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Designing for Reliability in Wind Turbine Condition Monitoring Systems

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Abstract

For wind turbine condition-based maintenance to be economically advantageous over the more conventional periodic based maintenance, high reliability is required of the systems which carry out the monitoring. The use of condition monitoring systems (CMS) is becoming common place in offshore wind turbines, due to the high cost associated with maintenance; however for onshore wind turbines the benefits aren't quite so obvious. Still, for both onshore and offshore wind turbine condition-based maintenance, it is essential that these systems can operate for long periods of time providing an accurate diagnosis of the state of the wind turbine's health. Through the build and installation of one CMS and the design, build and installation of another the author aims to share experience and lessons learnt to aid the design of any new CMS. A brief description will be given of the first system installed followed by the issues that were experienced following its installation. The author will then go on to discuss the design of a new CMS which has been installed in a Vestas V42 wind turbine and the improvements that were made to it to increase its reliability and ruggedness.

Key words: Wind turbine, condition monitoring, reliability, robustness

1.0 Introduction

Worldwide wind power has reached an installed capacity of 51GW[1] and is the leading source of renewable energy. An increasing percentage of this is coming from offshore wind which has the benefits of higher and more favourable wind conditions. Associated with offshore wind however is the increased operational and maintenance costs caused by the remoteness of these installations. It is apparent that for offshore wind turbines the use of condition monitoring systems (CMS) can play a key role in reducing the operation and maintenance costs. However for onshore it may not be so obvious. McMillan and Ault [2] have addressed this through the use of discrete-time Markov Chains, Monte Carlo methods and time series modelling in order to quantify the benefits of condition monitoring for onshore wind turbines. Their paper concludes by considering the reliability of condition monitoring systems themselves. It was found that in order for condition based maintenance to be more cost-effective than periodic maintenance the condition monitoring system must diagnose problems accurately over 80% of the time (for the pessimistic case of £50K for operating costs).

In order to achieve this level of reliability condition monitoring systems must be designed for the harsh environments in which they are to operate. In a previous paper by the authors [3] 4 main categories of robustness were defined which should be considered when designing a wind turbine condition monitoring system:

- Weather robustness,
- Wind turbine operational robustness,
- Handling robustness,
- System signal robustness.

Taking these factors into consideration will result in a more reliable system and reduce the likelihood of issues associated with a poorly designed system. These issues may include:

- False alarms,
- Undetected faults,
- Inaccurate measurements,
- Loss of historic fault data.

The aim of this paper is to provide guidance for future designers of wind turbine condition monitoring systems. The authors of this paper have been directly involved in the design, build and installation of two wind turbine condition monitoring systems in operational Vestas wind turbines. Lessons learnt from this experience will be used to provide guidance to those designing new condition monitoring systems in order that they can reliably operate within the wind turbine nacelle environment.

2.0 Vestas V47 Condition Monitoring System

2.1 System Overview

The first condition monitoring system designed and built by the University of Strathclyde was installed in a Vestas V47 wind turbine in collaboration with the Supergen Wind Consortium. The wind turbine for the installation was located at Wind Farm in Scotland which was selected due to the harsh weather conditions it was exposed to. Turbulent winds with a high salt content, due to its coastal location, have resulted in a high number of gearbox failures. For this reason it was seen as a good location for installing a condition monitoring system for research purposes.

The system which is described in [4] was the first wind turbine condition monitoring system that had been built by the university. The objective of the system was to continuously acquire high frequency measurements taken from an array of sensors located on and around the wind turbine drivetrain. Since it was not known yet what fault signatures or degradation patterns were likely to be seen or what data was required to investigate these parameters it was deemed best practice to capture as much data as technically and logistically possible. It was decided that two acquisition rates would be used for capturing the data: a higher rate of 20 kHz and a lower rate of 50Hz. Table 1 shows the measured parameters and the rates at which they were sampled.

