

**Case Study: Ten Years Remotely Monitoring
a GE Frame 6 Gas Turbine**

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Abstract

Detecting and diagnosing faults in plant critical equipment is essential to minimise costs and maximise availability. Early detection can provide significant benefits including the avoidance of unscheduled outages and possible equipment damage. A monitoring and diagnostic system is a vital tool that is used to achieve this and can be used on site or by support staff at remote locations.

This case study describes the systems and resources in place to carry out the remote monitoring of a GE Frame 6 gas turbine and how they were used and developed over the course of ten years, resulting in best practice for remote monitoring.

It gives details of the monitoring and diagnostic system and the staffing structure and skills needed to provide the remote monitoring service.

In this case study, some problems are identified early, leading to scheduled outages whilst other issues lead to turbine trips that need to be investigated after the event.

Communication with the site is very important as some fault conditions are due to external factors such as lightning strikes. A number of problems persist across the years and are due to site issues. Particular issues with steam injection and combustion spreads are described.

Introduction

Monitoring of the GE Frame 6B gas turbine was carried out on a manual basis by visiting site until a remote monitoring diagnostic system was installed in 2002. This paper explores lessons learned over the course of the last ten years and details some of the evolution of what the monitoring and diagnostic system does and the evolution of how it is used.

A monitoring and diagnostic system is a tool used by staff to provide assistance to site to increase turbine reliability and availability, and ultimately reduce costs. The interaction between site, the monitoring and diagnostic team and the software is a key element in ensuring success.

Installation

The original installation of the monitoring and diagnostic system gathered data from the Speedtronic Mk IV controller which had a data dump card feeding the DCS. The data feed came out of the controller via a RS232 serial connection at 9600 baud with the broadcast frequency set to one data set per second. The points sent were 80 analogs, 80 digitals and 256 alarms.

When first connecting to Speedtronic Mk IV, there was a concern that the data set would not be big enough to create useful diagnostics. However, it was found that monitoring and analysing the data at once per second was effective, even for a small number of points.

The signal that was transmitted to the DCS was split using an RS232 passive signal splitter as shown in figure 1 and the serial wiring to the monitoring and diagnostic system was set to listen only.

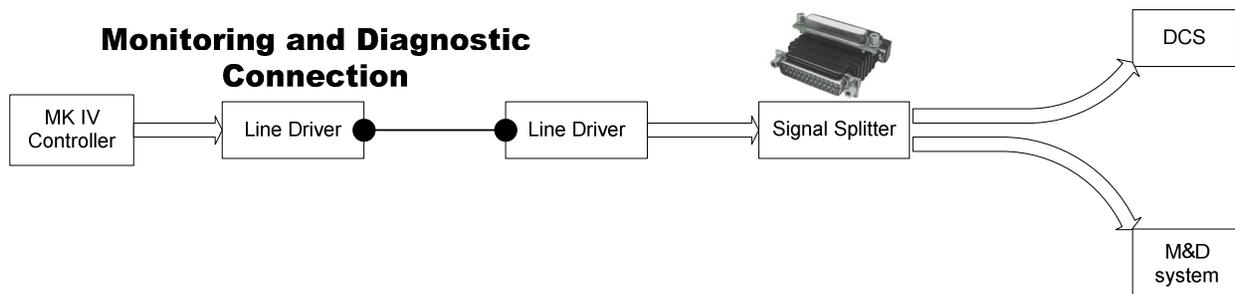
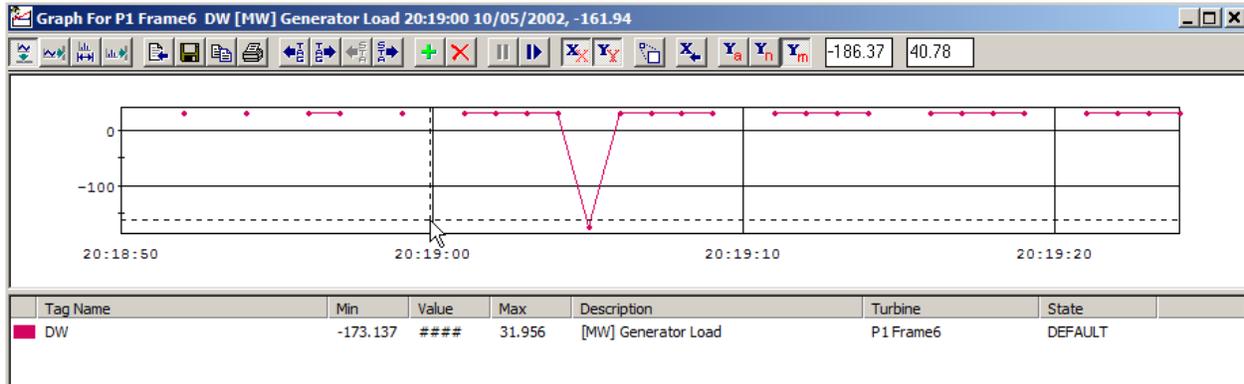


Figure 1: Connecting to a MkIV data dump card

After installation it was noticed that the system was dropping data due to CRC check failures and getting some very strange values from analogs and digitals that did not make any sense. For example, the graph below shows data gaps and a drop of power from 32 Mw to -173 Mw with the digital tags changing as shown in figure 2.



