to meet widely varying real-time consumption.

The concept of VPP can be applied for Portfolio management and Outage management in Indian scenario for mutual benefits of Consumers and Power Utilities..

As of now efficient merit order operation is maintained by the following mechanism:

A generating utility is required to submit the schedule of availability (declared capacity) in 15 minutes time blocks for next 24 hours. Similarly, Distribution entities also submit their load requirement in 15 minutes time blocks for next 24 hours. The Regional load dispatch centre starts allocating the schedule in the order of increasing variable cost (fuel cost). The generating utility is entitled to get its full fixed cost reimbursed through beneficiaries (already decided based on power purchase agreements) if its declared capacity is more than 85% of its installed capacity. The instantaneous load demand imbalance results in frequency variations, which are taken care of by special tariff for unscheduled load interchange which is a function of grid frequency (UI charges). UI charges are high at lower frequencies and low at higher frequencies.

AT first sight the current system looks perfect. Power is allocated in the order of merit to the stations; fixed cost is reimbursed proportionate to the capacity being maintained. Unscheduled interchange tariff is acting as a frequency stabilizer, incentivizing more generation and lower consumption at lower frequencies and higher generation and higher consumption and lower generation at high frequencies.

However, the current system does not efficiently address the needs of customers and generators when a plant in merit order is not available due to any reason. Customers fail to get the low cost power which they would have got, if the plant would have been available. Similarly the generator does not get the fixed cost reimbursed which they have already spent for that plant.

Virtual power plant concept can overcome these limitations and give a new leap in the Power Generation business. In this revolutionary new concept, surplus capacity of a group of power plants of a generating utility is virtually pooled together in a Virtual Power Plant. Any shortfall/sudden outage of a generating unit can be met through this VPP. This shall enable the uninterrupted energy flow to the customers at the contracted price and also the generating utility can reimburse both the capacity charges and energy charges of the unavailable unit. The source of Power to a VPP shall be the available overload capacity, margins in auxiliary power, and URS(Un-requisite declared capacity).

## VPP AS A WIN- WIN SITUATION

Considering a situation when a plant high in merit order (having lower variable cost) is suddenly tripped or is not available due coal shortage/ overhauling/ or any other fault, the consumer need to meet its requirement through costly Unscheduled Interchange. Subsequently the consumer is scheduled power from a plant lower in merit order. The VPP concept can meet the contingencies of plant trip, forced unavailability or scheduled overhauls. In such a situation the consumer's demand is met at the contracted fixed and variable cost. The Generator is also benefitted as it can honour the contract and does not loose the fixed cost and the incentive. There can also be benefits from higher efficiency and lower percentage of auxiliary power consumption due to plant operating at peak load.

## (E) INTEGRATION AND DATA CONNECTIVITY FOR A VIRTUAL POWER PLANT (GENERATION SIDE)

Highly interoperable communication between all the components is the backbone of the Smart Grid. In today's Power Utility enterprise information exchanges between the various generation, transmission and distribution management systems and other IT systems is not only desirable but necessary in most cases. That means that both data semantics and syntax need to be preserved across system boundaries, where system boundaries in this context are interfaces where data is made publicly accessible to other systems or where requests for data residing in other systems are initiated.

The concept of VPP is based totally a common semantic (data model), common syntax (protocol) and a common network concept. The various interoperability standards which are relevant and a must for development of Power Utility VPP concept are:

(i) IEC 62357 Reference architecture addresses the communication requirements of the application in the power utility domain. Its scope is the convergence of data models, services, and protocols for efficient and future proof systems for integration of all applications for the industry.

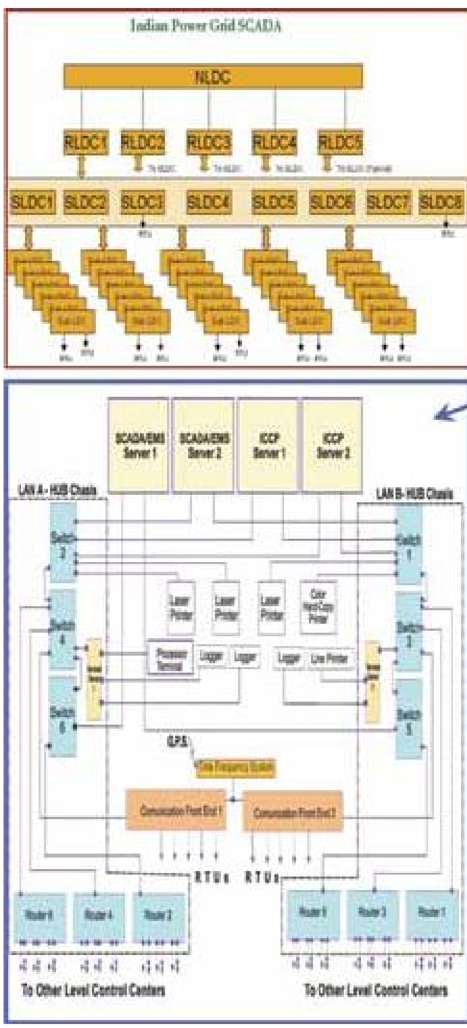
(ii) Communication technology has continued to develop rapidly over the past few years and the TCP/IP protocol has become the established network protocol standard in the power supply sector. The data from the IED's in the each of Switchyard, Smart Grid, Generator and Plant electrical systems are required to be integrated to create the VPP. The Ethernet based IEC 61850 is the world wide standard protocol for protection and control systems used in the modern Power utilities. IEC 61850 supports the direct data exchange of data between IED's thus enabling switching interlocks across feeders independently of the station control units. An important key technology in IEC 61850 is the process bus application.

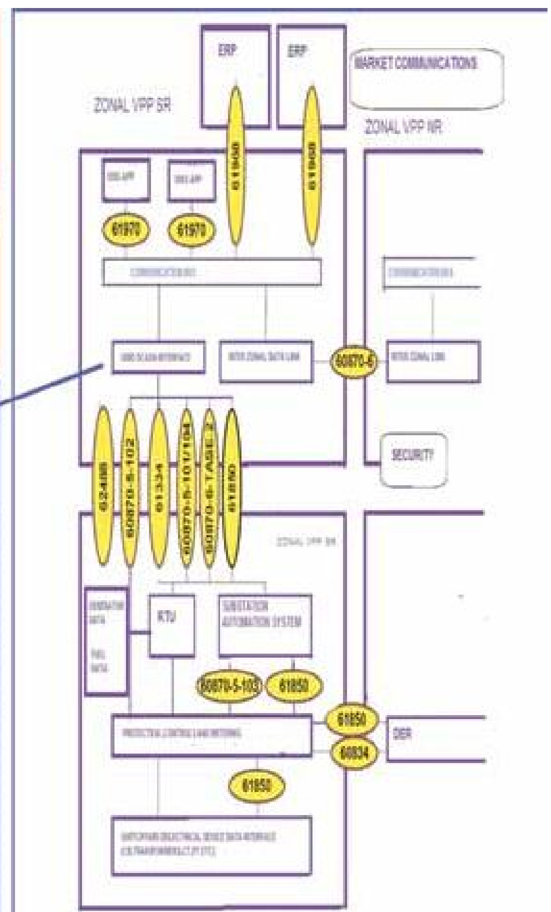
(iii) The relatively new standard IEC 61850-7-420 is perfectly suited for the IEC 62357 reference architecture and Zonal VPP concept for distributed energy resource logical nodes. As the VPP concept needs bidirectional communication between decentralised generating units and central control center. The specical structure of VPP places high demand on the mathematical models for optimization.The models need to be very precise and dependent on DER data. Essential requirement for DER are the Interface, data Models and Protocols for communication between the components of VPP with the management unit. An interface to other web applications shall also be necessary for an integrated approach.

(iv) IEC 61970 for Common Information Models (CIM) is the other relevant and core standard for implementation of VPP .In order to survive and flourish in the energy market, Power utilities face the urgent task of optimizing their portfolios in the competitive market. CIM defines the direct language and data modelling with the object of simplifying the exchange of data between Zonal VPP and the Central Management stations and also with the external environment (Supply Grid/Market etc) to the VPP.

## SYSTEM ARCHITECTURE FOR THE VPP CONCEPT

Considering the recommended reference architecture under IEC 62357, network architecture for the Generator side VPP model is conceptualized. The Generator




*DATA INTERFACE MODEL OF THE VIRTUAL POWER PLANT BASED ON REF ARCHITECTURE OF IEC 62537*

VPP concept system necessitates a network control system which has service oriented architecture with standardised process, interface and communication specifications based on standard IEC 61968 and IEC 61970 which shall form the base for integrating the network control systems in the enterprise environment of the Power Generating Utility. The services of such a network control system shall be data services, functional logic services and business logic services. A typical data integration based on the Reference Architecture IEC 62357 is shown in Fig: 6

The data from the Power Grid SCADA need to be integrated with the VPP model. In the Indian Power Grid each regional grid is managed by a control centre called Regional Load Dispatch Centre (RLDC) and each state power system is controlled by a State Load Dispatch centre (SLDC). System under SLDC has further been divided into Sub-Load Dispatch Centers (Sub-LDCs).

National Load Dispatch Center (NLDC) coordinates the activities of all RLDCs. NLDC, RLDCs, SLDCs and Sub-LDCs have their own SCADA systems, integrated in a hierarchical structure. RLDC being at the top of hierarchy at regional level, coordinates the day-to-day operation of a region in consultation with SLDCs. The RTU communication is on IEC 65870.5 – 101 protocols.

## (F) APPLICABILITY OF THE VIRTUAL POWER PLANT (VPP) CONCEPT AND ITS BENEFITS

Information and communications technology will play a key role in ensuring successful power plant Management in the coming years. This technology will be particularly valuable when it comes to linking a spectrum of energy suppliers into a tight network thus creating the virtual power plants. As the power generation mix becomes more complex over the next several years with the adoption of distributed generation, storage technologies, and demand response (DR) programs, VPP model will be a vital real on line management tool to make every megawatt count. The virtual power plant concept complements the big utility companies with their large, central power plants by creating new suppliers with small, distributed power systems linked to form virtual pools that can be operated from a central control station. The advantages of creating a dynamic Generator side VPP are

(a) Real time Visualization of the Generation status and capability along with fuel, emissions status, and available evacuation lines capability and on line cost of generation.

(b) Analytical Capability and controllability of the model for effective portfolio management and asset utilisation.

(c) Two way communication with the Power Grid for Smart Power Generation options.

Virtual Power Plant Models for Generation side is a unique concept aiming at promoting technology innovation to achieve affordable, reliable, and sustainable power generation. With a common digitalized platform, the VPP shall interact with the Smart Grid for increased flexibility in control, operation, essentially foster the resilience and sustainability of the Power Generators, and eventually benefit the customers with lower costs, improved service, and increased convenience.

The concept is futuristic but the power generation utilities at this juncture need to start aligning themselves to the Smart Grid concept and consider the starting of building the concept of Virtual Power Plant for sustainable business growth.

## (G) CONCLUSION

Physically, a virtual power plant (VPP) isn't really a power plant at all. VPP is the Power Plant of the IT mind - a Plant locked in the digital world that can shift from traditional generation to Smart-grid-enabled parameters. Thinking of Futuristic Power Utilities in emerging business environments, they shall need to assess and forecast energy demand and available resources and draw up cost-optimized generation plans. In addition, market data will need to be combined with power generation data in near real-time and everything will have to be available online.The Virtual power plants lend a macroeconomic advantage by creating and presenting more efficient and competitive business models by analyzing the real time data, historical data and optimizing for the best despite grid fluctuations, varying generation schedules. To sum up, Generator Virtual Power Plant concept is the much required lever to squeeze the extra power from the system and optimize generation in today's era of limited resource. **VPP concept shall make the Power Generators work smart rather than hard!**

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Ms Saroj Chelluri is presently working as Deputy General Manager in Project engineering division of NTPC Limited. Her job involves the design of Protection and Controls for auxiliary power supply systems in power plants, including concept designs, preparation of technical specifications, tender engineering, detail engineering, testing, and execution. She has about 25 years of experience in Electrical design department of NTPC Ltd. She has been extensively involved in medium- and low-voltage system automation designs for the last five years. Saroj has worked on IEC 61850 networks and SCADA systems. She has authored an international paper titled 'Integration Considerations for Large-Scale IEC 61850 Systems' presented at Western Power Delivery Conference conducted by Washington State University at Seattle, USA.

Mr Prasenjit Pal is the currently the President of ISA Delhi section .On The Professional front, he works for the largest Power Generation Company In India NTPC Ltd. and serving as Dy. General Manager(Engineering) & Special Technical Advisor to Director(Technical), NTPC Ltd. In a career spanning 23 years in the Power Sector, he has mainly worked in the Engineering of Coal fired power Plants from Concept to commissioning. His areas of work broadly include Engineering & Design of Power Plant Control & Automation Systems - For coal fired stations, Engineering of solutions for Renovation & Modernisation of Coal Fired Power Plant I&C Systems, Engineering Management & Project Administration for Power Plant Projects, Business Planning, Monitoring & staffing functions etc. Prasenjit's areas of specialization include Engineering of Thermal Power Station Control & Instrumentation Systems including Plant wide IT integration systems and Renovation & modernisation solutions for such systems, Engineering of Training Simulators for Fossil Power Plants and Engineering of Performance Analysis Diagnosis & Optimisation (PADO) systems for Power Plants.

Mr. Amit Kulshreshtha is presently working as Deputy General Manager in Project engineering division of NTPC Limited. His job involves Development of Technical specification, inputs for feasibility Report, Review of Design/ Engineering Drawing/Document, and Interface Engineering for super critical thermal power plants, developing software for engineering and design applications to improve accuracy and speed, Induction of New Technologies such as large size supercritical units, Technology Scanning and techno-economic evaluation of emerging power plant technologies, Technology Mapping of NTPC. Techno-economic Analysis of Solar hybrid power plant with coal fired plant, Quantifying the effects of efficiency improvement technologies on carbon emission for getting CDM benefits and Benchmarking engineering procedures of NTPC against world leaders and suggesting and implementing means to improve engineering procedures.

Mr. Kulshreshtha has done M. Tech from IIT (Delhi) in Power generation technology. His M. Tech thesis on Some Aspects of Automatic Generation control of a Two Area system" dealt with two area model simulation of a power system using a new type of controller for predictive frequency control resulting in better time frequency response.

# Application of Foundation Fieldbus and DART Technology in Power Plants

**Arasu Thanigai**
**Pepperl+Fuchs Pte Ltd, Singapore**

## ABSTRACT

Though traditional control and automation methods have been helping the process industries, the recent trend shows it is time to adapt to the digital arena to further improve the efficiency and reduce the cost of the plant automation. Foundation Fieldbus technology can help increase plant efficiency and reduce total cost of ownership. This paper discusses fieldbus technology and in particular DART, its benefits and advantages in power plants.

## KEY WORDS

Benefits, Cost savings, CAPEX and OPEX, Application Methodologies High Power Trunk, FISCO, DART, Advantages installation, operation, commissioning, maintenance

## INTRODUCTION

Digital technology is increasingly driving changes in the power industry. Its application is evident in all sectors of the power industry, including instrumentation. The introduction of fieldbus technology for instrumentation is closing the digital data communication gap between automation systems and field devices. The result is more accurate values and transmission of values, bidirectional communication, and flexible structures with fewer components.

The 4-20mA signal is the standard used in the power industry for the transmission of process values from the field devices to the control system and from positioners to actuators. The introduction of this standardized current signal resulted in a process automation revolution, saving users time and money with instrumentation. The 4-20mA signal, however, has reached its transmission capacity limits. By contrast the digital signal transmission offers broader bandwidth for plausibility checks and status signals. The digitization of process signals and the associated decentralization represents the most important development that paves the way for the application of a fieldbus system. The subsequent introduction of the fieldbus in power plants has changed the structure of control systems. Fieldbus technology allows shifting central functions into field devices and leads to decentralized structures in the automation systems. These decentralized structures reduce the costs for wiring and assembly and increase the availability. Availability is also increased by improved maintenance and diagnosis through smart instrumentation. Additional cost improvements can be achieved for installation, commissioning, operation, and also space requirements. The introduction of DART (Dynamic Arc Recognition and Termination) fieldbus technology for instrumentation is closing the gap of digital data communication between automation systems and field devices.

## FIELDBUS IN POWER PLANTS

Distributed automation solutions based on open Fieldbus are the current standard for many sectors of the process industry. Fieldbus technology provides more information about the process and the field instrument itself. For the selection of a fieldbus system, not only are costs saving potentials important, but also selecting the "correct" system for the plant. An important characteristic of networks is open communication and interoperable. Open communication is typical for standardized networks where specifications are public. Interoperability of hardware and software components from different manufacturers is therefore guaranteed. Digital communication has been around for a long time but only as proprietary protocols. In the mid-1980's several companies and consortiums started working on a standard protocol. The efforts resulted in Foundation Fieldbus which is a standardized, open, digital communication system for applications in process automation. The protocol is based on the international standard IEC 61158. The technology is suitable for replacement of discrete and analog signals.

## BENEFITS OF FOUNDATION FIELDBUS

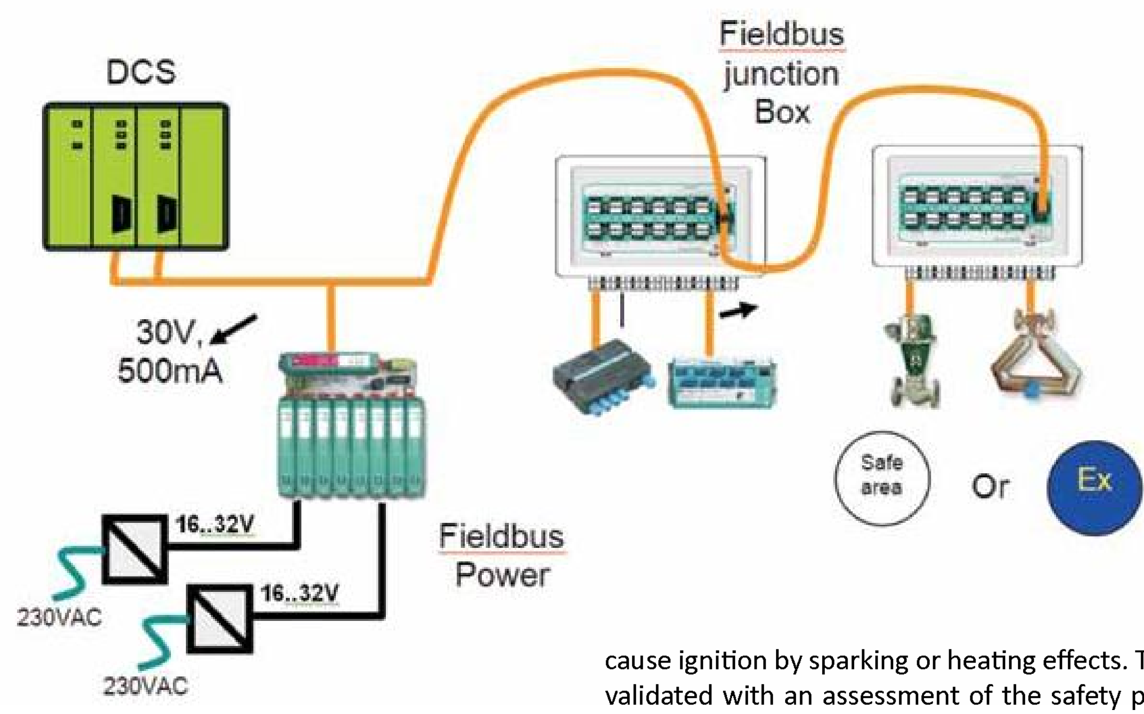
Foundation Fieldbus offers advantages in many areas. The standard has led to a variety of similar products from which customers can select the solution that best fits their needs. In order to increase availability requirements, most components can optionally be redundantly structured. Redundancy can be provided in various stages, starting with a fully redundant structure including DCS and Power supply modules. Availability can also be increased by advanced physical layer diagnostics and diagnostic information from the fieldbus devices. Fieldbus devices can provide more information than just the process value. Digital communication can also send diagnostic information like process temperature, electronic temperature, sensor status etc. Other benefits of fieldbus devices include:

- Preventive maintenance of instruments
- Early prediction of sensor failures
- Fast and precise error recognition of the field devices via diagnostics
- Most importantly CAPEX and OPEX savings

The improved availability increases the life cycle of the plant and is therefore important in reducing the total cost of ownership. Other factors that contribute to this reduction include increased performance and quality improvement. The benefits are achieved through configuration, cabling, engineering, documentation, assembly and commissioning, as well as through plant operation.

