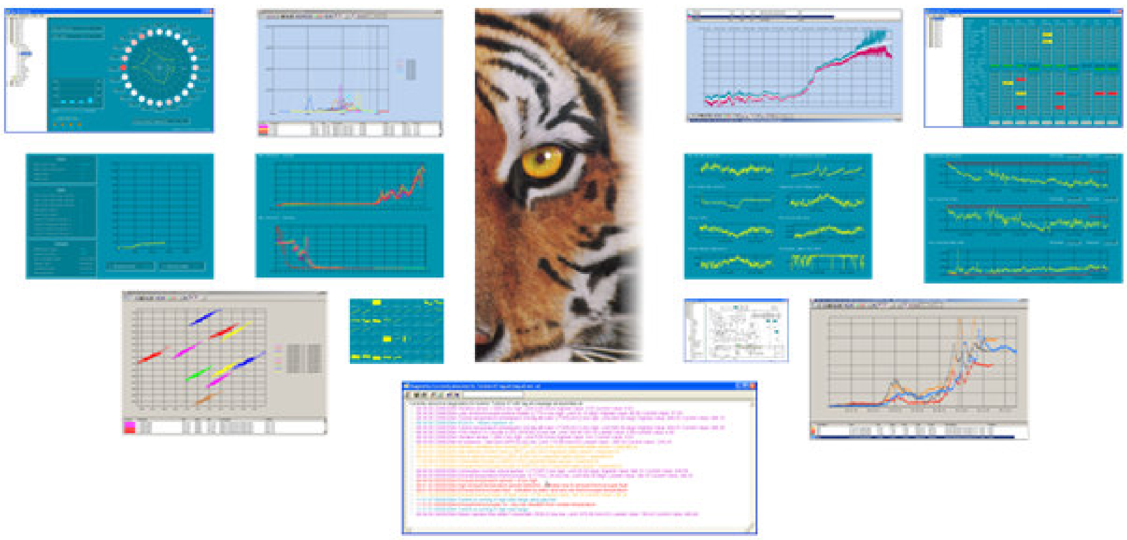
ADVANCED MONITORING AND DIAGNOSTIC SYSTEMS FOR INDUSTRIAL GAS TURBINES



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Abstract

Detecting and diagnosing faults in plant critical equipment is essential. 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 used to achieve this. It can be used on site or at remote locations.

Key problems are:

- Availability of staff for monitoring
- Filtering large quantities of data for significant events
- Identifying details of faults that require repair
- Installation and maintenance of remote diagnostic systems
- IT security issues that can limit system deployment
- Informing staff of faults and enabling fault analysis using the latest mobile technology

A remote monitoring and diagnostic system (TIGER) enables staff to identify turbine problems remotely, without the need to visit the customer site. Monitoring and diagnostics is available to plant and support staff via a remote client or a browser based web version of the system. These get data from a web server running in Glasgow, Scotland.

The web based remote monitoring and diagnostics system will also run on an I-Phone or I-Pad or an Android phone, in a standard WEB browser.

Out of hours support can be facilitated by the transmission of diagnostics via text messages to the cell phones of plant and support staff, and automatically generated diagnostic reports via email.

Two case studies describe problems that occurred on two separate GE Frame 6 gas turbine COGEN installations.

In one case the plant engineers were located two miles from the site diagnostic system data server. However, they were able to use the web based remote monitoring and diagnostics system to identify problems with the turbine.

In both cases, support company engineers were also able to analyse these problems in more detail at their office location in Glasgow Scotland, and feed this information back to staff on site, in a rapid and timely manner, avoiding any need for support staff to be sent to the customer site.

Introduction

Chromalloy Turbine Services (CTS) is a total service provider to operators of industrial gas turbines throughout the world. A key part of the service provision is to carry out repairs and maintenance work for these turbines. This can either be carried out as part of a long term service agreement (LTSA), or as required by customers.

In order to plan maintenance and repair activates efficiently, CTS utilises a proprietary remote monitoring and diagnostic system called: TIGER. This system can monitor turbines remotely using modems and phone lines, the internet or internal company networks.

Remote Monitoring and Diagnostics - Overview

Remote monitoring and diagnostics can be carried out at a centralised monitoring centre at which the staff and IT infrastructure is located to support this service. However, TIGER has a flexible client-server architecture which enables a centralised approach to be adopted if required, but also enables it to be de-centralised to any location that is able to connect a client system remotely to a server system.

This provides flexibility in the way the services are carried out and also enables staff within the turbine operating companies to use a remote client system to carry out monitoring themselves, or to view key turbine data as and when required in conjunction with the services provided by CTS. It also enables CTS staff to carry out monitoring activities wherever they are located, as long as they can connect to a system remotely.

Remote Monitoring and Diagnostics – System Architecture

The flexibility of the system is enabled via the client-server architecture. A data server system is installed at a turbine site and it acquires and archives data from the turbine controller (and possibly other sources).

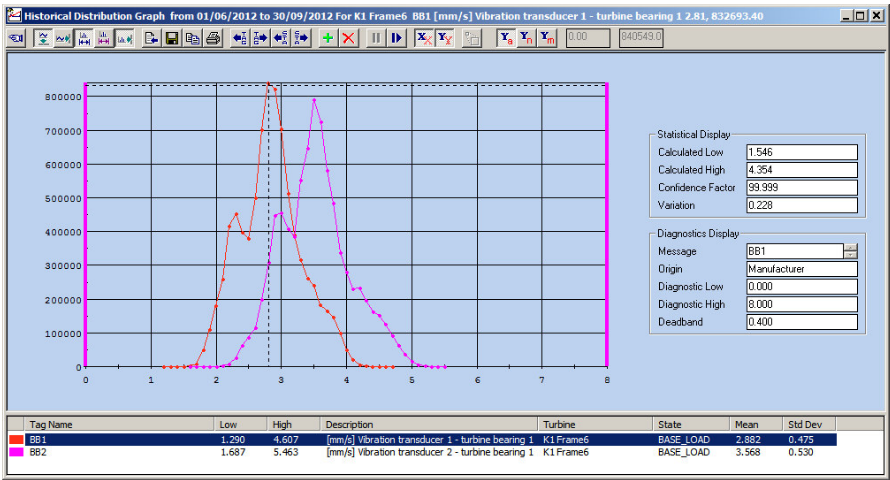
A typical data set will contain 400 analogue and 1500 digital tags which are acquired each second and analysed 24/7. It is impractical analyse all this data manually, so the data server analyses the data in real time using diagnostic rules and pre-alarm checkers, providing diagnostic messages which are also displayed and archived on site.