20:16:05 10/05/2002 Full Speed No Load (L30D_FSN) changed from 0 to 1
 20:16:05 10/05/2002 Ratchet Did Not Start (L30A78) changed from 0 to 1
 20:16:07 10/05/2002 Ratchet Did Not Start (L30A78) changed from 1 to 0
 20:16:07 10/05/2002 Full Speed No Load (L30D_FSN) changed from 1 to 0

Figure 2: bad data showing a one second 200Mw drop along with “nonsense” digitals

It was noticed that the frequency of the CRC failures was about once every 30 seconds, suggesting some sort of radar sweep interference. It also transpired that the DCS had been getting the bad data long before the monitoring and diagnostic system was installed. A section of the communications went outside the building which was picking up the interference. The problem was resolved by installing high quality line drivers over the exposed section.

The controller was upgraded to a Speedtronic MK VIe in 2008. The data is now acquired using an OPC connection to a Cimplicity HMI. The monitoring and diagnostic system is now acquiring and analysing 306 analogs and 1048 digitals every second.

Remote Connectivity

Remote connection to site was provided using a modem on an analog telephone line. Several modems failed in short succession and it was found that substantial anti-surge protection was needed due to the prevalence of lightning storms.

In the first instance, remote connectivity consisted of one client connecting in at any time using an analog telephone modem at each end. Subsequently the monitoring and diagnostic system was developed to have a central remote access server that dialled to sites enabling users to connect to the central remote access server over ethernet based networks. This meant that the data was only collected once from the phone line and stored in the monitoring and diagnostic system remote access server for dissemination to all users.

The functionality of this remote access server developed over the years. For example, the analysed data is downloaded in advance of users requests and this lead to the automated production of reports on a weekly and monthly basis. Reports are then generated when certain events occur on the turbine, such as startup, trip and shutdown. All these reports are then emailed to a distribution list. The server also generates SMS messages on nominated events.

For this site, connectivity issues with modems occurred sporadically over time. Many of these were related to operating system hang-ups within the RAS subsystem of Windows. In the end a line monitoring module was implemented that rebooted the monitoring and diagnostic PC if it had not heard from the remote access server connection for twelve hours.

Another issue with analog phone modems occurred because the phone system is digital. Typically fax and modem lines are handled differently and it is not possible to plug the modem into a digital phone socket. From time to time the circuitry got switched around, causing loss of communication for lengthy periods of time until the issue was traced and resolved.

Modem connection was replaced by internet in 2014 providing substantially better access.

Turbine Data Handling

The monitoring and diagnostic system stores all of the data forever. The data is stored in chunks of four minutes in compressed files. These files are independent of each other and can be copied and emailed to other computers that have the monitoring and diagnostic system installed. This

data can then be replayed as if it were live. This feature of the monitoring and diagnostic system has proved useful when there has been an extended period without phone communication.

The storage of the data in discrete files allows for easy backup and dissemination of the information. The monitoring and diagnostic system copied the daily files onto a USB memory stick and this was sent to the remote monitoring centre on a regular basis. This “snail mail” solution has worked well for many years and avoids trying to download all of the data over a phone line – a time consuming and costly process. This backup process has now been replaced as it is not needed when there is an internet connection and an associated remote server. The remote sever acts as a cloud back up and all the data for a day is transferred to the remote server each day, typically during the night.

The monitoring and diagnostic system analyses the data on-site and makes this analysis available remotely. This is essentially a feature extraction on the raw data and is the key information to download. It allows drilling down to specific once-per-second data directly from the diagnostics and summary trend graphs.

This summary data is collected by the remote server every 15 minutes. The volume is small enough to make analog telephone line connection economic. The remote server then looks at the summary data and decides whether to issue automatic reports and SMS. It also decides whether to download specific once-per-second data for particular events such as startups and shutdowns. This higher resolution data is included in the automatic reports.

Typically the data volume in compressed files for this site is 1.6 Gb per month for MKVIe and was 0.25GB per month for MkIV. These data files are arranged in folders with a folder per year, containing a folder per month, containing a folder per day, containing folders for the once-per-second data, diagnostic messages, specific model analysis and summary trend graphs.

Each file in the folder structure has its name encoded with the turbine, time stamp and type, enabling individual files to be identified out of context. They can then be placed in the hierarchy manually on another remote system when received separately by email or other means.

Scanning of once-per-second data over years takes a long time. The diagnostics and summary trends are themselves summarized on monthly, quarterly and yearly basis so that a query need only look at the summary files covering the required period.

Software Provides Notification of Events and Abnormalities

Generally the turbine is reliable and will run for months without issues. With 306 analogs and 1048 digitals every second, it is not a viable proposition to have someone look at these on a continuous or semi continuous basis. If there is an event such as a trip, then staff will go back and use the replay facilities to look for clues as to what has happened. Even then, there are a lot of tags and cross checks to be carried out.

It is the job of the monitoring and diagnostic software to analyse the data, continuously looking for faults and abnormalities by applying algorithms and checks. It has knowledge of what is normal for that class of turbines and for that specific turbine. It analyses every second, all the time, and uses the diagnostics to indicate issues to be investigated. In this way the software provides early warning of issues developing and highlights relevant information should an event occur.

Monitoring Staffing, Structure and Process

The turbine being monitored is a base loaded machine that operates for extended periods. The monitoring process is carried out on a daily basis. This was found to be sufficient for this base loaded turbine.

Daily monitoring involves checking the status of the turbine each morning and investigating any indicated issues. The monitoring is carried out by junior staff and should further investigation be needed, there is a pool of gas turbine experts that can be called upon to assist. The monitoring task is only part of the duties of staff. Experience has shown that it is more efficient to spread the monitoring task around so that the staff responsible for a particular turbine are the ones that monitor it. This allows context information about site conditions to be added to the mix to help with the best advice for resolution of issues.

