Preventing Plant Problems Before They Occur

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ABSTRACT

The process industries are facing many challenges and are awash with data that is often wasted. The costs for raw materials, utilities and energy are rising rapidly with no end in sight. There is also global warming, shortage of technical skills, loss of knowledge from an aging workforce and other big challenges to face. To overcome these challenges, manufacturing sites must focus and invest in technologies to do more with the existing resources – data, people, and systems. Failure to do so may impair the organization's ability to survive. The need to get more value from their existing data is now a high priority.

The value of this data is well recognized because, as one BASF engineer says "the process (data) always tells on itself". FALCONEER Technologies smart plant solution takes this data and adds "wisdom" or intelligence to the raw information by using engineering models (dynamic mass and energy balances) to capture the plant's process knowledge and uniquely combine with the real-time process data. This helps operators, engineers, and managers to focus on the information that's most critical to preventing problems and optimizing operations and costs, making plants smarter, safer and more profitable.

A real case study from the power industry on both the benefits and barriers to this technology will be discussed. However, this case study is also relevant to many chemical, petrochemical, and other industries that own/operate their own steam plants or co-generation plants.

INTRODUCTION

FALCONEER Technologies has developed a patented smart plant technology called FALCONEER™ IV Process Performance Solution. This solution works with a wide variety of existing process control systems to increase the value of the information available to managers, supervisors, engineers and operators. This smart plant technology leverages the information used to design and operate the process with the real-time information from the process. FALCONEER™ IV takes the data from DCS and SCADA systems and adds wisdom or intelligence to the raw information. It further provides intelligence by using the plant's process knowledge combined with the raw process data. This intelligent system comprehensively accounts for ALL process information by concurrently auditing & alerting at the highest, process-wide level as well as the individual sensor level. The intelligent software manages all the information about how the process should run (design and/or optimum conditions) and currently is running (normal, problems, out of control or out of specification). It analyzes and presents this information continuously and in real-time to the engineer, supervisor, manager or operator, helping them to focus on the information that's most critical to optimal costs and operations. Tools that are normally used offline by these groups are incorporated into a comprehensive online auditing and advisory suite. These tools include alarming, charting, reporting, emails, real-time key performance indicators, and soft sensors. Identifying and preventing a single incident can often provide immediate payback for this software.

How do managing and analyzing this information and providing the right advice at the right time in a way that facilitates the decisions help the company and the engineer prevent plant problems before they occur or become significant? For example, companies have invested in systems (DCS, Data Historians, Networks, PCs) to generate, collect and save operational information while also using it to improve control over the their systems and plants. However, most of the time, this information is not used and simply wasted, thus losing the opportunity not only to increase the ROI on this capital investment, but to fully utilize the information to identify problems and abnormal conditions.

With a smart technology such as FALCONEER™ IV in place, most of this information management process is now automated, saving the engineer's time to best use his/her skills to provide the optimal energy utilization solution rather than manually sorting through data or sitting and watching the process to figure out what is happening. It is like having a virtual engineer or supervisor doing these tasks continuously to free up the real engineer or supervisor. The most acceptable smart technology automates the data COLLECTION and ANALYSIS using the existing knowledge of the process systems, not a black box approach. For example, FALCONEER™ IV uses the design equations, the mass and energy balance equations, key performance indicators. These equations and models capture the knowledge and expertise of the engineers, supervisors and operators. These are the equations and models that the engineer used to build the process and uses, when he/she has time, to evaluate the performance of the process or to identify how to optimize energy or other parameters and costs.

Finally, it is important that smart technology can also automate the process performance auditing and advising to MAINTAIN the improved and/or optimal conditions, for this example, energy utilization. In addition, when the process system is operating at desired or target conditions, the smart plant software will diligently audit and advise when deviations or problems or failures are occurring from these normal conditions. When detected, it will also identify the most likely causes so appropriate decisions and adjustments can be made to avoid problems and to maintain proper.

