GAS TURBINE PEAKING UNITS – PROBLEMS AND SOLUTIONS FOR MONITORING AND DIAGNOSTIC SYSTEMS

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Abstract

Detecting and diagnosing faults in plant critical equipment is vital. Early detection can provide significant benefits including the avoidance of unscheduled outages and possible equipment damage, and ensure that turbines can be started reliably when despatched. A monitoring and diagnostic system is a vital tool used to achieve this. It can be used on site or at remote locations.

When used to monitor peaking units, there are different issues to address as compared to base load units.

Key problems are:

- Location and availability of staff for monitoring
- Filtering data for significant events
- Identifying details of faults that require repair
- Installation and maintenance of remote diagnostic systems
- Informing staff of faults and enabling fault analysis using cell phone technology
- Providing reports on turbine runs and start-up and shutdown problems
- Distributing reports via email to remote staff
- Ensuring turbines are ready to start when required

A remote monitoring and diagnostic system can enable staff to identify turbine problems remotely, without visiting the customer site. Monitoring and diagnostics can be made available to plant and support staff via a remote client or a browser based web system. These get data from a web server running at a remote location. This system can also generate reports automatically for turbine start-ups, shutdowns and trips and also for a complete turbine run. These can be distributed to key staff via email. They can also be informed via cell phone messaging of key events, such as start-ups and trips.

A case study where this system has been recently deployed to monitor a fleet of gas turbine peaking units is described. This fleet of turbines includes turbines of different types and manufacturer with a variety of different control systems. The key issues involved in the deployment and solutions adopted are described.

A second case study of how the monitoring system was used to analyse a serious combustion fault on another peaking turbine is also described, along with the consequential actions and repair work carried out.
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 its own remote monitoring and diagnostic system called TIGER. This system can monitor turbines remotely using modems and phone lines, the internet or internal company networks.

The system is also available to customers who wish to carry out the monitoring activity themselves. They can use the system in a similar way to CTS staff, but use their own engineering expertise and have their own arrangements for repair and maintenance of their turbines.

As the system is independent of the turbine manufacturers it can be deployed in any way that suits a particular customer, rather than what might suit an OEM. Also, it can be used across a wide variety of gas turbine makes and models, and other plant if required. As an example a power utility customer in the USA has a fleet of gas turbines including the following types:

- GE Heavy Duty
- Pratt and Witney Aero-Derivative
- Siemens Heavy Duty

These are all peaking units, and the customer has an interface to the CTS servers in Glasgow via the internet to monitor the units remotely themselves. In addition the system is setup to send diagnostic messages to their cell phones and to email reports direct to their staff.

Remote Monitoring and Diagnostics - Overview
TIGER has a flexible client-server architecture which enables a centralised monitoring centre to be used, but monitoring can also to be de-centralised to any location that is able to connect a client system remotely to a server system. The system can also support a remote client running in a web browser, if required.

This system architecture provides flexibility in the way the monitoring is 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).

Any number of remote client systems can be setup to connect 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 at the systems data collection rate of one sample per second 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.

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

**Diagnostic System**
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 550 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 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 FIG 1, 2, 3 and 4 below).

**Figure 1 – TIGER 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 system can generate diagnostic warning messages (at three colour coded ascending fault severity levels) to be generated if the turbine starts to migrate out of this tuned envelope, or if a fault occurs. 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. The system can also be setup to calculate turbine performance parameters such as compressor efficiency, or corrected power and heat rate.

The acquisition of digital data from the controller allows the on-site data server to log and display controller alarms, and enables diagnostic analysis of the turbine in the context of the turbine run state (e.g. start up, shutdown, base or part load) and of the detailed operation of the turbine by the control system. This is particularly important for peaking units, as these units are frequently being run through successive turbine run states.

The collection of the controller digital data 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 store the millisecond time stamp for the alarms, thereby enabling the determination of first-out alarms within the one second data sample rate.

**Trending**
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).

**Figure 2 – Trend Graph – MIN/MAX**
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 as the distribution graph above) of four months. This graph can also be used to assist in the process of adjusting limit checkers and other diagnostics. Note the gap in the data is for a period when the turbine was on shutdown and therefore not running in base load.

