MICROWAVE BLADE TIP SENSING: CAPABILITIES FOR TURBINE OPERATORS

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ABSTRACT

Blade tip measurements, on both blade tip clearance and vibration, have been used by turbomachinery developers in validating the performance and safety of their machines. However, long term use of this instrumentation was impractical without defined business cases and proven long-term reliability. Recent developments of microwave blade tip sensor technology suited for long-term monitoring has the potential to provide benefits for operators of gas/steam turbines in the energy sector. This paper discusses the potential uses of blade tip measurement and some of the potential benefits.

KEYWORDS

Microwave Sensor, Tip Clearance, Blade Tip Sensing, Machine Condition Monitoring, Machine Protection.

BACKGROUND MICROWAVE BLADE TIP SENSING

Microwaves are particularly well suited to long term operation in the turbine environments relative to other sensor technologies:

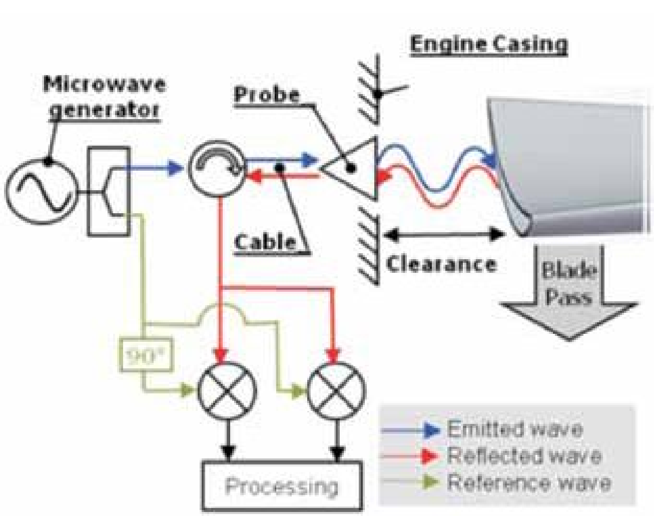

Figure 1. Microwave Topology

1) Microwave sensors are immune to common causes of signal integrity issues in other sensors: high EMI interference, ionized particles, dirt, oil, and other contaminants.
2) Microwave sensors with GHz carrier frequencies are capable of making fast measurements without any frequency response/speed effect.
3) Microwave sensors have traditionally better range than competing sensors for a sensor diameter.

The microwave generator sends the microwave energy through the circulator to the probe which transmits the microwave energy between the probe and the blade. The signal reflects from the blade and the signals are compared to the original reference signal with 2 mixers 90 degrees out of phase. The resultant signal is an analog sine wave quadrature.

The phase of the resultant signals and changes can be scaled by the transmit frequency wavelength to indicate distance. The microwave circuit is designed with microwave coplanar waveguide transmission lines that are incorporated directly in the layout of a printed circuit board. The microwave components are all surface mount SMD devices. In this way, the microwave card and data processing electronics can be installed in a standard VM600 condition monitoring/machine protection rack system. This topology is slightly different than normal systems in that there is no signal conditioner—only a long cable to connect the card to the probe.

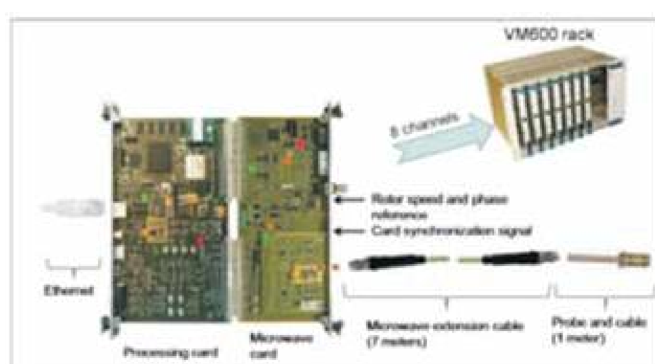

Figure 2. Microwave Electronics Card

By integrating to a standard machine condition monitoring rack, all the standard gateways to plant control systems can be made through the standard protocols (Modbus, OPC, etc…) The future potential is to provide clearance and blade health information to the control system or to machine operators to better enable decision making.

BLADE TIP CLEARANCE

By measuring and controlling the tip clearance, engine efficiency can be improved and engine degradation from engine rubs avoided. Turbine manufacturers in the aviation industry have for years cooled turbine cases at cruise to recapture efficiency. On the energy side, OEMs have started to install cooling jackets on turbine cases to reduce clearance when in stable operation for up to 2% fuel efficiency gains.

As the turbine rubs and ages, clearances increase. This causes the turbine exhaust temperature rises because less energy is going into turning the motor and the gas is staying hotter. The hotter gases at the exit of the engine degrade those parts. Clearance control to shrink clearance on worn engines can help to preserve efficiency over the engine life.

In addition to preventing early overhaul by reducing EGT, sensors also measure the clearance of each individual blade over time. If the blades are damaged due to cracking the root of the blade, creep, or coating degradation, small changes in tip clearance can provide telltale warning signs of impending failure as blades stretch or untwist due to damage. There is good potential to use such methods to move hot section parts toward condition based maintenance instead of conventional lifetime timeouts.

In gas turbines, measuring clearance enables operators to assess their hot restart risks. Typically, after a gas turbine engine trip/shutdown for any reason, a large gas turbine operator has an immediate opportunity to restart or must wait a longer time interval to avoid blade rubs. Risking a restart in the intervening period risks turbine rubbing—that can result in permanent clearance increase and efficiency loss.

A recent test was performed on a 25 MW Gas turbine in the Ukraine. Results obtained show excellent trend changes of clearance that can be expected with clearance control accomplished through case cooling. These changes in clearance can be directly linked to gains in thermal efficiency and reduced EGT.

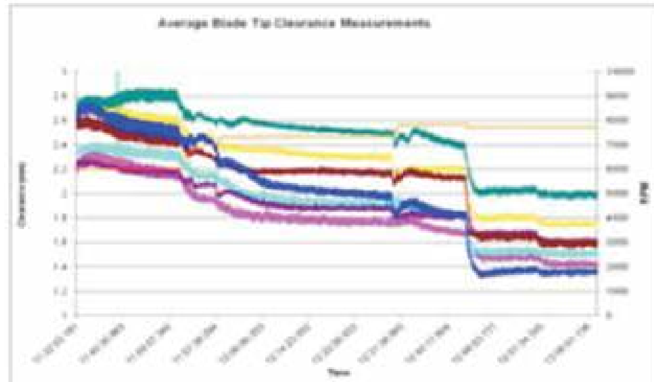

Figure 3. Note Clearance Changes

Note the clearance changes in Figure 3 that show a drastic clearance reduction when cooling air is applied to the turbine case. This graphic shows the average clearance at each sensor location around the case. Operating at reduced clearances is helpful for engine fuel efficiency where depending on the machine size, 0.25 mm can result in 1% fuel savings.

Average clearance is also important for assessing global rotor issues such as: case distortion, troubling rotor dynamics issues, bowed rotor problems, or warning of impending rubs.

Clearance changes are also measured on an individual blade level. Trending clearance changes on individual blades can provide early indications of blade cracking, creep, or other damage. However, studying a whole rotor of blades from up to 8 sensors can be difficult to manage with many trends to analyze. A simplified user interface was created to help better interact with such data analyses.

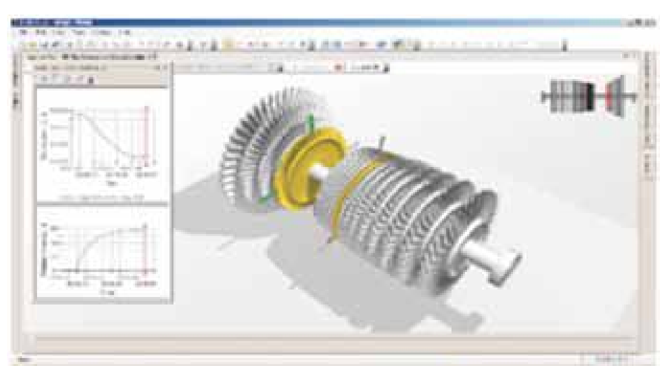

Figure 4. Graphical User Interface

A graphical user interface of a turbine is created in the VibroSight software from a set of simple parameters including: blade length/width, number of stages, sensors, etc... It is not an accurate CAD representation of the blades, but generic turbine and compressor blades scaled are suitable for the user interface. In the above graphic, a stage has gone into a warning alarm and turned yellow indicating that an operator should explore the cause of the alarm at that stage. Clicking the rotor brings up the next graphic.

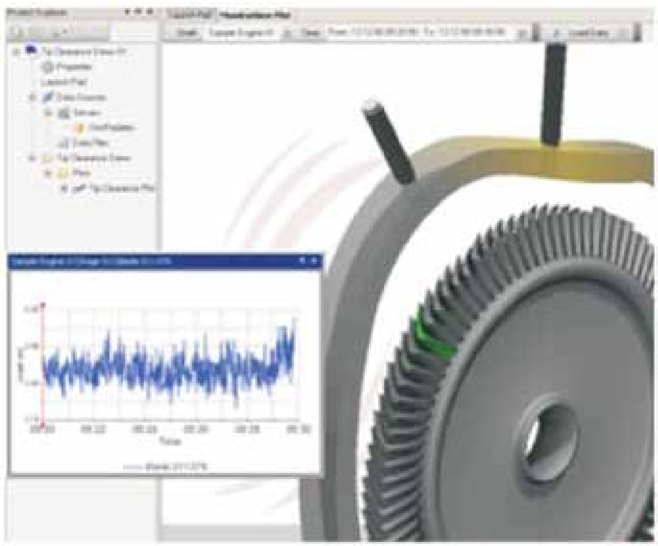

Figure 5. Stage / Blade Analysis

In this graphic, one can see accentuated representations of case distortions, blade variability, and rotor dynamics. This enables an intuitive interaction with a large volume of data that can otherwise be impractical.

BLADE VIBRATION

In addition to blade clearance indicating potential blade health problems, blade vibration can also indicate similar issues with turbine blade longevity.

In L-0 stages of Steam Turbines and early stage compressor rows of gas turbines can be subject to high cycle fatigue damage due to blade vibrations that are excited by turbine running conditions. With blade tip sensing, it is possible to directly measure blade vibrations such that: 1) operating conditions can be changed to avoid damaging vibration, 2) the accumulated damage to the blade can be assessed.

In an example seeded fault test in a lab test rig, blade tip sensors were easily able to detect resonance shifts in the blade due to a crack induced from high-cycle-fatigue. Small cracks only a few mm long were easily detectable.

Figure 6. Laboratory Test Blade after cracking.

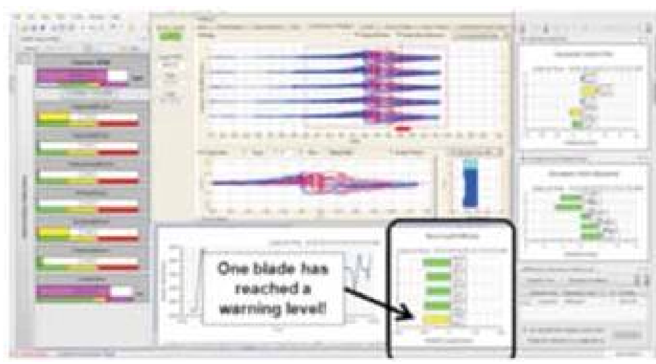

Figure 7. User Interface showing cracking.

FUTURE WORK

Blade tip clearance and Blade Vibration monitoring will become an integral part of future turbine condition monitoring systems. Traditionally, turbine rotating parts are replaced on a scheduled basis with only borescope inspections available to assess rotor condition. The use of blade tip sensors has good potential to also move turbomachinery rotor components toward a condition based maintenance approach with measurements of blade tip clearance and vibration down to an individual blade.

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Case Study-Captive Power Plants-Shriram Fertilisers & Chemicals-Kota

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KEY WORDS:

DSCL, CPPs, DDCMIS, ESP, EPIC, 505 Digital Governor & Triconex for Turbine controls, Master Pressure control, AFBC Boiler,

INTRODUCTION:

DCM Shriram Consolidated Limited (DSCL), Kota complex has five (5) captive power plants (CPPs) for meeting its captive requirement of power. These units are as below:

Sl. No.	Plant	No. of boilers	Turbine
1	P-35	Two -2 (90TPH each) of PF type Make: Mitsubishi CE	Mitsubishi, Japan commissioned in year 1969 Double extraction regulated straight, Condensing turbine.
2	P-10	One (54.5TPH). It was spreader stoker boiler. This boiler was up-graded to AFBC technology in the year 2000 by CVL.	Stal-laval radial flow condensing turbine, commissioned in the year 1983.
3	P-30	Two-2 (90TPH each AFBC) Make: CVL	Siemens, commissioned in the year 1994.
4	P-10.3	No Boiler	ABB, Germany commissioned in the year 2000 to utilize the surplus capacity of 30MW Boilers
5	P40	175 TPH AFBC Make: CVL	BHEL, India commissioned in the Sept.2005

All the units are automated & working on State of the Art Distributed Digital Control, Monitoring & Information System (DDCMIS) CS-3000. They are operated from two control rooms namely one for 35 MW & other for rest units. Inspite of old thermal units, they operate with good efficiency & gas emission parameters well within prescribed limits.

CHALLENGES:

Power production facilities are under ever-increasing pressure to reduce production costs to

compete in a market environment that is more complex today than it's ever been in the past.

Failure to effectively reduce production costs of power to a competitive level means higher production of the raw material. The situation is further complicated by the need for production facilities to balance costs against compliance with a growing number of stringent air quality and particulates. These challenges often manifest themselves in a conflicting effort to reduce

day-to-day operating costs while managing offsetting capital investment and maintenance costs.

Prior to stringent air quality regulations, primary objective was to provide a reliable source of

quality power. Whatever equipment was in place per original design could be used without a

great deal of concern for the quality or type of fuel being burned. Original equipment design

took into account the planned fuel formulation, and auxiliary equipment was selected primarily based upon these original specifications. Equipment deterioration was accepted as a normal cost of operation, and was dealt with through frequent and relatively long maintenance outages. In recent years, however, competitive market conditions combined with tough emissions standards have created entirely new challenges that generate potential conflicts between fuel procurement, asset managers, and maintenance teams. The result is that maintenance teams are expected to do more with less. To remain competitive market in the market the need of the hour is for innovative technologies by which scheduled stoppages can be extended.

1. Availability of Spares

In view of fast pace of technology growth, availability of spares is a challenge. We indigenized few items and revamped some critical systems.

ESP (Electrostatic Precipitators): In order to improve the environment across the world, governments are implementing more stringent regulations on emissions. In Boiler no. of 35 MW plant, ESP was revamped with Electrostatic Precipitator Integrated Controller (EPIC). Performance of controller is crucial to the efficiency of ESP. Installation of EPIC not only resulted in reduction in emission level but also reduced energy consumption, optimized rapping frequency which extends the service life of the ESP, with fewer unscheduled

outages. Ethernet communication provided increased flexibility. This revamp work was done retaining the old ESP panels thus same field cable & space utilized.

2. Coal linkages

Continuous availability of coal is essential for smooth running of the plants. Due to unprecedented rise in coal price in Feb, 2011 every utility sector had to revisit the use of coal types being fed to boilers. DSCL also changed the grades of coal & accordingly loops were tuned. Bio –mass feeding is also being done to economize and achieve desired efficiency.

3. Interface between the different units

As our complex has variety of plants, variation of load & its management has to be met accordingly. Inputs from various circuit breakers are taken to know the status and actual load. (Refer single line diagram). Similarly power export monitoring is also available to the operator on the screen live which gives ease of operation. (Refer a graphic)

4. Stacker Reclaimer automation

To stack coal in the coal yard we have a stacker which moves from left to right on a track along the coal yard. There are two conveyors on the stacker to create a heap of coal on the desired location in the yard. There was a need to provide a safety interlock between the conveyor on the stacker and the conveyor conveying the tippled coal from wagon tippler hopper to the stacker conveyor. This interlock was to protect the conveyors on the stacker and did not allow the conveyor conveying coal to the stacker to start until ON feed back signal is received from the conveyors on the stacker.

Since the stacker is located in a remote area and covers a large distance from left to right in the coal yard it was not convenient to lay a cable from the stacker to the PLC control room in order to obtain an ON feedback from the stacker conveyors.

To overcome this problem we installed a Radio Modem receiver and transmitter, which is a bi-directional remote relay system for controlling relay closures and feedback status information. So now the ON and OFF feed back of the conveyors on the stacker are transmitted via the radio modem from the transmitter of the radio modem on the stacker to the receiver of the radio modem in the PLC control room. This eased the operation of coal plant

5. ESP Hoppers getting shorted:

Problem we had:

- The level of ash being collected in the ESP (Electrostatic Precipitator) hoppers reaches above the required level.
- Shorting of ESP fields occur due to high level of ash in the ESP.
- Once the field is shorted, it can only be attended when the plant is shut down.
- A shorted field results in a downfall of the efficiency of the entire ESP system resulting in increase in dust density in the stack.

Solution we came up with:

- We installed RF level switch in each hopper
- The switch was installed at such a height which allowed us to identify the level of ash in the hopper before it could cross its desired level in the hopper and short the field.
- An alarm is generated for hopper high level via the

RF switch in the ESP control room.

- Now the operations have become easier & field shorting is avoided as operator has an idea about the level of ash in the hoppers and when to empty it.

6. UPS & battery back-up:

Problems we had:

- We had two UPS systems connected in parallel redundant mode to supply uninterrupted power for the plant and their three phase input power was fed from the same plant (say common power source).
- If there was a failure in the mains power supply, the input power to both the UPS systems failed as well as the single phase by pass supply also failed.
- Our battery bank comprised of VRLA batteries, and a defect or failure in either battery of the battery bank resulted in an open circuit, thereby leaving the UPS with no battery back up.
- Resulting in Total Black-Out.

Solutions we came up with:

- Now we have two different buses from two different plants feeding power to UPS-1 and UPS-2 respectively.
- Also we replaced our VRLA batteries with Ni-Cd batteries ,which saved us from the situation of leaving the UPS with no battery back up in case of battery failure.(In case of Ni-Cd batteries, failure of one or more battery does not leave the circuit open)
- Also we provided single phase bypass supply from state electricity board emergency supply feeder.

7. Combustion Control in Atmospheric Fluidized Bed Combustion (AFBC) Boilers:

The objective of the combustion control is to ensure that air flow into the furnace is proportional to the total amount of fuel entering the furnace at any instant. Normally, air flow will be slightly more than the theoretical air requirement for a given fuel. Due to vide fluctuations in fuel quality, it is very difficult to fine tune air flow control & fuel flow control.

In order to achieve better controls, it was tried to add the feed forward signal from rate of change of master pressure and rate of change of steam flow (load) in the Master Pressure control loop output however this could not work satisfactorily. Search is on to make this loop work on auto. (Refer graphic page of combustion control)

8. AFBC Boiler Optimization:

In view of varying load & variety of coal quality, suitable optimization package of AFBC boiler is yet to be implemented. This is more important in CPPs as there is sudden variation in the loads & sometimes islanding taking place. 40 MW plant having 175 TPH (Tones per hour) AFBC Boiler when installed in 2005 was of highest capacity the then.

TECHNOLOGY ADVANCEMENT:

Plant maintenance teams are experiencing greater and greater pressures to reduce the cost of maintaining mission critical equipment, and are expected to use innovative methods to extend the operating period between unit shutdowns. There are technologies available that have proven their ability, in both the laboratory and in the field, to provide substantial protection against some of the most common causes in a coal-fired power plant.

1. For level measurement in vacuum or low pressure applications, guided wave radar type level transmitter is being used. We have installed this in Hotwell level application in our 35 MW plant and working satisfactorily.

2. Cooling tower sump level measurement is changed from bubbler type transmitters which consume air continuously with Ultrasonic type transmitters giving better accuracy and no air consumption.

3. Continuous monitoring of Earth pit resistances: We have two separate earth pits for Power & System earthing which are checked once in summer & winters. This has avoided breakdowns.

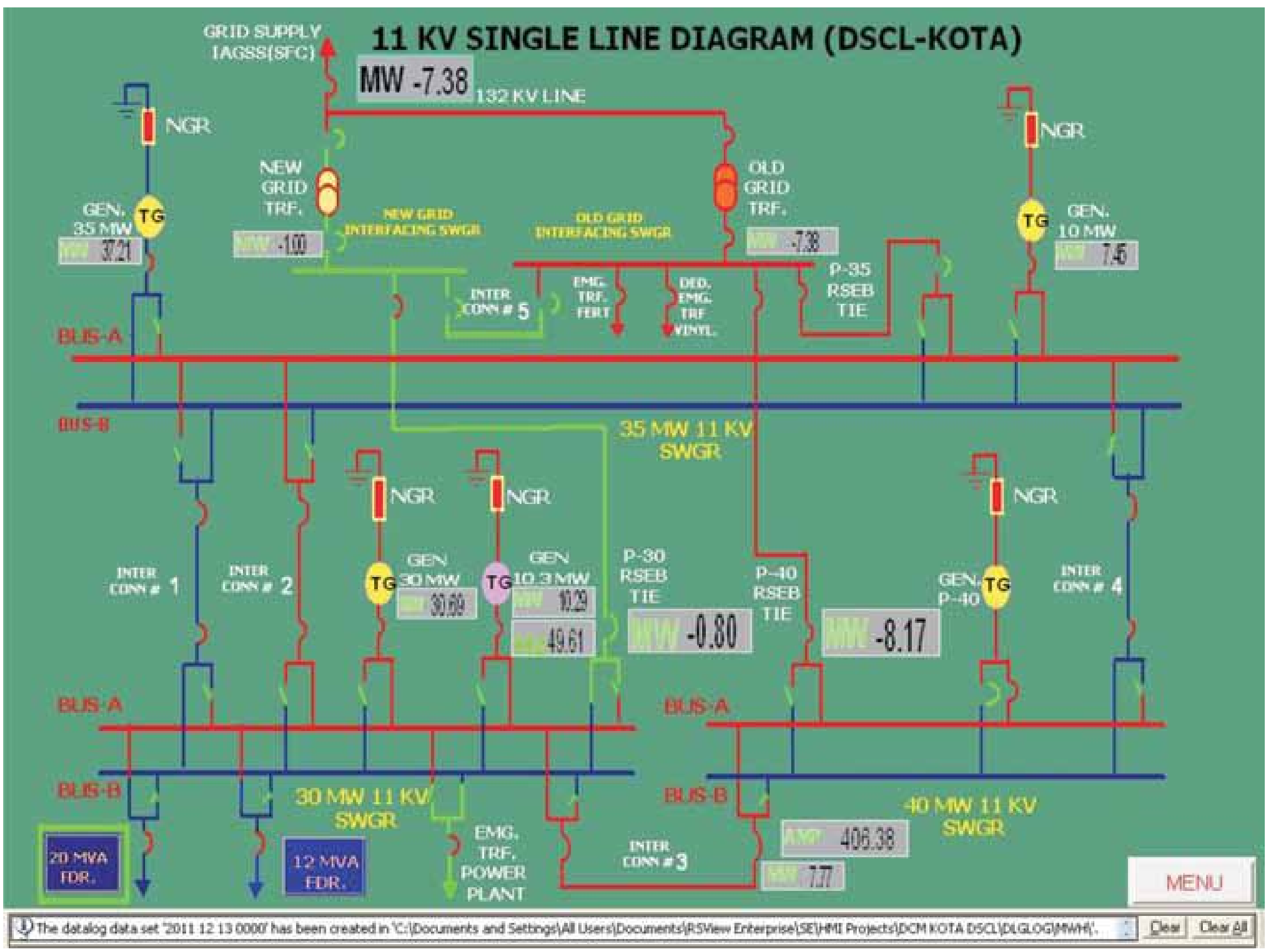
4. Surveillance and monitoring of critical plant assets: CCTV system has been installed at the critical entry locations of the plant and monitoring / recording in the control room has been provided. Wagon tippler is another area which needs safety for unloading

coal rakes. CCTV cameras have been installed to ensure double safety of the system. (Refer attached picture).

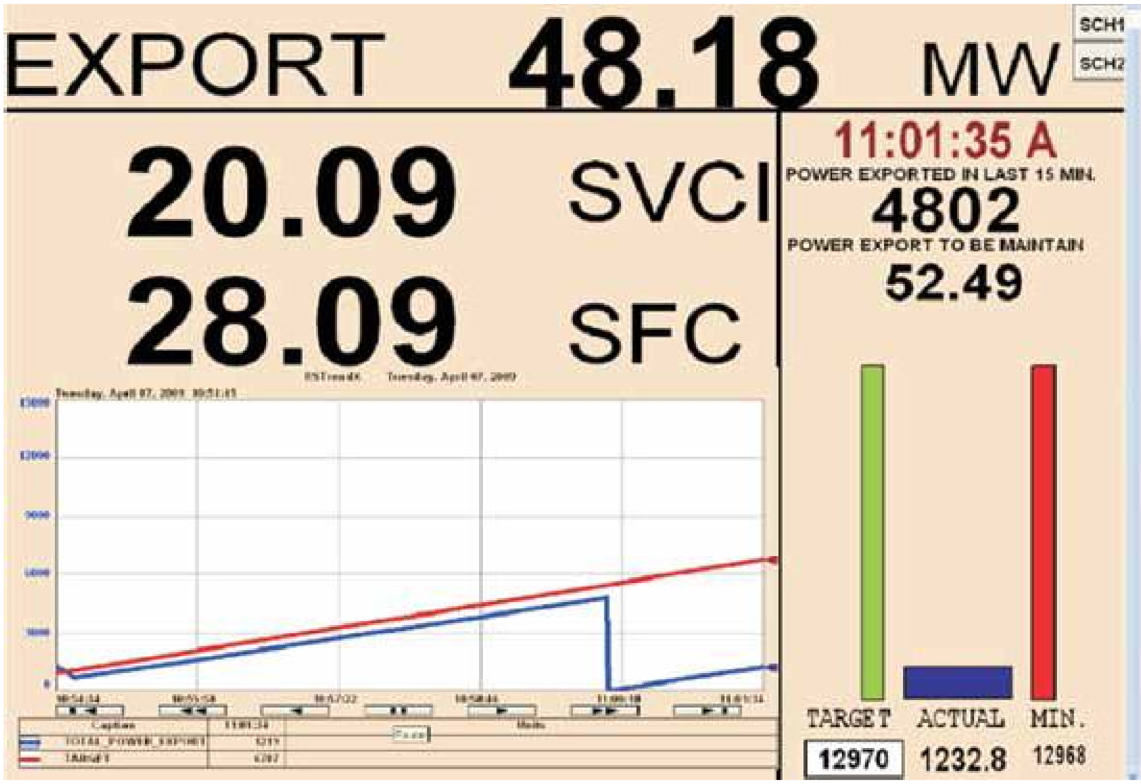
5. Advance Wear Protection Technology: In order to increase the life of coal burners, we have done Tungsten Carbide (TC) coating on their tips. This infiltration brazed TC cladding technology has proven very useful and burner tips with TC (done in 2010) when inspected in 2011 were found in good condition.

6. Turbine Controls: The control and protection of steam turbines require high integrity as well as safety. The continuous operation of the fault tolerant Triconex controller provides the turbine operator with maximum availability while maintaining equivalent levels of safety. Speed control as well as start up and shut down sequencing are implemented in a single integrated system. This is achieved by us in double extraction type Mitsubishi turbine of 35MW plant. This was of its kind when commissioned in the year 2002. Similarly Woodward Digital Governor 505 is installed for other turbines. With Modbus the parameters are taken in DCS also.

Interface between different units- Single line diagram

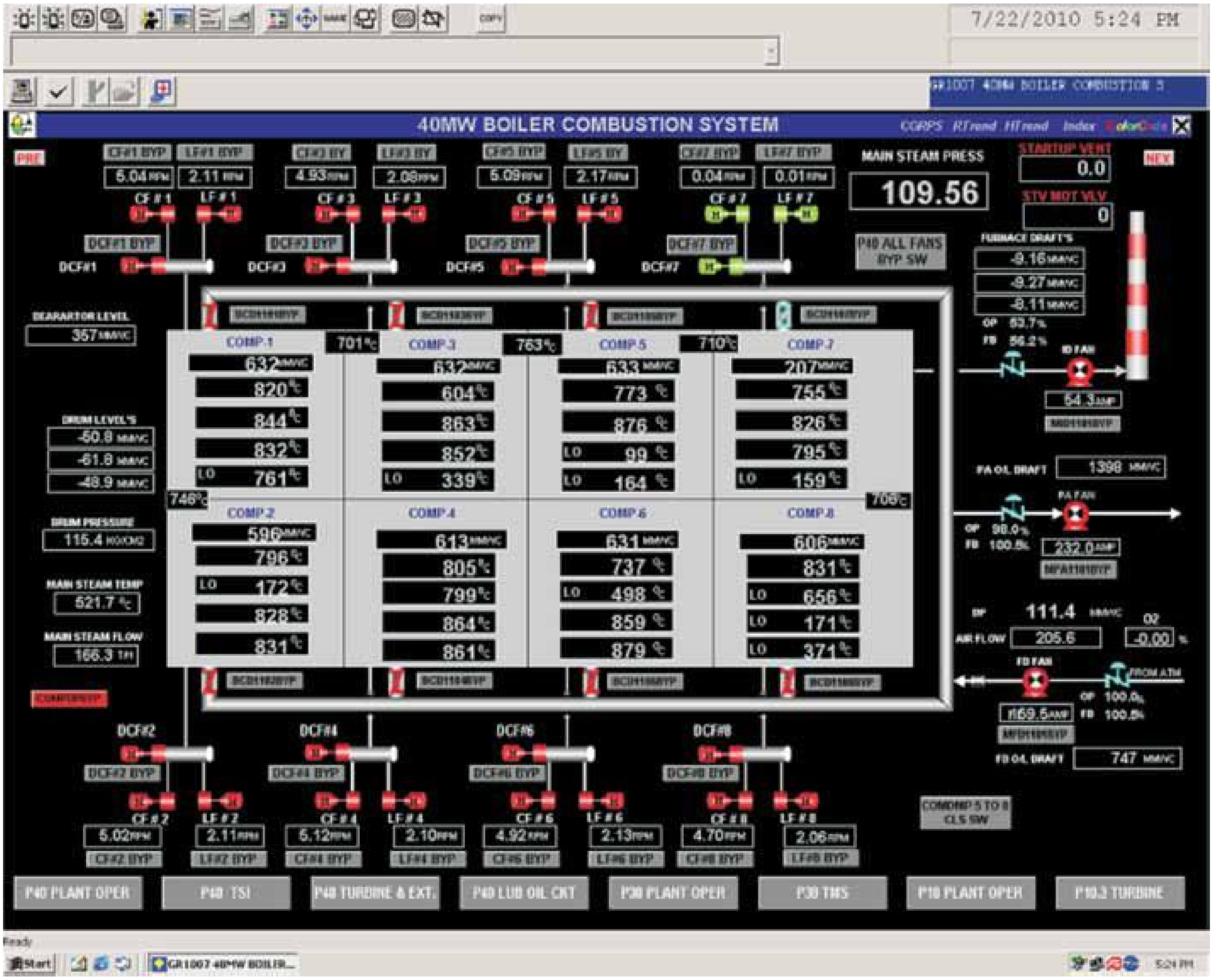


Power export



Wagon Tippler- CCTV view

Combustion control



Conference Title: POWAT 2012

Paper title: Applying Safety System Concepts in Power Plants

Author (s) name

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Key words

Safety Standards Evolution, Layers of Protection Analysis, Safety Life Cycle, Safety Requirement Specification, Hardware Configuration, Typical Example of Implementation of SIF.

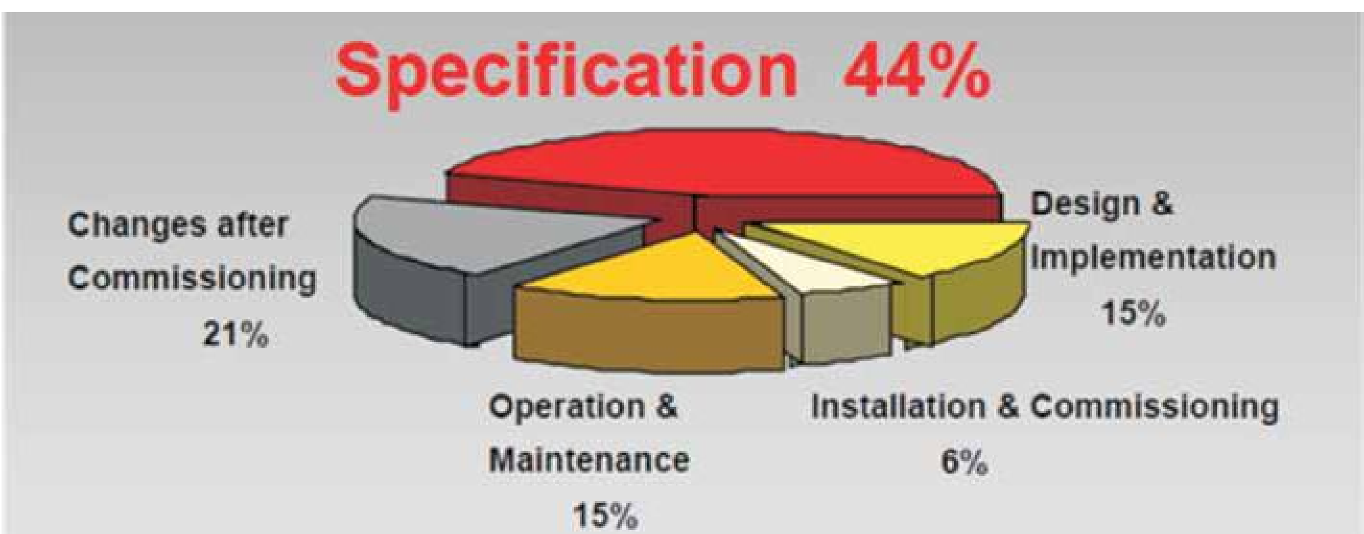
Safety Standards Evolution

Power production is the backbone of every industry and civilized society. The increasing gap between supply and demand in our country has put lot of stakes on the Reliability and Availability of the Power Plants requiring longer periods of continued operation with very narrow maintenance window.

Evolution of safety system standards were driven by the incidents leading to financial and personal loss. National safety standards evolved from company practices and many of these standards such as the NFPA 85 were prescriptive in nature with regard to application of definite safety measures to be taken for specific equipment such as Burner Management System. With the large scale evolution of the PLCs and software based controls in the 80s more generic analysis methods became necessary to apply the safety concepts across a wide variety of applications and also evaluate the Reliability claims of the vendors in to the same platform. Reliability studies in Sensors and Final control elements are relatively new compared to advanced strides made in Systems. Here one needs to realize that a safety function is only as reliable as the weakest link of the loop either the sensor or final control element. Functional standards such as IEC 61508 and IEC 61511, ANSI/ISA S84.01 evolved in the 90s to provide Life Cycle approach to safety systems using Safety Integrity Levels. Generic terms such as ‘proven’ or long ‘MTBF’ do not stand the scrutiny of analysis.

A business survey in 2010 indicates that the Top 20 affluent companies had the best Safety records.

Many Safety system studies indicate that ~ 44% of the incidents are created by Poor Specifications.



Picture Courtesy: Exida.com LLC

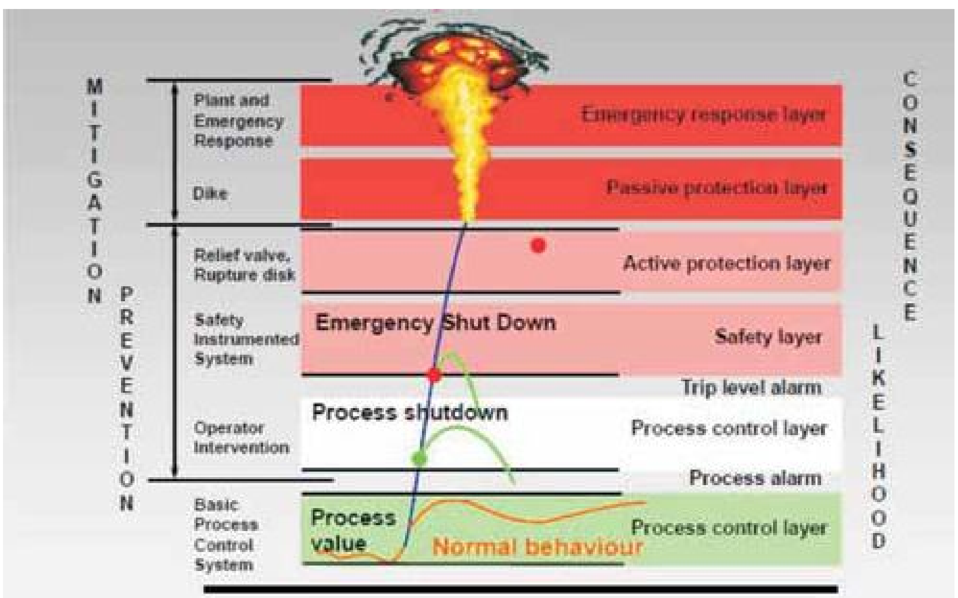
This could be a result of a poor Process Hazard Analysis or improper selection equipment. Hence studies made it clear that just focusing on System side of the control system is not sufficient, which lead to the fundamental concept of safety life cycle.

Following guidelines are used in globally in Power projects depending on the Client and project location.

- IEC 61508 (2010) Functional safety of electrical/ electronic/programmable electronic safety-related systems
- IEC 61511 (2004) Functional Safety - Safety Instrumented Systems for the Process Industry Sector, Section 1(e) states that this standard also applies to 'non-nuclear power generation'.
- ANSI/ISA-84.00 - Functional Safety: Safety Instrumented Systems for the Process Industry Sector
- NFPA 85 (2011) Boiler and Combustion Systems Hazards Code
- ISA TR84.00.05 (2009) Guidance on the Identification of Safety Instrumented Functions (SIF) in Burner Management Systems (BMS).
- BS EN 746-2 (2010) Industrial Thermoprocessing Equipment
- SANS 329 Industrial thermo processing equipment - safety requirements of combustion and fuel handling systems

Layers of Protection Analysis:

Tragic event such as the Bhopal tragedy indicate that accidents rarely have a 'single cause' and it are usually a combination of improbable events that people initially assumed as independent and unlikely to happen at the same time. Also several such incidents indicate that such industrial accidents do not occur during steady state operation but during start up, maintenance production interruption and shift changeovers.