The diagnostic rules and checkers are comprised of standard sets that have been developed by analysing real data for many turbines over many years. (In excess of 300 turbine years of data has been collected from various sites). These diagnostics range in complexity from simple pre-alarm analogue checkers to more complex diagnostic rules using Boolean logic combined with system functions that analyse data over various specified time periods. The diagnostics are defined in parameter files that are processed by the diagnostics system engine, and addition and adjustment of these parameter files is all that is required to adjust or add new diagnostics.

In addition, each turbine has the checkers and diagnostics tuned to an individual footprint for a particular gas turbine (see Figs 1, 2, 3 and 4).

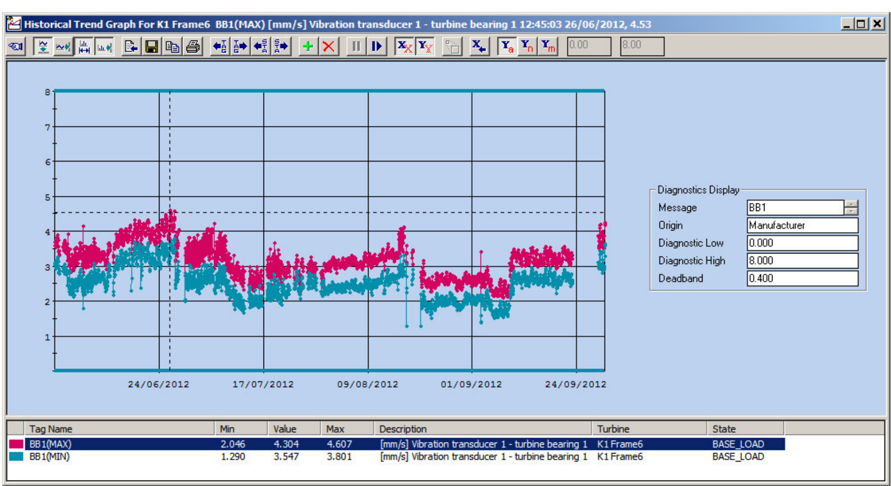
This enables diagnostic warnings (at three different and ascending fault severity levels) to be generated if the turbine starts to migrate out of this tuned envelope. The diagnostic parameters are periodically reviewed and retuned as the turbine changes with age and due to the maintenance and repair activities that are carried out over time.

Figure 1 – Distribution Graph
This graph shows the distribution of values for two bearing vibration transducers on turbine bearing 1 (BB1 and BB2) for the base load turbine run state over a period of four months. This tool enables the efficient adjustment of analogue limit checkers.



The acquisition of digital data from the controller allows the on-site data server to log and display controller alarms, and also enables diagnostic analysis of the turbine in the context of the turbine run state (start up, shutdown, base or part load, etc.) and of the detailed operation of the turbine by the control system. This also enables detailed post-mortem analysis of turbine operation to be made, which is invaluable in the analysis of turbine faults, such as turbine trips. In some cases controller alarm printer feeds are also acquired by the server, which also stores the millisecond time stamp for the alarms.

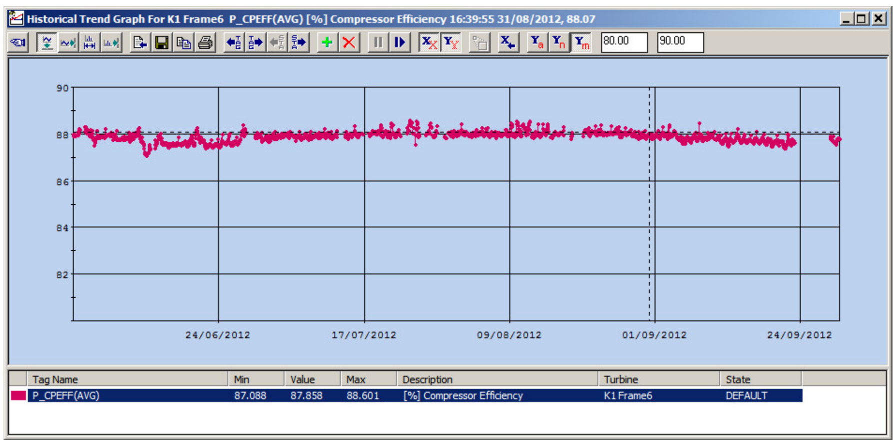
Figure 2 – MIN/MAX Trend Graph
This graph shows the MAX and MIN trend values of one of the bearing vibration transducers (BB1) for the base load turbine run state over the same period of four months. This graph can also be used to assist in the process of adjusting limit checkers.



For long term trending purposes, the data server creates trend files of all data for each day. These trend files contain the minimum, maximum and average values of the data sampled within a five minute time window. These trend files can also be used to efficiently create trends over longer periods of days, months or even years as required (see Fig 2, 3 and 4).

The average values in these trends are useful for analysing long term changes in turbine parameters, such as slow increase in vibration levels, whereas the MIN and MAX values reveal changes that occur within the five minute window that would otherwise be lost in the average data, such as a vibration spike. This can help to pinpoint unusual events and transients.

Figure 3 – AVG Trend Graph
This graph shows average trend values of the calculated compressor efficiency for the base load turbine run state over the same period of four months. This indicates a stable level of compressor performance throughout.



Another way that the system can be used to check the current footprint for the turbine is using event graphs.

Figure 4 – Start-Up Event Multi-Time Graph
This graph shows the maximum vibration levels including the critical resonance vibrations during four successive start-ups.