Table 1: Sampling rates of measured parameters

Sensors sampled at 20kHz	Sensors sampled at 50Hz
Accelerometer – Main bearing X	PT100 Temperature – Main bearing
Accelerometer – Main bearing Y	PT100 Temperature – Gearbox
Accelerometer – Gearbox X	PT100 Temperature – Generator
Accelerometer – Gearbox Y	PT100 Temperature – Nacelle ambient
Accelerometer – Generator X	PT100 Temperature – CMS internal
Accelerometer – Generator Y	PT100 Temperature – Nacelle external ambient
Accelerometer – Nacelle base plate	Dual axis accelerometer – Tower XY movement
Voltage – Generator Phase 1	Wind Vane
Voltage – Generator Phase 2	Accelerometer
Voltage – Generator Phase 3	Humidity
Current – Generator Phase 1	Atmospheric Pressure
Current – Generator Phase 2	LSS Rotational Speed
Current – Generator Phase 3	Digital Compass

2.2 System Critique using Robustness Categories

When designing for robustness in wind turbine CMS there are four categories, introduced in [3], which should be considered to ensure a robust system. These are:

- Weather robustness
- Operational robustness
- Manual handling robustness
- Electrical signal robustness

Following on from the experience of the installation of the first CMS a fifth category has been added to the list: system software robustness. This can be defined as the ability for the system's software to react to any error that occurs as a result of a hardware failure or a fault in the software itself.

Taking these categories of robustness into consideration this section will look at what issues have occurred in the system as a result of not designing with these criteria in mind. The following section will discuss how improvements have been made to the new system based on this system's pitfalls.

The first system was installed in the wind turbine for almost a year however experienced long periods of downtime in response to CMS events. These periods of downtime were the result of not being able to gain access to it due to restrictions caused by bad weather. Having lost communications between the nacelle enclosure and the tower base enclosure it was decided that it was not economically viable to continue to troubleshoot issues as they arose within the wind turbine. It was therefore decided that it would be better to uninstall the system, learn from the experience and put the equipment to better use in an environment which allowed for easier fault diagnosis and debugging.

2.2.1 Weather Robustness

On decommissioning the CMS several factors were found that could have caused signal degradation. One of these factors was the build-up of corrosion on the pins within one of the connectors. It is notable that the sensor with this corrosion was located at the hub of the wind turbine where the main shaft enters the nacelle. This increased corrosion may be the result of increased moisture levels at the hub where precipitation can more easily penetrate the nacelle.

Figure 1: Connector corrosion

It was also noted that on the junction box for the weather instruments one of the connectors had signs of sparking. There are several explanations as to why this may have happened. One explanation and the most likely is that a build-up due to corrosion caused a short circuit between the terminals resulting in over-currents. Another explanation may be that (prior to any corrosion) moisture had seeped in, possibly due to rainfall, and this caused short circuiting between the terminals.

Figure 2: Connector sparking

An observation made when removing the weather instruments from the met mast bracket was that the mast had been struck by lightning. A lighting rod that had been welded to the met mast was no longer present and there was evidence of hot sparks from markings on the fin of the wind vane. It is believe that the extreme currents and heat caused by the lightning strike had caused the weld to fail and thus allow the lightning rod to break off.

Figure 3: Wind vane following suspected lightning strike

2.2.2 Operational Robustness

Having collected several months' worth of data it became apparent when comparing the later datasets to the initial datasets that false readings were being obtained. Initially it was not known whether the sensors themselves had failed or whether it was another issue between the sensor and data acquisition module. Upon further investigation it was found that for the PT100 temperature sensors false readings were being obtained due to loose connections entering the signal conditioning modules. These modules use spring loaded terminals to clamp the incoming wires. It is believed that high levels of vibration due to normal wind turbine operation combined with a small downward force from the weight of the wire caused these connections to work loose. It would therefore be recommended that spring loaded terminals are not used within a wind turbine nacelle environment.

On one visit to the wind turbine for data collection it was found that the entire CMS was switched off. It became apparent that there was no power from the auxiliary power supply within the wind turbine. On speaking to the wind farm site supervisor it was discovered that there had recently been a grid trip meaning that the turbine had been disconnected from the electrical grid and had been without power. This in turn had caused the circuit breakers for the auxiliary power supply within the wind turbine to trip. This meant that the uninterruptable power supply (UPS) batteries for the CMS had been drained of all power and the CMS therefore shut down. It was not until the circuit breakers were reset that the UPS could receive power and switch the CMS back on. When a CMS is being run from an auxiliary power supply that is susceptible to power losses it is important that the power status is monitored to ensure that it can be restored as soon as possible following an outage. This issue may not always be something that can be avoided through the system design as it depends on the site's communications network but it emphasises the need for good communication between the condition monitoring team and the wind farm site supervisor.