## APPLICATION METHODOLOGIES

### GENERAL FIELDBUS TOPOLOGY




Process industries often deploy automation equipment in hazardous areas where equipment operates in the presence of explosive gases or dust. To ensure safe operation in hazardous areas, automation systems are typically designed to be intrinsically safe. Intrinsic safety (IS) is usually achieved by limiting the available power to keep electrical energy below a level that can cause ignition by sparking or heating effects. This can be validated with an assessment of the safety parameters of the power source, the supplied devices, and the connecting cable. IS is the safest method of explosion protection, but its downside is the inherent limit in power (typically less than two watts). This limited power always restricts the total number of devices that can be connected in a segment and the cable length between the control room and field.

## The Evolution of IS Fieldbus

Early solutions for intrinsic safety, such as the Entity concept and FISCO, provided the first methods or connecting multiple devices to a single power supply or fieldbus segment. The low power available limits the number of devices per segment and reachable cable distance, forcing users to design complex bus topologies with many branches and making fieldbus more difficult to cost justify.

### 1st approach – ENTITY

– Limited voltage and Current (Approx. 11V, 80mA). This severely limits the number of devices that can be connected in a segment to less than 4 and the cable distance of less than few 100 meters. It also could not offer the redundancy at the power supply stage. Due to lot of disadvantages, this method typically not used anymore

### 2nd approach - FISCO

– Slightly improved method. Marginal increase in voltage and current (approx, 12.5V, 120mA or 260mA) again limited in terms of number of devices and the cable distance as it could not go upto 1km trunk cable for example. It also could not offer the load sharing redundancy at the power supply stage. Due to lot of limitations, this method typically used at small applications

### 3rd Approach – HPT or FieldBarrier Method

Much Improved in terms of output voltage, current (30V, 500mA), load sharing redundancy, integrated diagnostics etc. Achieves the full capabilities of the FF topology (cable distance of upto 1.9km and number of devices more than 16). The only limitation is, the trunk cable is expected to be installed using increased safety methods either by armor cable of conduit wiring. However due to simplicity and cost efficient, HPT FieldBarrier methods are commonly used in process plant when it goes to Fieldbus.

### 4th and final method – DART

- A Dynamic Approach to Intrinsic Safety. The concept allows considerably higher direct power, while maintaining limitations on intrinsically safe energy via rapid disconnection.

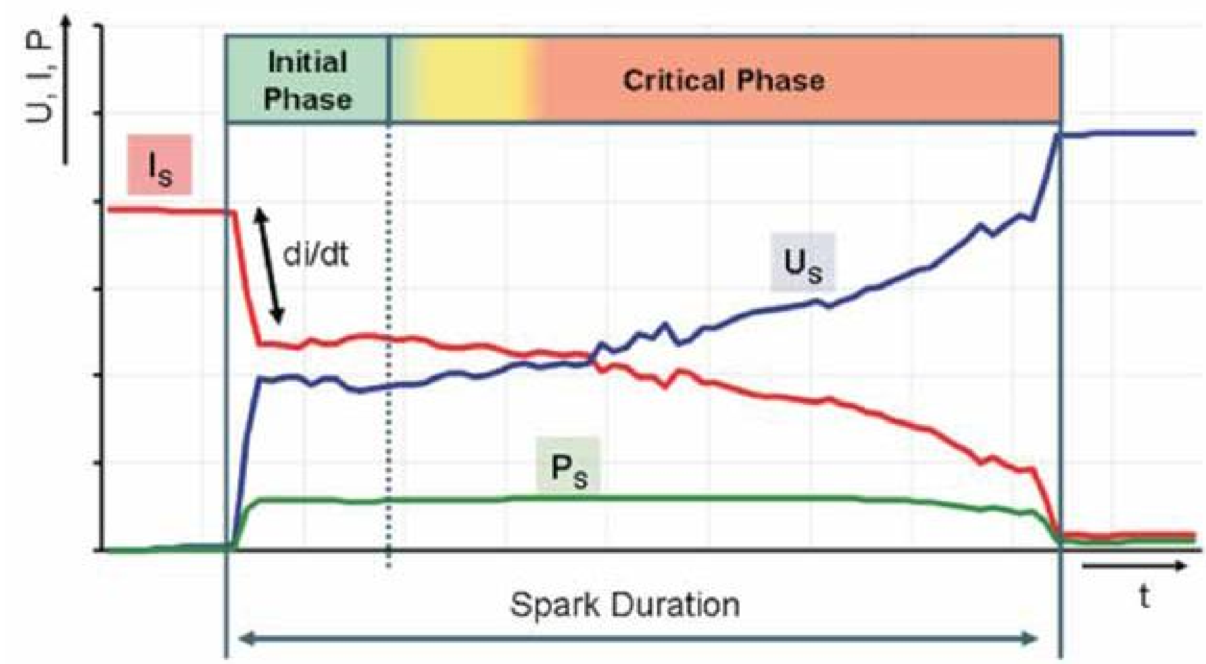



*FIGURE 2. The Electrical Characteristics of a Spark.*

The typical spark generation is shown below and traditionally the intrinsic safety keeps the V, I and P, L and C to a limited value to avoid the spark generation. However the problem is the limited voltage and limited current brings severe design limitation to Fieldbus as there is not enough power to connect more devices and more cable distance ( as in FISCO method, V= 12.5V and I = 120mA).

By re defining the energy limiting concept, the above drawback could be eliminated. DART does not limit the voltage and current permanent but only when there is a fault in the field, then the DART reacts to that. As long as the fault exists in the line, the DART power supply makes the energy limitation accordingly. Under normal operation there would not be energy limitation and the voltage and current parameters are kept considerably higher under normal state.

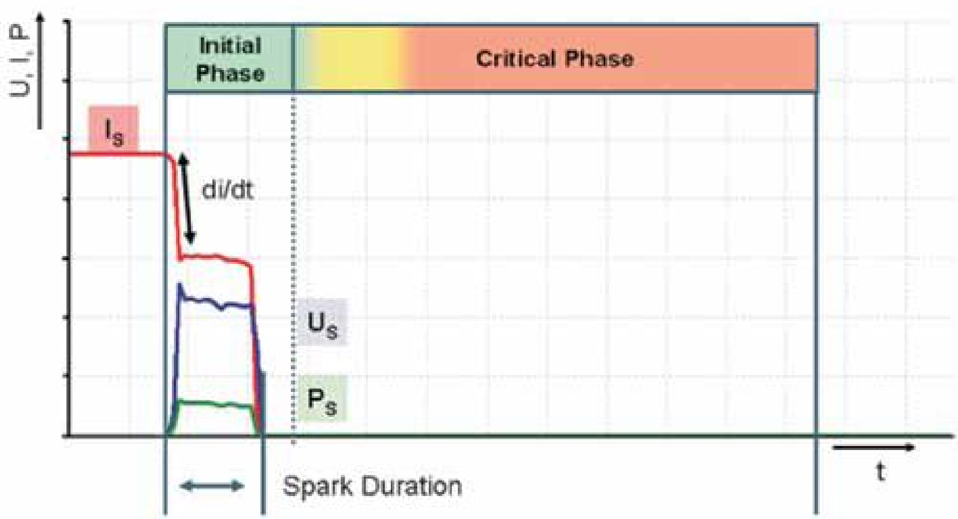



*FIGURE 3 – DART Behavior on sparks FIGURE 3 – DART Behavior on sparks*

DART Monitors the Characteristic Current Drop (di/dt) and Switches off Power before the Critical Phase is reached.

## DART FIELDBUS STRUCTURE

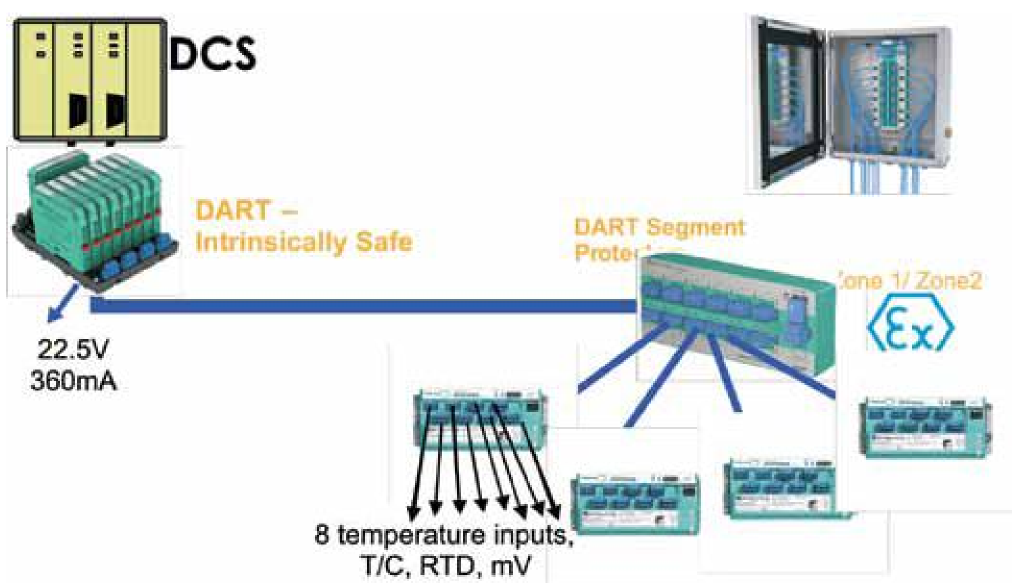



*FIGURE 4*

## TECHNICAL ADVANTAGES OF DART FIEDBUS

- Intrinsically safe protection of entire segment, including trunk line
- Power supply redundancy
- Support for existing intrinsically safe devices
- Continuous advanced physical layer diagnostics
- Trunk cable lengths to 1000m and spur cable distanced upto 120m- long enough for most applications and overall cable distance of upto 1900m
- Simple verification of IS during planning of each segment
- Could be used at Safe locations, Zone2 and Zone1 IS and non IS applications.

## ADVANTAGES OF FOUNDATION FIELDBUS and DART IN PROJECTS

The introduction of Foundation Fieldbus has closed the gap of digital data communication between automation control systems and field devices. The improved functionality of Foundation Fieldbus offers advantages throughout all stages of a project:

## INSTALLATION PHASE

- Reduced wiring, Material saved for cabling, reduced hardware such as IO cards and cabinets and therefore saving engineering and installation time
- Faster assembly and reduced errors

## Instruments can be installed in locations close to the process for direct measurement;

- Right design concepts such as fully redundant High Power Trunk (HPT) and DART are available that extends the digital communication to maximum field devices with longest cable distance possible to reach every process location.
- Multivariable fieldbus devices E.g. Single Fieldbus devices could handle eight temperature inputs or discrete inputs

## COMMISSIONING PHASE

- With onboard integrated Advanced Diagnostics device (ADM) on the DART Fieldbus power supply, to supervise the physical layer, the Commissioning time is reduced to > 50%
- A single technician could handle the commissioning procedure from the control room and no need to have large resources
- Communication faults can be located from the control room
- Unlike 4-20mA devices, calibration is not required since the digital device measures the full range of process values

## OPERATION PHASE

- High resolution of the measured value
- The original signal is not altered by analog/ digital conversion
- Higher transmission reliability
- Digital communication is not subject to noise or other environmental disturbances
- Multiple information form the field devices made available to improve the availability
- ADM continuously monitors the Fieldbus network and report to DCS system to increase the operational reliability

## MAINTENANCE PHASE

- Physical layer health and the device diagnostic information is continuously available at DCS for predictive maintenance; maintenance is performed only when scheduled or required
- Easy and fast troubleshooting from the control room with expert system advice provided by physical layer Advanced Diagnostics device
- Fewer trips to the field
- No periodic calibration
- Plug and play by downloading replaced instrument settings to the new instrument

With the demonstrated advantages at every stages of the Power plant process, Foundation Fieldbus offers the faster time to commission the plant and increase the availability of the plant to its highest level.

## CONCLUSION

Foundation fieldbus is a market leader for process plant applications which could be easily applied to power plants with its proven technological and economical advantages. Recent interface components are optimized with higher power delivering capability to the field and thus achieving economical fieldbus design. The decentralized architecture and the diagnostic information especially are increasing availability of plants. Additional availability can be achieved by choosing the right design concepts such as High Power Trunk (HPT) and DART and extending the digital communication to maximum field devices. The risks are limited because of the proven identical communication protocol with advanced diagnostics capability at the physical layer level and also at the device level.

With the benefits realized by using DART method even brings simplicity and cost savings to the projects at various levels of the plants starting from the design, installation & commissioning and the continuous operation,.

## ACRONYMS

CAPEX – Capital Expenditure

OPEX – Operations expenditure

DSC – Distributed control system

PLC – Programmable Logic Controller

FISCO – Fieldbus Intrinsic safety concept

HPT – High Power Trunk Concept

DART – Dynamic Arc Recognition and Termination

ADM –Advanced Fieldbus Diagnostics Module device

IO – Input / Output

IS- Intrinsic Safety

IEC- International Electrotechnical Commission

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## ACKNOWLEDGEMENTS

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## BIOGRAPHIES

Sh. Thanigai Arasu was born in Kancheepuram (Chennai), India in the year 1970. He holds B.Engg in Electronics and Communication Engineering from University of Madras, M.S in Control Automation from Nanyang Technological University Singapore and Business Administration from Manchester business School UK. He joined Pepperl+Fuchs Singapore in 1997. At present he is working as a Business development Manager for Fieldbus and wireless systems, which includes design, and Engineering of fieldbus projects around Asia Pacific. He involves in various fieldbus seminars, technology promotion and an active member of Foundation Fieldbus Asia Steering committee, Profibus, WirelessHART and FDT/ DTM technology groups.

## POWER TO CONTROL THE PROCESS CONTROL

Over the years the trend setters in the Process Control and Automation field have stressed on the need for enhancements in terms of Innovation in Technology, Uptime & Maintainability, Safety and Reliability. As the automation systems in process industry need to work on all continents in different conditions from Offshore to the Desert. Knowing the importance of the precise parameters and utilizing the same for the Control purposes is the hallmark. The Control System is the Heart of Process Industry (Power Industry) and the heart of the Control Cabinet is the Switch Mode Power Supply which pumps the required energy to the rest of the process components in the cabinet.

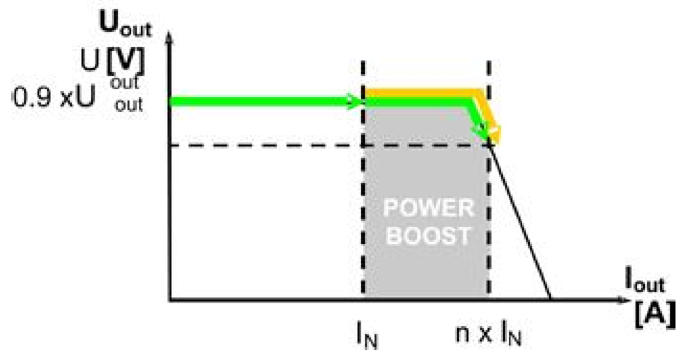
Availability of a control system therefore depends directly upon type of power supply equipment used in the cabinet. Proper selection of power supplies ensures the long life of connected electrical and electronic component. Any failure in power supplies immediately reflect on to the process and resulting products

For this reason it is important that the SMPS power supply equipment used for process control should satisfy all the stake-holders i.e.

- Engineering Designers and Consultants
- System Integrators
- End Users

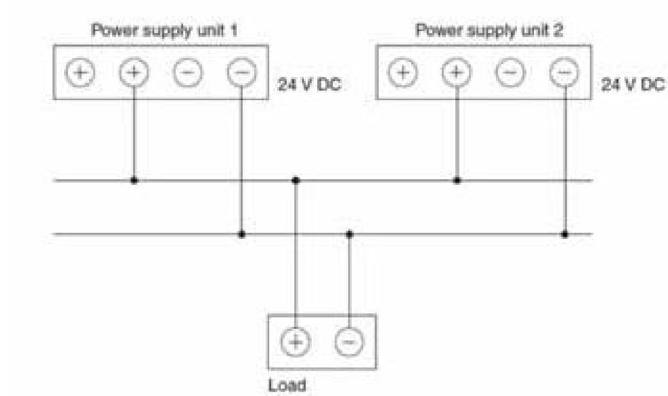
### POWER for ENGINEERING DESIGNERS and CONSULTANTS:

**Static Power Reserve :** For the system designer's it is very important that the SMPS is able to take care of any future expansions of the loads and also be over-rated for the un-expected high in-rush currents during start-up. If the SMPS has a Static Power Reserve feature then there is no need not to worry about anything else. Otherwise every time during start-up the additional current is drawn from the system, which reduces the power available to the other components temporarily and thereby reducing their performance or showing a PLC error.




The Phoenix Contact SMPS Power supplies equipped with static power reserve or POWER BOOST feature ensures that the power supplies deliver the necessary increased current of up to almost 50% above the nominal rated value. For Example, with the POWER BOOST feature, 40A SMPS can handle a load of 45A permanently ensuring flexibility in system designing and maximum reliability during start up.

Maximum Reliability throughout the entire system by Redundant Operation : Redundant circuits are intended to supply systems, which have a high demand concerning operational reliability. If a fault occurs in the primary circuit of the first power supply unit, the second device automatically takes over the complete power supply without interruption, and vice versa. For this purpose, the power supply units to be connected in parallel are designed large enough to enable the power supply of all loads using only one power supply unit. Also Load Sharing between both the Power Supplies is very important to increase their service life and ensuring maximum system availability for a longer time period



Phoenix Contact Power Supplies connected in Parallel serves both the purpose- Enabling Redundancy and Increase in Efficiency. Power Supply units shall be used in parallel if a single power supply unit does not cover the total current requirement of the system. For 'n' parallel connected Power Supplies, the output current can be increased to n x IN. For example for a load of 80A, two power supply units of 40A shall be used in parallel to achieve 80A load requirement.

Wide range input : The input range of the SMPS is also a very important criterion that has a decisive advantage. Whether the input is 120VAC or 230VAC or even a DC Voltage, the input voltage does not need to be set separately on the SMPS power supplies with wide-range input feature. Only this kind of a feature permits the entire control system installation to be tested at any location worldwide and delivered across the globe without faulty input voltage switching.

## POWER for SYSTEM INTEGRATORS

Dynamic Power Reserve for Selective Fuse Breaking capacity: In a normal practice it is seen that different types of loads are connected to the same power supply including the controllers. For the protection of different branches in the output of the SMPS circuits use of thermal circuit breakers is a common and economical practice.

