving the linkage between design risk assessment and handover testing may enable a more comprehensive set of ‘tests on completion’ or quality assurance checks to be introduced to improve the snagging process at the end of the construction period.

- *A more rigorous hazard and operability (Hazop) study at the end of construction would have been beneficial*

Key hazards should have been identified and mitigation put in place. Design risk assessment should have identified the need for more rigorous testing.

The poor quality sealing of the cable hangoffs on the airtight platform should have been captured on a non-conformance register generated as part of a snagging survey at the end of construction.

Cost implications

This was a costly issue to resolve. The issue stemmed from a poorly designed ventilation system – which is a relatively insignificant sub-assembly – and relatively small imperfections in the airtight platform, but the knock-on costs and efforts to manage the operational implications and remedy the design were significant.

The estimated total cost for design and implementation of the solution was £219,773. The elements of this cost are provided in the table below. In addition to this sum were additional costs from the loss of production revenue both during the week of stand down and in preparation of turbines to allow personnel to safely access the sub-structure.

Description of work / service	Out-turn cost	Comments
Hire of extraction units	£5,200.00	To extract gases and allow entry to TP/WTG
Supply of Belzona materials	£17,698.19	Supply of materials to complete sealing works
Provision of service vessel to access offshore WTGs	£30,130.00	TWL provided a shared work vessel to transport the offshore technicians and parts to and from the worksite. Boat charter rate @ £1100 per day (Claimed for via Davits SOW)
Support staff due to confined space	£26,000.00	Supervision and support offshore
TWL management and supervision of offshore works 20% day rate	£5,670.00	Project management services dealing with the resource and work planning
Charges from the Turbine Manufacturer for additional labour time for WTG / Coolant level access due to gas leakage	£128,000.00	Charges to be invoiced to TWL by the Turbine manufacturer for their additional labour time expended for accessing WTG's to perform service operations. Due to gas leakage, a three-man team was required for rescue. £97 p/hr, average of 10 hours per day, duration approx. 132 days
Ancillary equipment (portable lighting etc.)	£400.00	Ancillary equipment for safe access and work environment
Belzona training	£1,635.00	Training on use of Belzona materials

Conclusion

The identification and management of elevated levels of hydrogen sulphide gas in monopole substructures at Teesside offshore wind farm has provided an excellent lesson for the wider industry.

It is a known risk that this potentially dangerous gas is generated as a by-product of the cathodic protection of offshore monopoles.

However, ongoing management of health and safety hazards like this can be costly. A quick and focused response to fully investigate and resolve root causes of issues will minimise cost and risk.

Recommended reading

EH40/2005 Workplace exposure limits, Health and Safety Executive, 2002 (amended), available online at http://www.hse.gov.uk/pubns/books/eh40.htm, last retrieved on 31 March 2016

The Control of Substances Hazardous to Health Regulations 2002, available online at http://www.legislation.gov.uk/uksi/2002/2677/pdfs/uksi_20022677_en.pdf, last retrieved on 31 March 2016

Interviewees' biographies

James Wilson, Operations Engineer, Teesside Offsore Wind Farm

James has been an Operations Engineer at Teesside offshore wind farm for two years.

Prior to this, he has undertaken a range of power station roles, including working for GDF Suez as a high voltage SAP and control room operator followed by a position with EDF-ER Nuclear as an O&M technician.

Author Profile

Dr Conaill Soraghan is a Renewable Technology Engineer with ORE Catapult.

He has a background in applied mathematics and completed a PhD in wind turbine design.

Conaill's main area of expertise is the management and optimisation of operational assets: he has extensive experience of the design and development of benchmarking systems and data/knowledge-sharing for the offshore wind industry.

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