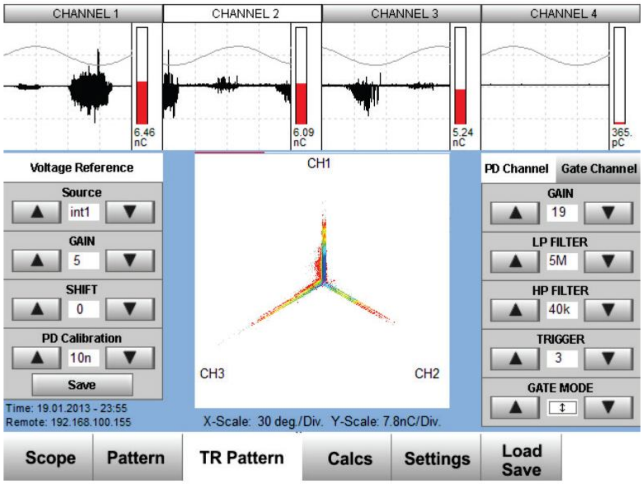

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X-Scale: 30 deg./Div. Y-Scale: 7.8nC/Div.

PD Channel | Gate Channel
GAIN: 19
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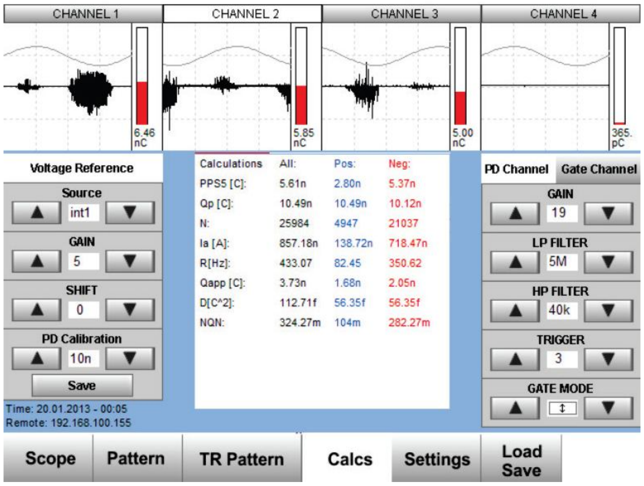
HP FILTER: 40k
TRIGGER: 3
GATE MODE: ↕

Fig. 12: Time Related Pattern



Voltage Reference
Source: int1
GAIN: 5
SHIFT: 0
PD Calibration: 10n
Save
Time: 20.01.2013 - 00:05
Remote: 192.168.100.155

Calculations	All:	Pos:	Neg:
PPS5 [C]:	5.61n	2.80n	5.37n
Qp [C]:	10.49n	10.49n	10.12n
N:	25984	4947	21037
Ia [A]:	857.18n	138.72n	718.47n
R[Hz]:	433.07	82.45	350.62
Qapp [C]:	3.73n	1.68n	2.05n
D[C^2]:	112.71f	56.35f	56.35f
NQN:	324.27m	104m	282.27m

PD Channel | Gate Channel
GAIN: 19
LP FILTER: 5M
HP FILTER: 40k
TRIGGER: 3
GATE MODE: ↕

Fig. 13: IEC Standard related measurement results

PD system shall be designed for harsh environment as for power plants or field testing. The installation of the system shall be possible with the minimum needs of cables, devices and boxes. Therefore, it is important to select compact and industrial PD system which is perfectly adapted including all features necessary for accurate and robust data acquisition. Various available enclosures from simple 35mm DIN Rail mounting or 19” rackmount covers most of customers requirements. Special attentions shall be taken wall mount enclosure, which is the ideal and cost effective solution for inside and outside installation with IP65 protection.

Profile of presenter

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A New Technology for Bunker/Silo Storage Weight and Level Measurement – ™

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Keywords

Bulk storage monitoring, silo inventory management, level measurement, weight measurement, bolt-on sensor, strain sensor, StrainCell

Abstract

Inventory monitoring of bulk materials stored inside silos, bunkers, or bins has historically presented challenges in accurate measurement, especially for skirted vessels. Monitoring methodologies have settled into two categories: level measurement and weight measurement. A variety of instruments, all with their own advantages and disadvantages, have been marketedin each category. Now a new bolt-on sensor technology has been invented, developed, and tested that offers continuous measurement data, tracking weight and level simultaneously with high accuracy. Field tests of performance have shown accuracyresults of better than 3% of full scale on steel skirted silos and 1% of full scale on steel vessels supported by legged structures.

Introduction

Accuracy in bulk storage monitoring is critical because (a) unexpected exhaustion of raw material inventories results in production downtime; (b) running out of material maydamage production equipment; (c) overflow spills are costly; and (d) serious discrepancies between actual inventory and company books is problematic for accounting reconciliation. Silo inventory management requires continuous, accurate data, but historically the available technologies have limited the industry.

Devices providing an indication of the level of the raw material inside the storage vessel often report erroneously because the material is rarely distributed with an even surface: The stored material forms peaks and cones in fill operations, and voids, avalanches, and funnels when material is drawn out. Conversion tables are then used to compute weight of the stored material, but conversion tables do not account for density variation, which is related to the temperature of the material and even to the method of loading material into the vessel. These level measurement errors combined may add up to 20–30% of full scale.

A weighing system, by contrast, is installed on the outside of the vessel and is therefore not hindered by the behavior of the stored material. Load cells offer the highest accuracy because their sensing elements are built into the vessel support structure, but they are generally too expensive for retrofitting existing silos, bins, or bunkers.Bolt-on strain sensors were historically hampered by the persistent problem of impact of temperature on sensor signals. In performance tests (Figure 1), bar-shaped and L-shaped bolt-on sensors reported errors as much as 30% due entirely to changes in temperature. During the illustrated test, ambient temperatures ranged from 65ºF (18ºC) to 107ºF (42ºC).

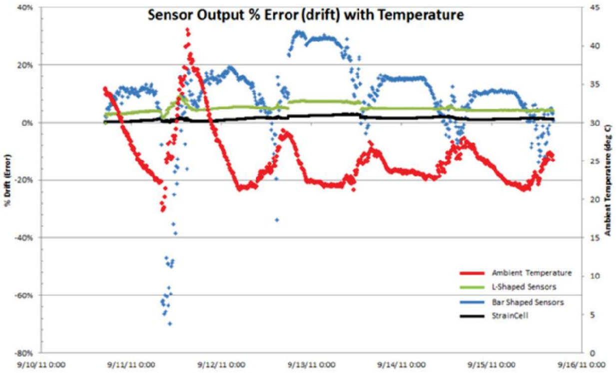

Figure 1. The new-technology sensorcompared withL- and bar-shaped sensors

Now a new technology for bunker/silo storage weight and level measurement has been proven to resolve the drawbacks not only of previous level measurement devices but also of earlier bolt-on weight measurement sensors.

Definition of the Technology

The new, patented technology (Figure 2) is a sensitive, dual-axis strain gauge invented by Walter Kistler to overcome the prevailing problem of temperature effect on readings in bolt-on sensors.The technology is used for accurate inventory monitoring of materials in bunkers, silos, and other bulk storage vessels. It installs with a single bolt to the external surface of the vessel support structure to provide nonintrusive, continuous monitoring of both weight and level. The sensor is paired with electronics that enable remote, as well as on-site, monitoring of readings.

Figure 2. New-technology, bolt-on strain gauge

Why the Technology Is Different

In physics, stress refers to a force or weight applied to a structure, and strain is the resulting compression of the structure under load. When steel silos or bunkers are supported by steel legged or skirted structures, measuring the strain in the support structures provides a means of monitoring the weight and volume of the vessel contents. Bolt-on sensors in the past have been designed to measure strain on a single axis, since loading or drawing materials will change the compression of the vessel in a single direction. This measurement – in thousandths of an inch – would be easy enough to monitor if the vessels were located indoors so that the only stress on the vessel was from the actual load of bulk storage contents. Instead, they are located outdoors, where solar radiation and resulting thermal changes have a huge impact. When sunrays hit the support structure and the instrument attached to it, the temperature fluctuation changes the length of the structure and of the instrument, and this fluctuation is reported in the signal as a change in strain. These temperature-induced changes in strain may be many times greater than the difference in length caused by the material inside the vessel. Further, the sun is often not hitting the structure uniformly, making it even more challenging to measure the very small changes resulting from stress and strain, and not the often much bigger change due to solar radiation.

The new technology mechanically compensates on dual axes against expansion and contraction due to temperature, amplifying deflections and distortions so that when the two directions expand or compress the same amount, there is no impact to the signal. By measuring in two directions, the sensor greatly minimizes, and often completely eliminates, signal fluctuation caused by temperature.

Technology Performance

For several months in 2012–2013, the technology underwent performance tests in direct comparison with reference load cells, which provided a means of verifying load and draw weights. The test vessel was a low-psi (1375 psi) skirted silo with an operating capacity of 165,000 pounds. Following the company's application engineering procedures, four of the new sensors were installed on the skirt. Display and electronics hardware were installed in the manufacturing area. Through several remote displays, silo weight readings were continuously monitored remotely, and daily weight readings were recorded from both the test system and the reference load cell system. After initial monitoring of the silo for several weeks, a customized calibration curve was generated, and calibration parameters were entered to the software/electronics remotely via email transmission. During the test period, ambient temperatures varied from 35 to 50 degrees F, with sporadic sunshine.

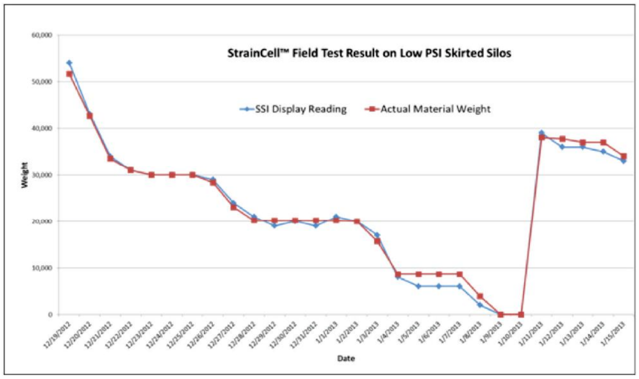

Figure 3. Field test readings from the new technology (blue) and reference load cells (red)

Data collected from the test weighing system and the load cells were plotted over time. The four-week test segment shown (Figure 3) started after the silo owner loaded 54,000 pounds of material into the silo. As material was drawn for production, the new technology being tested continued tracking the weight changes all the way to the point that the silo was empty. While the silo was empty, the test system continuously indicated a zero (silo empty) value and started picking up weight changes as the silo was reloaded with material.

Because the system includes smart algorithms in the electronics and the sensor is intrinsically temperature compensated, fluctuations in the measurement system during the test remained within 2,000 to 3,000 pounds (less than 2% of full scale) of the actual material weight as the raw material was drawn for production. Based on the reference load cell measurements, the test system readings stayed within an error band of 2% of the 165,000-pound silo throughout the test. The total error band statement includes maximum uncertainty errors for linearity, hysteresis, short-term repeatability, temperature drift, zero offset, full span offset, and all other errors caused by the external factors.

Applications

Bulk storage vessels vary by their support structure: legged vessels rest on I-beams, H-beams, square or rectangular tubing, or round tube legs. Skirted silos are supported by a series of steel panels surrounding the silo, protecting the cone and distributing weight to the ground. All of these support structures are used for placement of sensors, with best placements determined through application engineering procedures applied to each unique situation.

Stored materials are commonly coal, iron ore, plastic pellets, flour, cement powder, limestone, gypsum, and foaming liquids.

Connectivity Options

Weight and/or level measurement readings are viewable on-site or anywhere in the world via output interfaces for USB, Ethernet, 0-20 mA, 4-20 mA, 0-10 V, and R232/485. Applications and software programs for Android-based and Windows PC platforms enable monitoring, calibration, and troubleshooting remotely via cellphone, tablets, and private or publicnetwork computers.

Kennan Yilmaz
President, Strain
Systems Inc.

Kennan Yilmaz, a native of Istanbul, Turkey, is the President of Strain Systems Inc., based in Bellevue, Washington USA. He is responsible for all facets of the organization and management of the company, which provides inventory monitoring and process control for bulk storage silos, bunkers, and tanks.

Real time Process Improvement and Diagnostic for a Thermal Power Plant with Optimization & Expert Systems

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Key words

Thermal power plant, Boiler, turbine, plant chemistry, Optimization, neural networks, genetic algorithm, fuzzy curves and surfaces, Self Organizing Maps.

Abstract

Thermal power plant operations involve varied aspects and challenges associated with them. On one side it is important to optimize controllable parameters to maximize efficiency, while on the other side, maintaining plant chemical parameters is also of utmost importance. Both main plant and chemistry operations are vastly interrelated and complimentary to each other.

To optimize such varied areas of process, experts systems are need of the hour. NTPC is continuously working in the field of developing expert systems for various power plant aspects. The present paper focuses on two of process improvement aspect; one is for plant operation improvement by optimizing plant controllable parameters and providing advisory tool to the operator, another is plant chemistry process improvement by providing expert system tools to shift chemists, operators and other related plant personals.

INTRODUCTION

Thermal power plant processes are very complex, nonlinear and dynamic which behave differently with different operating, ambient conditions and operator's experiences. The complexity further aggravate due to the disturbances particularly for Indian conditions such as varying coal quality; high ash content, varying load demands, grid instability etc. hence posing challenges to maintain design efficiency of the plant.

On the plant chemistry side, in a typical power plant the deterioration of the chemical properties of working fluid water threatens the integrity of the plant equipment such as condenser, boiler, turbines and heaters. A major goal of plant chemical control is preventing solids build up and corrosion in the plant. The role of water chemistry in a plant is paramount, particularly for sub & supercritical boilers in preventing corrosion related failures. Real time monitoring & inspection of steam cycle chemical parameters provides a reliable and efficient method of controlling desired water chemistry to achieve the targets of reducing boiler tube leakages and reducing overhaul duration.

With the availability of real time process parameters through data historians, there is abundance of process data. However, with such huge data bank, it is very important to deduce the knowledge with the help of some intelligent tools. Also, NTPC has vast experience of power plant operations and control, so domain expertise is already available. Thus it is very much possible to tap that domain expertise, operations experience and to convert them into some tangible form using some tools. These tools once configured will automatically provide knowledge in real time. This knowledge can then directly be applied to achieve gain on efficiency or process improvement front. Such intelligent systems which are also commonly known as Expert Systems provide an excellent way to convert such a huge amount to data to some tangible and quantitative knowledge terms.

NTPC NETRA has developed several expert system tools targeting efficiency improvement and plant chemistry optimization. These software applications are already running in various NTPC plants. Replication to other NTPC units is also under process.

The paper describes methodologies to develop such expert systems in detail. The paper also provides the implementation details along with few case studies and results.

ARTIFICIAL INTELLIGNEC BASED REAL TIME OPERATOR ADVISSORY SYSTEM FOR PERFORMANCE IMPROVEMENT

Real time Boiler operation under optimum conditions implies efficient fuel combustion and reduced fuel cost for the same amount of electricity generated. A modest efficiency improvement of 0.5% in boiler efficiency for a 500 MW boiler at a pithead station should result in a huge annual saving. However operating boiler in an optimum zone is always a challenge due to many factors. Different boilers in the same station are being run under different operating regimes with no clear cut criteria. Setting of operation regime is highly depended on operators' experience, OEM's recommendation which many a times do not lead to optimum operation. The boiler and turbine testing for heat rate improvements are carried out at purely steady state with complete watch on operating parameters. These challenges for meeting the operational goal in real time require that an increasing amount of information to be simultaneously evaluated.

As a result of this increasing complexity, traditional single-value cause and effect models have reached a peak in their ability to address these operational goals. Artificial Intelligence (AI) is a modern tool that can be assigned the task of constantly reviewing recent data to aid in making multivariable decision to achieve goals. AI attempts to model complex processes using learning means rather than predefined equations or algorithm. The various operating parameters that are involved in control and optimization of power plant overall efficiency are one example of the kinds of complex interactions which can effectively address by using Artificial Intelligence. Various nonlinear parameters viz. WB press, FAD position, burner tilts, metal temperature etc. for which writing mathematical equations for plant efficiency is not possible, can easily be correlated with plant efficiency using Artificial Neural Network (Branch Of AI). Online retraining of ANN, addresses the model development for modified operating conditions, seasonal variations etc. very efficiently. Application of Evolutionary algorithms like Genetic Algorithm (GA) (another branch of AI) known for searching global optimum conditions eliminates the problems of incorrect advisory due to local optima in any other traditional optimization techniques. Further with advent of sensor, other monitoring techniques viz. flame imaging and advance control like model predictive control etc. this real time optimization using AI shall be able to give very accurate and powerful solutions to plant optimization.

The proposed system development involves multi-objective constraint optimization. The system suggests the updated set points for O2%, wind box pressure, FAD position, burner tilt, Coal flow, mill combination etc in order to directly maximize the boiler efficiency. The system also indirectly minimize TG Heat rate by reduction in left/ right steam temperature imbalances, reducing spray, maintaining metal temperature at its best through constraint optimization. The overall system as shown in Fig. 1 consists of a predictor, an optimizer, a fault detector and a family of mathematical models for SG-TG cycle. Predictor is developed using Fuzzy curves & Surfaces (FCS) and Neural Networks. FCS is used for input space compression for predictor and Neural Networks is used for modeling of Predictor. Optimizer is implemented using Genetic Algorithm and Fault detector comprises of Self Organizing Maps (SOM) for sensor failure and hybrid of GA and mathematical model based Data Reconciliation module.

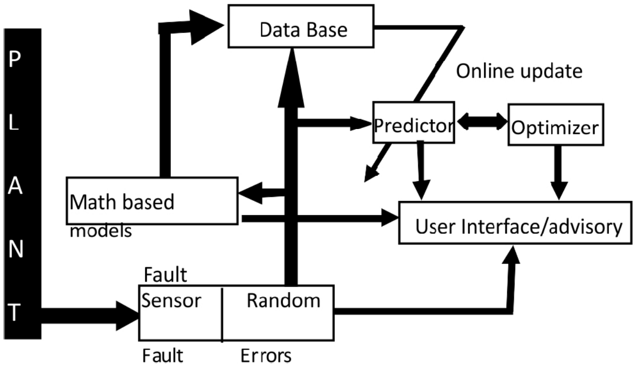


Fig. 1. System Architecture of AI Based Online optimizer

The system has been developed for a NTPC unit. As an initial step to the model building process, all the important online measurements required for the performance modelling were identified, added and validated using offline instrument / analysers. Oxygen probes and Temperature thermocouples in flue gas ducts at air heater inlet & outlet relocated to representative locations. To collect data of wide variation, a test matrix has been framed in consultation with plant operation by fixing maximum and minimum value of a controllable parameter and various Mill combinations. Training data was collected by conducting test in the running plant. Stable operating test conditions were set for a minimum of 2 to 3 hours prior to start of each test run.

Fig. 2. Screen for AI Based Optimizer

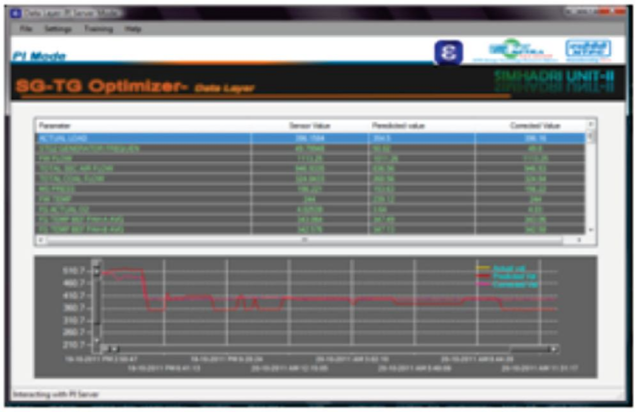


Fig. 3. User Interface for Data Validation

The system provides an operator advisory Graphical User Interface (GUI) as shown in Fig 2, displaying the recommended value of the controllable parameters and the predicted results of the objective functions on a real time basis. The GUI of system also consists of screens for tracking process data errors and sensor failure detection as shown in Fig 3, and displaying valuable process information to the operator that otherwise are unavailable normally. The backend comprises of hybrid of mathematical and data driven models where data driven models are used for predicting and optimizing purpose and mathematical models are used for knowledge base up-gradation and fine tuning of data driven models providing flexibility and robustness at the same time.

REAL TIME EXPERT SYSTEM FOR PLANT CHEMISTRY PROCESS IMPROVEMENT

Water and steam are the crucial components of any steam-driven power facility, and proper chemistry control is critically important to plant operation, reliability & the bottom line. Improper plant chemistry management can lead to various chemistry related issues which can be detrimental and can directly affect plant availability. Some of the common issues are boiler tube failures, turbine & boiler tube wall depositions.