PATENTED AND PROVEN TECHNOLOGY

FALCONEER Technologies FALCONEER™ IV Real-Time Process Performance Solution (*FALCONEER™*) includes sensor and process condition validation, continuous statistical process control monitoring, and predictive fault analysis. This intelligent software thus provides a single source means for complete, multi-level monitoring and analyzing all manufacturing & environmental process data in real time to identify and prevent plant problems or to optimize current process performance. This enhanced capability for process control and information systems helps improve reliability, yield and quality, avoid failures and accidents, and reduce costs. The patented smart technology is designed with many automated configuration features to significantly reduce the cost, time, and resource commitment to implement and to maintain.

FALCONEER™ consists of several software modules with display screens. These include the State Identification (**State ID**) module, the **S**ensor **V**alidation and **P**roactive **F**ault **A**nalysis (**SV&PFA**) module, the **V**irtual **S**tatistical **P**rocess **C**ontrol (**VSPC**) module and a configuration interface. This application can operate as a standalone system or run as Web service with alarm screens and information screens as Web clients with the capability of OPC messaging to notify pagers, cell phones, etc. Below is a summary of the purpose and operation of the different modules that add intelligence to the control systems and instrumentation.

State ID: The software program first determines whether the process is operating within standard conditions or not. This is accomplished with the State Identification (State ID) Module. *FALCONEER* is idle if the process is not operating intentionally in normal or standard conditions. The program begins its analysis of sensor measurements once startup is complete. It continues this analysis until the process is shutdown and then is idle again until the next startup completes. The process performance solution thus runs continuously and adjusts its analysis to current process operations accordingly.

SV&PFA: The Sensor Validation and Proactive Fault Analysis (**SV&PFA**) software module monitors current process sensor measurements to determine if they are either valid or incorrect. It also determines if certain processing faults (leaks, pump failures, controller malfunctions, etc.) are occurring or not. It does this by evaluating engineering models that describe normal process operation. By definition, when the process system is operating normally (i.e., fault free), the engineering models describing normal process operation should all close. When they don't close, this is evidence that something is going wrong in the process system. By looking at the patterns of all this evidence it is possible to infer the underlying fault(s) in the process that could cause such behavior. These results are then given as alerts to the users. If not found to be faulty, the sensor measurements are considered validated (i.e., trustworthy).

It is very common that the SV&PFA module reports more than one plausible fault at the same time, i.e., many alerts occur simultaneously. This is referred to as the diagnostic resolution of the analysis. In those cases all alerts need to be checked out further to identify the actual process problem occurring. In other words, although each alert given is a plausible explanation of the current process situation, it still needs to be verified as actually occurring or not by the user. Thus, alerts are meant to identify all the possible operating problems that can explain the process behavior currently being encountered. These alerts are continuously updated as process conditions warrant.

The evidence determined by evaluating the engineering models is combined together using a Fuzzy Logic calculation. This calculation determines a certainty factor associated with each fault hypothesis. These certainty factors can range from 0 (at least some evidence does not support that fault hypothesis) to 1.0 (that fault hypothesis is a highly plausible explanation of the current process behavior). Appropriate alerts are given if these certainty factors exceed the chosen alert thresholds. These alerts or alarms indicate that process operations are no longer considered to be normal and the identified fault may be the reason why. These threshold values, which are configurable, are chosen to be highly certain that those associated alerts are real. They make the SV&PFA module results conservative by not alerting until process conditions are well outside their normal operating ranges. The SV&PFA module should thus give few false alarms.

VSPC: The **V**irtual **S**tatistical **P**rocess **C**ontrol (**VSPC**) software module augments the SV&PFA module, providing an independent but complementary analysis of sensor measurements. The VSPC module uses Exponentially Weighted Moving Averages (EWMA's) as well as more traditional SPC approaches to determine in real-time if individual process sensors and process conditions are in control, are going out of control, or are definitely out of control. It directly flags out of control sensors and process conditions in real-time rather than after-the-fact. These alerts can also occur at levels that may allow the process operators to take appropriate control actions to reduce or eliminate disruptions to process operations or product quality. This method is considered virtual because the analysis is done automatically without the need for the operators to collect and chart any process sensor readings.