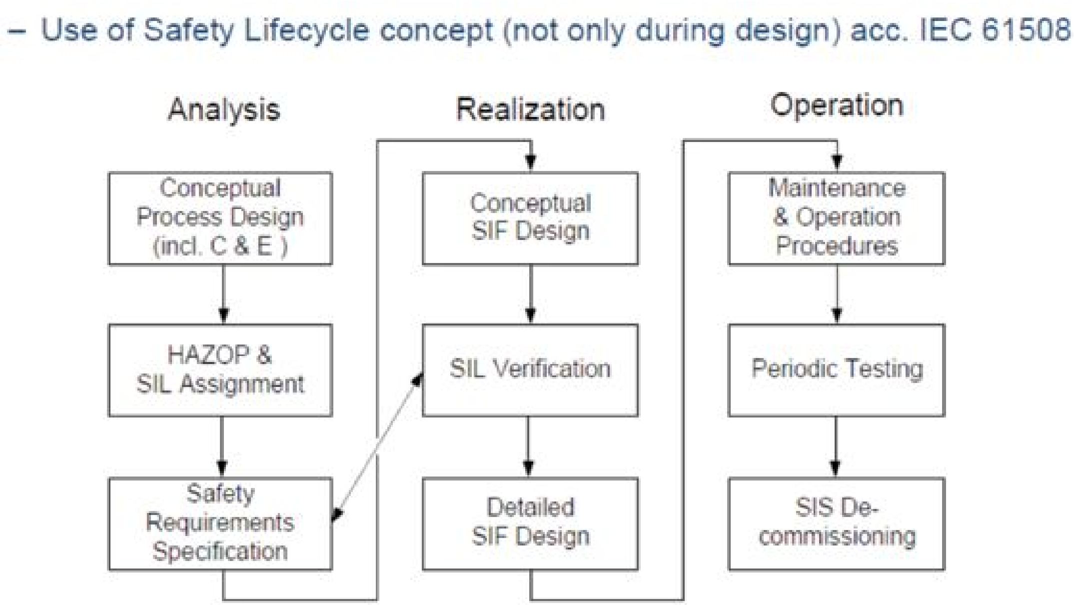
Picture Courtesy: Exida.com LLC

Increasingly, Clients prefer the Layers of Protection Analysis that clearly indicates the reasoning behind the separation of the Plant in to independent protection layers. The main layers include Process, Control system, Alarm systems, ESD systems and Mechanical protection systems for analyzing and arriving at a minimum acceptable risk level prescribed by the Plant owner. These systems are completely separated with their own set of sensors logic systems and final elements to avoid common mode errors. For example NFPA 85 Section 4.11.7 Requirements for Independence, infers the requirement for boiler management systems (BMS) separation from other systems such as DCS control functions. Similarly BS EN 746-2 (2010) Section 5.7, requires a full risk assessment to be performed and Figure 1 infers the classical functional separation between the normal process control and the BMS including specific combustion safety functions, e.g. air flow and air-fuel ratio. Even these independent protective layers develop holes if there are flaws in design specs, engineering, operations, operator errors and poor maintenance.

Basically an SIS system may consist of a number of Safety Instrumented Functions. Hence SIL assignment is done at SIF level and can vary from SIL 1 to SIL 4 in order to achieve the target risk reduction level. Hence Logic solvers handling multiple SIF functions require careful consideration. As goes the saying that 'what is not there' will not fail', Safety systems need to be 'Simple' and maintained independent of complex process control systems.

Safety Life Cycle

Safety Life Cycle contains all the steps from design till decommissioning of safety system. Fluor has adapted the Safety Life cycle concept 3 in all their project execution in process as well as power plants. Fluor uses integrated Life Cycle tools - exSILentia by Exida.



Picture courtesy: BSI standards Publications

The idea of Safety Life Cycle is that safety is ongoing process and shall be considered from conceptual process design and must be followed during every stage of the project.

The Safety Life Cycle is divided in 3 parts

- **Analysis**

This phase provided information regarding the risk associated with the process and amounted of risk reduction required based on the acceptable risk criteria of the operating company.

The key documents received from this phase are

1. HAZOP report
2. Target SIL levels
3. Safety Requirement Specification (Described later in detail)

The documents received from this phase are very important since they form the basis of the other phase, error or mistakes in these documents can be catastrophic. Proper execution of this phase can reduce the amount of money and effort during the subsequent phases.

- **Realization**

When the SIF (Safety Instrumented Functions) s are identified and documented, the design work can begin. Selection of technology, architecture and test philosophy per the requirements in the Safety Requirement Specification is done in this phase of the SAFETY LIFE CYCLE. The periodic testing is performed to ensure that system is fully functional and verify that no failures have occurred. IF there are any failure detected than they are corrected immediately upon detection during proof tests.

After these activities safety engineer do a reliability and safety evaluation based on the failure data to verify that the designed system meets its integrity requirement.

Once the conceptual design has been validated the detail design activities can begin. A I&C plan is developed to ensure that the safety system is installed per the design and is revalidated to ensure that it is ready to provide the necessary level of protection as defined in Safety Requirement Specification.

- **Operation**

Maintenance and operation personnel are usually involved in this phase of Safety Life Cycle. The system is validated and verified to ensure that the SIF and SIS under consideration meets in all respect the Safety Requirement Specification. This phase also ensures that the maintenance procedures are in place, O&M personnel are properly trained. It should also ensure that periodic testing schedule and details of items such as bypass, override, management of change and responsibilities of every individual is clearly indicated and properly documented.

The focus of maintenance planning is to ensure that the system stays safe throughout its entire operational life as it was just after commissioning.

The Safety Life Cycle ensures better designed safety systems, reduction in systematic errors and create cost effective system. Since Safety Life Cycle provided a feedback to previous activities performed hence it ensures that the design is optimized and any modification to the design can be done as early as possible.

Analysis shows that in a typical SIS about 70% SIF are over designed and 5% are under designed. Hence careful implementation of Safety Life Cycle ensures better design and cost effective solution for operating companies.

Safety Requirements Specification

Safety Requirement Specification is developed based on the Process Hazards analysis report, regulatory requirement such as the NFPA 85 and the identified list of SIF.

Safety Requirement Specification is the part of Analysis phase and forms the basis of the design and validation activities in other phase of Safety Life Cycle. The potential problems with the Safety Requirement Specification are a poorly done HAZOP and the information is not clearly transferred. The Safety Requirement Specification shall be properly analyzed, documented and updated to ensure that updated information is available to the user.

The measure of the quality of the Safety Requirement Specification is not the number of pages the document contains but rather how precisely and clearly the required information is passed to the user.

Safety Requirement Specification contains Functional and Integrity requirements.

- Functional Requirement
- The hazard & its consequences
- Frequency of occurrence
- Definition of process safe state
- Process inputs and trip points
- Relation between inputs and outputs
- Bypass requirement
- Consideration for manual shutdown
- Reset Requirement
- Operator interface requirement
- Selection of Energize or De-energize to trip
- Response time to bring process to safe state
- Maximum allowable trip rate
- Response actions on power loss or Instrument Air loss

- Integrity Requirement
- SIL level required for each SIF
- Process diagnostic or layers
- Reliability requirement
- Target proof test interval

Hardware Configuration

There are many hardware configurations available depending on the extent of reliability (perform the required safety function on demand) and availability (minimum spurious trips)

Architecture	**Objective**
1oo1	Base configuration
1oo1D	High Safety
1oo2	High Safety
1oo2D	Safety and Availability (more Safer)
2oo2	Maintain Output
2oo2D	Safety and Availability
2oo3	Safety and Availability

Note: D indicates Diagnostics.

Having more hardware does not ensure that the system reliability will increase. For example, 1oo2 has higher RISK REDUCTION FACTOR compared to 2oo3. The architecture shall be carefully chosen depending upon the requirement of the SIF.

A comparison is provided between various architectures.

For PFDavg (Probability of Failure Dangerous (on average))
1oo2D<1oo2<2003<1001D<1001<2002D<2002

For PFS (Probability of Failure Safe)
2oo2<2oo2D<1002D<2003<1oo1<1oo1D<1oo2

For Availability
1002D>2003>1oo2>1oo1>1oo1D>2oo2D>2oo2

- ## Reliability Data

The reliability of reliability data provide by the system, sensors and final control element is very important to ensure that the system designed and the verification done to provide the amount of risk reduction required as per Functional safety standards. The whole idea of probabilistic calculation depends on the availability of failure database . There are several sources of reliability data . The Process industry average of Probability of Failure on Demand for a final control element is a staggering 58% while the Sensing part contributes a Major 33% and the Logic solver accounts for only 9%.

- ## Industry Reliability Database

Several analyst and companies gather this data from various industries. The data acquired is based on estimates of time operation and calculate failure rates. The dataset is published in various books viz. OREDA, Guidelines for process Equipment reliability data etc.

The main advantage of this data is that is contains actual field data

However there are many disadvantages of this data

- It is not clearly identified that the failure was caused due to improper installation of selection of wrong equipment (Systematic error) or random error
- It is difficult to identify random failure from wear out failure
- Specific field and environmental condition are missed
- Source of failure / Stress is also not identified which makes it difficult to distinguish if the failure is caused due to improper installation or improper maintenance of the Equipment.
- It does not take into account the failure after the useful period of bathtub Curve.

Many operating companies maintain their own reliability data based on experience and performance of equipment installed in certain condition and service.

- ## FMEDA Data

Several instrument third parties like TUV, Exida carry out a detail analysis of the failure modes of several equipment / instruments.

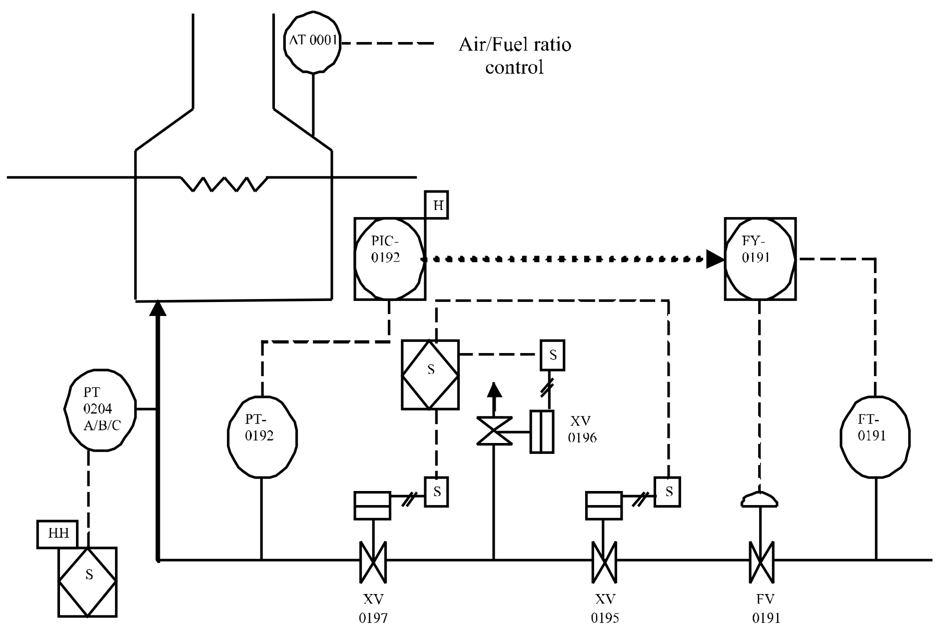
FMEDA (Failure modes effect and Diagnostic Analysis) is usually done in a factory environment and the certifying bodies provide the certificate and detailed report of failure of each and every component along with its effect on the working of the whole equipment. The report provides the failure rate of each component along with distinction whether the failure is safe, Dangerous, detected or undetected percentage. The FMEDA report also tells about the diagnostic coverage for online testing and SFF of all the failure modes.

Since this industry is relatively new and is still developing so the reliability data is not readily available. Many operating companies have started maintaining and collecting their own failure data rate which will help in having much more reliable data in future.

However the industry data also contains the systematic errors along with the random errors hence they are more conservative as compared to FMEDA. As a thumb rule if there is lack of information then most conservative data shall be considered.

Typical Example of Implementation of SIF

Please refer the process flow diagram of a typical heater



- **Hazard Identification.**

HAZOP is a systematic study used to identify all the possible causes of which has potential to cause a deviation in process from its normal intended function which can lead to hazardous situation. A HAZOP study for the Heater was carried out to identify the causes, consequences and available safeguards to detect and take the process to safe state within specified time and avoid the hazardous situation. Table shows a typical HAZOP report

Deviation	Causes	Consequences	Safeguards
More pressure	Failure of control loop causing FV-0191 fail open	If insufficient amount of air is supplied to the burner, unburned fuel, soot, smoke, and carbon monoxide are exhausted from the boiler. Resulting in heat transfer surface fouling, pollution, lower combustion efficiency, flame instability and a potential for explosion	AT-0001 O2/Combustion analyzer to control air /Fuel ratio High alarm on PIC-0192 for operator to take corrective action High-High pressure interlock to close XV-0197 and XV-0195 and open XV-0196 (SIS)

• SIL assignment

SIL allocation is done to identify how much risk reduction is required to reach tolerable risk.

Qualitative analysis provides numerical target for SIS into more broad categories of risk reduction and is based upon the operating experience. Following techniques are used

Risk Graph

Hazard Matrix

Quantitative analysis provides specific numerical target and is based on the frequency of the occurrence of the event. The frequency is provided by operating company or the industry database published by CCPS.

Each SIF identified is allocated a SIL level depending on the tolerable risk of the operating company based on category of consequence severity.

$$RRF = \frac{\text{Unmitigated Risk}}{\text{Tolerable Risk}}$$

SIL gives the PFDAVG value for the SIF

$$SIL = PFD_{AVG} = \frac{1}{RRF}$$

Per IEC 61508 there are 4 SIL levels defined based on PFDAVG. Low demand mode is considered for process sector since the frequency of demand for operation made on SIS is no greater than one per year and no greater than twice the proof frequency.

SIL	PFDAVG	RRF
4	≥10-5 to <10-4	10000 to 100000
3	≥10-4 to <10-3	1.000 to 10.000
2	≥10-3 to <10-2	100 to 1.000
1	≥10-2 to <10-1	10 to 100

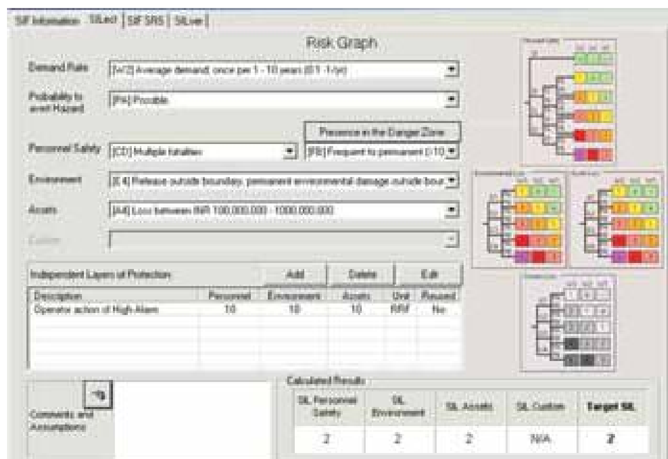
Picture courtesy: IEC 61511(2004)

All the available layers of protection for reducing the risk shall be considered. The residual risk after the application of all the layers of protection shall reduced by SIS. It should be ensured that all the IPL are considered since the cost of SIS is high and many other activities like maintenance and proof test shall be done to ensure that SIS provides the desired level of risk reduction.

In the above case study, there is a high alarm for operator to take corrective action and also analyzer to control air/fuel ratio. So credit shall be taken for BPCS and operator to take corrective action which provides a PFD of 10-1. However following criteria shall be fulfilled to take credit that operator will be able to take process to safe state

- Alarms: The Alarm priority and criticality shall be available to alert the operator
- Response Time: Sufficient time (min 15 minutes) shall be available for the operator to respond
- Training: The operator shall be trained on what actions shall be taken
- Occupancy: There shall be sufficient number of operator available to respond to alarm in case one of the operator goes for a break or take readings from field instrument

See the attached screen shot from exSILentia software for the SIL level to be achieved by SIF described above.



Picture courtesy: Exida.com LLC

• Integrity requirement

The selection of the architecture and technology shall be done such that the designed system provides the desired level of risk reduction with minimum cost implication. The design shall be fit for purpose, over specifying hardware adds more cost and complexity to the SIS.

Operating companies shall ensure that the proof test and PST are done at the time specified in the SRS, not adhering to these time intervals might not provide the desired level of risk reduction

- ## SIL Verification

Once the architecture and technology has been decided, the safety engineer validates that the SIF achieves the desired SIL.

Even if the SIF passé through the PFD calculation, it might still not qualify for the desired SIL level if it does not have minimum Hardware Fault Tolerant (HFT)

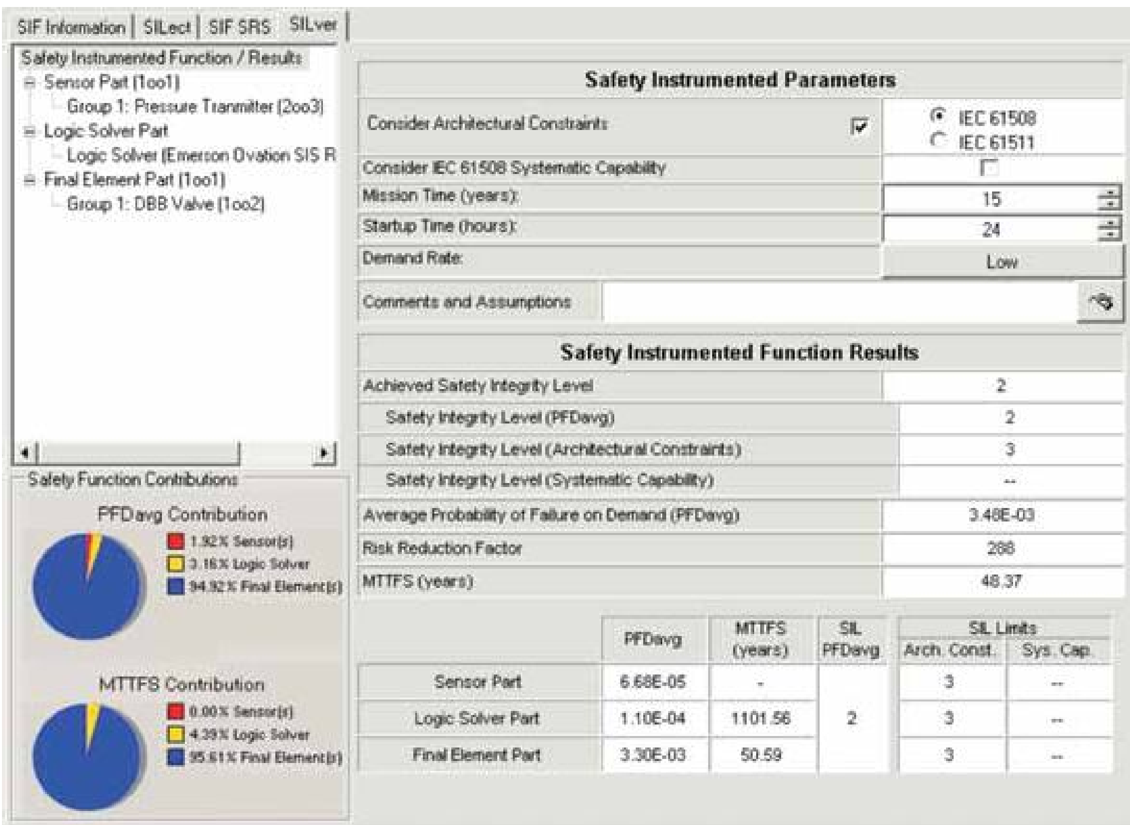
The SIF has to meet the minimum hardware fault tolerant per IEC61508/61511.

The HFT is the measure of number of random failure in hardware that a SIF can withstand without losing its capability to perform its intended function. HFT is a function of SIL rating and SFF(Safe failure fraction)

$$SFF = \frac{\lambda_{Total} - \lambda_{DU}}{\lambda_{Total}}$$

SFF is defined as the ratio of total average failures minus the dangerous undetected failure of the subsystem to total average failure rate of subsystem

The snap shot given below is for a typical SIL verification report from exSILentia.



- ## Conclusion

Analysis phase is the most important phase of safety life cycle. A good PHA reduces the efforts in design phase. It must be clearly understood and document what is the intended function of the SIF.

The SIS architecture and technology shall not be over designed since it increases the installed cost of the system.

A SIF with high spurious trips rate results in unnecessary down time of the plant which is directly related to the operating cost. Shutting down a power plant for 8 hours can result in major revenue loss for companies.

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A SCHEME FOR DESIGN OF INTELLIGENT MODEL PREDICTIVE SELF TUNING REGULATOR

P.K.SINGH

KEYWORDS

INTERNAL MODEL CONTROL PID CONTROLLER, KALMAN ESTIMATORS, SELF TUNING REGULATORS, INTELLIGENT MODEL TUNING, FAULT TOLERANT SYSTEM

ABSTRACT

In this paper an approach to internal model Control for self tuning regulators has been discussed. This discussion further leads to optimization of sampling rate for model predictive Controller based on intelligent model such as artificial neural net by kalman estimator and bilinear transform tustin approximation for a cascade control loop as used in power plants.

INTRODUCTION

Tuning methodology of Internal Model Control design technique for PID controllers and optimization of sampling rate for discrete PID Controllers when used with the Discrete Process Models is a tricky issue during design stage. The fact is that internal model control structure has been popular with many plants used in process control which have open loop stable nature and this is the reason that it has been popular among practicing engineers. By lapse of time as discrete systems became popular and the whole control system became discrete though the plant continued to be analog the chances of control algorithm mismatch increased due time lag between the process output and the model output and the chances of system instability increased and optimized tuning of IMC based PID controllers became difficult.

INTERNAL MODEL CONTROL PID CONTROLLER DESIGN :

A number of process models ranging from dead time with gain to second order over damped system with dead time imaginary roots and gain exist in the plant. Ziegler Nicholas tuning method require very little knowledge of Plant and the main design criterion for these methods is to determine the quarter amplitude decay ratio for load disturbance response (1,2). A typical internal model control block diagram without the estimator is shown in Figure:1. In this case Gc(s) is the stable imc controller, Gp(s) is the plant and Gm(s) is the model of the plant. This model is incomplete as it requires a filter for system identification to enhance the robustness of the control loop hence the improved model is shown in Figure:2. In this case a filter F(s) is added to the model which is responsible for making the model robust to minimize the tracking error R(s)-Y(s) to achieve the optimal control loop. In case of Figure:2 the external disturbance factor has been neglected as the disturbance is already accounted for in the plant observer Y(s).

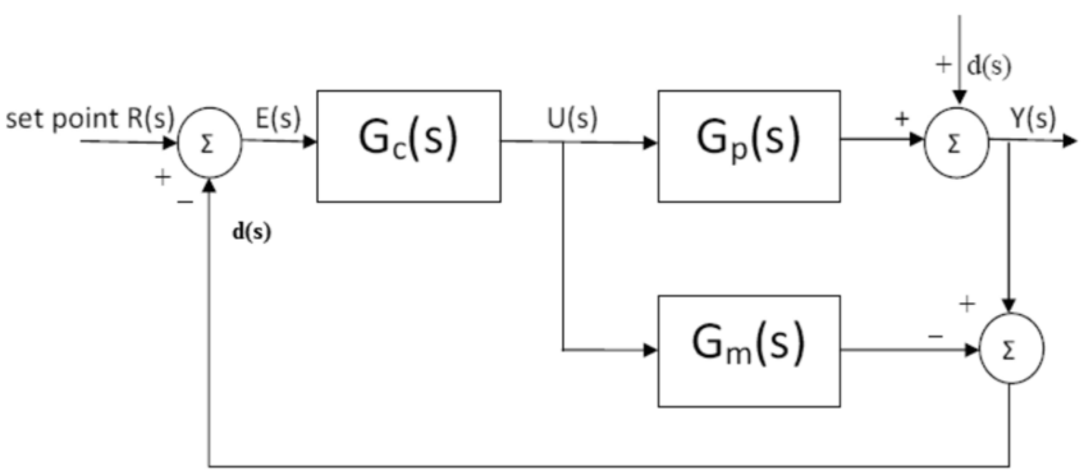

Figure:1 Block Diagram representation of IMC Control loop along with plant

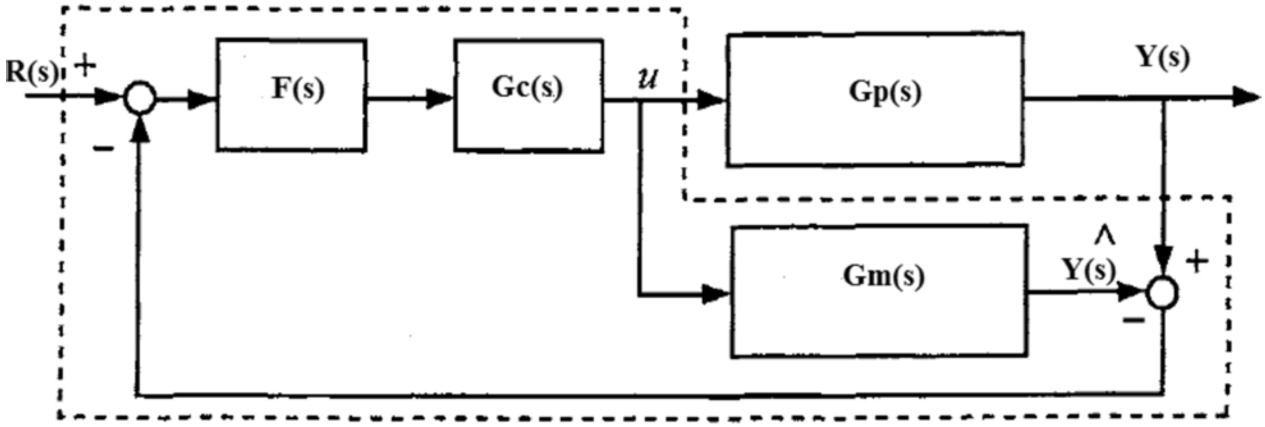

Figure:2 Block Diagram representation of IMC Control loop along with Filter and plant

Considering a simple first order plant model with dead time and time constant T the Gp(s) can be expressed as

$$G(s) = \frac{Ke^{-\theta s}}{1+Ts}$$

The dead time can be approximated by first order Pade approximation such that (3)

$$e^{-\theta s} = \frac{1-\frac{\theta s}{2}}{1+\frac{\theta s}{2}}$$

Hence the resulting rational transfer function of the internal model Gm(s) is given by

$$G_m(s) = \frac{K}{1+Ts}\frac{1-\frac{\theta s}{2}}{1+\frac{\theta s}{2}}$$

Now Gc(s) is chosen such that the H2 norm of [1-Gm(s) Gc(s)R(s)] is minimized (4)

$$G_c(s) = \frac{1+Ts}{K}$$

Since value of Gc(s) is not found to be suitable hence the estimator or filter F(s) is tuned in the manner such that

$$F(s) = \frac{1}{1+\alpha s}$$

So the equivalent feedback controller expression can be expressed as

$$C(s) = \frac{F(s)G_c(s)}{1-F(s)G_c(s)G_m(s)}$$

And the PID parameters can be extracted from this expression as

$$K_p = \frac{2T+\theta}{2K(\theta+\alpha)} \quad , \quad K_i = \frac{1}{K(\theta+\alpha)} \quad \text{and} \quad K_d = \frac{T\theta}{2K(\theta+\alpha)}$$

The first order pade approximation was used for time delay and it does not ensure a very robust model design especially when the plant is lag dominating type though it satisfies the L2 norms of the tracking error but gives poor response to load disturbances due to inherent pole-zero cancellation methodology used in design. It is also observed that all the values are sensitive to which is an approximation suitable to the design and the suitable value of $\alpha > 0.2T$ and $\alpha > 0.25$ has been proposed by Manfred Morari and Zafirico(5). It can be concluded that this type of design is suitable when $0.37 < \frac{\theta}{T}$ for (6,7). $\frac{\alpha}{\theta} = 0.25$ (6,7).

INTERNAL MODEL CONTROL DIGITAL PID CONTROLLER DESIGN :

In case of digital controller design the design is the transition of analog controller to digital controller and there are two options for design. In the first option one can design the digital controller and transform it to analog mode by bilinear transform and then obtain the optimum stable response and in the second case the plant along with the controller can be digitized and the stability can be evaluated in the digital domain however in either case merely using bilinear transform does not give an optimum value of because this transform does not take care of sampling rate which is very important aspect of digital control loop. The relation of z and in bilinear transform is expressed as

$$z = \frac{\omega + 1}{\omega - 1} \text{ and } \omega = \frac{z - 1}{z + 1}$$

These expression hold good for simple analog and digital transform but are not very useful when sampling rate has to be accounted for in the design and stability of the digital system (8). An improvement over this method is bilinear transform with Tustin approximation which is similar to Trapezoid approximation (9) and is expressed as:

$$z = \frac{2 + \omega T}{2 - \omega T} \text{ and } \omega = \frac{2}{T}\frac{z - 1}{z + 1}$$

In this case the sampling rate is also considered to optimize the transformation from digital to analog and vice versa in order to avoid the aliasing factor. It is the sampling rate which determines the z to s scale transformation for stability analysis of control loop along with the plant dynamic model(10). Now the design methodology will have to aspects i.e either on designs a digital controller based on difference equation to deploy the certainity equivalence principle or one can design an analog controller satisfying the routh condition and come up with a number of solution for stable controller so that a gain scheduler may be designed how ever this is also the limitation of analog controller. The benefit of direct digital pid controller is that it is based on the instantaneous previous values and can be deployed by using a simple micro controller which is very cost effective as compared to the analog controllers. Since these controller are sensitive to gain scheduling and sometimes because of the process dead time are likely to enter the integral wind up zone where a micro controller may fail to implement the algorithm as scheduled mathematically. In such case one has to look for State Space based system so that the system can be isolated into controller and observer methodology and the observation error will not effect the controller as it will tune itself towards the control gain rather then going directly for control implementation by certainity equivalent principle however this is suitable for over damped stable system i.e. systems with dc behavior(10).

MODEL PRDICTIVE FAULT TOLERANT SELF TUNING REGULATOR DESIGN:

The deployment of isolated observer from controller leads to the design of fault tolerant controllers. However one has to design the system in state space and it may cost more on the controller hard ware side. There are two types of state space controller usually deployed for linear or non linear system with ac response the system may be time varying but the estimate helps in stabilizing the system especially when it is linear. The first one is recursive least square technique for fault detection. In this case the non recursive estimation equations for *δ = (k+1)* and *δ = (k)* are subtracted from one another and the resulting equation is the recursive algorithm given as

$$\delta(k+1) = \delta(k) + \gamma(k)[y(k+1) - \varphi^T(k+1)\delta(k)]$$

Here *δ(k+1)* is the new estimate and *δ (k)* is the old estimate, y*(k)* is the correction factor, y(k+1) is the new measurement and $\varphi^T(k+1)\delta(k)$ is the one step ahead prediction of the new measurement. On solving it is observed that this recursive algorithm contains the variances of parameter estimates which is the diagonal elements of covariance matrix hence equation (10) can be also written in the simplified manner as:

$$\delta(k+1) = \delta(k) + \gamma(k)e(k+1)$$

Here e(k+1) is the prediction error. this type of predictor estimator can be shown by the block diagram shown in Figure:3 the estimation is done with white noise w which has more intensity then the normal process noise.

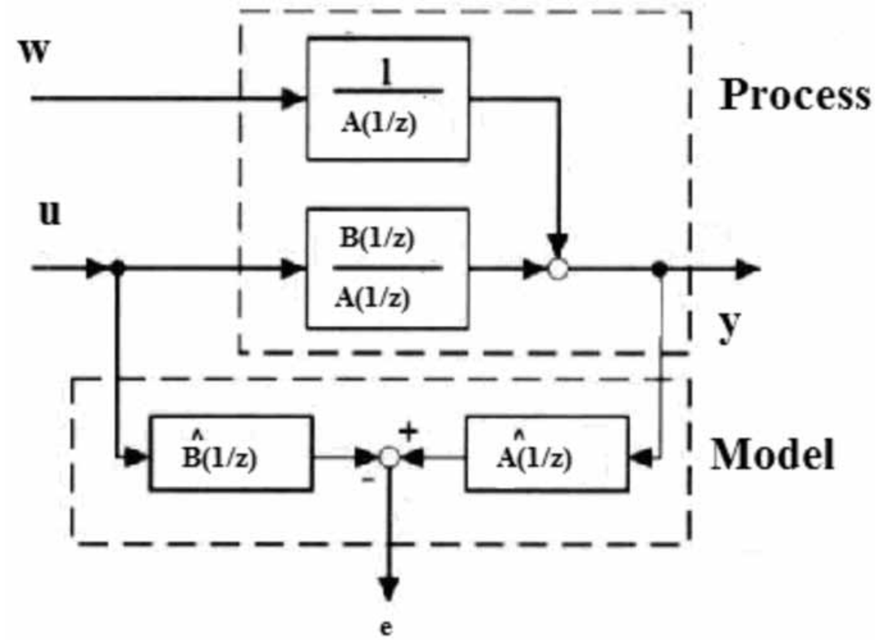

Figure:3 Model configuration for least square estimation technique

This method is good when microcomputer register length and memory is not an limitation however it is suitable for linear systems. When a non linear process has to be identified the the control designer has to opt for intelligent modeling tool such as Artficial Neural Net, Fuzzy Logic or Genetic algorithm. In such cases the parameter estimator or state observer stability evaluation becomes a problem contradicting the rules of controllability and observability because the process is slow and the model prediction is fast hence in such cases the synchronization of controller estimator and the processis not feasible. In such cases fault detection by state estimation is the solution to this problem and Kalman Estimator belongs to this type of solution.

KALMAN ESTIMATOR THE SOLUTION TO STOCHASTIC DISTURBANCES

In a state space model when it is supplemented by stochastic noise the state estimation error cannot converge to zero so one has to seek a method in which for time instance k+1 the state variable can be predicted by the state model with the information at time k. This leads to the design of Kalman filter which has an estimator and predictor combined in one algorithm. This algorithm can be expressed as:

$$\hat{x}[(k+1)/(k+1)] = A\hat{x}(k/k) + Bu(k) + K(k+1)[y(k+1) - C(A\hat{x}(k/k) + Bu(k))]$$

In this case $\hat{x}[(k+1)/(k+1)]$ is the new estimate, $A\hat{x}(k/k)$ is the old estimate, K(k+1) is the correction matrix , y(k+1) is the new measurement and $C(A\hat{x}(k/k)+Bu(k))$ is the predicted measurement based on old estimate(10 Fault tolerant iserman). The main difference between the recursive least square technique and kalman technique is that the convergence of first technique is based on one step ahead prediction by the model where as in second case the convergence is based on the old estimate as in case of difference equation of certainity equivalence principal self tuning regulators. This characteristics of kalman estimator make it suitable to estimate the sampling error between the intelligent model and the actual system to optimize the control algorithm. Moreover the identification of optimum sampling rate is also a parameter identification problem associated with model predictive control hence it is associated to nonlinear estimation problem. This occurs as a dynamic coefficient or measurement sensitivity of dynamic system state variable, therefore this problem is solved simultaneously with the state estimation problem by state vector augmentation treating the model as non linear(11).

STABILITY AND LIMITATION OF KALMAN ESTIMATOR:

Dynamic stability of a system in state space refers to the state variable behavior and not the estimation error i.e. the estimator is uniformally asymptotically stable if the system model is stochastically controllable and observable. The limitation of Kalman estimator when deployed in real time leads to all the limitation applied to an Harvard architecture processor and the details can be found in refrence (12)

AREAS OF APPLICATION:

This technique has been successfully deployed in evaluation of photovoltaic ANN models used for maximum power point trackers (13). It can be also deployed to Super Heater and Boiler drum level Control general predictive control and cascade control(14). In case of cascade control this technique will help in optimizing the model predictive control sampling rate in the outer loop and internal model control can be success fully designed based on equation (7) and the difference equation sampling rate for the individual model can be obtained from equation(9).

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REQUIREMENT OF COLD JUNCTION COMPANSATION & HIGH ACCURACY RTD

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ABSTRACT

With the growing demand of critical temperature measurement the requirement of accurate results is very important. For all the analytical or industrial purpose the measurement made should be very accurate

So that one can come to any exact conclusion regarding the process change or observation.

KEYWORDS

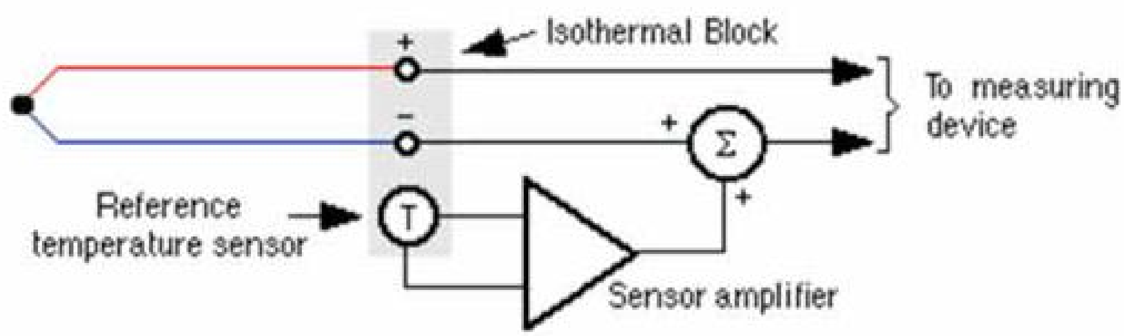
Cold junction, compensation, Reference junction, Temperature, Calibration, Uncertainty, Accuracy, Deviation,

REFERENCE JUNCTION UNIT FOR THERMOCOUPLES

- **COLD JUNCTION COMPANSATION**

Thermocouples measure the temperature difference between two points, not absolute temperature. To measure a single temperature one of the junctions—normally the cold junction—is maintained at a known reference temperature, and the other junction is at the temperature to be sensed.

Having a junction of known temperature, while useful for laboratory calibration, is not convenient for most measurement and control applications. Instead, they incorporate an artificial cold junction using a thermally sensitive device such as a thermistor or diode to measure the temperature of the input connections at the instrument, with special care being taken to minimize any temperature gradient between terminals. Hence, the voltage from a known cold junction can be simulated, and the appropriate correction applied. This is known as cold junction compensation. Some integrated circuits are designed to output a compensated voltage based on thermocouple type and cold junction temperature.



Hardware Reference Junction Compensation

For industrial application when accurate thermocouple measurements are required, it is common practice to reference both legs to copper lead wire at the fixed & known temp point so that copper leads may be connected to the emf readout instrument. This procedure avoids the generation of thermal emfs depend on the cold end temperature at the terminals of the readout instrument. Changes in reference junction temperature influence the output signal and practical instruments must be provided with a means to cancel this potential source of error. The EMF generated is dependent on a difference in temperature, so in order to make a measurement the reference must be known. This is shown schematically in Fig below and can be accomplished by placing the reference junction in a reference junction unit at a constant Temperature. The emf of this reference junction unit is fixed and added to the output.