Boiler tube failures continue to be the single largest source of forced outages and a concentrated effort is required to minimize boiler tube/condenser tube failure occurrences in industrial type steam generators. The combined effects of corrosion, scaling, stress, temperature, erosion and vibration cause deterioration of boiler/condenser tube material properties and reduction in wall thickness. Most of these problems are caused by transients such as start & stop of units, change in load, etc, rather than routine operational procedures. Therefore, it is essential that incipience of deviations from normal water chemistry be promptly recognized and factors causing these deviations be removed in a timely fashion.

In comparison to grab sample analysis, real-time online measurements are more representative of the water chemistry at the instant of measurement. Tracking short term water chemistry transients with on-line monitoring equipment ensure, rapid warning of water chemistry changes may be caused by cooling water ingress, inadequate water treatment, or condensate polisher malfunction, thus allowing speedy corrective action and minimization of resulting damage to operating equipment (e.g. in the steam/water cycle), optimization of cleaning schedules for heat transfer surfaces etc.

There are three critical aspects of monitoring instrumentation for fossil plants: (i) the installed cycle chemistry instrumentation (ii) the sampling methods and (iii) the sample frequency. These are sufficient to provide early alert of any deviation from the guided limits considered best practice.

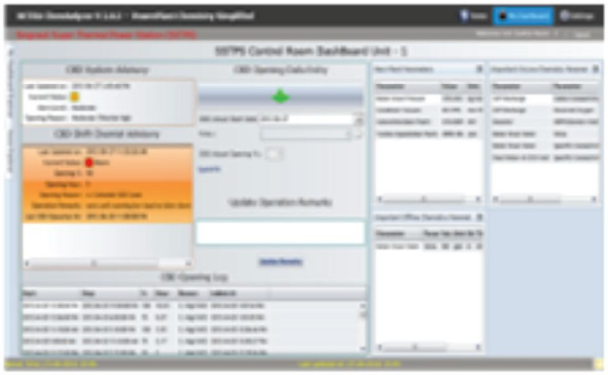
With the advent of supercritical units power plant chemistry management became even more crucial.

Plant chemistry norms are even more stringent in the case of super critical units. Also, there are various different water treatment regimes such as AVT (All Volatile Treatment), AVTR (AVT – reducing), AVTO (AVT – oxidizing), OT (Oxygenated treatment). Few power plant units use different water chemistry treatment for different phase of plant operation such as alkaline treatment for startup and OT for full load operation. Therefore, it is important to manage plant chemistry according to plant status as well as water chemistry treatment / metallurgy etc.

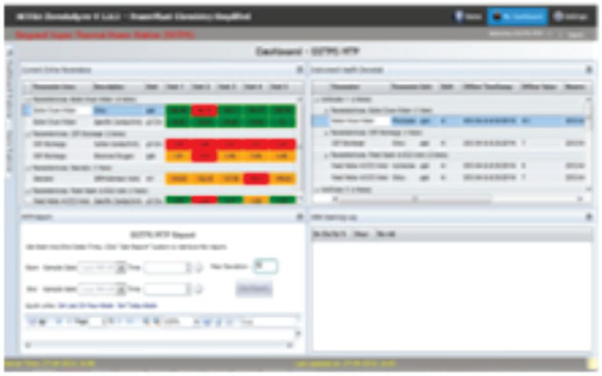
Real time chemistry parameters provided from various online analyzers provides surplus amount of data. However, there is a need to convert the huge amount of data into some useful & meaningful information where domain expertise of plant chemists could be used. Domain expertise of plant chemists could be tapped and can be converted into some tangible form which can be used in real time to manage plant chemistry in a more efficient manner.

Statistical models using non-linear regression analysis is also used to create various soft sensors for power plant chemistry calculations. EPRI, PPCHEM and other literature work provide various correlations among chemistry related parameters. These correlations can be converted to mathematical equations using non-linear regression analysis. At run time, these models can provide various predictions such as boiler drum chloride, feed water ammonia, and feed water CO2. Such calculations along with various online chemistry parameters can be feed to various fault detection algorithms to generate fault cases, notifications and advisories.

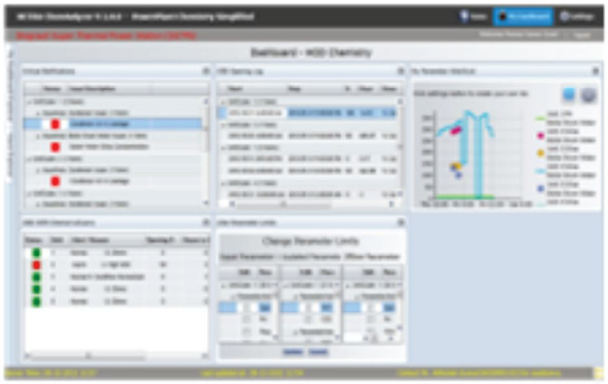
Role: Shift Chemist



Role: Unit Control Room



Role: MTP



Role: Chemistry head

Figure 4: Role based dashboards

The system provides user interface as depicted in Figure 4, which shows various chemistry related parameters online values for different role through role based dashboards. System also shows current values of various calculated parameters based on different non-linear regression models. Based on current parameters and domain expertise, system finds the current status for various chemistry related issues such as condenser leakage, condenser air-in leakages, boiler water contamination, need of CBD operation (Continuous Blow Down), need of dozing (HP and LP dozing), colloidal silica passing, phosphoric acid formation etc.

SOLUTION ARCHITECTURE

Expert systems described above are integrated into robust solution architecture. The solution is developed on industry standard Service Oriented Architecture (SOA) and thus can be integrated seamlessly with existing, future or legacy systems.

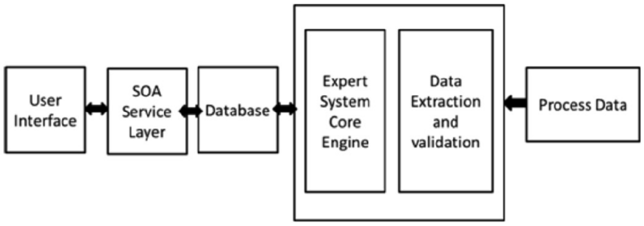


Fig 5: Solution Architecture of expert systems

Typical solution architecture of developed expert systems is shown in figure 5. First of all process data got extracted and validated and then fed to expert system core engine. The core engine then performs certain calculations, run models, provide predictions, and provide advisories.

These values, calculations, predictions and results get stored to database. SOA service layer provides many services to access the database. User interface utilizes the service layer and show the values, calculations, predictions & results on the screen to the user.

RESULTS AND DISCUSSION

Complete package for efficiency improvement expert system was tested and validated at 500 MW NTPC power plant. Few of the results from that expert system are shown in table1.

S.No	Present Condton	Recommendation Followed	Obtained Condition	Improvements
1	Load:525 Eff: 86.6 TGHR: 2052 UHR:2367	WB Fur DP 85-→91.1	Load:524.9 Eff: 86.68 TGHR: 2048 UHR:2362.6	Eff: 0.08 TGHR: 4 UHR:4.4
2	Load:522.6 Eff: 86.6 TGHR: 2078 UHR:2399.5	WB Fur DP : 83.9-→94.9	Load:524.75 Eff: 86.606 TGHR: 2072.8 UHR:2393.53	Eff: 0.006 TGHR:5.12 UHR:6.01
3	Load:526 Eff: 86.75 TGHR: 2056 UHR:2366.5	FAD: 35-→ 48	Load:525.2 Eff: 86.851 TGHR: 2051.7 UHR:2361.8	Eff: 0.101 TGHR: 4.3 UHR:4.7
4	Load:524.1 Eff: 86.5 TGHR: 2042.7 UHR:2361.5	Tilt: 79-→ 74	Load:524 Eff: 86.577 TGHR: 2037.9 UHR:2354.3	Eff: 0.076 TGHR: 4.8 UHR:7.2

Table 1 shows initial conditions, followed recommendations and obtained condition. Table also shows values improvement in efficiency, TGHR and UHR.

Results show that such expert systems can effectively be used to improve efficiency while maintaining stability and availability.

Some of the observations of notifications of data captured by ChemAnalyzer (Expert System for Chemistry process improvement) and correlated with actual site conditions are given in Table-2.

Unit No	Problem detected	Actual condition	Action/benefit
# 5	CEP column Exhaustion	Column Exhaustion	replaced
#5	Condenser leakage	Problem occurred	Stabilized
#1	Analytical Problem	Silica analyzer faulty	Calibrated/ standards replaced
#2	Boiler contamination	High sodium	Normalized after blow down
#5	Condenser leakages, CEP exhaustion, Air-in-leakages	Unit shut down	New logics introduced Drum pressure also included
#5	CEP column Exhaustion	CEP column not in service	User interference required. Logics are modified
#5	Boiler conductivity – K > 25	Boiler contamination	Conductivity reduced by Blow down

Table-2: Action taken based on problem indicated in ChemAnalyzer

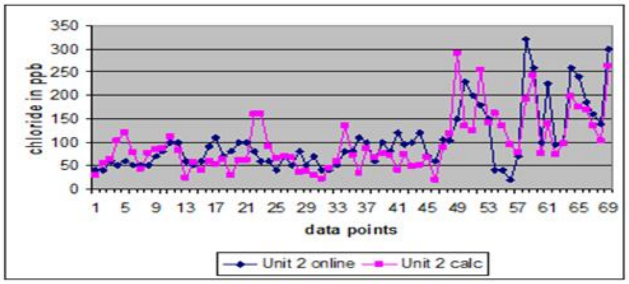


Fig 6 : Boiler water chloride predicted vs online values

Fig-6 depicts comparative result of online and calculated (using non-linear regression models) values of boiler water chloride for one of NTPC power plant unit. The results are quite encouraging. Thus, such models can be used as soft sensors where online analyzers are not present.

CONCLUSION

With the advent of reliable sensors, analyzer and efficient data acquisition systems, surplus operation data and domain expertise is available with NTPC. Thus, it is very important to apply domain expertise on available data using some tools. Expert systems can provide such tools which can be customized and utilized for different purposes such as efficiency improvements, process optimizations. In-house developed expert system by NETRA, NTPC have focus on utilizing the domain knowledge of NTPC experts and providing user-friendly solutions for real time process improvement. The system being developed is customizable, re-trainable according the plant conditions and inputs from plant personal. Such expert system tools can thus help power plant operators to run plant efficiently while maintaining equipment health.

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J S Chandok, M.Tech from IIT, Delhi in Power generation technology and more than 20 year of experience in Power plant C&I engineering and maintenance and software development.He is currently involved in development of intelligent system for power plant performance and diagnostic. He is also focusing research on Solar PV testing and grid interaction and cost effective solution, Smart grid solution etc. He is presently working as Additional General Manager (AGM) at NETRA.

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Remote Monitoring & Diagnostics Solutions

ABSTRACT

In this paper we intend to talk about Data Analytics for Actionable intelligence & mobility devices can bring information anywhere anytime to improve visibility, sustainability and increased productivity with minimal investment and clear ROI.

KEYWORDS

Sustainability, ROI, Remote Monitoring & Diagnostics, Mobility. Analytics, Predictive Analytics

INTRODUCTION

With advent of Analytics &mobility devices it has become an imperative that we adopt to these technologies and utilize them in industrial world to increase productivity and cut down on costs and downtime. With diminishing domain expertize it has become a necessity to make systems smarter to ensure they play the role of experts when providing information about asset functioning.

The key is to ensure equipment performance, availability, and reliability by detecting, diagnosing, and prioritizing equipment and process problems before they become costly failures.

CHALLENGES IN POWER PLANT

The challenge customers have in hand today with the existing systems is -

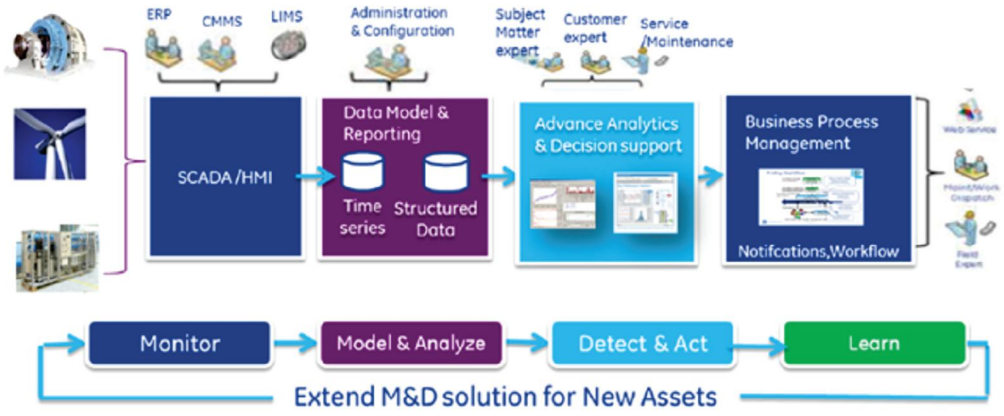
- Assets are remotely located with minimal or no visibility of asset's performance parameters.
- End user has very little information on the current state of the asset.
- Very limited intelligence built in the system to ensure the operators are empowered to take any corrective actions.
- Most of plant are run on a particular individual's know how and lack domain experts in operations.

REMOTE MONITORING AND DIAGNOSTICS SOLUTIONS

Remote Monitoring & Diagnostics tool helps customers with the following -

- Builds connectivity to existing and new assets.
- Creates treasure of past & current performance making it available at finger Tips.
- Uses past data to benchmark performance and provides guidance information to operators.
- Keeps monitoring asset performance for any abnormality by comparing it with the blue print of stable system.
- Predict any abnormality & probable downtime based on statistical model.

TYPICAL ASSET INTELLIGENCE– FLOW OF DATA AND DECISION MAKING



SECURED ROI

Identify Optimum Performance

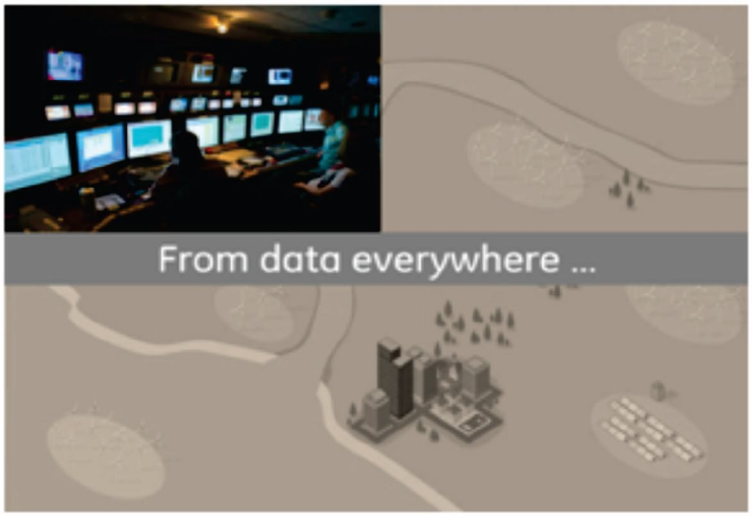
Ensure Optimum Performance

Increased Throughput

Improve efficiency

Increase in Operating Margins

Increase in ROI



From data everywhere ...

... to Actionable Knowledge Anywhere Anytime!

Truly anywhere ...

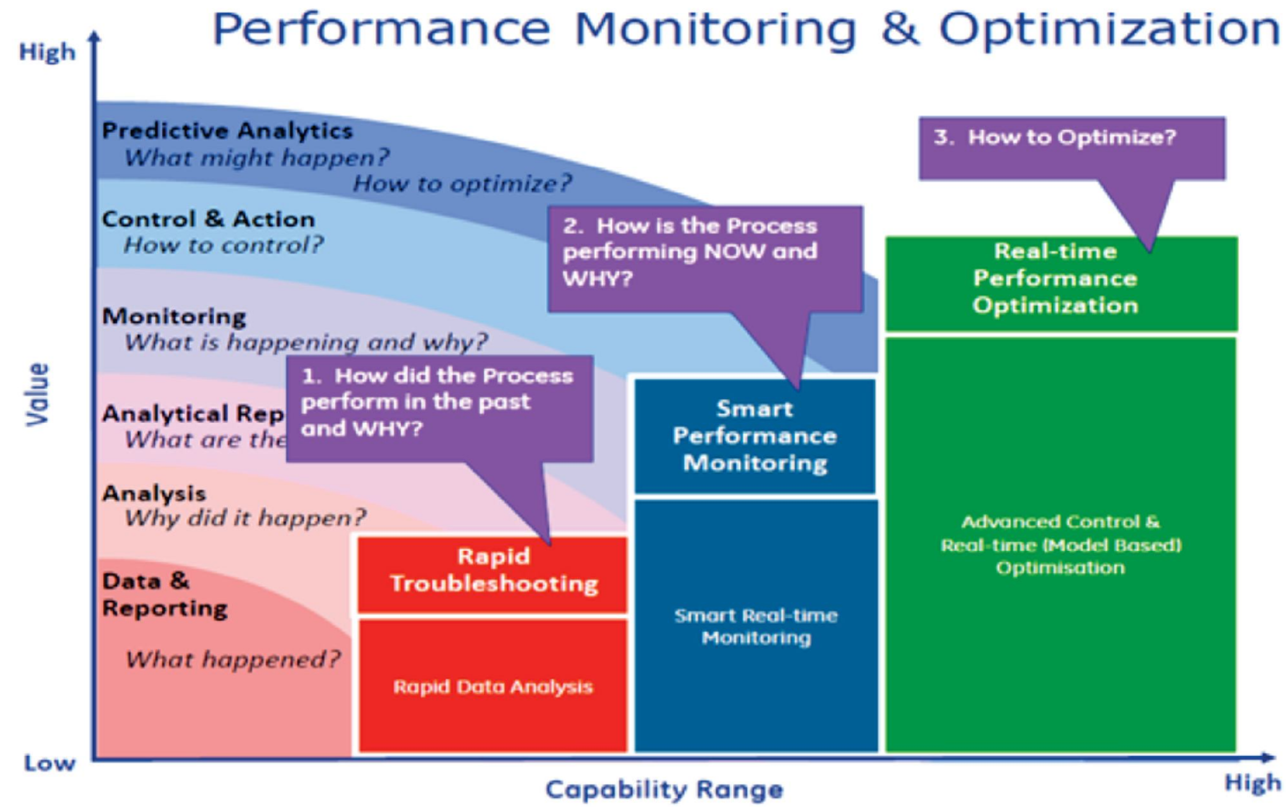
Analytical Delivers Process Intelligence from Disparate Data Sources

The Solution delivers process intelligence by aggregating data, contextualizing the data through a data model, and providing appropriate analytics. Leverages a company's Existing manufacturing and IT systems through its ability to aggregate, on-demand, different data types from disparate sources and create end-to-end manufacturing context, insight, and intelligence.

Finding the root cause of variability is not easy, but it is essential to improving operations. A plant creates a lot of data. As products and processes become more complex, so does the data. Within this complex data lies valuable information about the product and processes. But, typically, the data is difficult to get at and even more difficult to interpret. Most often, if used at all, the data is used solely by the system that created it. This is unfortunate, as the answers to reducing variability and improving process resides within this data.

Many useful methods and solutions available on the market provide different visualization and perspective of the data. However, very few solutions provide a holistic view of the data – from the start-to-finish of an entire process – in a single environment. For instance, ERP solutions offer companies significant value, but typically do not delve deep enough into the plant floor to provide process understanding. Plant floor systems typically provide only a partial view of what is happening. Dashboards offer excellent process and performance monitoring and visibility, but rarely provide Root cause based on the chemistry, physics of the process as to why something is happening. Many production problems go unresolved simply because of the inability to aggregate and analyze comprehensive data sets that contain multiple data types or complex batch.

Aggregating and analyzing data from disparate sources is challenging for many reasons. Data collected at different points in the manufacturing process and at different times are difficult to correlate, not only because the data resides in different systems, but also because the



data is often of different types. For instance, data can be continuous, transactional, or replicate.

Correctly accessing and correlating this data in the proper context of the manufacturing process requires access to the data, putting the data into proper context via a sound data model, and tools to visualize and analyze the data.

