ON-LINE MONITORING OF POWER PLANTS

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1. INTRODUCTION

In recent years significant changes in the business relationships between customers and original equipment manufacturers (OEMs) could be observed in the power industry, which led to new forms of cooperation between those partners. Remote online monitoring is one important outcome of this development.

An analysis gives various reasons for these changes:

Since the early nineties a strong trend towards gas turbine application for power generation could be noticed. Decreasing gas prices in connection with high efficiency in combined cycle mode and small staff required made this technology attractive compared to the traditional coal based power generation.

In the late nineties advanced gas turbines became available with more than 250 MW electrical output and 38 % simple cycle / 58 % combined cycle efficiency. This impressive development could only be realized by applying the most advanced technologies and materials available.

As always, you do not get things for free. The more complex the machines got, the higher the turbine inlet temperature was pushed, the more exotic cooling techniques and materials had to be applied, resulting in an increased risk for abnormal behavior with the threat of non-availability on the horizon.

In traditional business relationships, OEMs sold gas turbines to utilities, and –after a fixed guarantee period– the customer had to carry all the risk and to cover the repair costs for his machine to the full extend.

With the new high performance engines being introduced in the market, customers, in particular independent power producers (IPPs), OEMs and insurance companies were looking for new structures in their relationship. As a consequence, O&M Contracts and Long Term Service Agreements were established that are designed to cover the greater part of the lifetime of the engine or even the entire combined cycle plant, which under certain contractual conditions include an OEM contribution on repair costs. This made the situation more calculable for the customer, but resulted in additional risk for the OEM, as he eventually had to pay for repairs without knowing how the engine was actually operated.

At the same time as these changes were occurring in power generation, a real boost in information technology took place, allowing the transfer of large masses of data over long distances. As a result the idea of using remote monitoring to mitigate risk for long term service contracts was born.

2. REMOTE MONITORING STRATEGY

After a basic research phase to select the best technologies available, Siemens Power Generation (PG) decided to establish a pilot remote monitoring center in Orlando, Florida, in late 1999. Since that time, the remote monitoring of Siemens' advanced gas turbine / combined cycle fleet has been largely extended, primarily focusing on long term maintenance contracts (Long Term Programs - LTPs). Continuous remote online monitoring was officially introduced in February 2002 as "Power Diagnostics® Services" (PDS) to enable both customers and OEM to mitigate risk on a 24/7 basis. In the following chapters the Power Diagnostics® concept, infrastructure, and applied tools will be presented, along with some typical findings which actually prove the concept of risk mitigation, creating a win-win situation for both customers and OEM.

2.1 Power Diagnostics® Services

Power Diagnostics® Services is the Siemens PG remote monitoring and diagnostics strategy targeted to provide early detection of abnormal operating conditions of power plant equipment to help improve plant availability and operations. Multiple data acquisition tools can be used for obtaining daily operational data from customers' power generating equipment such as gas turbines, steam turbines, heat recovery boilers and generators. Advanced diagnostic software helps experienced engineers identifying issues before they reach conventional alarm levels. The diagnostics engineers are supported by specialists from all parts of the company, bringing in the entire knowledge of Siemens PG into remote monitoring. Early detection of faults allows service teams to prepare parts and manpower, under certain conditions it is possible to turn a potential forced outage into a scheduled event (**Figure 1**).