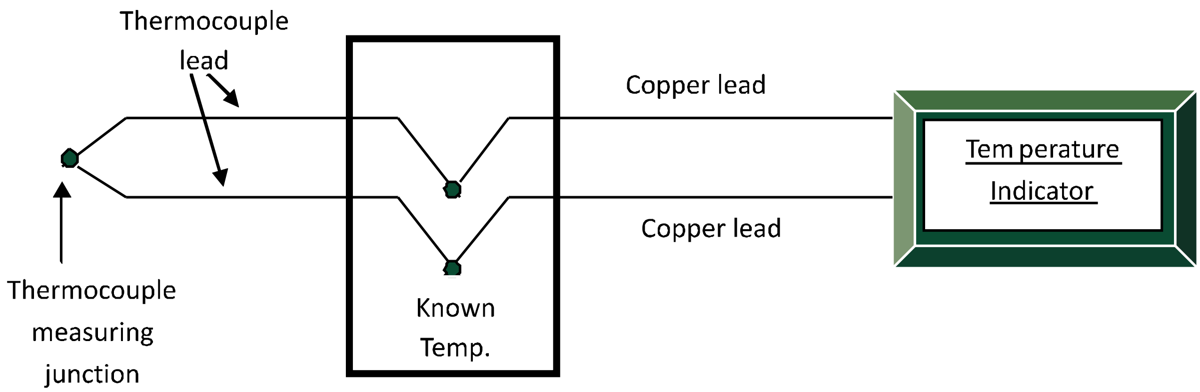
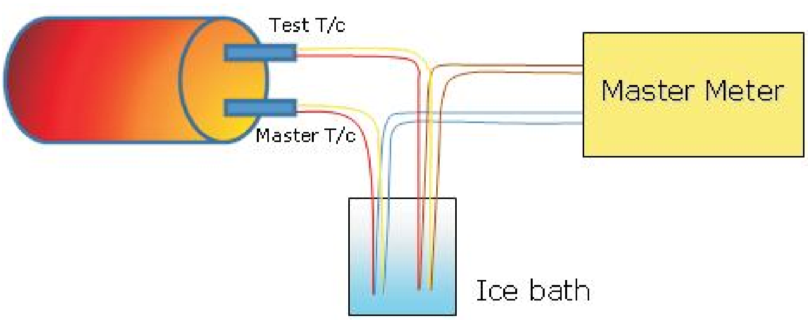


Fig. for reference junction application

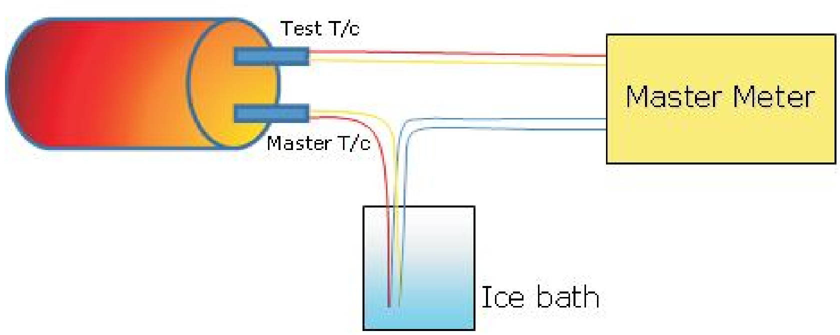
The method of using reference unit for cold junction compensation of thermocouples is widely accepted because the unit provides very stable cold junction compensation at desired fixed temperature point.

We take a practical example (for a typical laboratory condition) to understand above point more clearly

NOTE: The test and master for below observations are already calibrated from accredited lab with deviation at 1200 deg as 0.1 deg C between them.



Test 1 : Test T/c with Cold junction compensation



Test 2 : Test T/c without Cold junction compensation

OBSERVATION (with zero reference)

Sr. No.	Master Reading (R type)		Test Reading (S type)		Diff.
	mV	Temp.	mV	Temp.	
1	13.19	1197.23	11.919	1197.37	0.14
2	13.19	1197.28	11.92	1197.46	0.18
3	13.191	1197.35	11.917	1197.28	-0.07
4	13.191	1197.32	11.917	1197.3	-0.02
5	13.192	1197.41	11.918	1197.36	-0.05
6	13.192	1197.45	11.917	1197.39	-0.06
7	13.191	1197.38	11.919	1197.42	0.04
8	13.191	1197.35	11.92	1197.48	0.13
9	13.192	1197.43	11.919	1197.45	0.02
10	13.192	1197.46	11.919	1197.4	-0.06
Average	**13.1912**	**1197.366**	**11.9185**	**1197.391**	**0.025**

OBSERVATION (Master with 0 reference & Test without 0 Reference Internal mode)

Sr. No.	Master Reading (R type)		Test Reading (S type)		Diff.
	mV	Temp.	mV	Temp.	
1	13.188	1197.11	11.766	1197.56	0.45
2	13.188	1197.13	11.768	1197.66	0.53
3	13.189	1197.2	11.77	1197.85	0.65
4	13.189	1197.23	11.771	1197.9	0.67
5	13.19	1197.31	11.773	1198.02	0.71
6	13.191	1197.38	11.77	1197.9	0.52
7	13.192	1197.42	11.772	1197.95	0.53
8	13.191	1197.35	11.769	1197.8	0.45
9	13.19	1197.3	11.769	1197.82	0.52
10	13.191	1197.33	11.771	1197.92	0.59
Average	**13.1899**	**1197.276**	**11.7699**	**1197.838**	**0.562**

As we can conclude by observing the average difference between the master and test thermocouple from above example that using practical cold junction compensation is much better way to get the accurate results.

HIGH ACCURACY RTD (SSPRT)

With the growing demand of precision measurement, the need of highly accurate temperature sensors has to be fulfilled with the introduction of the new SSPRT which is an excellent solution between the highly accurate, stable, delicate SPRTs and less stable, accurate, robust IPRTs.

These semi standard PRTs are made specifically to withstand in Industrial Shock and Vibration Environment and comes complete with ITS 90 Constants and Temp vs Resistance Chart.

SPECIFICATION OF SSPRT 660

Temperature Range	Upto 660 Deg C
Outer Diameter	6 mm
Outer Sheath	Inconel 600
Lead Wires	Platinum/Platinum coated Palladium Wires
RTPW	100 O (± 1 O)
Stability	± 50 mK
Long Term Drift	± 50 mK
Termination	M-F Gold Plated 4 Pin Lemo Connector
Calibration Uncertainty	< 15 mK at 0. 01 Deg C
	< 30 mK at 29.7646 Deg C
	< 40 mK at 231.928 Deg C
	< 40 mK at 419.527 Deg C
	< 40 mK at 660.323 Deg C
Calibration	NABL Accredited Calibration Certificate with ITS 90 Constants and Resistance Vs Temperature Chart in 1 Deg C Increment.

• INTRODUCTION STRUCTURE AND DESIGN

Metal Sheathed Semi Standard Platinum Resistance Thermometers are widely used as references to calibrate various temperature probes, particularly in secondary calibration laboratories.

SSPRT-660 is constructed with a 6 mm outer diameter inconel sheath for high durability. Inside the sheath, the sensing element is protected by a thin platinum housing that shields the sensor from contamination from free floating metal ions found within metal environment at high temperatures. The electrical configuration is a four wire current-potential hookup to eliminate effects of lead wire resistance.

All parts used in SSPRT are cleaned and fired carefully before assembly. The SSPRT resistance element having RTPW as 100 ohm +/- 1 ohm is shielded by a sensor protection capsule.

A special powder mixture is filled into the sensor capsule to support the element wire to protect the element from mechanical shocks. A powder is chosen that will not contaminate the platinum and is specially mixed not only to protect the element from mechanical shocks but also to enable the platinum sensor wire to expand and contract freely.

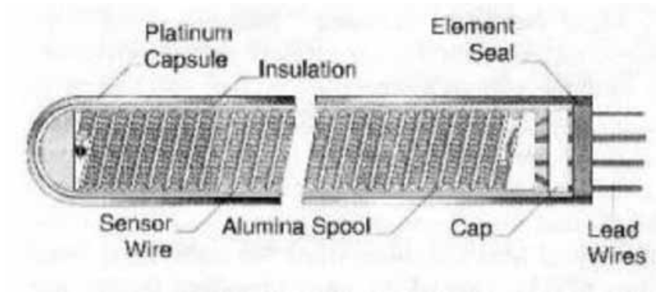
After all element parts and powder are assembled into the sensor protection capsule, a pure mixture of gases, including oxygen, is filled into the sensor at high temperature. The sensor is hermetically sealed under pressure.

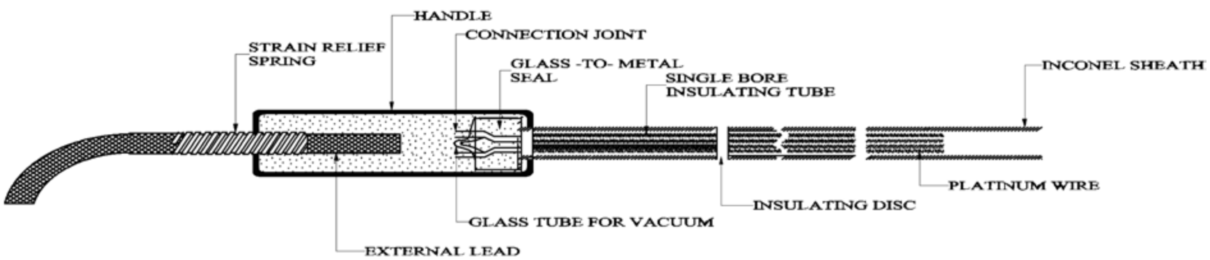
The four thermometer leads are insulated by thin walled single bore alumina tubing. A 6 mm outside diameter Inconel 600 Sheath encases the sensor and leads in a pure gas mixture atmosphere, which includes oxygen. The unit is hermetically sealed using a glass to metal seal.

The junction between the platinum leads and the external copper leads is designed to minimize thermal EMF generated by temperature differences.

• IMPROVING STABILITIES OF SSPRT

There is a trade-off between the oxidation effect and element contamination in metal sheathed semi standard platinum resistance thermometer. Excessively high O_2 leads to sensor contamination. The oxygen content in a thermometer may become unknown after a period of operation due to slow oxidation of the metal sheath and consequent loss of oxygen in metal sheathed SSPRT. This can significantly affect the thermometer's performance. Research has shown that a thermometer may eventually become contaminated due to deficiency of oxygen surrounding its element. A feasible solution to protect against contamination is to seal the element separately from its sheath. This solution can resolve the conflict between the oxidation effect and element contamination and improve the long term stability of Metal Sheathed SSPRTs.





The new SSPRT was developed to fill the gap between highly accurate but fragile SPRTs and rugged but less accurate IPRTs, based on a compromise of structure design.

The structure of the thermometer is similar to that of SPRTs. The differences include the applications of certain techniques to protect the element from contamination at high temperatures and mechanical shocks. Not only does the sensor need protection from contamination and mechanical shocks, it should also exhibit excellent performance in the areas of thermal cycling and thermal hysteresis.

ACRONYMS

ITS International Temperature Scale

RTD Resistance Temperature Detector

SSPRT Semi Standard Platinum Resistance Thermometer

SPRT Standard Platinum Resistance Thermometer

IPRT International Platinum Resistance Thermometer

RTPW Resistance at Triple Point of Water

EMF Electro Motive Force

BIOGRAPHY

Mr. Vinay Rathi (Director Tempsens Instrument (I) Pvt. Ltd) born in Dec 1973 is graduate in Electrical Engineering has done MBA in Entrepreneurship from TAPAI Management Institute in 1996. He has ten year experience in Pyrotech Electronics, from year 2004 he is working with Tempsens and under his supervision today Tempsens is supplying products world wide to more than 40 countries

Automation in Combined cycle Power Plants

Remote operation and Monitoring of Origin Power station and Managing security of control systems.

Ravi Malik
Instrumentation and Controls Lead
Origin Energy, Australia.

Abstract (Case study):

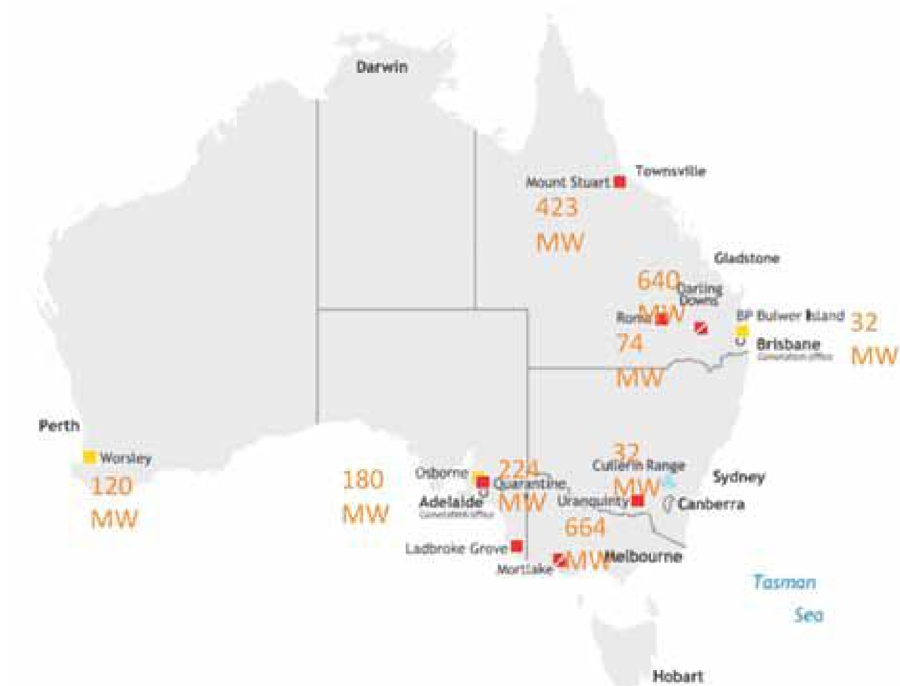
This paper highlights the need of remote operation and monitoring of power stations due to growth in power generation and managing security risks of Control Systems with remote access requirements. This paper is divided into two major sections.

First section explains establishing remote operation of an open cycle peaking power station (664MW) from Energy Trading Centre at Sydney located 500km from Power station. This will discuss few challenges while setting up remote operation and monitoring of power station. This also highlights tangible benefits and triggered the need to develop large scale Monitoring and Support Centre for Generation fleet wide power stations.

Second section will explain how we managed security risks with restricted external access to Plant DCS. This will discuss architectures and strategies considered and implemented around control network, operational and physical security. This will also explain criteria for selecting the standard architecture with security zones to mitigate risks from increased cyber security threats.

Section 1: Remote operation and Monitoring setup:

Origin Energy has owned and contracted Energy assets of 6000 MW based on diversified fuel and technology and represent Australia's largest share of Generation portfolio. Uranquinty Power Station is one of the open cycle power station within Generation portfolio comprising of (4*166MW) Siemens SGT-2000E Gas Turbines with modernized T3000 Distributed control system. This power station was commissioned in 2009 and established remote operation thereafter. This is Origin's first power station to run remotely from Electricity traders Desk at Sydney.



Origin Energy - Generation Portfolio

Uranquinty Power Station, Australia

Uranquinty Power Station is a peaking power station which operates when electricity demand goes up in peak period. Origin Energy trading team watch the electricity market more closely for right opportunity to pump in power to Grid network to nullify electricity demand during peak periods. This is very critical scenario in highly volatile electricity trading market. Origin Generation had few lost time opportunities in highly volatile Australian electricity market conditions which led to loss revenue on few instances. This drove the need to remotely operate this plant to pickup opportunity in electricity market during high demand period. Few of the requirements of remote operations setup are as below:

Require ments:

1. Minimise reaction time to have units available and run up to full load.
2. Maximise opportunity to trade electricity in volatile market.
3. Optimise site resources.
4. Increase availability and start reliability.
5. Reduced risk of human intervention and error which has potential to cause delays.
6. Buildup in house capability.
7. Pilot trial project to support large scale growth in future.

Challenges to setup remote operations:

Being first of its kind within Origin Generation portfolio, we faced few challenges whilst establishing remote operation of Uranquinty Power Station and they were resolved with defined risk mitigation strategies in consultation with key stakeholders. Few key challenges are as below.

1. Train Commercial traders to operate power plant:

This was one of the biggest challenge to train commercial traders (non technical) about power plant knowhow in simple and easy to understand technical language. Plant operational competency model was developed with following core inclusions:

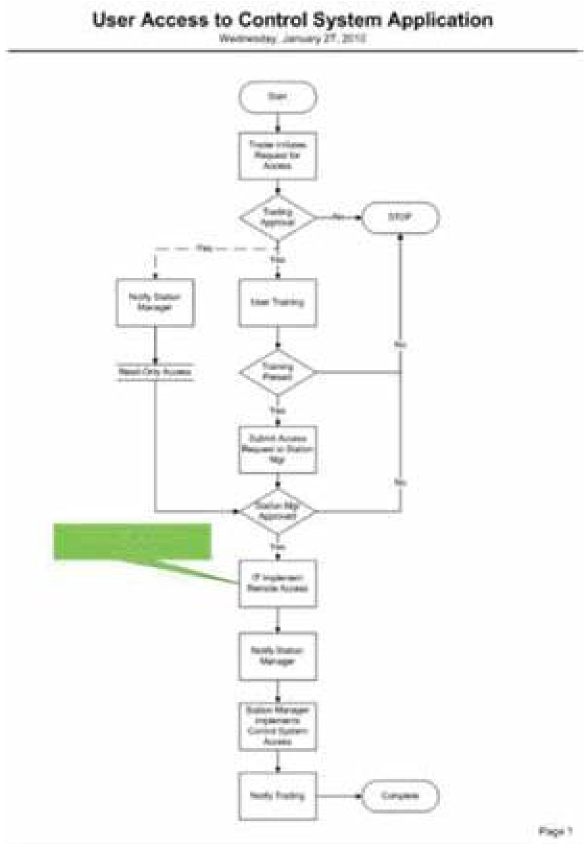
- Plant Operational Training package
- Customised trader HMI only for trader control.

Customized HMI for Traders

- Customised and Limited DCS hands on operational training.
- Theory and practical test.
- Final signoff to allow unit operation from customised HMI.

2. Access Control :

Following process was setup to allow access to Traders for unit operation with sign off from appropriate levels.



User Access approval process

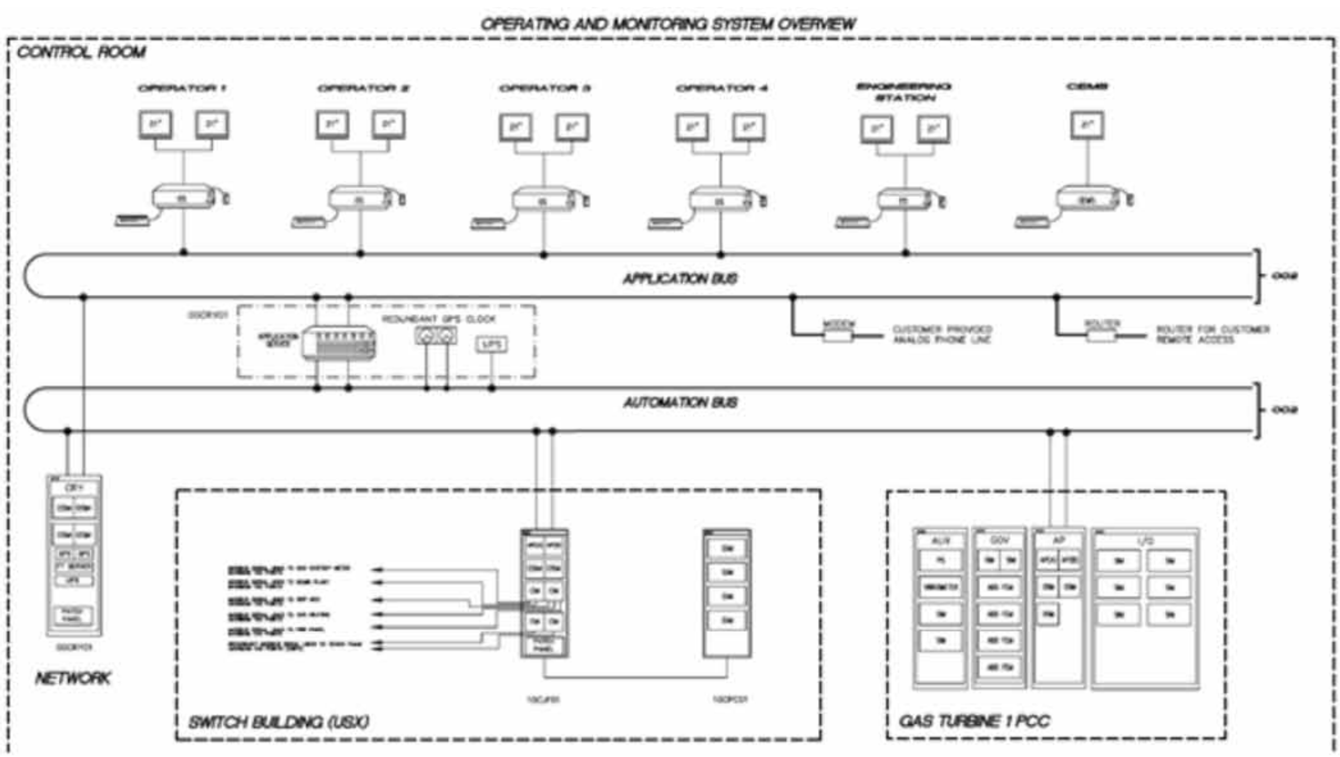
3. Operational Procedures:

Operational procedures with documented step by step instructions for unit startup and shutdown with alarm escalation strategies explained. There are four units in this plant and each unit has about 100 starts every year. On average, Trader starts atleast one unit every day.

4. Customised logic design Strategy:

With the development of customised HMI graphic with limited access to unit operation function blocks, control system logics were also designed to mitigate risk due to any inadvertent human double ups or unforeseen errors. Control logics were set for site operator to enable/ disable access for Traders anytime. Site operator will have complete authority to allow or relinquish control for traders.

T3000 DCS is state of the art technology and being released by Siemens in 2008. Each unit has S7 – 400 series redundant controllers; one for turbine control and other for turbine protection. This is TUV approved safety controller with fail safe control logic implemented.



T3000 DCS configuration

5. **Alarm Escalation:**

Alarm escalation strategy was developed for Traders to contact site on-call operator and asset management team in case of any plant operational contingencies.

6. **Emergency Trip situation :**

Risk assessment was conducted based on risk scenario when traders can't communicate with on call operator due to some natural disaster or major system failure. Traders have to take decision to trip the unit in extreme circumstances. As T3000 system had E stop PB hardwired and ESV trip as soft PB for unit trip from HMI. Traders have been provided with additional plant emergency trip soft pushbuttons to trip unit in extreme rare occurrence. System has been configured as fully redundant to avoid any failure event. This is derived from Origin Risk assessment guidelines.

7. **Alarm Standardisation:**

Alarm Standardisation was one of the key pre emptive tasks carried out which has not only helped Traders but also to site operators and being valued across the business.

Tangible Benefits:

Remote operational setup was first of its kind to be operated remotely with Origin capability and it had high Return on Investment (RoI) immediately after successful completion and paid off whole investment within a month. Generation had few days of high volatile electricity market prices and traders have to operate these units to pickup market opportunity. Had this been

Cost Saving:

Initial investment of this project was almost 1/10th of what was proposed by OEMs. This has contributed to huge savings to start with.

In-house skill uplift:

Engineers and Operational teams were trained in the system design and commissioning of the remote setup. Learning's from the project helped build in-house skills and have been of great influence for upcoming projects.

Scalability:

Origin's next peaking power station (Mortlake power station – 580MW) in Victoria was also setup on similar concept and successfully commissioned remote operation prior to practical completion of power station.

MSC Project Evolution:

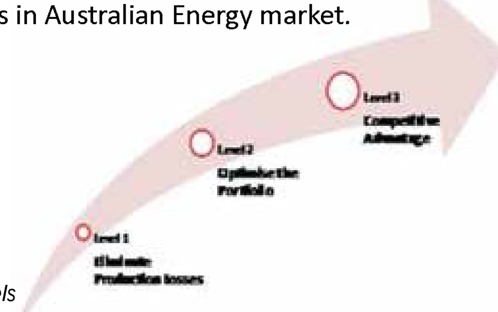
This has triggered the need for developing the bigger picture and concept for significant improvement in the business performance with added asset management operational objectives and kick off Monitoring and Support Centre (MSC) Project. Origin Energy Generation is seeking to establish a remote MSC to :

– Facilitate the centralised dispatch, production monitoring and support of Generation's assets
– Provide the required systems and capabilities for data collation, interrogation, analysis, and reporting on power plant performance across Generation's fleet.
– Improve reliability, performance and availability of Generation's assets.
– Enable Generation to proactively prevent asset failure.
– Enable Generation to forecast future performance of its assets.
– Reduce risk related to the operation of Generation's power portfolio.

Above vision and goal could only be possible by initial foundation being setup for remote operation and monitoring of power stations across the fleet.

Competitive advantage:

Origin Generation's vision is to move towards operational excellence by eliminating production losses and optimized portfolio of all Generation assets and will have a competitive advantage in Australian Energy sector. Learning's from International Energy giants like DTE Energy and Transalta in US and Canada have brought awareness and concept within Origin Generation, to excel and achieve to be one of the best amongst their competitors in Australian Energy market.



Maturity Levels

Section 2: Security of control system

Establishment of remote setup to access control system for unit operation had few advantages as explained above however this has sparked security and system vulnerability issues on the way. We analyzed security threats with IT, OEM and Control system experts and considered security measures to develop standardized security architecture for Generation Business.

Security threats from:

1. Network (Controls and IT)
2. Operational
3. Physical

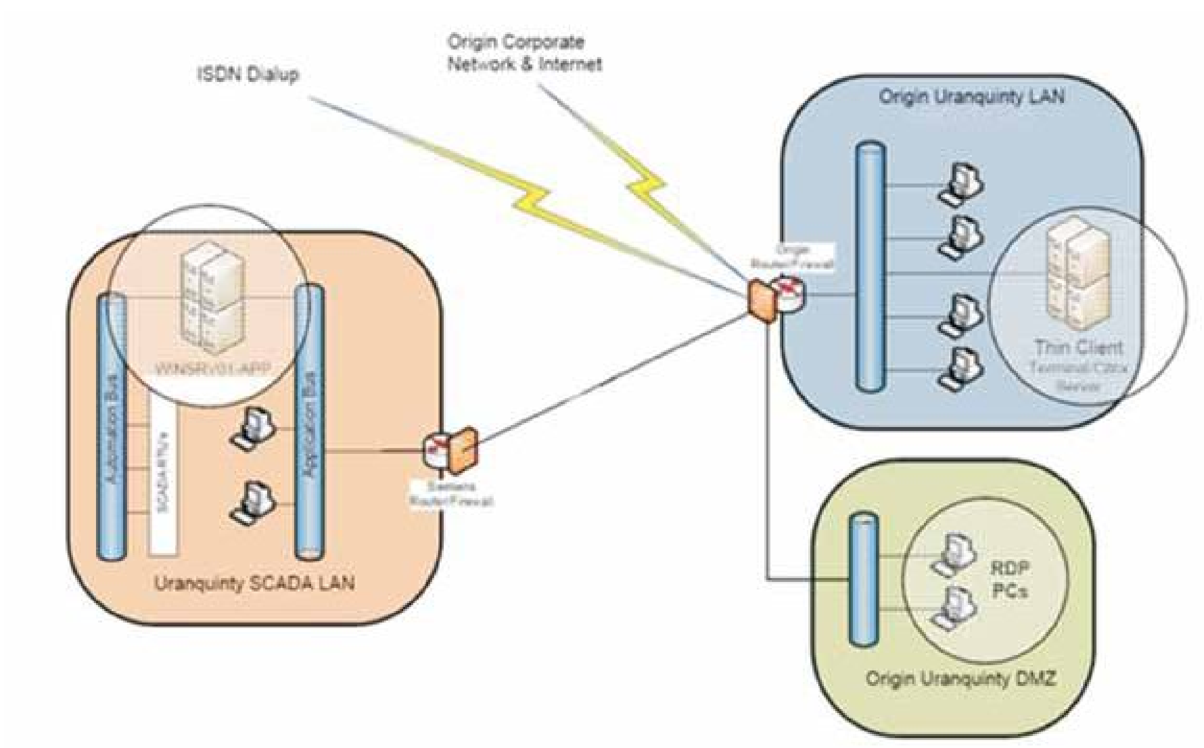
These key areas have potential to cause damage to Generation assets and company reputation.

1. Network Security:

Network security was considered from control network and corporate IT perspective since traders were provided access to Plant Distributed control system (DCS) via Origin IT corporate network. Security assessment was carried out based on following underlying documents from respective functional groups.

- OEM advice: Siemens White paper – T3000 Security
- IT Vulnerability assessment Guidelines about Application security and Intrusion detection.
- I&C Standard Guideline for remote access to Control Systems.

Based on advice from all stakeholders and their underlying documents, Blue print was established to benchmark the standard network architecture for secured remote access to control system. No direct access to control system was allowed. De-Militarized Zone (DMZ) was setup as an intermediate interface with firewall at both ends to remove possibility of any direct connection from either network. Remote user say trader will remotely desktop into DMZ PC client application which can communicate with control network servers. The SCADA DMZ is utilised as a secure interface to the Distributed control systems (or SCADA network) that serve the purpose of accessing operational data and providing the ability to remotely monitor and/or operate the plant through client systems.



Standard Architecture showing DMZ

Standard Architecture with Network security Zones:

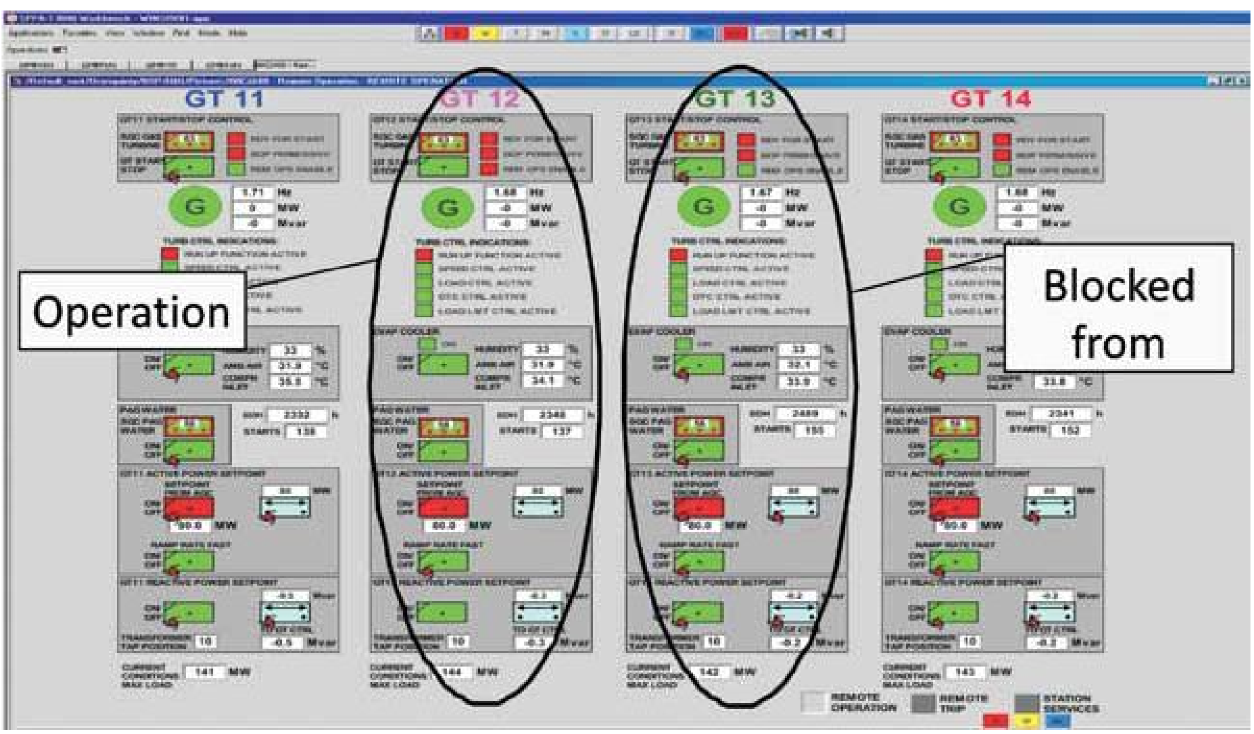
- Provision of a secure SCADA Demilitarized (DMZ) Network that serves as a security buffer between the Origin Business Network and the SCADA/DCS Network.
- This network is considered a "Restricted" zone in accordance with Origin Enterprise Security Architecture - Logical Network Zone Model.
- The security of the DMZ Network shall include a network firewall device that is compliant with Origin architecture
- Restrict access to the DMZ Network and Applications to only authenticated users and specified network communication protocols required for the applications running on the host computers
- DMZ Network communication shall be given priority over general Origin Business Network communications
- DMZ devices should be physically located in a secure environment and have the ability to physically disconnect the communication link to the Origin Business Network in controlled manner in the event of any external threat
- The DMZ consists of 2 network security zones; the DMZ being restricted and the SCADA/DCS being secured

Criteria for High Availability and Reliability of Network :

- Triple Redundancy of PCs in DMZ
- Assigned PCs for Operations and Traders
- Additional T3000 Client Licences
- Monitoring of user logins and notifications.
- Limited Access to users

2. Operational Security:

Although control system designed for Gas turbine is self reliant for safe operation and shutdown of unit in the event of any plant or system failure, however operational security was one of the critical issue being considered to avoid any double up or racing off between Trader and site operations team. Following control measures implemented in controls logic to remove any possibility of inadvertent unit operation.



HMI with controls enabled

- Enable and Disable remote operation of Gas Turbine: Operators have full control to select and allow any units for operation by traders.
- Provide Emergency GT Trip for Trader customised graphic: Emergency Trip graphic and associated logic was specifically designed and developed to avoid any unforeseen condition when traders loses contact with site operations team.

3. Physical Security:

This was one of the important aspect which often taken as obvious at our power stations and control room. A tight security measure minimizes possible risk of any unwanted threats to our business. Physical lockout and swiping card access was installed at Traders office at Sydney and dedicated users were given access to remote control centre and Alarm will be sent to operator if main entry door to remote control centre left open for longer than normal duration.

Summary

This project setup a benchmark within Origin Generation to operate its first power station remotely from Energy trader desk and paid off project cost within a month although calculated NPV had target of 2 years. This new approach has been rolled out across Origin's other power station to support large scale growth of business by introducing new ways of doing things better and have competitive advantage over other energy market players.

This project got into the eyes and ears of Origin Energy Board and published in Energy Market News Publication.

Output Loss Analysis – A tool to monitor Real time performance losses of a CCGT power station

Authors:

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Mr. Diwakar Kaushik is Deputy General Manager (ERP) in NTPC Limited. He is a member of ERP Operation Module core team constituted for ERP implementation in NTPC. His qualifications are B.Sc.(Mechanical Engineering), MBA (HR). He is also a qualified Energy Auditor from BEE. He has work experience of over 18 years in different capacities in commissioning, operation & efficiency sections of CCGT stations and is subsequently working as ERP Operation Module core team member for last five years.

Vinay Pratap Singh

Mr. Singh is AGM (ERP) in NTPC Limited. He is B.E.(Mech.) from Manipal Instt. of Technology. He has work experience of over 34 years in different capacities in Erection, Commissioning & Operation in BHEL and Operation Services and implementation of ERP in NTPC Coal & Gas Power Stations.

As a part of ERP implementation in NTPC, PI system of OSISoft was commissioned all across the organization. The main objective of taking PI system as a part of ERP package was to make available real time process information along with the business transactions to the management for effective decision making. On top of the PI system, various operation performance monitoring applications were built upon using PI tools to assist the operators for taking real time machine performance optimization decisions.

1.0 PI System & its implementation in NTPC

1.1 Pre-PI System scenario:

Real-time process data was available in process control systems of DAS, DDCMIS etc. and would be stored in Data Historians of the control system vendor. This had the following limitations –

- The data historians would be of proprietary nature and would need certain programming knowledge to retrieve or access the data.
- The storage capacity was limited, typically of a few days.
- Since NTPC has a variety of control systems and of various vintage, lot of time, effort & cost would be required to access even small amount of data.
- Dependency on the C&I engineer would be necessary for data access.
- Access to real-time data was limited to control room and hence not available to other users at station, Regional or Corporate office for any analysis.
- Disparate systems such as DCS, ABT & EMS packages were not integrated in a single platform.

1.2 Post PI System Scenario

PI system was installed & commissioned at each of the 15 nos. coal based & 7 nos. gas based power stations and one at the corporate office. The various real time information systems in the station were connected to station PI servers & its data was made available on station intranet for ease of access by users. Critical parameters (about 10 to 15%) from each station PI server were brought to Corporate PI server. The real time information which was available in localized pockets previously was now available across the organization overcoming the limitations of pre PI system scenario.

1.2.1 Introduction to the PI System

PI stands for Plant Information

The PI System, a Data Historian, is a Real Time Information Management System with Client Server Architecture designed to fully automate the collection, storage and presentation of plant information for visualization and analysis.

PI System turns volume of operations data into a powerful, focused corporate asset. This advanced information management system acquires data from the plant or process, usually from automated control systems or other sources. Sophisticated processing tools transform that data into relevant intelligence that people can rely on to make timely decisions. Configurable, interactive displays deliver information wherever it's needed. The salient features of PI System are:

- Unique Compression technology
- Huge Volumes of real time data storage
- Fast Data Retrieval Speed
- Connectivity using Over 300+ interfaces
- User Friendly client tools

1.2.2 Network integration

Prior to PI System implementation, the process control network and the Metering network have been isolated from the IT network. Hence, integration of these networks has been done with required security infrastructure to ensure power generation continuity.

The typical network diagram is given in Fig:1 (attached in Annexure – 1)

Various Performance monitoring & operator assistance applications were configured over station PI data base using PI tools. OLA is one such performance monitoring application configured for CCGT stations.