The distributed nature of the monitoring and diagnostic software facilitates the spreading of tasks throughout the organisation. Each engineer has the ability to use the monitoring and diagnostic system to help as and when required. This is done using their laptop/tablet/smartphone from wherever they are located at that point in time. There is no diagnostic centre as such, as the capabilities are distributed throughout the organisation. Latterly a multiscreen meeting room was created to enable easy group discussion of turbine issues.

When the monitoring and diagnostic system was first installed it did not provide automatic notification of issues. Site would phone to request an investigation if an event occurred after the daily checking had been performed. The software was enhanced over time to provide automated emailed reports and SMS phone messages, so that staff could respond to specific incidents during the day.

When an incident or abnormality is observed a report is constructed and issued to site. To date there have been 401 reports issued since monitoring started in 2002. These reports consist of

- Specific event reports
- Quarterly summaries of status and events with site comments
- Summary reports prior to an outage to identify issues needing fixed
- Before and after outage reports

Daily Monitoring Activities

The daily monitoring of a base loaded turbine is a repetitive task. The monitoring and diagnostic software has been developed over time to make this as efficient as possible by highlighting new issues that have not been already reported.

Diagnostics

The primary means of checking is to examine the diagnostics. These are categorised according to severity to highlight the most important detections. Many issues will not be fixed until the next outage, for example faulty sensors. The controller can cope with bad sensors as long as

there are not too many of them and replacement sensors can be sourced to be installed the next time the turbine is down.

It is not helpful to have newly occurring faults mixed in with faults that have already been reported. The monitoring and diagnostic software was enhanced to allow the filtering of diagnostics so that only new ones are shown. In addition, notes can be attached to diagnostic messages to indicate the history of the reporting and resolution of the fault. The filtering mechanism also includes an inverse filter to see what diagnostics have been suppressed. The filtering and note mechanism enables easy transfer of the monitoring activity between personnel and make clear the status of the monitoring activity, highlighting new issues.

Summary Trends

The monitoring and diagnostic system also provides summary trend graphs of all tags. These summaries can cover years of data but it was found that a weekly trend going back from the current time was most effective for the daily monitoring process as it allowed a quick visual check on key turbine parameters to corroborate the diagnostic messages and to indicate unusual behaviour that the diagnostics might have missed.

The trend graphs show three points every four minutes for each tag. The average, maximum and minimum of each tag is displayed. This allows detection of events that only last for a few seconds, as in this case the maximum and minimum of the tag within the four minute interval will be far apart and further drilling down into the data is required. If the maximum, minimum and average are close together we know that the tag value has been stable in the four minute period.

The diagnostics are in continuous development and it has been found that they pick up almost all abnormalities shown by the trends. The trends were more important in the early years and showed slow drifting of tags that were not picked up by the diagnostics at that time. In this case the diagnostics were enhanced to detect the drifting of tags.

Toolsets and Reports

The daily monitoring involves bringing up windows for

Diagnostics for the past day of

- Filtered number of occurrences
- Inverse filter of number of occurrences
- Filtered currently abnormal
- Inverse filter of currently abnormal

Trend graphs for the past week of

- Exhaust thermocouples
- Exhaust thermocouple differentials
- Exhaust spreads
- Flame vector angle and length
- Flame detectors
- Power
- Speed
- Wheel-space thermocouples
- Lube oil temperatures
- Bearing metal temperatures
- Vibration
- Compressor inlet flange and discharge temperature
- Steam temperature, pressure, flow and differential pressures

Trend graphs since 2008 of

- Compressor efficiency
- Corrected power
- Corrected heat rate

The process of creating graphs and querying diagnostics for all this information is a lengthy one. The monitoring and diagnostic system was enhanced from an early stage to allow the definition of multiple graphs and diagnostic queries and to store them in a “toolset” for future recall. The process of calling up multiple graphs and diagnostic windows is now by a single click on a toolset name. The system provides a set of standard toolsets and the user can also define their own. By layering one graph exactly on top of each other, the user can position the mouse so that one click moves to the next tool. This allows an efficient visual check of all the trend graphs and diagnostics.

The standard toolset also provides the basis for a status report that is produced in Microsoft Word. The remote access server also automatically produces this report. Reports like this are useful summaries but it was found that if an issue was detected then the full monitoring and diagnostic system is needed to allow drilling down for further investigation and so this is the preferred method for checking the turbine each day.

An event report typically consists of diagnostics that have triggered, supporting graphs (once-per-second), summary trends (longer time periods) along with explanation and analysis. This is created in a Word document, converted to PDF and loaded to a cloud space to enable downloading by site. The reports are generally too large to be sent by email.

The diagnostics are saved as Word files and cut and pasted into the report. The graphs are set up to show the relevant features and an image is taken of them. Initially these graph images were captured using screen capture tools. In time, the monitoring and diagnostic software was developed so all open graphs, trend and diagnostic windows can be saved in a single Word file, thus saving the need for many individual screen captures.

Examples

Steam Flow Example

The steam to fuel ratio was detected as being too low from July 2003 and diagnostic messages indicated this was getting lower. The reporting of this allowed the site to plan for fixing this

problem as an upcoming event instead of just reacting to it. Site decided to drop some load if necessary to get the NOx production numbers down to enable the turbine to run until the scheduled outage in October, which would be the off-peak season for electricity. The outage found that the internal passageways in the combustion can covers were plugged with deposits from the attemperation water system.

The trend summary in figure 3 shows the steam flow issue developing. The maximum and minimum on the summary trend graph get further apart indicating that the steam flow was blocking and freeing up within the summary sample period. Note that the average value does not show this information.