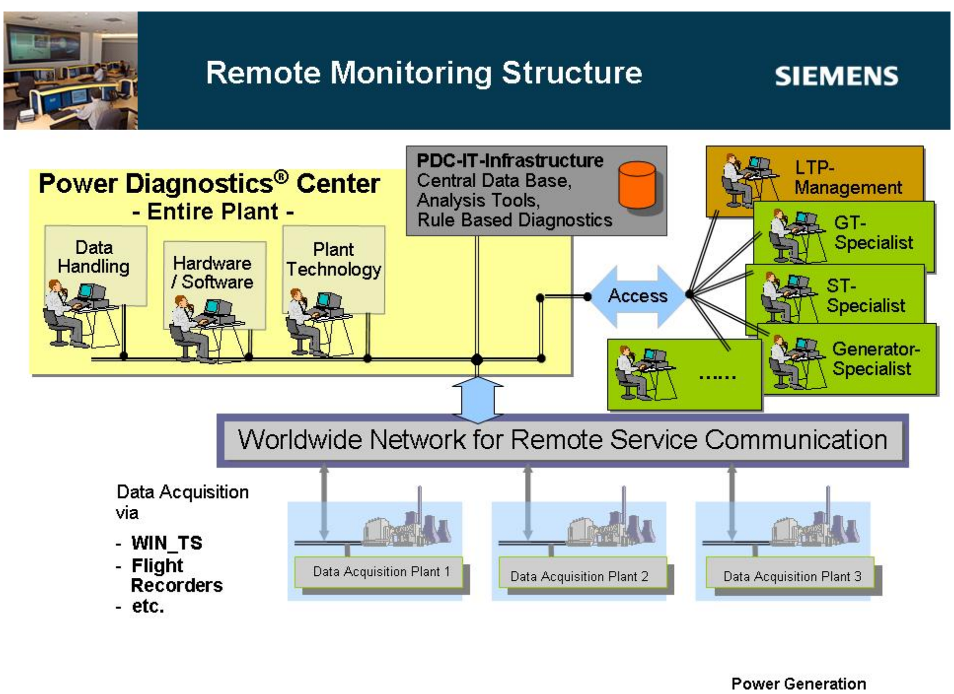

Figure 1: Power Diagnostics® Remote Monitoring Infrastructure

Once the data is transmitted to a Power Diagnostics® Center (PDC), it is processed through a series of advanced data analysis tools, and the results are posted for the Siemens Engineers to review on a regular basis. Upon detection of an anomaly, the engineers will prepare a report summarizing the details of the issue, possible causes and suggested actions. This report is then sent to the technical and regional service managers who communicate and discuss the report and possible courses of action with plant personnel considering the severity of the issue, dispatch of the unit, and the availability of parts and labor.

3. DATA ACQUISITION

The process starts with the collection of the data of interest from the plant's instrumentation & control (I&C) system.

Power Diagnostics® Services uses multiple acquisition tools for obtaining the daily operational data from their customers' gas turbines, generators and other major plant components. The primary system for data acquisition is WIN_TS™, a PC-based software developed by Siemens PG that is passively connected to the site's I&C system. This data acquisition system receives data from the plant's control system along a one-way data highway. There is no interaction with the site's I&C system, and in particular no threat of interference with the actual engine operation. **Figure 2** shows the general data flow configuration from the power plant site to the remote monitoring centers. This configuration is designed to comply with the plant's and with Siemens PG's data security procedures.

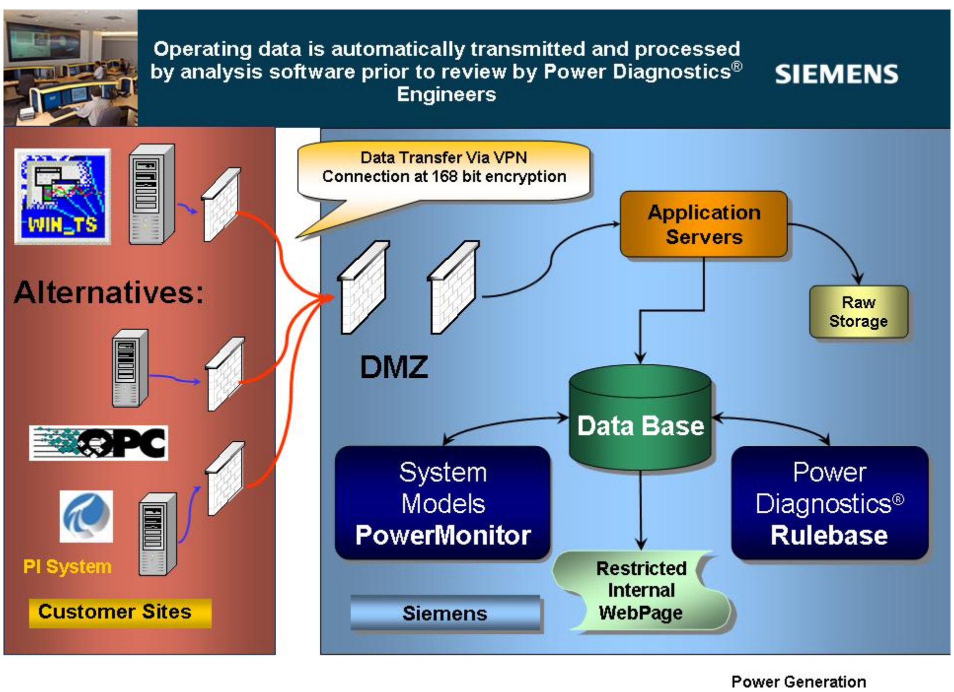

Figure 2: Data acquisition, transfer, and processing/evaluation/storage in the Power Diagnostics® Centers. Before the incoming data can enter the PDC, they are checked in the Demilitarized Zone (DMZ), a data storage area protected by firewalls.