Predictive Analytics for Actionable intelligence

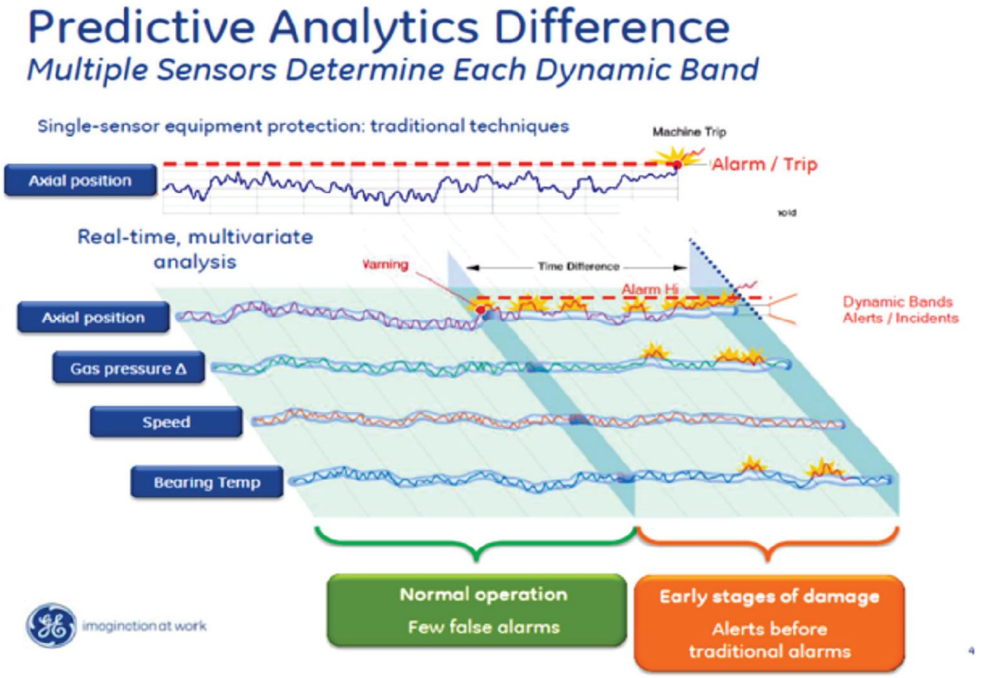
Optimally, the key to successful prevention is to predict developing equipment problems with accuracy and clear notification well in advance of failure. This requires an effective monitoring solution that recognizes every piece of equipment as unique, and works on all types of equipment to detect, diagnose and prioritize problems across a wide array of assets and failure modes that other methods cannot see. That is exactly what today's predictive analytic solutions can do.

The amount of data being retrieved, recorded, trended and viewed in plants and Monitoring centers has been growing exponentially. Given the variability of the data and the quantity of data being stored, the job of the analyst to make sense of the raw data is next to impossible. The all too common flaw with Condition Monitoring and other legacy monitoring system is that operators find themselves data rich, but information poor.

Every company has a unique combination of people, equipment, processes and technology. The key to optimizing resources is to get the right information to the right people at the right time – to turn the data into intelligence.

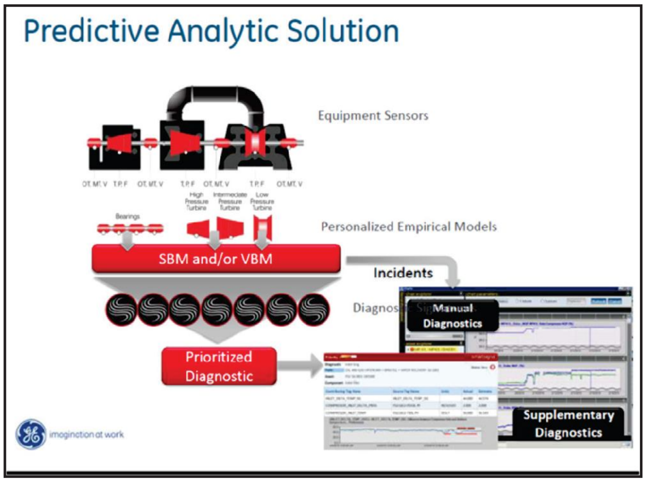
Predictive analytic applications supplement the "eyes and ears" at the plant – capturing equipment knowledge that can help leaner, less-experienced staffs detect and diagnose equipment failures and prioritize their actions to eliminate them. Because the analytics are data-driven, the information and the decision-making are less subjective. With predictive analysis on the job 24/7, plant workers can spend their time solving problems – not looking for them.

Predictive analytic technology can monitor and analyze the performance and mechanical condition of equipment and can detect degradation in advance of the OEM monitoring systems, thus averting potential failures. These new predictive analytic solutions focus attention on abnormal equipment conditions, resulting in improved system performance, reliability and availability. Analysts do not need to be involved in direct data trending. The data is monitored by the software, and analysts only review the data when an exception is identified, giving ample time to respond to the changing condition.



Predictive Analytics Difference

Multiple Sensors Determine Each Dynamic Band


Predictive Analytic Solution

By highlighting only signals that deviate from a pattern, monitoring is more efficient. If indicators show that a piece of equipment is continuing to operate normally, a scheduled overhaul can be delayed. Steady slow changes in readings enable plant engineers to detect impending failures early – before the equipment's condition worsens to the point of needing urgent (more costly) attention. Early awareness of a problem makes it possible to schedule repairs during planned production downtime, and gives plant managers time to schedule technicians best qualified to do the work. Predictive analytics fill an important Industry void – complementing traditional condition-based monitoring systems, and going well beyond to complex analytics for early warning and insights into root causes of problems. Predictive analytics significantly reduce problems related to aging equipment, lean personnel and other constraints, while increasing production capacity and profitability. Predictive analytic solutions complement existing CM and other legacy systems, and are scalable for individual plants to entire fleets. They monitor all critical equipment – rotating and non-rotating – for all industries with critical equipment. Companies successfully implementing a predictive analytics initiative can reasonably expect a return on investment in a matter of months.

Integrated Power Plant Visibility

ABSTRACT

In this paper we intend to talk about the sustainability as the key imperative for success in the market dominated by Price and competition and the importance of Data with actionable intelligence which can provide path for Sustainability. The importance of information at anytime, anywhere across the enterprise which would result in increased productivity with minimal investment.

KEYWORDS

Sustainability, ROI, Remote Monitoring & Diagnostics, Mobility. Analytics, Predictive Analytics

Need for Integrated Visibility:

Sustainability has become one of the key imperatives in the modern world where competition and price points are becoming tougher day by day. ROI for every $ invested becomes a key for production/manufacturing units. The key to sustainability is to bring in integrated visibility at a single point to allow the operational team to have complete control about what's happening in their plant and how things can be managed in a more efficient manner.

Sustainability has become one of the key imperatives in the modern world where competition and price points are becoming tougher day by day. ROI for every $ invested becomes a key for production/manufacturing units. The key to sustainability is to bring in integrated visibility at a single point to allow the operational team to have complete control about what's happening in their plant and how things can be managed in a more efficient manner.

In Thermal Power Plants, there are various disparate systems feeding in and out of the main Boiler and Turbine System. The visibilities to these systems have become more and more important with increase in coal, water and chemical prices.

Traditionally getting Balance of Plant information at was limited by:

1) Interfacing between various makes of PLCs

2) Chances of loading DCS Network if BOP and DCS Network are mixed for data exchange.

3) Lack of remote monitoring tools.

4) Lack of troubleshooting systems.

5) Lack of reporting tools

GE Intelligent Platforms has been constantly working on enhancing its hardware and software openness to empower customers to get better visibility, analysis and reporting mechanisms.

GEIP has proposed solutions to integrate balance of plant systems and bring in better visibility to our customers by following :

1) Integrate various makes of PLC and get the data into centralized location for better plant level visibility

2) Versatile troubleshooting mechanism using historical data replay on process screens

3) Remote thin client to visualize & control system; enable remote consultancy & AMC

4) Daily, weekly, monthly & annual performance reports.

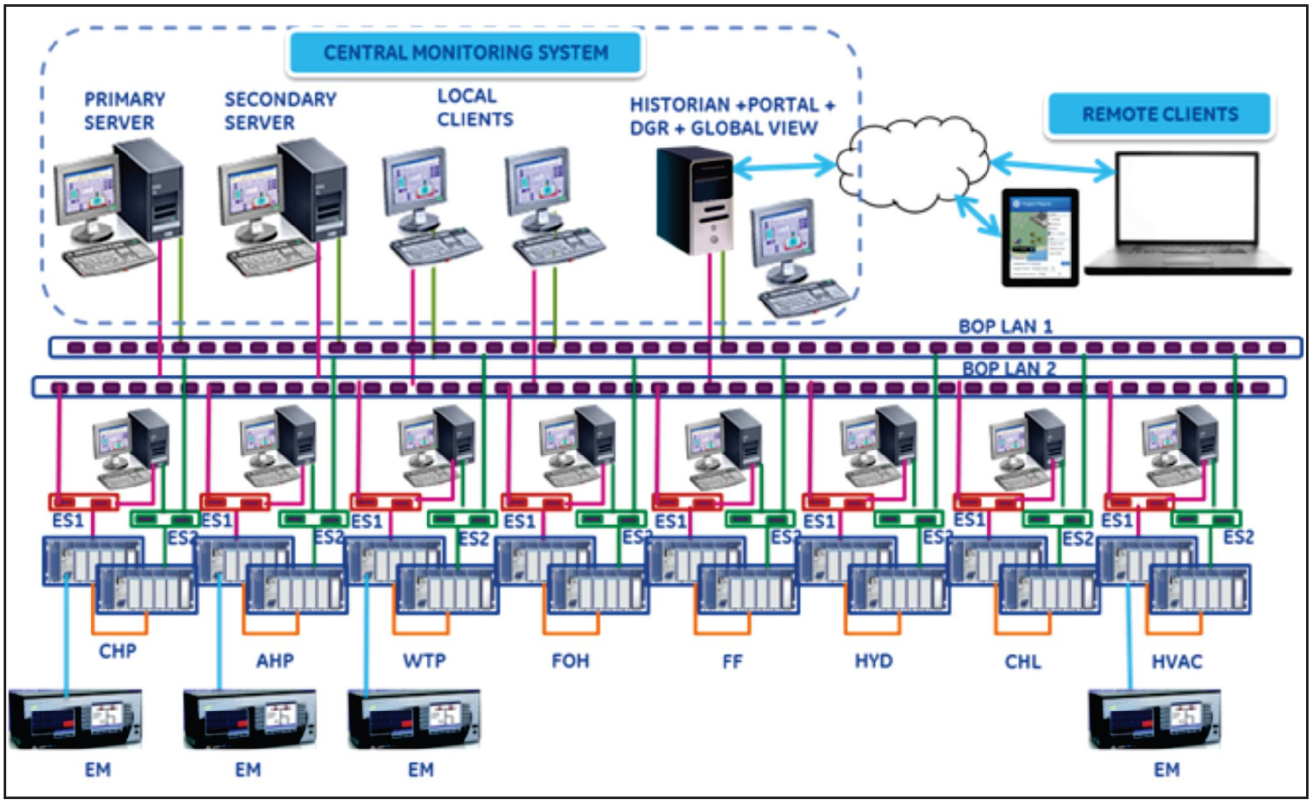
5) Comparative view of real time/historical data of KPIs

Integrated Energy Management:

GE IP provides additional lever to increase productivity by creating visibility into the energy getting consumed inside the plant with minimal additional hardware to the existing system.

This helps customer to keep check on local consumption and run the plant more efficiently.

GEIP integrates Energy Meters from various plant machinery to give visibility into internal energy consumption & provide heat map of energy consumption.



Key highlights

Get visibility into your plants operation

Get you to know your power consumption for plant operation

Dashboards and comparative performance of your KPIs

Information availability on your mobility device from any remote location

The role of Rugged Industry Data Base in Seamless Integration & faster response to dynamic changes:

Built-in Data Collection That Leverages OPC and Specific Built-In Drivers to Legacy or Non-Standard Equipment :

Industrial Data Base includes built-in data collection capabilities and can capture data from multiple sensors and systems. It uses manufacturing standards such as Object Linking and Embedding for Process Control (OPC), which facilitates communications by providing a consistent method of accessing data across devices. Instead of having to build custom software for every type of data source as required for other solutions, Industrial Data Base does not need to know any of the details regarding the propriety data sources. It can instantly connect to any OPC-enabled solution to collect data, providing flexibility, time savings and reduced costs.

Faster Speeds

In contrast to the modest performance of relational databases for large data sets or associated periods of time, Industrial Data Base provides a much faster read/write performance and “down to the millisecond” resolution for true real-time data. Industrial Data Base is built to store, and more importantly, retrieve production/process data in the way you need it. Its aggregation and retrieval methods would be difficult in other database technologies. This capability enables better responsiveness by quickly providing the granularity of data needed to analyze and solve intense process applications.

High Data Compression :

Industrial Data Base comprises powerful compression algorithms, which enable you to store years of data easily and securely online—enhancing performance, reducing maintenance and lowering costs. For example, you can configure Industrial Data Base without the active maintenance and back-up routines that a relational database requires. Archives can be automatically created, backed up, and purged—enabling extended use without the need for a database administrator

Quick Time to Value :

When installing Industrial Data Base, you can “normalize” the implementation, using standard interfaces to decrease implementation time by approximately 50%. You don’t need to manage or create data schemas,” triggers, stored procedures or views—resulting in quick installation and configuration without custom coding or scripting. Industrial Data Base has a pre-built interface to the automation layer, providing a single environment whereby you only have to configure tags once, and you can store process data seamlessly in a secure, central location.

Role of Interactive Web reporting tool in analysis of Current & Past Data :

Time-based Data Analysis :

Web reporting tool provides interactive analysis of real-time and historical data sources through trend charts, grids and data links. This provides users with insight into the operation of their plant for making crucial improvements to quality and efficiency. • Connect and interact with plant-wide, real-time and historical data sources and adjust system parameters with read/ write capabilities.

Visualize, annotate, and analyze process data, strings or other information with the Time chart. Analyze your process by event (such as comparing batch or production runs) usingthe event component. Drill into detail data using intelligent grid components that allow data to be easily sorted, printed, and exported.

Common Web Client :

A single web client that combines content from other

GE applications such as HMI/SCADA – iFIX* and from across data sources within the plant and the organization allows for real-time decision making at all levels. Solve your plant manufacturing intelligence needs with a single script and in an HTML-free environment. Combine the client functions of our full software family with information from legacy andthird-party systems on the same screen at the same time. Graphically create a library of parameterized SQL statements that interact with plant floor and corporate data stores. Web reporting tool supports SELECT, INSERT, UPDATE, DELETE and CALL statements. Build and deploy sophisticated, web-based views and dashboard applications with KPIs and drill down by linking forms components, buttons, hyperlinks, charts, and more.

Graphical Presentation:

Graphical presentation rapidly communicates essential information from more complex data sets for notification of alerts, status changes, and data summaries. Graphical presentation can alsobring a familiar look and feel when moving plant floor applications to the web, providing a complete graphics library of shapes,images, etc./ Common graphical tools for drawing displays(align, group etc). Web reporting tool Features and Benefits like Animation of shape properties from any data source and command actions for navigation and drill down

Enterprise-wide Quality :

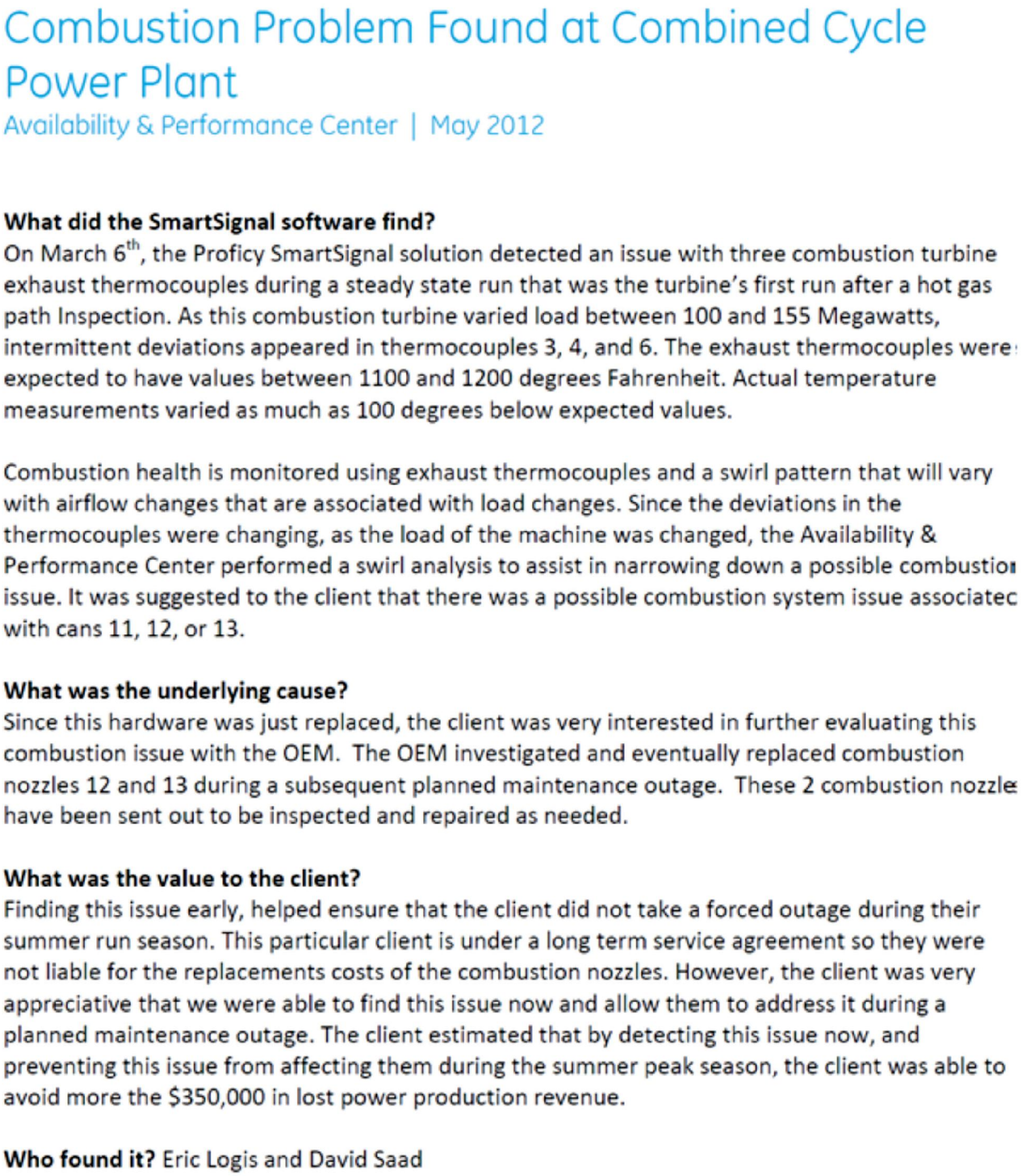
Enterprise-wide quality takes data from other GE Quality applications (Shop Floor SPC, Quality) and other third-party or legacy systems and provides SPC charts and components for monitoring and performing root cause analysis. This feature supports consistency, quality, Six Sigma, and other continuous improvement initiatives across the plant and across the entire organization. As the web client for the entire GE software portfolio, Web reporting tool provides a consistent set of tools for analyzing and reporting disparate process, lab and shop-floor SPC systems, along with interfaces to off line Six Sigma tools such as Minitab.

Analysis & Diagnostics on the fly : - Event Replay Solution

The Event Replay Solution lets you go back in time and graphically analyze events that occurred in the past. Using data that is logged in Industrial Data Base or SQL Server, the Event Replay lets you replay graphical screens to determine cause of events or alarms, allowing you to optimize your application, or prevent conditions that led to alarms. You can play back from a point in time, or have the Event Replay search for conditions in the data and automatically set start and stop times based on those settings. Play back in slow motion, real time or up to 10x the speed. You can also view multiple screens just as if you were viewing live data.Thesolution can used to troubleshoot/troublesome alarms, find root cause of alarms, perform Post Trip Alarm analysis, analyze timing of events. This is a benefit for unmanned operator stations, training, quality and replaying production in regulated environments

Mobility solution : -Full-featured HMI/SCADA over the web

Mobility Solution extends your SCADA application viewing and control abilities right into a web browser such as Internet Explorer or Firefox. As a full-featured SCADA client, Mobility Solution doesn't compromise on features, graphics, or functionality. The client is updated on changes directly from the SCADA, so users can react in real time. Support for multi-tab browsers. . Mobility Solution accommodates third-party controls with the same ease as CIMView! .Mobility Solution supports SCADA's built-in, easyapplication navigation toolbar—delivering the same interface to your users as your thick clients. Mobility Solution supports SCADA displays with animations. All control elements are operable in Mobility Solution and inherits the SCADA applications security setup. In Mobility Solution we canView, ack and silence just like a thick client. Mobility Solution launches third-party apps triggered from within your SCADA application



Combustion Problem Found at Combined Cycle Power Plant

Availability & Performance Center | May 2012

What did the SmartSignal software find?

On March 6th, the Proficy SmartSignal solution detected an issue with three combustion turbine exhaust thermocouples during a steady state run that was the turbine's first run after a hot gas path Inspection. As this combustion turbine varied load between 100 and 155 Megawatts, intermittent deviations appeared in thermocouples 3, 4, and 6. The exhaust thermocouples were expected to have values between 1100 and 1200 degrees Fahrenheit. Actual temperature measurements varied as much as 100 degrees below expected values.