On uninstalling the system from the wind turbine it was discovered that the fibre optic cable had snapped. The way in which the cable was frayed suggests that the cable had snapped after coming under excessive strain as opposed to general wear and tear. It was therefore obvious that this break of the fibre optic cable had resulted in the loss of communications between the enclosure in the nacelle and the enclosure at the base of the tower. This was in fact the second fibre optic cable that had broken this way. It is believed that the reason for this breakage was due to a lack of slack in the cable. The fibre optic cable ran down the tower alongside the four power cables which are separated by a circular spacer. This spacer allows the cables to twist at the same time as the turbine yaws and prevents them from coming under excessive strain through twisting.

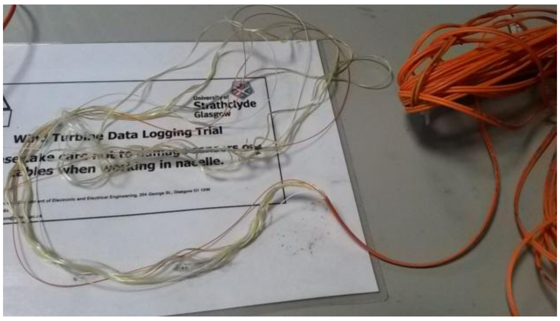

Figure 4: Frayed fibre optic cable

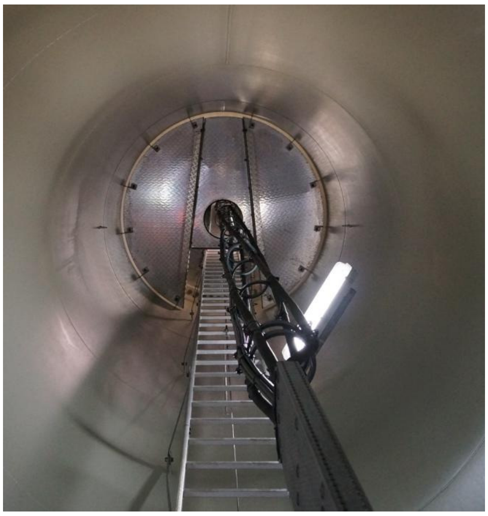

Figure 5: Wind turbine tower with power cables in centre

Fibre optic cable by its nature does not have a lot of flex in it and therefore when subjected to excessive strain will break relatively easily. To prevent the fibre optic cable from coming under excessive strain it must be installed in a way that allows it to have enough slack in it to prevent over straining yet be secured in the right places to avoid any one part bearing the weight of the cable below it. Where possible any new fibre optic cable being installed should follow as closely as possibly the path of the existing fibre optic cable which is used for the wind turbine control communications. The most likely location in the wind turbine for the fibre optic cable to come under excessive strain is at the yaw deck. It is therefore crucial within this area to leave sufficient slack to be taken up as the wind turbine yaws. A turbine will typically be able to yaw two complete rotations in either direction before it corrects itself.

With the system uninstalled from the wind turbine it was brought back to the university so that it could be further tested and the reasons for its failure identified. The cabinet located at the base of the tower was tested first. This cabinet housed the Host PC which had the purpose of allowing communications with the system in the nacelle and also of receiving the data from it and storing it on an external Ethernet drive. When power was supplied to the enclosure, the PC and Ethernet drives started up as normal and all files and folders could be accessed. This enclosure is less susceptible to issues caused by the rising and falling of temperature which would be experienced by the nacelle enclosure whenever the wind turbine was shut down or started up. To protect this base cabinet from low temperature conditions a heater had been fitted inside it along with fans to draw out any moisture.

After confirming that the tower base cabinet was functioning as normal attention was moved onto the nacelle enclosure. This is the main enclosure for the CMS and houses all the crucial data acquisition hardware including a PC. On removing the enclosure cover it was found that there was a large volume of thick black dust covering everything.

Figure 1: Large volume of dust inside enclosure

It was found that the UPS would not power on, either when supplied with external power or from a replacement battery. The UPS supplies the power to all components of the CMS within the nacelle, and therefore with it not switching on, nothing else could receive power. This behaviour suggests a serious fault with the UPS.