The average trend values are useful for analysing long term changes in turbine parameters, such as slow increase in vibration levels, whereas the MIN and MAX values can reveal changes that occur within the five minute trend data sample window that would otherwise be lost in the average data, such as a vibration spike. This helps to pinpoint unusual events and transients.
Figure 3 – Trend Graph - AVG
This graph shows average trend values of the calculated compressor efficiency for the base load turbine run state only over the same period of four months. This indicates that efficiency increased after the shutdown period. This was because the shutdown was for a maintenance outage when repair work and compressor cleaning was carried out. Note the gap in the graph is when the turbine was not running on base load, and was shut down for the outage.

Multi-Time Event Graphs
Another way that the system can be used to check the current footprint for the turbine is using event graphs. Typical events would be start-ups, shutdowns and trips. Data for different time periods can be plotted on the same graph, allowing comparisons to be made.

Figure 4 – Multi-Time Graph - Start-Up Events
This graph shows the maximum vibration levels including the critical resonance vibration peaks during four successive start-ups. The graph shows that there was higher vibration during one of these start-ups.

The example above shows the comparison of vibration profiles over several previous start-ups to the current one, which enables checking for any developing vibration issues over successive start-ups.
Figure 5 – Multi-Time Graph - Shutdown Events
This graph shows the turbine speed profile during four successive shutdowns. This shows flame-out occurred later on some of these shutdowns.

The example above shows how the run down speed profile of the turbine can be compared for several previous shutdowns, which can indicate problems such as bearing rubs.

This tool is particularly important for turbines that are run as peaking units, as start-ups and shutdowns can be frequent events.

Data Replay
Post-mortem analysis of turbine incidents such as trips can also 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).

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 of one sample per second.
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.

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 each overview screen (see FIG 7) with a total of 30 turbines being monitored on two overview screens. 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 1

To support the remote server, the client-server architecture was extended so that it can act as a client and as a server simultaneously. The remote server 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. The remote server can also be configured so that selected diagnostics messages can be relayed to any number of cell phones using SMS or email (see FIG 8 below).

In addition the system can be configured to automatically generate diagnostic reports for particular events such as trips or turbine run reports (for peaking units). These can be sent to selected users via email.

**Figure 8**

The system features described above ensure site support can be provided when monitoring staff are not at a work location, for example outside of normal business hours or for distributed peaking turbines which do not have full time engineering staff present at each gas turbine site. Staff at remote locations can be alerted automatically to turbine problems and events as they occur.

The key benefit of the remote server is that the customer’s turbine can be monitored remotely from any 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.

**WEB Based Client**

The remote server can also be interrogated via a secure web server. This enables a version of the monitoring and diagnostic system to be run in a standard web browser (see FIG 9 below) 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, or if the remote system is running on a tablet or smart-phone.

The overview screen is shown below (FIG 9) in remote mode running in a Firefox web browser. It is displaying live data for a turbine on site. The data from the turbine site is downloaded every second via the Remote Server in Glasgow. This can be switched to replay mode at any time and data downloaded and replayed for any specified time period. This enables analysis remotely of turbine incidents after they have occurred.

**Figure 9 – WEB Remote Client Overview Screen in Firefox Browser**

![Remote Client Overview Screen in Firefox Browser](image)

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**

![Remote Client Overview Screen on IPhone](image)
Case Studies
The first case study describes how this system has been recently deployed to monitor a fleet of gas turbine peaking units. The second case study describes how the system was used to diagnose a serious combustion problem that occurred on a GE Frame 6 peaking unit.

Case Study 1 – Deploying a Monitoring and Diagnostic System
This fleet of turbines in the USA is operated by a power utility company and includes turbines of different types and manufacturer with a variety of different control systems.

Hence one of the major issues to be addressed for this customer was to provide a uniform remote monitoring system for all the different types of gas turbines in their fleet, plus some additional plant.

Another issue of concern to them was a wide geographical spread of turbine sites, over about 200 miles. A remote monitoring system addresses this problem, and enables engineering expertise to be applied remotely to fix turbine problems, obviating the need for time consuming trips by engineers to remote plants. This process was made more effective by the ability to remotely replay data for an event such as a turbine trip, a powerful aid in diagnosing turbine faults.