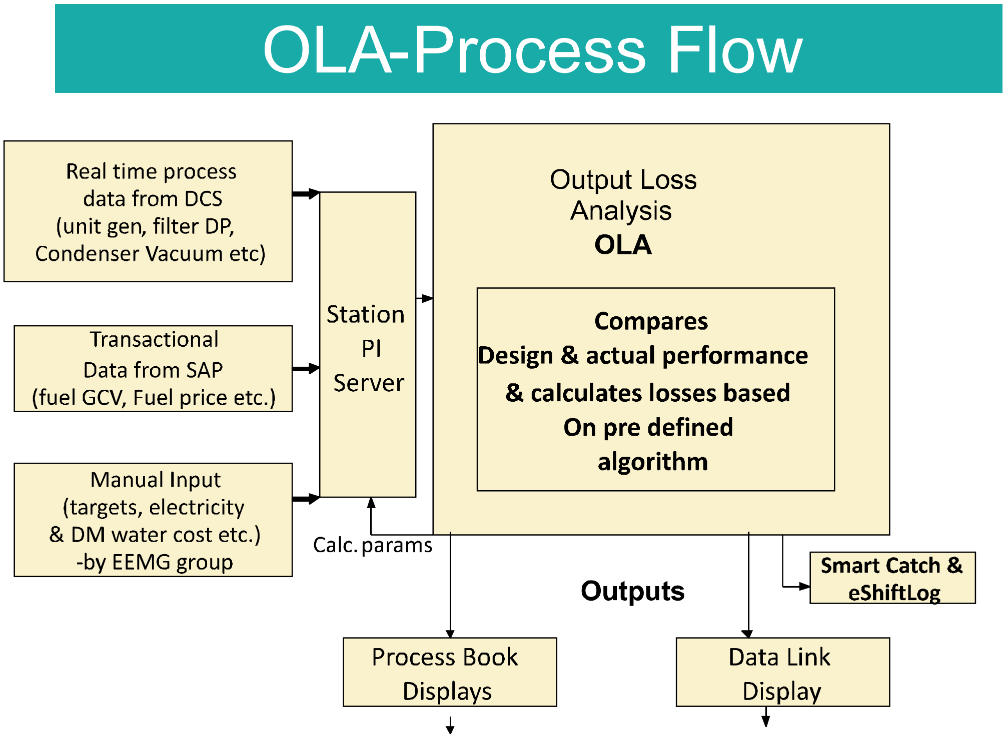
2.0 OLA – The Application

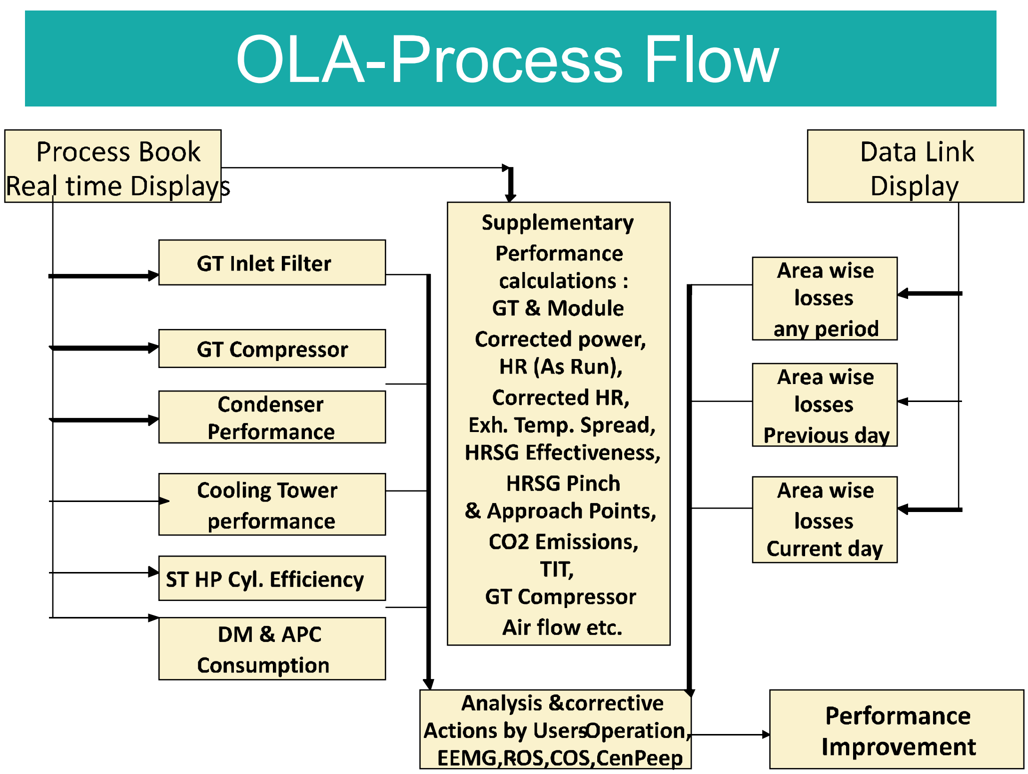
OLA is Output Loss Analysis. The problem of output loss with time is a predominant feature of gas turbines. A part of this loss could be irrecoverable owing to mechanical reasons, but rest of it is possible to recover provided the loss break up is accurately available under various loss heads along with its trending information since last major maintenance works. OLA is a step in this direction. It is a PI server based application which runs on the PI tool of PI Process Book. It calculates & displays the real time output loss in MW as well is in Rupees/hr under various loss heads. Any abnormal deviation in performance or loss head is immediately detected in the application through the visual displays (graphic & values) & period trends of the Key Performance Indicators. The application is primarily designed to indicate losses & performance calculations at stable base load conditions, but at part load conditions also, reasonably authentic figures are displayed. Figure – 2 shows a snapshot of OLA overview. (attached in Annexure – 1)

OLA is basically meant for CCGT Power station operation engineers. Station efficiency group can also take first hand information of the current performance parameters & the trending information since last inspection using the application. The application works on the base data derived from station PI server, registered data specific to the station (e.g. targets…, entered manually), manual data (e.g. cost of power…., requires periodic updating) & transaction data from SAP (e.g. fuel GCV….). Besides, the performances parameters that are calculated in the application are written back to PI for trending & archiving.

2.1 OLA – The Software

The OLA application has been prepared using PI-ACE programming tool of OSISoft on .Net platform. Station signals are available in the respective station PI Server, these signals have been attached to the respective input aliases defined in the PI-Module Data Base. These aliases have been used as inputs in the OLA software which runs at a predefined interval & writes its output to a set of output aliases. Each output alias is attached to a PI tag which gets refreshed whenever the output alias receives a new value. Thus a common OLA software is used across all CCGT stations. The work involved in rolling out OLA in a new station is just to attach relevant PI tags to the software input & output aliases & scheduling OLA software in the respective station PI server.





2.3 OLA - Losses covered

The total losses in a CCGT station can be classified into Controllable & Uncontrollable losses. Uncontrollable losses are due to environment & low grid frequency on which the operation engineers have no control. On the other hand, controllable losses can be controlled by human intervention. This intervention could be directly made by the operation engineers themselves or may be scheduled for next inspection or overhaul in consultation with station Maintenance & planning sections.

2.3.1 Uncontrollable losses in OLA

Losses due to Ambient temperature, Ambient pressure, Ambient RH & grid frequency are calculated & displayed in the application based on the real time values of these parameters in PI. These losses are calculated based on the station specific master data/curves. The correction factor & the output losses are individually displayed. Besides, the corrected output & corrected Heat rate are also displayed after applying these corrections to the As Run output & Heat Rate Values.

The difference between the station rated capacity (rated ambient conditions & 50 Hz) & corrected output falls under the category of controllable losses.

2.3.2 Controllable losses in OLA

The controllable losses & their impacts have been displayed in OLA under various tabs/screens. These losses have been displayed as output loss in MW. The cost impact of the losses has also been displayed along with MW loss for ease of impact comprehension by the user.

2.3.2.1 Loss due to GT Inlet Air filter DP

GT Inlet air filter differential pressure indicates the dirtiness & choking status of the Inlet Air filters. It is important to monitor the condition of the air filters as fouling of air filters will result in a fall in air inlet volume, thus a fall in exhaust mass flow which will have a cascading effect on the WHRB efficiency and the plant output and efficiency. Higher inlet air filter DP increases the GT inlet pressure drop which adversely affects GT compressor inlet mass flow of air. Output loss in MW due to GT IAF DP deviation from the target is displayed in real time for all the GT's individually. The target value of IAF DP should ideally be the filter DP of the new filters.

2.3.2.2 Loss due to GT compressor efficiency

With the passage of time, GT compressor blades start accumulating deposits because of fine dust particles passing through GT IAF. These deposits affect the air flow through the compressor. GT compressor efficiency is one performance parameter which can indicate the deterioration in compressor performance over time. It can also be used as a guide to decide the frequency of compressor online washing. In the application, real time GT compressor efficiency is monitored against the target value of GT compressor efficiency. The target efficiency is taken as the rated isentropic efficiency of the GT. The deviation of actual efficiency w.r.t. the target value is displayed as GT out put loss in MW. Figure – 3 displays the GT Performance display of OLA. (attached in Annexure – 1)

2.3.2.3 Loss due to Aux power consumption

Plant auxiliary power, as a % of actual generation is monitored against a target value of APC. The target APC is derived from the station specific master data/curves for module loading vs APC so that the application gives authentic loss figures even at part load conditions. Besides, it also gives the current status of critical auxiliaries running in the plant.

2.3.2.4. Loss due to Condenser Back Pressure

Real time condenser back pressure is monitored against a target condenser BP. The target BP is derived from station specific master data/curves. The deviation of actual condenser B.P. from the target value is represented on terms of ST output loss. The break up of the condenser B.P. deviation is also displayed in the application under the heads of CW Inlet Temperature, CW Flow/velocity, Condenser Heat Load etc. The other critical performance parameters of the condenser such as TTD, Temperature rise, condensate depression, LMTD of each pass are also displayed is real time to trend / monitor the condenser heat transfer. Figure – 4 shows the Condenser back pressure display of OLA. (attached in Annexure – 1)

2.3.2.5. Loss due to Excessive DM water consumption

DM water consumption for the day is monitored against a target value of DM water consumption (% of MCR steam flow). The actual figure displays the % of DM water consumption (of MCR steam flow) till the current time starting from 000hrs of the day. Deviation of DM water consumption from the target value is converted to output loss in MW with station specific ratio of HP/LP steam heat loss. Target value is a manual input & can be the internal target set by the organization for the station for the current period.

2.3.2.6 Loss due to HP/LP steam flow/pressure/temp deviation

Actual values of HP/LP main steam flow, pressure & temperature are monitored against the target values at that ST load. The target values are taken from the station specific master data/curves for these parameters. The deviation of actual from the target values are converted & displayed as ST output loss in MW.

2.3.2.7 Loss due to cooling tower performance deviation

From the available ambient temperature & humidity values in PI, wet bulb temperature is calculated on line & is used to display the real time Cooling tower Approach, Range & Effectiveness values. Expected CW cold temperature is also derived from the OEM curves for 90/100/110% CW Flows & is used to calculate CW predicted flow & CT capability. Based on the actual & expected cold water temperatures, output loss due to CT performance is calculated & displayed in MW as well as Rupees/hr.

2.4 OLA - Additional Performance Monitoring

Besides the loss monitoring of various areas, the application also monitors the performance of CCGT module, GT, HRSG & Steam Turbine separately.

2.4.1 GT Performance Monitoring

It includes GT Output corrections for uncontrollable reasons, GT actual & corrected output, GT actual & corrected O/C heat rate, GT Water Injection Corrections, GT overall cycle efficiency & GT compressor efficiency. GT exhaust temperature deviations are monitored against GT exhaust average value & GT exhaust temperature spread is displayed in a spider web graph to monitor combustion healthiness. Figure – 5 shows GT Exhaust Spread display of OLA. (attached in Annexure – 1)

2.4.2 HRSG Performance Monitoring

It includes calculated HRSG overall efficiency & its section wise effectiveness. HRSG economizer approach, HRSG evaporator pinch point & HRSG Exit temperature are also displayed & trended in the application.

2.4.3 ST Performance Monitoring

It includes calculated HP cylinder efficiency & ST heat rate displayed beside HP/LP steam process parameters. The trends of these parameters are also displayed. Figure – 6 show ST performance display of OLA. (attached in Annexure – 1)

2.4.4 CCGT Module Performance Monitoring

It includes module output corrections for uncontrollable reasons, module actual & corrected output, module actual & corrected HR beside key performances indicators of individual GT/HRSG & ST .CO2 emissions are also displayed in real time based on the current fuel flow & fuel composition. Figure – 7 show CCGT Module performance display of OLA. (attached in Annexure – 1)

2.5 OLA – Loss Summaries

Loss Summaries are available for ‘Time Interval’ (last one hour), ‘Previous Day’ & ‘Current Day’ (from 0:00 hrs to current time). These monitors contain the average MW loss parameter wise & total cost of these losses in the period. Figure – 8 shows Time interval Loss Summary Report of a CCGT Module in OLA. (attached in Annexure – 1)

3.0 OLA - Benefits

Following major benefits have been observed of OLA implementation at stations.

- Improved CCR /Performance Engineer awareness of critical plant performance parameters
- Identification of loss areas aids decision making process for targeting resources to specific problem areas
- Losses can be targeted prior to the monthly efficiency reports
- Allows key operational staff to make critical cost effective decisions based on evaluated plant conditions
- Archiving facility for all loss data
- Cumulative Impact on machine performance of

operator's actions for a problem helps choosing best course of action at that point of time

- Maintenance effort can be quantified based on pre & post work cost of losses

4.0 OLA - Future Roadmap

OLA has already been rolled out in 4 nos. CCGT stations of NTPC. It is to be rolled out in remaining three stations. We have also received feedback from the implemented stations for further improvements in the application. Some of the identified improvements in OLA are:

- Providing advice for GT Inlet air filter replacement based on filter replacement cost & output loss due to high filter DP.
- Providing indicators for GT Inlet temperature & compressor mass flow in GT Performance
- Providing alerts for GT compressor efficiency based on GT compressor performance
- Connecting information from station Energy Management System in OLA
- Providing balance instrumentation at stations to complete OLA roll out
- Making non OPC compliance systems OPC compliant for OLA roll out

5.0 Conclusion

Commissioning of PI Systems at stations has been a revolutionary step with respect to plant process information availability across the organization. Implementation of Performance enhancing applications on top of it have really provided a new dimension to the level & quality of information available with the plant operation staff as well as to the experts sitting outside. Using these applications, the operation staff has been able to try different operator action combinations to optimize station performance. Availability of cost of loss has also tremendously improved the operator's awareness on commercial front & he frequently uses this information to validate & justify his actions leading to commercially correct plant operation. With such a scenario, the demand for more applications of such nature & addition of new features in existing applications is increasing day by day.

The real time inter station comparison of plant performance has also been made possible by uniform application availability across all the stations. It is further motivating the knowledge sharing amongst stations with regard to the operator actions to specific problem areas & thereby perform better as a station, thus contributing to the overall improvement of company performance.

Annexure – 1 – Figures 1&2

* The data contained in screenshots below is only sample data.

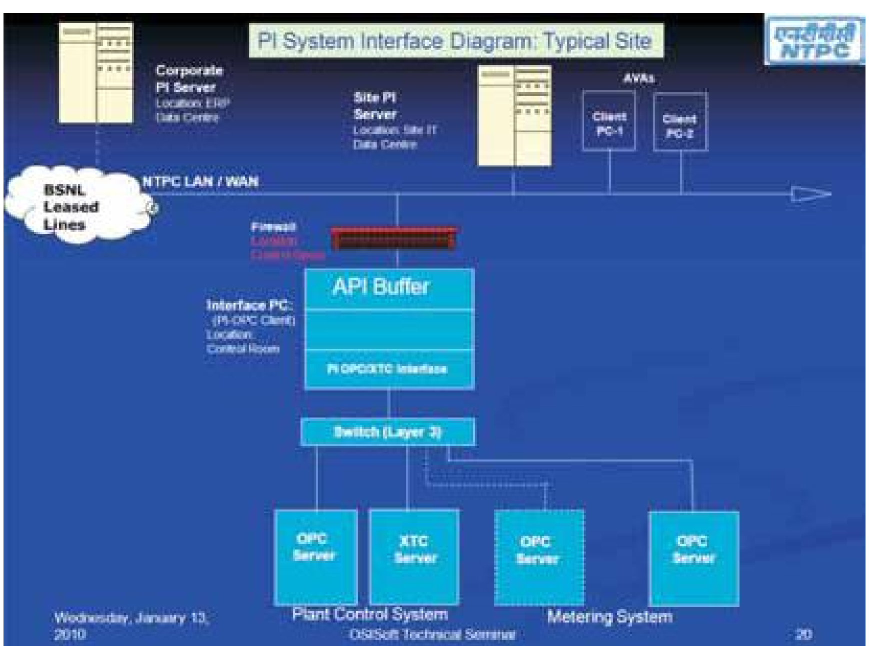


Fig: 1 Typical PI system

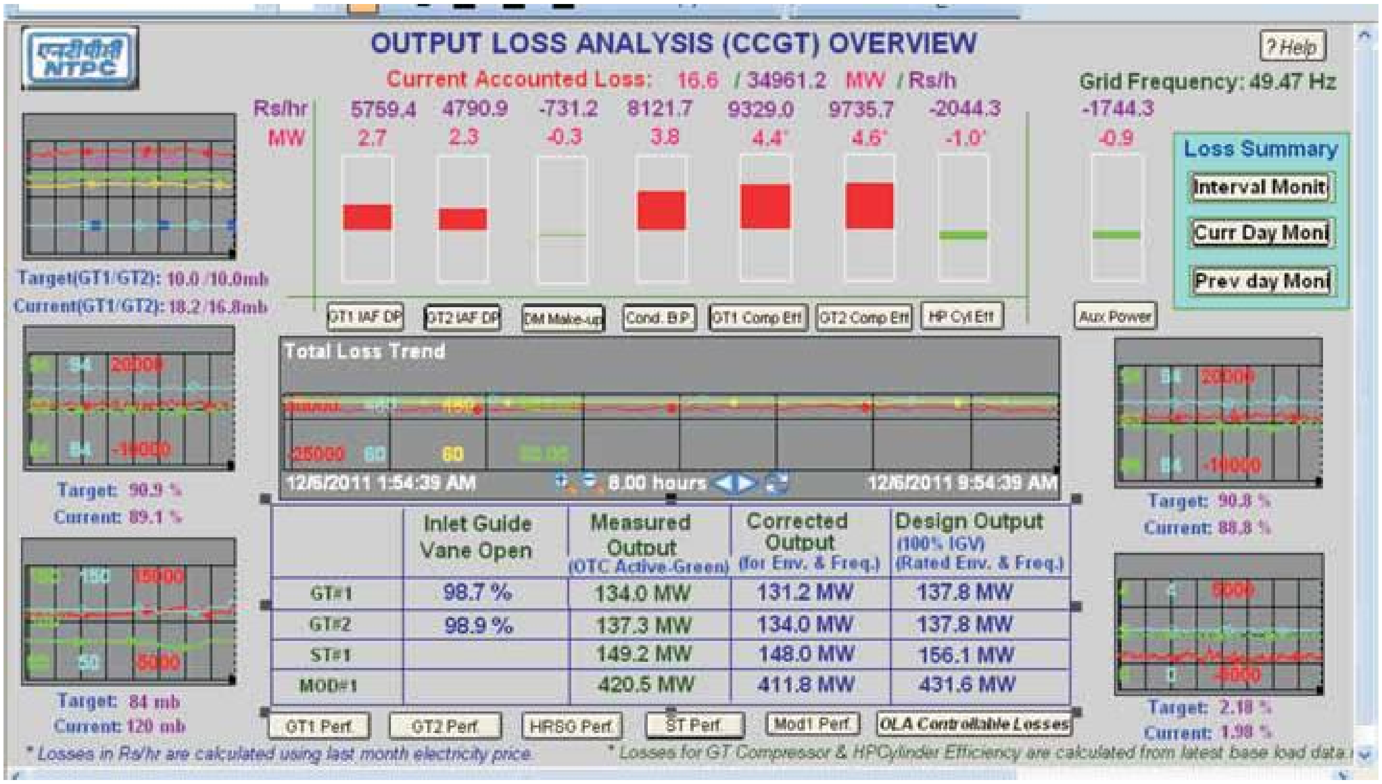


Fig: 2 OLA Overview Display

Annexure – 1 – Figures 3&4

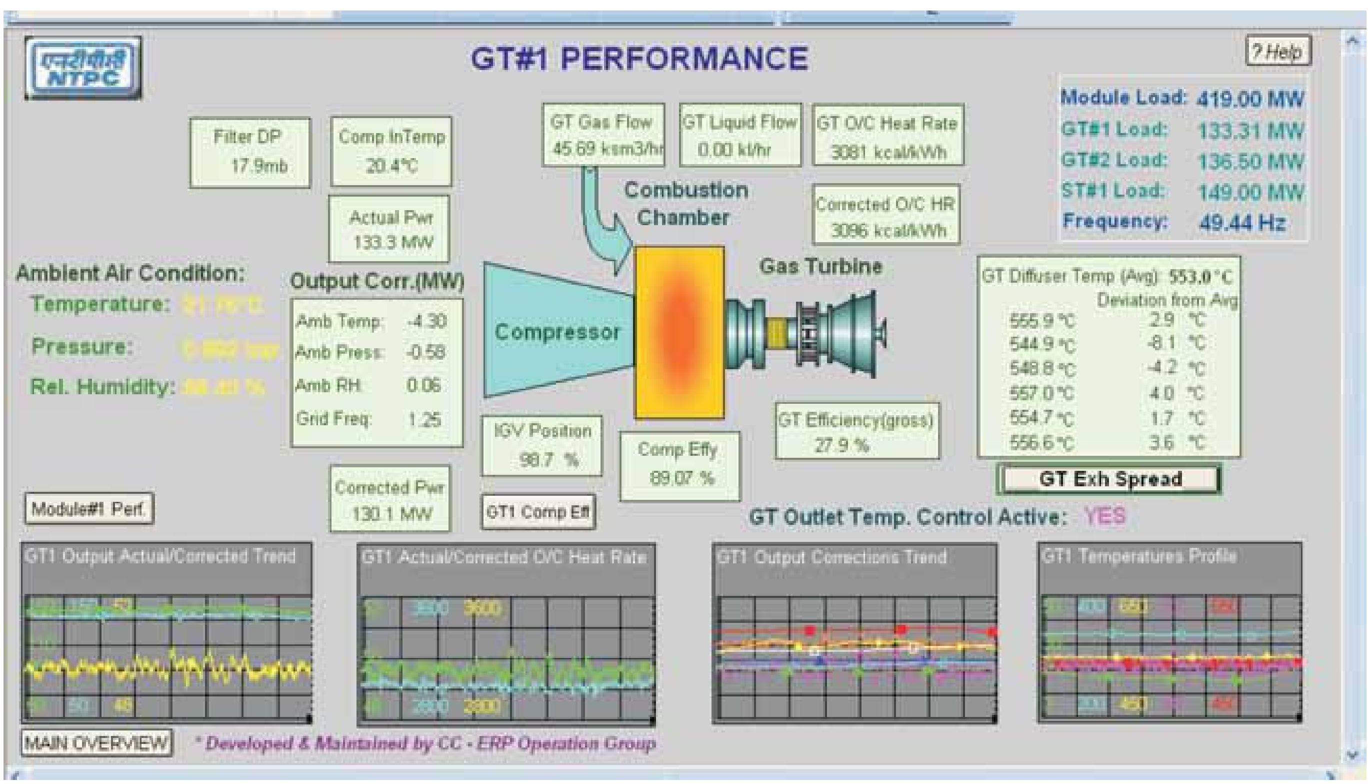


Fig: 3 GT Performance

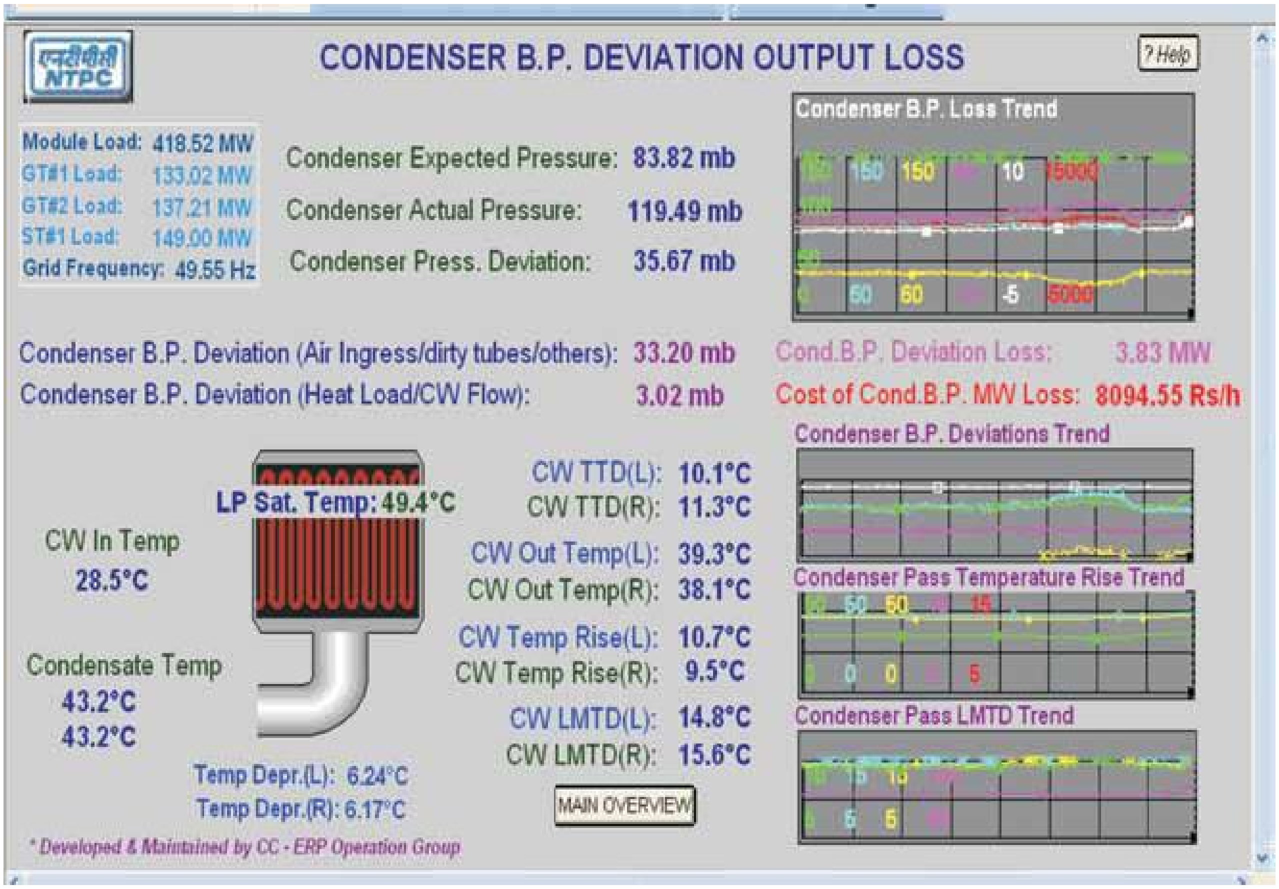
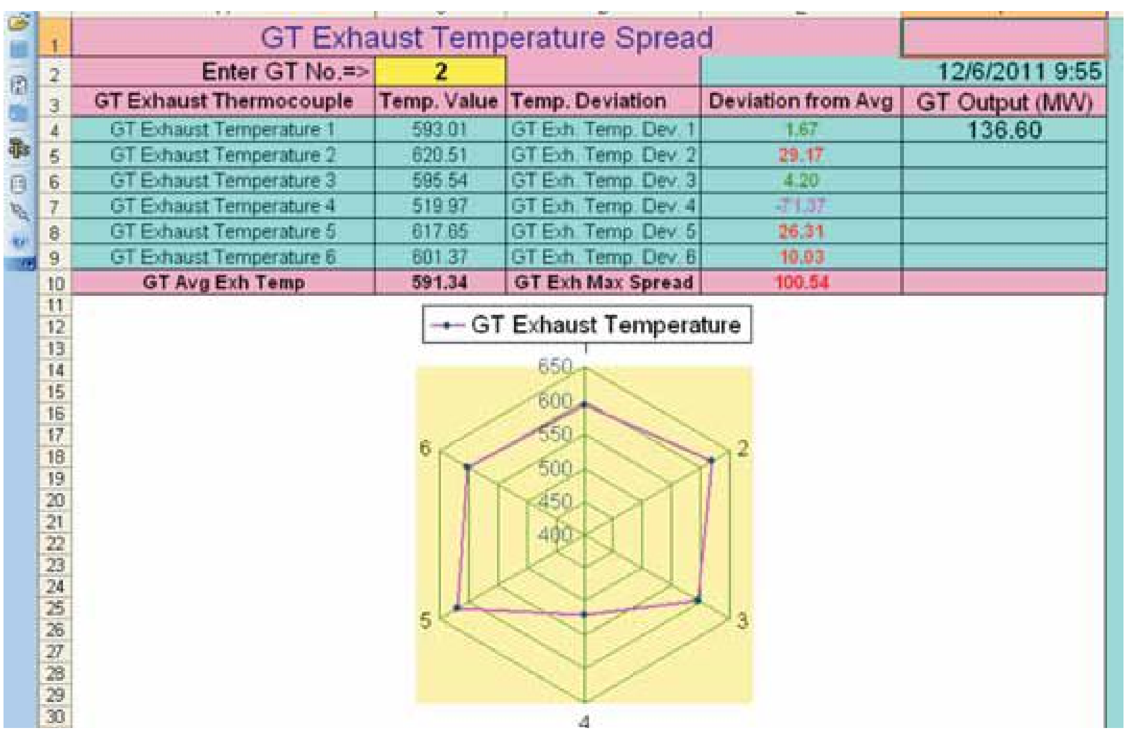


Fig:4 Condenser Back Pressure Display

Annexure – 1 – Figures 5&6



GT Exhaust Temperature Spread				
Enter GT No.=>	2			12/6/2011 9:55
GT Exhaust Thermocouple	Temp. Value	Temp. Deviation	Deviation from Avg	GT Output (MW)
GT Exhaust Temperature 1	593.01	GT Exh. Temp. Dev. 1	1.67	136.60
GT Exhaust Temperature 2	620.51	GT Exh. Temp. Dev. 2	29.17	
GT Exhaust Temperature 3	595.54	GT Exh. Temp. Dev. 3	4.20	
GT Exhaust Temperature 4	519.97	GT Exh. Temp. Dev. 4	-71.37	
GT Exhaust Temperature 5	617.65	GT Exh. Temp. Dev. 5	26.31	
GT Exhaust Temperature 6	601.37	GT Exh. Temp. Dev. 6	10.03	
GT Avg Exh Temp	591.34	GT Exh Max Spread	100.54	

Fig: 5 GT Exhaust temperature spread

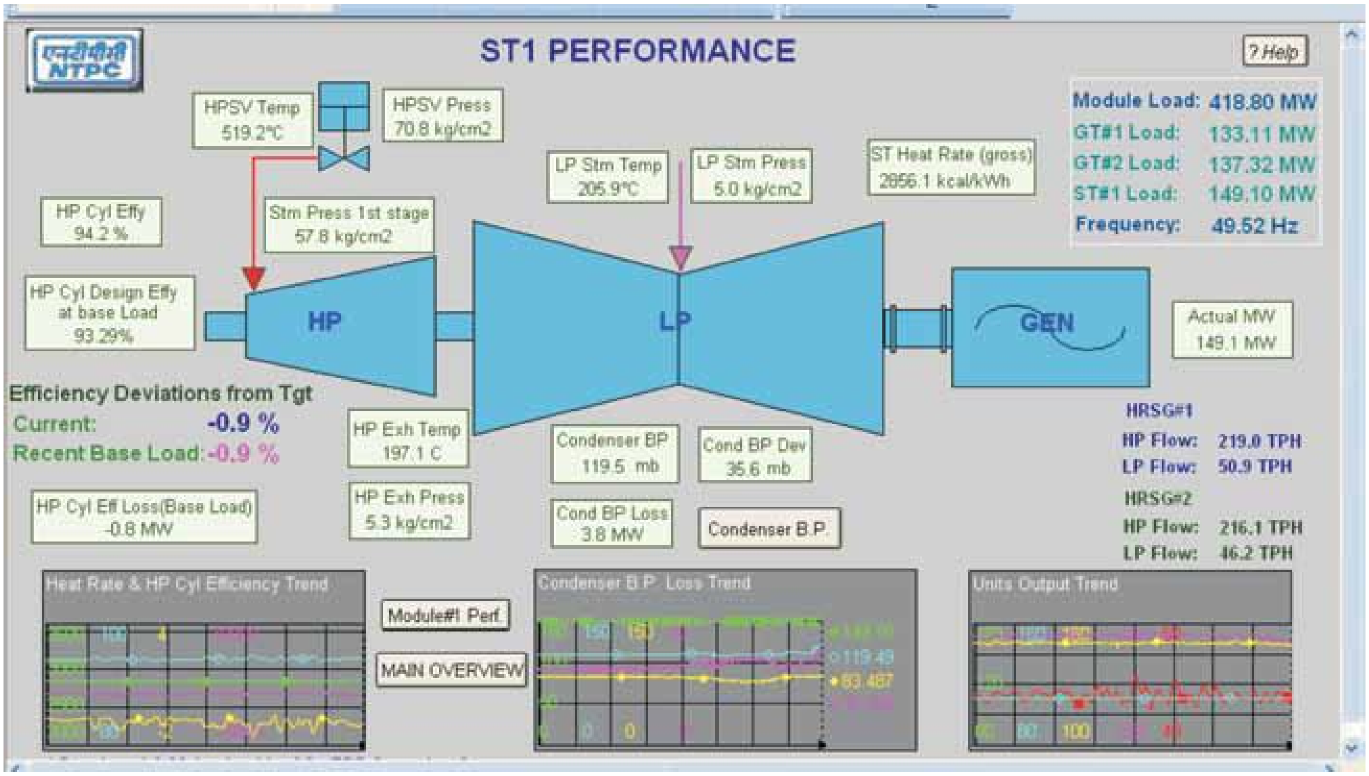


Fig:6 ST Performance

Annexure – 1 – Figures 7&8

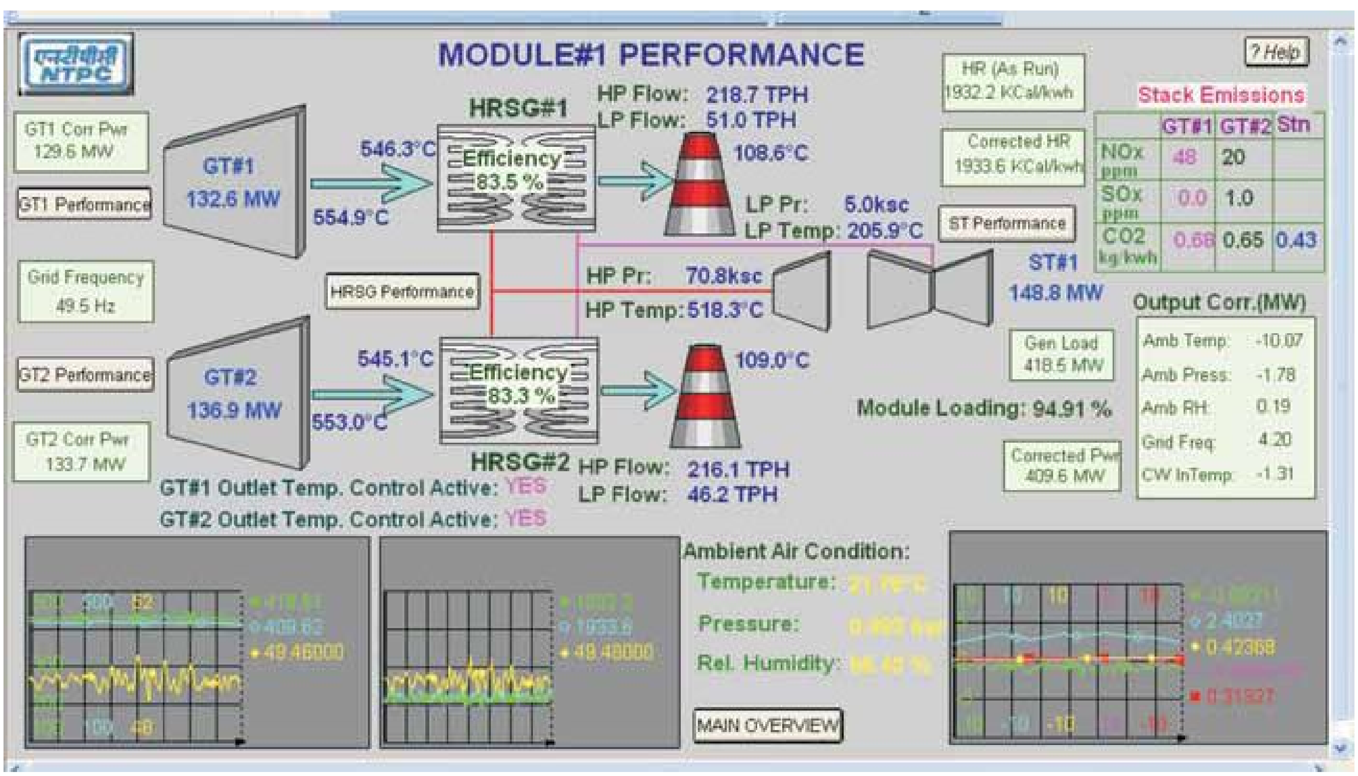


Fig:7 Module Performance

Interval Start Time 06/12/11 08:58 | 06/12/11 09:58 Interval End Time

Time Interval Loss Monitor

** The monitor gives* ***true representation of losses for base load operation*** *of the station. At part loading also, trending of losses can be done to monitor degradations.*Other losses include* ***partial losses due to grid,fuel & planned restrictions*** *also.*

S.N.	Parameter Description	Time Interval Loss (MW)				Loss Cost (Rs)
		GT#1	GT#2	ST#1	Station	
1	***Uncontrollable Parameters***					
	Output Loss due to:					
1.1.1	Ambient Temperature	-4.876	-5.032	-1.964	-11.872	
1.1.2	Ambient Pressure	-0.608	-0.593	-0.714	-1.915	
1.1.3	Ambient RH	0.057	0.053	-0.057	0.053	
1.1	**Environment Total**	**-5.427**	**-5.572**	**-2.734**	**-13.734**	
1.2	**Grid Frequency**	**1.144**	**1.124**	**0.917**	**3.184**	
	Sub Total Uncontrollable	**-4.284**	**-4.448**	**-1.818**	**-10.550**	
2	***Controllable Parameters***					
	Output Loss due to:					
2.1	GT High Inlet Air Filter DP	1.798	1.390	1.811	4.999	10762.83
2.2	GT Poor Comp Efficiency	2.839	3.004	3.277	9.119	19171.08
2.3	Deviation in Aux Power Cons				-0.947	-1987.13
2.4	Deviation in DM Make up Cons				-0.349	-733.04
2.5	Condenser Pressure			3.358	3.358	7049.17
2.6	ST HP Cyl Efficiency Deviation			-0.832	-0.832	-1688.97
	Sub Total Controllable	**4.637**	**4.394**	**7.614**	**15.349**	**32573.95**
	Average Gross Gen	136.205	139.471	149.955	**425.631**	
	Installed Capacity	137.758	137.758	156.070	**431.586**	
	Total Gap	**1.553**	**-1.713**	**6.115**	**5.955**	
	Total Accounted Loss	**0.353**	**-0.054**	**5.796**	**4.799**	
	Other Losses	**1.200**	**-1.659**	**0.319**	**1.156**	
	Corrected Heat Rate	**3063.5**	**2907.7**	**2849.5**	**1927.3**	
	OTC Control Active Time (hrs)	1.00	0.92			

Sheet1 / Sheet2 / Sheet3

Fig:8 Time Interval Loss Report

REDUCING UNCERTAINTY IN FUEL GASE MEASUREMENT BY MASS SPECTROMETRY

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KEYWORDS

Process Mass Spectrometer, Accredited Calibration, Fuel Gas, Process Analytical Technology

ABSTRACT

This paper considers aspects of instrumental design which influence both the reproducibility and accuracy for the on-line analysis of complex fuel gas mixtures by mass spectrometry. Effects of electron energy, ion energy, peak shape, temperature, pressure, calibration and sample gas composition and sample inletting are discussed. Performance benchmarks developed by an accredited calibration laboratory will be used to illustrate the potential for bias errors and uncertainties. Example data are presented including Monte Carlo error analysis of variable fuel blends.