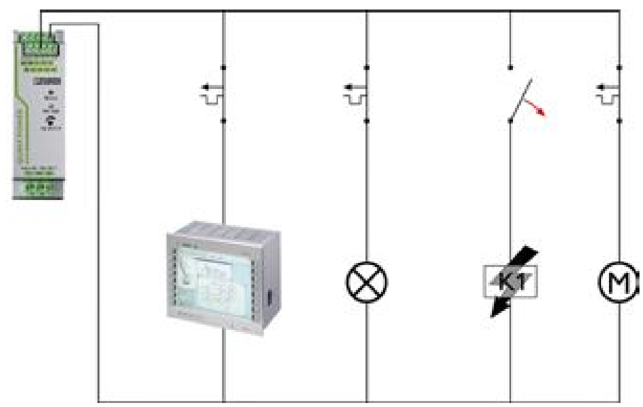
In the event of short circuit in any branch of the connected load, one of the following may occurs when a conventional power supply is connected –

- √ Circuit breaker dedicated to that particular branch load does not trip instead main circuit breaker trips.
- √ In worst case none of the branch circuit breakers trips and further leads to stress in the circuit
- √ Power supply folds back (0 VDC output) due to higher load demand from faulty circuit

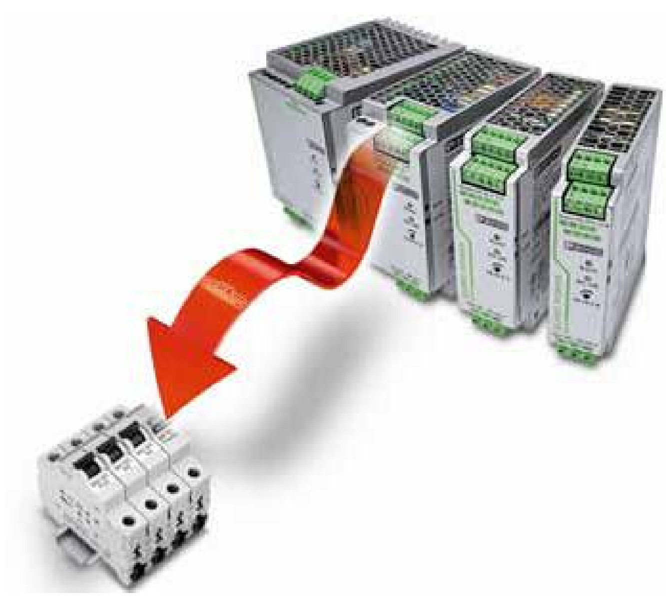
Which results in a total shutdown of the control system power supply including power supply to the controllers.

Why?

Because conventional SMPS Power supplies does not have the Dynamic Power Reserve and hence can not give in the required current sufficient enough to trip the lower rated thermal circuit breakers in the required time before the complete Power Supply trips. Only the EXPENSIVE fast acting special electronics circuit breakers can trip under such a case but the cost of such sensitive circuit breakers prevent the control system integrators to use the feature.




Whereas the Power Supplies with Dynamic Power Reserve are designed to sense the short circuit and to deliver the 6 times the nominal rated current for 12ms max, which 100% ensures the tripping of normal type of Class B Circuit breakers without having the need to install expensive fast acting special breakers. And after disconnection of short circuited load in less then 12ms time, remaining healthy loads works uninterrupted which gives the optimum design flexibility to a system integrator to selectively design their control circuit.



## POWER for END USERS;

**Preventive Function Monitoring (The early warning solution for the system)**: 24 X 7 availability of the system is the biggest challenge for the End Users. With respect to the control power supply, one of the challenges for a maintenance engineer is to get an advance warning before any failure. Phoenix Contact SMPS Power supply with preventive function monitoring feature therefore comes in very handy for the operators in process plants from the advance diagnosis point of view due to which the Output Voltage and current can be permanently monitored with the help of LEDs and remote monitoring is also possible through active signal outputs available on the SMPS.

Permanent monitoring of the output voltage and output current allows critical situations to be visualized in advance and hence preventive actions can be planned in advance.

The early diagnostics that should be available Power Supply can be summarised as below

| Output condition at the Power Supply | Visual Indication | Indication to the controller |
|---|---|---|
| **I ≤ In** (Nominal Range)<br><br>Load Current is within the Nominal Current range | **LED "DC OK"** | Active "Nominal" Output |
| **I > In** (Power Boost)<br><br>Load Current exceeds the Nominal Current and reach the power reserve mode | **LED "Boost"** | Active "Power Boost" Output |
| **U < 0.9***Un (Overload)<br><br>**I>Iboost**<br><br>Load current exceeds the Power Reserve range | **LED "DC OK"** | Flashing Floating "Overload" Output |

**Conclusion :**

The reliability of the power supply is an important factor that crucially influences availability in complex systems. For each application, therefore, the best possible solution to satisfy all the technical requirements must be found. In process (Power) plants and special machine engineering technical features such as a static power reserve and dynamic power reserve are among the primary selection criteria considered by System designers and End Users for whom advanced signaling features are also among the primary selection criteria. Power Supply like Phoenix Contact SMPS meeting the selection criteria at all the level shall ensure the highest availability and reliability of a system.

## BIOGRAPHY :

Ms.Anuja Thukral, born in Delhi is an Instrumentation Engineer and has an experience of more than 7 Years with Phoenix Contact India Pvt Ltd in the field of Control and Automation

Presently she is working as the Product Manger – Interfacing Solutions. She has few major contributions in introducing Innovative Interfacing and safety solutions in the Indian market for Process Automation

# Implementation of BOP PLC Standardization and BOP Network at Rosa Power Plant

By Viswanathan Kumar
Reliance Infrastructure Limited, Noida

## Abstract

Reliance Infrastructure Ltd is executing a 4 X 300 MW Coal based Rosa Power Plant at Shahjahanpur in U.P. In this plant it was decided to have a Centralized Control Room for Monitoring and Control of all four Units as well as the switchyard and the BOP (Balance of Plant). To achieve objective, this it was decided to standardize the PLCs used for Control and Monitoring of the BOP systems as well as to bring all the BOP PLCs on a single Network.

In this paper I would like to share my experience in designing the architecture, vendor selection methodology, implementing standardization of PLCs and integrated BOP Network at Rosa Power Plant and its benefits.

## Introduction

## Rosa Power Plant Overview

Rosa Power Plant is developed by Rosa Power Supply Company Limited which is subsidiary of Reliance Power. The plant is constructed in two stages of 2 X 300 MW each. It is located at Rosa village in Shahjahanpur district in Uttar Pradesh. The nearest Railhead is Rosa station and the nearest airport is Lucknow which is 170 Km from the plant. Coal for the plant is sourced from North Karanpura mines of Asoka Block, CCL. Water is sourced from Garrah River, HFO/LDO from IOC Mathura Refinery. Power Evacuation and beneficiaries will be 900 MW to UP State Electricity Company and 300 MW will be distributed as merchant power.

### Control / Automation Philosophy Implemented at Rosa

In Rosa Power Plant the following Main Plant Equipments are controlled and monitored from the DCS (Distributed Control System).

- Boiler & Auxiliaries
- Turbine & Auxiliaries
- Generator Auxiliaries
- Cooling Water & Cooling Tower System
- Makeup Water System
- Fuel Forwarding System

The Turbine Control and Protection are implemented in the Digital Electro Hydraulic (DEH) System & Emergency Trip System (ETS) respectively.

**The following Main Plant Auxiliaries are Controlled and Monitored by PLCs.**

- ESP
- Chemical Dosing System
- Condenser Tube Cleaning System
- APH Infrared Hot Spot and Gap Adjust Control System
- Hydrogen Dryer System

The above systems for Rosa are supplied by the BTG vendor (Shanghai Electric Company, China).Control Systems for the BOP is procured from India through the respective package OEMs. (Original Equipment Manufacturers).

## Central Control Room

Control and Monitoring of the complete plant i.e. all four BTG units, switchyard and most of the BOP can be done from the Centralized Control Room. The Central Control room is located on the Main Turbine Hall at one end near the Unit-1 Turbine. It has four Unit desks for each of the four units, one BOP desk for Switchyard, BOP PLC network and Fire System PC and one Shift charge Engineer desk. It has also two Large screen displays (LVS) for each unit and two large screen displays for the BOP-Switchyard systems.

## BOP PLC Network Architecture at Rosa

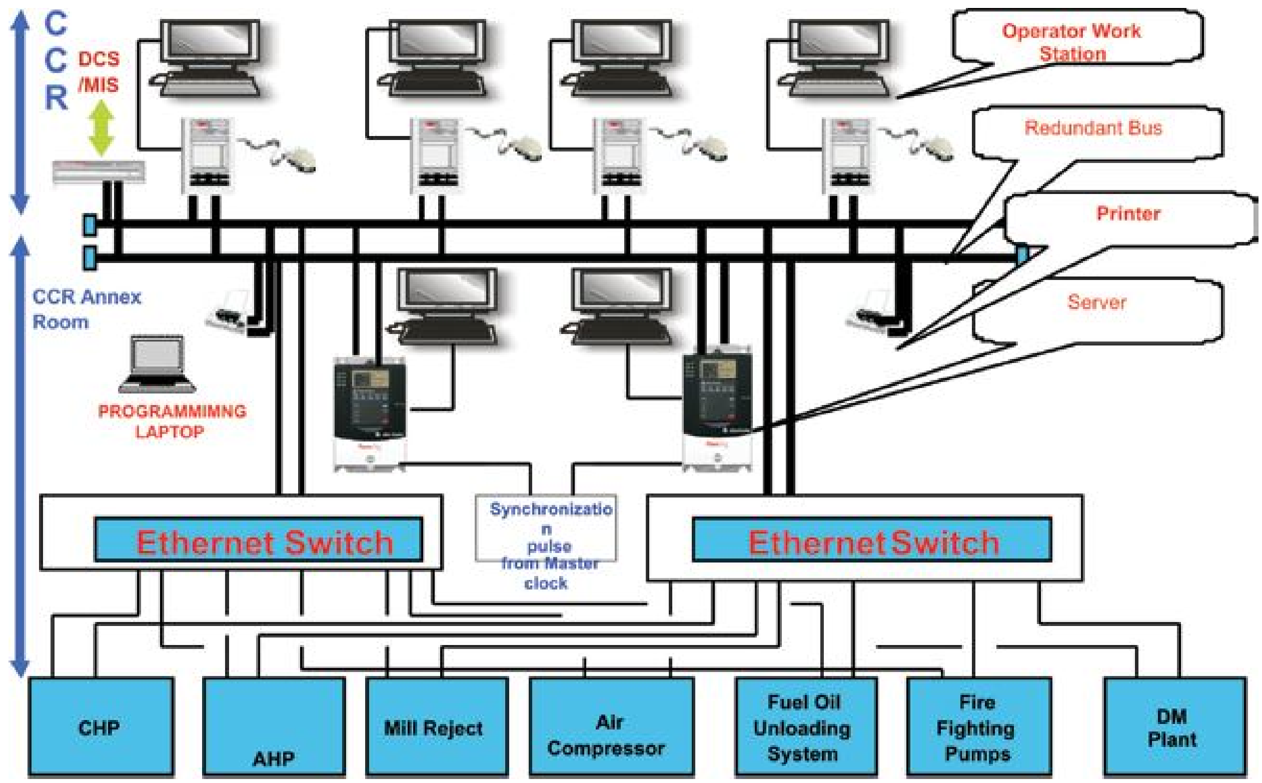



*Fig No. 1 BOP Network Configuration at Rosa - with Star Topology*

## BOP Network Design Criteria

Some of the main design criteria the BOP PLC Network are listed below:

- BOPNS (Balance of Plant Network System) shall basically control and monitor the entire BOP package systems and pumps through the four work stations from the Central Control Room (CCR) during normal operation of the plant. Redundant industrial grade Ethernet TCP/IP 100 Mbps (minimum) bus has been envisaged for the network.
- However, local control and monitoring facility of the equipments from the respective package control room shall also be available during commissioning and emergencies. If required, based on operator choice, normal operation from the local control room shall also be done.
- Server Client concept for package control & monitoring network. Redundant Servers along with programming workstations shall be installed in the Central Control Room/Annex Room. The control room operator shall have also access to common database for all the packages.
- All the screens as available in the local package monitors will be also available one to one basis in the BOPNS screens. Alarm monitoring / reporting, generation of logs, trends, calculations, printing of logs & reports etc. shall be available in local workstations as well as in remote BOPNS workstations .In case of failure of BOP PLC network or both Servers, control and monitoring of the individual packages shall still be possible from the Operator Work Stations in the respective package control room
- There shall be flexibility in operation from CCR BOPNS operator workstations. Any of the BOP packages can be controlled and monitored from any of the workstations. . The operator work stations in the CCR shall have maximum graphics updation time of 1 second. System shall have capability to configure trends for upto 10,000 tags and operator shall be able to view trends in time frames from 1 min to 30days.

- OPC interface between the BOP package network and plant DCS / MIS for limited monitoring at DCS / MIS and data transfer from BOP package network to Plant Optimization System (POS) through this interface.
- Provision of accepting IRIG B signal in the BOPNS server from Master Clock system. All PLCs in the network are thereby synchronized with the Master Clock system which is synchronized with the GPS satellite.

## BOP Network Design Basics

- Four Monitors for operation in CCR
- Redundancy in
- Servers
- Network components like Ethernet switches, Cabling & Interface Modules
- Time synchronization with Master clock system.
- Connectivity with DCS through OPC.

## BOP Network System Components

**Details of equipment of Network system -**

- Server – 2 nos.
- Make – HP- Compaq, ML 350
- Configuration - Processor – Intel XEON 3 GHz., RAM – 4 GB, HDD – 320 GB with RAID level 10 mirroring.
- Softwares –
- RS Logix 5000 STD, RS Networkx Bundle
- RS View SE server Unlimited Display
- RS View Studio for RS View Enterprise (Contain Panel View software also.)
- RS Linkx Classic Gateway
- Windows 2003 Std. server, Service Pack-2

- Client – 4 nos.
- Make – HP- Compaq, DX 2480
- Configuration - Processor – Pentium 2.8 GHz. RAM – 1 GB, HDD – 80 GB.
- Softwares –
- RS View SE client
- Ethernet Switch – 2 nos.
- Make – CISCO , WSCE 500 – 24TT
- Type – Manageable, 24 port

- FO to Ethernet convertor – 20 nos.
- Make – D link, DFE 855

- FO cable - Multimode 6 Fiber Armored FO cable

- Printer – 2 nos.
- 01 no. A3 size Inkjet color , 2800
- 01 no. A3 size Laser color, 5550
- Make – HP

## Packages Controlled / Monitored from BOP Network System

The following systems of the Rosa Power Plant are controlled / monitored from the BOP Network System. ( BOPNS)

- Coal Handling Plant
- Ash Handling Plant
- Mill Reject Handling System
- Compressed Air System
- Fuel Oil Unloading System
- Fire Water Supply System
- DM Plant
- Raw Water Pre-treatment Plant
- Effluent Treatment Plant
- Miscellaneous Water System Pumps – Raw water Intake, Raw water, Rain water, Service water, Potable Water, CT Make up, DM feed, Boiler Fill and Cycle Makeup pumps etc.

## BOP PLCs Design Basics

To achieve Standardization in BOP Package PLCs the following design philosophy was envisaged.

PLCs

- All PLCs are of
- Same make
- Same family

- Diagnostic Input / Outputs for all PLCs
- Larger packages are of Rockwell Control Logix family- with Redundant Processors.
- Coal Handling plant
- Ash Handling plant Stage-I
- Ash Handling System Stage-II
- Mill Reject System Stage-I
- Mill Reject System Stage-II
- DM Plant /ETP/Raw Water Pretreatment Plant/ Miscellaneous water system pumps
- Smaller packages are of Rockwell Flex Logix family- with non-Redundant Processors.
- Fuel Oil Unloading system
- Compressed Air System
- Fire Water Supply System

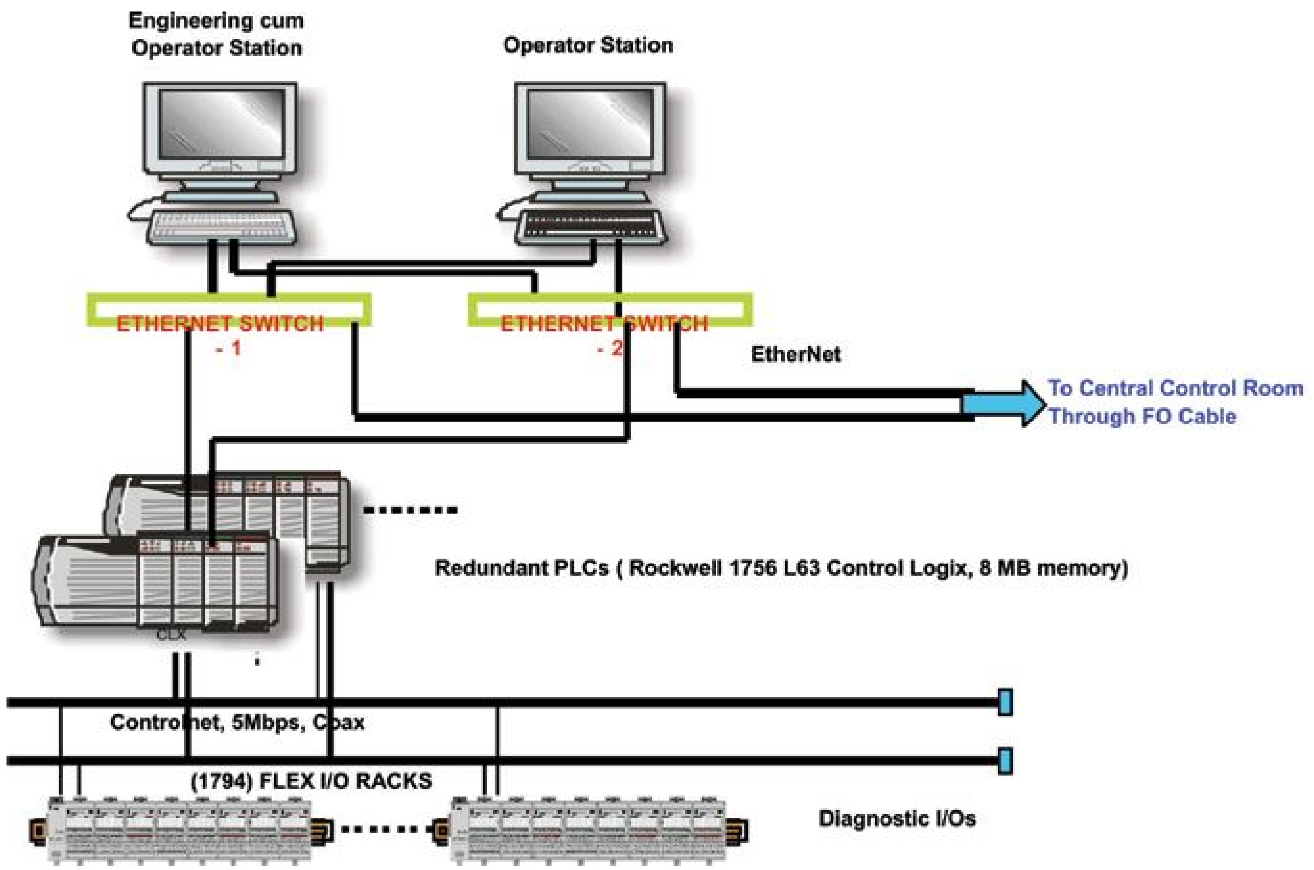



*Fig 2: Typical PLC configuration for Large Packages*

## D. BOP PLC and Network Vendor Selection and Implementation Methodology

The specification for different BOP packages are prepared and ordered separately and the bidders/ OEMs for the different packages are diverse. However it order to achieve standardization in BOP PLCs and Network the following strategy for Vendor Selection and Implementation was evolved.