Also as these turbines are peaking units it was imperative for plants to be ready to start when despatched, and when run to provide maximum information to widely and thinly spread engineering staff on the performance of the plant in terms of plant output, fuel usage and any problems and faults identified during each run.

To address these issues ready to start indicators were added to all the plant overview screens (See FIG 11) and customised run reports were also added to the system. These and other automatically generated reports were setup so the system would email these automatically to designated staff, and turbine status messages would be sent to their cell phones.

Figure 11 – Alarm Server Overview Screen with all Turbines Ready to Start
Key Issues Involved in System Deployment

1. Interfacing to three different types of control system
2. Creating UI screens for five different types of gas turbine
3. Creating diagnostics for five different types of gas turbine
4. Creating custom reports for five different types of gas turbine
5. Setting up remote access via a remote client or web browser to the gas turbines
6. Setting up cell phone message notification for the gas turbines

Interfacing to Three Different Types of Control System
The three different types of control systems in use were:

- GE Mark 6 – for Frame 7E and Frame 5 gas turbines
- Siemens Teleperm T3000 – for SGT6-4000F and SGT6-5000F4 gas turbines
- Woodward – for Pratt and Witney FT4 Twin gas turbines

Interfacing to GE Mark 6 Controllers
The solution adopted was to use the GE EGD system. The EGD system broadcasts tag data from the controller via the gas turbine controller Ethernet network. To acquire the data for the TIGER system in a secure manner, a firewalled connection between the TIGER PC and this network was setup. For maximum cyber-security the firewall was setup to only allow the EGD data packets to be broadcast out through this firewall on one port and one IP address. All other ports and IP addresses on the firewall were blocked (See FIG 12 below).

Figure 12 – Site Network Diagram for GE Mark VI with EGD

The TIGER PC also had a connection out to the Internet via another firewall. This was setup to allow data to be transmitted out via one port and IP address to a fixed external port and IP address via a secure and encrypted tunnel with all other ports and IP addresses blocked. This external IP and port was setup on the firewall for the TIGER servers in Glasgow, Scotland, and this allowed through the data traffic to the servers there. This then enabled remote access to the turbine data by any customer staff either using a remote client or a web browser via the firewalled Glasgow servers internet interface.
Interfacing to Siemens Teleperm T3000 Controllers
The solution adopted was to use the Siemens OPC system. Tag data was acquired from the controller using the OPC server via the gas turbine controller Ethernet network. To acquire the data for the TIGER system in a secure manner, a firewalled connection between the TIGER PC and this network was setup.

For maximum cyber-security the firewall was setup to only allow in OPC data requests and OPC data packets out using the Matrikon OPC tunnel through this firewall on one port and one IP address. All other ports and IP addresses on the firewall were blocked.

The TIGER PC also had a connection out to the Internet via another firewall to the Glasgow servers. This was setup in the same way as described above (see FIG 13 below).

Figure 13 – Site Network Diagram for Teleperm T3000 with OPC Tunnel

Interfacing to Woodward Controllers
The solution adopted was to use the Woodward OPC system. Tag data is acquired from the OPC server via the gas turbine controller Ethernet network. To acquire the data for the TIGER system in a secure manner, a firewalled connection between the TIGER PC and this network was setup.

For maximum cyber-security the firewall was setup to only forward outbound the data through this firewall on one port and one IP address. All other ports and IP addresses on the firewall were blocked.

The TIGER PC also had a connection out to the Internet via another firewall to the Glasgow servers. This was setup in the same way as described above (see FIG 14 below).
Creating UI Screens for Five Different Types of Gas Turbine

The TIGER system has a system called MVIEWS for setting up a set of screen interfaces. This system is implemented via parameter files which are configured as required, and does not involve additional code being added to the TIGER system, unless new screen widgets are needed.

For gas turbines that are similar to other systems that have been installed previously, these screens are created by basing them on existing parameter files which are modified as required. For new turbine types the screens are newly created.

For this customer only the screens for the Siemens SGT6-4000F and the Pratt and Witney FT4 Twin were newly created. The screens for the GE Frame 7E and Frame 5 turbines were created by modifying screens that had been created previously for similar installations.

