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SHELL SMARTCONNECT TO IMPROVE RELIABILITY AND PRODUCTION IN SHELL OIL & GAS FACILITIES

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ABSTRACT

Shell SmartConnect (SSC) is the Shell In-house developed Technology Platform to improve reliability and availability of Rotating Equipment. Based on proven engineering models it transfers data into actionable information for site staff and dedicated specialists in Shell Projects and Technology who can provide remote diagnostic support. The data is available on a shared platform and combines reliability/availability, performance and condition monitoring information in a single user interface.

Work has been ongoing with major vendors of dynamic condition monitoring tools like Bently Nevada and Brüel & Kjær Vibro to integrate the information and present a single platform to Shell SmartConnect users. Similar arrangements are in place with the major OEMs to make use of the platform to provide support where needed. The Shell SmartConnect system provides users a comprehensive overview of:

- Reliability/availability data and main sources of downtime
- Aerodynamic/Hydraulic Performance information of critical Rotating Equipment
- Vibration and diagnostic Condition Monitoring information
- Auxiliary system information from Lube Oil- and Seal systems

The toolkit is implemented on more than 6000 machines in all businesses of Shell across the globe and has been selected as the group standard for monitoring rotating equipment. The support team is based in 3 strategic locations capable to cover 24/7 surveillance support; the largest part of the team consists of experienced rotating equipment and condition monitoring specialists that provide real time support and remote troubleshooting of machines with problems. This Operational support team has been key to a successful transfer the typical management perspective of Condition Monitoring – from cost into added value which impacts the profit of the organization. The platform is also supported by a team of in-house IT specialists who ensure the high availability of the application and continuously develop improvements to the platform.

INTRODUCTION

Since the mid 2000's remote condition monitoring of equipment has been done, albeit in smaller separate instances in the UK, USA, and Canada. It was decided later on to combine these into a single platform and standardize the tools and spreadsheets being used for equipment surveillance. The outcome of this integration was Shell SmartConnect, with the goal creating value to the business by providing timely equipment performance information, which then enables early collaboration and intelligent decision making.

SSC helps add business value in:

- safety, thru machine operating window management;
- condition monitoring, or early detection of anomalies in equipment health resulting in increased reliability and ultimately reduced downtime, and;
- emissions reduction, by driving low specific energy usage for a train or an entire plant using cross discipline performance monitoring.

There is quite a number of condition monitoring tools available, and the question begs: why did Shell develop its own?

One has to realise that traditional Condition Monitoring Systems have been around for many years and used in Shell assets, examples are from reputable vendors like Bently Nevada, Brüel & Kjær Vibro, SKF etc. the results have been mainly influenced by how consistent the usage on site over many years has been (sometimes lack ownership) and if the data was available for specialists on site only or also for remote users (complex IT infrastructure). On top the traditional systems are very good in detecting a failures understood by vibration specialists but not very well tailored to suit the requirements of facility operators and how it may impact production.

Figure 1 shows a typical machine condition behavior over time. As the machine gets used, its condition degrades. Typically when a vibration alarm or a high differential lube oil pressure is seen in the operator control screen, the equipment is already near towards the minimum acceptable condition, and majority of the actions that are done in response will not considerably extend the machine life. The aim of SmartConnect is to bring this point earlier in time (green arrow) thru observation of trend behaviors of key parameters, correlating different and sometimes seemingly unrelated variables that serve as early "alarm bells". By detecting incipient failure early enough, equipment is given the right attention and solutions are identified before the issue escalates and causes downtime. This gives that extra reliability and allows the equipment to run longer than what it would have been without this proactive intervention. Often times this equates to greater production, increased margins, and improved overall plant efficiency.