4. DATA EVALUATION

The Power Diagnostics® approach to remote diagnostics is rather unique in the industry. Siemens does not only have experts that analyze data daily in centers around the world, but also provides the customers with some diagnostic capabilities on-site using WIN_TS™. This chapter will highlight the potential of diagnostic capabilities and show the value added by Power Diagnostics®.

4.1 On-site Analysis via WIN_TS™

The WIN_TS™ computer at site provides real-time data analysis capabilities utilizing several tailor-made diagnostic modules that monitor key parameters of engine operation such as the turbine outlet temperature profile, shaft vibrations and bearing conditions, et cetera.

Real-time viewing of these important operational data and the related analysis results is possible via several customized screens. **Figure 3** shows an example.

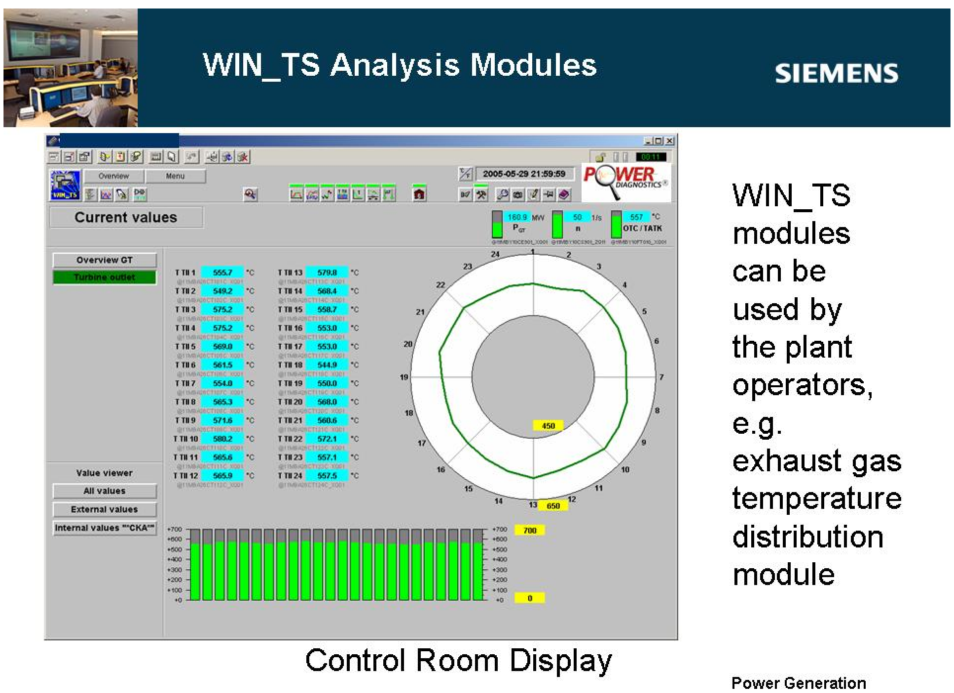

Figure 3: WIN_TS™ screen for direct online monitoring at the plant.

The goal of these WIN_TS™ modules is to catch hardware failures or operational anomalies before they reach the existing control system alarm limits. Early detection of these types of events or conditions can potentially prevent engine trips, forced outages, and additional impacts. The alarm limits in the modules are customized to each unit by analyzing the specific characteristics of the engine in an evaluation period. During this period (designated by the assigned engineer), baseline operating conditions are determined for each of the unit's modules. After fine tuning of the modules, the actual monitoring period begins, and significant deviations from the determined baseline are to trigger an alarm. If there is a WIN_TS™ alarm that may indicate a serious problem, a Watchdog File is automatically transferred to the PDC. This file is a special data compilation that contains information regarding the alarm, permitting the Siemens engineers to react to the potential problem in a timely manner. If the issue is severe enough, the assigned engineer may contact the site directly. It should be noted that the customer has access to the WIN_TS™ screens and can use them for his own analyses and evaluations.

4.2 Power Diagnostics® Center Analysis

The majority of the data analysis is carried out at the Power Diagnostics® Centers in Orlando, FL, and Mülheim, Germany. Once the data is transmitted and has successfully passed the security checks in the DMZ, it is processed through a series of advanced neural network models and artificial intelligence software (see right side of **Figure 2** and **Figure 4**). The results are posted for a Platform Team consisting of the responsible Long Term Programs Engineer (liaison to the customer) and representatives from the Sales Force, Local and Technical Service Organizations for review on a daily basis and to initiate action, if required.