## Vendor Selection Methodology

- Prepare technical specifications and functional requirement / concept note of PLCs and Network system.
- Freeze architecture of individual PLC including interface with BOP Network System.
- Estimate I/O counts package wise

- Mandatory spares included in the specification
- Invite bids from reputed PLC Vendors
- Bidders to offer one consolidated quote with Package wise price break up
- Bidders to quote unit rates as well for modules ( Processor, I/O cards, Communication controller etc)
- Reliance evaluate and decide the PLC supplier.
- MOM signed with PLC supplier for package wise price and unit rates.
- In case of Rosa , Rockwell was selected through the above methodology for supply of PLCs and BOP Network

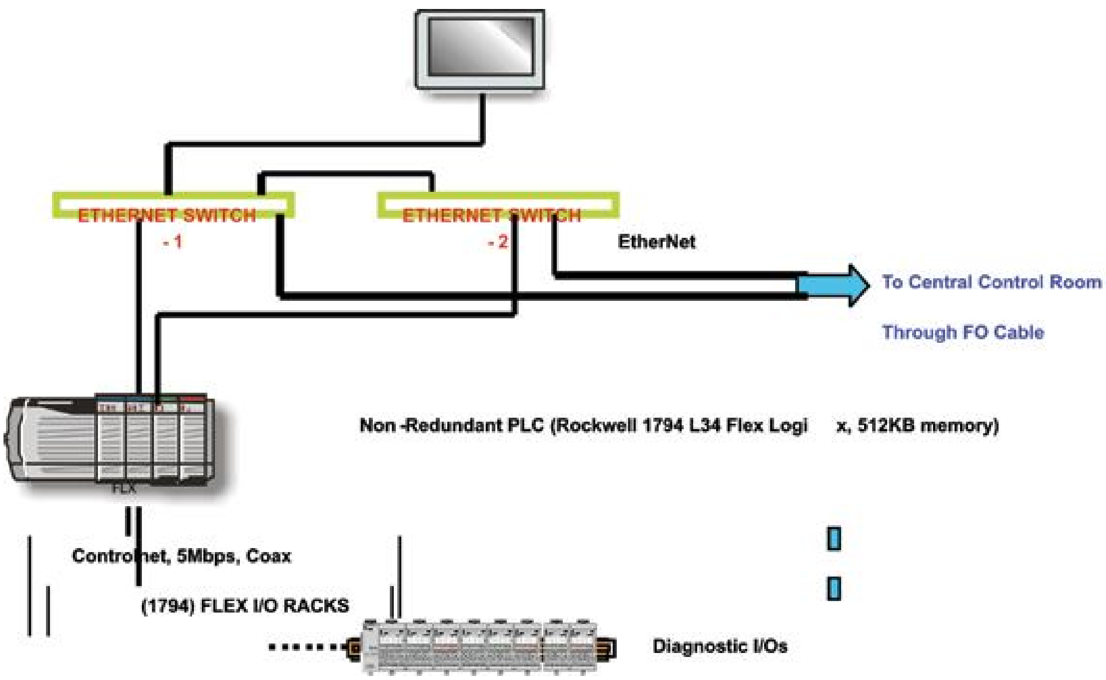



*Fig 3: Typical PLC configuration for Smaller Packages*

## PLC and Network Procurement and Implementation Methodology

- For PLC
- Sourcing of PLC through Mechanical Package OEMs.
- While evaluating Mechanical package OEMs , Reliance communicate their intent of PLC standardization
- OEM place order on Reliance selected PLC supplier
- PLC Supplier takes complete responsibility of supply, commissioning and warranty of PLC system (to OEM)
- OEM has overall commitment of warranty (to Reliance directly)
- For BOP Network System
- BOP Network system ordered directly on PLC supplier
- PLC Supplier takes complete responsibility of supply, commissioning and warranty of PLC system (to Reliance directly)

## E. Advantages of Standardization of BOP PLCs and BOP PLC Network

The following are some of the benefits because of Standardization of BOP PLCs and implementation BOP PLC Network:

- Control & Monitoring of all BOP Packages from Centralized Location (CCR)
- Operational Flexibility- Operation can be done either from CCR or Local Control Room as per Operational requirement
- Operation of any of the BOP package from any

Client station in CCR

- Operator Familiarization & Training is easy as all BOP packages have similar type of HMI screens (Look & Feel)
- Operation can be done with reduced man power.
- Engineering / Maintenance/Troubleshooting can be done from Engineer's room for all packages.
- Maintenance, Familiarization & Training is easy as all are same type of PLCs.
- Maintenance can be done with reduced man power.
- Time synchronization of BOP PLCs with Master clock system at one point so that individual PLC time synchronization is not required.
- Connectivity of BOP PLCs with DCS/ MIS at one point through OPC so that individual PLC is not required to be connected with DCS
- Spares Inventory minimized.
- Standardization of Engineering, drawings and ease of execution as the same PLC vendor is involved in all the packages as well as the Network.

## F.MPath ahead , Challenges and Conclusion

Based on the successful implementation in Rosa, Reliance Infrastructure is also implementing the BOP PLCs Network system in the following projects:

- Butibori – 2X300 MW Coal Based Power Plant
- Samalkot – 2400 MW Combined Cycle Power Plant
- Sasan – 4000 MW Coal Based Ultra Mega Power Project

While there are immense benefits to be obtained from the Standardization of the BOP PLCs and implementation of BOP network, the concept of Control and Monitoring of BOP Packages from the Central Control Room is a new and innovative concept, the challenge is to educate the Plant Operation team to accept the concept and use the same effectively to maximize the benefits.

## G. Acronyms

APH- Air Preheater

BTG – Boiler, Turbine , Generator

BOP – Balance of Plant

BOPNS – Balance of Plant Network System

CCL- Central Coalfields Limited

CCR- Central Control Room

DCS – Distributed Control System

DEH- Digital Electrohydraulic system

ESP – Electrostatic Precipitators

ETS- Emergency Trip System

FO- Fiber Optic

IRIG –B Inter Range Instrumentation Group B

HDD – Hard disk Drive

HFO– Heavy Fuel Oil

LDO- Light Diesel Oil

LVS – Large Video Screen

MIS-Management Information System

OEMs – Original Equipment Manufacturer

OPC- Open Protocol Communication

PLC – Programmable Logic Controllers

PC- Personal Computer

POS-Plant Optimization System

RAID – Redundant Array of Independent Disks

## H. References and Acknowledgments

Model Numbers of Hardware and Application Software of OEMs like Rockwell, HP, Compaq, CISCO, D link, Intel have been used.

## Biography

Sh. Viswanathan Kumar was born in Aruppukottai, Tamil Nadu in the year 1966. He graduated in Electronics and Communication Engineering from Anna University, Chennai in the year 1987. He joined NTPC Ltd in the year 1987. During his career he has been associated with Engineering, Commissioning and Maintenance of I&C systems at Various Coal and Gas based Power plants. He is working with Reliance Infrastructure Limited as Additional Vice President since 2007.

# Plant Asset Management

# FLEET MANAGEMENT THROUGH REAL TIME ENTERPRISE INTEGRATION

**David Thomason**

**OSIsoft, LLC, USA**

## ABSTRACT

The following paper identifies several areas of opportunity for optimizing fleet management in the power generation industry. These examples can be extended beyond power generation. It should be noted that these use case examples are only a small sampling and other solutions for fleet optimization are available.

## KEYWORDS

Data Historian, Fleet Management, Enterprise Integration

## INTRODUCTION

In many power generation facilities, the current use of the data infrastructure tends to be site specific and the coverage is far from complete. With the growth of concern in sustainability for generation assets and personnel, the need for a unified data infrastructure across all assets and sites has grown.

The graphic at the right depicts typical implementation areas where data collection, analysis and visualization can be used to support fleet management. At each layer, specific functionality supports either the collection of data, the analytic against the data, or the visualization or integration of the data.


The following describes some typical use cases in support of each possible solution at the respective layers.

## DCS - LARGE POPULATION OF DATA

What is very common within power generation is that there are wide spread installations of Distributed Control Systems (DCS) in the enterprise.This proliferation of control systems has created a large number of data points that need to be collected and analyzed. What impacts this condition even more is that there are pockets of data at each plant that also need to be aggregated.

Because of this volume of data, analyzing the raw data would provide no beneficial results. So the question arises of how to utilize this volume of raw data and turn it into information.

Developing a solution set that has the capability to capture the raw data and perform analysis is important to understand the impact and correlation of this much data. Areas where this may be important include:

- **Post Trip Analysis**
- **Process Monitoring**
- **Optimization**
- **Early Warning Systems**
- **Alarming**

ENGINEERING APPLICATIONS

The next layer in the stack are engineering application solutions specific to discrete processes. There are many possible solution points in this area which may include:

- **Thermal Performance**
- **Fuel Tracking and Costing Analysis**

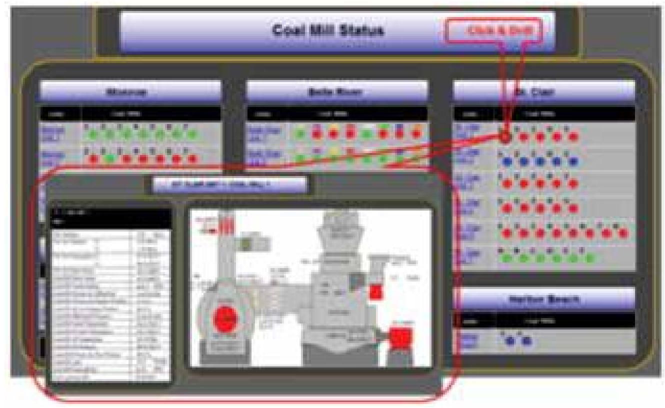
- **NOx Emissions**
- **Energy Management**
- **Automatic Generation Control**

These solutions are specific to the engineer responsible for the daily operations of their site and can extend to an enterprise level of analysis.

## WEB VISUALIZATION

One of the most valuable tools is the ability to provide information through a variety of client tools. These tools can include thick clients (standalone software programs that access the data directly) or thin clients such as Internet browsers. Of course, utilizing a data distribution channel through thin clients has many advantages; one being the ability to quickly update and distribute changes to the framework of the data without having the worry of deploying a new application to the user's desktop.


Many solution options fall into this category. One very interesting solution is to use a visualization tool to replay events using historical data. Using data in this fashion allows the operating engineer to go back through the sequence of events in order to determine the root cause of an anomaly. This ability of analyzing historical data requires that the data infrastructure needs to not only integrate the various data sources, but also effectively store this data online throughout the life of the generation assets, sometimes up to 30 years!!!




## SYSTEM DASHBOARDS

Tied to web visualization are the concepts that support system dashboards.System Dashboards provide a "view" of the data that is static by design in order to easy recognize any anomalies or abnormalities with the systems. However, another function of the system dashboard is to link the static information being displayed to an ad-hoc capability in order to allow the operational engineer to drill down into more specific data and correlate different data streams against one another.

This ability to represent static data and provide a deeper dive when needed is key to successful implementations.
EXPERT SYSTEMS

Expert systems are an effective tool which help byautomatically analyzing large amounts of realtime and historical data.Instead of engineers working to on the data, the expert systems get the system to work on the data, thereby moving the system usage from pull to push. Because of the ability to interface with many other data sources and repositories, the data infrastructure should support the deep analysis needed by these third party solutions such as pattern recognition, anomaly detection, predictive algorithms, etc.

## KPIs

Key Performance Indicators or KPIs have become a standard mechanism by which organizations attempt to gauge their own performance and remediate situations where performance is not meeting expectations or goals.

"How to organizations use KPI's to manage their fleet across the enterprise?" This is not a simple question to answer.

The design process for a KPI driven system has two major phases. The first is a "top down" phase. This phase begins with the definition of the KPIs, drills down to define the calculations which produce the KPIs, then finally identifies the source data that constitute the calculation input data set. Once the data details are fully discovered and documented, the "bottom up" portion of the design can be completed. This phase produces designs for the data collection, analysis and presentation components of the architecture.

There are many possible solution sets that support a fleet optimization strategy. Some of these are:

- Actual Generation
- Target Load
- Frequency Modeling & Alarm
- Deviation from Target Load
- Target Frequency
- Actual Frequency
- Fuel Oil Price
- Coal Price
- Unit Oil Burned
- Imbalance calculation
- Average imbalance
- Generation Revenue
- Efficiency
- Controllable Losses
- Cost of Losses
- Price Forecast Data
- Unit Availability
- MW Actual Generation
- MVAR Actual Generation
- MW Target
- MVAR Target
- Fleet KPIs (scorecard)
- Unit Derate
- System Buy Price
- System Sell Price
- Cost of Imbalance
- Unit Heat Rate
- Forebay elevation
- Spill
- NOX Credits Commodity Price
- Regulation Unit performance
- Capacity Factor
- Vibration Data
- Green Energy Value
- NOX Credits
- Forecasting & Planning
- Individual Unit Asset Performance
- Condition Based Maintenance
- Reserve Margins
- Fuel BTU lab data

## Process Model

One of the first steps in developing a fleet optimization strategy is to build a process model in order to better define the activity needed to support the data analytics. A typical example model may be to perform efficiency calculations. This model includes:

- Unit cost of generation
- Turbine heat rate
- Boiler efficiency
- Net unit heat rate
- Controllable costs

Focusing on controlling costs, the following target areas may be considered:

- Throttle Temperature and Pressure

- Hot ReHeat Temperature
- ReHeat Pressure Drop
- RH Attemperation Flow
- Turbine Condition
- Condenser Performance
- Feedwater Heater Cycle
- Auxiliary Power
- Station Heating
- Steam and Water Losses
- Sootblowing Flow
- Air preheating Flow
- Blowdown
- Boiler Excess Air
- Excess Stack Temperature
- Coal Moisture
- Unburned Carbon in Ash

## CONCLUSION

While this paper attempts to cover some aspects of fleet management, the list of solutions available for fleet management is huge. An effective fleet management solution must be built on a solid foundation of a data infrastructure that is vendor-neutral, scalable, and flexible. Only then can the modular building blocks of a fleet management system be effective in providing sustainable benefit to the organization.

## BIOGRAPHIES

Mr. David Thomason has 29 years of experience in applying information technology to the requirements of the electrical utility and power generation industry. He specializes in and is an active advocate for the use of advanced analytics and technologies to enhance business value. Having both IT and business background, David focuses on turning data into actionable information as it applies to predictive / proactive maintenance and operational processes. As Sr. Manager of Wholesale IT – Plant Applications for GenOn Energy and predecessor companies (Reliant), his responsibilities included managing the company's multi market Energy Management System, Plant Analytic Systems, Custom Software Development, Internet / Intranet WEB team, SAP Work & Materials management, and Client Support Teams. He currently works as Global Business Development Manager for Power Generation at OSIsoft, LLC.

# Effective Planning Of Resources And Monitoring Overhaul Preparedness Through ERP


## AUTHORS:

### Anand Prakash

*Mr. Prakash is Manager (ERP) in NTPC Limited. He is one of the team members in Plant Maintenance Module of ERP implementation in NTPC. His highest qualification is M.Tech. from I.I.T. Delhi. He has work experience of over 15 years in different capacities in maintenance of coal based thermal power plants and ERP implementation in NTPC Ltd.*

### 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.*


KEYWORDS: Activity Based Budgeting, Overhaul Preparedness Index, ERP, Procurement, Resource


## ABSTRACT:

Enterprise Resource Planning (ERP) has evolved as the most important development in the corporate use of information technology. Key to an ERP package is tight integration between modules, so that all of the core business processes are related. NTPC Ltd. has implemented ERP for all its major business functions across all its locations. As part of redesigning of Operation & Maintenance Budgeting and Procurement Process, Activity Based Budgeting (ABB) has been designed and developed in ERP. The main objective of ABB is to increase the effectiveness of planning resources and automation of repair & maintenance budgeting and procurement process. ABB involves listing down of maintenance activities and dates along with resources i.e. material and services required for performing those activities. Based on above, repair & maintenance budget is automatically derived for the next three financial years. Procurement process of material is triggered for the next two financial years from the approved activity based budget data. Overhaul Preparedness Index (OPI) has been designed and developed in ERP as a tool to monitor preparedness of unit overhaul with respect to the resources required for carrying out the overhaul. This index is automatically calculated by the system based on the procurement status of the resources i.e. material and services required to carry out the overhaul. Activity Based Budgeting (ABB) and Overhaul Preparedness Index (OPI) were not part of the standard SAP package of ERP. These systems have been developed in-house in SAP and have been implemented across all NTPC stations. This paper gives an insight into the details of the effective planning of resources and repair and maintenance budgeting/procurement process based on the same. Monitoring of overhaul preparedness through ERP has also been dealt with in this paper.


## 1. INTRODUCTION

Every organization has legacy information management system for different modules like Finance, Material, Human Resources, Operation, and Maintenance operating on different platforms. Enterprise Resource Planning (ERP) is software which integrates all functionalities of the organization on a single database. Enterprise Resource Planning (ERP) integrates all functions and processes of a business and generates a comprehensive view of the entire company in a real time environment. Its purpose is to facilitate the flow of information between all business functions inside the boundaries of the organization and manage the connections to outside stakeholders. Most important advantage of ERP is integration of all the business processes on a single platform, which reduces unnecessary paper work, documentation, repeated entry, better MIS etc. ERP has evolved as the most important development in the corporate use of information technology as it provides seamless information for the efficient and effective use of the resources like material, manpower, service contract and finance of the company.

Effective planning of resources impacts the profitability of the organization and if done well, it turns into competitive advantage. The goal is to identify which resources are required, by time period into the future as far as is reasonable, and then to schedule them as effectively as possible to ensure seamless coverage across all business requirements. As with conventional goods, creating and delivering a business service requires the use of resources whether capital assets such as infrastructure and equipments, consumable resources such as materials, service contracts, labor hours by skilled employees, or intangible assets such as an individual's skills or an organization's proprietary data or processes. Two of important resources required for the maintenance of the assets of an organization are material and service contracts. Effective planning of these resources and budgeting/procurement are critical to the overall maintenance process.

Broadly, the maintenance processes of the assets of an organization are classified into two heads, routine maintenance and overhauling. Routine maintenance mainly comprises of preventive maintenance, corrective maintenance and condition based maintenance. Overhauling of an asset is the most important maintenance activity which, if performed well, should result in zero breakdown of the asset. Time-based and counter-based strategies are used to decide the time when the overhauling of an asset should be done. In the time-based strategy, overhauling of an asset is done at fixed time intervals, whereas, in the counter-based strategy, overhauling of the asset is taken at fixed running hours of the asset. Resources required to carry out overhauling should be available at the location before the start of overhaul. Monitoring of the preparedness of the overhaul with regards to the resources required for the same is a critical component in the overall overhauling process.

## 2. RESOURCE PLANNING AND REPAIR AND MAINTENANCE BUDGETING/PROCUREMENT

Budgeting essentially lays down the physical and financial operating plan/targets for the budget period and lays down the standards/yardsticks for inputs and the outputs associated with the various activities. It is an important tool for managerial appraisal and control over operational expenses and working capital and to inculcate greater cost consciousness in the organization. Each generating station is a budget center and prepares the budget estimates. The station level budgets are consolidated at the region level (RHQ) and then at the Corporate Centre (CC) level to arrive at the company budget. RHQ and CC are also budget centers for expenditure incurred at their level. The stations compile the budget at the budget heads and the cost centers as per the Costing system. The budget estimates are reviewed and recommended by the budget committee at the station and RHQ and approved at the CC level

### 2.1 BEFORE ERP

The budget was prepared on an annual basis for a financial year. In the budget, estimates were prepared in respect of the following:

- Revised estimates for the next financial year
- Budget estimates for the year thereafter

The budget was prepared at the station level for each cost center for different activity types i.e. overhauling, preventive, corrective etc. Resource heads such as material and service contracts were taken for preparing the budget. Planning of resources was not done at the lowest level i.e. activity level to arrive at the budget. Procurement of the resources was also not automatically derived from the budget.

### 2.2 AFTER ERP

Contrary to traditional cost-based budgeting, activity based budgeting is being used for effective planning of resources and repair and maintenance budgeting/ procurement process. In this process, budget is prepared on an annual basis and the estimates are prepared in respect of the following:

- Revised estimates for the next financial year
- Budget estimates next two years thereafter

The budget is automatically derived from planning of resources at the lowest level i.e. activity level. Procurement of the resources is automatically derived from the approved budget.

## 3. ACTIVITY BASED BUDGETING (ABB)

Activity Based Budgeting is a method of budgeting in which the resources are planned at the activity level and the costs of the activities are used to arrive at the repair and maintenance budget. The budget estimates are arrived through assessment of each item of the budget without any reference to the expenditure incurred on this account in the past. It stands in contrast to cost-based budgeting practice in which a prior period's budget is simply adjusted to account for inflation or revenue growth. As such, ABB provides opportunities to align activities with objectives, streamline costs and improve business practices.