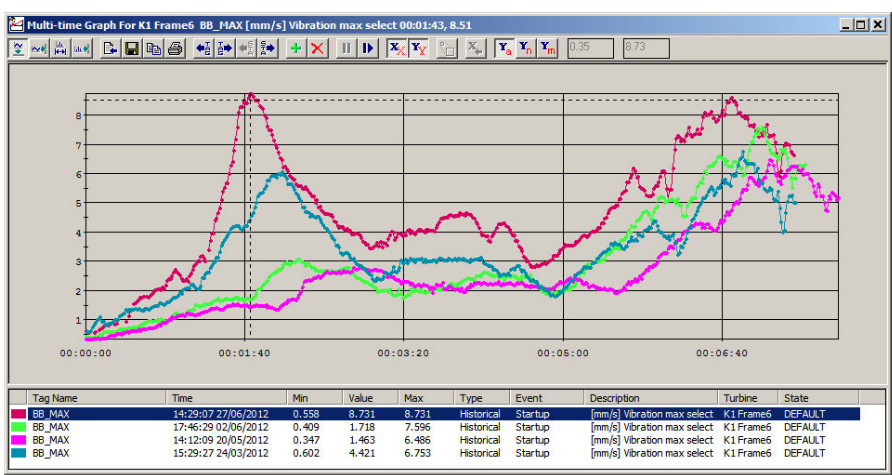
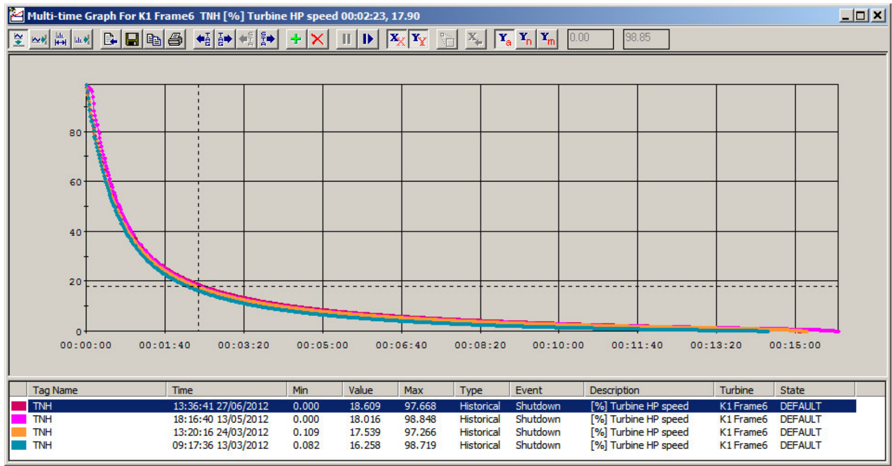


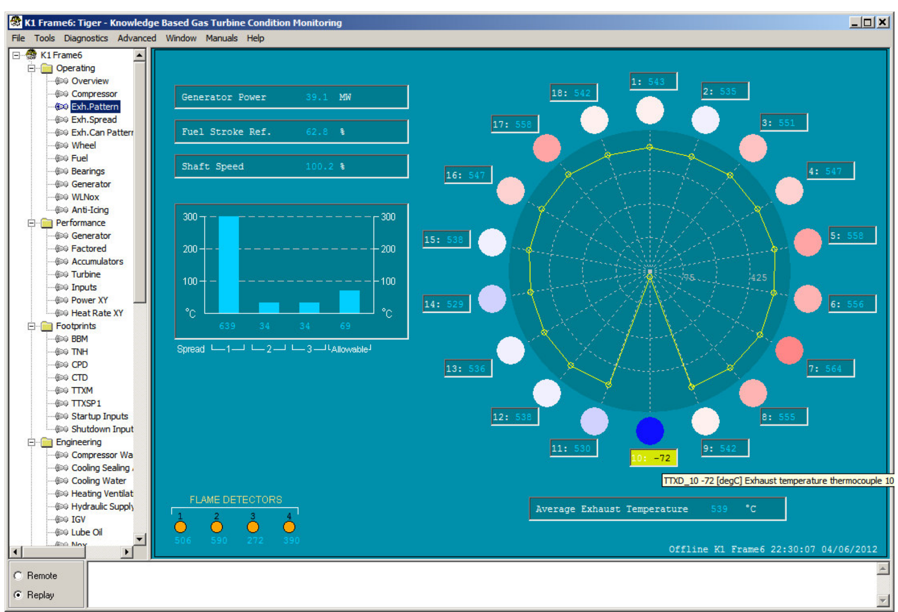
Figure 5 – Shutdown Event Multi-Time Graph
This graph shows the turbine speed profile during four successive shutdowns.



These graphs allow data from different times to be plotted on the same graph. Typical trigger events for this are turbine start-ups and shutdowns. For example, this allows the vibration profile to be checked over several previous start-ups to the current one, which enables checking for any developing vibration issues over successive start-ups. Also, the run down speed profile of the turbine can be compared for several previous shutdowns, which can indicate problems such as bearing rubs etc. (See Fig 4 and 5).

Post-mortem analysis of turbine incidents such as trips can be assisted by the data replay feature, which enables historical data to be replayed through the system and viewed and analysed, just as it occurred at the time of the actual events (see Fig 6).

Figure 6 – Data Replay - Exhaust Thermocouple Screen
This screen shows data being replayed whilst the exhaust thermocouple screen is being viewed. In this case one of the exhaust thermocouples has failed.



The replay feature is made possible as the system stores all the data in a compressed format on disc with no loss of the data resolution in time or value, so any data from the past can be replayed through the system at the original resolution.