Creating Diagnostics for Five Different Types of Gas Turbine

The TIGER diagnostic system is comprised of different types of checkers, from simple limit checkers to more complex diagnostics involving Boolean logic spanning defined time intervals.

This system is implemented via parameter files which are configured as required, and does not involve additional code being added to the TIGER system, unless new diagnostic constructs are required.

The diagnostics are also structured into three different levels in a hierarchy which are:

- Turbine manufacturer
- Turbine class
- Specific for a particular gas turbine

A configuration build process is used so that diagnostics from the relevant levels in the hierarchy are used to build an individual turbine configuration. Each lower level in the
hierarchy will override the same diagnostic that occurs at a higher level. For example, this means that an analogue checker at the manufacturer level will be overridden by one at the class level, and that this will also be overridden by one specific for a particular turbine. Additional diagnostics can also be added if required at any of the levels.

An example of this hierarchy could be: GE Heavy Duty -> Frame 5 -> My Frame 5 Turbine

This means that generic diagnostics can be used when appropriate, but specific versions can be created if required. See FIG 15 below for a schematic illustrating how this works.

**Figure 15 – Configuring Turbine Diagnostics**

For this customer, only the diagnostics for the Siemens SGT6-4000F and the Pratt and Witney FT4 Twin were newly created. The others used diagnostics previously setup for similar installations, which were then added to and adjusted as required.

**Diagnostics Tuning**

In addition, turbine data was acquired over time and used to tune the existing diagnostics. This tuning process was carried out using a combination of distribution graphs, trend graphs and historical diagnostics for an extended period of time, usually a minimum of one month of data. This enables limit checkers and other diagnostics to be adjusted to fit the normal operating profile for the turbine (see FIG 16 and 17 below).

**Figure 16 – Distribution Graph – Manufacturer Limit**
The distribution graph above shows four months of data for the lube oil header temperature for base load. As can be seen below, the data distribution slightly exceeds the current manufacturer analogue checker limit of 143 °F.

**Figure 17 – Distribution Graph – Specific Limit**

![Distribution Graph](image)

The distribution graph above shows four months of data for the lube oil header temperature for base load. As can be seen below, a turbine specific analogue checker limit has been added with a slightly higher top limit of 148 °F.

**Creating Custom Reports for Five Different Types of Gas Turbine**

As these gas turbines are all peaking units, the customer was particularly interested in reports that recorded an entire turbine run. TIGER reports are setup to be automatically generated in MS Word or PDF format and are triggered by specific events such as start-ups, shutdowns and trips.

**Turbine Run Reports**

A run report is setup to be initiated at the start of a turbine run and created at the end of the run. These were customised to add additional information specifically requested by the customer, including total fuel consumption and power generation. The reports were then setup to be automatically sent by email to designated staff. A report for a particular event can also be manually selected when required from the TIGER UI, and then automatically created (see FIG 18 below).

**Figure 18 - Excerpts from an Automatically Generated Run Report**

```
Run Stats
Starter Motor Time Off .......................................................... 09:59:45 13/08/2014
Generator Breaker Time On ...................................................... 09:57:25 13/08/2014
Generator Breaker Time Off ..................................................... 21:10:59 13/08/2014
Turbine Firing ......................................................................... 09:48:14 13/08/2014
Total Run Time ................................................................. 11:43:17
Total Gas Fuel Used (MCF) .................................................. 7505.13
Total Liquid Fuel Used (gallons) ........................................... 0.00
Total Power (MWATT Hours) .............................................. 697.54
```
Turbine Monthly Reports

The customer was also interested in reports that summarised turbine run data on a monthly basis. These reports were setup to be automatically generated in Excel format and are triggered at the month end.

The reports were customised to add additional information specifically requested by the customer, including total fuel consumption and power generation etc. The reports were then setup to be automatically sent by email to designated staff.

Given the customer’s wide geographical distribution of power plants, this feature enables the easy centralisation and combination of key plant data to be fed into the customer’s management information system, facilitating better management of the various power plants (see FIG 19 below).
Figure 19 - Excerpt from an Automatically Generated Monthly Report

Setting up Remote Access Via a Remote Client or Web Browser to the Gas Turbines
Once the communications pathway has been setup (as described previously) and the Glasgow server has been setup for the customer turbines, the customer is simply issued a URL and login name and password to setup a remote connection to a gas turbine via a web browser. The web browser interface involves no software setup for the customer, and contains the same functionality, such as the ability to view live data or replay old data.