When the CMS was designed and built a fan was fitted on top of the UPS air inlet in an attempt to increase the circulation of cool air and prevent the UPS from overheating. However it became apparent from the level of dust within the UPS that the fan had in fact caused more harm than good by drawing dust inside of it. Part of the reason for drawing in so much dust was due to the absence of the correct fan filter which would have prevented such a level of dust passing through. However given the excessive volume of dust, even with a filter in place, airflow would soon have been restricted as the dust saturated the filter. It is therefore believed that the dust drawn inside the UPS by the fan caused the fan to overheat, resulting in its failure.

Figure 2: Failed UPS due to excessive dust

To continue to test the rest of the system, the working UPS from the tower base enclosure was used to replace the faulty UPS. Power to the UPS is supplied via a connection and switch on the outside of the enclosure. The enclosure is also fused and the mains supply enters a terminal block before connecting to a slow-start relay and the UPS. On trying to switch on the UPS a clicking noise could be heard from inside and it would not switch on. This clicking noise is likely to be the automatic voltage regulator (AVR) attempting to correct the input voltage level. The UPS has an AVR boost function which uses the internal transformer to increase that voltage and an AVR trim function which uses the internal transformer to decrease the input voltage. Bypassing the enclosure external connection, switch, fuse and slow start relay stopped this clicking and allowed the UPS to switch on as normal. A voltage drop within the enclosure caused the UPS to attempt to correct the voltage however was unable to correct it to a level that allowed it to switch on.

With the UPS now powering the rest of the system attention was turned to testing the sensors. As stated previously the signals from the sensors are acquired via two data acquisition (DAQ) modules: a high speed module acquiring at 20kHz and a low speed module acquiring at 50Hz. On attempting to run the acquisition software it was found that the DAQ modules were not being seen by the computer. On closer inspection it was found that the DAQ modules were not powering up. It was assumed at this stage that they must have failed as a result of extreme temperatures, dust or moisture ingress. To confirm this, the low speed USB DAQ module was removed and connected to another PC. Surprisingly the module powered up as normal and could be seen by the PC. On connecting it back into the CMS and after further investigation it was discovered that the reason they DAQ modules were not being seen by the CMS PC was due to an NI MAX database corruption. NI MAX is the measurement and automation explorer that allows hardware to be connected to the PC and managed. Database corruption can occur if the system is not shut down properly usually caused by a power loss and in this case this corresponds to the failure of the UPS. Under normal circumstances if the UPS had simply run out of battery the system would have shut down safely prior to this. However since the UPS failed it is likely that no signal to shut down safely was received by the PC.

With the corrupted database restored the sensors could then be tested. Of the six PT100 temperature sensors it was found that only one was faulty. It was not the sensor itself that was faulty but the corresponding signal conditioning module. The cause of failure of this module is unknown however due to the other issues associated with the terminals of this module it would not be recommended for use again for such an application.

Another notable observation was the difference between enclosures that were IP rated compared to those that were not. The enclosures that had an IP rating of 56 which prevents dust and splashing liquid, had no dust inside them at all (Figure 3) compared to those that had no IP rating (Figure 1). The reason that there were enclosures with no IP rating is because they were purpose built in-house.

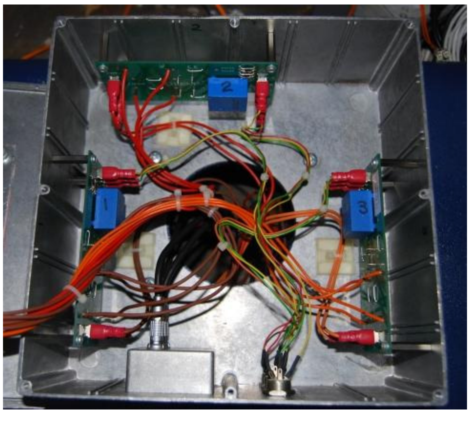

Figure 3: IP56 rated enclosure

2.2.3 Manual Handling Robustness

Manual handling robustness is applicable at different stages of the systems' lifetime. The first stage was when the system was being tested. During this stage the sensors were connected and disconnected from the system numerous times which resulted in some fatigue to the cable where it enters the connector. It was also found that some cables were coming loose from their connectors due to the cable diameter not being a perfect fit for the connector. It is therefore essential that when cables and connectors are specified during the design that they are a suitable match for one another.