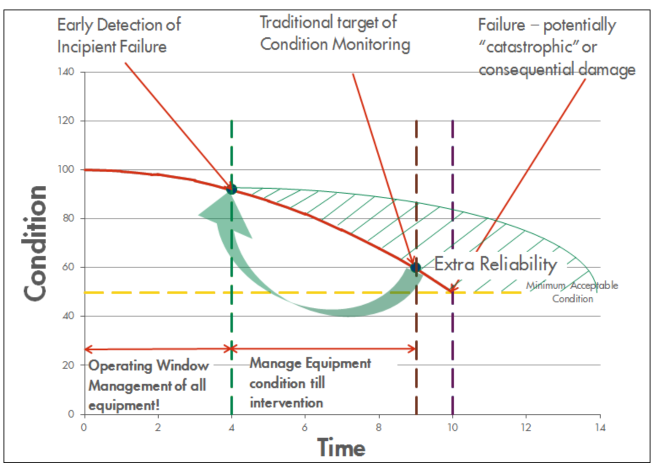


Figure 1: Remote monitoring and diagnostics target

It is worth to note at this point that Shell SmartConnect's focus is observation of trends ranging from several days to several years, (e.g. useful in turnaround planning). At the moment it is not effective in picking up fast changes of data in the minutes or seconds domain, as that would normally be picked by the site DCS, Operators and safeguarding systems which are used on a 24/7 basis. Integration of specialized vendor monitoring tools of Brüel & Kjær Vibro and Bently Nevada is underway, and this will leverage the strengths of these providers in providing spectral data. It is also not, and will never replace, a plant's safeguarding system.

Currently there are over 6000 machines across the Shell fleet that are deployed in SmartConnect, including a lot of gas turbine-driven machines. To date since its inception, it has generated a substantial amount of savings for Shell in the upstream, downstream, and integrated gas sectors, mostly captured from preventing unscheduled deferment and better turnaround scoping.

NOMENCLATURE

B&K	Brüel & Kjær Vibro
BN	Bently Nevada
DCS	Distributed Control System
GUI	Graphical User Interface
KPI	Key Performance Indicator
MTA	Maintenance and Turnarounds
PFAS	Pipeline and Flow Assurance
REDAS	Rotating Equipment Data Acquisition System
RMD	Remote Monitoring and Diagnostics
SSC	Shell SmartConnect
UHT	Utilities and Heat Transfer
VPN	Virtual Private Network

PLATFORM DESCRIPTION

Shell SmartConnect operates on a secure IT platform bringing data to the user's web-connected computer. Simply put, it gathers data from equipment instrumentation through PI, brings these data through calculation engines, and visualizes the results in a web-based user interface.

Data Transmission

The SSC database gets information from PI. Most of the information that SSC currently gets is what is called *scalar* data i.e. pressure, temperature, level, gas composition. From the field instrument, the reading gets into the plant's DCS and onto their PI server. Figure 2 shows a high level diagram illustrating the process.

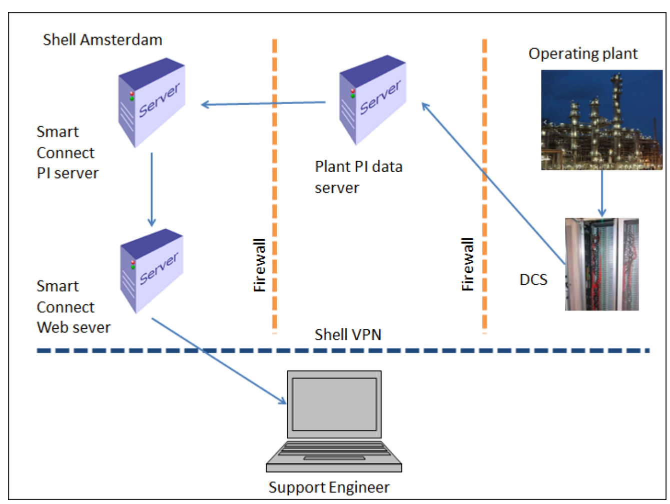


Figure 2: General/scalar data hi level network topology

SmartConnect has its own server and it copies these values from the plant PI server, uses them to perform the calculations needed in the "levels of smartness" (described in the succeeding section). The calculations are done in a separate space and are copied back to the SmartConnect server. The scan of each parameter tag and corresponding calculation is done once a minute, which is largely enough to capture essential appreciable changes in behavioral trends.

The results are carried over to the web server where the visualizations and integration in the web interface is done. Any user in the Shell VPN can then access the SmartConnect web portal, corresponding to the level of permission granted. Most often, users assigned to a particular asset are only granted access to view the deployed machines therein. The users are able to then view a diverse coherent set of machine and reliability parameters/KPIs, do trending of any critical thermodynamic data – both raw and calculated, and export to excel or a pdf file.