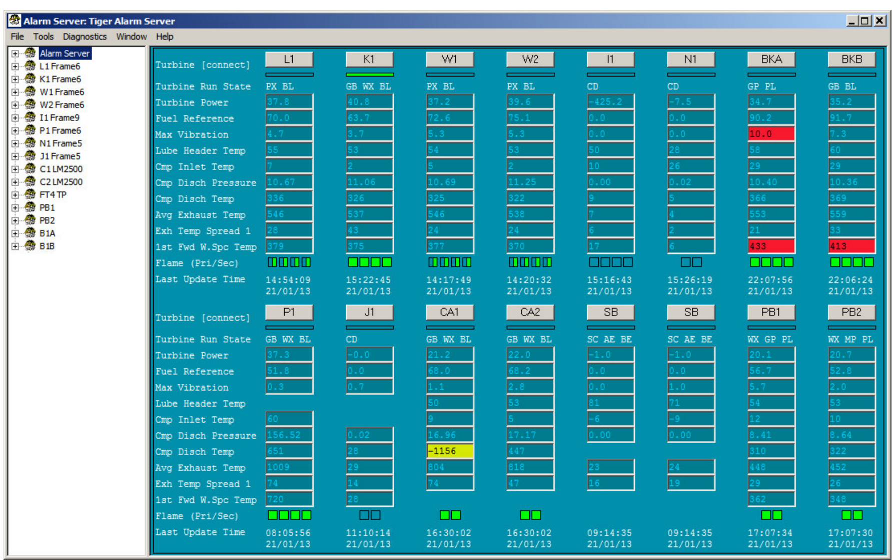
Any number of remote client monitoring and diagnostic systems can be setup to connect remotely to a data server on site. The client systems can connect within the turbine operating company using an internal LAN, or remotely via a WAN, the internet or a modem connection.

Data update rates for the remote client systems can be configured to suit the bandwidth of the connection being used. This can be in real time over LAN or internet connections, or once per hour for slow modem connections. If remote connections have limited bandwidth, the remote client systems can be configured to only download the trend data and diagnostic messages on a daily basis, which reduces the size of the data transferred to a manageable size.

Remote Monitoring and Diagnostics – Remote Server

Gas turbines are monitored worldwide using the Remote Server in Glasgow. There are two rows of turbines shown on the overview screen (see Fig 7) with a total of 16 turbines being monitored. Each turbine can be analysed in more detail using the detailed mimic screens and the various graphs and diagnostic messages for each turbine.

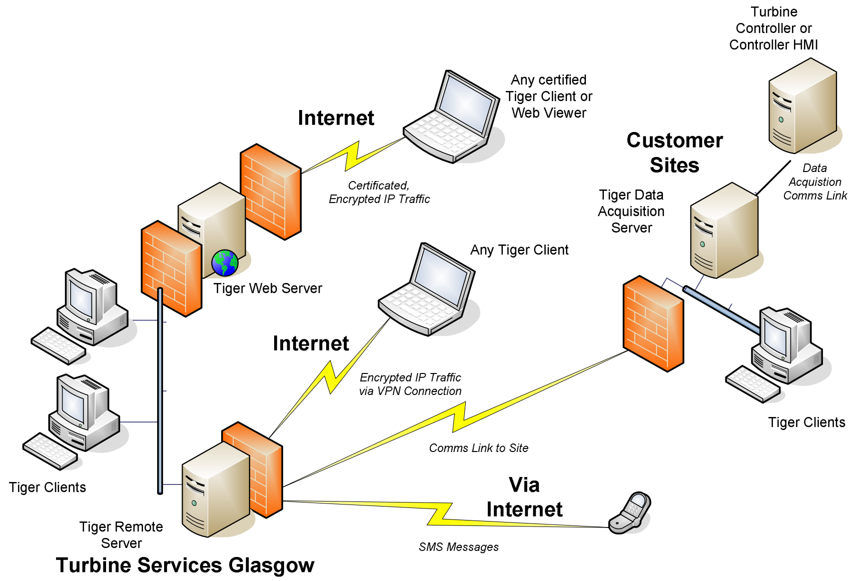
Figure 7 – Remote Server Overview Screen



To support the remote server, the client-server architecture was extended so that it can act as a client and as a server simultaneously, so it acts as a client for the onsite data servers, and connects to these at predefined time intervals to download data. It also downloads trend files and diagnostic message files each day, and stores them. Remote clients can also connect to the remote server to download data on demand, and to connect to a remote site in online mode (called remote mode) if required (see Fig 8).

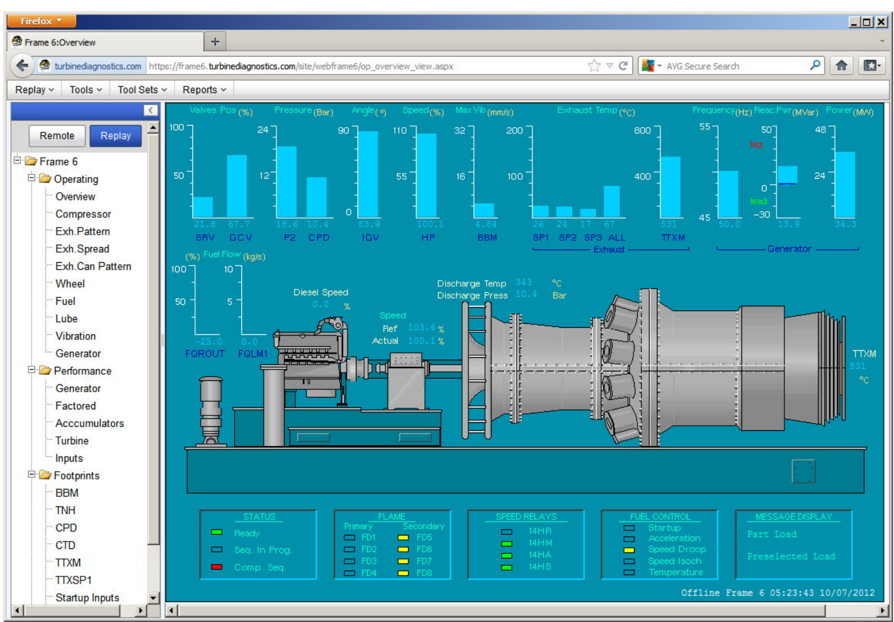
The remote server can also be configured so that selected diagnostics messages can be relayed to any number of mobile phones using SMS. In addition the system can be configured to automatically generate diagnostic reports for particular events such as trips which can be sent to selected users via email.

Figure 8 – Remote Server Network Diagram



These features ensure site support can be provided when monitoring personnel are not at a work location, for example outside of normal business hours (see Fig 8) and can be alerted automatically to turbine problems as they occur.