To setup a remote client, a TIGER system needs to be installed on the customer PC or laptop, licensed and then setup up with a valid certificate to enable communications. Once this is done, all the same functionality is available as is available on site. In addition, any updates made to the software will be transmitted to the remote clients, ensuring that remote users are kept up to date with the latest versions of the software.

Setting Up Cell Phone Message Notification for the Gas Turbines
To setup a remote cell phone messaging, the message trigger and the cell phone numbers are added to parameter files for the turbine on the Glasgow server.

Figure 20 – Example of Text Message Sent to a Cell Phone
GT1 21:19:03 13/08/2015 R_FLAMEOUT0,1 Turbine Flameout
Case Study 2 – Hard Re-Ignition Incident

This turbine is part of a CHP installation in a chemical plant. It is being used as a peaking unit at present. It is a GE Frame 6B with DLN1, running on gas fuel and the turbine is maintained by CTS under a LTSA contract. The TIGER system is installed and is used as part of the support package for the customer and the turbine is monitored remotely at the CTS offices in Scotland using a secure TIGER data feed via the internet.

The incident occurred at about 2.30 pm on 19th June 2015. The plant operator contacted CTS staff to report that as the turbine was being shutdown, there was a loud bang which shook the control room:

"as the unit was at approx. 26MW and falling there was a severe shudder felt in the Control Room / Office block *

CTS staff then used the TIGER replay feature to replay the shutdown as it had occurred. By analysing the diagnostic messages and also looking at the temperature pattern shown on the UI screens, it was clear that as the turbine was being shutdown there was a transient combustion problem on combustion cans 1 and 10. This occurred as the turbine transferred from premix mode to lean-lean mode which is a normal shutdown sequence.

Figure 21 – Exhaust Thermocouple Pattern Screen

This indicates poor combustion detected by thermocouples 6, 7 and 8.

The DLN1 combustion system uses two combustion nozzles, the primary one at the upstream end of the can and the secondary one at the downstream end of the can. In pre-mix mode only the secondary nozzle is ignited, with the primary not ignited but supplying gas fuel.

Analysis indicated that as the fuel was ramped down during the shutdown the combustion switched automatically from pre-mix combustion mode to lean-lean combustion mode with the primary and secondary fuel nozzles both supplying gas fuel. At this point combustion can 1 and 10 may have flamed out.
This was indicated on the combustion can pattern screen (FIG 22 below) which is calculated by TIGER using the exhaust swirl for the turbine load and interpolating the thermocouple temperatures values with respect to their swirl position.

**Figure 22 – Estimated Combustion Can Temperature Pattern Screen**

This indicates poor combustion on combustion on can 1 and 10.

As the cross fire tubes will only work on the primary fuel nozzles and not on the secondary fuel nozzles, these cans lost flame for two or three seconds during which time a significant amount of unburnt gas fuel was dumped into the cans.

Eventually the primary fuel nozzles in can 1 and 10 ignited via the cross fire tubes and then all the gas in the cans ignited, causing the noise and vibration reported by the operators – a hard re-ignition. After this point the turbine shutdown sequence switched to primary combustion mode and then continued to shut-down normally.

The combustion problems were also indicated by the graphs and diagnostics (See FIG 23, 24 and 25 below).

**Figure 23 – TIGER Diagnostics**

Diagnostic messages indicate combustion problems.