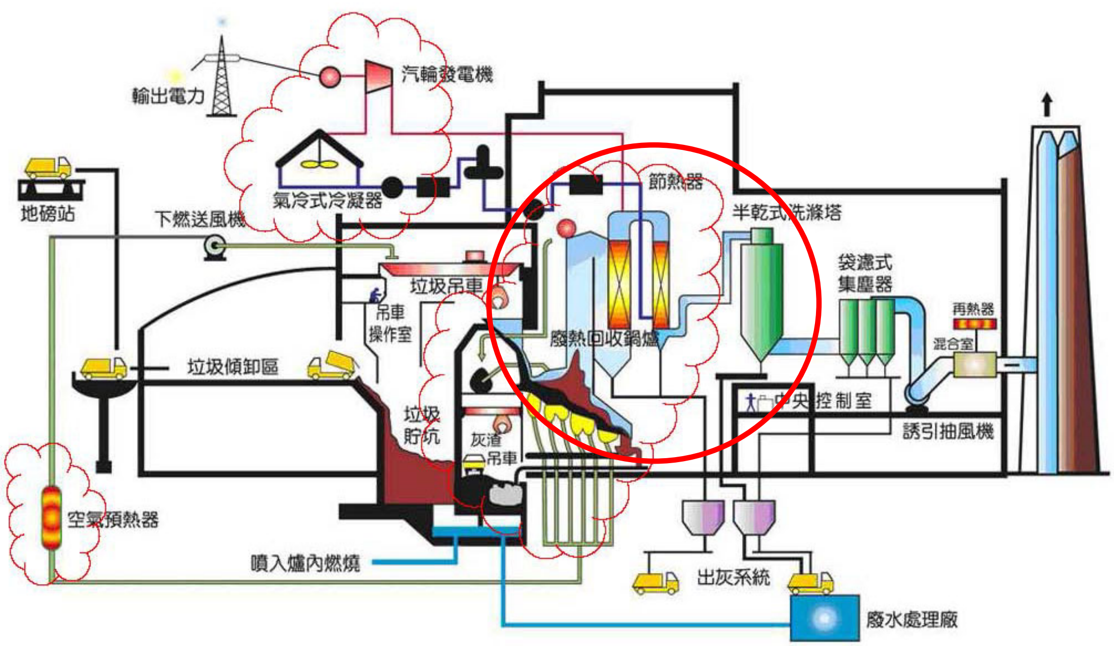
Statistical Process Control (SPC) is a tool used to assess whether a process is currently under or out of control. Various techniques exist for doing this analysis depending upon the nature of the process being monitored. In continuous processes (as opposed to the manufacture of discrete, individual units), process data collected at a particular moment in time is not completely independent of its previous data. This phenomenon is referred to as auto-correlation between the data. SPC techniques for continuous single point samples that handle auto-correlation in the data include Cumulative-Sum (CUSUM) as well as EWMA. These techniques can better handle the effects of auto-correlation and allow small but statistically significant shifts in an observed variable's value to be readily detected. With this smart technology for continuous processes, the EWMA calculation is the preferred method because of its ability to not only monitor current process operations but to forecast where the process is headed. There are two classes of sensor variables that can be used by this module: sensors that are being directly controlled and those that are not.

Since this analysis is based solely on statistical calculations, false alarms are possible. Measurements may be identified as out of control and then rapidly determined to be in control once again. Such spurious alerts can be minimized by choosing update times for the analysis that are close to one time constant for the process being monitored. However, they cannot be totally eliminated. Therefore, VSPC alerts also need to be further confirmed by the users before any control actions based on them are taken.