It is Power Diagnostics' strategy never to rely on one system alone. The analysis and diagnosis process is a mix of automated applications of different software tools and the judgment and expertise of human experts. This expertise comes not only from the PD engineers, but from available specialists within the entire company as well. This assures that the diagnoses -being communicated to the Long Term Programs engineers (liaison to the customers) and the plant operators- have a high level of confidence (more in the following chapters were actual findings and their consequences are presented).

The software tools listed below are the backbone of the data analysis procedure in the Power Diagnostics® Centers Orlando and Mülheim:

- PD Automated Processing System APS
- PowerMonitor
- PD Rulebase
- PD Operation Database
- PD WebPage Reporting System

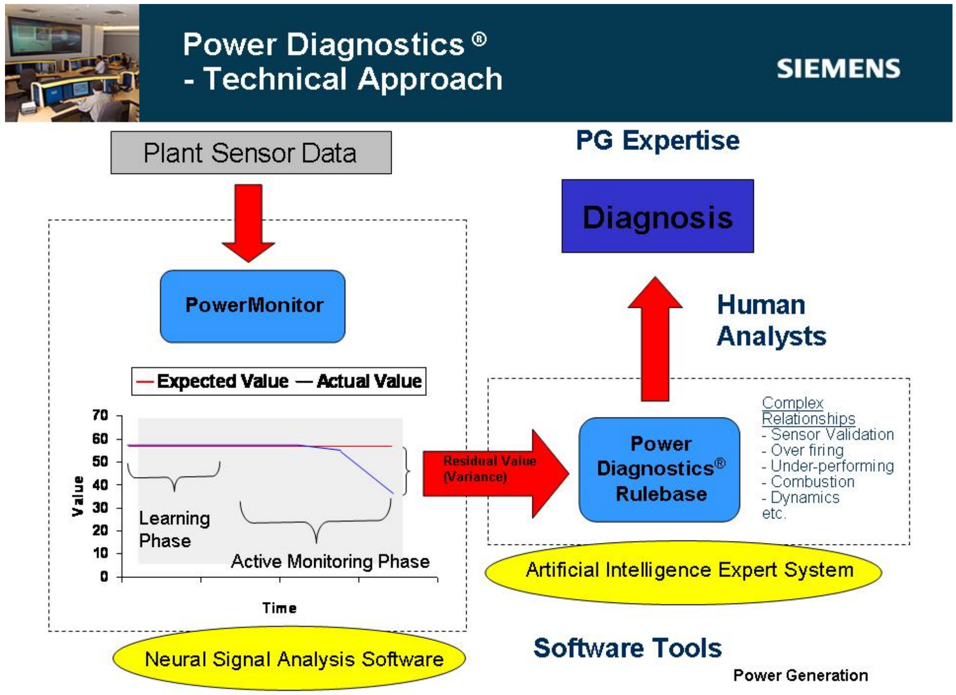

Figure 4: Power Diagnostics® Technical Approach

For dealing with a fleet of now more than 200 advanced gas turbines worldwide, it is a must to have a highly effective, automated and fast data processing infrastructure available. As Power Diagnostics® has its own Research and Development organization, the tools are tailor-made for the application in the centers. It is a great advantage that software developers and research engineers work as close as possible with the PD operations engineers who perform the actual data analysis on a daily basis. PD Research & Development cooperates in certain fields with Siemens Central Technology (CT), in particular with its American branch Siemens Corporate Research (SCR) to take advantages of synergies resulting from research work from other branches such as Siemens Medical, another vanguard in remote diagnostics technology.

4.2.1 Automated Processing System APS

This is the overall control system for the analysis process. APS administers the incoming data, transfers it to the analysis tools PowerMonitor and PD Rulebase and stores raw and processed data as well as the results in the central PD Database.

4.2.2 PowerMonitor

PowerMonitor is a self-learning tool developed in close cooperation with Siemens Corporate Research (see Figure 5). After a short learning period (training mode) the code is able to determine the correlations between operation parameters. In the subsequent monitoring mode the program calculates an expected value for each measured parameter based on the knowledge gained in the training mode. The calculated expected values are compared to the measured values, and deviations trigger an alarm.