INTRODUCTION

Process mass spectrometers (PMS) have been successfully deployed to provide fast, accurate and complete gas composition analysis in a wide range of applications for the purpose of process optimization, enhanced safety and regulatory compliance. Ever-increasing global competition and strict requirements for carbon emission auditing will require continuous improvements in process analytical technologies (PAT) and mass spectrometry is expected to play a major role in the next generation of process gas analyzers. Any true next-generation PAT will need to provide significant improvements in accuracy, precision and stability in a package that is highly reliable and easy to deploy and maintain.

In order to evaluate competing technologies it is necessary to understand the degree of uncertainty that is inherent in any measuring device so that the value of the measurement can be fully quantified. This paper will discuss the design elements that have the most profound effect on the quality of the measurements provided by a modern, high-performance process mass spectrometer.

PRINCIPLES OF OPERATION

Magnetic sector mass spectrometers rely on the interaction of ionized sample molecules and magnetic fields in order to filter and measure individual atomic mass components that collectively contribute to the total sample composition. The ions are formed in an ionization chamber by interaction of the neutral gas-phase sample molecules with a beam of energetic electrons. The newly formed ions are immediately accelerated towards the magnetic field. Each charged particle will experience a sideways force that is proportional to the strength of the magnetic field, the component of the velocity that is perpendicular to the magnetic field and the charge on the particle. This force is known as the Lorentz force and is given by:

$$F = q(v \times ß) \qquad (1)$$

Where: F is the force in Newtons,
q is the electric charge of the particle in Coulombs
v is the velocity of the particle in meters per second
ß is the magnetic field in Teslas

If a charged particle is injected into a magnetic field with constant velocity, then the Lorentz force will act on the particle and cause it to move in a circular orbit of constant radius. The radius of orbit is dependent upon the velocity of the particle and its mass, and is also governed by the strength of the magnetic field and the charge on the particle. The relationship is given by:

$$\frac{M}{e} = \frac{ß^2 \times r^2}{2V} \qquad (2)$$

Where: r is the radius of orbit

M is the mass of the particle

V is voltage applied to the particle to accelerate it to velocity v

ß is the magnetic field strength

e is unit charge (the charge of one electron)

This is the basic magnetic sector mass spectrometer equation.

The analyzer used in the tests detailed here, operates with a fixed radius (r) of 6 cm and a constant ion energy (V) of 1kV. The available magnetic field strength provides a measurement range of 0 - 150 atomic mass units (a.m.u.)

ANALYZER DESIGN

The analyzer under evaluation was designed using 3-dimensional CAD/CAM software (Autodesk Inventor). This allowed the dimensional data of the vacuum chamber to be exported to a 5-axis contour milling machine in order to obtain the highest available manufacturing precision. The vacuum housing is machined from a single block of aluminum alloy in order to provide tight positional tolerances for the ion optical lenses, electro-magnet pole pieces and ion detector assemblies. Figure 1 illustrates the layout of the optical assemblies and shows the ion trajectories for a sample gas consisting of oxygen (32 a.m.u.) and carbon dioxide (44 a.m.u.).

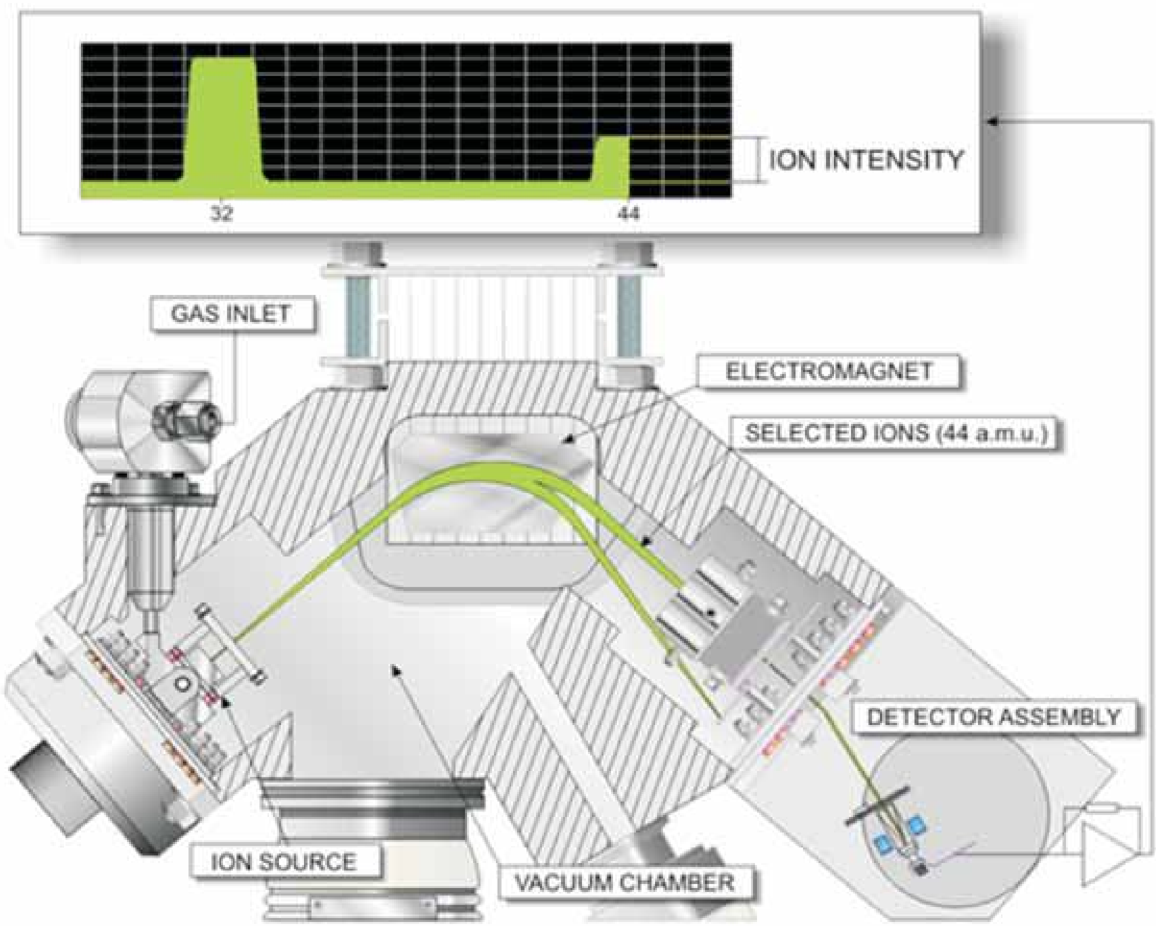

FIGURE 1. MASS SPECTROMETER SECTION SHOWING ION TRAJECTORIES

METHODS AND PROCEDURES

Historical performance data recorded by Thermo Scientific Prima ?B analyzers were reviewed in order to establish the current performance baseline with respect to accuracy, precision, speed and stability[1]. The contributions to measurement error from variations in electron energy, ion energy, ion source pressure, temperature and peak profile were evaluated. These results were used to guide the design of the new mass spectrometer. The effect that each one of these parameters has on analyzer performance can be summarized as follows.

Electron Energy (EE): The electrons are typically accelerated to 70 eV for maximum energy transfer so as to induce ionization and fragmentation. For some applications EE is set to 45 eV to prevent the formation of certain doubly ionized molecules in order to simplify the deconvolution process. Small statistical variations in EE do not make a significant contribution to analyzer inaccuracy.

Ion Energy (IE): Which is V in equation (2) determines the mass range of the spectrometer. This was set to 1,000V for the evaluation unit resulting in a mass range of 150 a.m.u. This mass range is adequate for most PMS applications. The electrical noise on this supply should not make a significant contribution to analyzer inaccuracy providing the peak profile has a flat top since small side-to-side variations in peak alignment will have no effect on the recorded peak intensity.

Ion Source Temperature: This is set to a value appropriate to the application and is nominally controlled to ± 0.1o C. Small variations in source temperature do not contribute to analyzer inaccuracy.

Ion Source Pressure: The recorded ion intensities are directly proportional to the pressure in the ionization chamber therefore variations in this parameter that occur after calibration will result in analysis errors. Data normalization takes care of normal pressure fluctuations but there is potential for reducing analytical errors if source pressure variations can be reduced or eliminated.

Peak Shape: Although the peak profile of a scanning magnetic sector mass spectrometer is nominally flat-topped, close examination of the peak top can reveal non-Gaussian features which do not result from normal ion statistics. Small changes in mass alignment will introduce measurable changes in signal output as a result of these features. The principle cause of this effect is thought to be electrons that are liberated from the metal surface of the Faraday Cup detector by the action of the high-energy ion beam. Careful design of the collector shape and the secondary electron suppressing electrode can eliminate this effect.

SAMPLE PRESSURE REDUCTION

The traditional method of sample introduction into the ionization chamber is by the use of a capillary with bypass. This arrangement is designed to manage the transition from viscous flow to molecular flow. The dimensions of the capillary are chosen to provide a pressure drop from 1,000 mbar at the sample inlet to approximately 10 mbar at the bypass point. The pumping speed and the leak dimensions are designed to produce an ion source pressure of about 10-4 mbar. Figure 2 illustrates a typical bypass capillary arrangement.

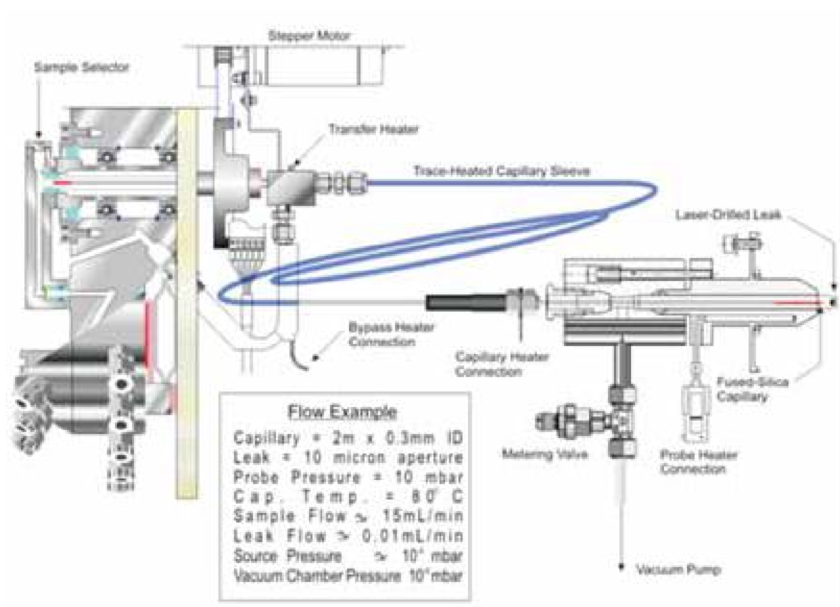

FIGURE 2. CAPILLARY WITH BYPASS

This configuration provides good linearity and is suitable for use when measuring a diverse range of complex gas mixtures. There are two problems associated with this design, however. Firstly, it is difficult to tightly control the capillary temperature along its entire length. The viscosity of the sample gas (and hence the ion source pressure) depend upon the kinetic energy in the sample molecules so the number of molecules presented for analysis will be temperature dependant. Secondly, any polar molecules present in the gas mixture, that is molecules with asymmetrical charge distribution, will be somewhat 'sticky' necessitating longer stream settling times. Example polar species include water, ammonia, methanol and isopropyl alcohol (IPA). Fortunately, most carbon compounds are non-polar and transit through the capillary in less than 1 second.

A new design for the pressure reduction and transfer of sample gas into the mass spectrometer was developed in order to reduce temperature dependence and improve the accuracy, stability and speed of the analyzer. The new design details are illustrated in Figure 3.

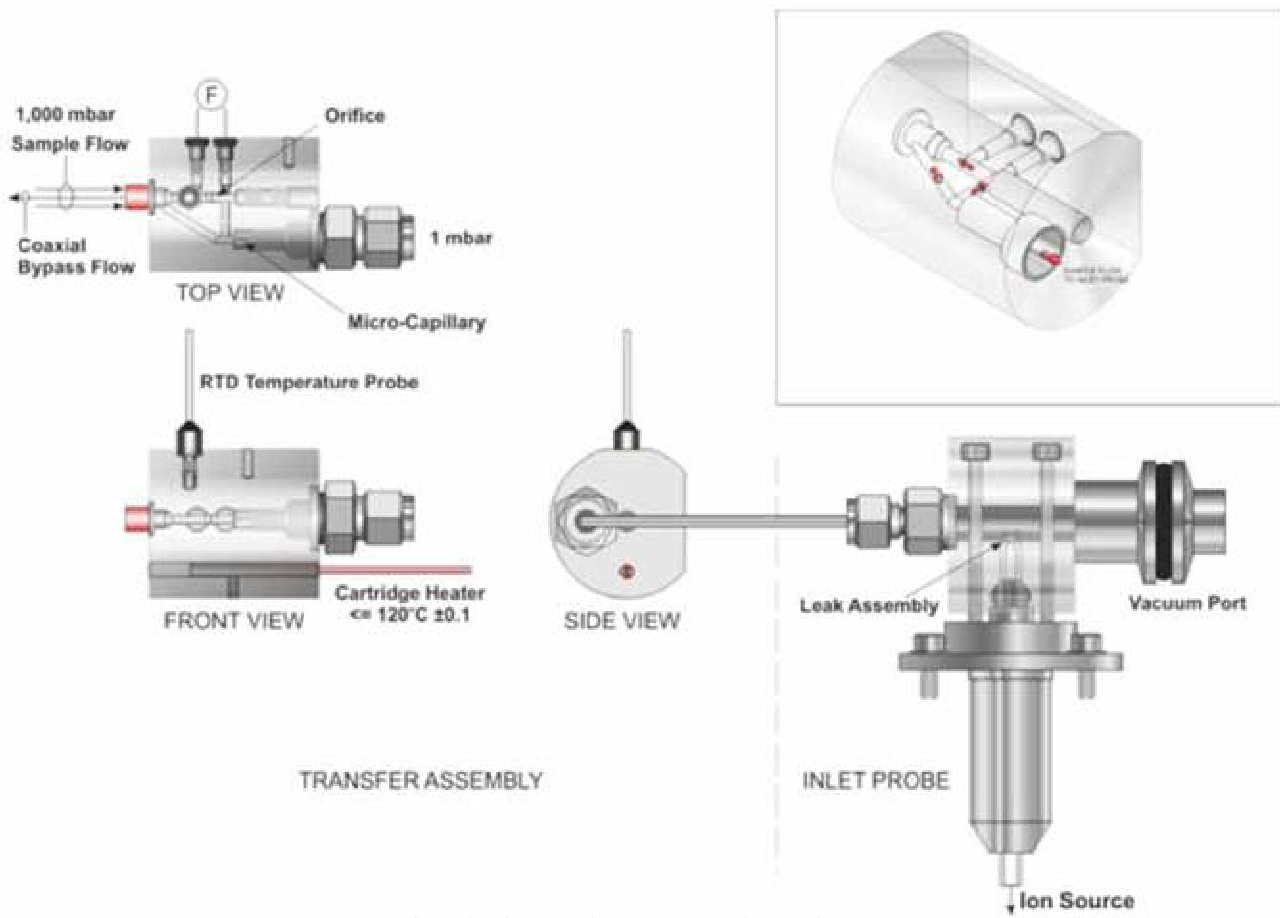

FIGURE 3. ENCAPSULATED CAPILLARY TRANSFER ASSEMBLY

The new sample transfer assembly relies on the encapsulated micro-capillary to reduce the sample pressure from about 1,000 mbar to 1 mbar. The whole assembly is heated and temperature controlled to a maximum of 120oC ± 0.1. Molecular flow between the transfer assembly and the inlet probe has a mean free path of around 1mm at this pressure so there is no temperature dependence in this tube. The encapsulated capillary is designed for easy replacement in the event of plugging. The atmospheric pressure fast-loop sample flow path includes an orifice plate so that the sample flow rate can be measured using differential pressure. The sample flow measurement is useful for many applications and is a helpful diagnostic for tracking sample system performance.

Figure 4 illustrates the improved response to a 100 ppm injection of IPA that is achieved by the new transfer assembly when compared to that of the standard heated bypass capillary.

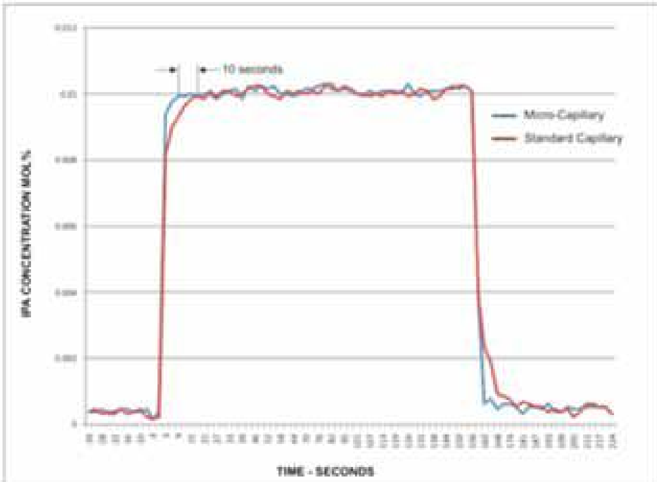

FIGURE 4. IPA RESPONSE PLOTS

ACCREDITED CALIBRATION

In the field of measurement science it is generally important to validate the performance of new analyzers and to identify any bias in the data that they produce. It is also necessary to understand the uncertainties that are always associated with the measurement of physical properties. These uncertainties result from analyzer imprecision and calibration composition tolerances. The recent international standard ISO15796 gives guidance on how to estimate overall uncertainty associated with measurement systems. The conventional method for assessing the performance of on-line process gas analyzers is in accordance with ISO 10723. An accredited UK laboratory was selected to assess the performance of the new design. The appropriate accreditation standard for the laboratory is ISO 17025.

For the purpose of the evaluation, a set of 9 reference gases were used in the application of the standard. See Appendix A - Statement of Traceability. The reference gases used cover a range of concentrations for each component that exceed the typical ranges found in fuel gas. Table 1. shows the composition ranges of the reference gases used during the evaluation. Within each range, a number of intermediate equally spaced concentrations were measured. A set of 5,000 simulated calibrations were performed for each component and a set of physical properties were calibrated based on the calculated concentrations. The calculated physical properties included gross calorific value (GCV), net calorific value (NCV), carbon dioxide emission factor - gross (CEFG), carbon dioxide emission factor - net (CEFN), carbon dioxide emission factor - quantity (CEFQ), base density, relative density, real Wobbe number and molecular mass.

TABLE I. CALIBRATION GAS COMPOSITION AND EVALUATION RANGES

Component	Calibration Gas (%mol/mol)			Sample composition range (%mol/mol)	
				minimum	maximum
Nitrogen	9.0000	±	0.0150	0.10	9.94
Carbon Dioxide	5.0000	±	0.0150	0.05	2.50
Methane	9.0000	±	0.0200	9.85	64.90
Ethane	5.0000	±	0.0130	0.50	24.75
Propane	10.0000	±	0.0250	0.11	19.72
Ethylene	5.0000	±	0.0015	0.10	10.06
Propylene	5.0000	±	0.0130	0.10	4.90
Hydrogen	43.0000	±	0.0700	10.01	68.69
Carbon Monoxide	9.0000	±	0.0150	0.10	6.79

RESULTS AND CONCLUSIONS

The relationship between instrument response and gas concentration for each component analyzed by the evaluation unit was determined by measuring the set of 9 reference gas mixtures described above. Each response/concentration was modeled by a simple polynomial function of third order. The true calibration functions Fi,true (xi) determined for each function are in the form:

$$F_{i,true}(x_i) = a_0 + a_1x_i + a_2x^2_i + a_3x^3_i \quad (3)$$

Regression analysis was performed in accordance with the international standard ISO 6143 using generalized least squares (GLS) which accounts for the uncertainty in both the concentration (amount of fraction) and the response measurements. The mathematical derivation of the parameters listed in Table II is outside the scope of this paper.

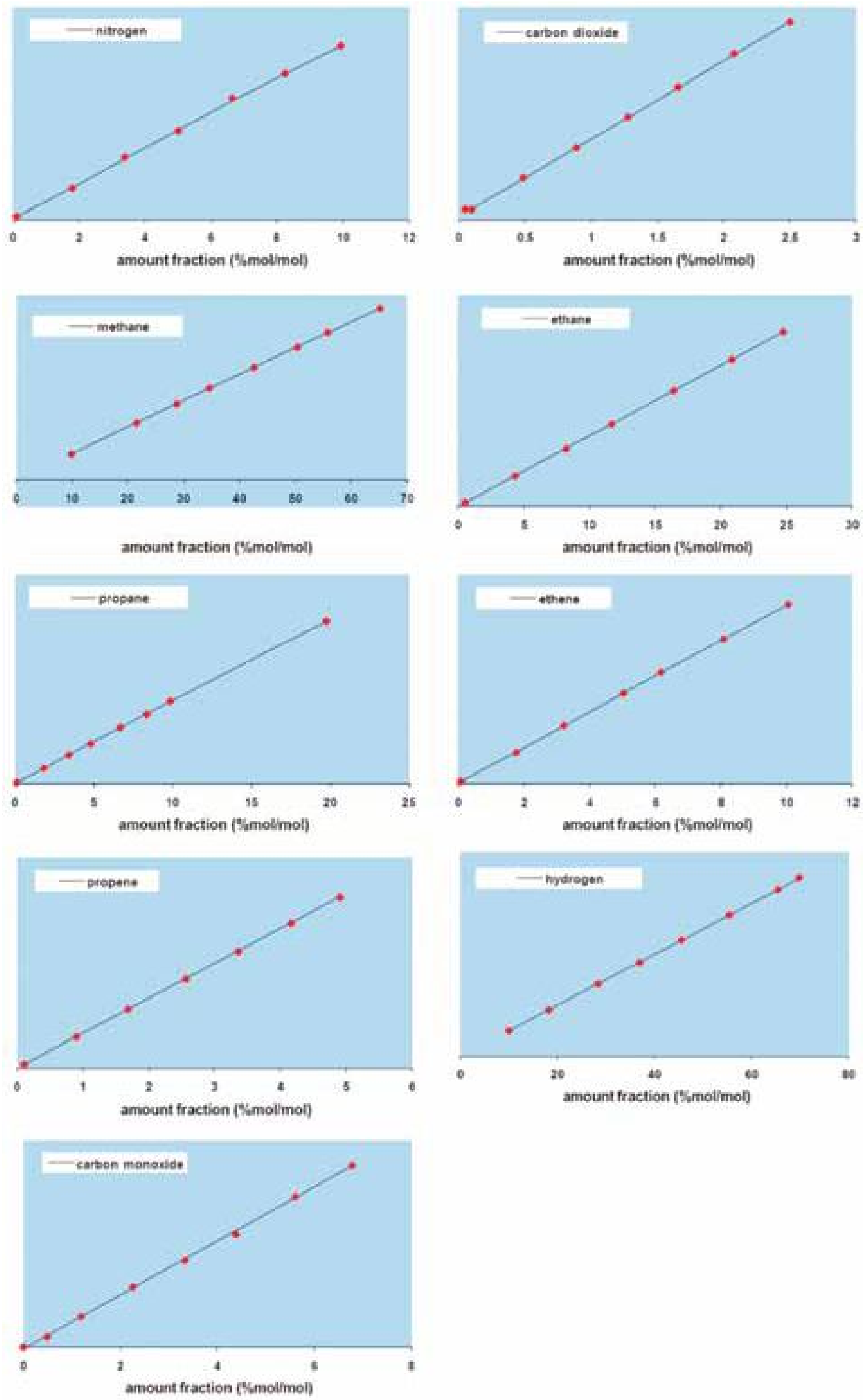

FIGURE 5. CALIBRATION FUNCTIONS FOR ALL COMPONENTS

TABLE II. PARAMETERS OF THE TRUE CALIBRATION FUNCTIONS

Component	polynomial parameters			
	a0	a1	a2	a3
Nitrogen	0.051557	0.972131	0.010978	-0.001040
Carbon Dioxide	0.042765	0.896143	0.007302	0.000000
Methane	-0.161740	1.024971	-0.000750	0.000000
Ethane	0.007534	0.987963	0.001039	0.000000
Propane	-0.001060	0.997690	0.000554	0.000000
Ethylene	-0.005280	0.999062	0.008676	-0.000650
Propylene	-0.001810	1.014861	-0.011450	0.001607
Hydrogen	-0.015100	1.000123	0.000000	0.000000
Carbon Monoxide	-0.055580	1.044891	0.000000	0.000000

BIAS ERRORS

When the analyzer calculates the concentration of components of a sample gas it assumes an ideal calibration function which is first order (a0=a2=a3=0). The reported concentration will be biased for any component whose true response deviates from ideal behavior. For this evaluation bias errors were determined by a Monte-Carlo simulation. A data set of 5,000 hypothetical random compositions was constructed where each gas component concentration lay within the range of gases expected for a typical refinery fuel gas. For the purpose of this study, these ranges correspond to the range of the reference gases as listed in Table I.

Table III illustrates a typical gas composition evaluated for a single iteration of the Monte-Carlo simulation. ***Actual*** is the true composition of the gas being measured - the 'simulated composition'. ***Measured*** is the unnormalized concentration which would be measured by the instrument when analyzing the simulated gas in combination with the nominal composition of the current calibration gas. ***Measured Normalized*** is the actual result that would be presented by the mass spectrometer when analyzing this gas. The calculated bias errors are shown in the final columns expressed in absolute and relative terms. Clearly, the bias errors will be propagated to any derived physical properties. Gross and net calorific values are shown as examples.

Figure 6 shows the bias errors on gross calorific values for each of the simulated compositions within the specified range. The error in GCV is shown as a function of increasing hydrogen content.

TABLE III. BIAS ERRORS FROM A TYPICAL SIMULATED GAS COMPOSITION

Component	Cal. Gas (%mol/mol)	Sample Gas Composition (%mol/mol)			Bias Error	
		actual	Measured	Measured normalized	absolute (%mol/mol)	relative (%)
Nitrogen	9.0000	5.0197	5.1153	5.1105	0.0909	1.8100
Carbon Dioxide	5.0000	1.2748	1.2780	1.2706	-0.0042	-0.3270
Methane	9.0000	37.4370	37.4281	37.3933	-0.0437	-0.1170
Ethane	5.0000	12.6265	12.6792	12.6674	0.0410	0.3250
Propane	10.0000	9.9226	9.9230	9.9138	-0.0087	-0.0880
Ethylene	5.0000	5.0785	5.0794	5.0747	-0.0038	-0.0750

Propylene	5.0000	2.5021	2.4974	2.4951	-0.0070	-0.2800
Hydrogen	43.0000	22.6935	22.6864	22.6653	-0.0282	-0.1240
Carbon Monoxide	9.0000	3.4455	3.4125	3.4093	-0.0362	-1.0510
Gross CV MJm-3		40.2520		40.2380	-0.0140	-0.0340
Net CV MJm-3		36.6190		36.6070	-0.0130	-0.0350

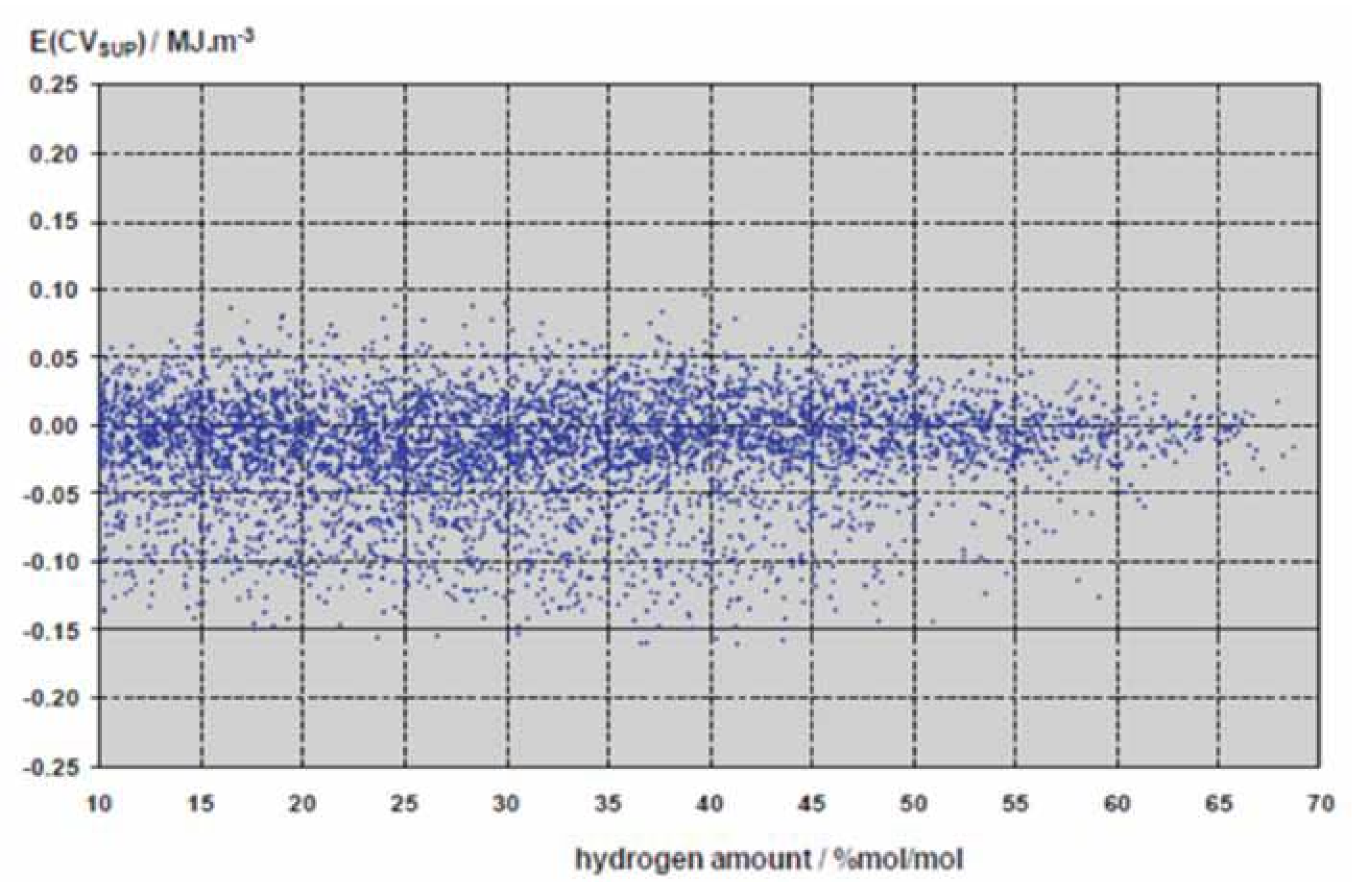

FIGURE 6. BIAS ERRORS ON CALORIFIC VALUE FOR EACH SIMULATED COMPOSITION

The scatter plot in figure 6 shows a small negative bias in the gross calorific value (CV SUPERIOR) with all values falling within an error range +0.1 to -0.16 MJ/m3

PMS APPLICATIONS THAT BENEFIT FROM THE IMPROVED ANALYSIS

In nuclear power plants, online analysis by mass spectrometry is quite common. One measurement of interest is the percentage isotopic abundance of Deuterium (i.e. 100 x D/(D+H)). The percentage isotopic abundance can be measured to a precision (single standard deviation) of better than or 0.1% relative for a 10 second analysis.

The calibration laboratory was instructed to evaluate the new analyzer performance characteristics when measuring the physical properties of fuel gas. Clearly, the accurate measurement of the energy content of fuel is important for many industries. One example is for control of fuel gas mixing at an integrated steel mill where it is common practice to mix coke oven gas (COG) blast furnace gas (BFG) and natural gas (NG) for use in re-heat furnaces and degassers. Accurate measurement of combustion air requirement index (CARI) minimizes the use of expensive NG, reduces flaking of the steel caused by excess oxygen and extends burner lifetime. Mixing of these very diverse complex gases in order to provide a consistent fuel requires the speed and linearity provided by the PMS.

In the petrochemicals industry, a number of manufacturing units rely on fast and accurate gas analysis for optimum performance. One such application is olefins production. When refinery liquids are cracked to produce ethylene, propylene and butylenes the kinetic severity function (KSF) is used to maximize production of the target olefin while minimizing coke deposition in the furnace tubes. As market conditions change, the product slate can be optimized by making changes to the feedstock residence time in order to target a new KSF value. Downstream applications that benefit from accurate PMS measurements include ethylene oxide/ ethylene glycol (EO/EG), polyethylene[2], polypropylene and acetic acid production. In the chemicals market, ammonia production benefits from very accurate measurement of H/N ration, steam to carbon ratio and methane slippage.

Biotechnology is a fast-growing market segment that relies on online process analytical technology for monitoring cellular activity. When suspension-adapted animal cells are used to produce valuable therapeutic proteins, there are considerable challenges that require non-invasive measurements (that don't compromise sterility) while providing very precise comparisons of influent and effluent gas composition. In particular, very precise oxygen measurements are required in order to calculate oxygen uptake rate (OUR) which is an indicator of metabolic activity and nutrient availability. Mammalian cells are very fragile and slow-growing (when compared with microbial fermentations) so sparge-gas flow rates tend to be low and the corresponding volumetric oxygen consumption is low, hence the need for high precision comparisons of influent and effluent oxygen concentrations. Figure 7 illustrates the precision available with the new analyzer. Note that this represents an improvement by a factor of 3 in both precision and speed when compared with its predecessor.

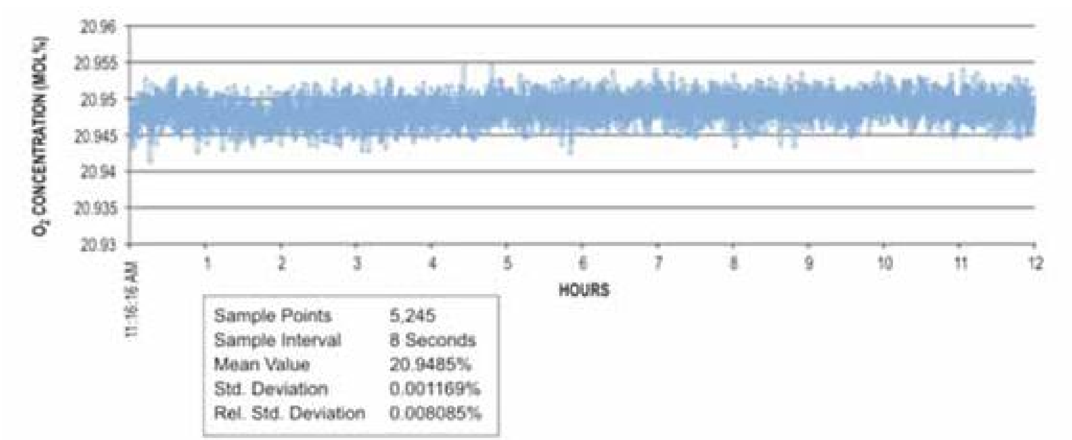

FIGURE 7. OXYGEN STATISTICS (DRY AIR)

SUMMARY

In accordance with the international standard ISO 10723 the test instrument shows good linearity and high precision when monitoring a diverse range of fuel gas mixtures. The maximum bias errors in real net CV and CO_2 emission factor were 0.149 $MJ.m^{-3}$ and 10.4 $g(CO_2).m^{-3}$ respectively. The maximum uncertainty in the unbiased estimates of net CV and CO_2 emission factor were 0.039 $MJ.m^{-3}$ and 2.6 $g(CO_2).m^{-3}$ respectively. The combined bias and uncertainties in measured properties result in a maximum total uncertainty in net CV and CO_2 emission factor of 0.19 $MJ.m^{-3}$ and 13.6 $g(CO_2).m^{-3}$ respectively.

The increased speed, accuracy and precision provided by the new generation of process mass spectrometers will be of benefit to a wide range of process analytical applications, particularly in the energy, chemical/ petrochemical, steel production and the biotechnology industries.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the invaluable contribution made by Dr. Paul Holland of EffecTech for his expertise in the field of measurement science as it relates to analytical technologies in the oil & gas industries. Paul was the author of an extensive report that included much more data than could be included here.

APPENDIX A

STATEMENT OF TRACEABILITY

Refinery Gas Reference Mixtures

EffecTech provides traceability of measurement to recognized international standards in the field of refinery gas, and to the units of measurement realized at the National Physical Laboratory (NPL) or other recognized international standards laboratories.

The laboratory holds a series of reference gas mixtures of a high metrological quality. These gases contain nine components typically found in refinery gas – hydrogen, nitrogen, carbon dioxide, carbon monoxide, methane, ethane, ethane, propane and propylene. The amount fractions were designed to cover a number of refinery gas applications. The series of gas mixtures cover the range of composition listed in the table below:

Component	range (%mol/mol	
hydrogen	10.005	69.88
nitrogen	0.10	9.94
carbon monoxide	0.097	6.79
carbon dioxide	0.05	2.5
methane	9.84	65.03
ethane	0.5	24.75
ethylene	0.098	10.05
propane	0.1	19.74
propylene	0.098	4.906

NPL have determined the reference values for each gas mixture and their associated uncertainties of measurement. The reference gas mixtures were manufactured to our requirements by a gravimetric method using mass pieces traceable by weight to the National Physical Laboratory (NPL) in Teddington, United Kingdom. Thereafter, each mixture was re-certified by direct comparison with a set of primary reference gas mixtures (PRGMs) which were gravimetrically prepared, verified, certified and issued by the NPL. The NPL is an internationally accepted institute who hold sets of primary standard mixtures (PSMs) of the highest metrological quality in the field of natural gas. The compositions of the PSMs held by the NPL have been verified by interlaboratory comparisons between metrology institutes worldwide.

The set of reference gas mixtures is stored in a carefully controlled environment and undergoes regular checks for internal consistency. In addition, the mixtures are verified on a regular basis through consistency checks with primary reference gas mixtures from the NPL & the Nederlands Meetinstituut (NMi) in Delft, Netherlands. All verification and consistency checking is performed in accordance with the international standard method ISO 6143:2001 Gas analysis - Comparison methods for determining and checking the composition of calibration gas mixtures.