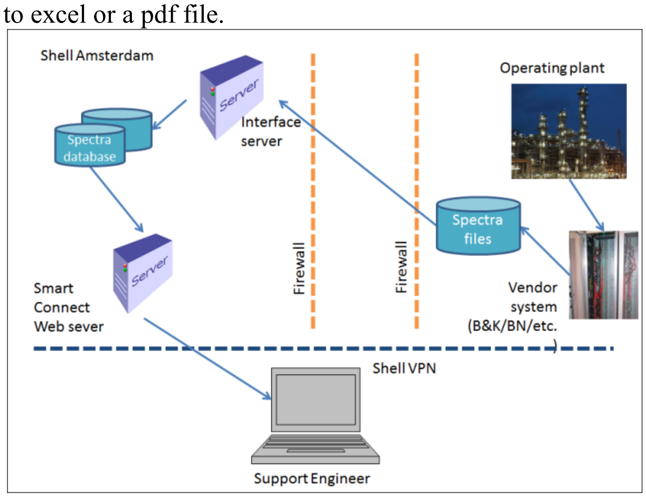


Figure 3: Spectra data hi level network topology

Figure 3 illustrates a how hi-speed or spectra data (waveforms, bode plots, etc.) is exported from vendor systems at site. The overall topology is similar to scalar data, except that it is making use of spectral data packs rather than individual PI tags. This system also makes use of an interface server in the SSC domain to host these spectral data, which is then transmitted onto the web server for eventual display in the user interface. For the Shell SmartConnect user it makes no difference if the spectrum is copied for REDAS vendor A or B as it is visibly identical in the SSC web display. This makes it very easy for the user to find the data, i.e. he/she does not need to be a specialist in the local configuration of the systems feeding the spectral measurements.

Equipment Performance Models

SmartConnect models provide a way to visualize the machine, define, and input live data (in the form of PI tags) to the calculation engine. High fidelity performance models are developed for key rotating equipment classes with varying degrees of sophistication:

1. Centrifugal compressors
2. Centrifugal pumps
3. Reciprocating compressors
4. Screw compressors

Incorporated in these models are various main rotating equipment drivers:

1. Gas turbines
2. Steam turbines
3. Electric motor

SmartConnect has model building tools to provide a standardized and sustainable way to make a model. Example below is one such tool for a centrifugal compressor:

Figure 4: Centrifugal compressor performance model builder

The engineer takes the relevant data, curves, PI tags of a particular machine train of interest. The relevant PI tag parameters like flow, suction pressure, etc. are entered in the model builders for both the driven machine and the driver. This piece of information is then fed or "deployed" to the calculation engine, which then calculates the KPIs for the particular machine (e.g. efficiency, theoretical flow, % deviation to theoretical head, equivalent compressor maps, current heat rate, etc).

Remote Monitoring and Diagnostics

An integral part of the whole SSC package is a team of rotating equipment engineers and condition monitoring specialists in three locations globally. Using SmartConnect they provide daily RMD support to sites under their care and do regular engagements as seen fit. They are also working closely with other rotating equipment experts to troubleshoot and diagnose anomalies observed in critical equipment. Often times, site staff do not have the luxury of devoting time to monitor and analyze their equipment's health on a regular basis, and this is where the RMD staff can fill in. A significant number of equipment failures are caused by a "slow death". Through dedicated remote surveillance, increasing trends can be identified readily and not just step changes. A number of services offered through the RMD team are:

- Remote surveillance of facilities, process units
- Review of vibration monitoring system for potential root causes and mitigation measures

- Turnaround review via equipment health assessment to support turnaround scope
- Root cause analysis participation

LEVELS OF SMARTNESS

Within the SSC platform, information is clustered in different levels of "smartness" enabling the SSC team and the asset staff at site to discuss a common language and understanding. Having information categorized as such also allows for a more streamlined user interface structure. Furthermore, associating different KPIs to levels of "smartness", according to the ease of deploying the underlining technology, is a key success story in getting the users' buy-in. The first level is just to show the equipment is running or not, and if not if it is available/standby or out of service. The next levels are performance and health rules. Each is described below.