Figure 3: Steam flow reducing to zero over five months

This issue repeated and the deterioration was monitored and the plugging cleared at each outage. The trend summaries in figures 4 and 5 below show the steam flow over ten years.

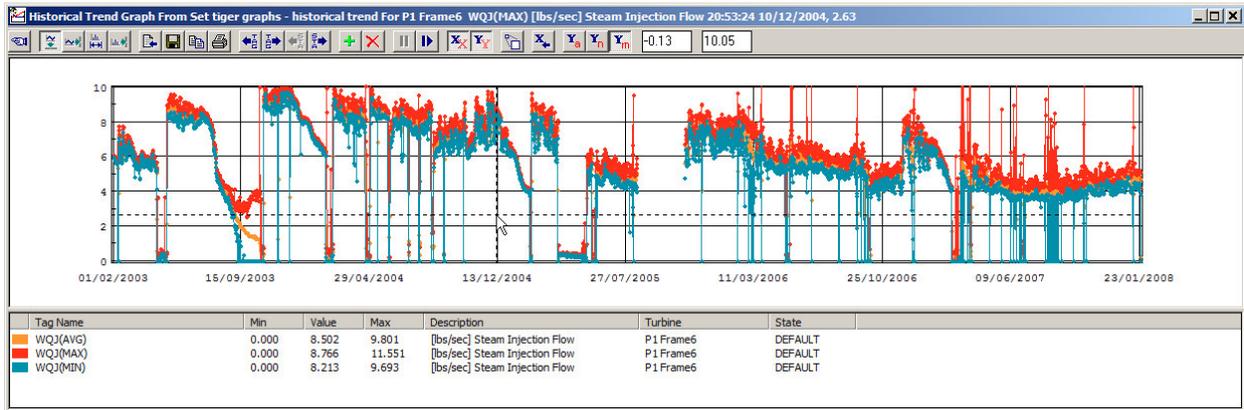


Figure 4: Steam flow from 2003 to 2008

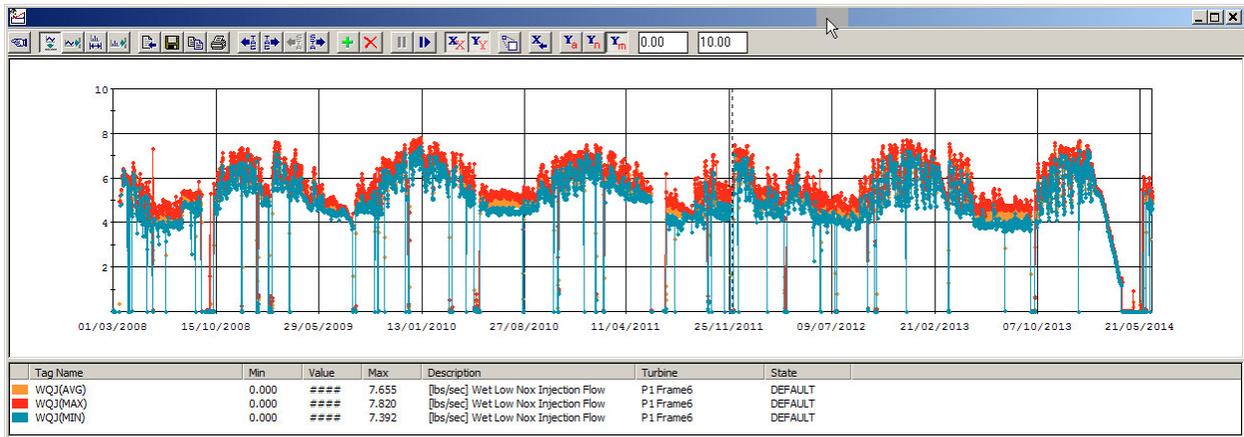


Figure 5: Steam flow from 2008 to 2014

The deterioration of the steam flow resulted in exhaust spreads increasing towards trip levels as shown across ten years in figures 6 and 7. Monitoring of the steam flow made the cleaning of the steam nozzles planned events.

In figure 8, it can be seen that the turbine was kept running until it was convenient to shut down. This planned shutdown date was extended by reducing the power to keep within the trip limits.