Figure 9 – WEB Remote Client Overview Screen in Firefox Browser



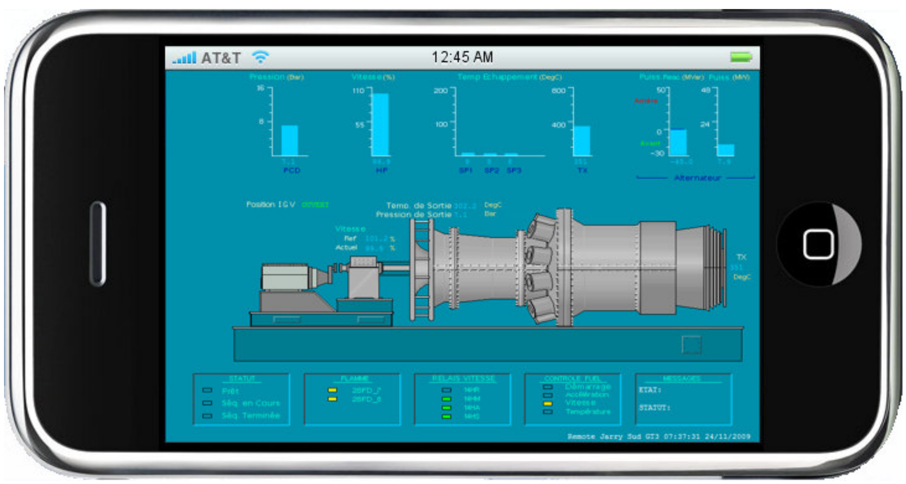
The remote server can also be interrogated via a secure web server (see Fig 9). This enables a version of the monitoring and diagnostic system to be run in a standard web browser, and via the internet this can be used to access turbine data, in the same way as if using a remote client system.

The customer or CTS engineer only needs the URL, login name and password to use this facility. This is useful when users do not wish to have the overhead of installing and maintaining remote clients on their PC's or laptops, or where there are IT security issues that prevent the use of a remote client system.

The overview screen is shown replaying data for a turbine incident (see Fig 9). It can be switched to remote mode, at which point it will connect to the turbine site and download data every second via the Remote Server in Glasgow.

The internet browser based system also enables the monitoring and diagnostic system to be run on a smartphone or tablet (see Fig 10). This enables the monitoring and diagnostics service to become fully mobile if required.

Figure 10 – WEB Remote Client Overview Screen on IPhone



Using Remote Monitoring and Diagnostics to Support Customers

The key benefit of the remote server is that the customer's turbine can be monitored remotely from the Glasgow offices, or from any other location (such as at home) where staff can connect via the internet to the remote server. This remote monitoring can also be carried out by customer staff in the same way.

To show how this benefits the customer, we describe below two case studies where remote monitoring and diagnostics were used remotely to carry out detailed analysis of turbine problems.

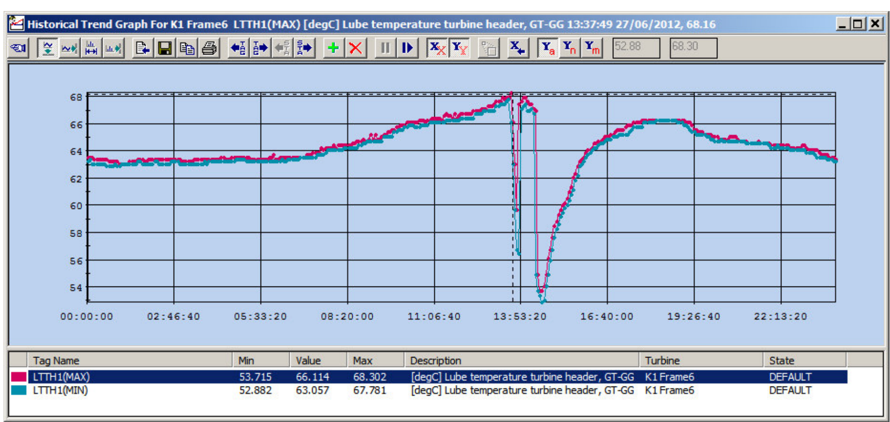
Case Study 1 - GE Frame 6 WLNOX Gas Turbine COGEN Installation

The monitoring and diagnostics system at this site has internet access for downloading data externally via firewalls. This data is downloaded to the remote server in Glasgow every five minutes. Remote client or browser based systems can also connect via the Glasgow server and get real time data direct at once per second from site via the internet link.

On 27th June 2012 at 13:30 there was a high lube oil temperature trip. The diagnostic system sent a message via SMS to the mobile phone of the on-call CTS engineer, and also an automatically generated trip report was sent via email. This showed that lube oil temperature had increased to 68 °C when the trip occurred, but diagnostic messages also indicated that there was a calibration fault on one of the high lube oil temperature trip signals.

Figure 11 - Daily Trend Graph - 27th June 2012 - Lube oil temperature

This shows that lube oil temperature is increasing up to the time of the trip. It rises again after the turbine is re-started, but increases to a lower level.

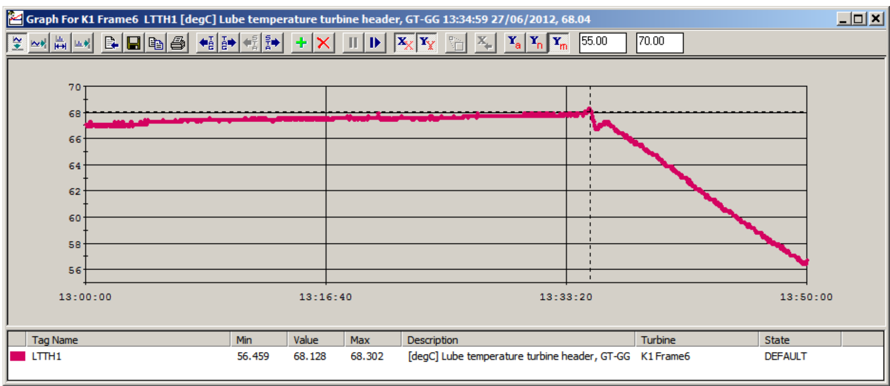


The engineer then called site, and it was agreed to re-start the turbine. The engineer then monitored the turbine as it started up using a remote client. At full speed, the operator tried to connect the generator to the grid, but this failed.