Combustion health is monitored using exhaust thermocouples and a swirl pattern that will vary with airflow changes that are associated with load changes. Since the deviations in the thermocouples were changing, as the load of the machine was changed, the Availability & Performance Center performed a swirl analysis to assist in narrowing down a possible combustion issue. It was suggested to the client that there was a possible combustion system issue associated with cans 11, 12, or 13.

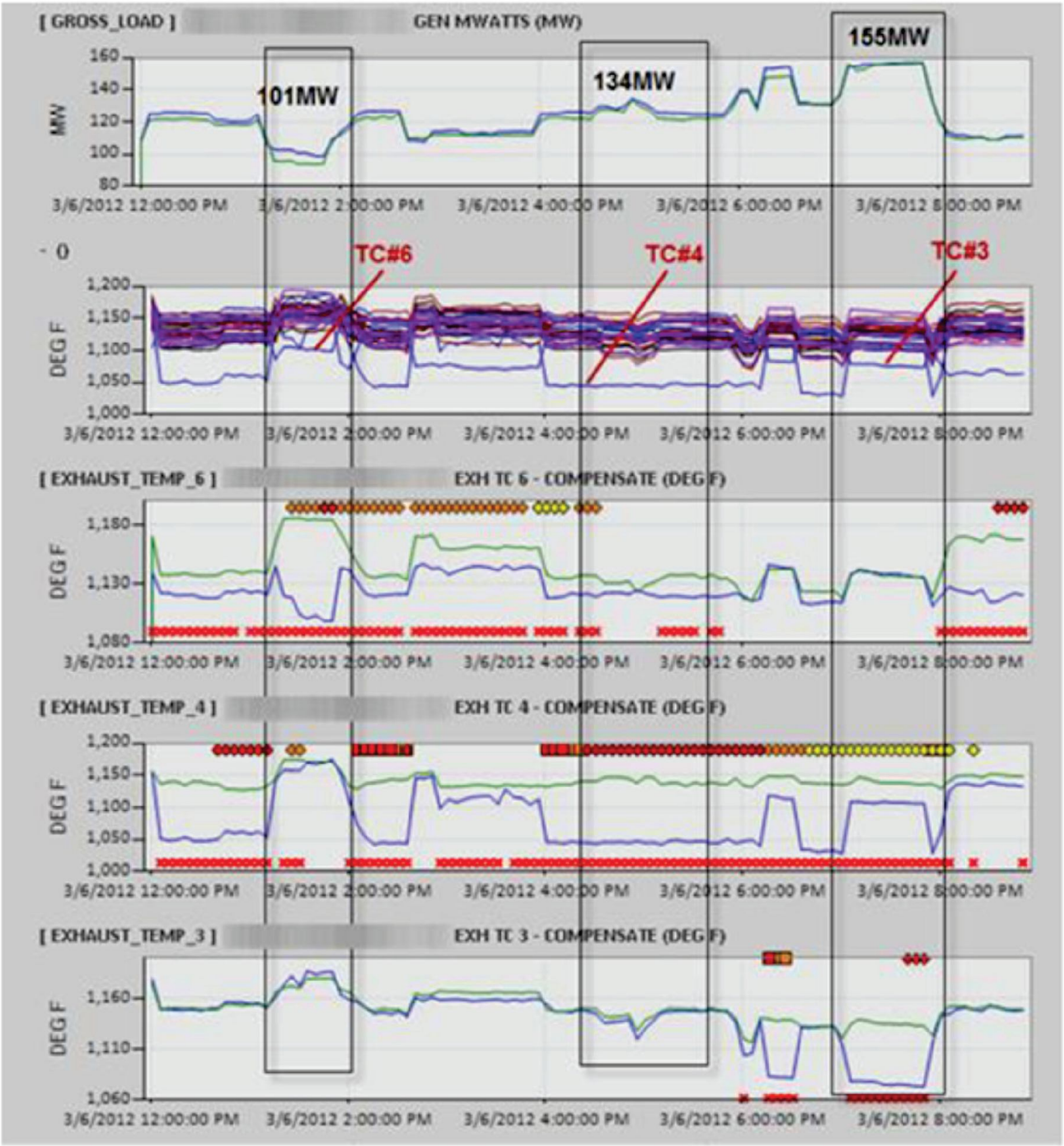
What was the underlying cause?

Since this hardware was just replaced, the client was very interested in further evaluating this combustion issue with the OEM. The OEM investigated and eventually replaced combustion nozzles 12 and 13 during a subsequent planned maintenance outage. These 2 combustion nozzle have been sent out to be inspected and repaired as needed.

What was the value to the client?

Finding this issue early, helped ensure that the client did not take a forced outage during their summer run season. This particular client is under a long term service agreement so they were not liable for the replacements costs of the combustion nozzles. However, the client was very appreciative that we were able to find this issue now and allow them to address it during a planned maintenance outage. The client estimated that by detecting this issue now, and preventing this issue from affecting them during the summer peak season, the client was able to avoid more the $350,000 in lost power production revenue.

Who found it? Eric Logis and David Saad



Screenshot depicting increases in actual (blue) versus expected (green) power for combustion turbine power [TOP], actual exhaust temperatures [SECOND FROM TOP], and actual (blue) and expected (green) values for exhaust temperatures [BOTTOM THREE].

Wiped Bearing Detected on a Feedwater Pump at a Combined Cycle Power Plant

Availability & Performance Center | August 2012

What did the Proficy SmartSignal software find?

On July 14th, the Proficy SmartSignal solution detected changes in the mechanical profile of the outboard bearing of a feedwater pump at a combined cycle power plant. Vibration on the outboard bearing increased to 7.55 mm/s from an expected value of 3.98 mm/s. At the same time, the temperature in this outboard bearing jumped to an actual value of 270 °F (132 °C) before quickly dropping to values around 170 °F (77 °C). The temperature for this bearing was expected to remain around 190 °F (88 °C). The Availability & Performance Center sent a high priority notification to the client and started closely monitoring this issue with the client. Follow up reports were sent to the client on July 15th and July 16th. On July 16th, the outboard bearing temperature fell to values around 115 °F (46 °C). At the same time, the inboard bearing metal temperature increased to 184 °F (84 °C) from an expected value of 170 °F (78 °C).

What was the underlying cause?

Upon the initial notification, the client quickly confirmed that the mechanical system on this feedwater pump was failing. When the pump was finally taken offline, the client confirmed that the pump “was smoking.” After the pump was inspected, it was found that the bearing Babbitt had been wiped. When the replacement pump was brought online it was noted to have high thrust bearing temperatures so the plant shut down and trimmed the balance drum position. This caused the thrust bearing temperature to return to normal but caused the motor outboard bearing vibration to increase and an abnormal sound to emanate from the bearing. The client and GE Intelligent Platforms personnel collaborated on a review of the high speed bearing data and diagnosed a coupling alignment issue due to the trimming of the balance drum on the replacement pump that had just been installed. The new pump was brought offline and an axial misalignment of approximately 0.05 inches (1.27 millimeters), due to the trimming of the balance drum, was discovered and corrected. Once the new spare pump was returned to service, the plant was able to verify motor outboard bearing vibrations and noise abated.

What was the value to the client?

In this particular case, it was more economical for the client to run this feedwater pump to failure rather than try and take an outage and repair the pump. The early identification of the issue allowed the client to have a spare pump staged and ready to install. This allowed the client to minimize their outage and lost production costs. In addition, the collaboration with the client helped identify a coupling alignment issue on a newly installed spare pump and prevented damage to the pump and the lost production that would have been caused if the plant had lost the spare feedwater pump.

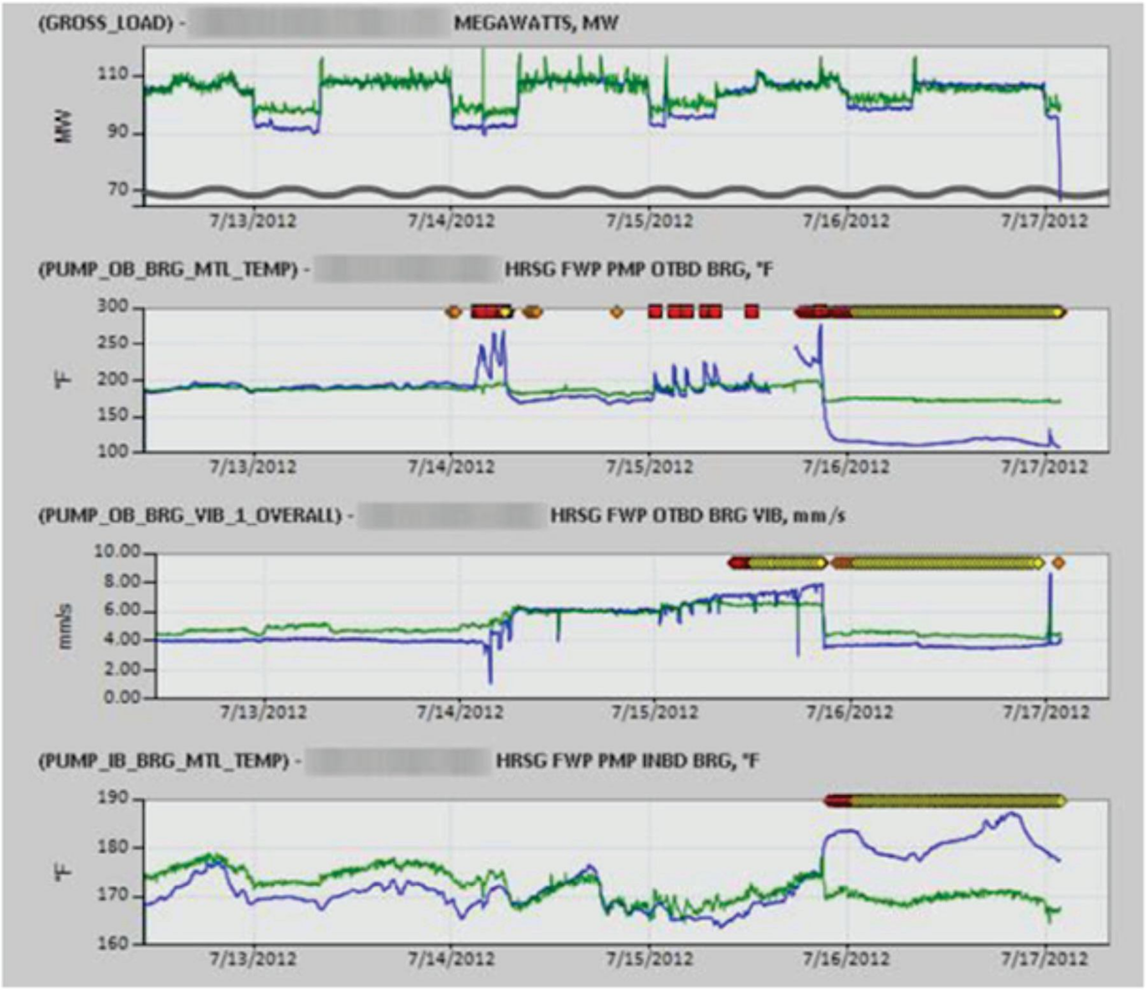
Who found it?

Pat Bauer,
Industry Engineer

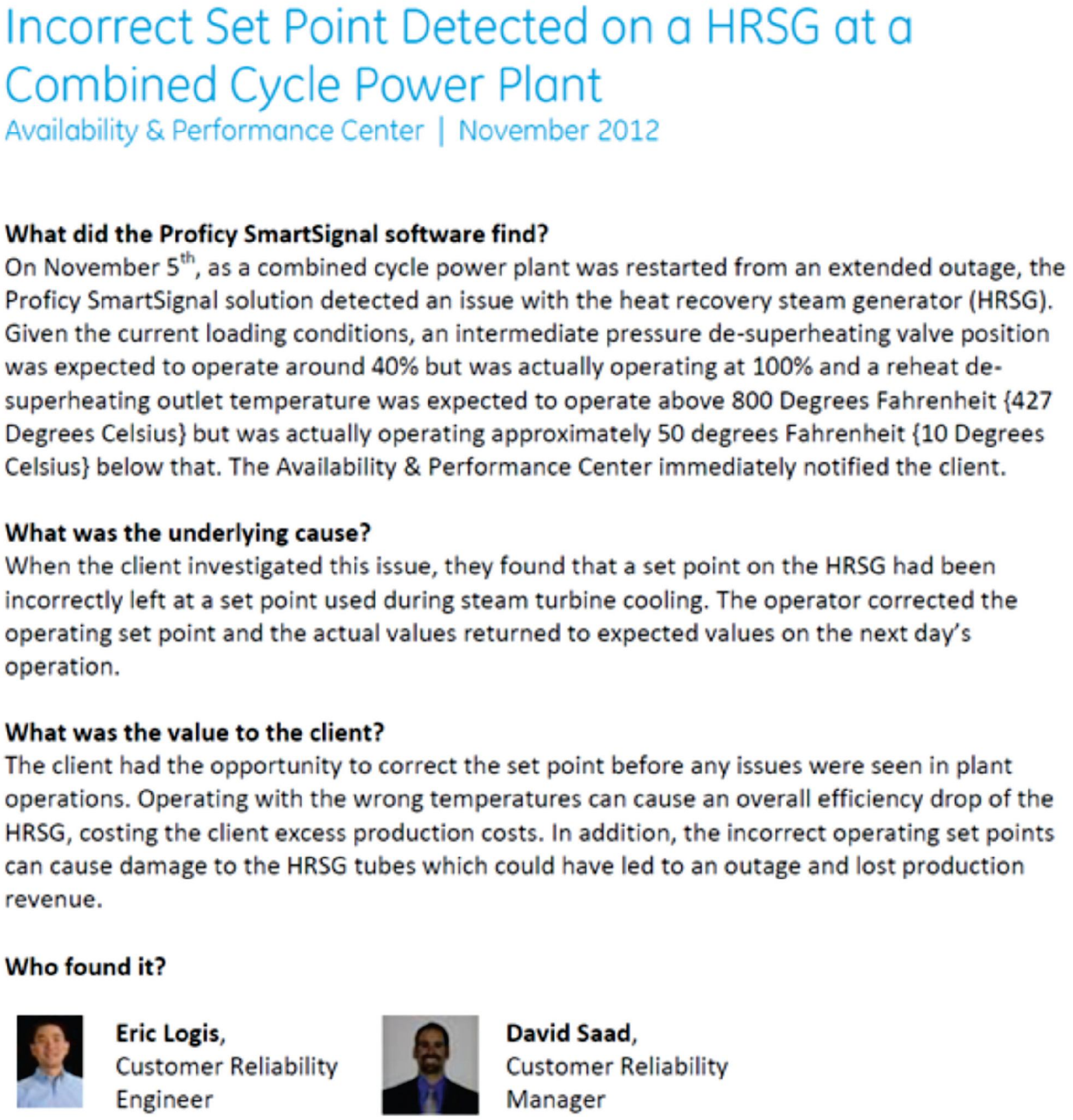
Justin Whitty,
Customer Reliability Engineer

Mike Reed,
Customer Reliability Manager

Don Doan,
Principal Engineer



Screenshot depicting actual values (blue) and expected values (green) for a feedwater pump. Changes in vibration levels shown in graphs 2 and 3, and changes in bearing temperature shown in the bottom graph.



Incorrect Set Point Detected on a HRSG at a Combined Cycle Power Plant

Availability & Performance Center | November 2012

What did the Proficy SmartSignal software find?

On November 5th, as a combined cycle power plant was restarted from an extended outage, the Proficy SmartSignal solution detected an issue with the heat recovery steam generator (HRSG). Given the current loading conditions, an intermediate pressure de-superheating valve position was expected to operate around 40% but was actually operating at 100% and a reheat de-superheating outlet temperature was expected to operate above 800 Degrees Fahrenheit {427 Degrees Celsius} but was actually operating approximately 50 degrees Fahrenheit {10 Degrees Celsius} below that. The Availability & Performance Center immediately notified the client.

What was the underlying cause?

When the client investigated this issue, they found that a set point on the HRSG had been incorrectly left at a set point used during steam turbine cooling. The operator corrected the operating set point and the actual values returned to expected values on the next day's operation.

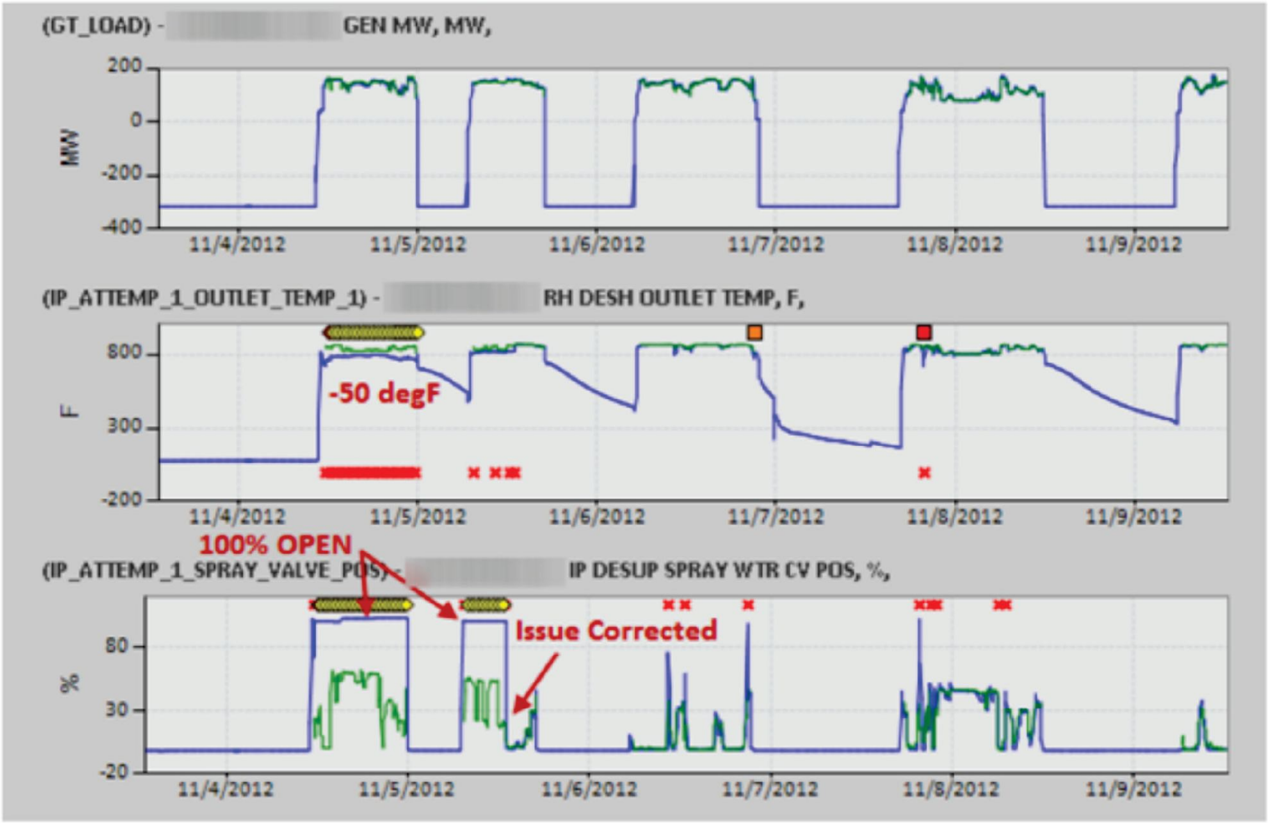
What was the value to the client?

The client had the opportunity to correct the set point before any issues were seen in plant operations. Operating with the wrong temperatures can cause an overall efficiency drop of the HRSG, costing the client excess production costs. In addition, the incorrect operating set points can cause damage to the HRSG tubes which could have led to an outage and lost production revenue.

Who found it?

Eric Logis,
Customer Reliability
Engineer

David Saad,
Customer Reliability
Manager



Screenshot depicting actual values (blue) and expected values (green). Unit load shown in top graph. Steam outlet temperature shown in middle graph. Spray valve position shown in bottom graph.