The prepared budget is reviewed at the station and region level and approved at the Corporate Centre level. The budget is approved on-line through workflow process. After approval of the budget, procurement process of one of the resources i.e. material is automatically triggered from the approved data. Procurement of the other resource i.e. service is done by manually raising purchase requisitions based on the approved data.

After completion of the procurement process of the resources, these are actually consumed while performing the maintenance activities. The actual cost incurred while performing the maintenance activities is compared with the budgeted cost to get the budget utilization.

## 3.1 PLANNING OF ACTIVITIES AND RESOURCES

Repair & Maintenance activities to be performed on the assets of an organization are planned for the next three financial years. Planning involves listing down of detailed activities, linking of resources i.e. materials and services along with the quantities required to perform these activities and scheduling of the activities. Materials are of spares, consumables, lubricants and tools and plants (T&P) types and are required to be consumed while performing a particular maintenance activity. Services are the contracts required to perform the particular activity. The maintenance activities are planned on the main systems and sub-systems in which assets are installed and are of following main categories:

a) Preventive maintenance
b) Corrective maintenance
c) Overhauling
d) Reliability
e) Exceptional
f) Buildings and other assets related jobs
g) Township related jobs

The listing down of detailed activities along with linked materials and services is done in the task list, whereas, scheduling of these activities is done through maintenance plan. The planning of resources as explained above is done by department executives and reviewed by Head of Department.

## 3.2 REPAIR & MAINTENANCE BUDGET

The planned activities and resources prepared by different departments (explained in section 3.1) are automatically collected by the system and the following are projected at department level and station level:

a) Summary of budgeted figures separately for various activity categories on material and services heads for the next three financial years.
b) Detailed data including asset on which activity is to be performed, date of performing activity, cost center, resource qty. & value.
c) Report showing summary of budgeted figures on main systems separately for material and services.
d) Report showing budgeted figures and past consumption figures for each material and services.
e) Details of the cost ratios based on the budgeted figures.

Hence, the repair & maintenance budget is automatically projected based on the detailed maintenance activities and resources required to perform these activities. Material and services unit prices are picked up automatically from the data present in the system for calculation of the budget. There is a provision for projecting budget for contingency requirement i.e. for performing unplanned activities. Contingency budget provision is calculated based on a certain percentage applied over the budgeted figure obtained from the planned activities. In the figures given below, a few screen shots taken from the system are shown.

Figure 1 shows the summary report as obtained from activity based budgeting. This report shows the summary of budgeted figures for the next three financial years.

ABB Budget Summary Report as per Finance Format A/S/08

| Repair & Mtc. | Head | 2009-10 | 2010-11 | 2011-12 | BE (2012-13) | RE (2012-13) | BE (2013-14) | BE (2014-15) |
|---|---|---|---|---|---|---|---|---|
| (i) Plant & Machin. | | | | | | | | |
| Overhaul | Material | 13.03 | 253.92 | 508.10 | 173.08 | 110.90 | 408.90 | 675.79 |
| | Contractor Cost | | 11.08 | 429.50 | 24.77 | 10.27 | 409.19 | 403.21 |
| | Others (Tools) | | | 4.64 | | | | |
| Preventive | Material | 140.38 | 122.69 | 61.61 | 145.17 | 25.55 | 22.34 | 7.44 |
| | Contractor Cost | | 44.95 | 68.37 | 95.22 | 147.33 | 144.19 | 145.63 |
| | Others (Tools) | | | | | | | |
| Corrective | Material | 213.17 | 106.75 | 75.70 | 137.04 | 379.26 | 379.26 | 379.26 |
| | Contractor Cost | | 16.80 | 26.00 | 100.04 | 109.92 | 110.45 | 109.82 |

**Figure 1** ABB Budget Summary Report of one of the stations of NTPC

**Figure 2** shows the detailed data display of ABB. This figure shows the asset, date, resource quantity and value regarding the activity to be performed.

| MntPlan | Planned Da | Functional Loc Desc | Task Description | Material Description | Service Short Text | Qty | Net Value |
|---|---|---|---|---|---|---|---|
| [illegible] | 16.02.2014 | GT#1 DO HYDRAULIC | CHK OF C&I EQ GT1 DI | | Local Pr. Switches | 3.000 | 273.24 |
| [illegible] | 17.08.2013 | GT#1 DO HYDRAULIC | CHK OF C&I EQ GT1 DI | | PR.GAGE (<=) Che | 5.000 | 455.40 |
| [illegible] | 17.08.2013 | GT#1 DO HYDRAULIC | CHK OF C&I EQ GT1 DI | | Control Panels(<=) | 1.000 | 74.52 |
| [illegible] | 17.08.2013 | GT#1 DO HYDRAULIC | CHK OF C&I EQ GT1 DI | | SOL V/V (1/2"-1") C | 4.000 | 364.32 |
| [illegible] | 17.08.2013 | GT#1 DO HYDRAULIC | CHK OF C&I EQ GT1 DI | | TRANSMITTER (<= | 2.000 | 245.09 |
| [illegible] | 17.08.2013 | GT#1 HYD OIL SYSTEI | MI OF GT1 HYD OIL SY | | Local Pr. Switches | 10.000 | 910.80 |
| [illegible] | 17.08.2013 | GT#1 HYD OIL SYSTEI | MI OF GT1 HYD OIL SY | | Control Panels(<=) | 1.000 | 74.52 |
| [illegible] | 17.08.2013 | HEAT RECOVERY STE | HRSG ACTUATOR-MI | POSTN FEED BACK | | 1.000 | 0.00 |
| [illegible] | 07.03.2014 | GT#2 LIQUID FUEL S | OH OF C&I EQ. GT LIQ | | TRANSMITTER (<= | 10.000 | 1,225.40 |
| [illegible] | 04.12.2013 | GT#2 HEAT RECOVEF | HRSG ACTUATOR | | Motorized Actuator | 50.000 | 8,367.00 |
| [illegible] | 17.08.2013 | HEAT RECOVERY STE | HRSG ACTUATOR-MI | AIR LOCK RELAY | | 1.000 | 3,627.08 |
| [illegible] | 16.02.2014 | HEAT RECOVERY STE | HRSG ACTUATOR-MI | POSTN FEED BACK | | 1.000 | 0.00 |

**Figure 2** Detailed data display of ABB of one of the stations of NTPC

## 3.3 APPROVAL OF BUDGET

ABB data is confirmed by Head of Operation & Maintenance (O&M) of the station after review of data by Heads of Department. Workflow process is also triggered by Head of O&M for on-line approval of the budget. The approval process goes through the approvers at station, region and Corporate Centre before being finally approved by Corporate Finance. An auto generated message goes to the approvers as well as the initiator of the workflow process intimating of approval at different stages. On-line status of approval process of ABB is also displayed through a report.

**Figure 3** shows on-line status of ABB approval of all NTPC plants in a single page.

**Figure 3** On-line Approval Status of ABB of all NTPC stations

3.4 AUTOMATIC TRIGGERING OF PROCUREMENT PROCESS

Regarding simplification and automation of procurement process, a system is in place to automatically generate the purchase requisitions of materials for the next two financial years from the approved ABB data. In ABB data, we have the dates on which maintenance activities are to be performed and quantities and unit prices of the materials to be consumed for the same. The stock and pipeline quantity of the material is subtracted from the consumption quantity to get the procurement quantity. The procurement quantity is further broken up into quarterly requirements spread across two years based on the planed maintenance dates of the activities. Grouping of materials in the purchase requisitions takes place based on the nature of material and other data pertaining to the material master. There is also a provision to create manual purchase requisitions from the contingency budget if the particular material has not been planned in ABB. Purchase requisitions related to services are created manually in the system based on approved ABB data. Necessary steps are taken by Contracts & Materials department after generation of purchase requisitions so that the resources are available before the planned maintenance date of activities.

## 3.5 BUDGET UTILIZATION

The procurement process of the resources results in delivery of material and placement of purchase order of the services before the planned maintenance date. The resources are consumed through the maintenance order while performing the maintenance activities resulting in actual material and services cost. Customized reports are available in the system which compare the budgeted vs. actual cost in a plant for different categories of maintenance activities. This comparison can be done on monthly, quarterly or yearly basis.

Figure 4 shows the budgeted vs. actual cost comparison of one of the plants of NTPC. This report shows that cost comparison can be separately done for different types of resources i.e. material as well as services.

| Repair & Mtc | | Apr Mon(B) | Apr Mon(A) | Apr YTM(B) | Apr YTM(A) | May Mon(B) | May Mon(A) |
|---|---|---|---|---|---|---|---|
| (i) Plant & Machin | | | | | | | |
| Overhaul | Material Cost | 45,563,514.31 | 15,771,943.14 | 45,563,514.31 | 15,771,943.14 | 356,230.46 | 21,298,795.97 |
| | Contractor Cost | 53,980,055.67 | 7,991,602.91 | 53,980,055.67 | 7,991,602.91 | 19,868.33 | 14,504,350.39 |
| | Sub Total | 99,543,569.98 | 23,763,546.05 | 99,543,569.98 | 23,763,546.05 | 379,098.79 | 35,803,146.35 |
| Preventive | Material Cost | 1,899,014.94 | 161,426.46 | 1,899,014.94 | 161,426.46 | 1,520,826.91 | 446,772.04 |
| | Contractor Cost | 682,434.74 | 196,063.99 | 682,434.74 | 196,063.99 | 1,101,717.06 | 322,172.72 |
| | Sub Total | 2,581,449.68 | 357,490.45 | 2,581,449.68 | 357,490.45 | 2,622,545.99 | 768,945.56 |
| Corrective | Material Cost | 13,702,602.86 | 838,684.74 | 13,702,602.86 | 838,684.74 | | 318,100.09 |
| | Contractor Cost | 10,069,887.09 | 71,718.02 | 10,069,887.09 | 71,718.02 | | 78,519.14 |
| | Sub Total | 23,772,489.95 | 910,402.76 | 23,772,489.95 | 910,402.76 | | 397,620.03 |

**Figure 4** Budgeted vs. Actual Cost report of one of the stations of NTPC

Report is also available for comparison of key cost ratios calculated on the basis of budgeted and actual costs. Figure 5 shows the key cost ratios comparison for budgeted and actual costs of one of the plants of NTPC.

| Key Cost Ratios | Apr Mon(B) | Apr Mon(A) | Apr YTM(B) | Apr YTM(A) | May Mon(B) | May Mon(A) | May YTM(B) | May YTM(A) |
|---|---|---|---|---|---|---|---|---|
| Rout Mat Cost/Total Rout Cost (%) | 59.20 | 78.88 | 59.20 | 78.88 | 57.99 | 65.57 | 59.09 | 72.50 |
| OH Mat Cost/Total OH Cost (%) | 45.77 | 66.37 | 45.77 | 66.37 | 84.76 | 59.48 | 45.96 | 62.23 |
| OH Cost/(Routine+OH) Cost (%) | 79.07 | 94.93 | 79.07 | 94.93 | 12.63 | 98.04 | 77.52 | 96.07 |

**Figure 5** Budgeted vs. Actual Cost ratio report of one of the stations of NTPC

The comparison between budgeted vs. actual cost and cost ratios gives the variance between the two and helps in better planning of resources for the next year.

4. BENEFITS OF ABB IN ERP

The traditional budgeting process focuses on what managers are allowed to spend, and not the resources they actually need to add value to their business. Activity Based Budgeting (ABB) is a technique for enhancing the accuracy of financial forecasts and increasing management understanding.

Main benefits of ABB are given below:

- It is a quantity budget and linkage with maintenance activities enables better requirement planning.
- Availability of item wise requirements enables a more systematic reallocation of budgets after sanction from Corporate Office.
- Availability of item wise requirements helps in monitoring of consumption and procurement of the item.
- It significantly improves the requirement planning and hence, may lead to lower inventory.
- Purchase requisitions are triggered in advance form the approved budget and hence, there is no need to raise requisitions for regular items.
- Quantities of the resources are checked at the budgeting stage.
- Stock and pipeline is incorporated in the preparation of purchase requisitions of materials.
- Activity Based Budget helps in systematically documenting the knowledge of maintenance activities existing with the maintenance personnel.

## 5. MONITORING OF OVERHAUL PREPAREDNESS

The objectives of zero forced outage between overhaul to overhaul, increasing the gap between overhauls, improving plant efficiency to design levels and attaining 105% capability of machine can be achieved by quantum improvement in the quality of overhauling of the assets of an organization. This requires advance planning and monitoring the preparedness of overhaul of the generating unit since two years prior to the start of the overhaul. Preparation of Engineering Declaration in which detailed scope of work along with resource requirement is given is done two years prior to the start of the overhaul. The scope of work is finalized taking inputs from past experiences, knowledge teams, RLA analysis, failure history analysis, performance assessments etc. This is reviewed at regular intervals of time. A system is already in place in ERP to upload Engineering Declaration through Document Management System (DMS).

It is also vital to ensure timely availability of resources i.e. materials and service contracts before the start of overhaul so that a quality overhaul is ensured. Overhaul Preparedness Index (OPI) has been devised as a tool to measure the degree of preparedness of overhaul over two years period with respect to the resources required for the same. It provides the management a means through which it can monitor the preparedness of overhaul and take corrective actions with regards to the procurement of the resources.

### 5.1 OVERHAUL PREPAREDNESS INDEX (OPI)

An automated system has been developed in ERP in which OPI score is calculated based on the current status of procurement of the resources required for the particular overhaul. The heads which are considered for calculation of OPI score are as follows:

- Spares
- Consumables
- Tools & Plants (T&P)
- Service contracts

Spares are further divided into Critical and Non-critical categories. Critical spares are those items which are very important for completion of the overhauling process. Overall OPI score is calculated combining the score of the individual heads. The score of an individual item is calculated based on target for that month and actual achieved.

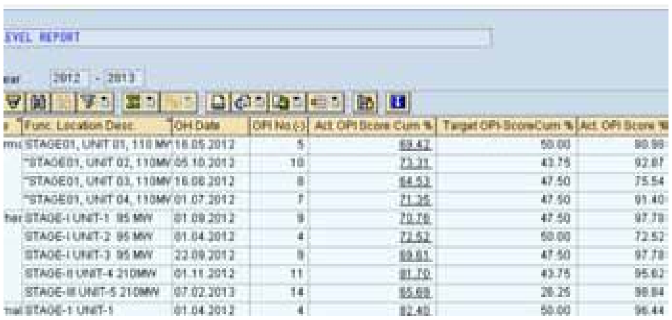
Following 5 activities in the process of procurement of spares, consumables and T&Ps are considered for calculation of OPI score:

- Identification of items
- Purchase Requisitions raised (of no. of items)
- Purchase Enquiries issued (of no. of items)
- Purchase Orders placed (of no. of items)
- No. of items received

Following 5 activities in the process of procurement of service contracts are considered for calculation of OPI score:

- Identification of contracts
- Purchase Requisitions raised
- Purchase Enquiries issued
- Offers received
- Purchase Orders placed

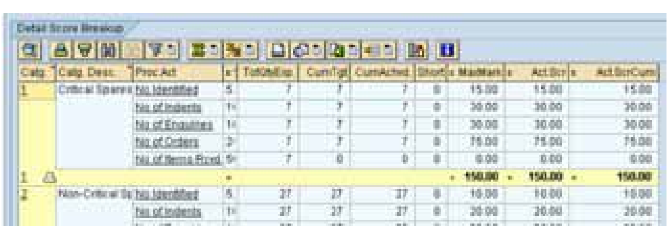
**Figure 6** shows on-line OPI score of the overhauls of all NTPC stations on a single page. Two scores are calculated, cumulative and monthly. "OPI No." denotes the no. of months prior to the start of overhaul at the time of display of the report. OPI is used to monitor status of preparedness of overhaul on monthly basis starting from 24 months prior to overhaul. "OH data" denotes the date of start of overhaul.



| Func. Location Desc. | OH Date | OPI No.(-) | Act. OPI Score Cum % | Target OPI-ScoreCum % | Act. OPI Score % |
|---|---|---|---|---|---|
| STAGE01, UNIT 01, 110 MW | 18.05.2012 | 5 | 69.42 | 50.00 | 90.98 |
| STAGE01, UNIT 02, 110MW | 05.10.2012 | 10 | 73.31 | 43.75 | 92.87 |
| STAGE01, UNIT 03, 110MW | 16.08.2012 | 8 | 64.53 | 47.50 | 75.54 |
| STAGE01, UNIT 04, 110MW | 01.07.2012 | 7 | 71.35 | 47.50 | 91.40 |
| STAGE-I UNIT-1 95 MW | 01.09.2012 | 9 | 70.78 | 47.50 | 97.78 |
| STAGE-I UNIT-2 95 MW | 01.04.2012 | 4 | 72.52 | 50.00 | 72.52 |
| STAGE-I UNIT-3 95 MW | 22.09.2012 | 9 | 69.61 | 47.50 | 97.78 |
| STAGE-II UNIT-4 210MW | 01.11.2012 | 11 | 81.70 | 43.75 | 95.62 |
| STAGE-III UNIT-5 210MW | 07.02.2013 | 14 | 65.69 | 28.25 | 98.84 |
| STAGE-1 UNIT-1 | 01.04.2012 | 4 | 82.40 | 50.00 | 96.44 |

Figure 6 On-line OPI score of overhauls of all NTPC stations

OPI score as shown in Figure 6 is calculated combining individual OPI scores of various heads e.g. critical spares, non-critical spares, consumables, T&Ps and service contracts. Figure 7 shows detailed break-up of OPI score of spares for one of the overhauls.



| Catg. | Catg. Desc. | Proc Act | s | TotQtyExp | CumTgt | CumActvd | Short | MaxMark | ActScr | ActScrCum |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Critical Spares | No Identified | 5 | 7 | 7 | 7 | 0 | 15.00 | 15.00 | 15.00 |
| | | No of Indents | 1 | 7 | 7 | 7 | 0 | 30.00 | 30.00 | 30.00 |
| | | No of Enquiries | 1 | 7 | 7 | 7 | 0 | 30.00 | 30.00 | 30.00 |
| | | No of Orders | 3 | 7 | 7 | 7 | 0 | 75.00 | 75.00 | 75.00 |
| | | No of Items Rcvd | 5 | 7 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 |
| 1 | | | | | | | | 150.00 | 150.00 | 150.00 |
| 2 | Non-Critical Sp | No Identified | 5 | 27 | 27 | 27 | 0 | 10.00 | 10.00 | 10.00 |
| | | No of Indents | 1 | 27 | 27 | 27 | 0 | 20.00 | 20.00 | 20.00 |

**Figure 7** Detailed OPI score break-up of spares for one of the overhauls

**Figure 8** shows detailed break-up of OPI score of service contracts for one of the overhauls.

| Catg. | Catg. Desc. | Proc Act | s | TotQtyExp | CumTgt | CumActvd | Short | MaxMark | ActScr | ActScrCum |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | | | | | | | | 100.00 | 100.00 | 100.00 |
| 5 | Services | Contracts Identified | 5 | 20 | 20 | 20 | 0 | 12.50 | 12.50 | 12.50 |
| | | No of Indents | 2 | 20 | 20 | 20 | 0 | 50.00 | 50.00 | 50.00 |
| | | No of Enquiries | 1 | 20 | 20 | 19 | 1 | 37.50 | 35.63 | 35.63 |
| | | No of Offers Recd. | 1 | 20 | 0 | 24 | 0 | 0.00 | 0.00 | 25.00 |
| | | No of Orders | 5 | 20 | 0 | 15 | 0 | 0.00 | 0.00 | 93.75 |

Figure 8 Detailed OPI score break-up of service contracts for one of the overhauls

5.2 BENEFITS OF OPI SYSTEM IN ERP

OPI system in ERP is an automated way of monitoring preparedness of overhaul with respect to the resources required to carry out the activities during the overhauling process. Before ERP, the OPI score was being calculated after manually updating the status of procurement of the different resources. In ERP, the procurement status of the resources is updated and OPI score is calculated automatically by the system. A few benefits of OPI system in ERP are as follows:

- Identification of resources is done two years prior to start of unit overhaul.
- This is a tool to monitor the preparedness of overhaul of a generating unit over a certain period of time.
- Status of preparedness of overhaul of all the generating units of NTPC stations is displayed on a single page.
- Procurement status of different resources required for carrying out unit overhaul is automatically updated and OPI score calculated.
- Exceptions in the process of overhaul preparation can be identified and submitted to higher management.