The testing stage was the only stage that resulted in issues with the system. There were no issues caused to the system by personnel at either the installation or maintenance stages. The main enclosure had been designed so that it was capable of supporting the weight of any personnel working within the wind turbine nacelle.

2.2.4 Electrical Signal Robustness

A wind turbine nacelle is an inherently noisy environment in terms of electrical signals. The two main causes of this noise are the power cables from the generator and also the generator itself. The system was designed and built using only shielded cable in order that electrical noise was kept to a minimum. It was also designed so that signal and power cables were kept as far away from each other as possible. It was clear from the data collected that there was a degree of noise within the signals however without other data to compare against it was not possible to classify the level of noise.

2.2.5 System Software Robustness

Shortly after the completion of the installation of the system and having left it acquiring data for one week it was found that the acquisition program for logging data had crashed. After some time troubleshooting the issue it was found that it had crashed due to a VISA-read virtual instrument (VI) in the software being unable to establish a serial connection with the electronic compass.

This problem with the electronic compass highlighted a potential area for improvement early on. The concern was not due to the fact that the sensor was not being read but was due to the fact that the program had not handled the error well. A well designed software program should be able to handle an error in a way that allows the rest of the program to run uninterrupted rather than causing a complete system crash.

One difficulty in troubleshooting a CMS within a commercial wind turbine is the time-pressured environment brought about by the loss of revenue being accrued for every minute that the blades are not turning. Wind farm operators are very reluctant to shut down a wind turbine unless it as absolutely necessary. The wind turbine must be shut down anytime access to the nacelle is required.

Troubleshooting within this time-pressured environment highlighted another area for improvement with the system software: readability. Trying to identify a problem within a large program under pressure and having not written the program was challenging. National Instrument's Labview is a graphical programming environment which prides itself on its usability and ease in which engineering problems can be implemented. This however relies on the careful use of subVIs similar to a subroutine in a text-based programming language. Using subVIs increases the modularity of the program making it more readable and easier to debug. In this case subVIs were not used as well as they could have been which resulted in a very large and difficult to read main VI.

3.0 New and Improved CMS for a Vestas V42 Wind Turbine

Following the experience with the first CMS system the university was involved in another collaborative project to design, build and install a CMS in a Vestas V42 wind turbine. The V42 is almost identical to the V47, except for a slightly smaller generator of 600kW. The difference this time being that the system designed would have to operate in conjunction with two other systems designed and built by different project partners which added its own challenges.

3.1 System Overview

The system designed by the university has the task of capturing data from 29 sensors which are spread across the nacelle. These included vibration, temperature, voltage and current, and meteorological parameters. The system also acts as the master to the two other systems designed by the other project partners. This means that the system provides a valid timestamp taken from a GPS signal, monitors the status of the UPS which supplies power to all three systems, monitors the health status of all three systems, and manages the data storage for all three systems.

One key requirement for the new system, based on the experience from the last system, was to reduce the complexity and increase ruggedness. The previous system required a significant amount of signal processing interfaces prior to the signals entering the DAQ modules. These additional interfaces increased the complexity of the system and the number of areas in which issues could occur. The key component in the new system which allows simplification and ruggedisation is a National Instruments CompactRIO (cRIO).

The use of a cRIO also allowed the main CMS enclosure to be significantly smaller in size. Figure 4 shows the new CMS enclosure. The cRIO can be seen located in the centre of the enclosure with its power supply sitting to its immediate right. The 24Vdc power supply for the cRIO is also used to supply power to all of the sensors. A DC-DC converter seen on the right-hand side of the enclosure is used to convert the 24Vdc in to ±12Vdc and 5Vdc required for different sensors.

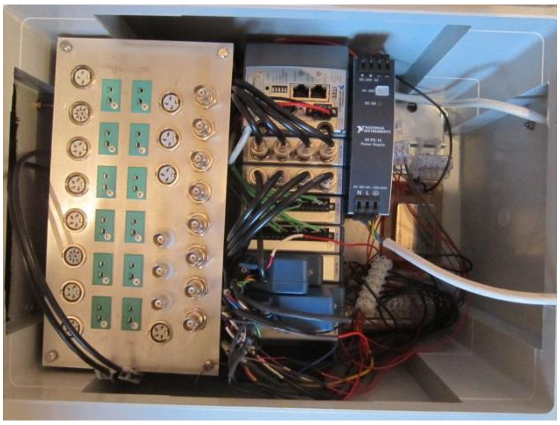

Figure 4: New CMS enclosure

3.2 Improvements using the five categories of robustness

The first CMS was a very worthwhile project in terms of learning about the environment and challenges faced by a wind turbine CMS. The new system was designed and built with the five categories of robustness in mind and the improvements made are discussed in this section.