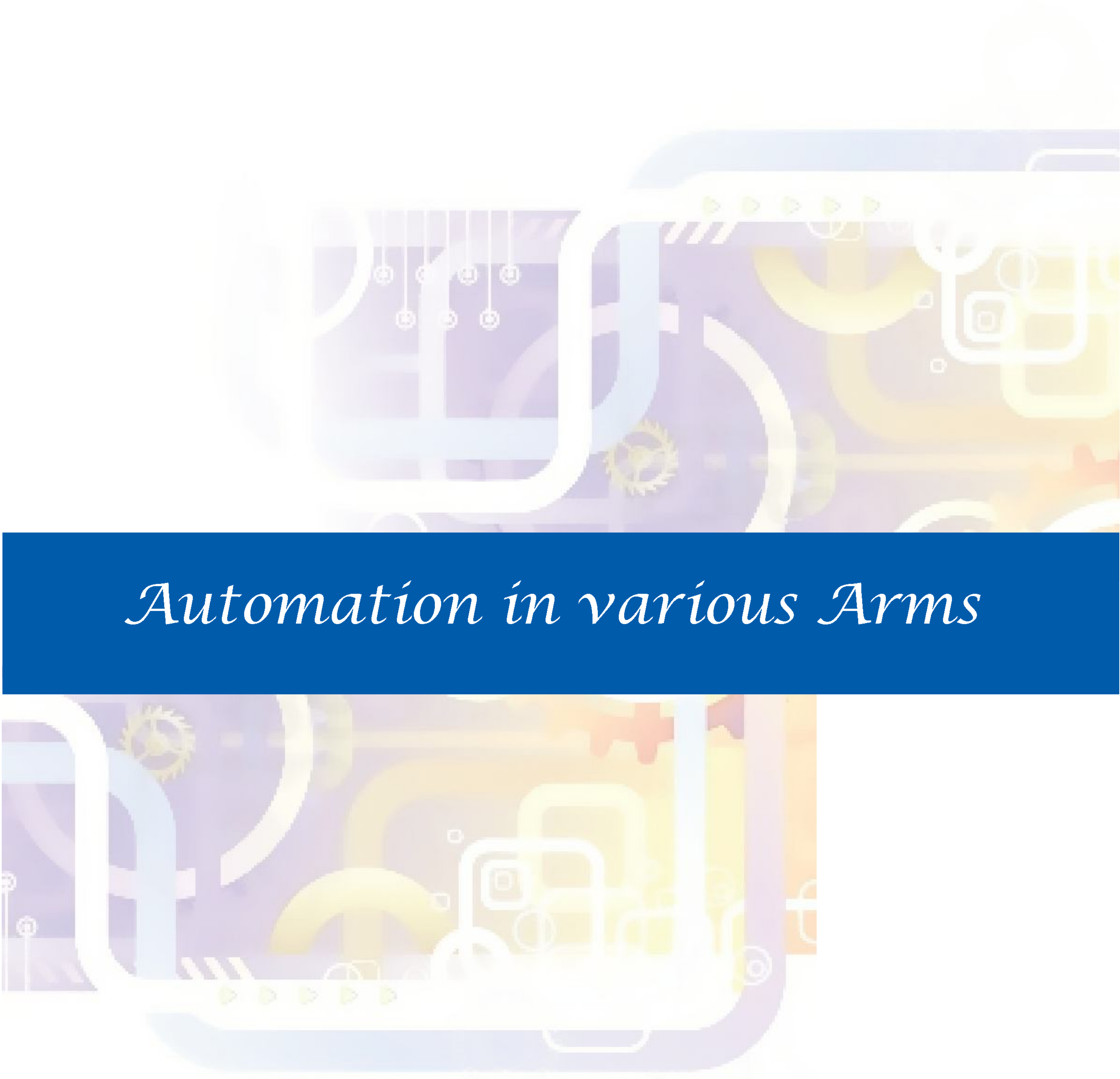
BIOGRAPHIES

Ramji Vasudevan

Born in 1977 finished Engineering from BVB College Hubli, Karnataka in Instrumentation. Has been working with GE from the year 2000 in various roles ranging from designing and commissioning of automation solutions to supporting and selling various GE products.

Prashant Kapadia

Born in 1973 Completed Master of Science from Rajkot, Saurashtra University in Electronics and MBA in Marketing & Finance from Sikkim Manipal University. Has been working with GE as a Business Development Manager Advanced Process Solution.



Automation in various Arms

Analysis of Power System failure at IFFCO-Aonla and subsequent measures to enhance reliability–a case study

by
A.K.Maheshwari, Executive Director

A.K.Bhaduri, General Manager (Tech)

B.S.Bajwa, Jt.General Manager(E&I)

Abstract

At IFFCO Aonla Fertiliser Complex there is a PLC based Load Management System (LMS) designed to operate and control the load on various electrical feeders from one central Control Room. However, as a philosophy LMS was designed as a "Load Management system" and not as a "Load Shedding System" which are usually associated with very fast action. As a result there has been instances of tripping second Gas Turbine Generator (GTG) on overload in case the first one trips.—This has caused major power outage in the complex and trip of Ammonia Plants.

The present case study gives the analysis of the Electrical System and detail of modifications conceptualized and implemented to make the existing LMS work faster as an effective Load Shedding Scheme to sustain one GTG in case the other one trips. This in turn enhances the reliability of the Electrical system of the complex. The case study also gives detail of the problems of the Process Plants in case of such outage of GTGs and the operational priorities and measures to sustain the most critical Plants/equipments under power crisis situations.

Introduction

IFFCO-Aonla Fertiliser complex consists of two streams of Ammonia Plants of Haldor Topsoe Technology and of present capacity 1730MTPD each. There are four Urea Streams of Snamprogetti Technology and of present capacity—1515 MTPD each along-with related Utility & Product Handling plants. There are two nos. of Gas Turbine Generators (GTGs) at Power Plant, each of 25MW ISO capacity at 11KV level to cater the total Electrical power requirement of about 30MW of the complex. Additionally there is connection with the Grid of State Electricity Board (UPPCL—also on 11KV after stepping down from 132 KV) on which the usual load is 0.35 MW. Also there are two numbers of Auxiliary Mains Failure sets (Emergency Diesel Generators designated as AMF Sets) of 2187 KVA each to support the important LT consumers like lube oil pumps etc. in case of a power outage.

The first stream of Ammonia plant (now designated as Ammonia-I) of the then capacity 1350MTPD was commissioned in 1988. It was designed with steam turbine driven equipments to run unaffected in case of failure of Electrical power. There was a PLC based Load Management System (LMS) designed to operate and control the load on various electrical feeders from one central place namely Power Plant Control Room.

Subsequently Aonla Expansion Project (AEP) came with identical set of Ammonia& Urea Plants (Ammonia-II & Urea-II Plants)in 1996. Further to this Energy saving & Capacity Enhancement Projects came in and additional units of Purge Gas Recovery and Carbon di-Oxide recovery were put in.—Thus there was major change in Power demand on the same two GTGs. Under Frequency Relays were added to augment the LMS after AEP. However there has been instance of total power outage due to tripping of second GTG as a consequential effect of trip of another GTG.

Experience of one such typical instance is given below.

A typical Fault of GTG on 14.05.2010

On the night of 14.05.2010 all the plants of Aonla complex were running normal. Gas Turbine Generator No.1(GTG-1) was running at 16 MW and GTG-2 was running at 13 MW. At around 23.20 hrs GTG-1 tripped and within 5 seconds GTG-2 also tripped The total load (about 18 MW) shifted to UPPCL grid resulting overload tripping of UPPCL breaker which led to total blackout of the complex.

This resulted in tripping Urea-I and Urea-II plants and also total shut down of Ammonia-I plant which was not supposed to take place. However, Ammonia-II plant survived as one turbine driven cooling water pump was running and AMF set power was available in time for important auxiliaries. Steam Generator (SG) unit also survived as turbine driven F.D fan was running.

This major failure of Power System and tripping of Ammonia-I Plant called for detailed analysis and working out long term solution.

Analysis of events

GTG-1 tripped with alarm "Fire in exhaust plenum zone" Both ventilation fans of reduction gear box tripped on overload which actuated fire detector (heat detector --set at 230 deg C) and tripping of GTG-1.Both the ventilation fans are fed by same feeder and same circuit breaker. Mechanical jamming of one caused the overload tripping of circuit breaker and thus tripping both the fans.

- Prior to trip GTG1 was running at 16MW and GTG-2 at 13MW. **LMS** and under frequency relay together shed the load from 29 MW to 23 MW in next 5 seconds.
- The additional 10MW load was thrown on GTG-2. GTG-2 could not cope up this large step of load change and tripped.
- Thus the **root cause** of tripping of GTG-2 was to carry large step of load change which in turn is due to **slow action of LMS.**

It was further found that tripping of Ammonia-I plant was primarily due to failure of utilities like Cooling Water Pumps, Lube oil Pumps on non availability of AMF set Power in time etc.

Reviewing the Operation Philosophy & Priorities for the complex under power crisis condition

Ammonia Plants are most critical and most energy intensive. On detailed deliberation and overall analysis of the complex under power crisis condition it was felt prudent to ensure healthiness/running of

- At least one GTG
- Both Ammonia Plants (at least the Primary Reformers in worst case)
- Cooling water system and
- Lube oil system of major rotary machines
- Tripping of all Urea Plants may be allowed to save one GTG and Ammonia Plants.

In a Power crisis situation it is also found logical to ensure --

- Actions take place automatically through interlocks and communication gap/confusion and delays thereof are avoided.
- Operators' Actions are to be pre defined where automatic actions are not possible.
- Steam crisis must not get superimposed on power crisis.

Accordingly it was prudent to review/analyse:

1. The Power system & the Load Management Systems
2. Process/Equipment Problems those usually get super imposed over Power Crisis
3. Operational Priorities in different Power Crisis situations.

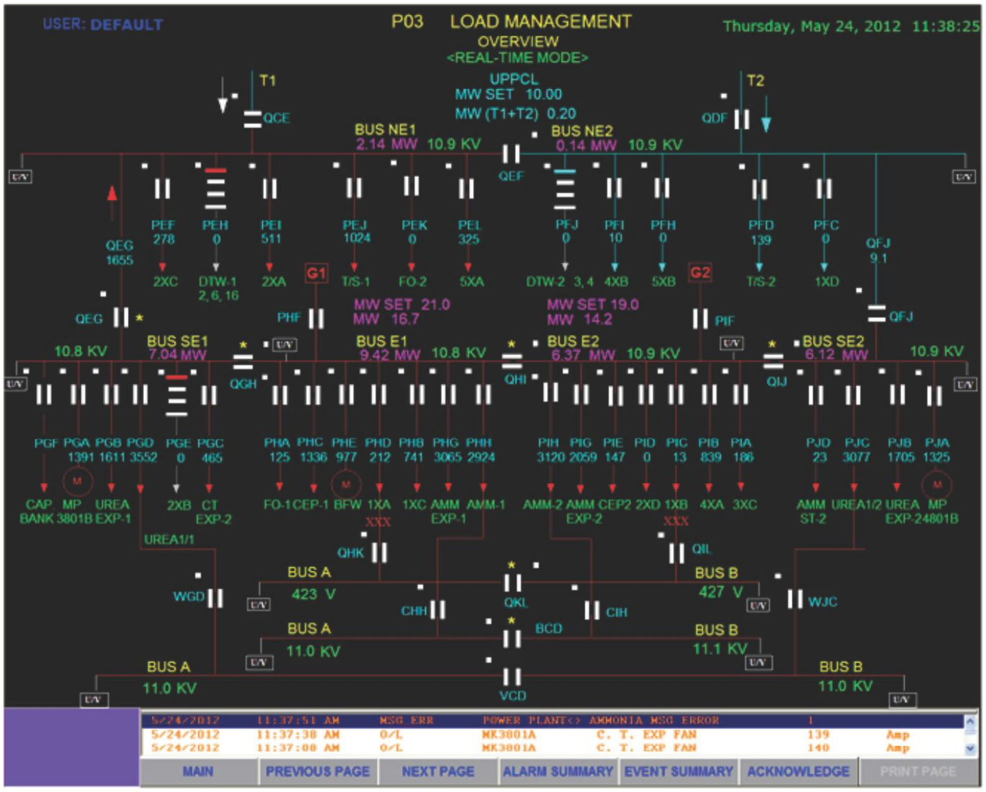
Plant operating procedures would be updated accordingly for such situations and adequate instructions be passed on to relevant persons. Also a method of periodic checking/refreshing of awareness will be developed. Similarly the recommended modifications are to be implemented quickly and be periodically checked for healthiness of the systems.

Further Analysis and taking corrective measures were done in light of the above points.

1. Analysis of Power System & Load Management System (LMS)

The Power system

The major consumers at 11KV level are Cooling Water Pumps of Ammonia ,Urea Plants and other consumers generally above 1000KW capacity, while Ammonia and Carbamate pumps of Urea Plants and other consumers between 200-1000KW are at 3.3 KV level. Other pumps of less capacity (below 200KW) and other consumers like A/cs, UPS etc. are at 415 V level. An overview of the Power system is shown below (Fig.1)



```
5/24/2012    11:37:51 AM    MSG_ERR    POWER PLANT<> AMMONIA MSG ERROR    1
5/24/2012    11:37:38 AM    O/L        MK3801A       C. T. EXP FAN        139    Amp
5/24/2012    11:37:08 AM    O/L        MK3801A       C. T. EXP FAN        140    Amp
```

Fig1 (Snapshot-LMS overview screen)

The LMS

The PLC based LMS was originally designed with Allen Bradley (latter known as Rockwell Automation) PLC model 3/10 to operate and control the load on various electrical feeders from one central place namely Power Plant Control Room. However, as a philosophy this was designed as a "Load Management system" and not as a "Load Shedding System" which are usually associated with very fast action.

The detail of LMS hardware and their interconnection is shown in snapshot-2 below. There are four sets of processors & Input/output modules respectively for Power, Ammonia-I, Urea-I and Ammonia-II& Urea-II Plants combined. These were up-graded in phased manner to 5/80,5/60, control logix 5000 and5/80 series respectively. All these are compatible to each other. The processor in Power Plant acts as the Master and communicates with the processors of the other plants on an Ethernet data highway This data highway involves a 24 port Ethernet switch which often becomes a bottleneck causing jamming of data traffic.- As a result communication between Power plant processor to other processors often suffer from a time **lag** anywhere between **1 to 5 sec.**

As such the typical scan times of the processor (from Fig-2) lies in the range of **23 to 89 ms**, which are fast enough.

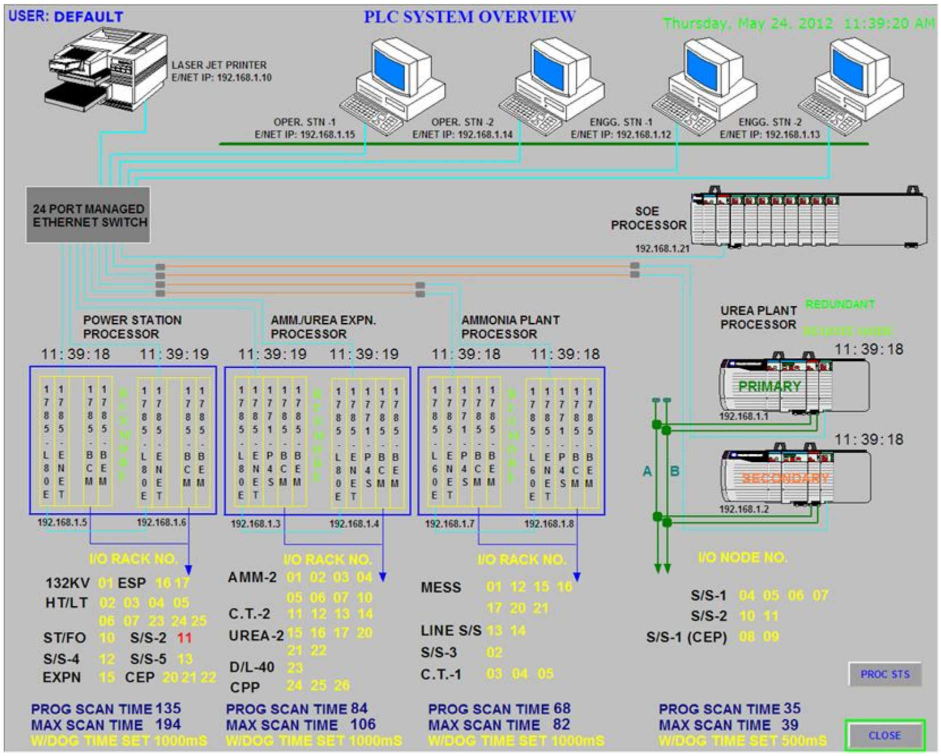


Fig-2 (Snapshot-LMS PLC hardware configuration)

The existing software algorithm is configured to start after an initial time delay of 5 sec, to avoid unwanted load shedding initiated by Electrical transients. After this time delay there are 45 nos of steps with defined consumers and their rated load quantum. (Table1, Annexure). Once there is a gap between Generation & Demand beyond 0.5 MW lasting for more than 5sec the load of step-1 is cut (shed). If the gap is still more than 0.5 MW the step-2 load is cut and so on till the gap becomes less than 0.5MW.Flowchart is shown in Fig.-4. The initial delay & communication delay makes the LMS in-efficient as a Load Shedding System.

Under Frequency Relay

Parallel to LMS, one high speed Under Frequency Relay (MICOM 10-40 ms. scan time) was also installed after commissioning of AEP (Fig.-3). This senses fall in frequency as well as rate of change of frequency on situations of large gap between power generation and demand & cuts off the plant load in steps of around 1MW up to 6.2 MW starting from frequency of 49.76 Hz, till 48.6 Hz .(Table-2,Annexure).

Fig.3 (Photo—Under Frequency Relay)

Under Frequency Relay has so far shed load faster than the existing PLC based system. However on 14th May 2010 only two steps of above relay operated instead of all the steps. This was an abnormal behavior. As per available trends the frequency fell from 50 Hz to 49.76Hz in about 800 ms. Later on it was found that there was a configuration error at the third step. Spare Under Frequency Relay was subsequently installed after proper configuration and calibration.

Conceptualising the solution--the Fast Path Load Shedding Scheme –

The existing LMS with its unpredictable communication delays may sometime shed load very slow and sometimes act little faster. –This in turn decide the quantum of fall of frequency of the system and hence the number of load steps to be cut off by the Under Frequency Relay.— It is very difficult to predict the combined effect of these two systems.---The overall effect may not always be very quick and repetitive in all situations of GTG tripping. Hence it is logical to update the LMS as a repetitive primary means of load shedding scheme. Under Frequency Relays can be there as stand-by.

- Our GTGs are designed to take a maximum step load of **4MW** and then settle for at least one minute to take further load and so on upto a maximum of around 19MW at usual ambient conditions.(Equivalent to 25 MW at ISO ambient conditions).
- Both GTGs together generate about 30 MW, with each individual GTG sharing about half the load. Hence it will be prudent to cut down a load of about 13 MW at a time from about 30 MW level.
- In our Power system "the critical fault clearing time is around 0.32 seconds"(320ms).—In other words the GTG has to be made free from overloading ,if any, within this much time.--It is reasonable to take **320 ms** as the time limit to shed extra load by the Load Shedding Scheme. Also the LSS should function in such a way that at any point of time the load step on GTGs do not exceed 4MW and a total maximum load beyond **19MW.**
- Existing LMS does not fulfill the execution speed. The under frequency relay system nearly matches the execution speed but falls short in terms of quantum of load step it sheds **(Table2) .**
- 13 MW load reduction is possible only when power to all the 4 Urea Plants are cut along with other consumers like Township, Bore-wells, PH plants etc.
- In other words there has to be an arrangement to shed the load enlisted on **Table-1 Sl. No. 1 to 24** (total connected load 14.95MW) **at a time** at a very fast speed less than 320 ms.
- As per software algorithm this scheme will essentially form a parallel (fast) path to the existing algorithm shown in **Fig.4 below.** Hence this scheme can be designated as ***"Fast Path Load Shedding Scheme" or"Fast load shedding scheme".***
- Transfer of trip command from Power Plant Processor to Urea Plant Processor must avoid use of data links and delay/traffic jam thereof.—It will be prudent to generate a hardwired contact as the output of Power Plant processor, connect the same through hardware connections to Urea Plant Processor as input for this.

Implementation

In the existing PLC, the fast path load shedding implementation necessarily calls for following steps:

- Ensure hardwired connections for command transfer from Power Plant Processor to Urea Plant Processor.
- Respective PLCs are to be configured suitably to recognise these hardwired contact output and inputs and perform the required load shedding functions as per Table-1A. Also GTG Trip contact shall provide a software bypass of the initial 5 sec. delay.
- To reduce the execution time to the minimum possible in case of fast path loads.
- To re-write the ladder logic in the form of separate sub-routine pertaining to the loads related to the fast path scheme. This is for easy maintenance and trouble shooting and display of status on the screen.