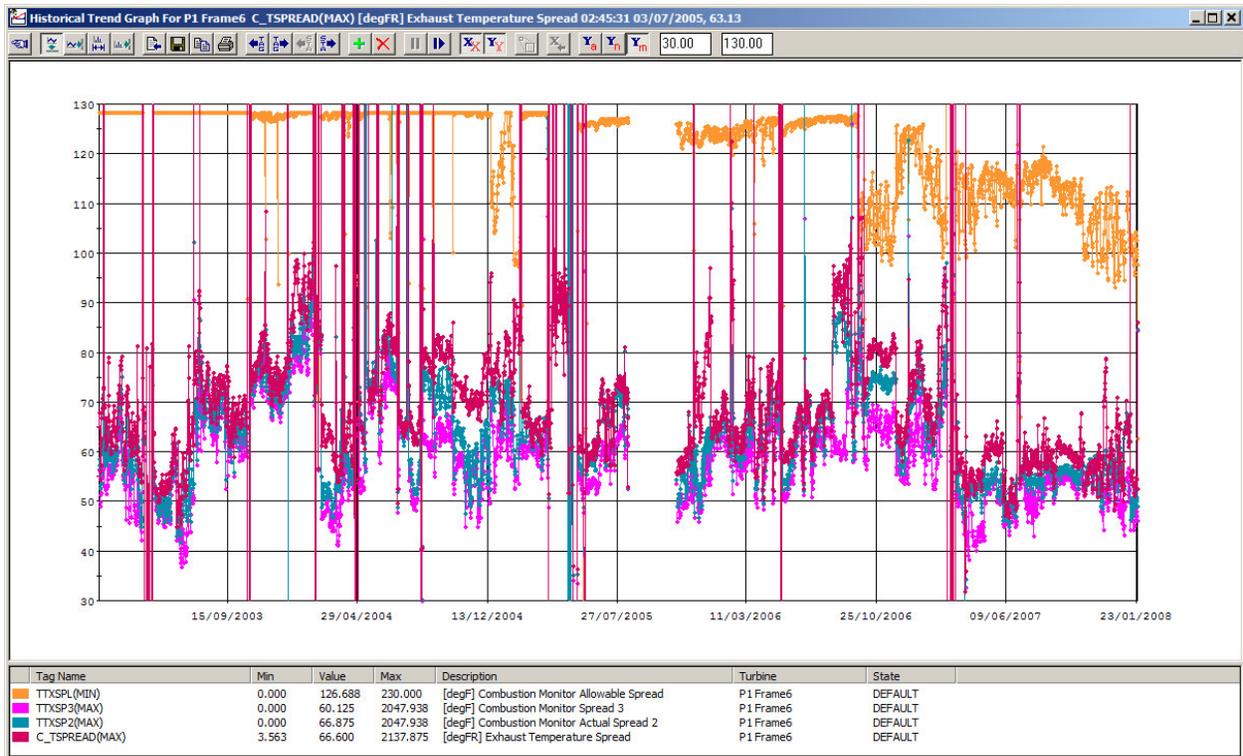


Figure 6: Combustion spreads and limit from 2003 to 2008

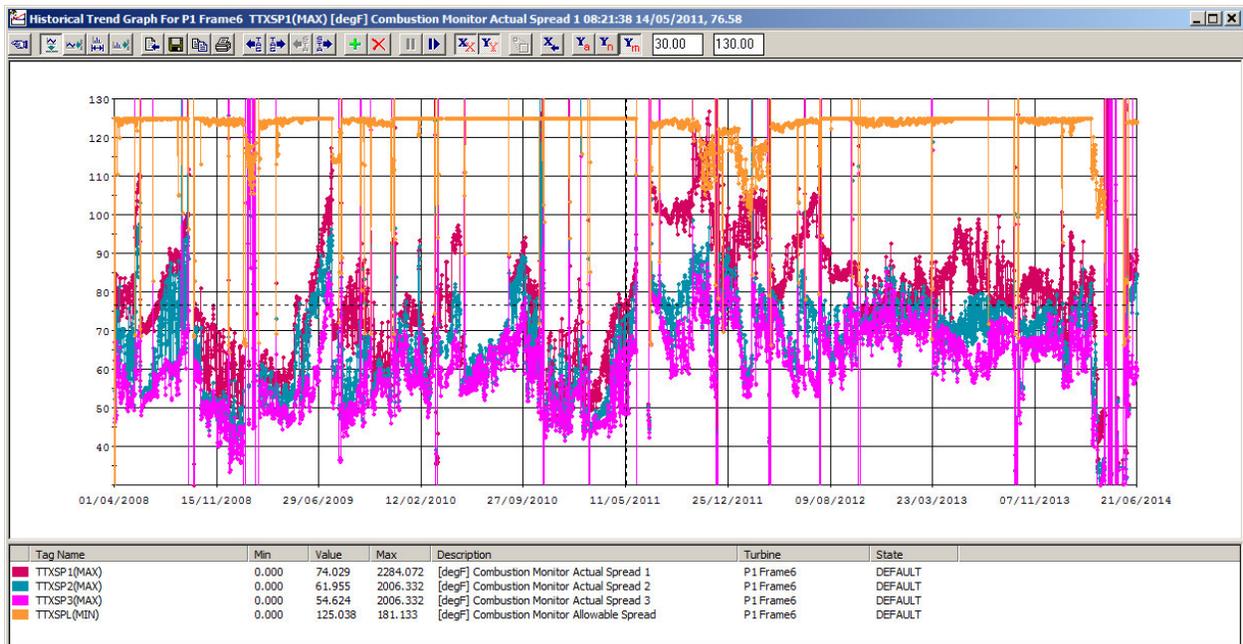


Figure 7: Combustion spreads and limit from 2008 to 2014

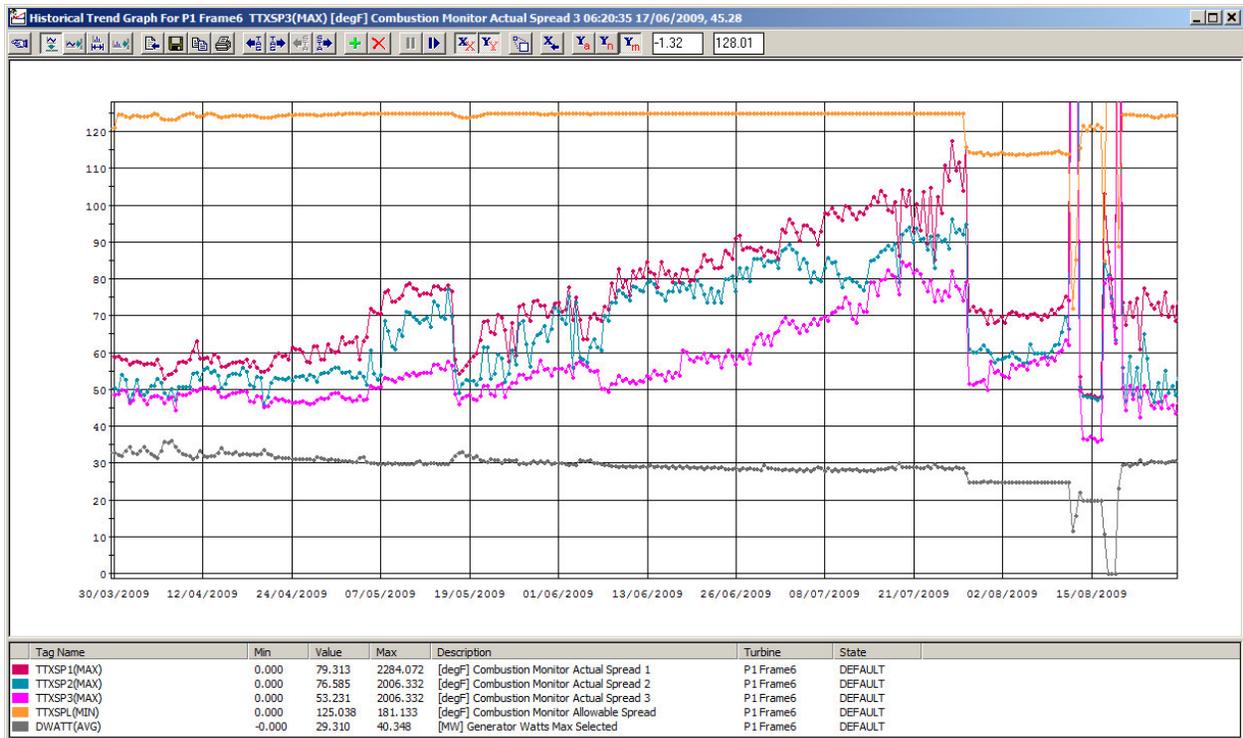


Figure 8: Combustion spreads and limit monitored to prevent a trip

Exhaust Temperature Spread Trip Example

On 8th February 2009 at 18:05:48 there was an exhaust temperature spread trip. This was caused by a series of large transients in exhaust temperature spreads which started at 18:01:22, which got progressively more