The operator then contacted the engineer by telephone for assistance. Using his remote client system, the engineer was able to see that the diagnostic system messages indicated that autosync mode had been selected, but that the auxiliary hydraulic oil pump was still running. This would prevent synchronization.

The engineer then informed operations who then manually stopped this pump. The turbine generator was then synchronised to the grid, and the unit was brought back online.

Figure 12 - Data Graph - 13:00 to 13:50 on 27th June 2012 - Lube oil temperature
This shows that lube oil temperature is increasing up to the time of the trip, and then it falls.



Diagnostic Messages – Key to Severity Levels

Critical – Red
Fault Indicators – Orange
Controller Alarms with Millisecond Time Stamp - Grey
Warning – Purple
Event – Cyan
Information – Green

Diagnostics – Turbine Trip

13:34:13 27/06/2012 Lube oil high temperature 2 - incorrect calibration
+ 13:34:14 27/06/2012 Lube oil temperature trip - bad calibration or switch fault
13:34:14 27/06/2012 Turbine trip at full speed
13:34:14 27/06/2012 Lube oil high temperature switch fault
13:34:14 27/06/2012 Lube oil high temperature above high high limit
13:34:14 27/06/2012 Trip on high lube oil header temperature - but sensor temperature below proper trip level

Diagnostics – Synchronization Problems

14:45:21 27/06/2012 Warning - auto synch selected when auxilary hydraulic oil pump is running - cannot synchronize
+ 15:17:05 27/06/2012 Matching generator to grid voltage
15:17:06 27/06/2012 15:56:48.875 FALSE T1 Q 0118 PALARM AUX HYDRAULIC OIL PUMP MOTOR RUNNING
15:17:19 27/06/2012 Failure to synchronize (L3Z) changed from 0 to 1
15:17:20 27/06/2012 15:57:03.156 TRUE T1 Q 0189 PALARM FAILURE TO SYNCHRONIZE
15:17:26 27/06/2012 Master reset (L86MR1_CPB) changed from 0 to 1
+ 15:17:37 27/06/2012 Generator connected to grid - circuit breaker closed

Case Study 2 - GE Frame 6 DLN Gas Turbine COGEN Installation

The monitoring and diagnostics system at this site has modem access for downloading data externally. This data is downloaded to the remote server in Glasgow every hour. In addition, remote systems (client or browser based) can connect via the Glasgow server and get real time data direct from site via the modem link.

On 10th July 2012 operations reported to the site engineers that there had been a combustion problem and a high exhaust temperature spread alarm at 05:30. As a result, at 05:36 they had switched the turbine to lean-lean combustion mode, which appeared to solve the combustion problem and reduced the spreads.

The site engineers are based several miles away from the gas turbine control room in another part of the plant. Site IT security policy does not allow the use of remote client systems on laptops and PC's, so to investigate the site engineers used the WEB browser version of the monitoring and diagnostics system to look at current data for the turbine remotely and also to replay the event at 05:30 when the problem had occurred.

It appeared that combustion had become unstable just before this which may have caused a partial flameout of combustion on can 7, 8 and 9. The site engineers decided that they would ask operations to switch the turbine back to DLN premix combustion mode, and see if the combustion problem re-occurred.

However, before doing this they contacted the CTS engineers in Glasgow for a second opinion. The CTS engineers used a remote client system to look at current data for the turbine remotely and also to replay the event at 05:30 when the problem had occurred.

On investigation, it appeared that combustion temperatures on combustion cans 7, 8 and 9 had suddenly dropped, and the control system had compensated for this by increasing fuel flow to maintain turbine power at the pre-selected load of 34 MW. This had also increased exhaust temperature spread from 30 to 70 °C, above the spread alarm limit of 68 °C.

Having analysed the data, the CTS engineers agreed with the site engineers that this was most likely a temporary combustion problem. They agreed to monitor the turbine in real time from Glasgow as operations switched the turbine back to DLN premix mode.

Operations switched the turbine back to DLN premix mode at 10:12. It then appeared that the combustion problem had cleared. The turbine was then monitored by site and CTS engineers for any reoccurrence of this problem.

WEB Browser Trend Graphs – 9th and 10th July 2012

Figure 13 - Graph of exhaust temperature spreads

This shows a peak at 05:30, which then drop after the turbine was switched to lean-lean combustion mode. When the turbine is goes back to premix combustion mode at 10:12, spreads increase slightly, but are then much lower than before.

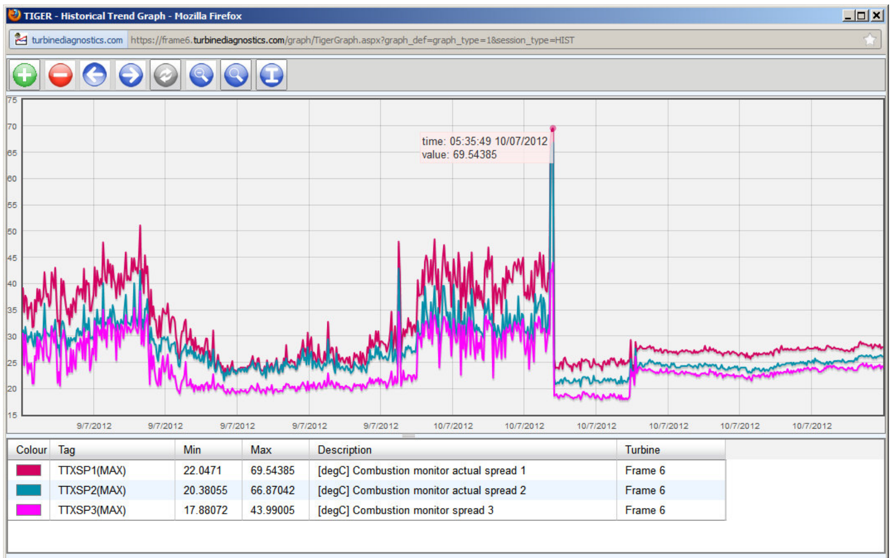


Figure 14 - Graph of flame detector levels

This shows the primary flame detectors detecting flame during the time that the turbine was in lean-lean mode. No loss of flame was detected.