3.2.1 Weather Robustness

There were two main issues that occurred as a result of the weather on the system:

- Corrosion on connectors
- Lightning strike

The main enclosure for the new system was selected to have an IP rating of 66 which means it is completely dust proof and capable of withstanding powerful water jets. Although it is unlikely that the system will be exposed to powerful jets of water there is a chance that it could be exposed to an oil leak or precipitation dripping from the nacelle roof.

As can be seen from Figure 4 the connector panel was brought inside of the main enclosure which will reduce the chances of moisture entering at the connectors which could result in corrosion. The sensor cables enter the enclosure via a brushed entry system which although reduces the enclosure's ability to prevent water from powerful jets it will still prevent large volumes of dust entering. To prevent any moisture ingress through drips from above a rubber seal with a flap which extends over the cable entrance was fitted to the enclosure.

As discussed in the previous section the lightning rod that was attached to the met mast was knocked off by a lightning strike. It was decided that for the new system it would be better not to have a lightning rod at all on the met mast. The reason for this was that unless the rod was fully capable of absorbing the full lightning strike and diverting the extreme current into the wind turbine's lightning system, it would do more harm than good by attracting a lightning strike. Since there was already a lightning rod on the wind turbine's own existing met mast, which sits higher than the new met mast, it would be better to allow it to absorb the lightning strike and direct the over-currents down the wind turbine's lightning protection system. Another precaution taken with regards to lightning strikes is that every part of the CMS equipment is well grounded so that any over-currents that they are exposed to can find an easy path to ground in order to prevent any damage to crucial parts of the system.

3.2.2 Operational Robustness

There were two main issues that occurred as a result of normal wind turbine operation on the system:

- Overheating due to excessive dust intake
- Snapped fibre optic cable

By locating the UPS in a separate enclosure, the main CMS enclosure has no requirement for cooling which reduces the risk of excess dust being drawn in by fans. Mounting the UPS in a separate enclosure means that the main CMS enclosure can be smaller, lighter and have reduced electrical noise. Having an additional enclosure for the UPS means that it can also be used for the networking equipment. The enclosure now housing the UPS is mounted in an IP rated enclosure which has fans built into it with appropriate filters to reduce the level of dust that could enter and risk over-heating. Each of the systems are also fitted with dehumidifiers to reduce moisture levels inside of them.

As stated previously the fibre optic cable was susceptible to coming under excessive strain causing it to break and therefore prevent data from being sent to the Ethernet data storage drives. To reduce this risk the routing and fixing of the cable was revised. Break points have been added to the fibre optic cable by way of patch cables and couplers. These break points have been added at the locations most susceptible to excessive strain. If the fibre optic cable comes under excessive strain the coupler will allow the main cable and patch cable to separate and avoid a breakage. In addition to the break point a spare fibre optic cable will be installed but not connected. If the one cable is damaged then the replacement can be simply connected in, again reducing data loss.

To reduce the risk of data loss a 2TB USB drive has been incorporated into the main CMS enclosure and connected directly to the cRIO. In the case that the fibre optic cable is damaged as it was previously, the USB hard drive will allow approximately one months' worth of data to be stored locally, significantly reducing the risk of losing valuable sensor data.

A final addition to the new system, to further increase reliability, is the use of three NAS (network attached storage) drives. Data from the three systems can be written directly to these NAS drives with no dependency on the Host PC. Although the Host PC directs the three systems to write to a specific drive, they would still be able to write to the drives should the Host PC fail. All three systems in the nacelle will write to the one selected NAS drive. Once this drive is nearing capacity they will all simultaneously begin writing to the newly selected drive. Should all three drives reach capacity prior to being replaced each of the systems has the capability to store their own data locally until an empty NAS drive is installed.

3.2.3 Manual Handling Robustness

There were two main factors which, although they did not cause any issues, were identified as potential areas in which a fault or failure could occur.