All these modifications are not possible in one step and with-out proper testing of the modifications. Accordingly implementation was decided in three steps as below:

1. As the first step the existing software was modified in such a way that 5 second time delay gets by passed whenever there is trip of any one the GTG. This was the minimum immediate modifications that could be implemented in May 2010. This modification along with combined effect of low frequency relay saved the plant on **18.6.2011.**

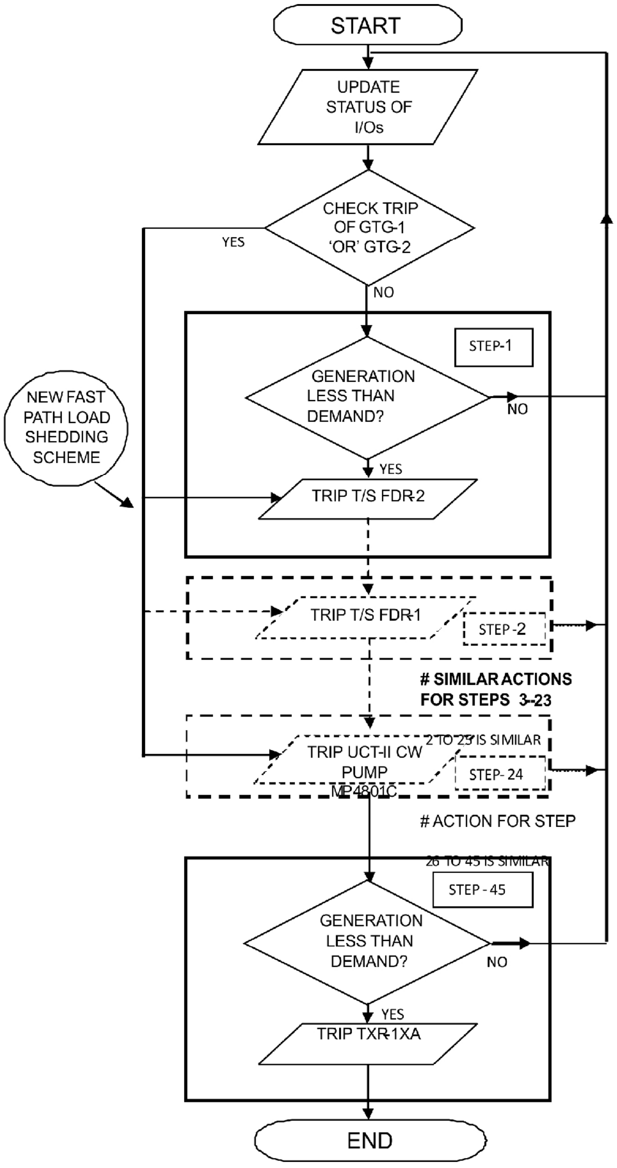
2. The second step was implemented during shut down of Aonla-I in March 2011. During this time parallel paths were defined over and above the existing "rungs" of the ladder logic to connect the loads pertaining to the fast path scheme. However during this period all the loads could not be connected to the scheme because Aonla –II plants were running and some of the loads could not be tested. Also writing separate sub- routine or minimizing the execution time could not be done at that time.

3. List of the loads which were connected to the fast path scheme is put on **Table-1 A** of Annexure and those which could not be connected are also put in **Table-1B.**

4. The under frequency relay, was modified to have more load on each step and have less number of steps compared to earlier. Cut-off frequency steps of Under frequency relay was reduced and load quantum on each step was increased totaling to about 12 MW as per Table-2A .Loads were shifted suitably and necessary modifications of the electrical circuits were done accordingly.

It has been observed in our Power system that when a heavy motor of 1.3MW takes start the frequency momentarily falls by 0.1to 0.15 Hz from normal value of 50 Hz. Hence it was considered safe (no spurious load shedding on transients)and prudent to set 49.76Hz as the first cut-off point and 49.4Hz as the last cut off point for loads of increasing criticality.

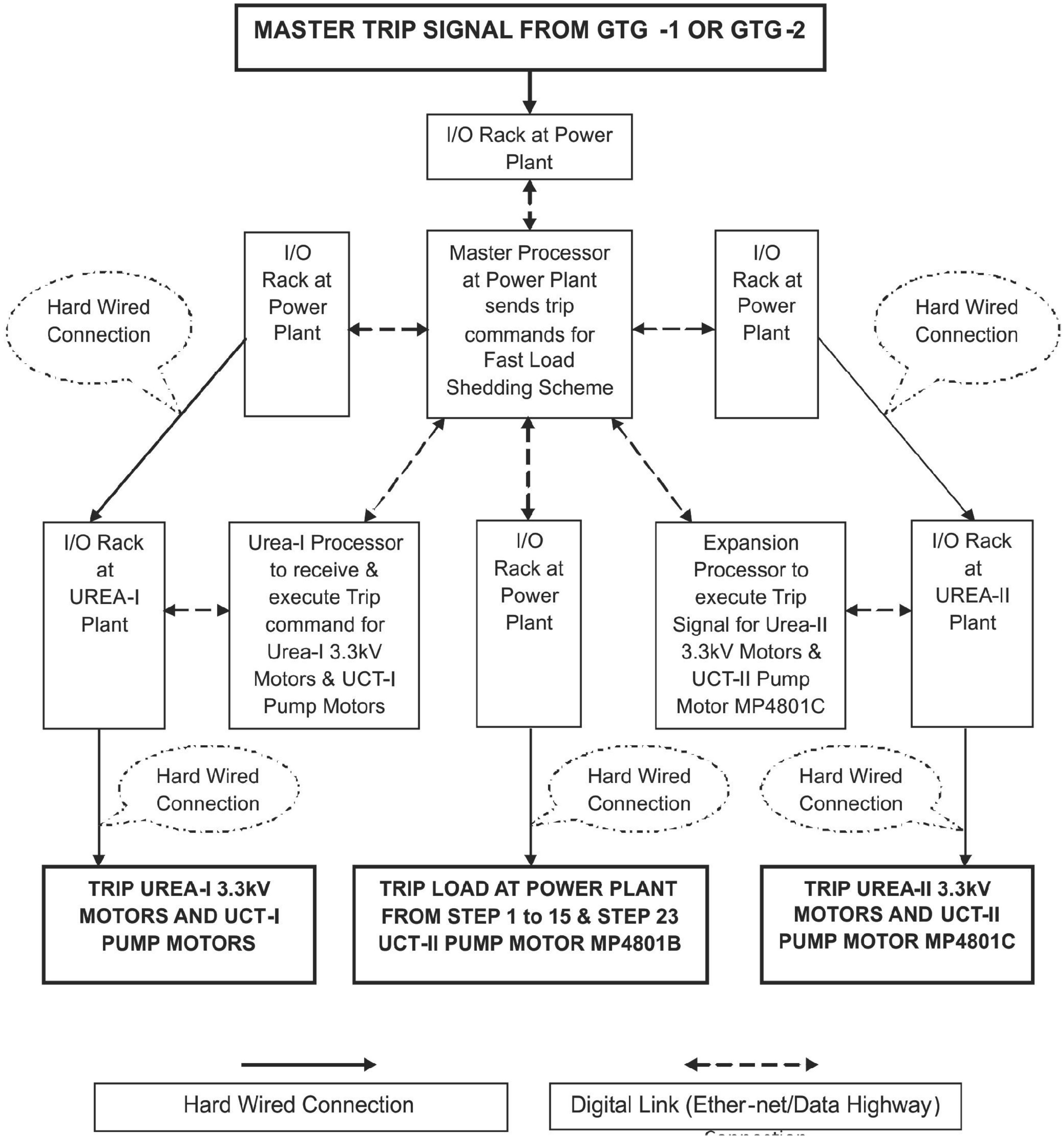
LMS Flowchart —Existing & Augmented with Fast Load Shedding Scheme



Note: In case load of a particular step is already 0 (zero) the system automatically proceeds to next step. This is not shown in algorithm.

Note:5 Sec.initial delay & its bypass not shown

PICTORIAL REPRESENTATION OF FAST LOAD SHEDDING SCHEME IMPLEMENTATION



Expected results with part(2nd.Phase) modifications

- As soon as one GTG trips, about 6-7 MW of load will be shed by fast path LSS and
- there will an imbalance of about 6- 8 MW between generation and demand.--
- This should result in fast fall of frequency to shed more load by under frequency relay.
- major part of load common to both systems will already be shed by past path LSS.
- Under this condition existing LMS had much less data traffic to handle for on-line calculations and communication between processors to I/Os. It is likely to act fast to shed further load without suffering from slow response due to jamming of data traffic.
- All the three systems together are likely to shed the required load within 200-500ms.

However when the implementation is complete the Fast Path LSS alone will serve the purpose and Under Frequency Relay will be a complete standby system thereby further enhancing the overall system reliability.

Actual results-- Load shedding on 25.11.2011 and 26.11.2011

GTG-1 of Power Plant tripped on two consecutive days 25-11-11 and 26-11-11 respectively Trip of GTG-1 was due to faulty actuation of a fire detector on both the days which was subsequently bypassed temporarily.

After receiving tripping signal from GTG-1, Load shedding was actuated and approximately 15.81 MW was shed on 25.11.2011 and 14.70MW on 26.11.2011 through combined effect of Fast Path LSS, Under frequency relay and existing LMS. On both the days GTG2 as well as both the Ammonia plants were saved and all the four Urea Plants tripped.

Actuation of Under frequency relay steps:

All the three stages of under frequency relay has actuated as under:

	Under Frequency Setting(Hz)	Details of Load Connected		Status on 25.11.11 & 26.11.11
		Loads	MW*	
Step-1	49.76	Township** Borewells** PH-Plant** Non-Plant Buildings**	1.70	Only PH-Plant (1MW) was on GTG supply other loads were on UPPCL supply. PH Plant was shed by Under Frequency relay.
Step-2	49.40	Urea-1 3.3kV switch gear UCT-1 Pump motors	4.60	These loads were shed by Fast Load Shedding Scheme before Under Frequency relay actuated
Step-3	49.20	Urea-2 3.3kV motors UCT-2 Pump motors MP4801C & MP4801B***		These loads were shed by Fast Load Shedding Scheme before Under Frequency relay actuated except MP4801B.

Note: It can be seen that load shed by Fast Path LSS is 7.2MW and by U/F Relay is 1MW.

Actual results – Load shedding on 26.11.2011

From analysis of happenings of both the days it appears following sequence of events have taken place in about 380 ms:

Time span(ms)	Scheme active/event	Load Shed(MW)	Remarks
0-200	Fast Path Load Shedding	7	
0-200	Freq .falls up to 49.2Hz		Due to 8MW imbalance
200-240	Under frequency relay	1	
200-380	Existing LMS	7	
	Total	15	

Following points may be noted here:

1. Loads pertaining to Aonla-II plant are not yet connected to fast path LSS running. Hence load cut was7MW only instead of 14-15 MW.

2. Fall of frequency was fast as imbalance between supply and demand was heavy to the tune of 8MW.The rate of fall will be slow in case of less imbalance quantum.

3. Existing LMS acted fast. Possible reason could be the fact that already major part of the loads were cut by other two schemes and existing LMS had much less data traffic to handle for on-line calculations and communication between processors to I/Os.—The system did not suffer from jamming of data traffic which used to be the case earlier.

As expected GTG-2 as well as both Ammonia Plants were saved on both the days.

Implementation of last phase of modifications in March 2012.

- During this phase the sub-routine was made separately.

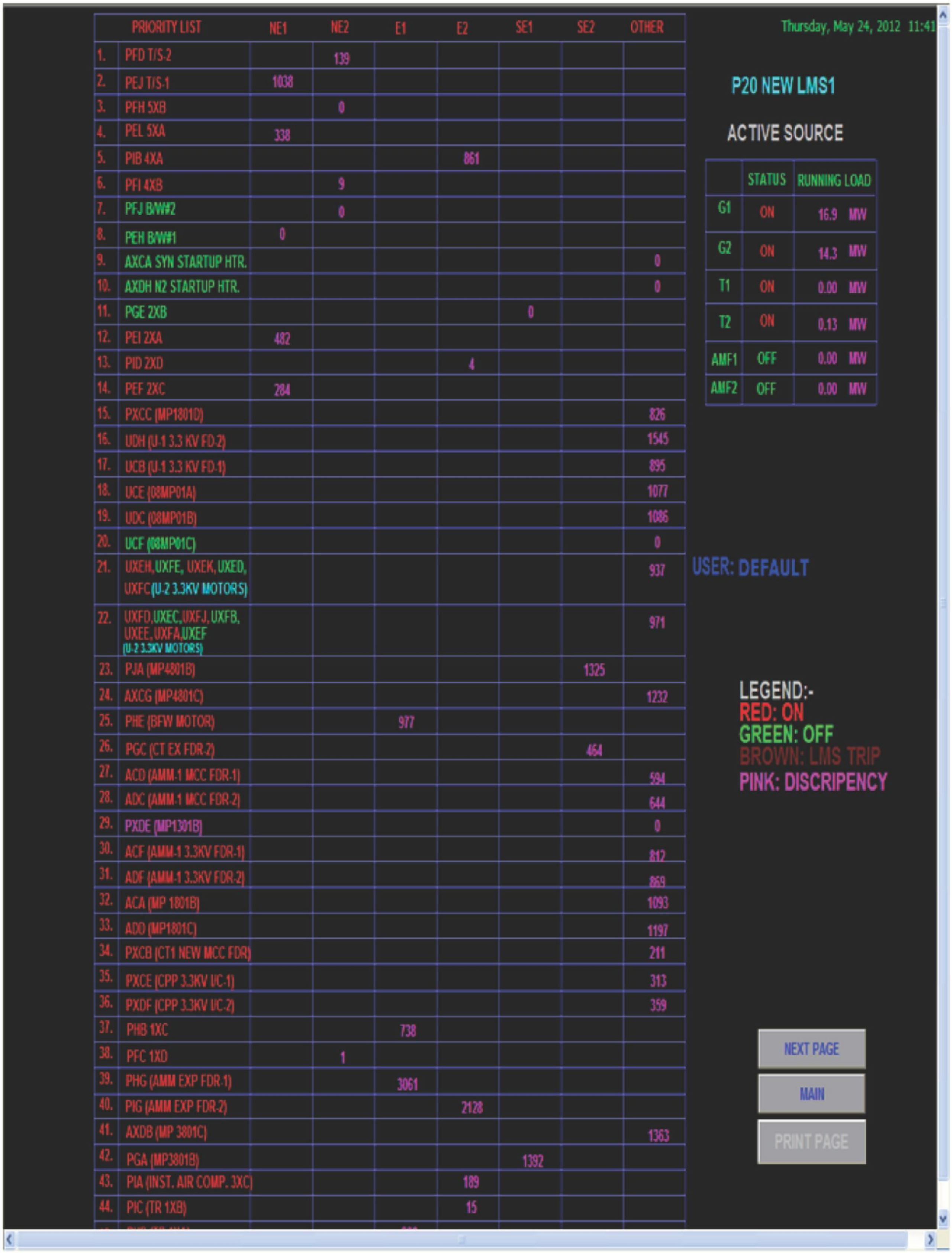
- The I/O channel communication rate for power plant and expansion racks for Fast Load Shedding(FLS) I/O was changed from 57.6K to 230.4Kbps for faster execution .

- All the steps as required by fast path scheme were implemented completely. The testing was done by way of simulating the fast path load shedding conditions and ensuring actuation of the auxiliary relay upstream of respective circuit breakers.

- The detail of the scan time as measured are also given below.

Processor	Scan time before adjustment (ms)	Scan time after adjustment (ms)	Remarks
Power Plant	250	90-120	
Expansion	120	60-70	
Overall (at U2 I/O Rack)		220-250ms	Reqd.320ms

Given below are the snap shots from the modification streams of the system.



	PRIORITY LIST	NE1	NE2	E1	E2	SE1	SE2	OTHER
1.	PFD T/S-2		139					
2.	PEJ T/S-1	1038						
3.	PFH 5XB		0					
4.	PEL 5XA	338						
5.	PIB 4XA				861			
6.	PFI 4XB		9					
7.	PFJ B/W#2		0					
8.	PEH B/W#1	0						
9.	AXCA SYN STARTUP HTR.							0
10.	AXDH N2 STARTUP HTR.							0
11.	PGE 2XB					0		
12.	PEI 2XA	482						
13.	PID 2XD				4			
14.	PEF 2XC	284						
15.	PXCC (MP1801D)							826
16.	UDH (U-1 3.3 KV FD-2)							1545
17.	UCB (U-1 3.3 KV FD-1)							895
18.	UCE (08MP01A)							1077
19.	UDC (08MP01B)							1086
20.	UCF (08MP01C)							0
21.	UXEH, UXFE, UXEK, UXED, UXFC (U-2 3.3KV MOTORS)							937
22.	UXFD, UXEC, UXFJ, UXFB, UXEE, UXFA, UXEF (U-2 3.3KV MOTORS)							971
23.	PJA (MP4801B)						1325	
24.	AXCG (MP4801C)							1232
25.	PHE (BFW MOTOR)			977				
26.	PGC (CT EX FDR-2)						464	
27.	ACD (AMM-1 MCC FDR-1)							594
28.	ADC (AMM-1 MCC FDR-2)							644
29.	PXDE (MP1301B)							0
30.	ACF (AMM-1 3.3KV FDR-1)							812
31.	ADF (AMM-1 3.3KV FDR-2)							869
32.	ACA (MP 1801B)							1093
33.	ADD (MP1801C)							1197
34.	PXCB (CT1 NEW MCC FDR)							211
35.	PXCE (CPP 3.3KV I/C-1)							313
36.	PXDF (CPP 3.3KV I/C-2)							359
37.	PHB 1XC			738				
38.	PFC 1XD		1					
39.	PHG (AMM EXP FDR-1)			3061				
40.	PIG (AMM EXP FDR-2)				2128			
41.	AXDB (MP 3801C)							1363
42.	PGA (MP3801B)					1392		
43.	PIA (INST. AIR COMP. 3XC)				189			
44.	PIC (TR 1XB)				15			

Thursday, May 24, 2012 11:41

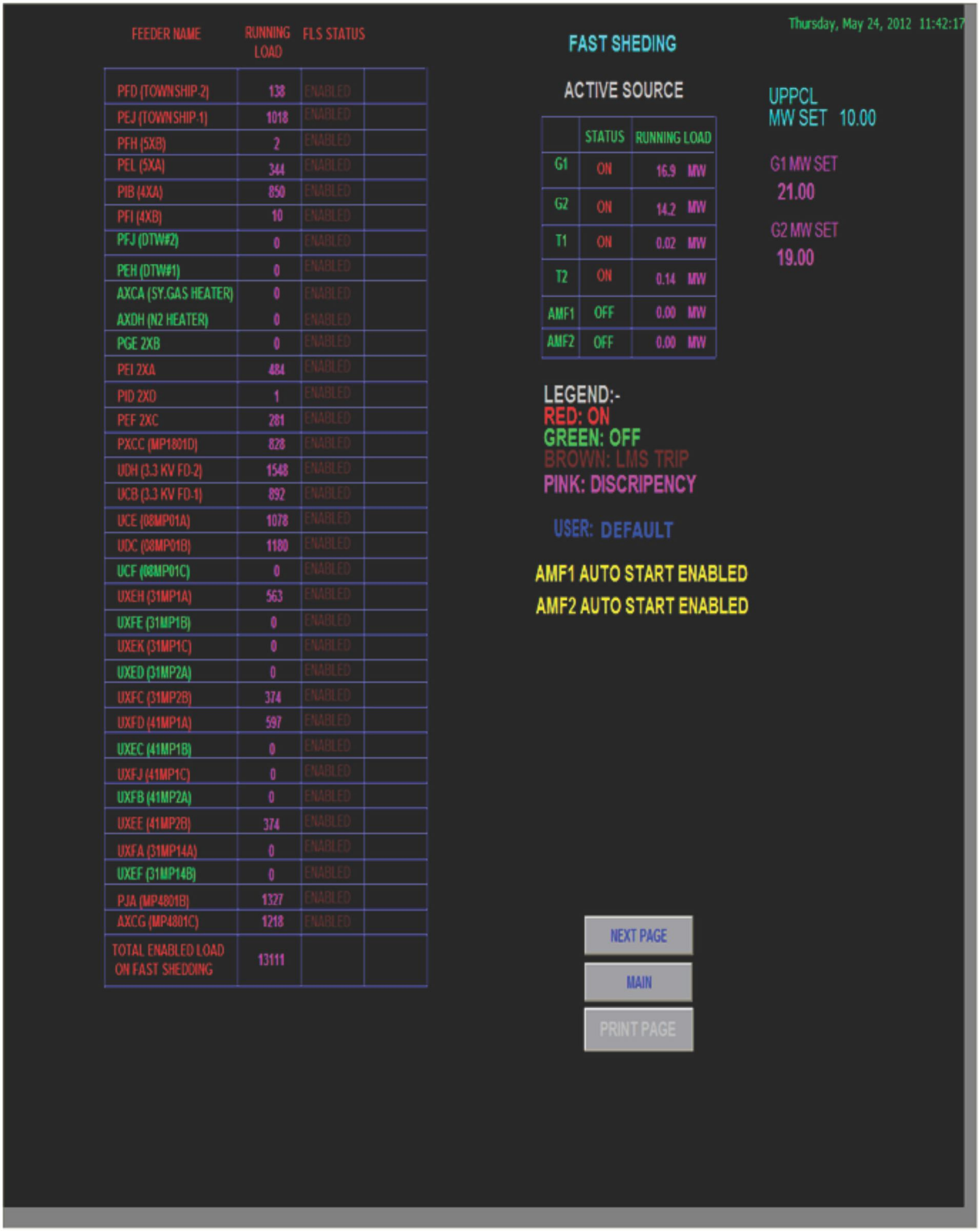
P20 NEW LMS1

ACTIVE SOURCE

	STATUS	RUNNING LOAD
G1	ON	16.9 MW
G2	ON	14.3 MW
T1	ON	0.00 MW
T2	ON	0.13 MW
AMF1	OFF	0.00 MW
AMF2	OFF	0.00 MW

USER: DEFAULT

LEGEND:-
RED: ON
GREEN: OFF
BROWN: LMS TRIP
PINK: DISCRIPENCY



Thursday, May 24, 2012 11:42:17

FEEDER NAME	RUNNING LOAD	FLS STATUS	
PFD (TOWNSHIP-2)	138	ENABLED	
PEJ (TOWNSHIP-1)	1018	ENABLED	
PFH (5XB)	2	ENABLED	
PEL (5XA)	344	ENABLED	
PIB (4XA)	850	ENABLED	
PFI (4XB)	10	ENABLED	
PFJ (DTW#2)	0	ENABLED	
PEH (DTW#1)	0	ENABLED	
AXCA (SY.GAS HEATER)	0	ENABLED	
AXDH (N2 HEATER)	0	ENABLED	
PGE 2XB	0	ENABLED	
PEI 2XA	484	ENABLED	
PID 2XD	1	ENABLED	
PEF 2XC	281	ENABLED	
PXCC (MP1801D)	828	ENABLED	
UDH (3.3 KV FD-2)	1548	ENABLED	
UCB (3.3 KV FD-1)	892	ENABLED	
UCE (08MP01A)	1078	ENABLED	
UDC (08MP01B)	1180	ENABLED	
UCF (08MP01C)	0	ENABLED	
UXEH (31MP1A)	563	ENABLED	
UXFE (31MP1B)	0	ENABLED	
UXEK (31MP1C)	0	ENABLED	
UXED (31MP2A)	0	ENABLED	
UXFC (31MP2B)	374	ENABLED	
UXFD (41MP1A)	597	ENABLED	
UXEC (41MP1B)	0	ENABLED	
UXFJ (41MP1C)	0	ENABLED	
UXFB (41MP2A)	0	ENABLED	
UXEE (41MP2B)	374	ENABLED	
UXFA (31MP14A)	0	ENABLED	
UXEF (31MP14B)	0	ENABLED	
PJA (MP4801B)	1327	ENABLED	
AXCG (MP4801C)	1218	ENABLED	
TOTAL ENABLED LOAD ON FAST SHEDDING	13111		