6. CONCLUSION

ERP system integrates internal and external management information across an entire organization, embracing business functions such as finance/accounting, material management, operation & maintenance, human resources etc. ERP automates this activity with an integrated software application. Best practices are incorporated into most ERP systems.

Effective planning of resources is vital to the overall maintenance process of the assets of an organization. Activity Based Budgeting system which has been developed in ERP and being used across all NTPC stations uses the concept of deriving budget automatically from the detailed planning of activities and resources for the next three financial years. This is a systematic and logical way of projecting the budget requirement and gives us an opportunity of focusing on questions about why we need to perform certain activities, how often we need to perform them, and the cost associated with it. It is different from traditional budgeting process in which budget figures are arrived at by applying a certain incremental factor on previous year budget/ expenditure.

Overhauling is the most important activity in the overall maintenance process of the assets of the organization. It is quite important to monitor the preparedness of overhauling of the generating unit since it helps in ensuring timely availability of resources and doing quality overhaul. Overhauling Preparedness Index (OPI) system which has been developed in ERP and being used across all NTPC stations is an automated way of monitoring the preparedness of unit overhaul with regards to the resources required for carrying out the same. It gives important and timely feedback to the top management about the actions to be taken for ensuring timely availability of resources before the start of overhaul of a generating unit.

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# Development of automation mechanism for inspection of power plant components in critical areas

**Kishore Aggarwal, Badri Vishal Gupta and Rakesh Kumar Chakraborty**


## Key Words

Robotics, Automation, In-pipe, Generator, Inspection



## Abstract

Recent advances in the field of automation provide us an opportunity to exploit the available technologies in enhancing the reliability of the critical power plant equipment and the processes. The critical equipment includes Boiler, Generator, Turbine, Fans, and Pumps etc. Applied Research in the field of robotics is playing a major role in developing automation mechanisms for such complex activities to aid and assist human operators in the plant in their day-to-day activities. Robots, in fact are very active in Nuclear power generation since last few decades. However this technology is actively foraying into conventional power generation also. Robotic system for inspection of boiler tubes consists of a robot and sensor which can locate the defect and measure its severity. But the real complexity in the development of robot lies in the boiler geometrical and material constraints. Different pressure parts of boiler are made of different types of steels with inhomogeneous spacing and clearance. Robotic system for Generator inspection consists of a robot and sensor which can manoeuvre inside generator with rotor inside condition and measure the different parameters indicating the healthiness of Generator. This paper is an attempt to provide an idea of complexities involved in the development of automation mechanism for Boiler tubes inspection and Generator inspection.


## 1. Introduction

Automation is the combined use of control systems and information technology, to control industrial machinery and processes, reducing the need for human intervention. Human-level pattern recognition, language recognition, and language production ability are well beyond the capabilities of modern mechanical and computer systems. However, automation is the necessity where the risk of human life and human error is involved, hence replacing the human from the complex environment and still handle the requirement to make things too fast or too slow is the need of the hour.

In power plant, there are many types of equipment and systems involved producing electric power. The increasingly competitive environment for power generation demands that utilities pursue all available options to lower power production costs. Typically, this means striking a balance between reducing maintenance costs and ensuring reliability without compromising safety. Currently, the overall inspection of complete equipment is not possible with existing manpower and inspection instruments within a short span of interval. Automation helps in increasing the reliability of the system or equipment without involving human risk.

Boiler Tube leaks is the dominant reason for the loss in availability of the Indian boilers. The poor calorific value which results in high specific coal consumption and the high ash content in Indian coal erodes the boiler metal surfaces in an unpredictable pattern and results in forced unit outages. An outage in the form of Boiler tube leak for a typical 500 MW units costs almost few million rupees for bringing back the unit and thus adds up extra cost to the generation. It is for this reason that Boilers in NTPC are comprehensively planned for periodic inspection. Any reduction in forced outage will improve the availability of the system. It is, hence in this direction, proposed to develop an automation mechanism for boiler tube inspection, thus attempting to improve the plant availability.

Generator being the most critical component in power generation needs special attention from inspection point of view. Its inspection is usually done in major overhauling at every 3-4 years. The removal of rotor and putting back is very crucial activity and takes more time than actual inspection. Robotic system for in-situ inspection of generator stator and rotor helps in reducing

50% inspection time. The inspection at regular interval ensures the reliability of the equipment and early detection of any critical problem. Generator inspection includes visual inspection, ELCID (Electromagnetic Core Imperfection Detector) test and wedge tightness test. ELCID test is based on the detection of core fault directly in the damaged areas of the core at only three to five percent of rated flux. The excitation level for generator is determined by a combination of the stator design parameter and power supply needed for the required flux. ELCID has proven to be reliable in the detection and locating of core problems, and determine the severity of core faults or inter-laminar insulation deterioration.

## 2.0 Boiler Inspection in NTPC

The entire operations of boiler tube inspection spread over 12 to 15 days, which is highly complex and labor intensive. The typical activities during planned outage for Boiler inspection are as follows:

- Cooling of the boiler after shutting down (min 24 hours),
- Washing of the heat transfer surfaces (24 hours),
- Erecting a scaffolding (96-100 Hours),
- Tube thickness survey (done in two phases:- phase 1 in furnace zone which is around 60-72 hours and phase2 in second pass-economizer, LTSH and extending up to reheater-120 hours).

All these activities are currently done under heavy manual intervention and supervision. Hence automation in these activities is going to reduce the unit down-time considerably and reduce the cost of power generation. NTPC Energy Technology Research Alliance (NETRA) has taken up an initiative to develop robotics mechanism for boiler tubes integrated with sensors.

## 2.1 Geometrical Complexities of Boiler

Boiler tubes of the fossil power plants consists of hundreds of steel tubes with diameter varying from 38 mm (Economizer) to 63 mm (water wall tubes) and over 75 m height. The diameter of LTSH tube is 44.5 mm with a longitudinal pitch of 96 mm and transverse pitch of 114.3 mm. Therefore the minimum gap or spacing between the tubes is 73.75 mm. Figure 2 showing the gap between the two assemblies of tube bundle separated by the support plates. The material of the support plates is also carbon steel. Also, the edges of tube near bends are shielded with stainless plates for a length of nearly 500 mm on the surfaces which faces the flue gas flow. This prevents erosion of the tubes to major extent.

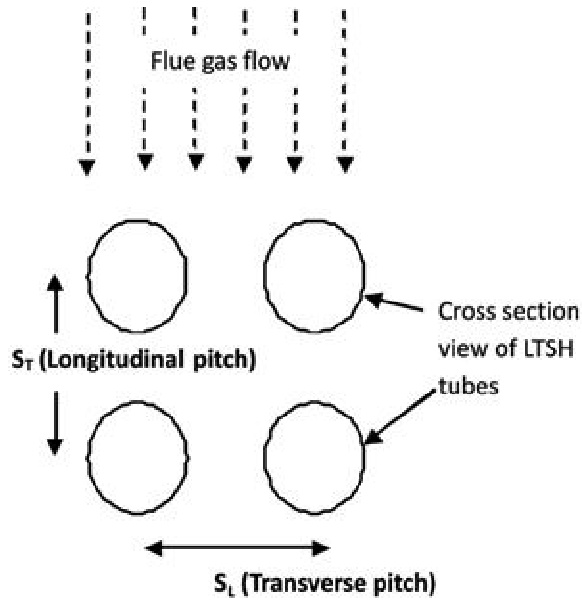


*Fig-2: Support plates separating two assemblies of coiled tubes.*

Figure 3 shows a schematic view of the coiled tube which contain three zones. Zone 1 and Zone 3 are separated by support plates from Zone 2.

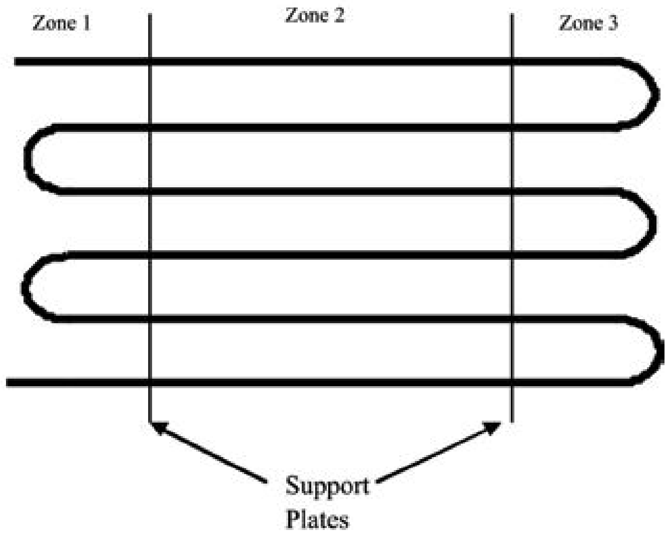


*Fig-3: Schematic diagram of the Economizer tubes*

Considering the complexities of the tubes arrangement, the possible movements of the robot are listed below.

1) Trace along a tube through different zones and bend around the corner and repeat the same motion as shown in Fig-4.

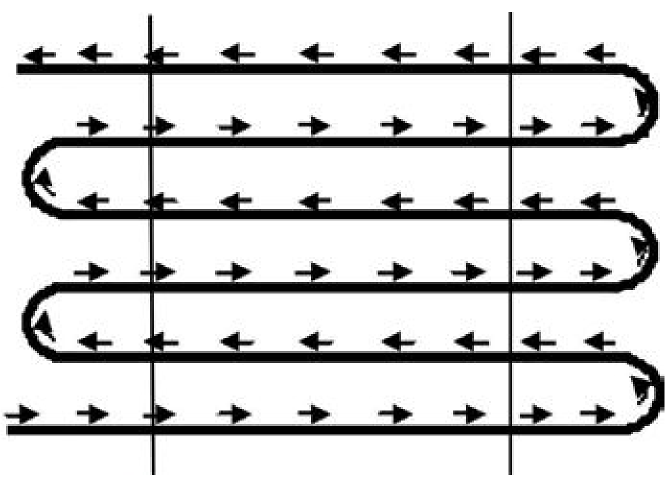

*Fig-4: Possible movement on coiled tubes.*

For this movement, the size of the robot along with the sensing and tube thickness detection mechanism should be small enough so as to pass through the support plates gap, which is approximately 40 mm wide.

2) Move in different zones independently with forward motion and lateral motion near the supports as shown in Fig-5.

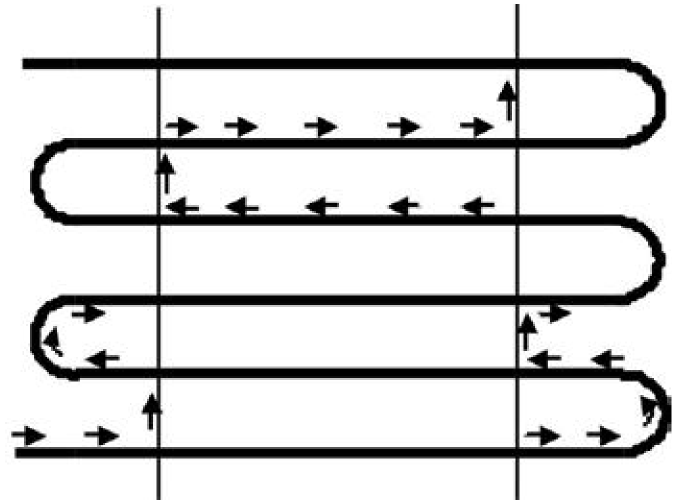

*Fig-5: Possible movement on coiled tubes.*

Due to the presence of the support plates, the movement from the Zone 1 to Zone 2 and Zone 2 to Zone 3 is very difficult due to small clearance near the supports. So the Second possibility seems to be in good agreement with in the given constraint. But the actual gap between the panels are much less and non-uniform so that robot movement in between the tubes is very difficult. Either Micro-bots or In-pipe robots can be the appropriate solution for meeting such requirements.

## 3.0 Generator Inspection in NTPC

Generator inspection is usually done in major overhauling at every 3-4 years. The removal of rotor and putting it back is a very crucial activity and takes more time than actual inspection time. So, the generator inspection at minor overhaul is not possible at present. If generator condition is assessed during minor overhauls, it will reduce the planning and maintenance time during capital overhaul. Inspection at regular interval ensures the reliability of the equipment and early detection of any critical problem. Generator inspection includes visual inspection, ELCID (Electromagnetic Core Imperfection Detector) test and wedge tightness test.

## 3.1 Geometrical Complexities of Generator

The geometrical and operational constraints for its basic design are shown in figure 6, the gap between rotor and stator is shown for a 200 MW generator. The air gap is 70 mm, throughout the length but 50 mm at the entrance because of the end ring. Moreover, rotor has wedges over its poles (each pole has 45 degrees circumferential length), which has staggered configuration. The inspection is to be carried out over a span of around 10 meter in length. Figure 7 shows the geometrical complexities in a Generator.

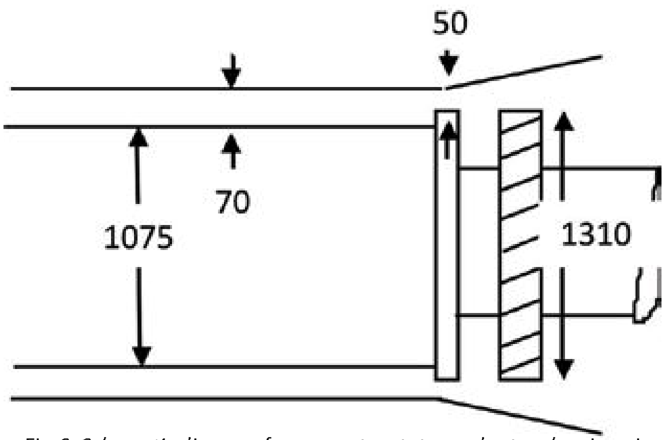


*Fig-6: Schematic diagram for generator stator and rotor showing air gap.*

*Fig-7: Generator of Vindyachal stage-1*

## 4. Projects

NTPC Energy Technology Research Alliance (NETRA) has taken up two projects to cater the technological needs in the area of automation in inspection system. One of the projects is for developing In-pipe robot for inspection in power plant tubes and pipes. Other project helps in Generator inspection with rotor in-condition. Both projects are being developed in-house and will help in the automation needs in power plant to some extent. The details of the projects are as follows:-

### 4.1 Development of In-pipe robot for critical power plant areas

Boiler second pass is more prone for ash erosion and the accessibility of tubes is difficult because of the coiled tubes and small clearances. The Inspection of the complete tube is possible only after cutting and lifting of the individual tube at multiple locations, inspection, welding and then radiography, which is time consuming task. Therefore, it is impossible to inspect each and every tube, resulting in unidentified defects which may lead to forced outages. An in-pipe robot for the internal inspection, In-house research project has been taken up by NETRA for developing proof of concept in the first phase of the project. The motion of the robot is based on the helical motion of rotor wheels. The robot is equipped with wireless camera, battery pack and led lamps. The robot motion can be controlled remotely by wireless module. It will be equipped with sensors for thickness measurement, which will provide the health condition of the tube or pipe. It will enable us to inspect the inaccessible tubes without removing the tube from its location in a much faster way without affecting its reliability. The work is going on optimising the design aspects of in-pipe robot and increasing its speed.

*Fig-8: In-pipe robot for internal pipe inspection*

## 4.2 Development of Generator Inspection System

Robot has been designed keeping the criticality of generator in mind and considering all constraints. The design of robotic crawler includes the design of mainframe, power unit, links, couplings, wheels, etc. After the basic design, other things that need to be taken into account are size of camera, sensor, encoders and cables etc.

A conceptual design of generator inspection system is presented. The design is developed based on the inputs from 200 MW/ 500 MW generator design data. A 3D model of design has also been developed and fabricated.

The constructional details of Generator Inspection crawler and the complete assembly are as follows:

1. A crawler was fabricated of Aluminium for light weight and non-magnetic properties.
2. The size of Traction unit is kept small so that it can go in small air gap of 50 mm.
3. Magnets are placed for the proper grip to the surface.
4. One DC geared motor is used for traction. The speed is controlled using PWM module.
5. The wheels are designed in such a way that stator tooth gap will be covered easily and the cylindrical surface is curved so that it will take care of the curvature of generator stator surface.

The stator has cylindrical shape and the crawler should take the curvature of the stator and capable of taking sensor inside in the right orientation as desired. This problem can be solved with the help of flexible coupling design for a range of curvature as the stator windings has large curvature before the entrance zone. The flexible coupling provides better grip because of more contact area.

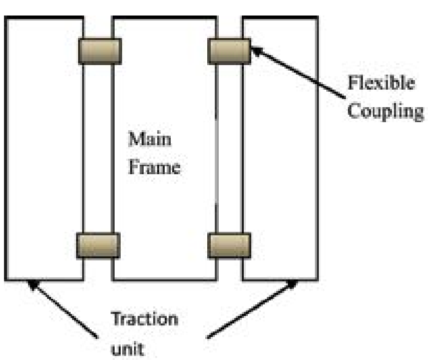

*Fig-9: Proposed architecture of Generator Inspection System*

The architecture shown in Fig-9, has two traction unit and body frame joined together by flexible coupling. The traction unit provides grip and locomotion to the robotic crawler and main frame carries the sensor, controllers, light, communication cable etc. Two DC motor can be used for providing locomotion to two different units. Belt drive is used to propel the wheels for better griping and motion. The speed of the robot is controlled by the motor controller and encoder provides the location of crawler inside the generator. The system will be integrated with various sensors like visual inspection, ELCID (Electromagnetic Core Imperfection Detector) test and wedge tightness test. The system integrated with sensors will be useful in faster and reliable inspection of Generator stator and rotor.

## 5.0 Conclusion

This paper helps in identifying the constraints involved in developing such automation mechanism for power plant critical areas. These systems can be useful in reliable inspection of the equipment and subsequently reduces the cost of production by increasing their availability.

Boiler second pass is more prone to erosion of tube and results in forced outages. Faster and reliable inspection can only be achieved by robotic system. For coiled tubes, In-pipe robot seems to be a suitable solution for internal inspection of pipes in critical areas. The sensor size also plays an important role in the development of automation system. The developed In-pipe robot can be useful for the inspection of tubes of in-accessible areas of all types. Generator inspection is also a tedious time consuming activity. Rotor removal takes more time than actual inspection. So, Generator inspection system with sensors will help in faster and reliable inspection without removing the rotor from generator. It will be useful in Generator inspection during minor overhauls, helps in early detection of fault and planning for major overhauls.

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## 7.0 Biographies

Kishore Aggarwal is B. Tech (Mechanical) from IIT Guwahati. He is presently working in NTPC Energy Technology Research Alliance (NETRA), Greater Noida in Sensor & Robotics group for developing automation mechanism for inspection of power plant critical areas.

Badri Vishal Gupta is Diploma in Electronics Engineering from UP Technical Board. He is working in Sensor & Robotics group of NETRA for developing and designing electronics circuit board for power plants application and research development projects.

Rakesh Kumar Chakraborty did M. Tech in Power System from IIT Kharagpur. He has an experience of 19 years, mainly in the area of condition monitoring & health assessment of electrical power plant equipment, sensor and robotics development for power plant application.

# Advance Vibration Analysis & Diagnosis System for Power Plant Rotary Machines
# It Saves Cost & Increases Up Time !

## PREPARED BY

**Mukesh Vyas**

**Division Head – India ( VMS Systems )**

**Forbes Marshall P Ltd**

**Email – mvyas@forbesmarshall.com**

**Phone – 00919823202290 / 00912027442020**

## What we need Vibration Monitoring Pumps, Fan & Motors ?

Power plants before 20 years used to shutdown more frequently for maintenance. But now it has become the need to monitor the plant to increase the plant uptime to 95%.