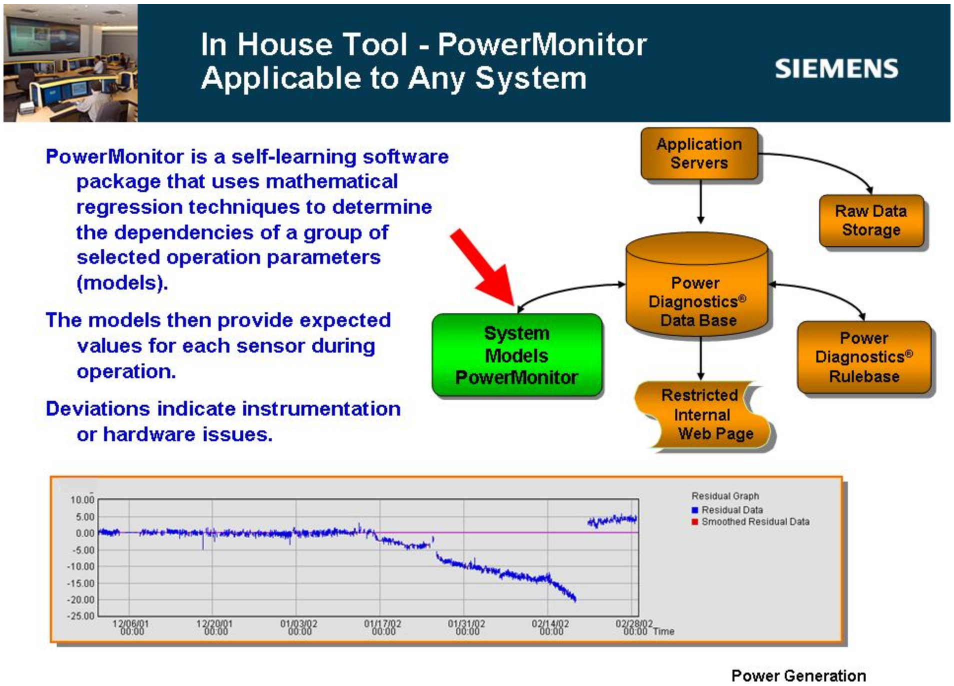

Figure 5: PowerMonitor results showing deviation of measured figures from expected (Residuum: Difference measured – expected values).

PowerMonitor is an effective alarming or early warning tool that takes away routine monitoring work from the engineers and let them concentrate on the severe cases. But PowerMonitor only tells you that something is developing; it gives no technical diagnosis. For that purpose the engineers are supported by an artificial intelligence expert system called the Power Diagnostics® Rulebase (or PD-Rulebase), a software system also developed and maintained by Power Diagnostics® ' R&D organization.

4.2.3 Power Diagnostics® Rulebase

Siemens operations and development engineers work together in writing rules for the Power Diagnostics® Rulebase to detect hardware and control system issues (see Figure 6) and to trend critical parameters over time.

The PD-Rulebase is also designed to analyze starts, trips and instantaneous load changes, and to calculate equivalent operating hours and equivalent starts accordingly.

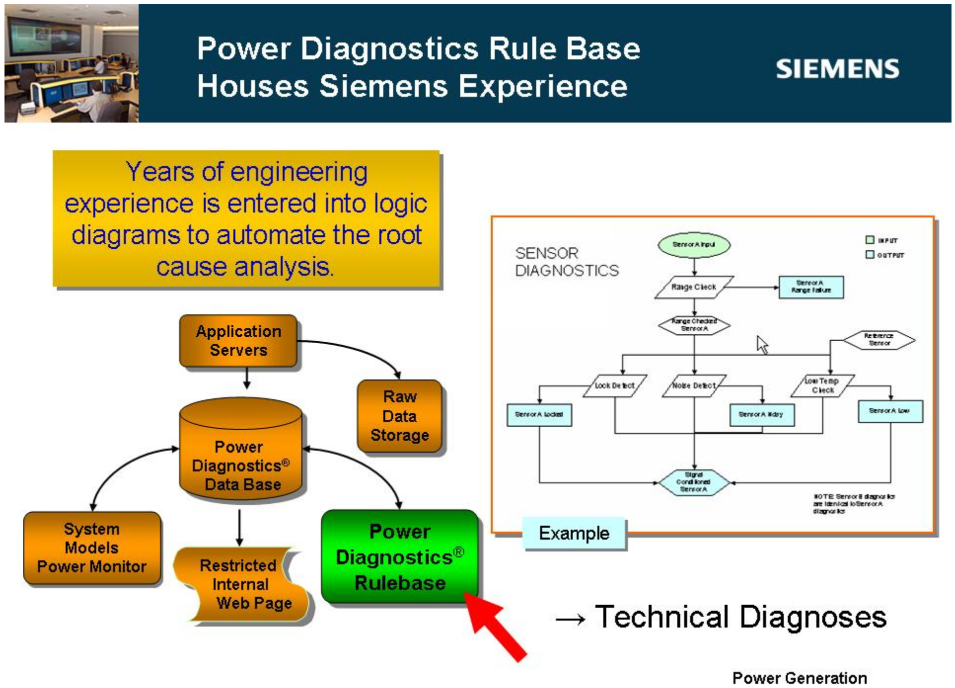

Figure 6: The Power Diagnostics® Rulebase contains years of engineering and operating experience to automatically provide technical diagnoses.