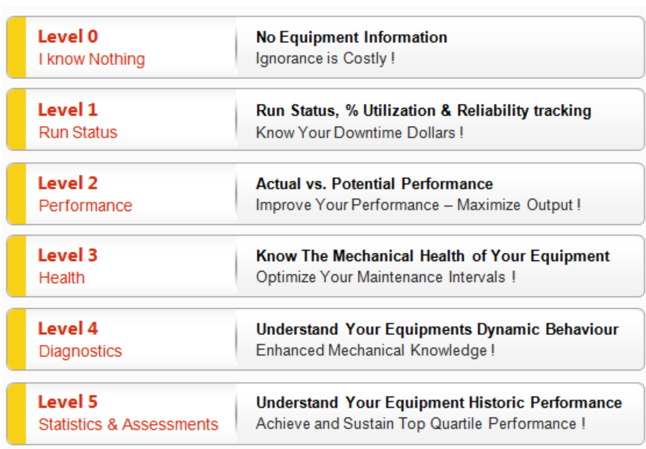


Figure 5: Shell SmartConnect Levels of Smartness

Level 1: Run Status

Simply put, Level 1 information shows the user if particular equipment is running or not. This is mainly useful in tracking equipment down time or reliability. It also shows the status of a particular *service*. For example when two pumps combine to deliver 100% service (a 2 x 50% configuration) and one of them is not running, the service will show as "red" even though the other pump is showing as "green".

The Level 1 models use a mix of equipment process PI tags to determine the run status. The models are made in such a way to reflect an accurate run status even in cases where some of these PI tags are in error state.

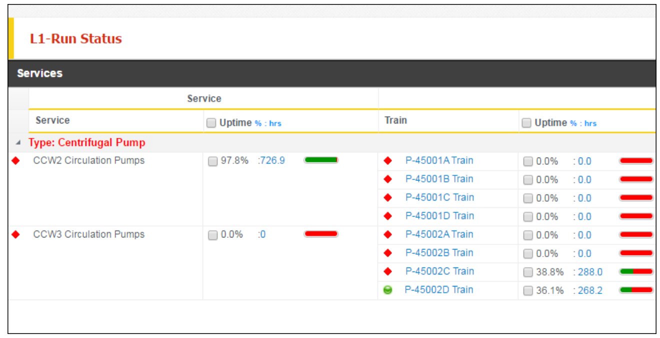


Figure 6: Screenshot of Level 1 for some pumps

Level 2: Performance

Level 2 focuses on the thermodynamic performance of the machine train. It acts as an enabler to identify problems with the working fluid path of the equipment that lead to drops in efficiencies due to internal/external leakages, fouling, erosion, and flow instabilities. This goes for both driver and driven machines.

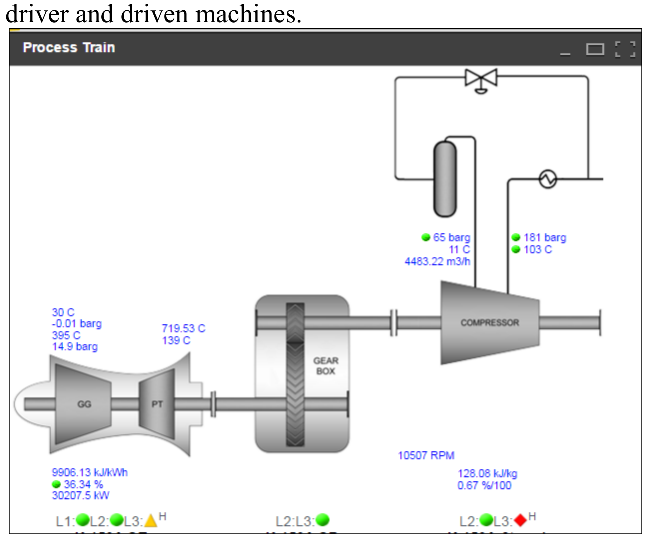
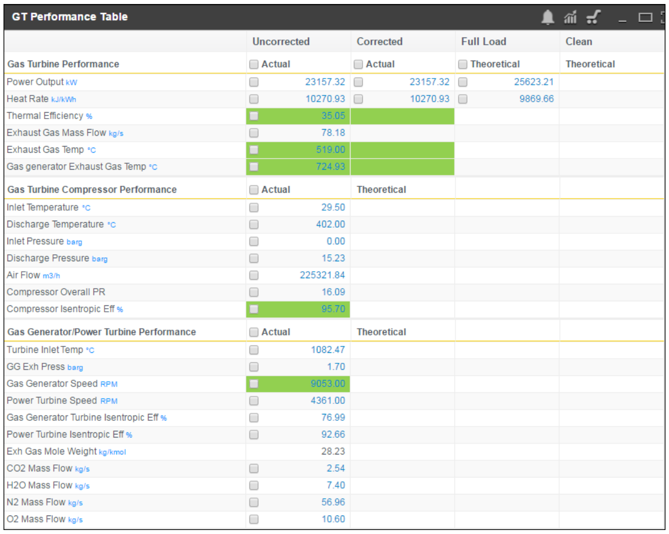


Figure 7: Level 2 process train diagram

Figure 7 shows a typical gas turbine-driven single stage compressor through a gearbox. The important process parameters are shown with traffic lights to indicate at a glance that these measurements are within specified limits.