Combined together in an integrated smart solution, the modules provide a very complete diagnostic tool for identifying likely causes of pending problems in a timely manner so that they can be prevented. Certain problems are more easily detected by one or the other module depending on its sensitivity to the sensor measurement. In the case where the SVPFA module may identify several possible root causes, most often the correct root cause is also concurrently identified by the VSPC module.

POWER UTILITY PLANT DISCUSSION AND RESULTS

The most persuasive way to demonstrate the power of this smart technology for identifying and preventing plant problems is with actual examples. For this paper, an example will be used from a power plant that generates steam to operate turbines for electricity generation. This case study is also relevant to many chemical, petrochemical, and other industries that own/operate their own steam plants or co-generation plants. *FALCONEER™* was configured and installed on the incinerator and boiler units at the Power Utility Customer's facility as shown in the figure below.



The Power Utility Customer's facility uses a Yokogawa CS3000 DCS system for control and data collection. *FALCONEER™* pulled the data from this system into its OPC Client/Server for analysis every 5 minutes.

For the pilot, *FALCONEER™* targeted 4 process areas including the incinerator, boiler, economizer and turbines to help the Power Utility Customer in a number of ways, including:

- Saving operational costs by improved real-time on-line monitoring of key dynamic performance indicators, such as energy & natural gas costs and raw material usages. Examples include
    - Tracking Low Heating Value (LHV) KPI deviations for burning control for efficiency and stability improvements due to fuel quality.
    - Tracking Urea and Lime usage KPIs, which may help optimize raw material use and reduce costs for unnecessary chemical addition.
    - Tracking Power Generation Efficiency KPI.
- Providing timely alerts of pending sensor, equipment or process failures or abnormal conditions to avoid unscheduled shutdowns
    - Tracking Boiler Leak Detection KPI to identify possible tube leaks requiring scheduled maintenance and avoiding unplanned failures and shutdown.
    - Reducing pipe corrosion inside the furnace.
    - Tracking Turbine Performance KPIs for maintaining good equipment performance and operation conditions.
- Validating sensor data & process information to help with control decisions and to meet environmental and safety reporting requirements.
- Tracking Incinerator Operation Stability and its associated Indices related to Incinerator Temperature, Steam Production, Boiler Output O2, Stack CO, SOx, NOx, HCl
- Avoiding environmental release or process safety events from sensor or process failures.
- Saving costs from avoiding unnecessary preventative maintenance instrumentation calibration.
- Improving steam & power generation by avoiding significant fluctuations from uncontrolled process variables.

To date, the Power Utility Customer operations have already begun to realize these benefits in several important areas – 1) cost savings from KPI advising & reporting, 2) instrument fault and abnormal condition identification and reporting. The result is more power generated from the same amount of steam produced at a lower cost. More power to sell brings in higher revenues. Higher revenues with reduced costs yield greater profits!! This case study will only summarize the fault and abnormal condition identification and reporting, which are key to preventing problems before they occur or create significant issues.

Based on the P&ID diagrams and the generated historical data, models of mass balances, energy balances and process specific equations were created. Examples of these models include

- Ideal Gas Model Overfire Air Outlet
- Overall Mass Balance around Boiler Drum
- Overall Mass Balance First Preheater
- Steam & Water Mass Balance on Boiler
- Low Pressure Steam Overall Energy Balance
- Economizer Overall Energy Balance

With these models, process and instrument fault diagnosis and analysis is achieved for the combustion system, the boiler system, feed water system, and the economizer system, with total of 59 critical tags covered with both the SVPFA and VSPC modules. When an abnormal situation occurs (sensor failure, process upset, equipment problems) involving the measured tag, *FALCONEER™* uses the model residuals and patent pending fuzzy logic estimation results to distinguish the possible abnormal tags. At the same time, it can determine the faulty tags' estimated value for operators to review in order to prevent operators from continuing to use the wrong measured values. Using wrong values can cause operators to make wrong operational decisions leading to poor and costly operation and/or high emissions. Early detection of the abnormal issues for tags allows operations and maintenance time to investigate or adjust the corresponding tags' reading or related equipment and control values. This timely response helps reduce the likelihood of unscheduled (and costly) system shutdowns or outages. In all cases, plant problems can be identified sooner and mitigated or prevented