FAST SHEDING

ACTIVE SOURCE

	STATUS	RUNNING LOAD
G1	ON	16.9 MW
G2	ON	14.2 MW
T1	ON	0.02 MW
T2	ON	0.14 MW
AMF1	OFF	0.00 MW
AMF2	OFF	0.00 MW

UPPCL
MW SET 10.00

G1 MW SET
21.00

G2 MW SET
19.00

LEGEND:-
RED: ON
GREEN: OFF
BROWN: LMS TRIP
PINK: DISCRIPENCY

USER: DEFAULT

AMF1 AUTO START ENABLED

AMF2 AUTO START ENABLED

Thursday, May 24, 2012 11:42:50

UNDER FREQUENCY SHEDDING

FEEDER NAME	FEEDER TRIPPED
PFD (TOWNSHIP-2)	NO
PEJ (TOWNSHIP-1)	NO
PFJ (DTW#2)	NO
PEH (DTW#1)	NO
PIB (4XA)	NO
PFI (4XB)	NO
PFH (5XB)	NO
PEL (5XA)	NO
UDH (3.3 KV FD-2)	NO
UCB (3.3 KV FD-1)	NO
UCE (08MP01A)	NO
UDC (08MP01B)	NO
UCF (08MP01C)	NO
UXEH (31MP1A)	NO
UXFE (31MP1B)	NO
UXEK (31MP1C)	NO
UXED (31MP2A)	NO
UXFC (31MP2B)	NO
UXFD (41MP1A)	NO
UXEC (41MP1B)	NO
UXFJ (41MP1C)	NO
UXFB (41MP2A)	NO
UXEE (41MP2B)	NO
UXFA (31MP14A)	NO
UXEF (31MP14B)	NO
AXCG (MP4801C)	NO
PJA (MP4801B)	NO

STAGE 1
49.76 Hz

STAGE 2
49.4 Hz

STAGE 3
49.2 Hz

PWR MASTER ENABLED
EXP MASTER ENABLED
UREA MASTER ENABLED

LEGEND:-
RED: ON
GREEN: OFF
BROWN: LMS TRIP
PINK: DISCRIPENCY

USER: DEFAULT

Now the LMS is expected to work much faster than the earlier and naturally the power system stability is better ensured than the system's response as has been experienced in earlier occasions.

Other measures for Reliability enhancement of Electrical System

Some of the other modifications implemented during year 2010 and 2011 are as below:

- Separate power feeders for GTG's Reduction Gear Compartment Fans provided to prevent tripping of GTG in case of fault in one of the fans.(Trip of 14-05-2010)
- Adjacent fire detectors are clubbed together to form 2/2 logic for tripping.
- LMS I/O rack panels of Power Plant are up-graded –transducers changed.

Fig. 5 (Photos—Protection Relays—old & New)

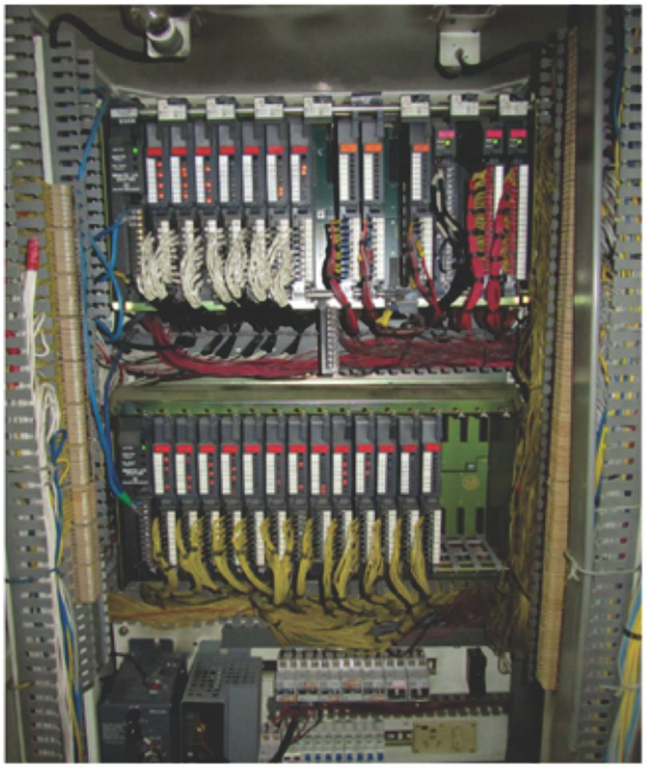


Fig. 6 (Photos—LMS I/O racks—old & New)

It was noted that both GTGs have earlier tripped on occasions of earth fault of Township overhead cables and earth faults at Ammonia-I sub station.

- The earth fault relay installed earlier at Township used to act slower than protection relay installed at GTG end and allowed the fault to propagate to GTGs and trip them. For some period the Township load was removed from GTGs and kept on UPPCL.
- New Microprocessor based MICOM relays are now installed for feeder protection of Ammonia Plant, Bore-well and Township Feeders for fast isolation of fault,
- Also an Isolation Transformer has been installed on Township Feeder to avoid heavy electrical faults in Township Over Head Line to propagate to GTG.
- Underground cables are now laid to connect about 1.5 to 2MW of Township load. Only bore-wells (about 100KW) are still on overhead cables.
- Township load is now put back on GTG.
- Old Analog AVR (Automatic Voltage Regulator) of GTG-1 is replaced by new Digital AVR. This was already planned earlier.

2. Corrective measures at process plants

On Analysis of the events on 14.05.2010 at Off-sites & Ammonia-I Plants the following observations were made:

- All the 03nos. motor driven Cooling Water(CW) Pumps supporting Ammonia Plant tripped on power failure. Turbine driven pump TP-1801A did not take auto start as its steam inlet valve was kept closed..
- AMF set-1 took "Auto" start after tripping of the GTGs. but soon tripped on high lube oil and jacket cooling water temperatures. This was due to failure of cooling water.
- Failure of Cooling Water caused Trip of Ammonia-I Process Air Compressor(PAC).
- Failure of AMF set caused tripping of the Auxiliary oil pumps(AOP) of Turbine driven GV Solution Booster Pump and Boiler Feed Water(BFW) Pump of Ammonia –I Plant. These caused tripping of GV section and back end of Ammonia-I Plant as well as trip of Primary Reformer (Front end) on Low boiler drum level.

It was noted that for AMF sets the time gap between CW failure to high temp. alarm- leading to trip- is about 5 minutes. That means corrective action, such as lining up fire water for cooling, must be completed within 5 minutes. In fact AMF set-II could be saved as fire water hose could be connected in less than 5 minutes.

Subsequently a permanent fire water connection with isolation valves as once through process has been provided. Also alarm for GTG trip and AMF set start status are provided at Water treatment Plant(DM Plant) control room where people are always available.

The medium pressure (SM) steam from Ammonia-1 Plant goes to drive turbine of CW Pump and the low pressure(LP)extraction steam goes to PAC Turbine as induction steam. Since this CW pump is not usually run the steam headers does not remain warm.—This makes condensate formation and as soon as the CW pump takes auto start on failure of motor driven pump ,wet steam goes to PAC Turbine and creates disturbance.—This has tripped the machine 02 times in past. Hence the Steam inlet valve was kept closed and the CW Pump did not take auto start during power failure.

A bypass line (1''size) across the steam inlet valve has now been provided to keep the SM steam header warm and avoid condensate formation. Also all the steam-traps are overhauled.

An overhead Lube Oil tank has been provided to cater lube oil at required pressure by gravity to the Booster Pump for GV solution during failure of Auxiliary oil pump (AOP).

However such overhead Lube Oil tank is not feasible for AOP of Boiler Feed water pump where the operating pressure is higher (6 kg/cm2). Power to AOP has to be ensured quickly by manual intervention.

3. Corrective Measures in Operational Practices in Power Crisis Situations

Case-A Trip of one GTG -- Optimum usage of Power to sustain Ammonia plants

In this situation the list of feeders/equipments to be kept on UPPCL and GTG are identified and enlisted at **Table-3** (at Annexure).The Loads will be 4.344MW on UPPCL and 19.394MW on GTG.

Table – 3. Trip of one GTG -- Optimum usage of Power to sustain Ammonia plants

Load on UPPCL (Description)	KW	Load on GTG (Description)	KW
Township-2&1	1150	PH Plant Feeder 4XA	200
Non Plant Bldg 5XB&5XA	500	Urea-1 CW pump 08MP01B	1100
PH Plant Feeder 4XB	250	BFW Motor GA-101C (P. Plant)	1000
Borewell FDR-2&1	250	Urea-2 CW Pump MP4801B	1300
Raw water Feeder 2XB& 2XA	684	New 3.3 KV Switchboard of CEP S/S I/C-A&B	250
FIre water Feeder 2X C	210	Ammonia-1 MCC FDR 1&2	1200
CT Expansion feeder-2	500	Ammonia-1 3.3KV FDR-1&2	1000
DM plant Feeder 1 X D	800	MP1801B & C Amm-1	2250
		Ammonia-2 CW pump MP 3801C	1350
		Ammonia expansion feeder -1&2	5250
		Inst.Air Compressor Feeder 3XC	50
		Power Plant TR 1XB&1XA	100
Total	**4344**		**15050**
Overall Total			**19394**

Trip of one GTG --the expected scenario and actions required at Urea plants

1. All urea streams 11/21/31/41 will trip. (3.3 KV motors)
2. Initially all motor driven CW pumps of Urea-I & Urea-II plants will trip. Immediately one CW pumps of Urea-I shall be started. Turbine driven CW pump of Urea-II plant shall be started immediately, if it was not running earlier. Ammonia-II CW turbine shall be started, if required, and one motor driven CW pump shall be stopped to conserve power,
3. CO2 Compressor of all urea streams 11/21/31/41will be on vent mode and kept on running. Power to LT motors (lube oil pumps and Condensate Pumps) will be available. Hence CO2 Compressors will not trip.

Trip of one GTG -- actions required at Power Plant, Utilities & Electrical

In-case any GTG trips, start command to both AMF sets will go automatically.AMF sets will start and act as additional sources of Power. It is required subsequently to oversee its operation. If auto start does not take place then AMF set(s) will be started manually.

- Tripping of AMF set at high temperature of lube oil/cooling water shall be avoided by way of quick changeover within 5 minutes to fire water header.
- Turbine driven CW pump start shall be ensured for Ammonia-I & Ammonia-II plants.
- IGV of running GTG is to be put on manual mode and opened completely within 3 minutes time. This will make the machine suitable to take more load steps than specified for 4MW without getting tripped on high exhaust air temperature.
- Load setting of UPPCL to be kept at 10MVA.

Load detail on UPPCL & GTG is illustrated above. Feeders are to be managed accordingly to save Ammonia plants.

- Running of AOPs in general shall be ensured.
- Good steam management is required at this condition, to sustain the CO2 compressors at low load. This will save start up time when power is available.
- Urea plants can be restarted one by one when Power becomes available.

Case-B .

In this situation the list of feeders/equipments to be kept on UPPCL are identified and enlisted at Table-4 below. Total load will be 6.395MW on UPPCL.

Table – 4 .Trip of both GTGs—Minimum UPPCL Power to sustain Ammonia plants

Ammonia-I		Ammonia-II		Other Plants	
Description	**Load(KW)**	**Description**	**Load(KW)**	**Description**	**Load(KW)**
All LT Motors	1255	All LT Motors	800	Power Plant Auxiliaries+ Lighting+ A/C	300
PGR	20	Inst. Air Compr	600	Off-sites-Auxiliaries+ Lighting+ A/C	100
AC +UPS	195	AC +UPS	200	Urea-I - Auxiliaries+ Lighting+ A/C	300
Lighting	200	Lighting	250	Urea-II - Auxiliaries+ Lighting+ A/C	300
CT fans (2Nos.)	160	CT fans (2Nos.)	160	PH - Auxiliaries+ Lighting+ A/C	200
Air Dryer	140	Air Dryer + off-sites	220	T/S & Bore-wells	1000
Total	**1965**		**2230**		**2200**
Overall Total					**6395**

Trip of both GTGs -- expected scenario and actions required—Urea, Electrical

To ensure survival of both Ammonia plants on UPPCL power following scenario will exist.

1. No power will be available to Urea Plants, hence all urea streams including cooling tower pumps and CO2 Compressors will trip.
2. To take safe shutdown of the plant, emergency power supply to 11/21/31/41 MP24A/B, 11/21/31/41 MP25, barring device, 11/21/31/41MP-5A/B, 11/31MP-6A/B, 11/31MP-10A/B, 11/31MP-11A/B and Prilling Tower lift shall be made available.
3. In case of tripping of both GTGs, we can draw power up to maximum 9 MW(10MVA setting) for a shorter period which may be helpful for the survival of both Ammonia Plants and handling emergencies. Further, it shall be reduced up to 4.5 MW manually, at the earliest possible after managing plant requirement.

Conclusion

The present up-gradation has been done without any investment at all. Rather innovative idea of hardwired connection was used to avoid the delays of old generation data highways and get the best within existing system itself.—This has avoided investment of several crores of rupees for a new PLC.

Since the implementation of the short term modifications itself there has been at least 03 occasions of trip of one GTG but no incident of total power failure nor there has been outage of Ammonia Plants due to power failure. In other words with the above modifications has been successful; with the modification and the measures the reliability of the Power System of the complex has improved a lot.

Annexure

Table -1 Load Steps--existing LMS & Fast Path LSS &co-relation with Under Freq. Relay

Sl.No& (Priority).	Bus name	Feeder Name	(Description)	Cut off freq. (Hz)-earlier	Cut off freq. (Hz)-Modified
1	NE2	Township-2	900	49.76	49.76
2	NE1	Township-1	250	49.76	49.76
3	NE2	Non Plant Bldg 5XB	500	49.76	49.76
4	NE1	Non Plant Bldg 5XA	0	49.76	49.76
5	E2	PH Plant Feeder 4XA	400	49.40	49.40
6	NE2	PH Plant Feeder 4XB	500	49.40	49.40
7	NE2	Borewell FDR -2	200	49.40	49.40
8	NE1	Borewell FDR -1	50	49.40	49.40
9	Amm-2	Syn Gas start up heater Amm-II	0		
10	Amm-2	N2 start up heater	0		
11	SE1	Raw water Feeder 2XB	200		
12	NE1	Raw water Feeder 2XA	300		
13	E2	Fire water Feeder 2X D			
14	NE1	Fire water Feeder 2X C	250		
15	P/P CEP	MP1801D Amm-1	850		
16	Urea -1	Urea-1 3.3 KV Feeder-2	2210	49.20	49.20
17	Urea -1	Urea-1 3.3 KV Feeder-1	190	49.00	49.20
18	Urea -1	Urea-1 CW pump 08MP01A			49.20
19	Urea -1	Urea-1 CW pump 08MP01B	1100		49.20
20	Urea -1	Urea-1 CW pump 08MP01C	1100		49.20
21	Urea-2	Urea-2 3.3kV Motors only			
22	Urea-2	Urea-2 3.3kV Motors only	3400		49.20
23	SE2	Urea-2 CW pump MP4801B	1300		49.20
24	Amm-2	Urea-2CW pump MP4801C	1250	48.60	
FAST	**PATH LSS**	**Steps 1 to 24 Total Load**	**14950**		

25	SE1	CT Expansion feeder-2		48.80	
26	P/P CEP	3.3KV switchboard of CPP S/S I/C-A (MIST + P/P FD Fan)			
27	P/P CEP	3.3KV switchboard of CPP S/S I/C-B			
28	E1	BFW Motor GA-101C (P/Plant)	1000		
29	Amm-1	Ammonia-1 MCC FDR-1			
30	Amm-1	Ammonia-1 MCC FDR-2			
31	PIP CEP	GV soln pump-B (fdr no.10 of new 11 KV swg p/p)			
32	Amm-1	Ammonia-1 3.3 KV FDR-1			
33	Amm-1	Ammonia-1 3.3 KV FDR-2			
34	Amm-1	MP1801B Amm-1			
35	Amm-1	MP1801C Amm-1			
36	P/P CEP	New CT MCC (Fdr No.2 of new 11KV SG)			
37	E1	DM Plant Feeder 1XC			
38	NE2	DM Plant Feeder 1XD			
39	E1	Ammonia expansion feeder -1 + Air Compressor O/s-II (3.3kV Amm2)			
40	E2	Ammonia expansion feeder -2			
41	Amm-2	Ammonia CW pump 3801C			
42	SE1	Ammonia CW pump 3801B			
43	E2	Instr. Air Compressor Feeder 3XC			
44	E2	Power Plant TR 1XB			
45	E1	Power Plant TR 1XA			

Table -1A List of loads already connected with Fast Path LSS (March 2011) :

Sl. No & (Priority).	Bus name	Feeder Name	Connected load (KW)
16	Urea -1	Urea-1 3.3 KV Feeder-2	2210
17	Urea -1	Urea-1 3.3 KV Feeder-1	190
18	Urea -1	Urea-1 CW pump 08MP01A	
19	Urea -1	Urea-1 CW pump 08MP01B	1100
20	Urea -1	Urea-1 CW pump 08MP01C	1100
21	Urea-2	Urea-2 3.3kV Motors only	
22	Urea-2	Urea-2 3.3kV Motors only	3400
24	Amm-2	Urea-2CW pump MP4801C	1250
		Total load	9250

Table -1B List of loads to be connected with Fast Path LSS (March2012) :

Sl.No& (Priority).	Bus name	Feeder Name	Connected load(KW)
1	NE2	Township-2	900
2	NE1	Township-1	250
3	NE2	Non Plant Bldg 5XB	500
4	NE1	Non Plant Bldg 5XA	0
5	E2	PH Plant Feeder 4XA	400
6	NE2	PH Plant Feeder 4XB	500
7	NE2	Borewell FDR -2	200
8	NE1	Borewell FDR -1	50
9	Amm-2	Syn Gas start up heater Amm-II	0
10	Amm-2	N2 start up heater	0
11	SE1	Raw water Feeder 2XB	200
12	NE1	Raw water Feeder 2XA	300
13	E2	Fire water Feeder 2X D	0
14	NE1	FIre water Feeder 2X C	250
15	P/P CEP	MP1801D Amm-1	850
23	SE2	Urea-2 CW pump MP4801B	1300
		Total load	**5700**

Table-2A: Existing & Modified Under Frequency Relay Cut-Off detail (March 2011)

Before Modification			After Modification		
Freq.(Hz)	**Load Steps**	**Cumulative KW**	**Freq.(Hz)**	**Load steps**	**Cumulative KW**
50-49.9	No load shedding	0	50-49.9	No load shedding	0
49.76	Township Fdr I & II	1150	49.76	Township Feeder I & II, S/S-5, PH Plant & Bore-well Feeders I & II	2800
49.4	PH & Plant Borewell Fdrs I & II	2100	49.4	3.3KV motors of Urea-I and 02 nos. Urea CT-1 11kV CW pump motors	7400
49.2	11MP1A&1B and 1MP 2A&2B	3120	49.2	3.3KV motors of Urea-II and 02 nos. Urea CT-2 11kV CW pump motors	12100
49.0	21MP1A&1B and 21MP 2A&2B	4140			
48.8	31MP1A&1B and 41MP 2A&2B	5180			
48.6	41MP1A&1B and 41MP 2A&2B	6220			12100

Note: Urea-2 CW pump MP4801B load 1300 KW is still to be connected to the above system. This motor has been connected with under frequency relay in March 2012.