A summary of extensive, relevant thermodynamic parameters – both theoretical and actual (where available) – are listed in another section of the Level 2 web page (see Figure 8). Traffic lights are also implemented in this and users can select any desired property to output a trend display over a pre-selected timeframe.

Pre-defined performance charts and trends are also displayed in the same page. A user can see at a glance where his/her gas turbine operating point is at this moment in a power vs. inlet air temperature graph. Fuel consumption can also be seen for instance, as well as the behavior of the heat rate over time. In this way, a lot of important information converge on a single web page rather than in separate personal spreadsheets and PI Processbook diagrams. This information can then be shared and discussed upon. It does not matter if the asset is offshore, and the support staff is on another continent. Both are looking at the same set of data display.



GT Performance Table

	Uncorrected	Corrected	Full Load	Clean
Gas Turbine Performance	Actual	Actual	Theoretical	Theoretical
Power Output kW	23157.32	23157.32	25623.21	
Heat Rate kJ/kWh	10270.93	10270.93	9869.66	
Thermal Efficiency %	35.05			
Exhaust Gas Mass Flow kg/s	78.18			
Exhaust Gas Temp °C	519.00			
Gas generator Exhaust Gas Temp °C	724.93			
Gas Turbine Compressor Performance	Actual	Theoretical		
Inlet Temperature °C	29.50			
Discharge Temperature °C	402.00			
Inlet Pressure barg	0.00			
Discharge Pressure barg	15.23			
Air Flow m3/h	225321.84			
Compressor Overall PR	16.09			
Compressor Isentropic Eff %	95.70			
Gas Generator/Power Turbine Performance	Actual	Theoretical		
Turbine Inlet Temp °C	1082.47			
GG Exh Press barg	1.70			
Gas Generator Speed RPM	9053.00			
Power Turbine Speed RPM	4361.00			
Gas Generator Turbine Isentropic Eff %	76.99			
Power Turbine Isentropic Eff %	92.66			
Exh Gas Mole Weight kg/kmol	28.23			
CO2 Mass Flow kg/s	2.54			
H2O Mass Flow kg/s	7.40			
N2 Mass Flow kg/s	56.96			
O2 Mass Flow kg/s	10.60			

Figure 8: Example gas turbine Level 2 table

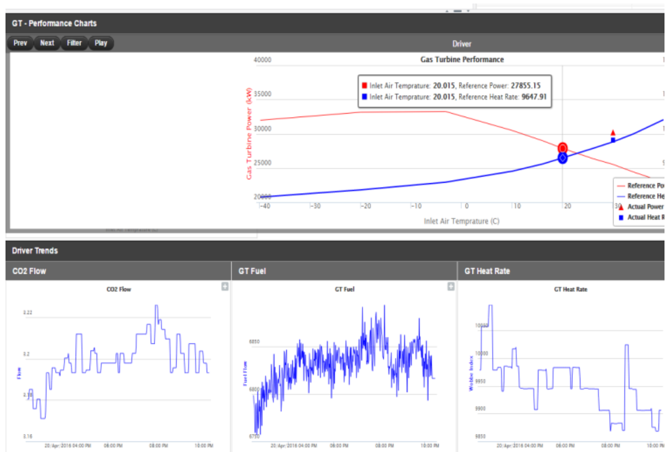


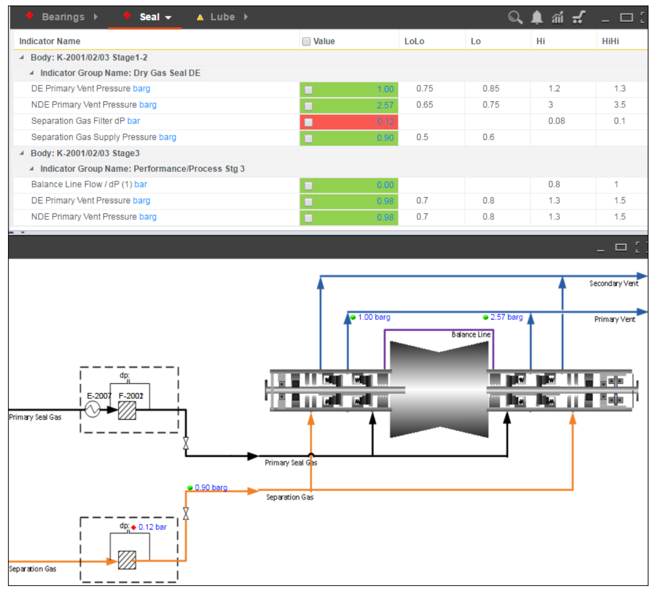
Figure 9: Example gas turbine Level 2 performance trends