4.2.4 Power Diagnostics® Operation Data Base

"Knowledge is power". To have access to the knowledge that lies within the years of operational data of an entire fleet is one of the advantages only the OEM has. The more data you have, however, the more difficult it is to evaluate and to derive the right conclusion from it. So it is very important to have powerful tools available to select comparable events and analyze them and come up with conclusions. This is realized by a close interaction of the actual database, where all raw data and analysis results are stored, with the PD-Rulebase. The internal structure of the rulebase kernel and the rules make it a very powerful combination to perform fleet comparisons, e.g. start-up analyses.

4.2.5 Power Diagnostics® WebPage Reporting System

In the beginning, data was analyzed using tools such as Microsoft Excel®, and daily diagnostics reports were created by hand. As the number of monitored units grew, this became impractical and led to the automation of many routine tasks. Reports to Siemens LTP engineers, customers and back offices are now compiled to a great extent without human interference. Much of this information is available on the corporate intranet via the Power Diagnostics® WebPage Reporting System. The structure of the WebPage ensures that only personnel with permission can see the selected results. For example, the LTP engineer of a certain unit can only see the data and results for his plant.

All these tools and systems have one feature in common. They provide unit specific operating characteristics which facilitate early detection of abnormal trends. If the PD engineers are faced with new or unusual issues, they can quickly and easily consult with one of many specific component and design engineers of the company. These specialists can add extensive expertise in the evaluation of operational or hardware issues.

4.3 Diagnostic Findings Information Distribution Process

Once the data is processed, the results are posted for the Siemens platform team of each unit to review via the PD WebPage. As mentioned above, access to each unit's data and diagnosis results is strictly controlled. Upon detection of an issue, the PD engineers prepare a report describing the event, possible causes and suggested actions. This report is then sent to the technical and regional service managers, who will discuss the report and possible courses of action with plant personnel considering the severity of the issue, dispatch of the unit, the availability of parts and labor, and the specifics of the contract. The following chapter gives examples of actual findings and their consequences.

5. DIAGNOSTIC FINDINGS AND BENEFITS

There are numerous potential benefits of remote monitoring that are generally shared by the customer and the OEM. By collecting operational data from the site and evaluating it on a daily basis, Siemens can help to reduce the potential for damage to the power plant equipment monitored. As described above, the diagnostic tools set in place are designed to detect already small indications of changes in monitored parameters from expected. These changes are thoroughly analyzed to make fact-based recommendations to the customer. Early fault detection under certain conditions may be able to limit the amount of consequential damage and it can also help reducing the overall repair costs by having the opportunity to plan all necessary actions upfront, such as having all manpower and spare parts required available at site when the engine is shut down for repair.

Sometimes power generation facilities are urged by the utilities or the government to postpone outages due to high demand for power, such was the case with the California energy crisis a few years ago. Under these types of circumstances, remote monitoring services can afford the customer better information to assess and monitor the risk of operation beyond the recommended service interval.

5.1 Examples of Remote Diagnostics Successes

To prove the benefits of remote monitoring performed by skilled OEM personnel in the following some typical examples of actual Power Diagnostics® findings will be presented.

5.1.1 Example 1 - Clogged Fuel Nozzle

In the first case Power Diagnostics® Services registered a shift in gas turbine parameters weeks before a planned maintenance outage. A Siemens specialist assessed the severity of the trend. Possible causes and effects were reported to the Siemens LTP Manager. The most probable cause was identified as debris in the fuel nozzles and the customer was made aware of the issue.