FALCONEER™ can be configured to include unmeasured variables such as leaks in process lines and tanks. Standard practice is to configure inlet stream leaks downstream from the flow meters and outlet stream leaks upstream from the flow meters. Such a leak detection system was created for the Power Utility Customer. For the purpose of boiler leak detection, *FALCONEER™* system setup virtual leak indicators as unmeasured variables and used these unmeasured variables in the mass balance models in order to help to identify possible boiler pipe leak conditions.

After completing the model configurations, several simulation tests, both offline and online, were performed to validate the fault diagnosis functions. These test results indicated that the *FALCONEER™* system can successfully provide timely and correct proactive fault diagnosis while validating instrument performance.

FALCONEER™ PROCESS VALIDATION & ABNORMAL CONDITION DETECTION RESULTS

For real-time validation and abnormal condition or fault detection, *FALCONEER™* is equivalent to a very intelligent engineer or operator looking at all the information and evidence. If the process conditions exist such that the evidence is clear and the cause of the fault can be found quickly, then *FALCONEER™* will find it as would a person looking through the data if they had the time. If the process conditions exist such that the evidence is weak or there are other problems that might be confusing or slowing down the analysis, *FALCONEER™* will eventually find the problem whereas a person might not or would take a long time to find the problem if they were actually looking.

Subsequently, the opportunity to use *FALCONEER™*'s additional troubleshooting and optimization capabilities was also evaluated. Live testing demonstrated *FALCONEER™*'s ability to effectively identify and communicate pending problems and abnormal conditions before the current control system alarms would detect these situations. During the duration of the pilot, *FALCONEER™* was able to validate critical process instrumentation and identify several examples of both abnormal conditions or failures or changes to the process.

In each case, faults and problems were identified correctly by one or more combinations of *FALCONEER™* integrated methods and modules:

- By Virtual Statistical Process Control (VSPC) Analysis
- By Sensor Validation & Proactive Fault Analysis (SVPFA)
- By both SVPFA & VSPC alarms when other possible causes do not have VSPC alarm

- By SVPFA & Estimated Value/Data Reconciliation analysis when other possible causes do not have reasonable estimated values assuming they were actual fault.

In all cases, detection and alarming occurred and was reported in less than an hour from the start of the problem or abnormal condition. This response is quicker than operations would likely have detected the problem unless they were lucky enough to be looking at that particular information at the right time and recognized the event before it triggered a High High or Low Low control system alarm.

A) Fault and Abnormal Condition Testing & Reporting

First, one important capability that the Power Utility Customer wanted was to identify and advise on instrumentation and process problems, failures, abnormal conditions in advance of control system High High or Low Low alarms that might also be associated with interlocks or lead to costly unplanned outages. The critical instruments, the conditions tested and the test objectives were the following.

Test	Test Conditions and Objectives	Tag
1	Simulate a leak from a pipe from boiler that doesn't contain any measurement instrument and hence, in the DCS operation control system, the balance of feed water and generated steam is messed up. The purpose for doing this is to have *FALCONEER*™ generate both leak alarms and KPI3 leak detection BEFORE DCS generates alarm associated with the FIC-06101A (there are no DCS leak detection alarms).	**FIC-06101A**
2	Generate abnormal low feed water flow from slowly declining (due to plug, instrument drift, poor control, etc.) flow so that *FALCONEER*™ can generate alarm before the DCS low-low alarm to occurs due to the low feed water flow. In addition *FALCONEER*™ should estimate the actual flow value for operations to use.	**FIC-06101A**
3	Generate primary air outlet temperature (TI-05114) abnormal condition or fault (especially low temperature condition) and the related primary air preheater flow (FIC-06106) condition or fault. The purpose for doing this is to have *FALCONEER*™ generated alarms for TI-05114 and FIC-06106 separately before the DCS alarms.	**TI-05114** **FIC-06106**
4	Generate the economizer flue gas outlet temperature (TICR-07113) abnormal high condition or fault. The purpose for doing this is to have *FALCONEER*™ to point out the TICR-07113 problem and calculate its actual temperature before the TICR-07113 temperature causes the DCS high-high alarm to occur.	**TICR-07113**

Two types of testing were conducted.