Level 3: Health

This level is dedicated to traditional equipment monitoring of violations of the equipment's operating envelope and prediction and detection of failure modes. The backbone of this is what is called "rulesets". A ruleset, done per equipment, is a series of instructions that tell whether a parameter or a KPI has exceeded certain user-set limits. Moreover, it gathers from a built-in database of equipment failure modes, and helps predict a possible failure occurring based on a combination of weighted parameters which are exceeding their limits. This can be done not just with the equipment itself but also with auxiliary systems like lube oil and dry gas seal systems.

Shown in Figure 10 is an example of a live Level 3 display for a dry gas seal of a compressor. The values have the traffic light system as well, so that users can see at a glance which parameters are in violation of the limits. Note that these limits or alarms are set more conservatively than the actual equipment alarms at site. These are set in such a way as to have an early warning notification.

The Level 3 pages also show other useful information such as % of time that a parameter was in "alarm" over a selected period, recommended actions, possible risks faced if failure is encountered, etc. As with all parameters in SSC, clicking on the numerical values will show a pop-up trend over a pre-selected timeframe. These tools are especially valuable during for instance, a root cause analysis or failure investigation. More importantly, a user gets notified whenever a violation has occurred (i.e. a value has crossed over a set threshold), and thereby warranting close monitoring and action even before the real alarm has occurred.



Indicator Name	Value	LoLo	Lo	Hi	HiHi
Body: K-2001/02/03 Stage1-2					
Indicator Group Name: Dry Gas Seal DE					
DE Primary Vent Pressure barg	1.00	0.75	0.85	1.2	1.3
NDE Primary Vent Pressure barg	2.57	0.65	0.75	3	3.5
Separation Gas Filter dP bar	0.12			0.08	0.1
Separation Gas Supply Pressure barg	0.90	0.5	0.6		
Body: K-2001/02/03 Stage3					
Indicator Group Name: Performance/Process Stg 3					
Balance Line Flow / dP (1) bar	0.00			0.8	1
DE Primary Vent Pressure barg	0.98	0.7	0.8	1.3	1.5
NDE Primary Vent Pressure barg	0.98	0.7	0.8	1.3	1.5

Figure 10: Level 3 – dry gas seal

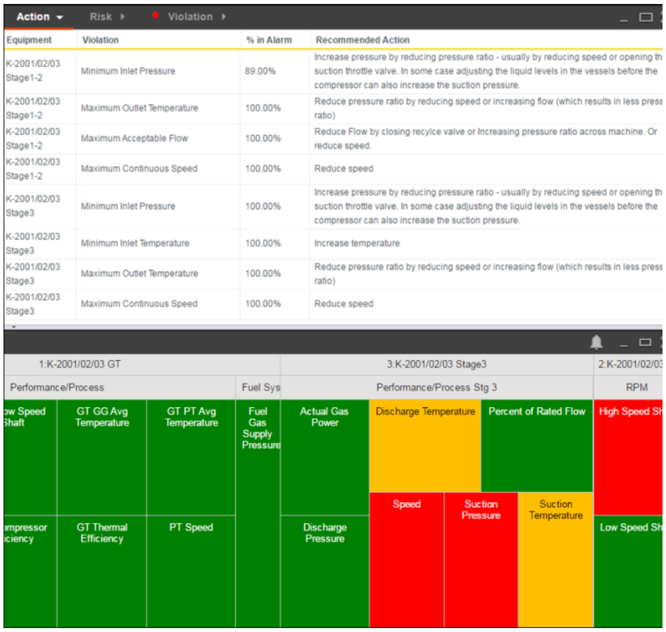


Figure 11: Ruleset monitor screen

Level 4: Diagnostics

Level 4 goes in-depth into the machine and here is where the interface with specialist vendor systems gets shown. It displays the spectra data like synchronous and asynchronous vibration spectra and waterfall plots.