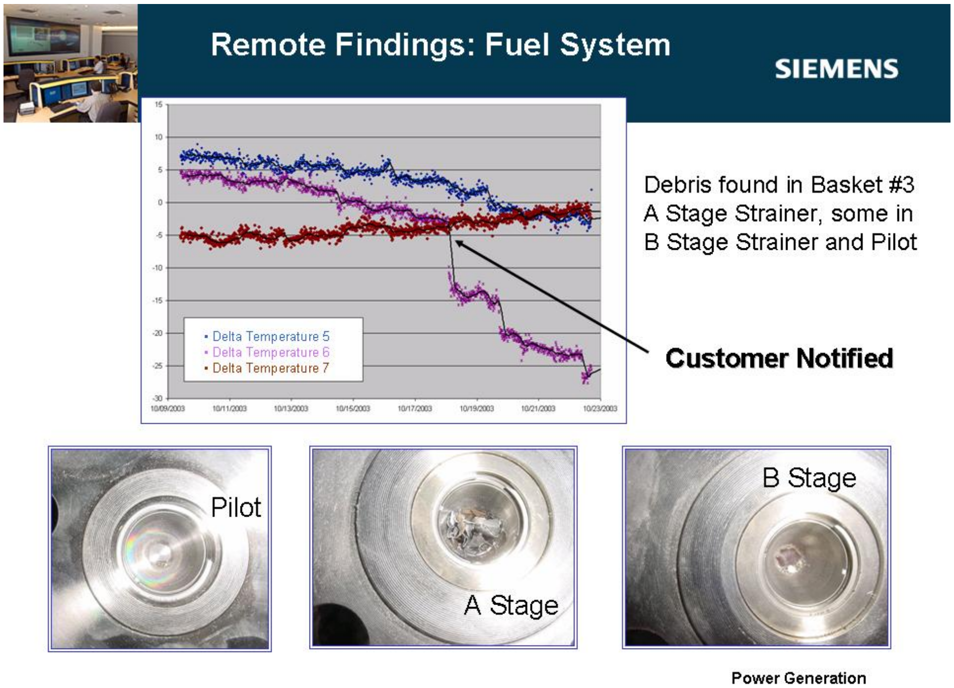

Figure 7: Debris in the fuel nozzles of a gas turbine, predicted and actually found after opening the engine.

Turbine hardware and operational impacts, such as potential complications during load changes, shutdown or start-up were assessed. The customer and Siemens worked together to monitor the parameters and keep the plant in operation until the next regular outage period. Because Power Diagnostics® Services were able to pinpoint the location of the problem, the clogged nozzles were easily identified (see **Figure 7**) and the debris removed, thus minimizing the outage. Siemens' precise assessment of the hardware issue allowed the customer to more fully evaluate the situation and helped them to develop a plan of action that met their operational needs.

5.1.2 Example 2 - Overheated Bearing

An increasing temperature trend on the compressor bearing of an advanced gas turbine with annular combustion chamber was detected by the Power Diagnostics® Rulebase (**Figure 8**) well before the I&C system would react (TXP warning at 110 °C, shutdown at 120 °C). Working in close cooperation with the customer, it was decided that the lifting oil pump should be activated and the oil cooler operation adjusted to relieve stress on the shell of the compressor bearing. Continuous monitoring was used as additional risk mitigation until an outage could be scheduled.

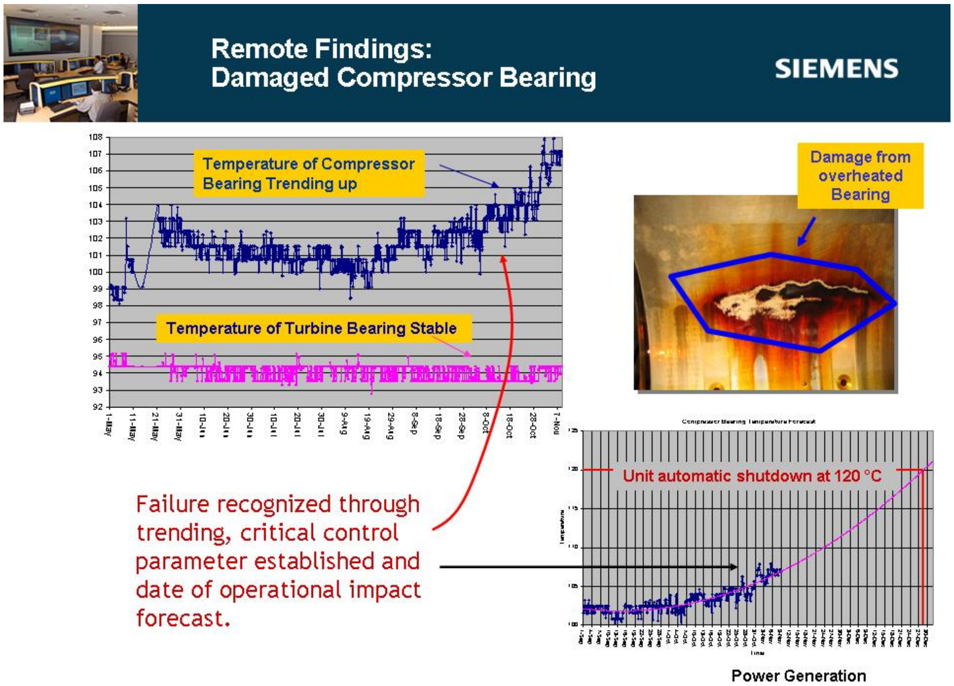

Figure 8: Early detection of a bearing issue by remote monitoring well before the I&C system would have alarmed. By counter measures the unit could be operated until a scheduled outage.