Simulation Test:
The test simulates the process operating at well controlled or ideal process operating condition (all model are well behaved and close). This test is done by manually changing the desired

test tag value on the OPC server (using KEPware Quick Client) and keeping all other tags' values unchanged. The purpose of this test is to show the *FALCONEER™* system's ability to diagnosis the fault tag and generate the SV&PFA and VSPC alarms as well as give a reasonable estimation or reconciliation of the actual field value. The simulation test results indicated that at present established models can successfully and quickly provide correct SVPFA diagnosis and VSPC analysis for all related problems.

Online Test:
Using current normal operating process conditions, the tag's value is changed manually on the OPC bridge (by multiplying the current DCS value by a factor to simulate abnormal differences from current DCS's value). The other tags' values vary as the current operating process conditions normally would behave. This testing is used to test whether or not *FALCONEER™* system can detect the fault and generate SV&PFA and VSPC alarms as well as give a reasonable estimation value under more realistic operational conditions.

TEST 1 (FIC-06101A: Boiler Feed Flow)

When FIC-06101A fault condition is created, this condition simulates both a flow or instrument problem and/or a possible boiler leak problem (if there is a pipe leak, then the control system would maintain the level balance and hence cause FIC-06101A to increase), *FALCONEER™* system's diagnosis result and simulation result is consistent – it identifies the fault correctly.

However, at the same time *FALCONEER™* generates LeakF06106, LeakF06102B as well as Leak F06101 SVPFA alarms. These alarms indicate that there are possible pipe leaks and simultaneously *FALCONEER™* system provides reasonable estimates of the size of these pipe leak quantities (around 3000~4000 Kg/Hr).

Test 1 results indicated that *FALCONEER™* system is capable to detect the boiler leak and or instrument problems, thus helping to prevent ensuing plant problems.

TEST 2 (FIC-06101A: Boiler Feed Flow)

When FIC-06101A slow declining failure condition is created, *FALCONEER™* system can immediate detect VSPC alarms. As the factor is decreased to simulate this abnormal condition, the SVPFA module's certainty factor is slowly increasing as it should. Finally, *FALCONEER™* system can generate the SV&PFA alarm and maintain this alarm state until the testing is over.

Simultaneously, *FALCONEER™* system can precisely detect the fault and no other fault alarms are generated. These alarms are well before DCS high and low alarm conditions, thus helping to prevent ensuing plant problems.

TEST 3 (TI-05114: Primary Air Outlet Temperature & FIC-06106: Primary Air Preheater Flow)

When TI-05114 high fault condition is created, *FALCONEER™* system can precisely detect the fault and generate the SV&PFA as well as VSPC alarms. However, when the TI-05114 low fault condition is created, *FALCONEER™* system can detect this fault, but at the same time generates other possible fault alarms that can also be explained by the current process condition evidence in the same process (secondary air heater).

At the same time, however, TI-05114 is the only tag that generates a VSPC alarm and these combined alarms correctly identify the most likely cause of the process behavior. So the TI-05114 low alarm, even with the other process fault alarms, can indicate possible process problem and abnormal condition issues.

When FIC-06106 is 15% higher than the real value, *FALCONEER™* system can precisely detect the fault and generate SV&PFA as well as VSPC alarms. When FIC-06106 value is only 10% lower than the real value, *FALCONEER™* system can detect the fault but also generate other process fault alarms (FIC-06101A and other Leak tags). Nevertheless, these alarms are consistent to the boiler system's pipe leaking condition; therefore, it can be thought as some valuable or useful alert to guide efficient troubleshooting.