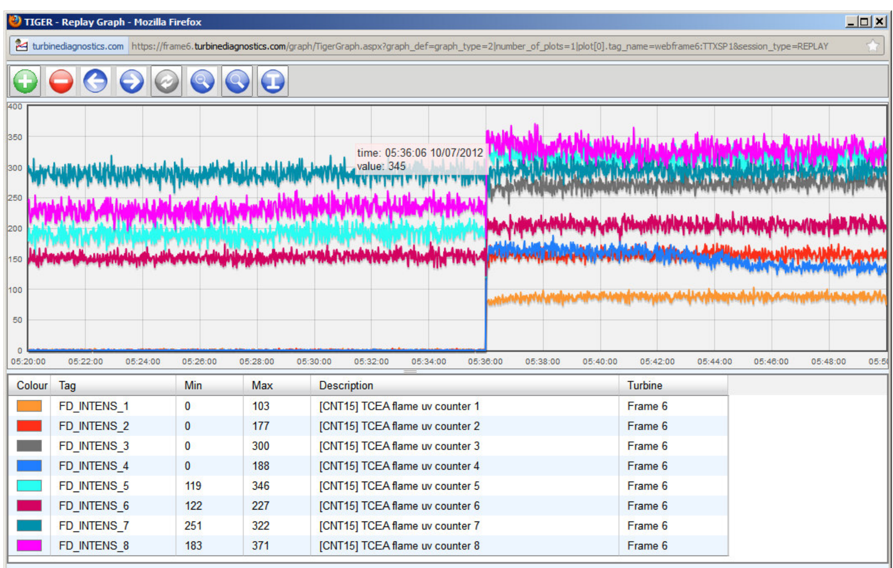
WEB Browser Data Graphs – 05:20 to 05:50 on 10th July 2012

Figure 15 - Graph of exhaust temperature spreads

This shows a sudden increase at 05:28. The spreads then drop when the turbine is switched to lean-lean mode at 05:36.

Figure 16 - Graph of flame detector levels

This shows flame is detected in the primary zone when the turbine is switched to lean-lean mode at 05:36. No loss of flame is detected.



WEB Browser Exhaust Thermocouple Pattern Screens

Figure 17 - Before combustion problem

Data from a replay shows that just before the combustion problem, spreads are low.

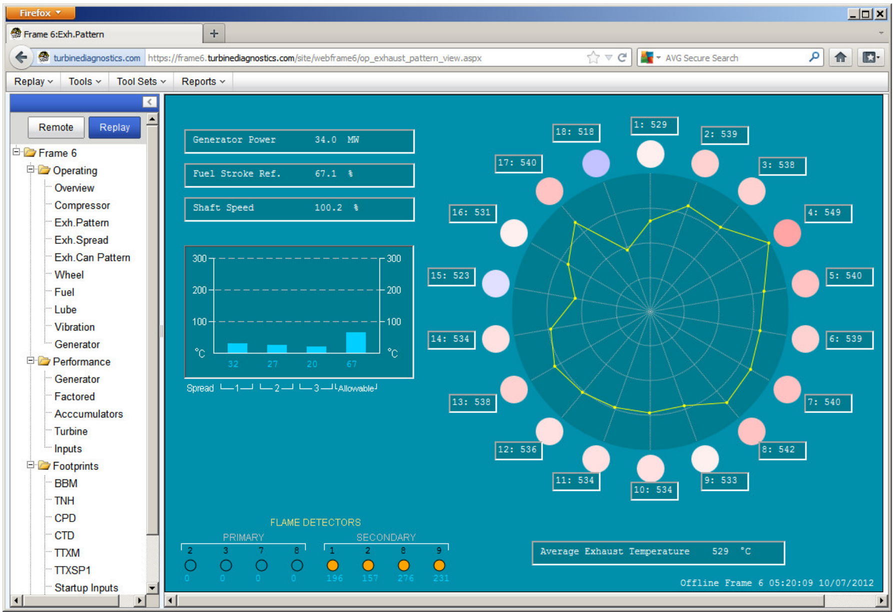
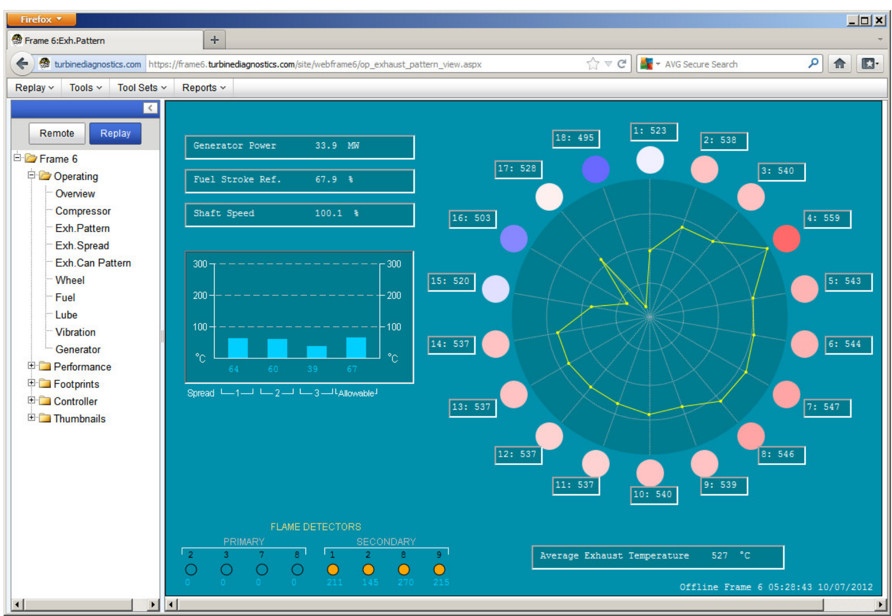


Figure 18 - During combustion problem

Data from a replay show that when the combustion problem starts a colder combustion area develops around exhaust thermocouples 15, 16, 17, 18 and 1.