- 14:24:46 19/06/2015 Flame Detected - Primary Zone
- 14:24:47 19/06/2015 Exhaust Temperature Spread (C_TSPREAD) too high. Limit 50.00 degCR
- 14:24:47 19/06/2015 DLN Lean-Lean Combustion
- 14:24:47 19/06/2015 DLN Premix Combustion ended
- 14:24:47 19/06/2015 Combustion problem - area of very low combustion temperature detected
- 14:24:47 19/06/2015 Exhaust Can 1 Temperature Spread (C_TCCANDIFF1) too low. Limit -25.00 degCR
- 14:24:47 19/06/2015 Exhaust Temperature Spread TC 7 (C_TCS7P) too low. Limit -30.00 degCR
- 14:24:47 19/06/2015 Exhaust Temperature Spread TC 8 (C_TCS8P) too low. Limit -30.00 degCR
- 14:24:47 19/06/2015 Exhaust thermocouple 7 - very low below median temperature
14:24:47 19/06/2015 Exhaust thermocouple 8 - low below median temperature
14:24:47 19/06/2015 Combustion problem - adjacent thermocouples have very low temperatures
14:24:47 19/06/2015 Combustion problem - thermocouple 7 and adjacent thermocouple temperatures are very low
14:24:48 19/06/2015 Exhaust thermocouple 8 and 9 diverged for 1 seconds by more than 30.00
14:24:49 19/06/2015 DLN Lean-Lean Combustion ended
14:24:50 19/06/2015 DLN Secondary Transfer Combustion
14:25:04 19/06/2015 DLN Secondary Transfer Combustion ended
14:25:04 19/06/2015 DLN Lean-Lean Combustion
14:26:09 19/06/2015 DLN Primary Combustion
+ 14:26:09 19/06/2015 DLN combustion transferred from Lean Lean to Primary
14:26:09 19/06/2015 DLN Lean-Lean Combustion ended
14:26:11 19/06/2015 Turbine Flameout - Secondary Zone

Figure 24 – Graph of Exhaust Thermocouples and Average Exhaust Temperature

This data (at one sample per second) indicates poor combustion was detected by thermocouples 6, 7 and 8 for 2 or 3 seconds.

Figure 25 – Graph of Estimated Exhaust Can and Average Exhaust Temperature

This data (at one sample per second) indicates poor combustion was detected on combustion can 1 and 10 for 2 to 3 seconds.
Here is an extract from the engineering report to the customer:

“The load reduces to below 26 MW and the combustion process becomes inefficient. Combustion inefficiency causes load to fall further until TTRF is reached for transfer initiation. During the period pre-transfer from Premix combustion in cans 1 or 10 or both become inefficient evidenced by related exhaust areas becoming cooler.

- Flame may have been lost in one or both cans
- Unburned gas may be present in the combustion area of cans 1 and/or 10
- When primary ignitors operate on falling TTRF combustion in cans 1 and 10 re-establishes (Note, lean/lean combustion can’t crossfire)

Initial Conclusions

Load negative excursion caused by combustion inefficiency. The following may have changed:

- Sequencing / control constants
- Combustion hardware
- Unburned gas ignites when flame establishes in primary zone causing a hard re-ignition
- Hard re-ignition resonates in exhaust duct and boiler causing an audible impulse and vibration”

Examination of the control system sequencing showed no changes had been made, so it was clear from this analysis, poor combustion in can 1 and/or 10 had caused the incident presumably due to problems with these fuel nozzles. It was also apparent that the combustion system may have been damaged during this event. The customer was advised not to run the turbine and a maintenance team was mobilised and arrived on site a few days later.

Extract from the final mechanical report issued to the customer:

“Initially number 10 and 1 primary and secondary nozzles were disassembled to investigate cold spot indicated on Tiger remote diagnostics system. Number 10 secondary fuel nozzle exhibited burning on tip and pilot tube loose within fit of nozzle so all remaining secondary nozzles were disassembled for inspection. No further visual anomalies were found on disassembled secondary fuel nozzles.”

**Figure 26 – Picture of damaged number 10 secondary fuel nozzle**
The decision was then taken to strip down the whole combustion system and replace any defective components.

The turbine was started up again on 10th July, and was monitored remotely by CTS engineers using the monitoring and diagnostics system as the combustion system was exercised in the different combustion modes and checked to ensure it was operating correctly. It was shown to then be operating as it should, and the turbine was returned to service.

**Conclusion**

The first case study detailed above shows how the monitoring system was deployed to monitor a fleet of gas turbine peaking units and how the system was configured and adapted to monitor a fleet of peaking gas turbines of different types and manufacturer with a variety of different control systems. The key issues involved in the deployment and solutions adopted were described.

The second case study shows how the remote monitoring system enabled CTS staff 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 cell 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, and effective and efficient remedial action to be taken.