Test 3 results indicated that *FALCONEER™* system can detect faults and abnormal conditions before the DCS High and Low alarms, thus helping to prevent ensuing plant problems.

TEST 4 (TICR-07113: Economizer Flue Gas Outlet Temperature)

When TICR-07113 high fault condition is created, *FALCONEER™* system can precisely detect the fault and generate SV&PFA as well as VSPC alarms. When a low fault condition is created, only a VSPC alarm is generated, which is sufficient. However, when a lower fault condition is created, *FALCONEER™* system can detect the fault and generate SV&PFA as well as VSPC alarms, but two additional fault alarms (AIR-07113) and (TI-06101A) have been generated that can also be explained by the current process condition evidence.

At the same time, however, TICR-07113 is the only tag that generates a VSPC alarm and these combined alarms correctly identify the most likely cause of the process behavior. So the TICR-07113 low alarm, even with the other process fault alarms, can indicate possibility of process problem and abnormal condition issues in a timely manner for problem prevention.

Test 4 results indicated that *FALCONEER™* system can achieve TICR-07113 high fault diagnosis, but the low fault's diagnosis precision needs further improvement if this condition becomes important for early detection (it currently is not critical).

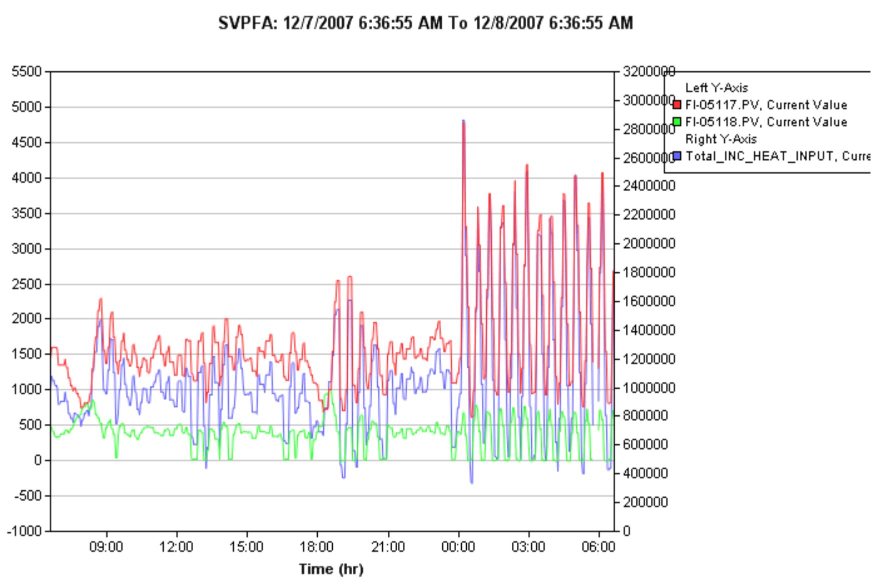
Conclusion:

For the 4 critical conditions tested with the *FALCONEER™* system through simulation test and online test, *FALCONEER™* system can detect the related tag or process problems and generate VSPC as well as SV&PFA alarms. Simultaneously, it can calculate the estimated or reconciled value that is consistent enough to the real value to be used for control or manual operation decisions. Testing results proved that *FALCONEER™* system related functions or tools can help the Power Utility Customer save unnecessary expenses, create even higher efficiency, and help to reduce the Power Utility Customer safety and operational risks at the same time – all while helping to prevent problems before they occur or become significant.

B) Actual Examples of Fault or Abnormal Condition Detection and Reporting:

Finally, two specific examples are provided of how *FALCONEER*™ features, dashboards and charts help identify abnormal conditions and problems in a timely manner so operators and engineers can adjust or address the situation.