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[1] Wright, R.G., On-line Analysis of Complex Gas Mixtures by Process MS Journal of Process Analytical Chemistry Vol. IV, (1998) pp.71-78.

[2] Traynor, P.J., Polyolefin Process Gas Analysis by Mass Spectrometry Journal of Process Analytical Chemistry Vol. VI, (2000) pp. 44-51.

RELEVANT ISO STANDARDS

ISO 10723 Natural gas - Performance evaluation of on-line analytical systems.

ISO 6976 Natural gas - Calculation of calorific value, density and Wobbe index from composition.

ISO 6141 Gas analysis - requirements on certificates for gases and gas mixtures.

ISO 15796 Gas analysis - Investigation and treatment of analytical bias.

ISO 17025 General requirements for the competence of testing and calibration laboratories.

GREENHOUSE GAS EMISSIONS REPORTING – COMBINED CYCLE POWER PLANT

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ABSTRACT

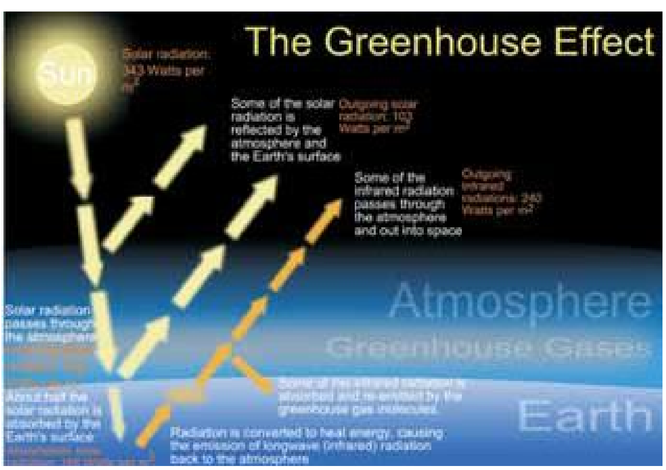
The Greenhouse Gas Emissions monitoring of a Combined Cycle power plant is very critical as the emissions emanating from the Exhaust Stack of a Combustion Turbine are to be controlled in order to comply with the statutory and local Federal regulatory requirements of Air Quality Permit. In this paper, the monitoring of emissions using a Continuous Emissions Monitoring System (CEMS), Control of Stack NOx emissions and Mandatory rule of Greenhouse Gas Emissions reporting are discussed.

KEYWORDS

Greenhouse Gas Emissions reporting, Mandatory Greenhouse Gas reporting rule, NOx emissions control and Continuous Emissions Monitoring System (CEMS).

INTRODUCTION – GREENHOUSE GAS OVERVIEW:

A greenhouse gas (sometimes abbreviated GHG) is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. When sunlight strikes the Earth's surface, some of it is reflected back towards space as infrared radiation (heat). Greenhouse gases absorb this infrared radiation and trap the heat in the atmosphere.



The primary greenhouse gases in the Earth's atmosphere are water vapor, carbon dioxide emissions (CO_2), methane & biomethane emissions (CH_4), chlorofluorocarbons and nitrogen oxides (N_2O). These principal greenhouse gases are sometimes referred to as High Global Warming Potential gases ("High GWP gases"). The rising concentrations of greenhouse gases produce an increase in the average temperature of the Earth, which in turn, produce changes in weather, sea levels, and land use patterns, commonly referred to as "Climate change."

The "Greenhouse Effect" the Earth is experiencing is due to the anthropogenic or man-made greenhouse gas emissions that are polluting the Earth's atmosphere and ecosystem. The Greenhouse Effect enhances or exacerbates the Earth's "natural greenhouse effect" with the greenhouse gas emissions from man-made sources include fossil-fuelled power plants such as natural gas power plants and coal fired power plants.

The seven sources of CO_2 from fossil fuel combustion are (with percentage contributions):

Seven main Fossil fuel combustion sources	Contribution (%)
Liquid fuels (e.g., gasoline, fuel oil)	36
Solid fuels (e.g., coal)	35
Gaseous fuels (e.g., natural gas	20
Cement production	2

Flaring gas industrially and at wells	< 1
Non-fuel hydrocarbons	< 1
"International bunker fuels" of transport not included in national inventories	4

Each gases' contribution to the greenhouse effect is affected by the characteristics of the gas, its abundance, and any indirect effects it may cause. The contribution is as follows: Water vapor (H2O): 36-72%; Carbon dioxide (CO2): 9–26 %; Methane (CH4): 4-9%; Ozone (O3): 3–7 %. In addition to the main greenhouse gases listed above, other greenhouse gases include sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons.

GREENHOUSE GAS EMISSIONS REPORTING:

The U.S. Environmental Protection Agency (EPA) issued the Mandatory Reporting of Greenhouse Gases Rule (74 FR 56260) which requires reporting of greenhouse gas (GHG) data and other relevant information from large sources and suppliers in the United States. The purpose of the rule is to collect accurate and timely GHG data to inform future policy decisions. In general, the Rule is referred to as 40 CFR Part 98 (Part 98). Implementation of Part 98 is referred to as the Greenhouse Gas Reporting Program (GHGRP).

A Greenhouse gas inventory is an accounting of the amount of greenhouse gases emitted to or removed from the atmosphere over a period of time, like one year, a greenhouse gas inventory also provides information on the activities that cause emissions and removals. The greenhouse gas inventories are used to track emission trends, develop strategies & policies, assess progress and develop atmospheric and economic models. Suppliers of certain products that would result in GHG emissions if released, combusted or oxidized; direct emitting source categories are covered in Part 98. Facilities that emit 25,000 metric tons or more per year of GHGs are required to submit annual reports to EPA.

EPA has proposed two rules to obtain “Clean Air Act permits” that address their greenhouse gas (GHG) emissions. EPA has finalized the Greenhouse Gas Emissions “Tailoring Rule” which specifies that projects that will increase greenhouse gas emissions substantially will require an air permit. The Greenhouse Gas Reporting “Tailoring Rule” covers large industrial facilities like power plants and oil refineries. The Clean Air Act requires states to develop EPA-approved implementation plans that include requirements for issuing air permits. The Clean Air Act Rule (CAIR) requirements for pollution reductions remain in effect and the CAIR regional control programs are operating while EPA is finalizing this Transport Rule.

EPA is developing a web based system, Electronic Greenhouse Gas reporting tool (e-GGRT) to support reporting under Greenhouse Gas Reporting program (GHGRP). EPA has also developed Greenhouse Gas Inventory Capacity Building templates and software tools targeting key sources, emissions factors, good practices, institutional infrastructure and use of the latest Intergovernmental Panel on Climate Change (IPCC) guidelines on greenhouse gas inventories. The IPCC publishes internationally accepted inventory methodologies that serve as a basis for all greenhouse gas inventories, ensuring that they are comparable and understandable.

The Greenhouse Gas Reporting Rule can be broken down into three distinct parts: GHG Monitoring Applicability Determination; GHG Monitoring Plan; and GHG Monitoring, Calculation and Reporting.

MANDATORY GREENHOUSE GAS REPORTING RULE 40 CFR PART 98:

The mandatory GHG reporting rule deals with Environmental protection, Administrative practice and procedure, Greenhouse gases, Incorporation by reference, Suppliers, Reporting and Recordkeeping requirements. The typical subparts associated with a Combined cycle power plant are: Subpart A-General provisions, Subpart B–General stationary Fuel Combustion sources and Subpart D– Electricity Generation.

For each electricity generation unit that is subjected to Acid Rain programs or is otherwise required to monitor and report to EPA CO2 emissions year-round according to 40 CFR 75, the annual mass emissions of CO2, N2O and CH4 must be reported and to follow the applicable QA/QC requirements for CO2 emissions. Because the CTGs and HRSGs are Acid Rain Sources, the CEMS will already need to comply with Part 75 regulations, which mean to comply with the GHG Mandatory Reporting Rule. The key will be ensuring that the DAHS is programmed for Part 75 and for the reporting requirements 98.46 refers to Subpart C at 40 CFR 36(b) & (c)(2) or (c)(3).

FINAL RULE OF MANDATORY REPORTING OF GREENHOUSE GASES:

The following are the salient features of the final rule of mandatory GHG emissions:

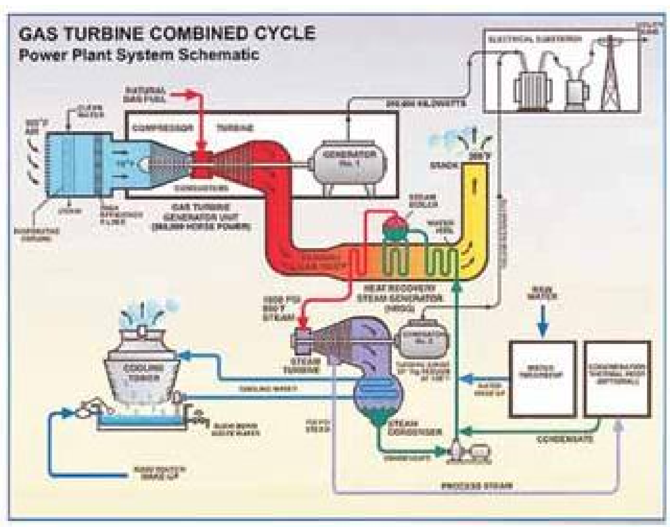
- Added a mechanism for facilities and suppliers to cease annual reporting by reducing their GHG emissions. Cease reporting after 5 consecutive years of emissions below 25,000 metric tons CO2e/ year; Cease reporting after 3 consecutive years of emissions below 15,000 metric tons CO2e/year; Cease reporting of the GHG-emitting operations or processes are shutdown.
- Add a provision to allow use of best available monitoring methods.
- In several subparts, added monitoring options, changed monitoring locations or allowed engineering calculations to reduce the need for installing new monitors.
- Sampling frequency: For Fuel Combustion and some other categories, reduced the required frequency for sampling and analysis.
- Exempt: Excluded R & D activities from reporting.
- Quality assurance: Added calibration requirements for flow meters and other monitoring devices including a 5 % accuracy specification.
- Report revision: Added a provision to require submittal of revised annual GHG reports if needed to correct the errors.
- Records retention: Changed the retention period from 5 years to 3 years.
- Verification: In several subparts, required more data to be reported rather than kept as records to allow EPA to verify reported emissions.
- Combustion sources: Added exemptions for Unconventional fuels, flares, hazardous wastes and emergency equipment. Reduced the need for mass flow monitors for some units or fuels. Allowed more facilities to aggregate reporting of emissions from smaller units rather than report emissions for each individual units.
- Manure Management Systems: Added an animal population threshold to reduce the burden of determining applicability. Reduced the monitoring requirements.

EPA has established a national Protocol Gas Verification Program (PGVP), under which EPA, in cooperation with the National Institute of Standards and Technology (NIST), will conduct an annual blind audit of EPA Protocol gases that are used to calibrate continuous emission monitoring systems (CEMS) and the instruments used in EPA reference methods.

CASE STUDY OF A COMBINED CYCLE POWER PLANT:

This technical paper brings a case study of one combined cycle power plant with two Siemens 501FD3 Combustion Turbine Generators (CTGs), two Heat Recovery Steam Generators (HRSGs) and one Electric Steam turbine generator (STG). Each of the natural gas fired CTGs will feed exhaust gases to its respective duct fired HRSGs. Steam from HRSGs will feed the STG. HRSGs are designed and constructed to operate within the maximum exhaust gas flow and temperature ranges of CTGs. Each HRSG has CO oxidation system to reduce CO in exhaust gas stream due to any contribution due to duct burner firing.

A typical combined cycle power plant block diagram:



The plant design is based on meeting the Emission limits while firing CTG in compliance with Bay Area Quality Management District (BAAQMD). CTG NOx emissions will be controlled by dry low NOx (DLN) combustors to 25ppmvd at 15% Oxygen. Selective Catalytic Reduction (SCR) systems are included for each HRSG to reduce the NOx levels to 2.0 ppmvd at 15% O2. Catalytic converters are included to reduce CO levels to 4 ppmvd at 15% O2. Aqueous Ammonia (19% wt.) is used for catalytic conversion of NOx emissions.

Emission	CTG output	RFP limits
NOx with SCR	25 ppmvd @ 15% O2	2 ppmvd @ 15% O2
CO with SCR	10 ppmvd @ 15% O2	4 ppmvd @ 15% O2 (By permit)
		2 ppmvd @ 15% O2 (Requested value)

A representative sample of flue gas is acquired from both the HRSG Stack and the SCR Inlet simultaneously with a sample probe and is transported to the Continuous Emissions Monitoring System (CEMS) shelter via a heated sample line. The SCR Inlet sample point uses a High Temperature version of the HRSG Stack sample probe. The Stack incorporate emission sampling ports in accordance with US EPA state and local regulatory requirements. The sample port for CEMS sample is located at approximately 43'6" downstream of the stack damper and approximately 10' upstream of the stack exhaust. The sample probe is 6' long and the representative point in the 18' 5/8" diameter stack. Four EPA ports are located a minimum vertical distance of 12" from the two CEMS ports.

NOx EMISSIONS CONTROL BY SCR PROCESS:

The SCR process consists of a catalyst bed, placed in post-combustion region of the duct, for converting NOx created during combustion. The optimal temperature range for the reaction is 550-700 deg F. When reacted in the catalyst bed, the injected Ammonia and NOx breakdown into water vapour and Nitrogen (N2) molecules, both inert in earth's atmosphere. Because of the hazards involved with storage and handling of pure (anhydrous) ammonia, a dilute version called "aqueous ammonia" is used. De-ionized water is mixed with anhydrous ammonia until the ammonia is 19-29% of the total mass of the solution. This water, along with ammonia reagent, is vaporized and diluted with air prior to injection upstream of catalyst bed.

The vaporization and dilution process take place on Ammonia Flow Control unit skid, which utilizes recirculation air from exhaust stream. The exhaust air enters the vaporizer tower and provides the energy needed to evaporate ammonia and water.

The NOx control portion of the scheme begins with feedforward estimation of the needed ammonia flow. This feedforward portion is fine tuned using a feedback control based on NOx concentration signal from an outlet CEMS analyzer.

The Feedforward control scheme is based on two values- SCR inlet NOx in ppmvd ref 15% O2 provided an inlet NOx analyzer and a determined exhaust gas flow rate in million-SCFH. These values derive a volumetric flow rate of NOx in SCFH. The inlet NOx is used to determine the percentage reduction needed as below.

Desired % NOx reduction = (SCR inlet NOx - Desired outlet NOx set point) / SCR Inlet NOx

Actual volumetric flow rate of NOx to be reduced by SCR = (Volumetric NOx flow rate) X Desired % NOx reduction

The Feedback control scheme is based on Stack outlet NOx signal measured by CEMS analyzer. This signal is fed to a PID controller as Process variable. Customer selects a set point to be fed into this PID controller. The resulting control value is -0.5 to 0.5.

Outlet NOx set point = (Desired % NOx reduction) + (Outlet PID control resulting value)

An additional signal is supplied by CEMS indicating the validity of NOx signal it is transmitting. In case of a failure, maintenance or calibration event occurring within CEMS, the SCR system operate based on the last known valid NOx reading. The feedforward control continues to respond load changes in the exhaust source.

Ammonia flow control: The actual volumetric flow rate of NOx to be reduced provides set point for NH3 PID controller. The gaseous ammonia volumetric flow rate is used as process value of this PID controller. The output of this PID controller is the amount of ammonia required to reduce NOx. In the SCR reaction, the needed ammonia volumetric flow rate is equal to the actual volumetric flow rate of NOx to be reduced. The SCR controller will open the valve to begin ammonia dosing only when all the ammonia injection interlocks are satisfied.

CONTINUOUS EMISSIONS MONITORING SYSTEM (CEMS):

The Exhaust gases emanating from the Stack are monitored and analyzed by the Continuous Emissions Monitoring System (CEMS) using an AllenBradley ControlLogix Programmable Logic Controller (PLC). The sample analysis includes Probes, Pre-conditioning, Conditioning equipment and Dual range analyzers to monitor the concentrations of Oxides of Nitrogen (NOx), Carbon Monoxide (CO) and Oxygen (O2). The heated Sample tubing umbilical is running from the connection on the Stack as well as connection in the HRSG before the SCR system for NOx analysis. The CEMS includes T200M Teledyne Advanced Pollution Instrumentation (TAPI) model T200M dual range (0-10/150 ppm) Chemiluminescent NOx analyzer for measurement of NOx at HRSG stack, a TAPI model T300 dual range (0-10/1000 ppm) IR-GFC CO analyzer and a single range (0-25%) Paramagnetic O2 analyzer.

The CEMS data acquisition and handling/reporting system (DAHS) is in accordance with the air permit. The CEMS meets the monitoring and reporting requirements of Acid Rain Program (40CFR 75) and in addition, the 40CFR75 data is used to meet the requirements of the Mandatory Greenhouse Gas Reporting (40CFR98). The daily CO2 emissions are derived from the calculations in the PLC and are reported to meet the performance specifications of 40CFR60, Appendix B and the certification requirements of the Acid rain programs. As a part of these requirements, CEMS certification testing will take place and a final test report will be submitted. Inputs from fuel flow and power generation are provided from plant DCS to CEMS. Emissions are calculated based on the plant fuel flows, analyzer readings and surrogate calculations based on the fuel analysis.

The primary operator interface with CEMS is through DAHS PC workstation located in the main control room. The PC provides operator access via a Windows XP environment to acknowledge alarms, retrieve data and generate required emission reports and includes exceedance/fault codes as appropriate.

The CEMS hardware and reporting package software meets the requirements of applicable permits. System reports include hourly, daily and monthly reports and a daily summary of average plant generation in megawatts and the average fuel flows. All the emissions data, CEMS in calibration and a common alarm are hardwired from CEMS controller to DCS. The PLC control units allow access to the operational status of the CEMS and provide capability to initiate both automatic and manual calibrations. The complete system is factory tested using NIST traceable calibration gases to confirm the function of all the required features. After installation, accuracy tests, Zero drift test, Calibration drift test, stratification test and an operational period test are performed. CEMS has its proprietary GHG software reporting module to report GHG emissions in the format designated by EPA.

The BAAQMD requires the plant operators to install, calibrate, maintain and operate a CEMS to measure NO_x, CO, and O_2. In order to report mass emissions (lb/hr), the gas fuel flow rate will be used. The 40CFR 98 fuel flow meter certification requirement will be satisfied by meeting the regulatory requirements of 40 CFR 75, Appendix D.

The 40CFR60 requirements are a 7-day drift test and a Relative Accuracy Test Audit (RATA) on the O_2 and CO analyzers. The RATA testing is performed while the plant is operating at normal load and the 7-day drift test is done while the plant is at least combusting fuel. The RATA on the CEMS involves verification by a third party test team, following 40CFR60, Appendix A test methods. Nine to twelve test runs are performed. During these tests, the sample location is tested for stratification. To perform the test, the DAHS is placed in an "Audit Mode" and values are recorded every minute and then averaged for the duration of the test period. These values are compared to the test team's values for the same test period. The difference between the two sets of values must meet the compliance requirements. Calculations are done for CO ppm @ 15% O_2.

The 40CFR75 testing consists of 7-day drift test, RATA, linearity and response time on the NOx and O2 analyzers. The results from the RATA testing are performed for 40CFR75 with results presented in NO_x lb/mmBtu. The linearity test consists of three runs using three levels of calibration gas. The response time test determines the upscale and downscale response of both the NO_x and O_2 analyzers.

The DAHS accomplish the calculations of emissions in units of the applicable standards and include Emission concentration corrected to a particular Oxygen concentration; Emissions rate in lb/mmBtu from ppmvd; Dry standard volumetric stack flow using fuel factors and fuel flow rates; Mass emissions rate in lb/hr using plant fuel flows; NH_3 ppmvd @ 15% O_2 (slip) for the BAAQMD; SO_2 emission using the 0.0006 lb/mmBtu emission rate in 40CFR75 Appendix D 2.3.2; Net Gas fuel flow rate for systems with duct burners on the combustion turbines; Annual average emission rate for each calendar year and Heat input from natural gas for each period and DuctBurnerMW2.

The daily CO2 emissions are derived from calculations in PLC as below:

Formula	**Parameters: CO2**
In lieu of using the procedures, methods, and equations in 40CFR75 Appendix G 2.1, as defined under 40CFR § 72.2, use the following equation and records of hourly heat input to estimate daily CO2 mass emissions (in tons). $$W_{CO_2} = \left(\frac{F_C \times H \times U_f \times MW_{CO_2}}{2000} \right)$$ Units: tons/h Reference: 40CFR75 Appendix G 2. $$CO_2 = \left(\frac{W_{CO_2}}{1.1023} \right)$$ Units: metric tons/hr Reference: 40CFR98.43(a)	• WCO2 = CO2 emitted from combustion, tons/hour. • Fc = Carbon based F factor, 1,040 scf/mmBtu for natural gas; 1,240 scf/mmBtu for crude, residual, or distillate oil; and calculated according to the procedures in 40CFR75 Appendix F 3.3.5 • H = hourly heat input in mmBtu, as reported in company records. See F-20 • Uf = 1/385 scf CO2/lb mol at 14.7 psia and 68 F. • MWCO2 = molecular weight of carbon dioxide (44.0). • CO2 = CO2 emitted from combustion, metric tons/hour. • W CO2 = CO2 emitted from combustion using 40 CFR 75 equation G-4, tons/hour. • 1.1023 = Conversion factor to convert metric tons to short tons

CONCLUSION:

Greenhouse Gas Emissions monitoring and reporting is very stringent in developed countries. Among the fast developing countries, India is the first country to publish the Greenhouse gas emissions inventory in the year 2007. In the years to come, we may have to achieve a similar level of advancement in the Emissions monitoring and reporting as in the developed countries and means to reduce the emissions.

ACRONYMS:

GHG : Greenhouse Gas Emissions

GHGRP: Greenhouse Gas Reporting Program

EPA : Environmental Protection Agency

e-GGRT: Electronic Greenhouse Gas reporting tool

IPCC: Intergovernmental Panel on Climate Change

CAIR: Clean Air Act Rule

PGVP: Protocol Gas Verification Program

NIST: National Institute of Standards and Technology

SCR: Selective Catalytic Reduction

CTG: Combustion Turbine Generator

HRSG: Heat Recovery Steam Generators

CEMS: Continuous Emissions Monitoring System

BIOGRAPHIES:

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Born in the year 1971 in Hyderabad. Graduated in Instrumentation from Osmania University. Currently working as Senior Engineer–Control Systems in Bechtel India Pvt.Ltd, New Delhi for the last 5 years. Total engineering experience is 18 years. During the career, worked on the detailed Engineering, Erection, Commissioning and Start up of Yokogawa Centum-CS 3000 and Honeywell TDC 3000 DCS systems with a wide exposure on the field engineering and construction activities.

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Born in the year 1972 in Eluru, Andhra Pradesh. Graduated from Osmania University College of Engineering. Total 18 years of professional experience. Currently, working as Engineering Group Supervisor in Bechtel India Pvt.Ltd, New Delhi for the last 10 years. Wide exposure in Power plant control engineering covering Coal, Combined cycle and Nuclear projects.

Automation in Nuclear Power Plants

Fuel Handling Controls in Pressurized Heavy Water Reactors

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ABSTRACT

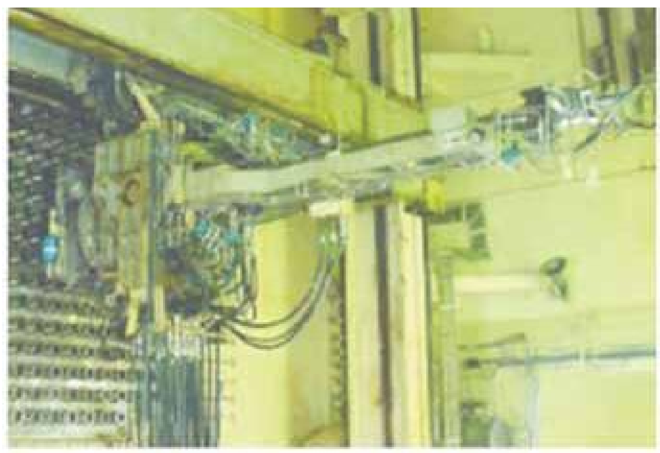
The Fuel Handling system is a very dynamic system with a number of equipment having complicated robotic mechanisms operated remotely using electrical and Fluid Power with D2O, H2O, oil and air The complete refuelling sequence which involves more than 1200 varied and complex operations with highly precise movements is performed by Fuel Handling Controls (FHC). FHC performs operations on the equipments to achieve position, force, speed etc with very high level of accuracy. These operations are fully automatic and designed such that the complete refuelling operation can be completed without operator's intervention. The operations in Auto mode are performed through custom built Digital I&C system developed in-house. The Digital I&C system also provides operator friendly interface to carry out various operations. In addition to Digital I&C system the safety of operations is also ensured by implementing interlock logics system called Manual and Safety Logic (M&SL). M&SL is implemented using Field Programmable Gate Array (FPGA). FHC system is designed to be very robust to ensure safe and reliable operations during refuelling. All commands issued by the digital I&C system are also checked in M&SL before issuing the same to respective actuators. The M&SL also facilitates to operate the system in manual mode due to outage of Auto mode without compromising the safety. This paper brings out salient features and importance of the Fuel Handling Controls System of PHWRs and the future plans for improvements in control system of upcoming plants.

KEYWORDS

FHC, Refuelling, M&SL

1. INTRODUCTION

In Pressurized Heavy Water Reactors (PHWRs) heat generated due to fission is transferred to coolant which in turn generates steam to run the turbine. Natural Uranium is used as fuel which has low excess reactivity. Because of low excess reactivity regular refuelling is indispensable for continuous operation. On-power refuelling is necessary for regular refuelling of channels. Fuel is contained in a large number of horizontal tubes, called coolant channels. The coolant channels are arranged in the square lattice grid and are contained in calendria. In 700 MWe PHWR each channel



consists of 12 fuel bundles, each about 500 mm long, with a shield plug at either end and closed by seal plugs. These bundles form a long string, free to move inside the channel due to the drag force of the coolant flow and held in position by shield plugs. Care has to be taken that the fuel bundle remains safe all the time. This is achieved by ensuring that:

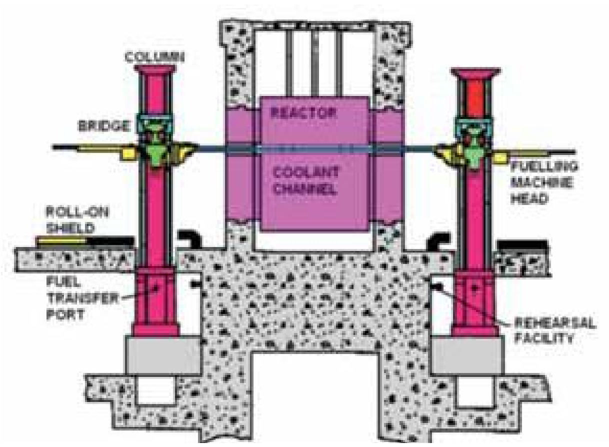
- The forces beyond allowable limits are not applied
- The speed of the movement is not exceeded
- Bundles are transferred only after proper alignment of the equipment is achieved
- Bundles are correctly positioned in the equipment before the next command is given
- Cooling for spent fuel bundles is maintained at all times to shun its over-heating

2. FUEL HANDLING SYSTEM OVERVIEW

The Fuel Handling System (FHS) is a very dynamic system with a number of equipment having intricate robotic mechanisms operated remotely using electrical and Fluid Power with D2O, H2O, Oil and Air. The FHS is divided into Fuelling Machine (FM) System, Fuel Transfer (FT) System, Auxiliary system and Remote viewing CCTV system. The FHS is responsible for the transfer of new fuel from new fuel room to Fuelling Machine, refueling of channels and transfer of spent fuel from Fuelling Machine to storage bay. FM system consists of various subassemblies like Ram Assembly, Magazine, Separators, Snout Assembly, Guide Sleeve, Z-drive and Head Antenna, Head, Bridge and Carriage, Leveling and Centralizing Assembly, Heavy water hydraulics, Oil hydraulics, Motor control, Rehearsal Tube Facility etc. The FT system consists of New Fuel Magazine, Mobile Transfer Machine and Tray Loading Machine.

2.1 REFUELLING OPERATION

For carrying out refuelling one Fuelling Machine is clamped at north end of the channel while the other is clamped at south end of the channel and both are operated in unison.



According to direction of coolant flow the upstream FM load new fuel into the channel while downstream receives the spent fuel. The loading of new fuel into FM and transfer of spent fuel from FM to Spent Fuel Storage Bay (SFSB) is carried out by FT equipment. In SFSB, the spent fuel is inspected for any damages and then kept for long term storage under water. The complete refuelling sequence which involves more than 1200 varied and complex operations with highly precise movements is performed by Fuel Handling Controls (FHC) System.

3. FUEL HANDLING CONTROL SYSTEM

3.1 KEY FETURES

- Fully automatic operation using custom build Digital I&C system developed in-house
- On-line and Off-line diagnostics to check healthiness of hardware and software
- Ensure safety of operation by checking safety interlock logic
- Ability to carry out all FH operations in manual mode during unavailability of Control Computers
- 2/2 logic for improving reliability of operation
- Operator friendly Interface
- Use of state-of-the-art FPGA to reduce complexity and improve maintainability
- Remote viewing CCTV system

3.2 BRIEF DESCRIPTION

The Fuel Handling Control System involves:

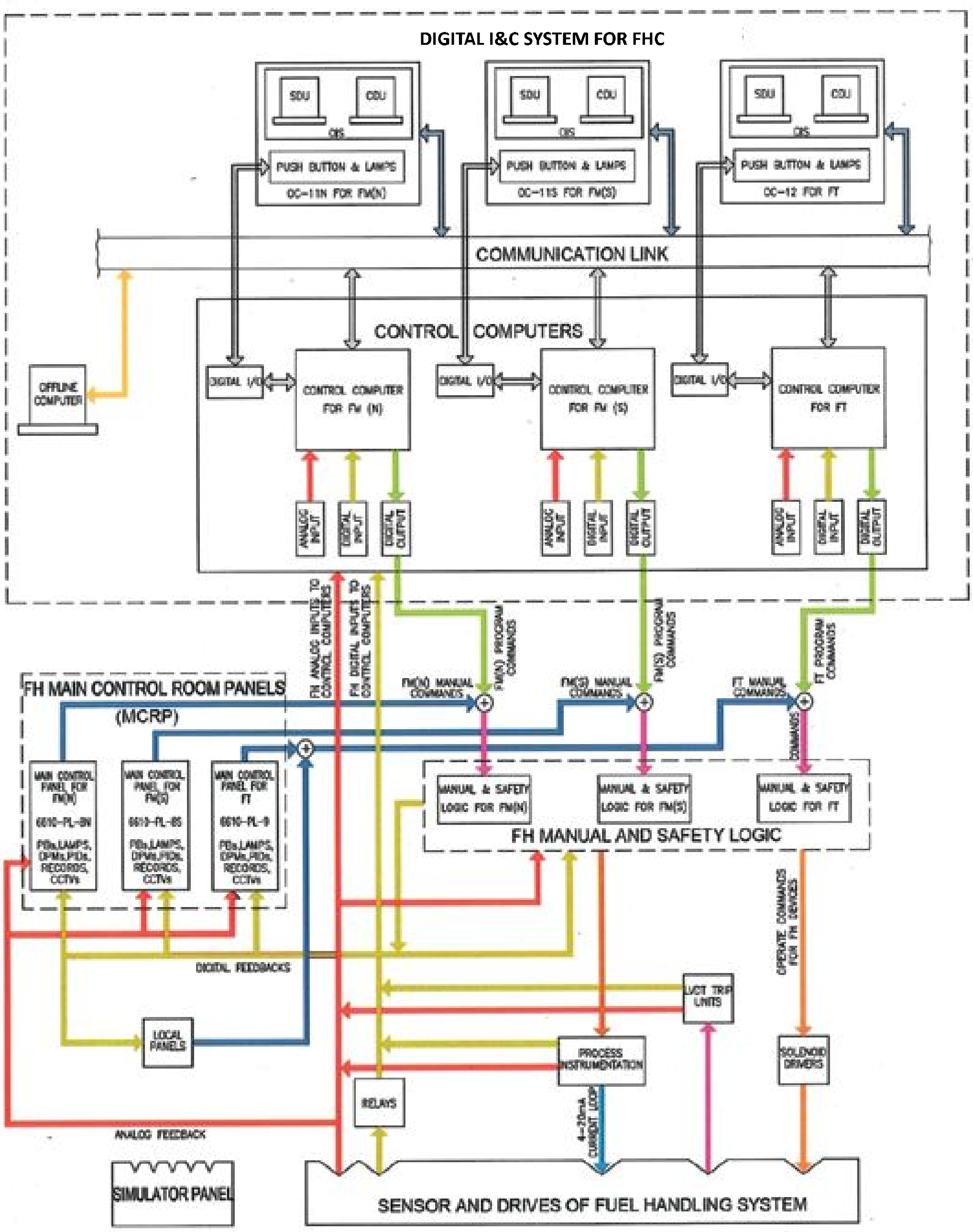
- Pressure control
- Level control
- Force control
- Speed control
- Position control (including Auto Positioning)
- Direction control

The operations of FHC system are fully automatic and designed such that the complete refuelling sequence can be completed without much operator's intervention. The entire operations are defined by a set of sequences consisting of several programs. Each program consists of several steps. These steps include:

- Selection of process set points,
- Accurate positioning of mechanical rams at pre-calibrated discrete positions,
- Advancing/retracting of hydraulic cylinders,
- Opening/closing of valves,
- Checking interlocks and
- Providing adequate indications.

A simplified block diagram of Fuel Handling Control System is given below. The FHC system consists of Digital I&C system, Operator Console, Manual & Safety Logic system and Main Control Room Panel as shown in block diagram. There are three control units, one each for the North FM, South FM and the FT system. The North and South FM control units are essentially identical, each controlling one Fuelling Machine. The control involves monitoring of various parameters of field devices. A large number of sensors are employed to monitor these parameters. The analog and digital signals from sensors are read by control system. The selection of sensors is based on application requirement. The types of sensors used in FHC system are:

- Potentiometers
- LVDTs
- Proximity switches
- Micro switches
- Reed switches
- Commutator switches
- Pressure, Flow, Level & Temperature Switches and Transmitters etc.



Advanced sensors like Ultrasonic based sensors, inductive and capacitive sensors are not used because they contain electronic components which normally does not qualify for use in radiation environment.

3.3 DIGITAL I&C SYSTEM

Digital I&C system encompasses Control Computers, Off-line computer and Display Units. Digital I&C system is used to carry out operation of system in Auto Mode, which is the normal mode of operation. In Auto Mode, the Control Computer controls the system by sequentially issuing required commands for the step by step operation. A number of related sequential steps are grouped as program and a number of programs, sequentially executed, constitute a sequence. Interlock logics are provided to ensure safety during operation. Each step checks for the permissive before issuing the commands in accordance with the logic programmed in the computer software. The program logic statements, logic interlocks, calibration tables of drives etc are specific to the system i.e. FM related are in FM control units while FT related are in FT control unit. The three Control Computers communicate with each other through dual LAN. The calibration of various drives for positioning is done by storing the digital equivalent value of feedback signal in calibration table. Auto positioning of various drives is done by comparing the calibration data with current value of corresponding drive feedback potentiometer. The Control Computers have in their scope monitoring of field sensors, checking of safety interlocks, issuing commands to operate field actuators etc. There are a large no. of inputs and outputs connected to the Control Computer. This includes 420 digital inputs, 62 analog inputs and 240 digital outputs approximately. The Control Computer read analog and digital inputs from field sensors. Digital outputs of computer facilitate to energize field actuators. All output commands are routed through Manual & Safety Level (M&SL).

The software of the Control Computer is organized into On-line and Off-line depending on the application. The On-line software includes all programs for controlling and monitoring the refuelling operation with minimum or no operator intervention. The Off-line software includes diagnostics of hardware of computer and various utilities for testing and transfer/storing of software modules. The On-line software of the Control Computer is cycle based and the cycle time is chosen as 50 ms to meet the accuracy requirement of the drives based on their speed. During each cycle the Control Computers read all inputs, execute the step logic, run all interlock tasks that are active and accordingly set/cancel the commands at the end of the cycle. The positioning accuracy of the drives required by operation is ±0.5 mm. The hardware design of Control Computer is modular. Modularity facilitates easy fault identification and quick replacement of the faulty board.

The FM and FT Operator Console provides controls for the start up and operation of the control system in Auto Mode. It consists of set of Push Buttons, Lamps, Display Units and Keyboards. There are two display units, Control Display Unit (CDU) and Status Display Unit (SDU). The CDU is used by operator to initiate rufuelling or FT sequence and issue of semi- auto commands in Auto mode of operation. The messages like non-availability of a permissive, non-availability of feedback, command cancelled due to non-availability of a particular interlock, diagnostic messages, logic statements, program messages, calibration values and errors in selection are displayed on CDU. The CDU also maintains a log of all operations performed and messages displayed during Auto mode of operation. The SDU displays additional information, such as status of Fuel Handling drives and actuators, to assist the operator.

3.4 DIAGNOSTICS

The Control Computer software includes off-line and on-line diagnostics to check healthiness of the system. The integrity of the software is checked during every cycle through external hardware (such as Watchdog timer). If any fault with respect to software integrity is detected the same is indicated using a contact type output. This signal also trips the FHC system. Also all digital outputs are forced to logical high level to bring the system in fail safe mode. These checks are run during on-line operation of computer, during idle periods in each cycle. Any corruption in calibration data is detected by the online diagnostic programs and this does not allow any further Auto Positioning.

On-line diagnostic programs also check function of each board of computer hardware. The diagnostics quickly identify and indicate the faulty hardware.