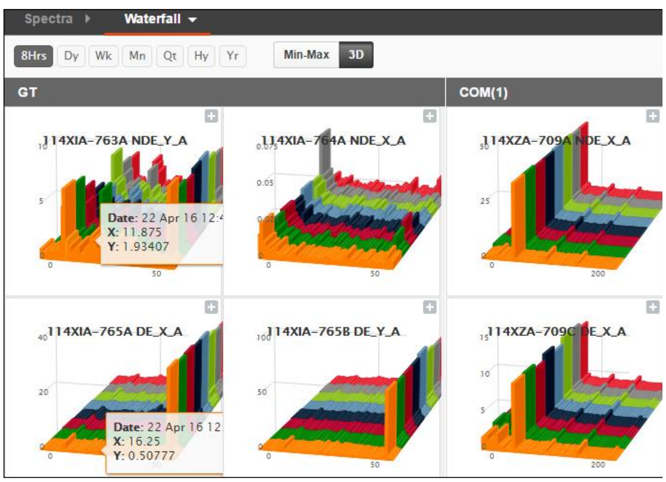


Figure 12: Waterfall plots screenshot

Level 5: Statistics and Assessments

This level is more geared towards fleet benchmarking and statistics. However, it was decided to mature the machine reliability aspect and expand it. Eventually the reliability assessments were put in the Level 1 space, and fleet benchmarking is still a work in progress.

Figure 13 shows the Level 1 "Event Log" page. The user can select a particular train and it will show reliability, utilization, and availability for each equipment deployed in SSC for a particular period. The calculation behind this is tied in the Level 1 run status and site inputs as well. Rotating equipment and reliability engineers at site are given Editor access to this page. He/she can then manually describe a reason for a particular equipment stop, either from selecting from a pre-defined database (in a drop down list) or entering their own descriptions. They could also manually create their own "event" – a downtime for example – and specify if this was caused by an error, breakdown, or other reasons. This feeds into the calculation of the reliability statistics.

Figure 13: Event log: reliability statistics

These charts are also customizable, and it could show in a few clicks the major causes of deferment in a particular asset. In Figure 14 it shows that for a particular plant, a lot of downtime count over the past year was related to control and monitoring. Clicking on this green bar will then show more granularities i.e. at which aspect of control and monitoring is causing the most downtime. The data from this comes from the user at site selecting and actively using this Event Log page, entering the high level cause selectable from a drop-down list already built in.

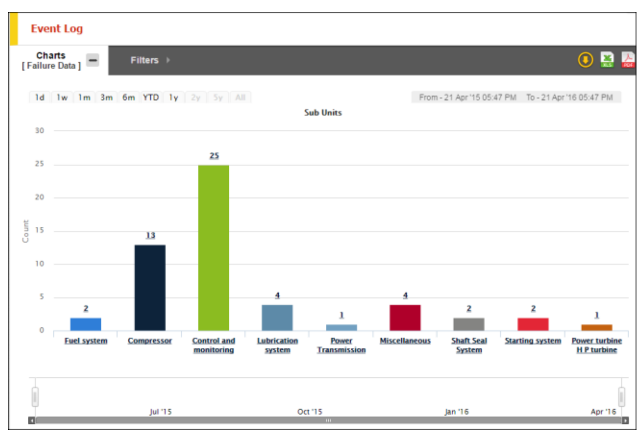


Figure 14: Event log: equipment downtime causes

GAS TURBINE APPLICATION

GT drivers form a critical component in the asset production as they normally drive the critical compressors and pumps, or provide the required power through the generators. As such, the Shell SmartConnect platform covers the GT's as well and there is clear focus on maximizing the reliability. As the machines are standardized and there is a large amount of identical machines, Shell gains a lot of experience by correlating and learning from incidents on identical machines in different areas and businesses across the globe.

For GT drivers the same levels of "Smartness" is applied, and hence we do have Run Status, Performance, Health, Diagnostic (Vibration), and reliability data covered. Some examples are shown below.