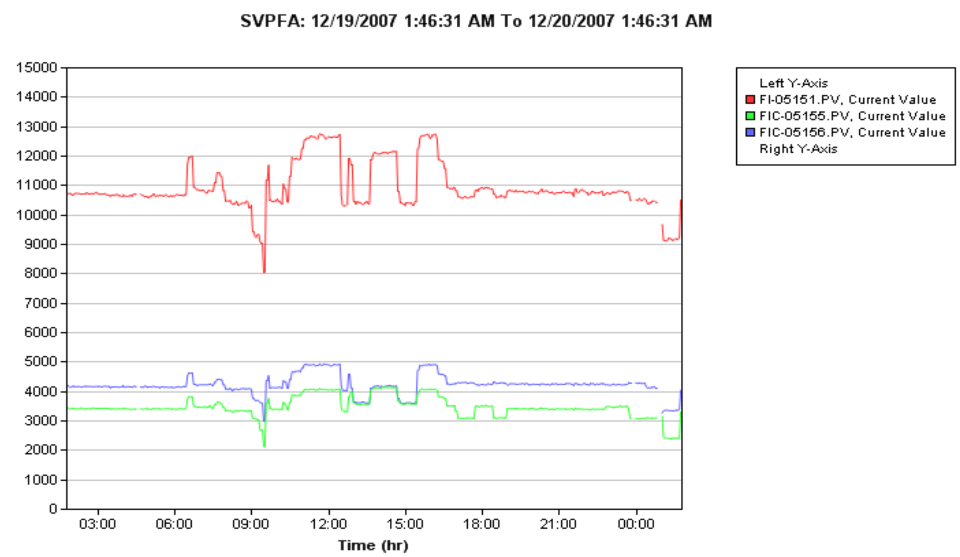
In the first example, there was a significant change in the variability of FI-05117 (Low Pressure heating steam flow of steam air preheater) and FI-05118 (High Pressure heating steam flow of steam air preheater). *FALCONEER*™ intelligent advisory alerts correctly identified this problem. It seemed to be directly related to a significant change in the variability of the "Total Heat Input to the Incinerator" – a calculated tag not previously available to operations, which is a factor for the incinerator control. This situation is shown in the Figure below using a *FALCONEER*™ multi-point trending chart.



In the second example, one of three tags associated with a diagnostic model seemed to be significantly different in December and January than the original historical data set from July. The explanations for this condition were either a fault, failure, abnormal condition or approved changed from previous performance. Using a combination of dashboard alarms and alerts with charting and trending features, this situation was discovered by *FALCONEER™* for the following tags: FI-05151 - Air flow on overfire air fan inlet; FIC-05155 - Overfire air flow on BL side; FIC-05156 - Overfire air flow on BU side.

FALCONEER™ was telling operation that either FI-05151 was significantly or abnormally higher than expected or FIC-05155 and/or FIC-05156 were significantly or abnormally lower than expected or there was a leak in the system.

In this case, FI-05151 was significantly higher (10,000 to 11,000 NM3/hr) than its historic average (7,000 to 8,000 NM3/hr), since it should be the sum of the two controlled flows. In fact, the Power Utility Customer engineers therefore found this tag to be reading incorrectly and recalibrated it for proper operation.



SUMMARY

The smart technology described comprises several modules providing continuous process performance auditing and optimization, sensor and process abnormal condition monitoring and detection, and sensor and process validation and reliability. All work together in a patented solution that can help to detect and prevent plant problems.

Simulated faults or problems were created for several critical instruments. In all cases, detection and alarming occurred and was reported in less than an hour from the start of the problem or abnormal condition. This response is quicker than operations would likely have detected the problem unless they were lucky enough to be looking at that particular information at the right time and recognized the event before it triggered a Hi Hi or Lo Lo control system alarm.

Several abnormal conditions have been detected and reported to operations. In some cases corrections or adjustments by maintenance or operations were made in a timely manner. Several instruments were found to require recalibration or adjustments to their control parameters compared to expected normal operational performance.