Power plants are divided according to the criticality into three categories as shown in the triangle below. The most critical machines are turbines, which depends on the secondary critical machines like ID fans, FD fans, PA fans, BFP, CWP, CEP and Mill Motors.

Looking at today's scenario it is the very need for monitoring these machines for increasing the efficiency and thereby reliability of the plant .

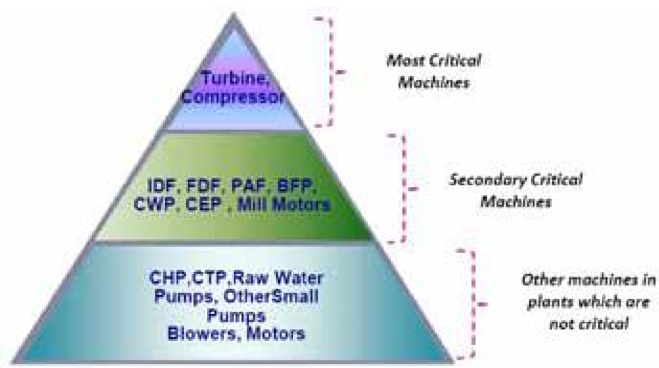



Fig: 1. Pyramid for machinery in power plants

This vibration monitoring solution is cost effective as maintenance tool which ensure the total availability of plant.

Condition characteristics of the machine such as bearing damage, unbalance, alignment or cavitation enable a differentiated evaluation of mechanical stress which will keep us on track for when to have the shut down and the process is ongoing without any manual interruption Hence we will be able to protect the equipment from expensive consequential costs.

For taking the machines for maintenance we need to know the healthy state of the machine without dismantling it. This is possible only by online monitoring. Implementing predictive maintenance leads to a substantial increase in productivity to up to (35%).

## Key Secondary Critical Rotating Machines in Power Plants are :

### A. Pumps & Motors :

Water pumping is the vital energy consuming area in thermal power plant and major pumps in thermal power plants are:

1. Condensate Extraction Pumps

These are medium size vertical pumps driven by an electric motor. The motor is direct coupled to the pump which may be 10 to 15 feet below the surface. Suction is at the bottom and output is at deck level, just below the motor.

2. Boiler Feed Water Pumps

These are large horizontal pumps that are driven by large electric motors. (In some cases, a small steam turbine is used as the driver). The motor is coupled to the pump through a hydraulic coupling which acts, in a sense, like an automatic transmission.

3. Cooling Water Pumps
4. Auxiliary Cooling Water Pumps
5. Circulating Water Pumps

These are much like the Condensate Pumps, medium size vertical pump driven by an electric motor. The motor is direct coupled to the pump which may be 10 to 15 feet below the surface.

### B. Fans & Motors

Other critical machines in power plants are fans used for ventilation and industrial process requirements. Induced Draft Fans (ID Fans) and Forced Draft Fans (FD Fans) are used to control air flow through the stack, maximizing the efficiency of the Boiler. Gas Recirculation Fans collect unburned gas and send it back to be burned again, reducing the particulates that are emitted to the air. As in vibration terms fans contributes to the maximum. The motor shaft is coupled to the fan through the coupling (plumer block), can be fluid coupling.

1. Induced Draft Fans (ID)
2. Forced Draft Fans (FD)
3. Primary Air Fans (PA)

## Vibration Monitoring System Design Standards – API 670

For Vibration monitoring system there is global standard as API 670 IV th Edition – Machinery Protection System. It is useful for the plant maintance to have uniform system such as API 670 Compliance Vibration Sensors , 19” Rack Based Monitoring System and required relayoutputs , 4-20 mA outputs , DCS Interface and 02 Raw Buffer Signal output for further integration.

API 670 helps customer to bring all suppliers on one plat form and possible to change sensors and monitors with other supplier incase they find problem during maintenance hence no supplier will be able to take customer for ride.

It will be good practice to follow API 670 Design standard for Turbine and other applicable BOP Machines in Power plant to avoid issues later on.

## Sensors used in Vibration Monitoring

The three principal vibration sensor or monitor types are displacement, velocity, and accelerometer. The displacement transducer is an eddy current device, the velocity transducer is often a spring held magnet moving through a coil of wire or piezo velocity sensor , and the accelerometer is a piezoelectric device somewhat similar to ultrasonic transducers. The following information briefly describes how these transducers work, where they work best, and what kind of results they provide.

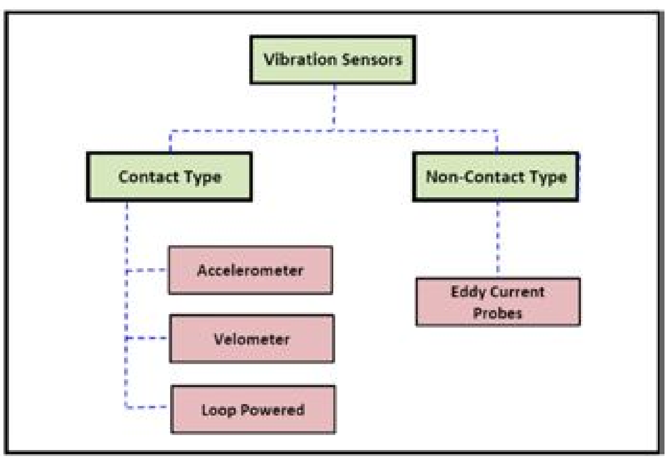


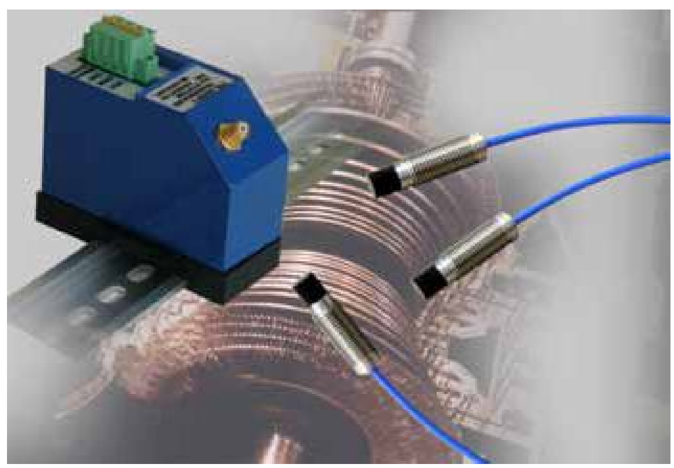

*Fig: 3. Vibration sensor types*

## Non-Contact Eddy Current type:

Displacement sensors are non-contact devices measuring the gap between the plant equipment and the fixed sensor. It is usually mounted 380-2,030 µm (15-80 milli-in.) from the part to be observed. The coil in the eddy current device is usually a pancake coil in the end of cylindrical tube that can be mounted close to the moving part. Excitation is very high frequency, about 240,000 Hz, for detection of small gap changes (as low as 1 µm [40 milli-in.]) at 0.5 MHz.

The sensor measures vibration as horizontal or vertical motion (requiring two different mountings of one sensor or two sensors). The best measurements are at low frequencies of vibration of the part, below 1,000 Hz, where signals as large as 4,000 mV/µm (100 mV/milli-in.) can be obtained. Since the signal can be large, very low amplitude displacements or vibrations can be measured. Displacement sensors work well for applications such as shaft motion and clearance measurements.

## Applications : Radial Shaft Vibration , Phase Marker , Axial Shift and others.



## Velocity Sensors :

Velocity sensors find use from the low to middle range of frequencies (10 to 1,500 Hz) or 600 to 150,000 cycles per minute of machine vibration.

The basic velocity pickup is a magnet (as a seismic mass) suspended on a spring moves through a coil of wire. The case of the sensor attaches to the device being measured such that the coil of wire moves through the magnetic field and generates an electrical signal.

No external electrical excitation is necessary for these "self-generating" devices. The signal generated is high level (milli volts) for the useful range of frequencies and is relatively free from high frequency noise signals. The sensors find considerable use in handheld probes, providing useful information for vibration monitoring and balancing of rotating machinery.

Currently we have Piezovelocity Sensors which is having similar performance.

## Application _ Absolute Bearing Vibration ( Casing Vibration )

### <u>Accelerometer Sensor :</u>

Accelerometers work well over a very wide range of frequencies (1 to 20,000 Hz). They work best for high frequencies where acceleration is large. Examples are the passage of turbine blades, which may be one hundred times the shaft rotation, or the meshing of gears or ball/roller bearings, which may be many times the shaft rotations per minute. Other advantages include their small size, lightweight, good temperature stability, and moderate price.

Accelerometers develop a voltage from a piezoelectric crystal that has a mass mounted upon it. A quartz crystal is frequently used. When the mass fixed to the crystal vibrates from the motion of the device upon which the sensor is attached, the crystal generates a voltage proportional to the force applied by the mass as it vibrates with the machinery. While no external excitation is required for the sensor to produce its voltage signal, the signal is small (self-generated) and requires a preamplifier. The preamp is often in the sensor case so the connecting cable must carry preamp power to the sensor as well as the signal from it. The accelerometer is the workhorse of vibration sensors because they offer such a wide range of working frequencies plus the other advantages given above.

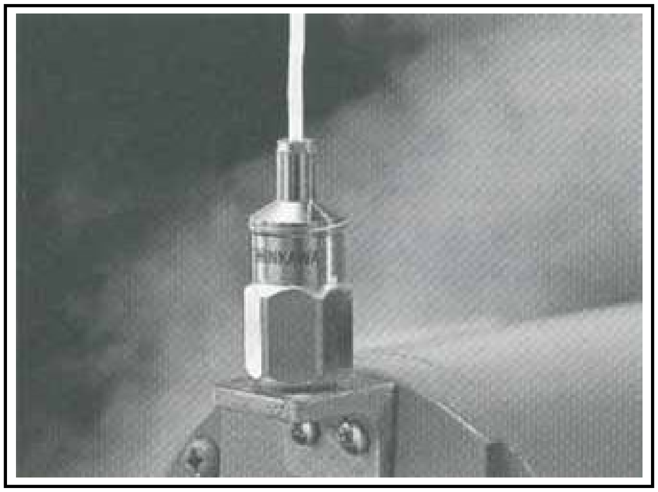
Application – Absolute Bearing Vibration ( Casing Vibration ) for High Frequencies.

## Applications of Sensors :

### Radial Vibration

Shaft vibration measurement relative to bearing is done with Non-contact (eddy current or proximity) type probes in dual X-Y mounting 900 apart. Radial vibration measures the radial motion of the rotating shaft relative to the case. This measurement gives the first indication of a fault, such as unbalance, misalignment, cracked shaft, oil whirl or other dynamic instabilities. Vibration measurements can be made in a single plane or a two plane (X-Y) arrangement where the sensors are 90 degrees apart and perpendicular to the shaft. Eddy current probes are usually installed in a hole drilled through the bearing cap and is held in place by either a bracket or a probe holder.

## Casing Vibration :



Presently in all new power plants, which are very well planned in Maintenance front are having on line Vibration Monitoring System for all Level 1 & Level 2 Critical Machines.

Level 1 Critical Machines – Turbine & Generators. Sometimes compressors if present in the power plants for gas turbines and so. (Typically 1 No in each Power Plant and will have Turbine Supervisory System)

Level 2 Critical Machines – Boiler Feed Pumps , Condensate Extractive Pump , Cooling Water Pumps , ID Fans , FD Fans , PA Fans , Mill Motors , Coal Handling Crushers , Make Up water Pump , Raw water Pump & Utility Compressors. (Typically Needs at around 100 Sensors / Each 250 MW or 500 MW Power Plants)

Level 3 Machines – Small Pumps & Motors – Vibration is monitored every week by Portable Data Collector to plan maintenance.

Typical Layout of Power Plant which Explains that where all we need Vibration Monitoring and How critical is each machine if there is shut down is shown in the below figure.

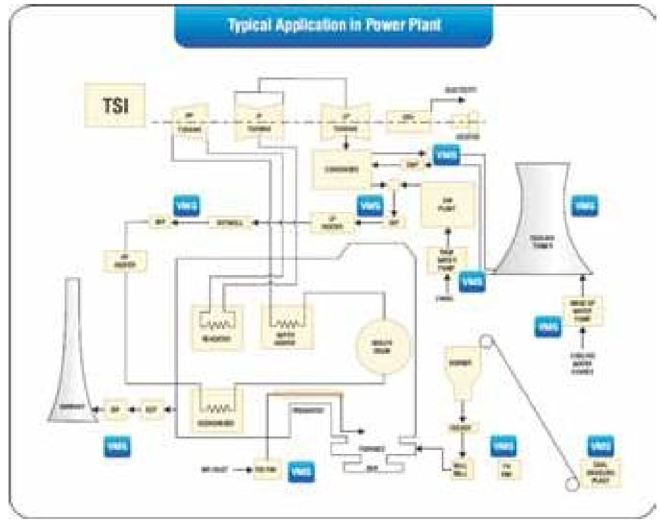
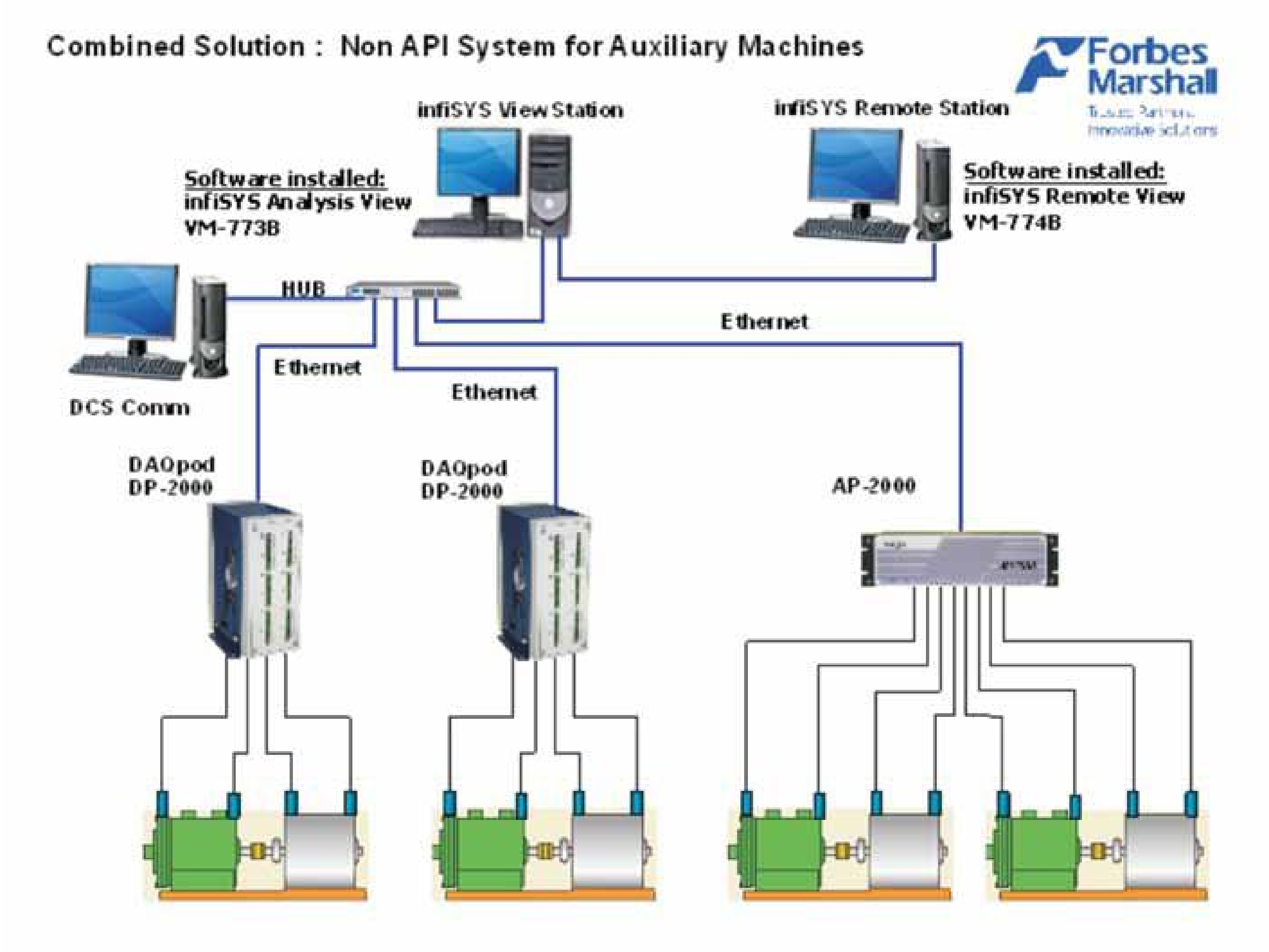



*Fig: 14. Application of VMS in Power plant*

## Vibration Monitoring Solution: Secondary Rotary Machines

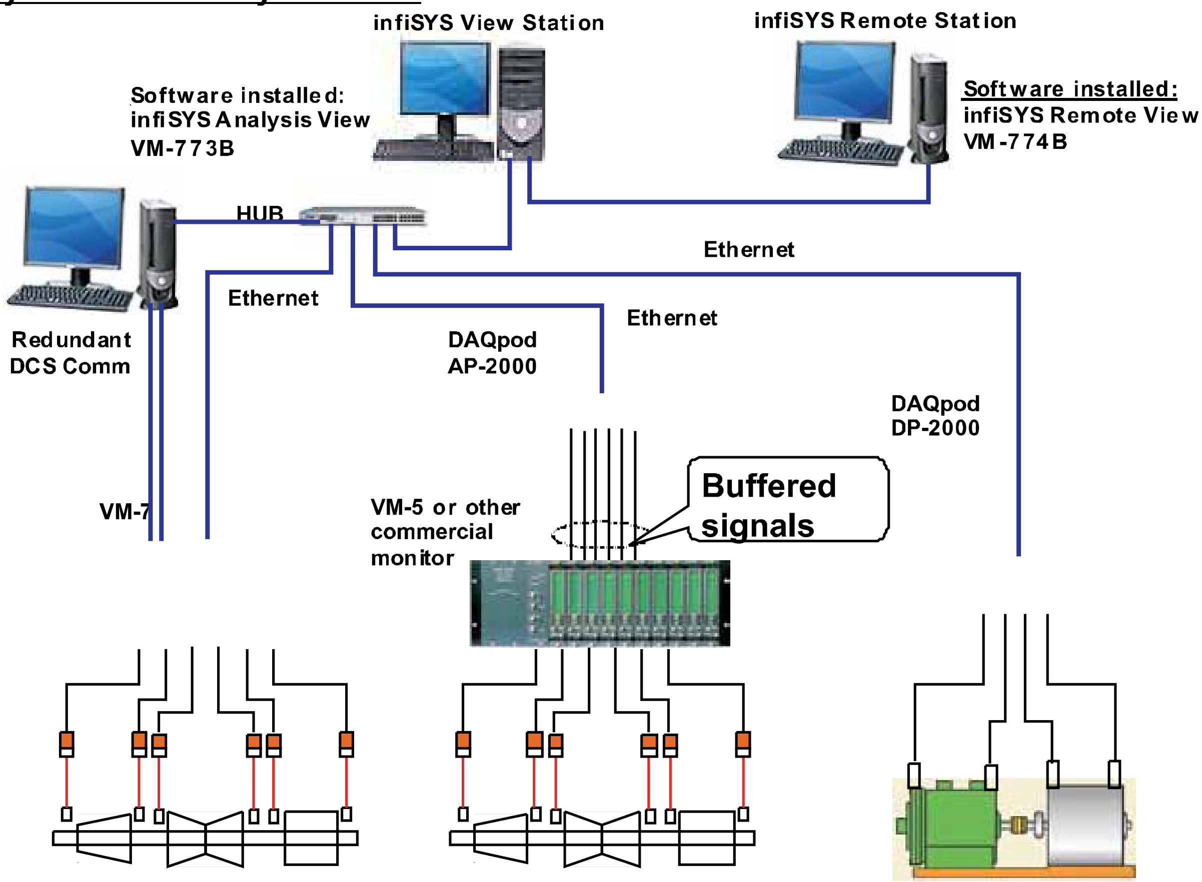
1) ID / FD / PA Fans , CEP / CWP / ACWP / BFP Pumps & Mill Motors
2) Coal Handling Plant Crushers , RWP , MWP & Cooling Tower ( IDCT )

## Option 1 : Non API 670 19" Rack Based System with Analysis & Diagnosis System.




**Option 2 : API 670 - 19" Rack Based Monitoring with Analysis & Diagnosis System. – For Complete Plant – Turbine & Other Machines Together and interface to any old supplied system.**

**Combined Solution : API 670 System for Critical Machines & Non API System for Auxiliary Machines**




## Main Turbine Vibration Monitoring with Analysis & Diagnosis System:

The most critical part of the power plant is the turbine. Main Turbine is the heart of the power plant. Turbine is the most critical part of the plant and it is mandatory to use maximum protections as well as on line measurements of different parameters to avoid any unexpected failure/shutdown.