3.5 BUILT-IN SAFETY

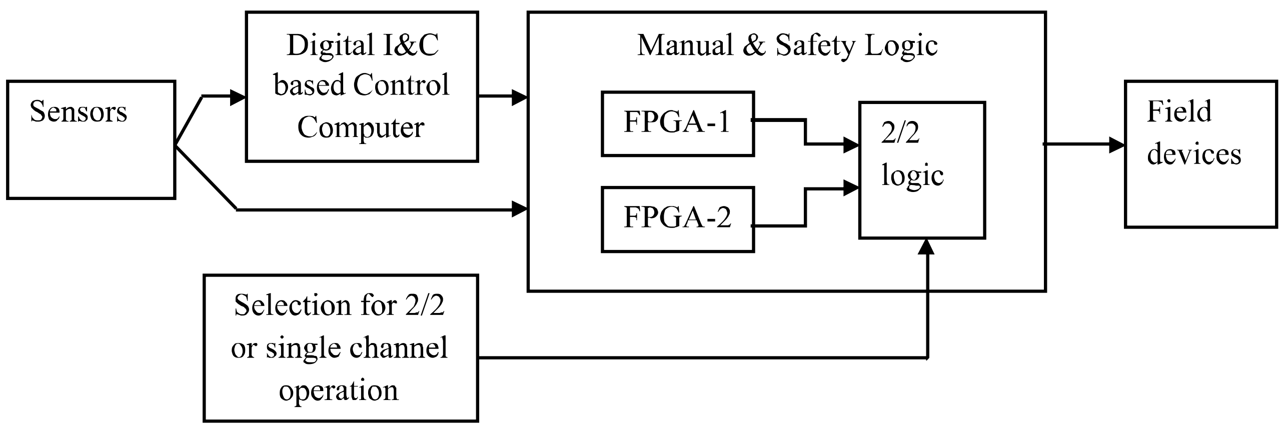
FHC System is designed in accordance with AERB (Atomic Energy Regulatory Board) safety code and guides. Safety of operation is ensured by interlock logic. 2/2 logic is implemented to ensure that any false command is not issued. Redundant Power Supplies are provided for all the modules of control system. For critical parameters redundant sensors and cabling is provided. The cabling of redundant sensors is done through diverse routes. In case of any event or failure, alarms are generated and indicated through alarm windows on Main Control Room Panel. The system is designed to have high Mean Time Between Failure (MTBF) and low Mean Time To Repair (MTTR). These can be achieved by ensuring that all components are:-

- Military/ Industrial grade (meeting temperature range of -10°C to +85°C)
- Seismically qualified
- Climatically qualified
- Adequately de-rated

3.6 MANUAL & SAFETY LOGIC SYSTEM

Major functions of Manual & Safety Logic (M&SL) system are: -

- To check safety interlocks
- To facilitate Manual mode of operations
- To provide auto initiated actions



M&SL is implemented using Field Programmable Gate Arrays (FPGAs). Use of state of the art FPGA for implementation of complex safety interlock logic reduces wiring complexity and improves maintainability. To check the healthiness of logic, periodic on-line diagnostics are also implemented in FPGA. Diagnostics are embedded along with interlock logic and runs concurrently. The 2/2 logic is used to ensure safety so that failure of a single component will not lead to issue of wrong operate commands to the field. This is achieved by implementing duplicate logic in two FPGAs and outputs of both FPGAs are used to validate the output commands through 2/2 logic. There is provision to bypass the command from one FPGA in 2/2 logic in case of failure of FPGA. All the analog and digital signals from field sensors through suitable signal conditioning are also fed to M&SL for checking interlock logic. In Auto mode, the commands issued by Control Computers and in Manual mode commands issued by operator from main control room panel are routed through M&SL to check for the safety interlock.

The manual mode operations are performed through Main Control Room Panel. The typical picture of main control room panel of one FHC system for 540 MWe PHWR is shown below.

It consists of a large no. of Illuminated Push Buttons, Indicating Lamps, Controllers, Recorders, Analog and Digital Meters, CCTV monitor along with its control unit etc. CCTV system is used for receiving and recording video signal of various equipments. Annunciation Windows are provided for operator attention in case of any event or failure. The colors for alarm windows are chosen according to severity of the event.

3.8 INTERFACES WITH OTHER SYSTEMS

The FHC system is connected with other control systems of plant through dedicated LAN. Information of other system's signals can be displayed on Status Display Unit. The Control Computer is synchronized with Central Clock Cystem. This provides time stamping of FH operations & events with real time.

4. ADDITIONAL ACTIVITIES OF FHS

In addition to refuelling of coolant channels, FHS is also involved in many important plant activities. This includes:

- Creep measurement of coolant channels
- In-service inspection of coolant channels
- De-fuelling of channels for en-mass coolant channel replacement etc.

These activities are carried out using some special tools by fitting them on the FM head. These additional activities are invariably required to be carried out during the plant outage according to planned schedule.

5. FUTURE PLANS

- There are Emergency Operating Procedures (EOPs) which are to be followed in case of emergency. The intelligence can be provided in operator information system to perform the operation according to EOPs and assist the operator to carryout operation.
- Animation of FH operations. When a command is issued to energize a drive, the actuation of field device is monitored by analog and digital feedbacks via lamps and meters. The various sequences of FH operations being performed can be animated and displayed based on feedbacks to ease monitoring by operator.

6. CONCLUSION

Fuel Handling Controls systems in Indian PHWR are designed to operate FHS in a safe and reliable manner. FHC facilitates fully automatic operation with minimum or no operator intervention through Digital I&C system. The device specific logic interlocks are implemented to ensure the safety of operations. Online and offline diagnostics are implemented to check the healthiness of control system. The degraded mode of operation is also allowed when Digital I&C system is not available. The future plans of FHC are to enhance operator information system with incorporation of intelligence and animation of operations. There is scope for improvements in field instrumentation subjected to availability of advanced sensors which qualify for use in radiation environment.

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Power Control Requirements, Instruments and Techniques for Indian PHWRs

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Abstract

This paper presents the power control of large nuclear reactors by Dual Computer Hot-Standby (DCHS) systems in Indian PHWR Nuclear Power Plants. The basic purpose of the reactor power control systems is to provide a means for starting the reactor, changing of reactor power, maintaining power and shutting it down in the course of routine operation or in the event of potentially unsafe conditions. The reactor power control system has a subsidiary function to shape the neutron flux in order to achieve optimum heat generation rate. The unique requirements and the main functions of power control for different modes of a large decoupled reactor, instruments and technique used to measure true fission power which varies about 14 decades from a newly built reactor core to full power operation, the control algorithm, various reactivity devices used to manipulate reactor power, and redundancy adapted from sensors to control systems to actuators for achieving high reliability, availability, and safety are briefly covered in this paper.

Keywords

Power control, Large nuclear reactors, Dual Computer Hot-Stand-by (DCHS), Indian PHWR, shape of neutron flux, fission power, full power operation, reactivity devices, redundancy

1. INTRODUCTION

Power level of a reactor at any instant is directly proportional to the neutron flux for a given fuel enrichment. In most situations reactor power is controlled by measuring neutron flux and altering reactivity.

Four general methods are possible for changing the reactivity in a reactor, addition or removal of 1) fuel 2) moderator 3) reflector 4) a neutron absorber (liquid poison or solid rod). Each of this method or a combination is used for reactor control. Most commonly especially in power reactor fourth option is used. Control elements are generally referred as 'control rods' because often they are cylindrical rod in physical shape.

2. REACTOR POWER CONTROL FUNCTIONS

The Reactor Power Control System performs the following main function

a) Automatic Control of Reactor Bulk Power (BP) to operator given set point and Power Maneuvering in the range of 10-6%FP to 110%FP in the Turbine-Follow-Reactor Mode.

b) Maintain the neutron flux distribution close to its nominal design shape avoiding violation of bundle or channel power limits during full power.

c) During operation, the reactor may be subjected to perturbation caused by refuelling, power cycling, reactivity device movement, change in Xenon concentration, fuel burn up, moderator poison concentration etc. These along with natural instability of the large core dictates the need of spatial power control to suppress Xenon induced oscillations with the help of inputs from Flux Mapping System and Zonal Thermal Power Measurement System.

3. UNIQUE REQUIREMENTS

a) Execution of Reactor Setback i.e., reduction of power with a rapid rate when any potential unsafe situation occurs. This functionality prohibits the unnecessary frequent actuations of reactor trip systems.

b) Withdrawal of Shut off Rods sequentially under supervision of Operator during Reactor Start up

c) Providing limited xenon over ride capabilities for quick restart of reactor after trip.

4. SENSOR INSTRUMENTATION

Reactor power control system monitors power level of the reactor over the full operating range. Between the beginning of a fresh core start-up and full operating range of a nuclear power reactor neutron flux may vary by a factor of 1014 or more. No single instrument can provide a satisfactory indication of the neutron flux over the whole possible range. Whole range is divided into three sub range namely source range, intermediate range, and power range. Different kinds of neutron detectors are used for different range. Adjacent range overlap by one or two decade of neutron flux is considered to provide continuity in measurement (for smooth switching from one type of instrument to another). For large reactors where reactor dimension is considerably large w.r.t to the migration length of neutron, zonal neutron flux need to be measured. In-core Self Powered Neutron Detectors (SPND) are the only option for measuring zonal flux in power range.

4.1 Start up instrumentation

The source range instrumentation is used from spontaneous fission power level approximately from 10-14FP to 10-9FP with one set of in-core detectors and from 10-11 FP to 10-6 FP with another set of out-of core detectors. This instrumentation system also used for fresh core start up as well as after a prolong shut down when normal flux measuring instruments are off scale. It also plays a dual role of reactor power control over the lowest power range and trip generation for reactor protection. In this range, the reactor is controlled manually by operator from control room with the help of neutron count recording instrumentation mounted in a mobile cabinet. Reactor trip is initiated when the count rate exceeds the set point or the rate of change is excessive.

4.2 Ion Chamber Systems

Ion Chambers are used for the intermediate range. The principles of the ionization chamber apply broadly to gas-filled detectors. Ionization chambers are used to collect and measure the electric charge of ions and electrons that result from the interaction of incident radiation and secondary radiation from the structure with the fixed, known volume of gas in the chamber. The quality of collected charge is a measure of the incident radiation. Reactor Power Control System employs the ex-core ion chambers for total average reactor power measurement. These along with its amplifiers are calibrated to measure log neutron power (10-6 %FP to 150%FP), linear neutron power (0 to 150%FP) and rate of change of log neutron power (-20% to +20% of present power /sec). These ion chambers respond to both the gamma and neutron flux, rather than to fission power directly. Moreover, due to non-uniform shadowing effects of control rod movements, poison concentration etc. signals of these detectors are different from the actual fission power. Therefore, it is necessary to modify the transient characteristics of the detector signals to more closely match the fuel power dynamics while retaining a dominantly prompt response, for which a correction of the detector signal is desirable based on indirectly measured bulk thermal power.

4.3 In-core flux detector

In-core detectors are used for power range. For point flux measurement during power operation, SPNDs are the only detector available for power measurements. SPND uses the basic radioactive decay process of its neutron activated material to produce an output signal. As the name suggests no external ionization or collecting voltage is required to produce signal current. SPND signals are used in a range from 5 to 150 % FP. The response of SPNDs differs widely depending on the sensor material and the underlying radioactive process. The output signals for some of the sensors are accurate but delayed (e.g. Vanadium, Rhodium). On the other hand some SPNDs (Cobalt) are prompt but inaccurate due to burn up and build up. Furthermore, they are affected by the continuous degradation when operated in harsh environment like inside the core. Many Vanadium detectors are distributed throughout the core to map the neutron flux of the core. On the other hand few Cobalt SPNDs are placed zone wise to get zonal flux.

4.4 Thermal power measurement

Reactor Thermal Bulk Power (TBP) is measured by Instrumented channel monitoring System (ICMS). TBP computed based on primary parameters i.e., differential temperature and flow values obtained from selected channels. Differential Temperature is measured using thermo well mounted RTD and flow is measured using venturimeter and flow transmitter. Channel power computation is done using following expression.

$$P_{tsc} = M \times C_P \times \Delta T$$

Where, P_{tsc} = Thermal Power for a particular selected channel in KW

M = Mass flow rate in the selected channel in Kg/sec

CP = specific heat of coolant in KJ/Kg/°C for mean channel temperature

ΔT = Differential temperature across selected channel

The method followed for estimation of zonal thermal power and bulk thermal power is weighted summation of selected channels.

5. ACTUATOR INSTRUMENTATION

Actuators are Reactivity devices and are those devices which can alter neutron multiplication rate. Following reactivity devices are provided for a large PHWR (540 MWe / 700 MWe) for precise power control.

5.1 Zone Control Compartment

14 Zone Control Compartments (ZCC) for slow, small, frequent variation of global neutron power and to achieve spatial power distribution by suppressing Xenon induced oscillation inside reactor core. Change in reactivity is achieved by varying Light Water level inside ZCC by controlling opening of a Control Valve in the inlet line. Liquid outflow from the ZCCs is kept constant.

5.2 Adjuster Rods

17 Adjuster Rods (ARs) grouped in 8 banks are provided to shape the neutron flux for optimum reactor power and fuel and burn up, and to supply positive reactivity beyond control range of ZCC. These also help to achieve limited capability Xenon Override during fast Reactor Start up. Change in reactivity is achieved by moving these rods Up/Down through rope/sheave and motor arrangement.

5.3 Control Rods

4 Control Rods (CRs) grouped into two banks are provided for coarse reduction of power. Change in reactivity is achieved in similar manner as ARs.

5.4 Liquid Poison

Moderator liquid poison is used to augment the negative worth of the reactivity devices.

6. POWER CONTROL ALGORITHM

6.1 Representative signal generation

The Reactor Power Control System is categorized as IB system (categorization as per AERB SG-D1). A lot of redundancy is provided in sensors, computers and actuators to immune the system from small process disturbance and measurement failure. Extensive diagnostic and validation algorithm like rationality check, median selection, two out three criteria, feedback of analog output signals, read back of digital output signals, conditional and absolute switchover etc. are performed to ensure that faulty sensors, computers and / or actuators are discarded meeting single failure criterion and improving availability.

6.2 Bulk power and zone power estimation

Bulk reactor power is determined by solely using ion chamber signal at low power level (up to 5% FP) and by using Weighted average of cobalt SPND of each zone at higher power level (above 15%FP) and combining both the signal between 5% FP to 15%FP. Zone power is calculated using cobalt SPND signal separately for each zone. However both zone power and reactor bulk power are continuously corrected by bulk thermal power and either by zone thermal power signal or correction factor from Flux Mapping System.

6.3 Demand Power Programme

Demand power programme generates reactor power set point on the basis of operator demand set point and the operator selected pre decided rate (Fast or normal). Any setback condition overrides operator demanded set point and decreases the power set point at a pre decided rate depending on the set back parameter and ensure power is reduced to a level to clear the causing parameter. A negative deviation limiter prevents the power set point from being more than 5%FP above actual bulk power to allow the reactivity devices to respond since saturation for maximum rate of raise is achieved at this error.

6.4 Effective Power Error Calculation

The Total control signal to the zone control compartment inlet valve consists of four term Bulk power error, power tilt error, level tilt error and permanent level tilt error. Control loop is basically conventional output feedback Proportional Control except for the bulk power error term, which is calculated as following.

Bulk Power Error Term = K_P x (log (BP)-log (DP)) + T_D x (Rate of log (BP) - Rate of log (DP))

Where, K_P = Proportional gain

T_D = Derivative time

BP = Bulk Power

DP = Demand Power

6.5 Reactivity Control Algorithm

The reactivity mechanism control logic is summarized in Fig.-1. The method of short term / fine reactivity control is by varying the light water level inside ZCC. Normally Adjuster rods are fully inserted, Control rods are fully withdrawn and average ZCC level is in between 30% to 50%. In case of shortage of negative reactivity / positive reactivity indicated by high / low ZCC level, Control rods and Absorber rods are driven in / driven out bank wise in a specific sequence. The ARs and CRS are driven at a speed proportional to power error.

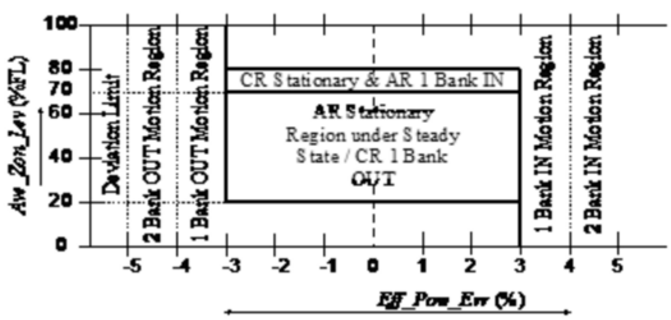


Fig.-1 Summary of reactivity control logic

6.6 Shutoff Rod withdrawal logic

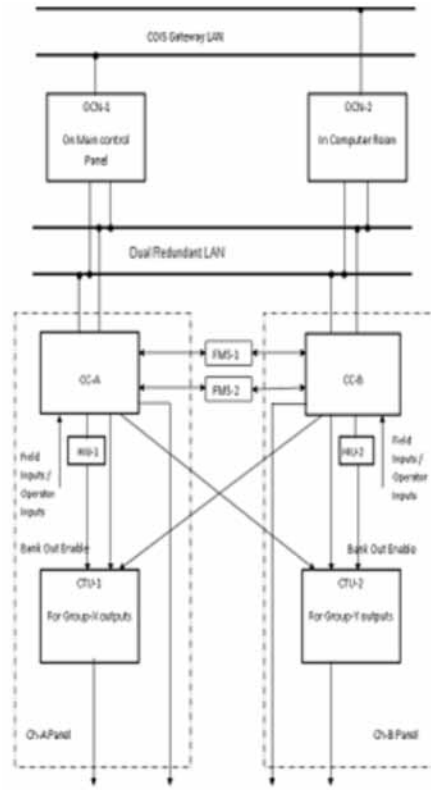
Dropping of shutoff rods are executed by Shut Down System-I but withdrawal of shutoff rods is controlled by Reactor Power Control System. Withdrawal is inhibited until reactor trip signal is cleared. 28 SRs are grouped into two banks. Normally SRs are withdrawn one after another bank. Withdrawal is stopped if power error or rate log power exceeds a specified limit.

6.7 Manual Control

Manual movements of ARs, CRs, SRs are limited during power operation to control the addition / removal of reactivity. Manual control of ZCC inlet valve is also possible during power operation. Manual operation is liberalised during low power (<0.1%FP) operation for initial physics experiments.

7. DUAL COMPUTER HOT STANDBY ARCHITECTURE

The Reactor Power Control algorithms are implemented on two independent but identical embedded computer referred as Control Computers (CC) using DCHS architecture.



Output to field / operator information

Fig.-2 DCHS Architecture

Each of the two CCs acquires all field inputs and operator inputs, performs all control algorithms and generates all the outputs in an identical manner. The outputs of the two CCs are selected and sent to field through a Control Transfer Unit (CTU) to control the reactivity devices depending on the healthiness of the CCs. Bank Out commands are passed through a Hardware Interlock Unit (HIU). In case of unintended Bank Out Commands generated by software, HIU detects the fault and restricts the addition of reactivity. The overall architecture is shown in Fig.-2.

8. CONCLUSION

Earlier Reactor Power control System was made using multi-nodal architecture with dependency on network for the control. Now it is attempted to implement similar requirement with DCHS Architecture independent of network for control purpose.

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RADIATION MONITORING SYSTEM IN INDIAN NUCLEAR POWER PLANTS

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Abstract

Nuclear energy is economical and environmentally clean option when compared to other main sources of energy like coal fired power stations. But it demands special attention to protect public, environment and plant personnel from undue hazards of nuclear radiations that are produced during reactor operation. These are Neutron, Alpha, Beta and Gamma. As Low As Reasonably Achievable (ALARA) principle is followed to keep radiation exposure minimum in all the operational and accidental conditions of the nuclear power plant.

Radiation Monitoring System monitors the different forms of radiation thus contributing in controlling and minimising the radiation exposure. This paper covers various radiation detection and measurement techniques like Ion Chambers, Proportional Counters, GM Counters, Scintillation Detectors, etc.

INTRODUCTION

The radiation exposure of the persons within the Nuclear Power Plant boundary and public is to be as low as reasonably achievable in all operational and accidental conditions. Any abnormal increase in radiation field in the operating plant or its vicinity is generally a consequence of a reactor incident or accident. Hence continuous monitoring of radiation levels at selected locations gives indication of reactor incidents and system malfunctions. This is particularly helpful in areas which are not accessible during normal operation of the plant. This paper explains the radiations basics and its effects, types of radiation exposure, radiation effects, radiation sources in Nuclear Power Plant, radiation detection techniques, various types of radiation detectors and various radiation monitors used in Indian Nuclear Power Plant.

RADIATION BASICS AND ITS EFFECTS

RADIOACTIVITY

The spontaneous emission of radiation from radioactive material is called radioactivity. The rate of emission depends on the half-life of that material. Half life of radioactive material is the time after which only half of the initial number of atoms remain or the initial radioactivity is reduced to half. The unit of radioactivity is Becquerel (Bq).

NUCLEAR RADIATION

During the process of radioactive decay, the unstable nucleus gives out energy in the form of radiations. Alpha, beta, gamma and neutrons are the primary radiations emitted by radioactive atoms.

Alpha Radiations (α)

These are energetic particles emitted from the nucleus of radioactive atom having low neutron/proton ratio and high atomic number (Z) such as uranium, plutonium, thorium, etc. Alpha particle contains 2 protons and 2 neutrons. Hence it is also called helium nucleus (2He4). Alpha particles are highly ionizing. However it can’t travel more than an inch in air and very less in other materials.

Beta Radiations (β)

These are fast moving electrons of nuclear origin approaching the velocity of light that are emitted from nucleus of atom having high neutron/proton ratio. They can be stopped by plastic or aluminum. Even high energy beta particles can be stopped by ½ inch of plastic or plywood.

Gamma Radiations (⍰)

These are electromagnetic radiations like light, X-rays, UV-rays. Gamma radiations are emitted from the nucleus of the atom when it moves from excited higher energy state to its ground state. It usually follows an alpha or alpha-beta emission. Gamma radiations have high energy and high penetrating power. Gamma rays can never be stopped completely. Heavy shielding of materials such as concrete, lead, iron, several feet of water is required to bring down the intensity to an acceptable level.

Neutrons

These are neutral particles. Neutrons have very high penetrating power. They are slow moving. Neutrons are emitted by elements such as uranium and plutonium during fission (splitting of an atom). Hydrogenous materials like water, paraffin, etc. can be used to absorb neutrons.

QUANTIFICATION OF RADIATION

Equivalent Dose relates the absorbed dose in human tissue to the effective biological damage of the radiation. Equivalent dose is the product of amount of average energy deposited per unit mass of the medium (in standard case the medium is air or human tissue) and radiation weighing factor (for gamma radiation it is 1). Equivalent dose is generally called as dose in Nuclear Power Plant. Its unit is Sievert (Sv).

TYPES OF RADIATION EXPOSURE

Plant personnel or public can be exposed to radiation by means of external and internal radiation. When the source of radiation is outside our body, the dose received is known as external dose. The external dose is mainly due to gamma radiation.

When the source of radiation is inside our body, the dose received is known as internal dose (through ingestion, inhalation, injection, or absorption through the skin). The major radioactive sources of internal exposure are Tritium (H-3), Iodine-131, Sr-90, Cs-137, Rb-106, etc.

RADIATION EFFECTS

The biological effects on human body are classified as High Dose (Acute) and Low Dose (Chronic). Exposure to high doses of radiation over short periods of time produces acute or short term effects like vomiting, skin burn, hair loss, radiation sickness, etc.

Exposure to low doses of radiation over an extended period of time can produce chronic or long term effects like various types of cancer, genetic effects, etc.

RADIATION SOURCES IN A NUCLEAR POWER PLANT

Fission Products and Activation Products are generated in nuclear reactor operation.

FISSION PRODUCTS

These are the byproducts generated during Nuclear reactions (fission) in the reactor. Nuclear fission products are the atomic fragments left after the fission of large atomic nucleus. Typically a large nucleus like that of uranium undergoes fission by splitting into two smaller nuclei. These two smaller nuclei are known as fission products. Along with this, a large energy in the form of heat, neutrons and gamma rays are also released. Most of these fission products will decay rapidly, since they have very short half-lives. However, several fission products have very long half-lives and decay very slowly. Fission products generally decay by beta and gamma emission. Some of the significant fission products found in the Nuclear Power Plants and their half life are listed below.

Sl. No.	Radio Nuclide	Half Life
1	Rb-88	17.8 m
2	Xe-133	5.29 d
3	I-131	8.01d
4	Nb-95	34.95 d
5	Ru-103	39.5 d
6	Cs-134	2.07 y
7	Kr-85	10.72 y
8	Sr-90	29.12 y
9	Cs-137	30.14 y
10	C-14	5728.8 y

ACTIVATION PRODUCTS

These are the radioactive materials which are produced by neutron exposure. The absorption of neutron by the nucleus of a substance changes itself into a radioactive nucleus. For example, Argon-41 is formed by activation of Argon-40 (about 1% of air) wherever air is exposed to neutrons. Some of the activation products found in the Nuclear Power Plants and their half life are listed below.

Sl. No.	Radio Nuclide	Half Life
1	N-16	7.13 s
2	O-19	26.9 s
3	Ar-41	109.5 m
4	H-3	12.4 y

Corrosion products are activation products removed from the reactor or systems by chemical or electrochemical reactions. Some of the corrosion products found in the Nuclear Power Plant and their half life are listed below.

Sl. No.	Radio Nuclide	Half Life
1	Ni-65	2.52 h
2	Fe-59	44.5 d
3	Zn-65	243.9 d
4	Mn-54	312.5 d
5	Co-60	5.27 y

DETECTION OF NUCLEAR RADIATIONS

All charged particles such as alpha and beta directly interact with the medium through which they pass by electrostatic interaction and produce ionization and excitation i.e. they split up the neutral atom into positively charged ion and negatively charged electron.

Gamma rays also directly interact with the medium through which they pass by the interactions (such as Photo-Electric, Compton and Pair-Production) and produce ionization.

As all radiations are associated with energy, its presence can be detected using an instrument by its property of ionization / excitation of medium through which it passes.

In general a Radiation Instrument has the following:

a) A sensitive volume of a suitable medium where radiation can produce ionization/excitation.

b) A device to convert the output of ionization to electrical signal.

c) A processing unit to process the electrical signal as per requirement.

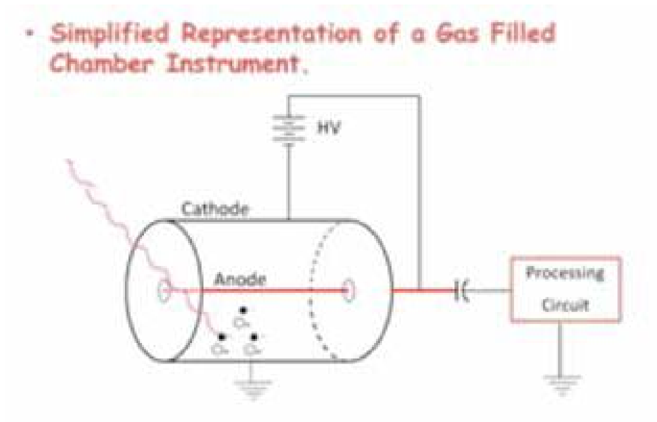
a) and b) together form a detector.

TYPES OF RADIATION DETECTORS

There are different types of radiation detectors such as Gas Filled Detectors, Scintillation Detectors and Semi-conductor Detectors.

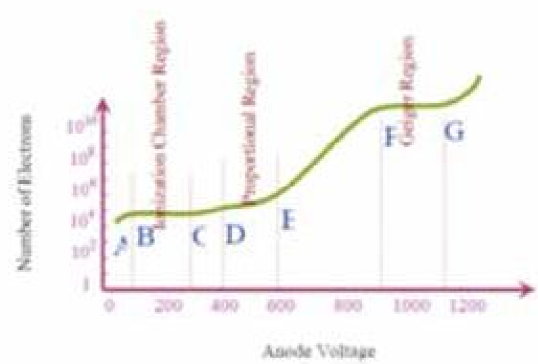
GAS FILLED TYPE

A gas filled detector consists of a chamber of volume ranging from 1 cc to 5 litre, filled with gaseous medium such as argon, nitrogen, air, etc. A pair of electrodes having high voltage (DC) of the order of 100-1000V across it collects the charge due to ionisation caused by radiation and produces electrical signal in the form of voltage pulse or current.



VARIOUS REGIONS OF OPERATION OF A GAS FILLED DETECTOR

In theory, the same detector can be used as an ionization chamber, a proportional counter or a Geiger-Muller counter, depending on the applied voltage.



Ionization Region

In this region (between B and C in above figure), the number of electrons collected is equal to the number of primary electrons produced. Ion Chambers working on this principle are used in high radiation areas.

Proportional Region

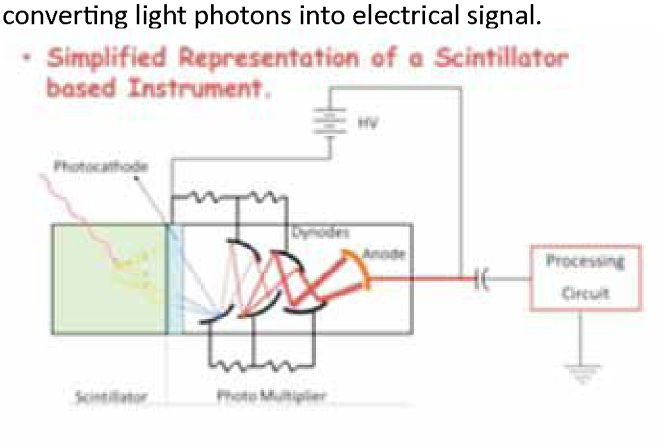
In this region (between D and E), the number of ion pairs collected is greater than the number of ion pairs produced initially. This is due to gas amplification phenomena. Detectors operating in this region are more sensitive and hence are used in detecting low level alpha, beta and neutron radiations.

Geiger-Mueller Region

In this region (between F and G), due to large gas amplification factor, a point is reached where the number of electrons produced remains pretty well constant irrespective of incident radiation. Detectors working on this principle are called GM detectors and are most sensitive to low radiation levels.

SCINTILLATOR TYPE

Scintillator type detector consists of a small sensitive volume of material which emits light when radiation interacts with it. Photo Multiplier Tube is used for converting light photons into electrical signal.



SEMICONDUCTOR TYPE

This type of detector uses a small volume (few cc) of semiconductor material (usually a PN junction) in which a depletion region is created to produce an active volume by using reverse bias. Charge in terms of electron-hole pairs is generated when radiation interacts with this depletion region.

A pair of electrodes, having high voltage (DC) in the order of 1500V across it, collects the charge and produces electrical signal in form of voltage pulse.

PROCESSING UNIT

The processing unit consists of electronic circuitry and modules, which amplify and shape the feeble electric signal obtained from the detector and pass it through various discriminators to gives output in any of the following forms:

- Rate of radiation - Rate meter.
- Integrated No. of radiations in a particular period – Scalar.
- Particular band of radiation energy - Multi or Single channel Analyzers.

The above outputs are calibrated to directly read in Dose, Dose rate, Activity, etc.

DIRECT READING DOSIMETERS

Direct Reading Dosimeters (DRD) have small gas chamber in which ionization produced can be directly calibrated to read in dose using electronic circuits. Electronic Dosimeters can have micro-processor based circuits to store other information also. These are used to measure gamma dose received by an individual.

THERMO-LUMINESCENCE DOSIMETERS

Thermo-Luminescence Dosimeters (TLD) have a special material which stores energy deposited by radiation and when processed by heating, emits scintillation which is directly proportional to amount of energy absorbed. Thus the scintillation output can be calibrated to read the integrated dose. It is used to measure gamma dose received by an individual.

FILM DOSIMETERS

Film Dosimeters have a photographic film kept under various types of filters (metal, plastic, etc.). The radiations produce blackening of film. The filters are useful to identify and distinguish different types of radiations. The degree of blackening is calibrated to read integrated dose.

RADIATION MONITORS IN NUCLEAR POWER PLANT

Radiation levels in and around the plant may be higher as compared to other normal areas by virtue of the radioactivity being present there. To monitor and ultimately ensure the radiation levels within the permissible limits, various radiation monitoring instruments and systems are installed. Prominent among them are:

1. Area Radiation Monitors: GM detectors are used to monitor radiations in the low radiation areas of the plant. Ion Chambers are used to monitor radiations in the high radiation areas of the plant.

2. Stack Activity Monitors: Scintillation type detectors are used to monitor any release of iodine, particulate and gamma activity though stack.

3. Environmental Radiation Monitors: Scintillation type detectors are used to monitor radiation levels around the plant boundary (1.6Km radius).

4. Ventilation Duct Radiation Monitors: GM detectors are used to monitor radiations levels in ventilation exhaust duct.

5. Tritium Monitors: Compensated Ion Chamber based detectors are used for monitoring tritium activity in air and plastic scintillation type detectors are used for monitoring tritium activity in water.

6. Process Water Activity Monitors: Scintillation type detectors are used to monitor N16/O19 activities in the secondary side of the heat exchangers to know the leakage from primary side.

7. Contamination Monitors (Friskers): GM detectors are used to monitor plant personnel clothes or equipment for any contamination at inter-zonal crossing points to restrict the spread of contamination.

8. Hand and Foot Monitors: GM detectors are used to monitor hand and foot of plant personnel for any contamination at inter-zonal crossing points to restrict the spread of contamination.

9. Portal Monitors: GM detectors or proportional counters are used to monitor whole body of the plant personnel for any contamination when exiting from the plant.

10. Radiation Data Acquisition System: This is a computer based system which acquires the signals from all the radiation monitors. It gives various types of displays like Alarm, History, Trend, etc. in the Main Control Room of the Nuclear Power Plant.

11. Portable Areas Survey Meters: GM detectors are used to monitor area radiation levels during the manual survey.

12. Personal Dosimeters: Used to measure radiation dose received by an individual.

13. Like any other power plant, liquid and gaseous effluents are monitored before its release to environments. In nuclear power plants these effluents are continuously monitored for detecting presence of any radiation.

CONCLUSION

Radiation Monitoring System monitors radiation levels in and around the plant during operation and accident condition to minimize and control the radiation exposure to plant personnel and public. New technologies like Online Multi Channel Analyser based gaseous activity monitors, Proportional Counter based Portal Monitors, Radiation Monitors with Ethernet/Wireless communications are being developed and introduced in the future Nuclear Power Plants to improve the sensitivity and remote operation of these monitors.

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BIOGRAPHIES

Shri Vinayak B., Executive Engineer (C&I), graduated in Computer Science and Engineering from BDTCE Davangere, Karnataka. He joined Nuclear Power Corporation of India Limited in 2002. He is presently working in NPCIL HQ Engineering Directorate – C&I group looking after Design and Engineering activities pertaining to Radiation Data Acquisition System, Radiation Monitoring System, D2O Leak Detection System for Pressurised Heavy Water Reactors (PHWR).

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Shri N. S. Kaintura, Additional Chief Engineer (C&I), graduated in Electronics and Telecommunication Engineering from IETE New Delhi. He joined Tarapur Atomic Power Station - 1&2 of Nuclear Power Corporation in 1981. There he was associated with maintenance activities for various Control & Instrumentation Systems including Radiation Monitoring System and Neutron Monitoring System. Since 2002 he is working in NPCIL HQ in the Directorate of Engineering - C&I Group looking after engineering activities pertaining to Radiation Monitoring and D2O Leak Detection System for new 700MWe PHWR plants. Shri N. S. Kaintura is also an MBA in Operation Research.

Reactor Control and Protection System of VVER-1000

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ABSTRACT

This paper provides an overview of typical Reactor Control and Protection Systems (RCPS) of VVER-1000 NPP. This system plays a key role in controlling, regulating reactor power during normal conditions and initiates protections (reactor trip, stepback, setback and holdback) based on neutronic and process parameters when their operating limits are exceeded. The paper deliberates upon various areas related to Reactor Control and Protection Systems (RCPS) like sensors, design philosophy, system architecture, implementation strategies, final control element, testing facility and software V&V aspects etc.

Keywords

Reactor Control and Protection System, Single Failure Criteria, Redundancy, Common Cause Failure, Fail Safe Operation, Main Control Room, Self Diagnostics, Online Testing, Optical Isolation, 2/3 coincidence logic.

Introduction

Russian VVER 1000 MWe pressurized water reactor is a leading type of VVER reactor worldwide. The design has been evolved from serial design of VVER plants and fall in the category of generation III +, advanced light water reactor with enhanced safety features. C&I systems are designed and developed based on international/ national standards like IEC/IAEA/GOST. It involves modern technology; advance features and uses hybrid combination of C&I to ensure safe, reliable and quality operation of NPP. RCPS is the most important C&I system which plays vital role in control and protection function of reactor.

Reactor Control and Protection System (RCPS)

The basic design target of a protection and control system is to achieve safe operation and shutdown of reactor when called upon. The reactor control part of the system is intended to operate safely and reliably, while maintaining maximum power output of reactor as per demand and by handling plant transient like load throw off etc., while the protection part of the system is designed to detect departures from acceptable plant condition and introduce adequate negative reactivity into reactor to shut it down. In order to achieve the above objective, the system monitors neutron and process parameters and uses control rods (distributed into groups) as final control elements. It encompasses the following subsystems:

A. Emergency Protection and Preventive Protection (EP-PP) System

B. Automatic power controller (APC)

C. Rod Control and Indication System (RCIS)

D. Final Control Element(Control Rods)

Each subsystem of RCPS is described as below:

A. Emergency Protection - Preventive Protection (EP-PP) System: It is designed to monitor the reactor (process and neutron flux) parameters and bring the reactor in sub-critical state by dropping all control rods under gravity whenever trip parameters exceed their set points and maintain the reactor in sub-critical state. It also performs preventive protection functions like set back (i.e. reduction of reactor power at predefined rate), step back (i.e. quick step reduction of power) and hold back (i.e. generation of prohibition for raising power).

Design Philosophy and Implementation: An EP-PP system is a hardwired system with limited use of software. It consists of two independent three channel sets, which take care of redundancy & single failure criterion. Each set is independent from each other starting from the parameter sensing to the final control element and are kept physically separate in different buildings. Each set has similar design and comprises of redundant signal processing channels, digital logic processing units and actuating equipments. All these equipments are arranged in such a diversified way that the potential risk of common cause failure is eliminated among the channels in a set and also between sets. By adopting local 2/3 coincidence for every trip parameter and as well as global 2/3 coincidence, spurious EP actuation is prevented. The EP hardware is designed as a failsafe system to maximum extent i.e. even if any damage/breakage of equipment or their failure to perform its intended function/loss of power supply occurs it will lead the reactor in safe state i.e. trip of the reactor. To avoid spurious actuation of EP due to control power supply failure, complete EP hardware is provided with two redundant uninterrupted power supplies. Moreover, EP being most critical system for nuclear power plant, use of software is limited only to transfer of information for display, recording purpose and also for calculation of complex algorithms to generate trip parameters like Departure from Nucleate Boiling Ratio (DNBR) and Linear Heat Generation Rate (LHGR). Protection software is qualified as per IEC 60880. Several modern features like, the conversion of current/voltage to frequency signal to achieve high noise immunity, self diagnostic, sharing of signals with proper galvanic/optical isolation etc are also adopted in designing of this system. Proper isolation for shared signals allows interaction of reactor trip with other control system ensuring that influence of control system failures on trip system is excluded. Moreover EP is designed in such that EP command has highest priority over control system. To enhance reliability and preparedness of the EP system, it is provided with online self testing facilities upto module level. Reactor trip can also be initiated by operator from main control room (MCR) and supplementary control room (SCR) (Provision for manual actuation).

System Architecture: EP system structure consists of hardware for EP as well PP function. It is logically divided into two parts viz initiating part and actuating part.