frequent and severe until the trip, as shown in figure 9. These transients had been occurring on a regular basis since 16th January 2009, and had been reported on in several previous reports. The fault developed within 5 minutes and was investigated after the event.

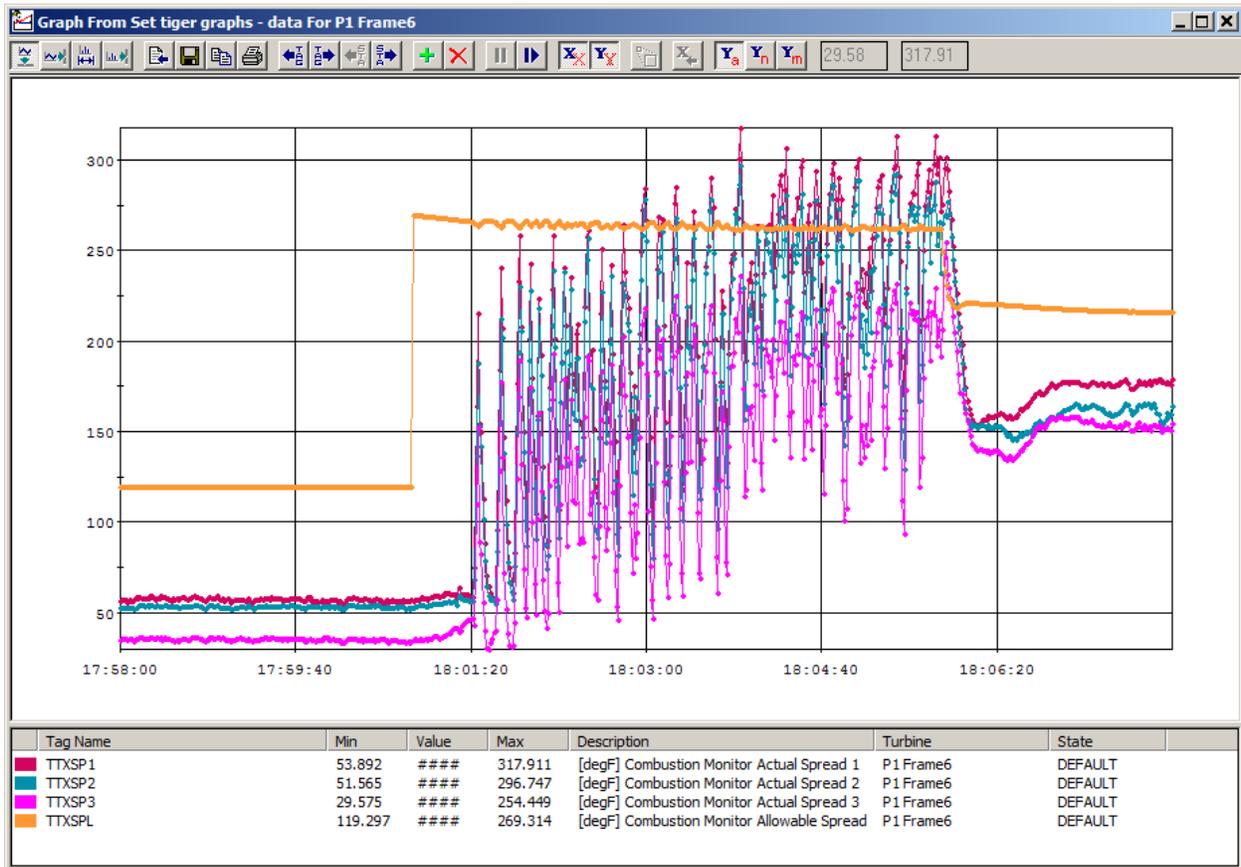


Figure 9: Combustion spreads increase to above trip limit

The indication is that the problem was most likely due to poor combustion (and possibly flameout) on combustion cans 6 and 7 as indicted by exhaust thermocouples 14 to 17 as shown in figure 10.