PROFILE OF MR. A.K.BHADURI

Mr. A.K. Bhaduri is presently working as Senior General Manager at IFFCO New Delhi.

He is an Instrumentation Engineer from Jadavpur University, and is a Fellow of the Institute of Engineers .He started his career at IFFCO in 1978. Since then has worked in all the Units of IFFCO and its overseas Joint Ventures at various capacities in maintenance and projects. He is a well travelled person.

During his tenure at IFFCO's Aonla Unit as General Manager(Technical),the Unit bagged prestigious SHE award of International Fertiliser Association,

Intelligent Combustion Optimisation as reaction to changing pulverised fuel properties – A Case Study

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Alexander C. Hanf – Powitec Intelligent Technologies GmbH, Essen, Germany

Content:

1. Summary

Combustion in large scaled coal fired boilers faces challenges from variations in coal type, fuel grinding degree, and fuel feed distribution. By increased observation of mills, separators and pulverised coal pipes an early knowledge about the decisive parameters is obtained and is used for intelligent closed loop control. The homogenised combustion leads to increased availability and improved boiler heat rate.

2. Challenges and Philosophy

Main challenge and main reason for a suboptimal combustion in a coal dust fired large scaled power plant are continuous changes due to variations in coal type, fuel grinding degree, and fuel feed distribution.

A suboptimal combustion comes with several challenges like high CO, NOx, increased excess O2, increased flue gas temperatures, temperature imbalances; thus effects causing material stress and low efficiency.

The natural product coal changes its quality variables like volatiles, ash and calorific value depending on its source. Changes in moisture content as well depend on the current season. The grinding degree depends on various variables like mill maintenance status, mill filling degree, mill pressure, separator speed (if available).

The fuel feed distribution typically is adjusted once during commissioning or sometimes during major outages. Due to a. m. reasons and due to differences in length and arrangement of PF pipes the coal dust flow to each burner elevation and to each burner is never equal. Different coal qualities in changing grinding degrees and amounts cause inhomogeneities in flame and thus in temperature distribution.

Steag Energy Services and Powitec offer an optimisation system for coping with these strong challenges. This system has the philosophy to

1. Increase observability and descriptiveness of the process
2. Improve the local air-/fuel-ratio at the burner-levels and improve the constant control suiting the current coal quality, mill maintenance status and fuel feed
3. To achieve the result of
   a. reduced problems from poor combustion and
   b. reduced flue gas left / right temperature imbalances and improved set point compliance
   c. thus the average reheat temperature meets its set point better and thus the total spray

is reduced

d. reduced material stress for super-heater and re-heater

e. all this increases boiler efficiency and boiler availability

These results were achieved in several power plants in the size of 195 to 750 MWel by an optimisation system which combines an improved observability with intelligent control.

3. Intelligent Control

Mill vibrations are monitored via piezo-ceramic sensors on the mills, separators and at the pulverised fuel pipes. This delivers early and permanent information about mill status, mill filling degree, coal quality and parameters and most important: about the pulverised fuel distribution.

This data is correlated with the classical data from the process control system and is processed by a non-linear predictive software based on self-learning neural networks. It permits a real-time prediction of process values (e.g. coal type, volatiles, water, flue gas temperature, O2, NOx, CO).

These process models allow to simulate control interventions and to analyse the simulated reaction of the process. The analysis of all possible predictions yields an optimum plan for the correction of all manipulated variables, which are then fed back into the process control system in real time. It thus becomes possible to achieve weighted optimization targets which may also consist of a weighted compilation of different individual targets. Figuratively speaking, the process control system is given ears and a brain by this approach.

3.1. Improved Observability

The vibration analysis is based on the observation, that mill characteristics and the consistency of the coal mix give rise to different vibration patterns, and that the load, coal properties and mill wear are reflected in acoustic properties.

Whereas the mill produces rather continuous, low frequency sounds, the separator system tends to yield periodic ones within a narrow range. The coal, on the other hand, emits a quite stochastic, broad band of high-frequency, discontinuous spectra. By analysing the level and spectrum, it is possible to derive scalar features.

The data collection requires an appropriate positioning of the sensor, determined after a one-day on-site measurement. The military-approved, industrial grade piezo-sensors are magnetically attached at points <160°C. The data obtained there are centrally fed to a high-performance server for the acoustic analysis. Here, the data evaluation is performed by analysis of spectral focus points, statistical moments, and correlation analysis (optimization of the transformation content). In other words, the wealth of information obtained is reduced to data exhibiting the greatest information content and the largest statistical independence between variables.

Through analysis of the frequency bands, spectral foci, statistical moments of the vibration spectrum, and calculation of a set of envelope curves (parametrized envelope filter) including their statistical moments, a correlation and entropy analysis can be carried out.

The result is a reduced set of period and stochastic characteristics yielding an optimum information content with regard to

- grinding fineness
- mill conditions
- changes in pulverized coal flow per pipe

3.2. Intelligent Control

The intelligent control system would use the following variables for tangentially fired boilers with burner tilt:

- Auxiliary air flow with elevation wise damper position -> homogenised temperature distribution
- Burner tilt -> homogenisation of left & right temperature imbalances - > reduction in reheat spray amount
- Mill loading and classifier temperature -> reduce flue-gas exit temperature
- Excess O2 and over fire air biasing -> Reduce

excess O2 (at same or reduced CO / CO-induced-corrosion at the water wall) to reduce amount of air to be transported, heated up, cooled down, cleaned -> increase efficiency

These manipulated variables to optimize plant operation depend on disturbances such as load conditions, fouling of the boiler, coal quality and ambient conditions which. Because these variables change continuously, a continuous adjustments of the manipulated variables is required. This task is complicated due to the huge number of parameters to be adjusted as well as through the fact that these variables may also affect operational constraints such as metal temperatures or the water wall atmosphere through increased CO. These variables are as well influencing each another and often do not follow linear functions. Additionally it has to be ensured that the operational constraints are not violated. In consequence combustion optimization is a complex, permanent, non-linear time variant and multi-dimensional challenge.

This challenge requires an intelligent optimisation system, using advanced neural nets in combination with additional knowledge about the currently used coal quality and pulverised fuel distribution. Thus the information from the vibration sensors is used together with normal process data to adaptively control the combustion process. This self-organising system automatically extracts relevant information from the vibration data and finds sought relations. The control structure using this extracted information is able to automatically adapt to process changes. The algorithms are permanently working well in a closed loop control cycle and provide robust and stable results in online operation under time varying process conditions.

The system has to be bi-directionally connected to the existing control system but integrates itself as an Add-On since the existing control system unchanged in place and only the adders have to be programmed. The switchover is bump-less and the optimisation system receives high/low limiters and a max biasing.

The software solution itself is fully scalable. It can be used as model predictive control without additional sensors as well as together with the described vibrations analysis or other inputs such as acoustic or radiation pyrometers or flame scanners. However, as pointed out earlier, under an operational regime with frequently changing coal quality additional sensors would improve observability these changes. In this context the vibration sensors are a cost effective solution which gives valuable information for the model predictive control with limited efforts for installation and maintenance

4. Results and Examples

At the 195 MWel Steag power station MKV in Fenne, using 10 to 12 different coal types, the described optimisation system has been in use since 2005 on one boiler with staggered opposed firing. The results for 2006 through today show the following:

- steam generator efficiency: + 0.4% = -324 t coal/a = - 2768 t CO2 /a
- O2 reduced from 4.2 to 3.2 %
- Auxiliary consumption: - 2000 MWh/a
- UciA reduced from 4% to 3.85%
- improved boiler wall atmosphere, reduced slagging, and increased availability

The 750 MWel boiler from power station Tanjung Bin in Malaysia is equipped with 30 burners and uses coal from 8 to 10 sources. 40 Vibration Sensors support the early analysis of coal and allow for in time reaction. Results show

- O2 reduced by 0.6 to 0.8% abs. (depending on coal mixture)
- Flue gas temperature reduced by 8.5%° C
- Coal Flow decreased by 0.5 t/h/mill, Total saving 15,600 t/year coal
- Total saving from reduced FD and ID fan: 2.3MW/day leading to additional energy production of 2700 MW / year

CSP POWER PLANT SIMULATORS

ABSTRACT

Simulation tools play an important role at different stages of the life cycle of a typical CSP project, especially for pre-feasibility studies, design and optimization of the plant, performance guarantee testing during the commissioning phase, performance monitoring of an operational CSP plant, training of plant operators and optimization of a running plant by simulation studies are a few examples. These tools assist the user to take corrective actions and timely decisions, thereby avoiding costly mistakes.

Simulators are broadly classified as steady state and dynamic simulators. A steady state simulator is based on algebraic equations and calculates the parameters over a longer period of time (maybe a full Typical Metrological Year), while a dynamic simulator is based on differential equations and is generally run for analysis over a shorter period of time. There also are quasi steady state simulators and the three types of simulators have important applications in the CSP industry.

A typical problem of CSP plants is the variance of solar resource according to the time of day, month and season while the turbine operation requires a constant supply of steam. Therefore the solar field must be optimally designed to maximize the turbine efficiency and operating hours while minimizing the costs including the thermal energy dumped. An oversized solar field size would dump energy during the peak hours and is expensive while an undersized field would not provide enough full load hours of operation. Thus a techno-economic optimization is needed and may be conducted with the help of Iterative Simulation with a steady state solar simulator. If the proposed project includes thermal storage then the Multi Variable Iterative Simulation (MVIS) technique is used for optimizing both the solar field size and the storage size for getting a least Levelized Cost of Electricity (LCOE). Such iterative simulation techniques use an hourly or a 10-minute DNI data to calculate the cumulative annual power generation and are integrated with internal or external financial models to help project developers in determining the levelized tariff.

For CSP plants, performance guarantee testing is a more challenging task than conventional power plants because the fuel (DNI) is not controllable. Therefore one of the methods to check its performance is to compare the actual generation of the plant with the simulated model wherein actual DNI data is used. Project developers, technology suppliers and the O&M contractors have the possibility of installing simulation tools at the site during the testing period.

These simulation tools are model-based steady state simulators and are capable of conducting the gap analysis of projected (simulated) and actual generation,

An operating CSP plant also requires optimization of several types. Both Steady state and dynamic simulation techniques help in these optimizations. Examples of these optimizations are maximization of power for given DNI, frequency of mirror cleaning, optimization of start-up time etc. Several simulation tools are available and many are under development to address these issues.

Dynamic simulation tools are best suited for training plant operators and conducting engineering studies. Dynamic simulators for both applications are available although not many companies have a presence in this field. Dynamic simulators used for training the operators have a full fledged Human Machine Interface (HMI) so that the operator is confident of operating the plant after training. This becomes an important tool for capacity building.

The paper focuses on the various simulation techniques and how they are applied to address the issues outlined above for CSP projects. Additionally, it covers the future developments and their potential for the CSP industry.

Keywords: CSP, Simulator, Model, Solar Power Plant, DNI

INTRODUCTION

TYPES OF SIMULATION

Simulators are broadly classified as steady state, quasi steady state and dynamic simulators. These are basically classified based on the parameters and equations used. All three types of simulators have important applications in CSP industry.

Steady state simulators

In steady state simulators, simulations are done at a particular point of time based on Algebraic equations. Simulations can be done over multiple time steps, but the simulation at a particular step has no relation with the previous step. e.g. DNI at a particular time step would not consider the DNI of previous step. In CSP industry, these simulators are mostly used as a design tool or cumulative output analysis tool. This however cannot be used for the study of transients.

Quasi steady state simulation

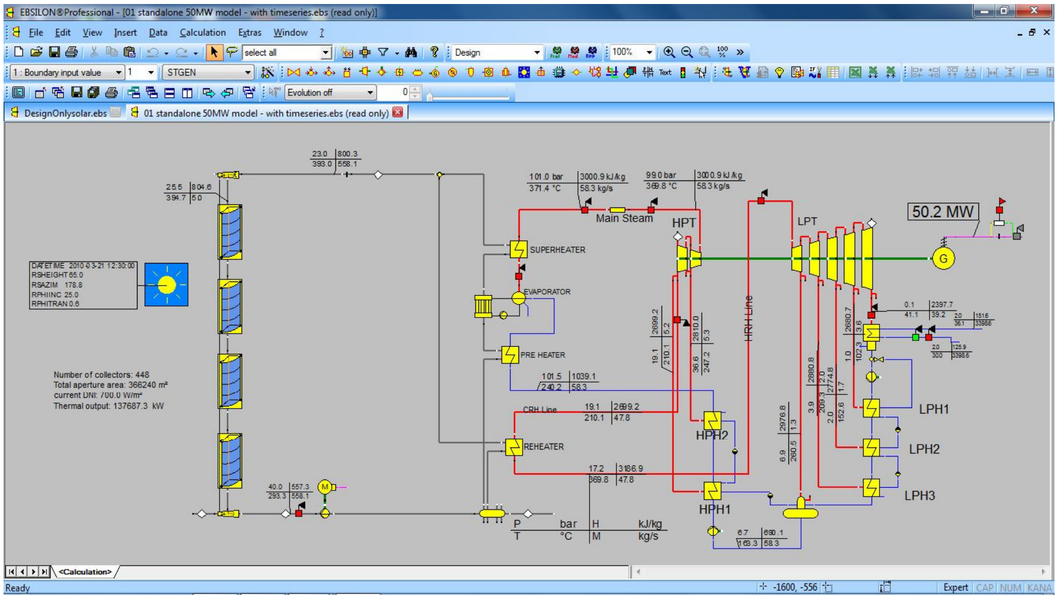
In quasi state simulators, simulations are done in discrete time steps, but the input state for a particular time step can be taken from the calculated state in the previous time step. It can take care of thermal inertia during start up / shut down, cloudy conditions, storage etc. to some extent.

Dynamic Simulation

A dynamic simulator runs like an actual plant. It is based on differential equations and is used to do the continuous analysis of transients. It is able to consider thermal inertia during the start up and shut down and clouding conditions satisfactorily. It is used for comparatively short duration analysis, since it needs a lot on computation power.

USE OF STEADY STATE SIMULATION IN DESIGN OF A SOLAR THERMAL POWER PLANT

Broadly there are three steps involved in the design of a solar thermal power plant. The first step is the creation of the topology of solar field as well as the power block. Each equipment/component is created by specifying the key parameters. This completes the basic simulation model.

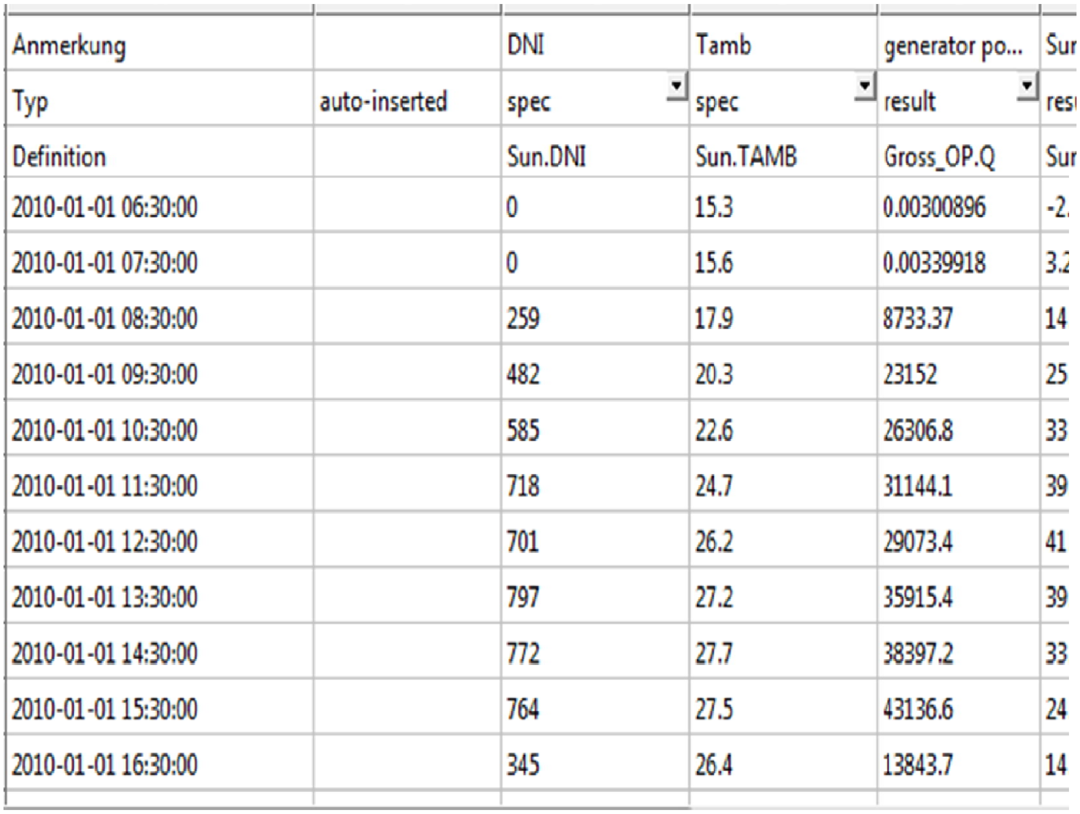


DATETIME 2010-03-21 12:30:00
RSHEIGHT 65.0
RSAZIM 178.8
RPHIINC 25.0
RPHITRAN 0.6

Number of collectors: 448
Total aperture area: 366240 m²
current DNI: 700.0 W/m²
Thermal output: 137687.3 kW

The second step is the initial sizing of the solar field that is done based on a design point on a specific day. For example the design point could be the noon time on 21st March and the design DNI could be 750 w/sqm. Based on these design conditions the model is simulated iteratively to arrive at an approximate solar field size that would give the nominal electric output at these design conditions.

Once the approximate size of the solar field is fixed, the next step is to calculate the cumulative electricity production that a plant with this size of solar field would give if the DNI is as per a given Typical Meteorological Year (TMY) file. This is done by linking the given TMY file with the simulation software. The simulation software picks up the datasets (comprising of DNI and other data) step by step from the TMY file and simulates the model with each dataset. It therefore calculates the power output at each time step and accumulates these outputs suitably to compute a figure for the cumulative annual power production. A portion of a TMY file is shown below for reference.



Anmerkung		DNI	Tamb	generator po...	Sur
Typ	auto-inserted	spec	spec	result	res
Definition		Sun.DNI	Sun.TAMB	Gross_OP.Q	Sur
2010-01-01 06:30:00		0	15.3	0.00300896	-2.
2010-01-01 07:30:00		0	15.6	0.00339918	3.2
2010-01-01 08:30:00		259	17.9	8733.37	14
2010-01-01 09:30:00		482	20.3	23152	25
2010-01-01 10:30:00		585	22.6	26306.8	33
2010-01-01 11:30:00		718	24.7	31144.1	39
2010-01-01 12:30:00		701	26.2	29073.4	41
2010-01-01 13:30:00		797	27.2	35915.4	39
2010-01-01 14:30:00		772	27.7	38397.2	33
2010-01-01 15:30:00		764	27.5	43136.6	24
2010-01-01 16:30:00		345	26.4	13843.7	14

Simulation of different designs:

Once the basic design is simulated, design alternatives can be simulated to arrive at a design that would give the maximum efficiency and output. For this the changes are made in the base model and different alternatives are created. For each design alternative, the procedure given above is repeated and the cumulative power production for a TMY and other important outputs are computed for each alternative and the best design is chosen.

Calculation of field size for minimum LCOE

One of the important uses of the simulation tools is to arrive at the minimum cost of production by optimizing the size of the solar field. It is not so important to maximize the power production or to minimize the capital cost by reducing the solar field, what is really important is to minimize the cost of production of electricity. The simulation tools can help in doing this by doing several iterations. It is a matter of common sense that an increase in the solar field size increases the power output because the full load operating hours increase for a given DNI pattern.