WEB Browser Estimated Exhaust Can Temperature Pattern Screens

Figure 19 - Before combustion problem

Data from a replay shows that just before the combustion problem, the combustion temperature pattern is quite smooth.

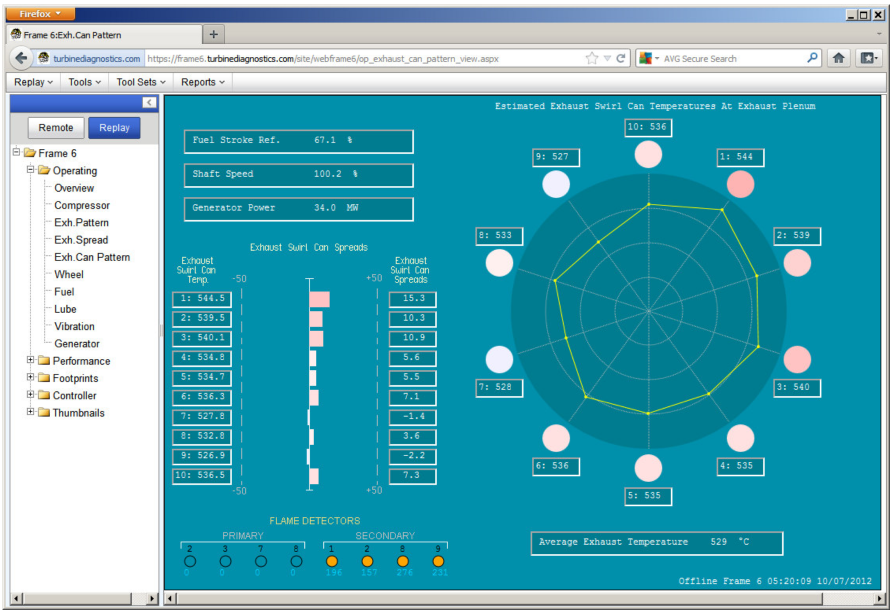
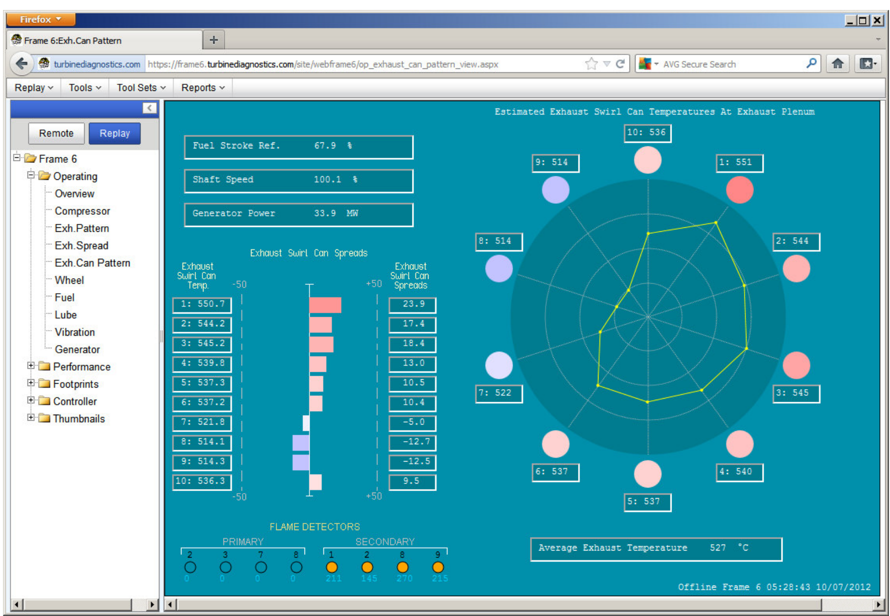


Figure 20 - During combustion problem

Data from a replay shows that when the combustion problem starts colder combustion develops on combustion cans 7, 8 and 9.



Note, the monitoring and diagnostics system estimates the combustion can temperatures by applying the exhaust swirl angle for the current power output and combining this with the interpolated exhaust thermocouple temperatures. This enables a quick identification of faulty combustion cans, and also helps to differentiate combustion from thermocouple problems.

Diagnostics – Combustion Problem

05:20:09 10/07/2012 Turbine is running in low load range
+ 05:22:57 10/07/2012 Exhaust temperature - rapid decrease
+ 05:24:29 10/07/2012 Exhaust temperature - rapid decrease
05:28:39 10/07/2012 Turbine significant power drop detected
05:28:40 10/07/2012 Exhaust thermocouple 16 - low below median temperature
05:28:41 10/07/2012 Compressor discharge temperature - rapid decrease detected
05:28:41 10/07/2012 Exhaust thermocouple 18 - low below median temperature
05:28:42 10/07/2012 Exhaust thermocouple 18 - very low below median temperature
+ 05:28:44 10/07/2012 Exhaust temperature - significant oscillation detected
05:29:04 10/07/2012 Exhaust thermocouple 16 - low below median temperature
05:29:05 10/07/2012 Exhaust thermocouple 18 - very low below median temperature
05:29:11 10/07/2012 Exhaust thermocouple 18 - low below median temperature
05:29:17 10/07/2012 Exhaust thermocouple 16 - low below median temperature
05:29:27 10/07/2012 Exhaust thermocouple 16 - low below median temperature
05:29:28 10/07/2012 Exhaust thermocouple 18 - very low below median temperature
05:29:29 10/07/2012 Exhaust thermocouple 16 - very low below median temperature
05:29:42 10/07/2012 Exhaust thermocouple 18 - very low below median temperature
05:29:49 10/07/2012 Exhaust thermocouple 18 - very low below median temperature

Conclusion

The two case studies detailed above show how the remote monitoring and diagnostics system enabled CTS and site engineers located off site to carry out detailed monitoring of turbine status, and that they could be alerted even if away from the work place to developing problems in a timely manner.

The monitoring and diagnostics system was also able to identify key problems from a large data set, and via a sophisticated diagnostic and messaging system could automatically alert monitoring personnel via remote system clients, emailed reports and SMS messages to mobile phones.

The comprehensive graphing systems and data replay feature provided also supported ongoing and more detailed analysis of the problems, enabling identification of the details of the faults.