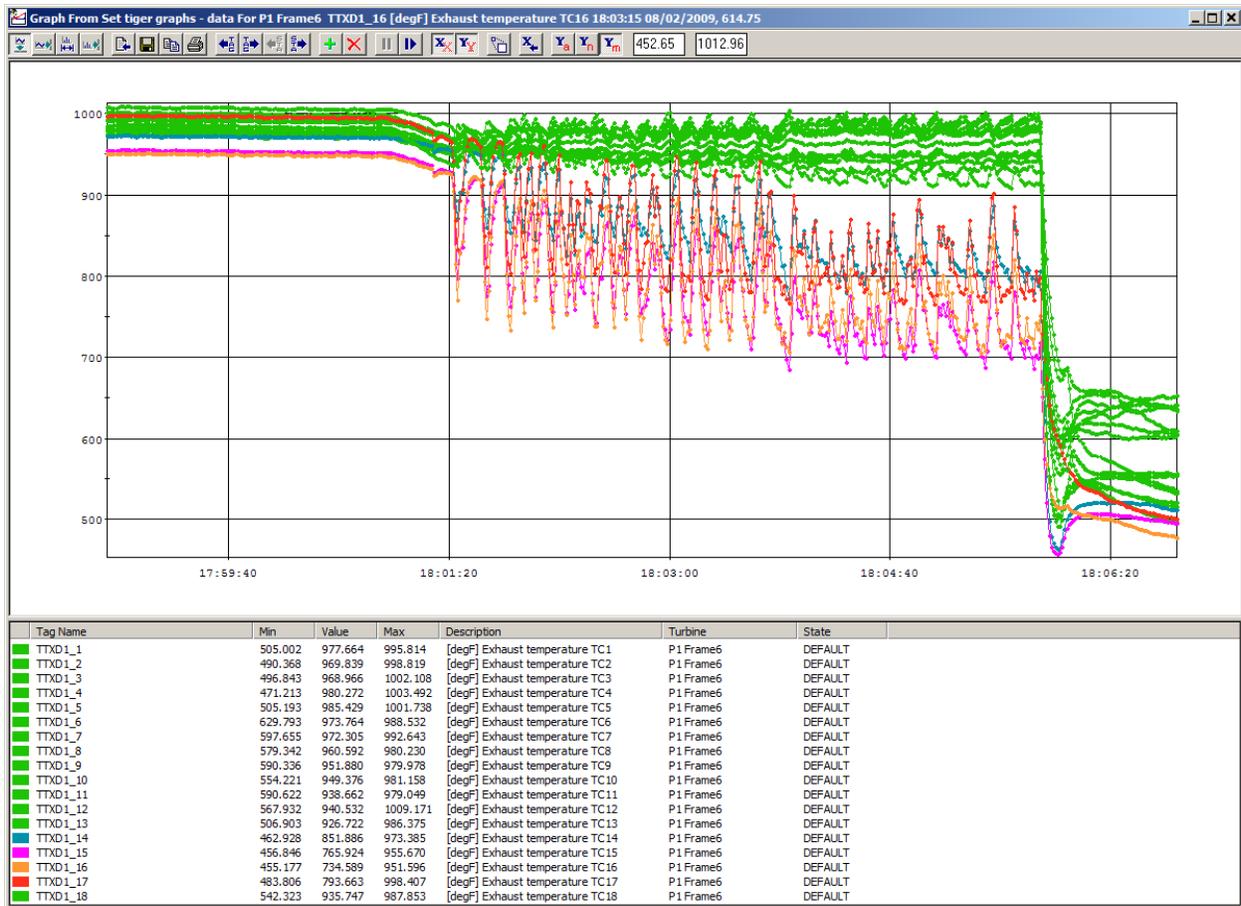


Figure 10: Exhaust thermocouples 14 to 17 go cold, increasing spread and leading to a trip

After the trip occurred, there was also a problem with the compressor bleed valves being slow to open, which caused a compressor bleed valve trip to occur as the turbine coasted down.

Corrected Efficiency Example

The monitoring and diagnostic system also produces efficiency calculations, with one point per day averaged over the whole day, taken when the turbine is at base load and stability criteria are met, as specified by the American Society of Mechanical Engineers. Figures 11 to 13 show the compressor efficiency, dry corrected power and dry corrected heat rate. The green line represents a base line for each respective tag after an off-line compressor wash. We can clearly see the degradation of efficiency over time. This allows the site to determine whether it is time to do an off-line compressor wash, though other operational factors often delay this. Of note is the

increase in efficiency of 3 Mw after the most recent outage. This information forms part of the outage report produced by the monitoring and diagnostics team.