1. Initiating Part: It consists of two independent sets of three channels each, acquires neutron and process signals, does set point comparison and performs necessary 2/3 local logic processing before generating emergency or preventive protection signals. It consists of sensors, signal processing and comparator blocks, logic processing blocks and display equipment. Each of these parts of the system are briefly described below:

Sensors: The parameters, which are monitored by EP-PP system, are mainly neutron flux, pressure, temperature, level, seismic effect etc. EP system measures neutron flux in the core starting from subcritical state to full power. This calls for elaborate arrangement to measure neutron flux over complete range as wide as 10 decades. To cater such wide spectrum, monitoring range can be divided into 4 sub-ranges with overlap of minimum one decade. Different neutron detectors like B-10 counters, ion chamber, fission counter/chamber etc are used to monitor neutron flux in different ranges. To monitor other process parameters, sensors like K-type thermocouple, pressure transmitter, level transmitter, capacitor type accelerometer etc are used.

Signal Processing and Comparator Block: The signals from neutron detectors as well as process sensors and transmitters are given to conversion units (CU) which is located near sensors. CU does the pre- amplification of received signals and converts them into the frequency signal of range from 0.5 to 50 kHz. The frequency signals are then transmitted to signal processing and comparator block which are located far off from CU. Signal conditioning and processing is done in signal processing and comparator blocks and frequency signals are converted into digital code. The digital code equivalent to the current value of a neutronic and process parameter is compared with the set point and discrete signal is generated whenever current value of monitored parameter exceeds set points. From sensor upto signal processing device, hardware is common for EP and PP function. From comparator block onwards, separate modules are used for EP and PP functions.

Signal Logical Processing Equipment: Each SLPE receives discrete signal from set point comparators of signal processing block. In SLPE, physically separated modules are used for EP and PP function. SLPE realizes 2 out of 3 voting on binary output signals for each and every trip parameter (local coincidence), performs time delay and executes AND/OR logical operations as per requirement. The output of SLPE thus generated is final EP or PP command at channel level, given to the actuating part with suitable isolation.

Display Equipment: It acquires information on current value, set points of monitored parameter and signals on EP-PP actuation for registration, archiving and display function. Additionally, it transmits the information to upper level plant control system for operator information and display purpose.

2. EP-PP actuation part: It has a two independent sets receiving triplicate EP-PP signals from Initiating part and generates final EP-PP signals after global 2/3 processing. Each set consists of two Emergency Command Cabinets (ECC) and two Power Supply Cabinets (PSC) units. Each of these parts of the system is described briefly in following paragraphs.

Emergency Control Cabinet (ECC): It receives the three generalized EP-PP signals from respective EP-PP initiating set. The signal transmission is done by proper optical isolation between EP initiating part and ECC units. Each ECC consists of 2/3 logic units that perform 2 out of 3 majority of three received signals. The two ECC units of a set are located in two separate rooms of a safety building, hence not affected simultaneously due to common cause failure.

Power Supply Cabinet (PSC): The output signals of ECC of a set are given to two PSC units of respective set. Each PSC unit has set of AC and DC breakers housed in it. These two PSC units for a set are located in a room called power interrupter room. On receiving EP signals from any ECC unit breakers get de-energized. As a result, AC (380V) as well as DC (110V) power supply to all CRs drives gets disconnected and leads to reactor scram by falling of all CRs under gravity.

elf diagnostics and online testing facility: The EP-PP system includes self-diagnostics of its hardware circuitry and the results of this diagnostics are displayed on the front panels of the cabinets. Additionally, information on the state of the equipment of EP-PP system goes to the local display equipment, where failures of the equipment of EP-PP system (up to the changeable module) are detected with the help of software diagnostic means (Online diagnostic). Generalized failure signals are formed according to the results of the diagnostics and transferred for display on Main control room (MCR), separately for each set of EP. Failure signals can be viewed by maintenance personnel with the help of video-displays on the monitors of server cabinets. In addition to this, EP-PP part allows to conduct automated checks of the equipment from sensor up to power supply contactors in the process of reactor operation at power without disturbing its operation. Extensive system diagnostics and modular construction ensures easy fault identification and its rectification.

B. Automatic Power Controller: The Automatic Power Controller (APC) is designed to control the reactor power by moving the control group of RCPS control rods through the Rod Control and indication system (RCIS).The APC can operate in the following modes:

- Reactor power control mode ‘N’ – APC maintains neutron power of reactor and turbine control system maintains steam pressure in the main steam header (MSH) in accordance with neutron power maintained by APC.
- Steam pressure control mode ‘T’ – Electric power is maintained by turbine control system and APC maintains constant steam pressure in the main steam header (MSH) by varying the reactor neutron power in accordance with electric power maintained by turbine control system.
- Flux control mode ‘C’– APC monitors the steam pressure in the MSH under the flux tilt control from the in-core flux mapping system.

Design Philosophy and Implementation: APC consist of two redundant cabinets; working on dual processor hot standby principle, i.e. one acts as working while other will be in hot standby mode. Each APC is capable of performing all operations individually (Redundancy). Normally all outputs are controlled from working APC cabinets which is selected by operator and the second cabinet remains in hot standby mode. Input signals to each APC cabinet are fed from independent sets of sensors (Independence). If the working controller fails, there is automatic bump-less switch-over to the redundant controller without interrupting the function of automatic power control of the reactor. The circuit solutions adopted in APC also ensure availability of APC in single failure mode. APC includes means for online diagnostics, the results of which are displayed on the front panels of the cabinets and transferred via network connections into the server cabinet which is part of RCIS (Online self diagnostic).

System Architecture: Each APC is a two-channel device based on micro controllers. The two channels are identical and operate synchronously. Micro-controller inside APC cabinet independently processes the input signals and generates the outputs as per selected algorithm in the form of discrete <UP> and <DOWN> command signals. However final command signal is formed based on coincidence logic of output signal from both micro-controllers and transferred to RCIS for “UP” and “Down” movement of control rods. With this dual processor hot standby configuration, it is possible to ensure high availability of the system with enhanced fault detection capability.

APC Mode Transition: “N” mode is the default mode for APC when it is switched ‘ON’ and after actuation of set back/hold back/step back function/ CR fall or on exceeding of the assigned value of the neutron power and reactor period, APC automatically switches over to “N”-mode from “T” or “C” mode. In “N” mode, if main steam header pressure exceeds 0.245 MPa from preset value, APC automatically changes over to ‘T’ mode. Otherwise APC enters into “T” only on operator command. APC also generates command to disconnect MCDS from the direct control when the preset steam pressure in the MSH is exceeded by 0.19 MPa in mode ‘C’, and simultaneous generation of the command for reduction of the reactor power. APC enters into “C” mode only when operator initiates direct control from the MCDS.

C. Rod Control and Indication System (RCIS): RCIS is designed for regulating reactivity and power distribution of the reactor by moving control rods individually or in groups automatically or manually based on command signal from APC or operator in MCR. RCIS also provides indication for all control rods positions extreme as well as continuous in the MCR with an accuracy of +_1.5 to 2%. The RCIS equipment performs the following functions:

a) Automatic decrease of the reactor power by means of dropping one preset group of control rods (CRs) or a part of it in response to step back signals;

b) Automatic setback of the reactor power by means of downward movement of CR groups with working speed, in a strictly prescribed sequence, starting from the last group withdrawn, in response to set back signal (action stops after removal of the set back signal);

c) Generation of inhibit to increase the reactor power in response to hold back signal (the inhibit is cancelled after removal of the hold back signal)

d) Automatic and remote control of CR groups in manual, semiautomatic, automatic and individual mode of operation.

e) Monitoring of CR position by means of position signals.

f) Indication of CR groups position on MCR and SCR and individual CR position on the monitor of the operator desk.

Design Philosophy and Implementation: It is micro controller based system which comprises of Power Control and Position Indication (PCPI) group complexes to perform the position monitoring and control of CRs. The circuit solutions adopted in RCIS ensures that no single failure of active component can cause reactivity insertion. In addition to this, CRs and groups of CRs are moved only at the availability of two commands – address command and control command “UP” or “Down”. Address and control commands are formed by different RCIS equipment, which increases reliability of control function and reduces the probability of unauthorized movement of CRs and groups of CRs during failures (Diversity). The means available for indication and display of information on CR position to the operator are redundant within RCIS scope. It also includes two redundant server cabinets which work based on hot-standby principle, ensuring acquisition, processing, archiving of the information on the position of all reactor CRs, state of CPS electric equipment, drives and CR position sensors. All necessary controls & indications are provided in main control room for operator interface (advance operator interface). All equipments of RCIS include means of online diagnostics, the results of which are displayed on the front panels of the cabinets and transferred via network connections into the server cabinets (Online self diagnostic).A generalized signal of RCIS failure is formed in server cabinet and transferred for display on MCR. The generalized signal is decoded with the aim of failure localization by the servicing personnel with the help of video displays on the monitors of server cabinets.

System architecture: As mentioned above, RCIS structure consists of power control and position indication group complexes, each of which performs the position monitoring and control of six CR belonging to one group. Each complex consists of:

- One no. of monitoring and control cabinet for position monitoring and control of six CR.
- two no. of power control cabinets (PCC) to control movement of six CR drive power

RCIS also includes Software-hardware complex of individual choice intended to implement the function of individual control of separate CRs or CR groups and Software-hardware complex of information and diagnostic network intended for acquisition and processing of the data related to CR position, state of CPS electrical equipment, CR drives and position indicators, as well as the diagnostics of electromagnetic drives and position sensors PPS, the transmission of the information to the upper level control system, formation of generalized failure signals and transmission thereof to MCR-SCR.

D. Final Control Element: The reactor control and protection system consists of upto 121 CPSAR (B_4C + Dy_2O_3) distributed into 10 groups. They are used for start up, power control, excessive reactivity compensation & reactor shut down. To control the reactor power, groups from 7th to 10th are used. To shut down the reactor, all the CR groups are used. During normal operation only gr 10 CPSAR will be inside the reactor core and all other CR (1-9 gr CPSARR) will be parked outside the core.

The CPSAR cap has a receptacle for bayonet engagement with CR-drive extension shaft. Extension shaft is coupled with displacement unit, displacement of extension shaft is performed by successive actuation of electromagnets by current cycles. During reactor scram, three electromagnets are de-energized, the latches are open and extension shaft with the CPS AR drops downwards by gravity. Drop time used in safety analysis amounts to 4s max. Function of reactor emergency protection is accomplished considering sticking of one CPS AR with the highest worth in the extreme upper position.

Software V&V aspects: Software used in RCPS has been designed using pre-developed sub-systems/ modules containing pre-developed software (PDS) and incorporating incremental modifications. V&V process of RCPS is in line with requirements of IEC 60880, IEC 62138 and AERB SG D-25. Guidelines of NUREG-6421and IAEA TEC DOC-1328 for qualification of commercial off the shelf (COTS) are considered.

Conclusion

RCPS of VVER-1000 is one of the most modern and reliable systems. Its advance features play a key role in enhancement of the safe, reliable and efficient operation of Power Plant. Among all C&I, RCPS contributes significantly by controlling reactor power during normal operation and tripping reactor at hour of need.

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BIOGRAPHIES

Smt Nabanita Pyne graduated in Instrumentation and Control Engineering from Applied Physics Department, Science College, Calcutta University in 2002. She joined Nuclear Power Corporation of India Limited (NPCIL) as trainee in 2002. After successful completion of NPC training, she joined as SO/C in C&I design group for Kudankulum Project (KKNPP) in NPCIL, Mumbai. At present she is working as Senior Executive Engineer (SEE) in Design Group of NPCIL, Mumbai for Kudankulum Project and associated design, design review, software V&V activity of MCDS, EP, and Reactor Control System.

Sh Kamlesh Nathani graduated in Electronics Engineering from SES COE, Pune University in 1997. He joined Nuclear Power Corporation of India Limited (NPCIL) as trainee in 1997. After successful completion of NPC training, he worked as commissioning engineer in Kaiga 1, 2 Power unit and contributed in commissioning of primary system and common services. At present he is working as Deputy Chief Engineer (DCE) in Design Group of NPCIL, Mumbai for Kudankulum Project (KKNPP) and associated design, design review, QA, software V&V activity of MCDS, TPTS, EP.

S.K.Sen is an Electronics Engineer from VNIT, Nagpur. He graduated from 29th Batch of BARC Training School and joined Narora Atomic Power Project (NAPP) in 1986. He was instrumental in commissioning of Reactor Control and Reactor Protection Systems of NAPS Unit-1 & 2, which were first of its kind in PHWR design. He became Senior Maintenance Engineer (Inst) of NAPS in 2002. He was deputed to World Association of Nuclear Operators (WANO) Tokyo Centre from 2005 to 2008 as Program Manager and NPCIL Liaison Officer. Since 2008 June, he has been working at NPCIL HQ as Additional Chief Engineer(C&I) for the design review of Control and Instrumentation of Kudankulam Nuclear Power Project (KKNPP).

Automation Advancements in various Fields including

EDIFYING THE SMART FUTURE OF POWER UTILITIES BY ANALYSING THE CONCEPT OF GENERATION SIDE VIRTUAL POWER PLANT

Saroj Chelluri DGM (PE-Elect) NTPC Ltd, Amit Kulsheshtra DGM (PE-Mech) and Prasenjit Pal DGM & STA to Director (Tech), NTPC Ltd

Abstract:

The Power Business is leaping towards a new Paradigm. The shift towards smart technologies, with intelligence inbuilt in devices, is making the electrical equipments visible, controllable and communicable. Digitized bits are taking us towards to a new revolution,' The SMART REVOLUTION'.

To realise the true value of Smart Grids, Power utilities which have generation units in a large geographical spread and which are injecting power into the Power Grid at different points need to re organise their business models and portfolio management to meet the future challenges.

The paper is a study report for utilizing the Concept of Generation side Virtual Power Plant for a large Power utility to optimize the entire portfolio, and also to leverage and optimise power generations from various stations to reduce/ shift power demands, optimize generation cost, fuel management and emissions. The Revolutionary Concept of Generation Side Virtual Power plant has been studied for the present Indian Power scenario and its various implications and benefits have been discussed.

Keywords

Smart Grid, Virtual Power Plant, Indian Power Grid, IEC 61850

(A) INTRODUCTION

The Power generation utilities are today in a period of change and challenge. There are the compelling issues of increasing size and complexity of grid with high power system loadings, increased distance between generation nodes and loads, fluctuating renewable, need for energy storage and increasing volume of energy transactions. The other constraints are cost pressures, increased transparency of energy consumption patterns and significant regulatory pressures both for transparent and competitive energy pricing and emission controls.

It is the time for Power Generation Utilities to start exploring the new business models that can be built by leveraging the two way connectivity with the customers that the Smart grid technology promises. The potential to physically and financially optimize both generation portfolio and day to day utility operations for optimized generation patterns and integrate commercial operations with demand response programs is quite large and realizable.

(B) THE INDIAN POWER GRID

India has a skewed distribution of natural resources like coal, gas and hydro required for electrical power generation. This necessitates generation of power at one place and its transmission to the load centres. Grid interconnections besides enhancing the reliability of power systems help in transfer of power from surplus eastern states to deficit areas. Indian Grid is one of the one the largest transmission network consisting of about 2700 Circuit km of 765 KV transmission lines, 90,000 Circuit km of 400 KV lines,1,23,000 Circuit km of 220 KV lines and carrying more than 1,50,000 MW of power every day to a large geographical spread with high availability.

The electricity grid in India is a conglomeration of the power systems owned by various utilities. The whole grid was originally divided into five regional grids namely the North, West, East, Northeast and South. As of now four of these are operating in the synchronous mode since August 2006 and the interconnection is called the "New Grid". The southern regional grid is presently connected to the new grid through several High Voltage Direct Current (HVDC) asynchronous ties and a few AC lines in radial mode. A power map of India is shown in

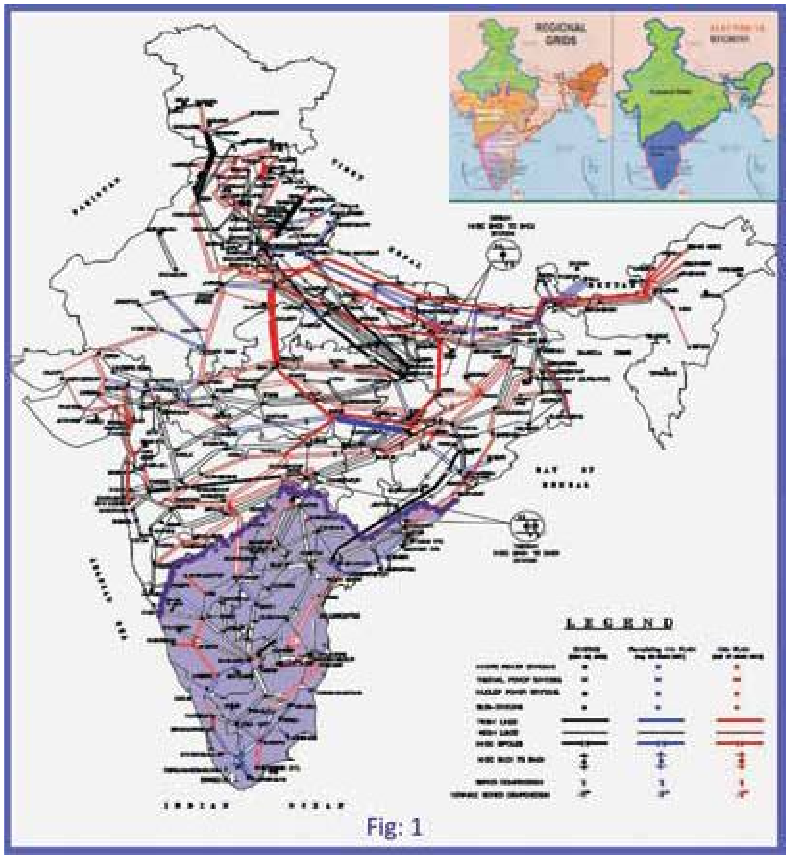


Fig: 1

National Load Despatch Centre (NLDC) is the apex body responsible for ensuring integrated operation of National Power system. Regional Load Despatch Centres (RLDC) as per the Electricity Act 2003 has been designed as the apex bodies in their concerned region for secure, economic and efficient operation of the grid. Regional Framework as provided by the Indian Electricity Grid code (IEGC) notified by Central Electricity Regulatory Commission (CERC) lays down rules, guidelines and standards to be followed by various agencies and participants in the system to plan, develop, maintain and operate the power systems in the most efficient, reliable, economic and secure manner while facilitating healthy competition in generation and transmission.

(C) SMART GRID - THE GAME CHANGER

The Indian Power Sector is growing at a fast pace and the business environment is changing rapidly under regulatory purview. The complexity of the National power systems is expected to increase with more and more interconnections, bulk power transfer corridors, international interconnections, higher transmission voltages and new technologies in generation and transmissions.

The advent of Smart Grid technologies, increase in competition among participants and evolving market mechanisms is likely to increase the pressure on system operations as well as on the generating utilities to evolve new models for efficient operations. The challenge is now to adopt the changing paradigm and facilitate new emerging concepts.

Smart Grid can be considered a game changer which shall change the unidirectional power flow in a grid to a bidirectional concept of power flow. The key strength of the Smart Grid Concept is a high level of visibility and controllability of the complex Power system with increased level of information sharing between the individual components and sub systems of the power supply system. With the roll out of a Smart Grid, the complexities concerning the economic dispatch, demand response, generation portfolio management become a challenge as well as an opportunity to implement a futuristic approach.

This technical paper presents a futuristic approach of creating Virtual Power Plant (VPP) for a Power Generation Utility with generation units spread over a large geographical area and injecting power into a large transmission grid at various injection points.

(D) VIRTUAL POWER PLANT (VPP) FOR A GENERATION UTILITY

SMB Smart Grid Strategic group (SG3) had prepared the IEC Smart Grid Standardisation Road map in June 2010. The roadmap conceptualizes the Virtual Power Plant concept. A virtual power plant (VPP) in this context is defined as a collection of decentralised generation units that can be monitored and controlled by a super coordinating energy management system. The concept of VPP has been mainly created for distribution side in the Smart Grid concept. This technical paper gives a generic concept of creating the Virtual Power Plant (VPP) for the Generation side and edifying the benefits for a Power Generator utility from such a model.

Consider a typical large Power Generating utility which is generating about 35, 000 MW of power injecting power into the Power Grid. The power is being injected in to the grid from about 25 power stations geographically located over entire India with the farthest point of in the south in the state of Kerala to Assam in north Eastern part. In such a scenario, the Virtual Power Plant (VPP) concept for Generation can phase in the benefits of the Smart Grid.

The entire generation portfolio needs to be divided into zones for effective integration of data, operations and control. The division can be dependent on a specific type of pricing, power purchase agreements, demand response, fuel type, and geographical areas depending on the point of connections and can also be based on the Utility's own decentralised control areas.

The Virtual Power Plant- The Centralised Management Centre (CMC) linked

to all Zonal VPPs giving the overall picture of Futuristic Power Business

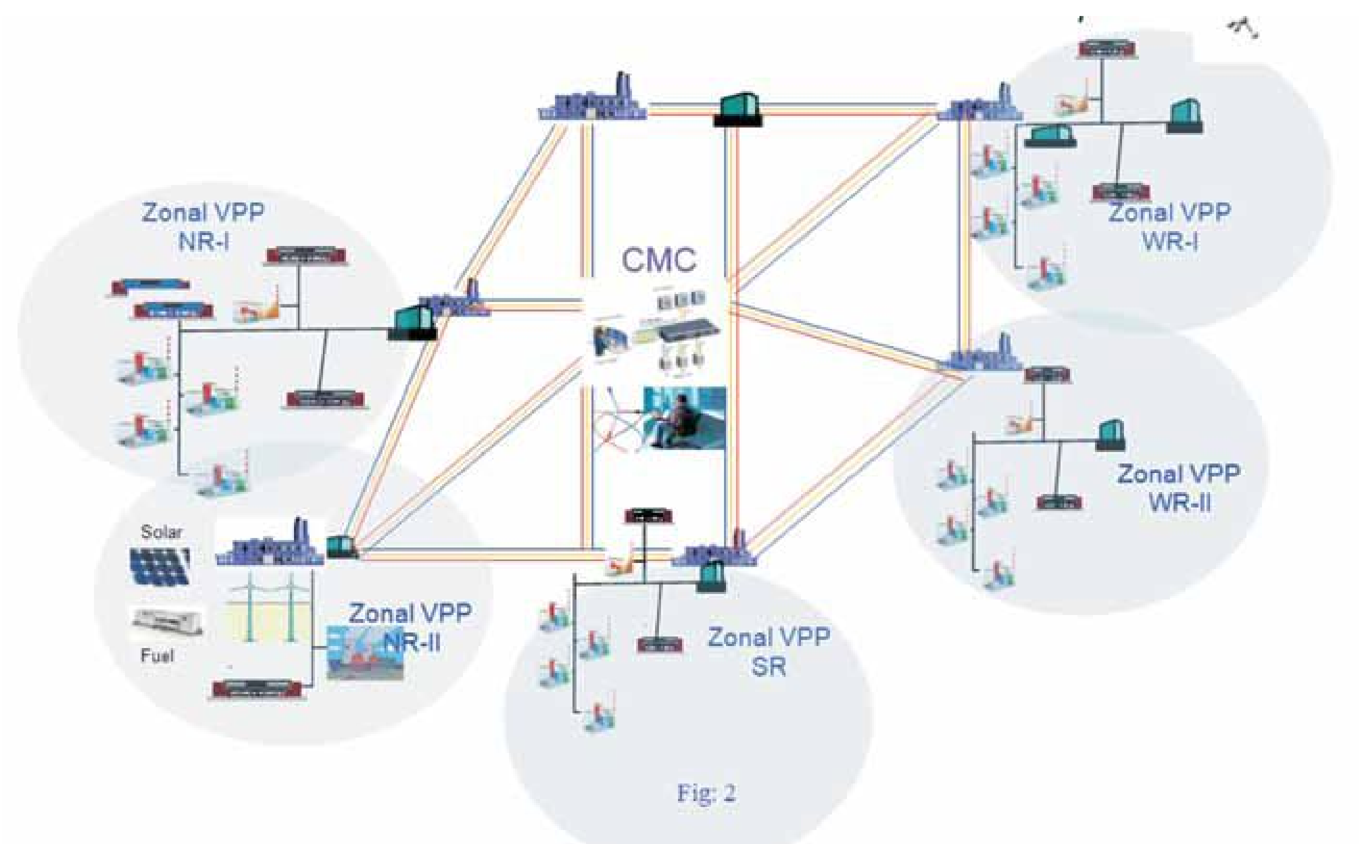


Fig: 2

The concept visualised in this paper has considered the geographical spread of the Power Utility Generation Stations and created geographical zone wise Virtual Power Plants (VPP).

The VPP shall be North I & II, South, East I & II, West I & II and a Central management Centre called the " Virtual Power Plant " The major functions for which the Generation side VPP shall be modelled and designed are:

- Generation Scheduling ,Dispatch and Outage management
- Transaction Evaluations
- Demand response and Short Term Load Forecasting
- Asset management
- Emissions Dash Board
- Status of Evacuation lines capability and availability
- Fuel Status and Monitoring
- Portfolio management

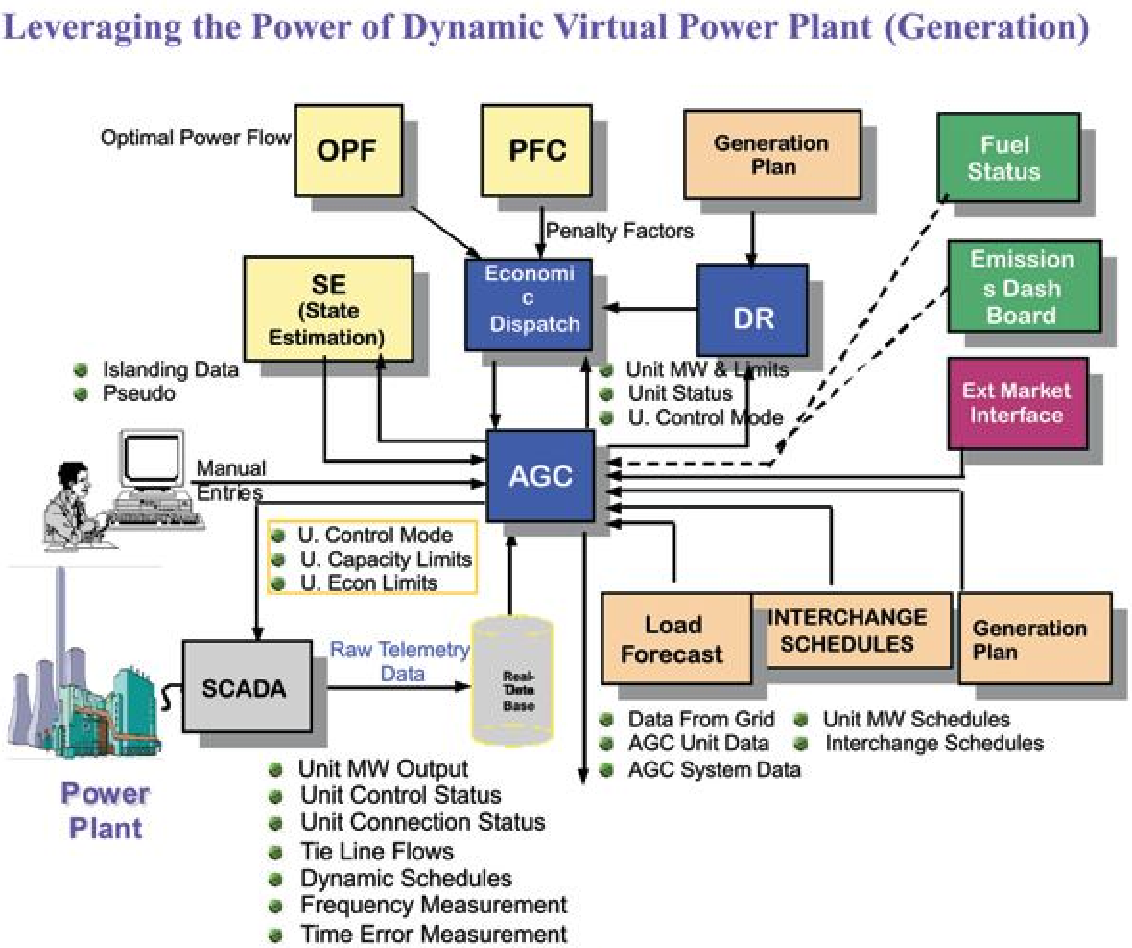


Fig: 3

(a) GENERATION CONTROLS AND DISPATCH SCHEDULING

Conventionally Automatic Generation Controls (AGC) regulates the power output of generating units in response to changes in system frequency, system time error and control area net interchange in order to maintain scheduled values. Standard AGC Software modules are offered by all. But in case of Zonal VPP the Concept can get extended to the group controls. In each of the zone the number of generators shall be more than one, a coordinated group control needs to be designed.

AGC needs also to provide Group control capability to control a group of generating units by sending a single control command for Zonal VPP Generation control Concept. Both raise/lower pulse and set point group controls are required to be provided.

The configuration of generator grouping shall be defined in the database. Each generating unit may provide an Individual/Group status signal to AGC in addition to the Local/Remote status. In a given group configuration, only the generators that have their statuses set to remote and Group will be controlled as a group. The units that are in remote and individual will be controlled individually. In addition, a Local/Remote status signal for the entire group may be defined so the plant personnel can switch the control of the group of generators from AGC to the local computer at the plant.

(b) MULTI AREA AUTOMATIC GENERATION CONTROLS

The system design needs to support multiple control areas, i.e., separate AGC and ED (Economic Dispatch) tasks are implemented for each control area defined in the database.

The Multi-Area ED function needs to solve each control area independently and produce economic base points and economic participation factors for the all the Generators in each Zone. Similarly, each AGC controls the generating units located in the corresponding Zone based on that area’s frequency deviation and net interchange deviation.

(c) TRANSACTION EVALUATIONS

The Transaction Evaluation (TE) function in VPP concept shall evaluate the economic results of possible energy transactions with interconnected utilities. The TE function is a valuable tool in traditional electricity markets also, when searching for the optimal production costs. The Unit Commitment module in the VPP can be used in the calculations to determine the costs with and without the proposed transactions for each of the unit generator in the VPP.

The Transaction Evaluation programs shall model for the cost and operational aspects of the Generators in the ZONE for including:

- Piecewise linear or polynomial incremental heat rate curves for each of the unit.
- Time-dependent start-up costs
- Maintenance and de-ration of units at selected hours
- Spinning and operating reserve
- Fixed generation at selected hours
- Fuels status
- Emission Penalties (futuristic)
- Fixed transactions

The Transaction Evaluation (TE) module is closely related to the Unit Commitment (UC) function, both in order to set up study cases and to evaluate selected sets of transactions. The TE can include different evaluation modes. Further, function for commitment comparison of thermal unit commitment schedules can also be included.

The module can determine the incremental and decremented costs of energy when compared to a base case generation requirement. The results can be used to suggest transactions that can be beneficial to the utility and should be considered for further study.

(d) COMMITMENT COMPARISON

The Commitment Comparison function compares any two Thermal Unit Commitment runs. Special displays can be included in which the differences between the two cases are presented in reverse video. Output displays can be provided showing hourly and total production cost and production cost differences between the studied cases.

The Transaction Evaluation function shall provide hourly summaries of generation, costs and losses and detailed generation and cost information for the "with transaction" and "without transaction" studies. The Transaction Evaluation modules provide the benefits of providing support for optimal generation schedules considering the Unscheduled Interchange (UI) benefits, fuel costs, Point of Connection (POC) charges etc. Outage management of any unit can be dynamically calculated with respect to the Contracted Power cost.

(e) DEMAND RESPONSE AND SHORT TERM LOAD FORECASTING

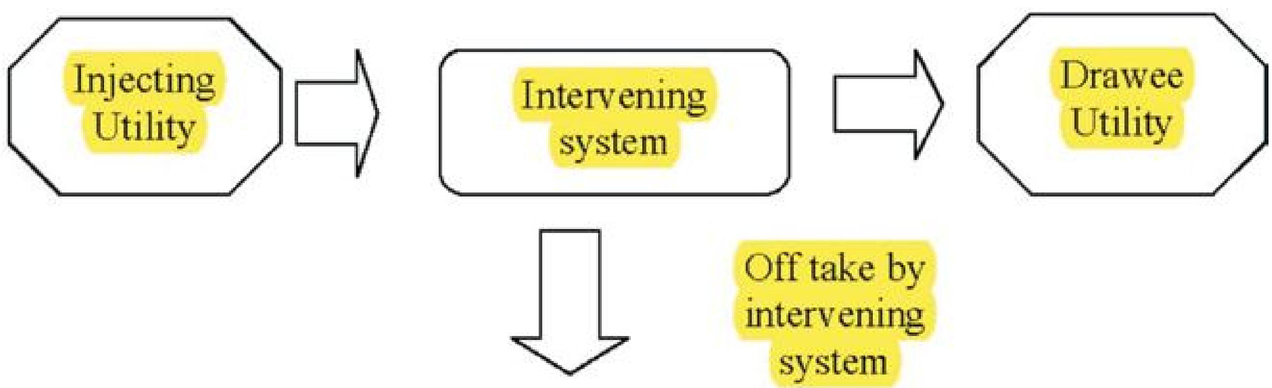
The ability to accurately forecast the short term load is inextricably tied to an electric utility’s financial performance and long-term success. With accurate load forecasting, generation utilities can improve revenues and alleviate dependencies in such areas as economic dispatch, unit commitment, transaction scheduling, and fuel purchasing and grid utilization.

The Smart Grid facilitates on line data availability and that will suit the Neural Network technology and an accurate forecast can be achieved using the adaptive pattern recognition technology of neural networks. Short Time Load Forecast (STLF) helps reduce operating costs through better scheduling of unit start up and shut down, as well as a lower spinning reserve. The Zonal VPP can also import externally generated load forecast for display and use in developing the load forecast. Using this advanced technology, the Network Manager STLF provides an indispensable tool for electric utilities during the shift from cost-based pricing to market based pricing.

(f) STATUS OF EVACUATION LINES CAPABILITY AND AVAILABILITY

Assessment of transfer capability from the associated transmission system is one of the important parameters for Portfolio management. Transfer capability of the network is heavily dependent on the network response to the various transactions between control areas in the system. The sharing of power by each element in the corridor (also known as distribution factor) is not equal. This implies that the transfer capability of a corridor cannot be determined by arithmetic sum of individual transmission capacities of all parallel transmission lines in that corridor. As the power transfer across the section is increased one or more elements could hit the limiting value before the others.

The total power transfer across the section would therefore have to be restricted to the value at which the first element reaches the limiting value. If the loading on each parallel element is balanced with the help of series compensation the transfer capability could be enhanced. However it would be seen that the transfer capability would vary depending upon whether the series compensation is in service or out of service during the period for which the transfer capability assessment is being carried out. The network limitations are also not constant and are time dependent. Very often if we solve any problem in one part of the network, the problem shifts to another part of the network.



Transfer capability is directional in nature. Each control area could estimate its import and export capability by modeling its own system in isolation. But as far as the integrated system is concerned this would be misleading because the component of network loading attributable to transactions between other control areas has been ignored. Further transfer capability is also heavily affected by the amount and firmness of the transaction between the control areas. Even the firm transactions may have deviations in real time which would have to be accounted .This is where the operating philosophy adopted in a grid influences the availability of transfer capability in the network.

Wheeling of power through intervening system

For instance, let us consider State A wheeling a huge quantum of power through the Inter State Transmission System (ISTS) passing through its geographical area. The state draws power from this ISTS as per its share in Central Sector projects. In a case, where the state's off-take from this ISTS varies considerably from the schedule (either high or low), the power transfer through the ISTS shall be impacted.

Thus On line real time data of evacuation system and availability data integrated into the VPP model shall provide the required leverage for Generation rescheduling and UI. As of now long time access contracts with states are tied, but in near future as more and competition is generated, the business scenes may change leaving the market in a free state where in the prices are controlled by demand and supply. Power companies may be facing a completely new situation with more and more deregulation of the energy market, as long-term contracts may get replaced by daily competition. The situation may seem futuristic but is the most probable.

(g) FUEL STATUS MONITORING

Fossil fuel shortages and Gas availability have become the constraints in Generation Planning. The Fuel status links in VPP shall be a vital input for generation scheduling. Also fuel data at other plants and zones can also trigger suggestive generation schedules from a particular Zone /Unit Generator to meet the Unit Commitment.

The parameters on the dash board can be Fuel Data such as Coal Parameters, Calorific value, Stock availability for next day/ week/month and sourcing Data.

(h) EMISSION MONITORING DASH BOARD

Concerns about climate change, environmental impact and sustainable energy solutions, along with a renewed personal sense of responsibility for limiting our carbon footprint, are key reasons consumers are pushing for cleaner, more efficient energy solutions. An integrated Smart Grid allows better planning and management of energy consumption while optimizing the grid through real-time generation and distribution control management.

Specific SOx (mg/Nm3)	
Specific NOx (mg/Nm3)	
Specific Mercury (μg/dscm)	
SPM (mg/Nm3)	
RSPM (μg/Nm3)	
Ash Utilization (%)	

Economic Despatch module in VPP shall enforces fuel and emission constraints through an interface with the Thermal Unit Commitment subsystem. In particular, Economic Despatch(ED) shall receive the data as shown. In the Thermal Unit Commitment to take into account the emission constraints.

The data for the Environmental Dashboard can be either taken from the direct Gas emissions measurement Systems installed in the Power Plants or alternatively estimated based on the calculations of Fuel data.

(i) PORTFOLIO MANAGEMENT AND OUTAGE MANAGEMENT

Portfolio management module in VPP shall provide additional information on "forecasting and usage planning" and "monitoring and control." As a result, a portfolio manager can view color bar graphs showing which power stations are currently running at peak load or at base load and how much power they are producing. The concept can be understood as below:

A Zonal VPP-I has to manage a power generation composed of eight generating units consisting of six coal-fired power stations and two gas turbines used only to provide reserve power, due to the higher fuel costs involved. Now zonal VPP ought to be required to maintain power generation at a reliable level so as to meet the demands of supply contracts, and to produce energy at the lowest possible cost under the agreed Contract. Due to Coal shortage at one the generating station in Zone I, it is required to run the two Gas based stations. The other business option can be using the Generation data, Evacuation capabilities and availability and fuel status from other VPP and reschedule power flow from the other Zonal station instead of running the two Gas based power plants and optimize profits.

That's the only way to ensure that all the information in the power generation system is networked and can be evaluated and processed by everyone involved. In a sense, such a system provides operational personnel with a basis for making decisions at the push of a button. In theory, the technology required to do all this is already available; but today's power supply systems have to be completely transformed in order to implement it. Instead of focusing on merely guaranteeing supply and maintaining sufficient reserves, power companies will have to work in harmony to shape their collective output