- Connectors on the connector panel

- Wear and tear of sensor cables running across the nacelle

In Figure 4 the connector panel can be seen on the left hand side of the main CMS enclosure. On the previous system the connector panel was mounted on the outside of the enclosure. This however meant that the sensor connectors were susceptible to being knocked off or damaged whilst maintenance work was being carried out in the nacelle. For this reason it was decided that it would increase system robustness to have the connector panel inside the enclosure. The sensor connectors enter the enclosure via a brushed opening which allows the connectors to pass through but reduces the exposed area in which dust may enter.

To reduce the risk of sensor cables being damaged within the nacelle all cables have been run inside protective conduit. This will protect cables from general wear and tear which may result from any work carried out within the nacelle due to the limited space.

3.2.4 Electrical Signal Robustness

Two areas in which noise reduction could be improved were identified:

- Noise from the UPS
- Noise from power supplies within the CMS enclosure

The main change to the CMS to reduce electrical noise on the monitored signals was to keep the UPS separate from the main CMS enclosure. To do this a separate enclosure was used which would house the UPS and the network equipment. The UPS can introduce a significant amount of noise due to the mains supplies in and out of it. By having it separate it meant that only one mains cable had to enter the main CMS enclosure to power the 24V power supply. To further reduce electrical noise in the signals the connector panel was mounted as far away as possible from the power supplies – this is difficult given the limited space available. As with the previous system shielded cables were used throughout the system to reduce noise levels as far as possible.

3.2.5 System Software Robustness

System software robustness was identified as a key area for improvement in the new CMS. There were two main requirements on the new software:

- Ability to handle errors
- Ability to debug more easily

The software for the new CMS can be split into three parts. The first is the software for the Host PC, located at the bottom of the tower, which is used to communicate with the systems in the nacelle. This program will tell the three systems in the nacelle which NAS drive they should be writing data to. It will also monitor the health of each of the systems by continuously receiving a health status pulse from each of them as well as any other information about errors in any of the systems. It can then send out a status email detailing the state of each system and if any errors have occurred. As well as monitoring the health of the systems in the nacelle it will also monitor the status and volume of data on the NAS drives. Although the Host PC is required to send out key information, the systems in the nacelle are not wholly reliant on it and are able to function should communications with the Host PC be lost.

The second part of software is the FPGA (Field-Programmable Gate Array) program. Programming an FPGA is slightly different from other programming in that it is all based on digital logic. This logic is applied on the FPGA by re-wiring the chip itself which is why such high processing speeds can be achieved. Within the FPGA program there are two main loops: one to acquire the high speed data at 20kHz and the other to acquire low speed data at 50Hz. These loops are initiated and triggered to begin acquiring data by the real-time program on the cRIO controller. Within each loop data is read from the sensors, combined into an array, converted into an appropriate data type and loaded into a DMA (direct memory access) FIFO (first in first out) queue, which can be read out by the cRIO controller's real-time application.

The third and main part of the software is the real-time application that runs on the cRIO controller. This application performs a number of key tasks including: defining system configuration, interfacing to the FPGA to acquire data, handling data logging, and communicating with the Host PC. The application is designed so that it can run for long periods of time without any human interaction. The main configuration for the system is written to a text file and stored on the cRIO to be read at the initialisation stage.

A key feature in the new system software is the built-in error handling. Should any error occur, such as an FPGA overrun, an error will be flagged and sent to the Host PC. The program will then carry on acquiring data as normal and not be brought to a halt by this error. The system also handles errors that are not related to the software. For example, if communications are lost with the Host PC (possibly due to fibre optic damage) then the cRIO will attempt to find a NAS drive to write to for itself. If a NAS drive cannot be found then it will begin writing data to the local USB drive.

The new software was designed to be easy to read and maintain. This was done through the careful use of subVIs (visual instruments) which increased the program's modularity. By careful use of subVIs, the main VI gives a very high level view and only by entering each subVI will a lower level view be obtained. This makes the program more readable for a user who may not fully know the workings of the system.

4.0 Conclusion

The wind turbine nacelle is a particularly harsh environment, more so that one would initially suspect. This is due to a number of factors including high vibration levels, high volumes of dust, extreme temperature fluctuations and also the risk of damage through personnel working within the nacelle. Through careful design and consideration of key factors it should be possible to design a reliably robust CMS that is capable of operating for long periods of time without human intervention whilst providing the wind farm operator with an accurate description of the state of the wind turbine's health.

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