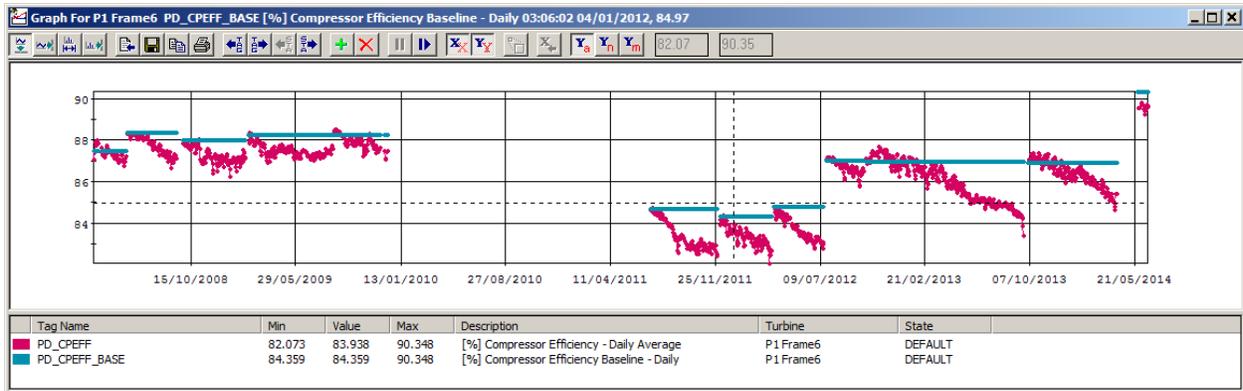


Figure 11: Compressor efficiency 2008 to 2014

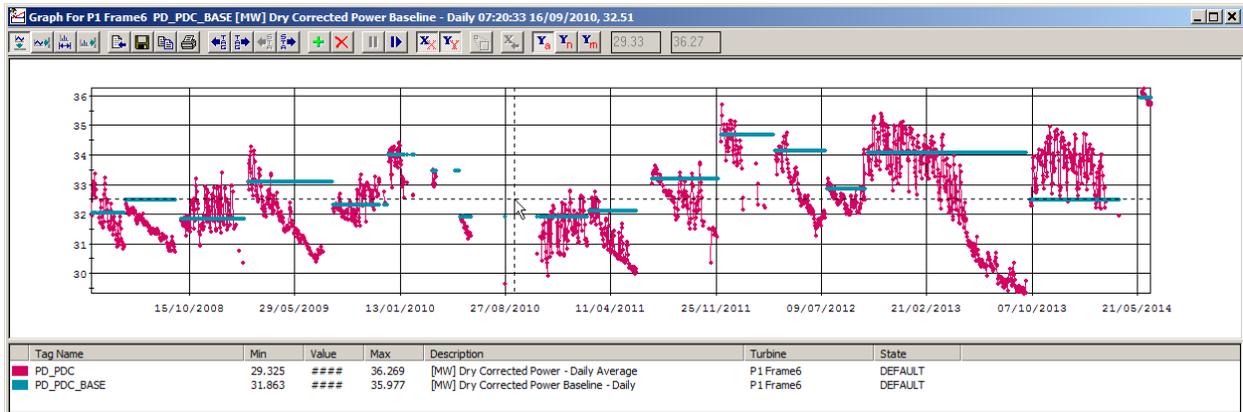


Figure 12: Dry corrected power 2008 to 2014

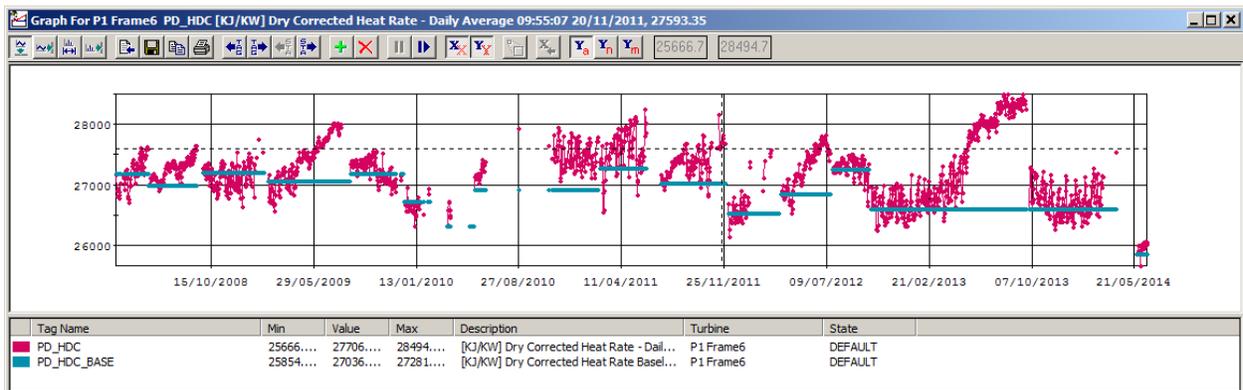


Figure 13: Dry corrected heat rate 2008 to 2014

Trips

Communication with site is important as it is not always possible to determine the cause of a trip from the data acquired by the turbine sensors and tags that are monitored.

Over the course of ten years, about half of the trips were triggered by outside sources

- Rain affected substation feed causing local utility to disconnect the grid, tripping the turbine
- Incorrect IP address set on generator monitor module
- Loss of flame during on-line water wash.
- UPS power supply fault
- Lightning strike
- Water leak in the generator compartment trips the generator and turbine
- Generator breaker trip due to grid x 2

Trips from within the turbine systems itself include

- WLNOX problems cause turbine trip
- Fire in gas turbine
- Fuel flow excessive on startup x 2
- Exhaust temperature spread x 3
- Lube oil high temperature
- High P2 pressure
- Lube oil pressure loss

Conclusion

A monitoring and diagnostic system is only useful if deployed effectively. The staffing and interaction with site are key elements to achieving increased turbine reliability and availability, and ultimately reducing costs. In addition, the features of the monitoring and diagnostic system need to make it easy and efficient for staff to use.