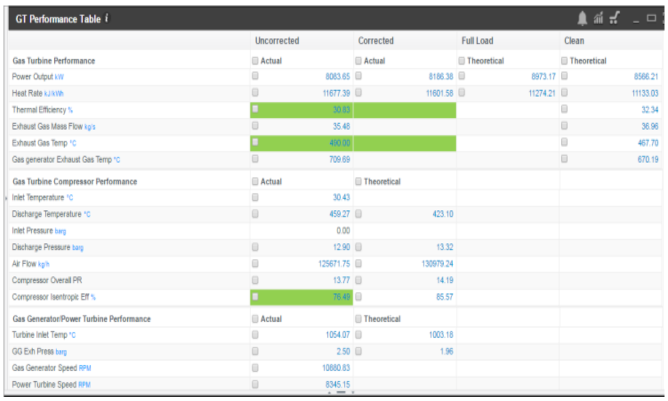


Figure 15A: Performance table

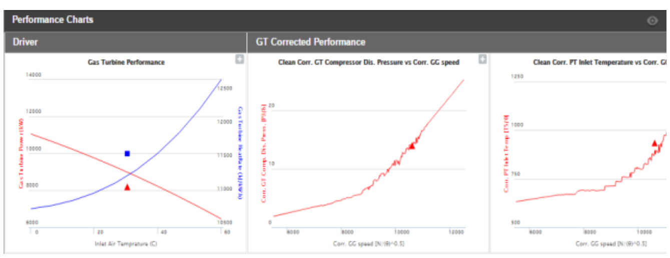


Figure 15B: Clean Engine curves and actual operating points

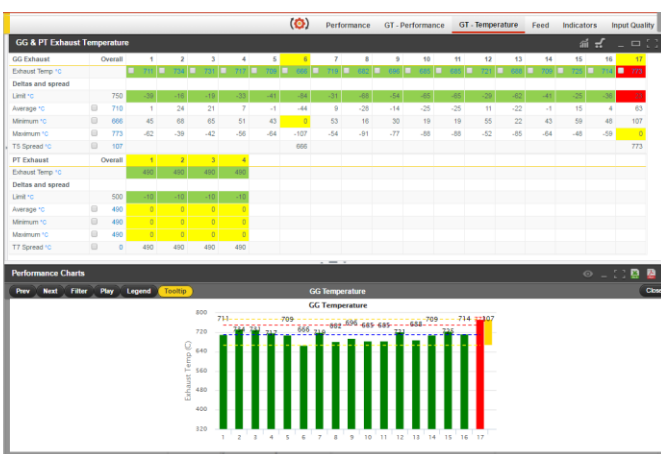


Figure 16: Exhaust Temperature screens

The GT driver module in Shell SmartConnect has provided several good case studies where problems were identified in early stages of development; examples are combustor problems, seal and lube oil problems and simple fouling of the compressor and filters. The fact that these were picked up in due time ensured that the reliability of the critical GT drivers has increased and major failures are reduced.

A complex issue for gas turbines is that quite often it is seen that the required data is locked in the GT Control Panel, and only available for the OEM. Only limited data is available for the asset and Shell SmartConnect specialists through the DCS and plant historian. Therefore additional interfaces are built to the control panels in order to import all required data. Since remote access to control panels is restricted as they also have a safeguarding function, the team is now developing the GUI's of the Control systems in the Shell SmartConnect platform to allow the OEM to access the data in the safe Shell SmartConnect environment.

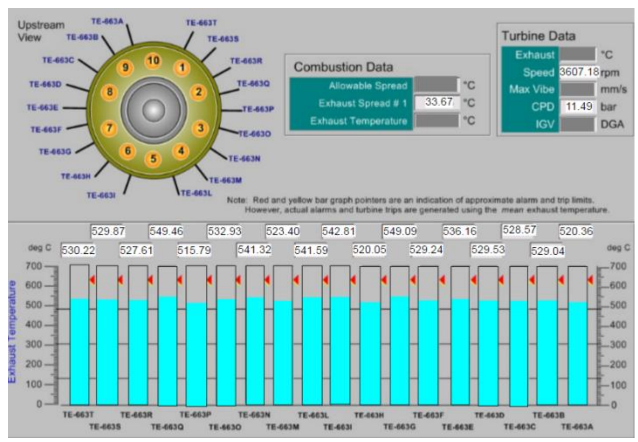


Figure 17: Building the HMI of the control panel into SSC

ONGOING DEVELOPMENT AND FUTURE EXPANSION

It has been readily observed and experienced that failures to rotating equipment are not always necessarily linked to the machine itself but rather on equipment and processes before or after it. Nowadays the drive to reduce unscheduled deferment and trim down on operating costs is greater than ever. Therefore, Shell SmartConnect is currently expanding beyond remote monitoring/surveillance of rotating equipment. Inter-disciplinary collaboration is ongoing, and has developed models for such equipment like Heat Exchangers, suction scrubbers, process units, and control systems.

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