5.1.3 Example 3 – Bad Sensor

Sensors going bad are very common events in the diagnostics world. Wrong readings are a dangerous phenomenon in all regions of a power plant, as they can actually result in wrong diagnoses. A lot of effort has been made to clearly identify wrong or unreliable readings using the automated processing tools PowerMonitor and PD-Rulebase. **Figure 9** is a PowerMonitor graph clearly identifying a bad sensor. Such dramatic oscillations in the residuals simply could not be caused by a physical effect.

Compared to the more dramatic findings of the previous examples, this sensor issue does not look very spectacular; it certainly doesn't have the threat of a multi-million dollar failure. But everyone should keep in mind that continuous diagnostics is not just about finding the big issues. Bad sensors make more than 70 % of all detections made, and a sensor which has impact on protection logic could cause a major issue. Therefore the focus of continuous monitoring lies on persistently evaluating all aspects of the plant and on cooperating with the customer to maintain the sensors and other equipment of the plant on the highest level possible.

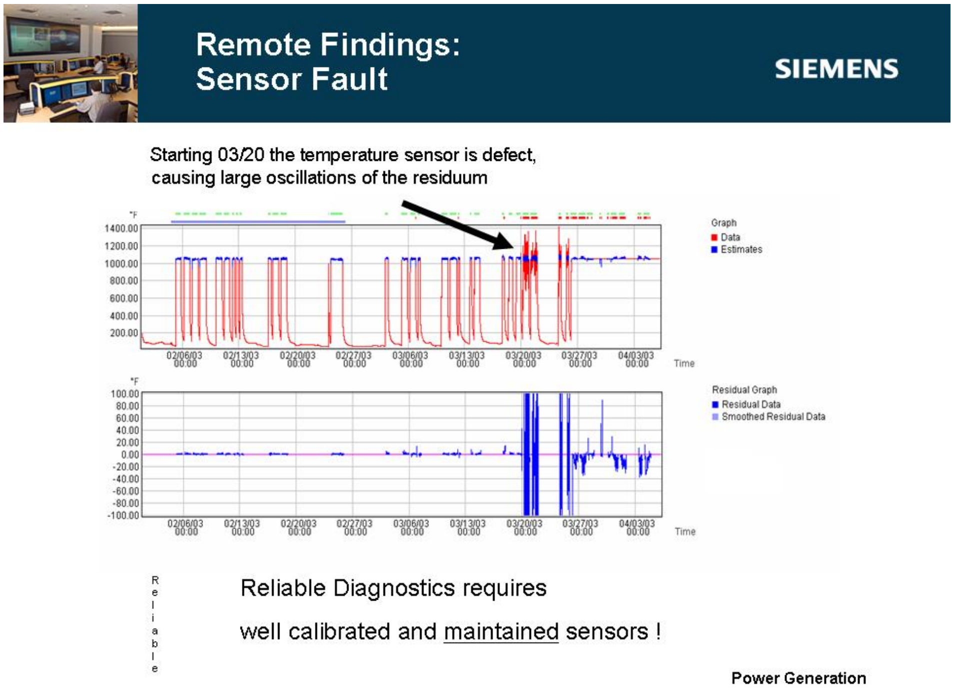

Figure 9: Example of the detection of a temperature sensor going bad.

5. SUMMARY AND CONCLUSIONS

Remote monitoring is rapidly growing in the power generation industry, and Power Diagnostics® Services is doing its part to take care of its customers. PDS provides data acquisition, analysis, storage, and versatile reporting capabilities that are used to help in the early detection of abnormal operating conditions of gas turbines and other power plant equipment. This information, along with associated recommendations, makes it possible to make more informed business decisions about the course of action regarding diagnostics issues. Fact-based decisions can have substantial financial benefits for both the customer and the OEM.
Maintaining good instrumentation health, starting reliability and optimum control settings by continuous monitoring are additional objectives that can help the operators keep plant availability high. Customers can help achieve these objectives through disciplined review, reporting, and follow-up, and addressing small issues before they combine into bigger problems. Only working hand in hand in an atmoshere of mutual trust can lead to optimum plant conditions and operation.

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