There are several reasons for the cause of vibration in machines. They can be due to:

- Unbalance of shaft
- Bearing problem
- Cracking of the rings
- Fluid coupling problem
- Shaft misalignment
- Oil whirl and other dynamic instabilities

These problems can gradually become so severe that it will lead to unplanned shut down. For

this industry people plan the shut down i.e. Time Based Maintenance System (TBM) that is called preventive maintenance. But today we can extend the life of the machines by monitoring it online in a cost effective way. This will increase the overall efficiency of the plant by contributing. Vibration Monitoring and Analysis is the easiest way to keep machines healthy and efficient in the long run. It reduces the overall operating cost as well as the down time period. The vibration sensors are used to predict the faults in the machine that is running without dismantling it. It gives the clear indication of the severity by showing the amplitude of vibration.

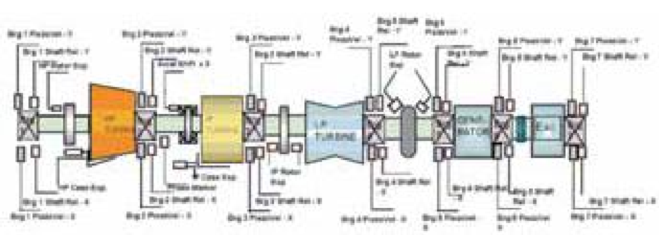
Vibration Monitoring System for Power Plants application

For Big turbines like 210 MW,500MW there are almost 10 to 12 nos of parameters which is to be measure with more than 36 online sensors + Monitors and analysis/ diagnosis system. This is what we termed as “Turbo Supervisory system”. To keep running Turbine in more efficient and better way it is always recommended to keep some second level critical machines under online Vibration Monitoring.

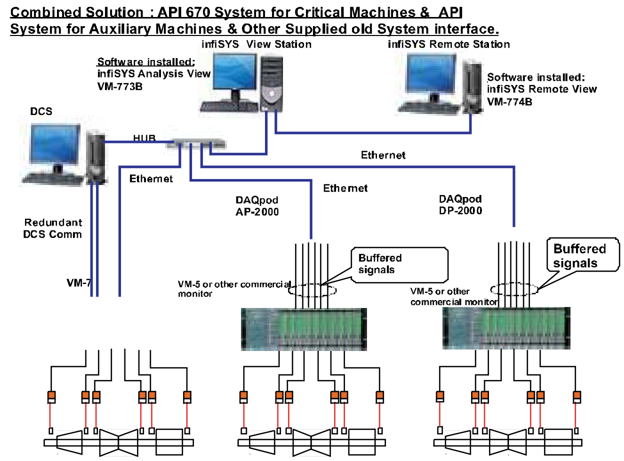
Major measurement categories for TSI are:

- Motion
  - Shaft Vibration
  - Eccentricity
- Position
  - Thrust, Rotor position
  - Case expansion
  - Differential expansion
  - Valve position
- Phase, Speed measurement
- Process Parameters
  - Temperature
  - Pressure
  - Flow

In short the layout of the turbine for instance the 500 MW TSI system commissioned is shown for your reference information.



**Main Turbine and other Machine Interface System :**




## Summary:

- By monitoring the performance of the critical machines & the secondary critical machines we can predictive shutdown of the plant instead of planned shutdown done very frequently
- The root causes of the machinery failure can be known by using vibration monitoring System.
- Lead to increase in the reliability of the system machinery.
- Reduction of manual intervention that is erroneous.
- Will eventually increase the plant uptime to 95% overall.

# Automation in Hydro Power and Renewable Power Solution

# Latest Technologies of Field Instrumentation, Data Collection and Reporting for Dams and Related Structures

V K Rastogi

Encardio-rite Electronics Private Limited, Lucknow, India

Keywords: dam, instrumentation, mobile phone, internet, web, wireless, blue tooth, inclinometer, vibrating wire, electrolytic, mems.

## INTRODUCTION

Monitoring of dams, tunnels, and other civil engineering structures or geological hazards like landslides by field instruments has become highly sophisticated and advanced over time. As adoption of safety monitoring is getting more widespread there is a need to design the safety monitoring network system to be cost effective to either reduce the cost of instrumentation or to allow monitoring of more parameters within the same budgeted cost.

Another essential feature of safety monitoring network is to make the collected data readily available in real or near real time to the different stake holders where ever they may be sitting around the globe. The collected data needs to be presented in an easy to understand format like charts or graphs including historical data of the parameters at that location. Stake holders today also expect the safety monitoring network to identify potential hazardous conditions or developments well before a catastrophic failure takes place and alert personnel with authority to take remedial measures as early as possible. This is very important as affected communities, governments, project owners and stake holders are increasingly adopting a zero tolerance towards loss of human life even for projects undertaken under the most trying conditions.

In this paper the author discusses some of the recent trends noticed in safety monitoring instrumentation networks used for monitoring dams as well as other associated structures and zones subject to geological hazards.

## ADVANCES IN SENSOR TECHNOLOGIES

One of the most used sensors for monitoring both horizontal and vertical ground surface or subsoil movement is the tilt sensor in many different forms. Although, strictly, a tilt sensor measures the tilt at the point where it is mounted, when mounted on a horizontal or a vertical beam of specified gauge length and installed as a linear array of sensors, it can be used for recording and plotting of vertical or horizontal movement profile over time.

The prime requirement for the tilt sensors for such measurement is high resolution, high accuracy and ruggedness for withstanding unavoidable field abuse like those from jerks, vibration, impact and other environmental factors. As any single type of tilt sensor is not able to provide all the desirable features required by different applications, different types of tilt sensors have to be used for different applications. Knowledge of different sensor types and their advantages and limitations will help in choosing a suitable tilt sensor for each particular application.

The electrolytic tilt (EL tilt) sensors with a range of +/- 0.5 degrees are able to monitor change in tilt with a typical resolution of around 1 arc second. Due to the inherent averaging action of the sensor the output is relatively noise free. However, due to its high sensitivity to temperature change the sensor needs to be mounted at a location that experiences least change in temperature over time. Electrolytic tilt sensors provide the highest resolution at a very economical cost.

Earlier the EL tilt sensors were difficult to integrate with off the shelf data acquisition systems as they required dataloggers with ac bridge inputs and were sensitive to cable capacitance that increases with cable length. Now manufacturers are offering electrolytic tilt sensors with integral signal conditioners that provide a voltage output signal so that the output of these EL tilt sensors can be measured by a wide variety of standard data acquisition systems.

For measuring sub soil horizontal ground movements, such as in In-Place Inclinometers, tilt sensors with a measuring range of +/- 30 degrees are preferred. The prime requirement is for a tilt sensor that provides the highest possible resolution. Earlier this could be achieved with tilt sensors based on servo accelerometer technology. However, servo accelerometer type tilt sensors are quite expensive, very susceptible to damage from even low level of shock or impact, and experience zero drift over time. As a replacement for servo accelerometer based tilt sensors manufacturers are now offering tilt sensors based on MEMS (Micro Electro Mechanical System) technology. These tilt sensors have performance that nearly meets that obtained with servo accelerometer type tilt sensors but in addition are extremely rugged and provide a stable output over their life. Typical resolution is around +/- 10 arc seconds near zero degrees. MEMS tilt sensors are also much less expensive than servo type tilt sensors for the same performance level.

Another significant trend in sensor technology is the replacement of sensors having traditional analogue output (in the form of voltage, current, resistance) or vibrating wire frequency output with digital output sensors. The analogue output sensors experience loss of accuracy when the output signal needs to be transmitted over long cable lengths. Output from digital sensors can be read by a variety of hand held or fixed location computing devices like palm top computers, mobile phones, notebooks, laptops and PC networks. As the digital sensors provide a numeric output to the data collecting device, the accuracy of the output signal never gets degraded irrespective of the distance between the sensor and the data collection device.

Most digital sensors store the calibration parameters inside the sensors and output the value of the measured parameters directly in terms of suitable engineering units which was not possible with analogue output sensors. Digital sensors equipped with certain type of electrical outputs can be connected over a single signal cable reducing cabling requirement. An advantage with many digital sensors is that they can be connected to a remote DAS or a computer using standard wireless modems. Analogue sensors require a sensor specific interface for connecting them to a wireless modem. Wireless links are discussed in more detail later on in this paper.

## ADVANCEMENT IN DATA COLLECTION TECHNOLOGY – USE OF MOBILE PHONES

Different types of analogue sensors require specific types of hand held readout units for monitoring their output at site. Even when using central DAS for collecting and recording data it is essential that the data acquisition system has the necessary signal conditioners matching with the output of the sensors deployed in a project. As an example most general purpose dataloggers do not have a suitable interface for accepting input from vibrating wire sensors. Only dataloggers specifically designed for use in geotechnical instrumentation are provided with suitable interface for use with vibrating wire sensors.

The use of digital sensors allowed the use of standard palm top computers to be used to collect data from any digital sensor provided it met certain communication standards. With the development of Bluetooth technology it is no longer necessary for the hand held computer to be connected to the sensor using a copper wire cable and the data from the sensor can be fetched wirelessly over the Bluetooth interface. However, there is a limitation. Because of the low production volumes and proprietary nature of the operating system palm top computers are quite expensive and the availability of software is severely limited. The palm top computer required the operator to go to a designated central location at the end of the day and transfer data to a host computer. It generally did not allow the operator to go through the earlier historical data for any sensor if the requirement arose.

The mobile phone is changing all that and promises much more. Today's mobile phones have evolved to become a very powerful computational platform. Most of the higher end mobile phones have a high resolution large colour graphics display, internal memory capacity that is specified in Gigabytes, Bluetooth wireless serial data link, cellular phone coverage nearly throughout the inhabitated areas of the world, cameras with pretty high resolution and image quality, connectivity to internet, and in built GPS receivers that can tell the user his position anywhere in the world. A few geotechnical instrument manufacturers have realized the potential of this new multifunctional device and are exploiting its features for field data collection in geotechnical or civil engineering safety instrumentation networks. **This has revolutionized field instrumentation technology.**

To highlight the advantages of using the mobile phone as a data collection device a typical application is described below.

The most common method of monitoring sub-surface horizontal ground movement is with a traversing type inclinometer system. A borehole is drilled in the area where sub-surface ground movement is required to be monitored. A special plastic tubing with four orthogonally arranged grooves is grouted in the borehole. The operator then lowers a bi-axial inclinometer probe fixed to the end of a cable marked in increments of 0.5 m or 2' intervals down to the bottom of the borehole. The operator then lifts the probe up by one mark interval and records the inclinometer reading on the portable readout. The probe is then rotated by 180 degrees and the process repeated. At the end of the day the operator would go to a central location and download the data to a host computer (PC). There the reading would be added to a database and the readings processed to yield a vertical bore hole profile. Finally the PC software would compute the difference of the current profile from a reference profile logged at an earlier date and present the result to the user.

This approach prevented the logged data to be monitored in near real time as the operator had to physically go to the central location and download the data. Also in most cases the operator did not have access to the earlier plots to detect if any unintentional error has crept in the logging process. Once the error was discovered at the end of the day the operator had to go back to the same borehole the next day and repeat the logging process. The conventional inclinometer dataloggers used till now were custom built instruments and required a physical cable to be connected from the indicator to the cable reel connected to the inclinometer probe for data transfer. As the reel rotated with the length of cable being wound or unwound on the reel, a slip ring connection was provided on the cable reel for connecting the datalogger so that the connecting cable would not rotate.

**The mobile phone has changed all that. One of the newer inclinometer offerings can work with Android operating system based mobile phones from different phone manufacturers. The data transfer between the inclinometer system and the mobile phone is through a blue tooth connection. As the inclinometer probe is a digital sensor, the output is a numeric value directly in terms of sine of angle of tilt.**

The mobile phone runs an application software that collects data from the digital inclinometer and appends it to a database. With an 8 GB memory the mobile phone is virtually capable of storing historical data for a large number of boreholes in the phone itself. The operator can see different types of plots for the logged data and compare the data with all earlier logged data in both tabular and graphical form. He can also zoom in to minutely inspect areas of interest. Once the operator is satisfied that the borehole has been correctly logged he can transfer the data over the GSM/GPRS network to the central server immediately. At the server end another application software plots the logged data and publishes it over the internet within a few minutes of receiving the data file. The latest bore hole log is thus immediately available to all authorized personnel of that project.

If the project is employing a web data service the operator can check out the historical data of any sensor that is part of the project instrumentation network from the location of the sensor itself using the standard web browser built in the mobile phone.

The phone camera allows the operator to photograph any significant site condition that can affect or cause a change in the sensor reading and send it in real time on the internet. **This information is most crucial in data analysis and in understanding the reason for the sudden change in readings or serve as evidence in case the instrument readings are subject to doubt.**


*Figure 1: Mobile phones as readout unit (left) and on site analysis of movement profile (right).*

While installing sensors for the first time, especially in the open, it is required that the **sensor location** be determined using surveying techniques. Traditionally a qualified surveyor with optical surveying instruments was required to determine the geographical coordinates of the sensor location. This process was time consuming and required additional surveying resources. With the in-built GPS receiver of a higher end mobile phone the operator can determine the Sensor location without requiring help of a surveyor.

**The video clip recording facility of the mobile phone allows the operator to record the installation of sensors if desired.** The video clip can serve as a record of the actual method followed to install the sensor, or can serve as a training video for other installation personnel. For installation of very sophisticated sensors or sensors requiring strict adherence to laid down procedures, the operator can use the video clip playback facility of the mobile phone to see an instructional video for installing that sensor at the site itself. Similarly, the internet browsers of the mobile phone allows the operator to access such training videos uploaded to video sharing portals like YouTube at the sensor installation site itself.

If a project uses many different types of digital sensors or distributed DAS with Bluetooth interface a mobile phone loaded with different application software would be able to down load and visualize data from all such devices. **Thus the mobile phone can save the cost of many different readouts/dataloggers required to read the different types of sensors in a conventional instrumentation network.**

As mobile phones are mass produced devices they have much more features and cost much less than proprietary portable readouts and dataloggers used earlier. Use of mobile phones with standard operating system like Android allows the users to choose from a wide variety of phones from many different manufacturers around the world. Earlier if a proprietary readout unit developed a fault the unit had to be returned to the manufacturer for repairs that took a lot of time. With mobile phones the user only needs to get another mobile phone and load the application software supplied by the sensor manufacturer. The memory card from the old phone can simply be transferred to the new phone and all the earlier data would be available to the user again.

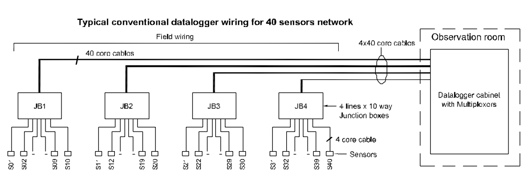
**The ubiquitous mobile phone of today equips the field engineer simultaneously with a phone, camera, location fixing, personal computer, web browser, video recorder and player, training manuals on demand and a host of sensor readouts and dataloggers in a small compact and economical palm top unit.**

## REDUCTION IN CABLING USING BUS TECHNOLOGIES

Traditionally all sensors in a typical instrumentation network are connected to a central data acquisition system (DAS) through copper cables. The output of the sensors are measured by the DAS using multiplexers which connect the output from the individual sensors one by one to the DAS input. Most current generation DAS after measuring the sensor output would mathematically compute the output in terms of suitable engineering units and store the result in its internal memory. The contents of the DAS internal memory is then retrieved by a PC which displays the measured values as a set of tables or graphs in a suitable format.

The traditional method requires that each and every sensor be connected to the central DAS using individual copper cable with at least two conductors at the minimum. A large number of sensors may require even more number of conductors between the sensor and the DAS.

To reduce the cost of cabling it is a common practice to combine the individual sensor cables, where ever possible, in a multi conductor cable using suitable junction boxes. A same length of 40 core cable is much cheaper than 20 individual 2 core cables. However even with this approach the cost of cabling required in an instrumentation network is a very significant fraction of the total instrumentation cost if the sensors are spread over a very large area.



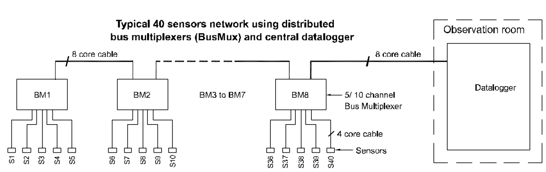



Figure 2: Schematic diagram showing savings in cabling by adopting distributed Bus Multiplexers.

To address this issue a few manufacturers are now offering distributed or bus multiplexers. Instead of providing all the multiplexers required by the DAS at a central location, the use of bus multiplexer allows the multiplexers to be placed nearer to each cluster of sensors of the same type. The output of the bus multiplexers connected to the same type of sensor can then be connected to a single multicore cable that is finally connected to the central DAS. As typical Bus Multiplexer requires a single 8 core cable for connecting all the distributed Bus Multiplexers and the central DAS in an instrumentation network. Depending on the area covered by the instrumentation network the savings in cable costs can be substantial even though the bus multiplexers themselves cost much higher than the conventional multiplexers provided inside the central DAS cabinet.

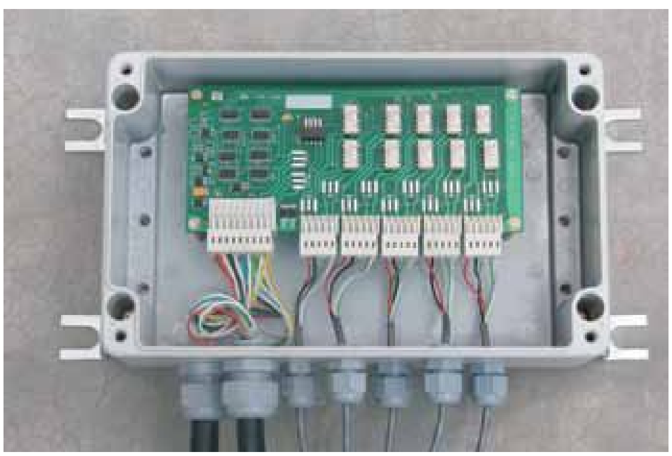


*Figure 3: A field mountable Bus Multiplexer in weather proof IP-67 housing shown with its cover removed.*

Another means of reducing cabling costs is to use digital sensors with SDI-12 interface. Sensors equipped with SDI-12 interface require a single 3 conductor cable for connecting all the sensors to the central DAS. A single cable can be used to connect from 10 to 25 sensors depending on the type of sensors. An additional advantage is that different types of sensors can be mixed on the same SDI-12 bus which is not possible with analogue output sensors. As the SDI-12 sensors are digital sensors the accuracy of the output (measured) value is not affected by the length of cable between the sensor and the DAS.

Adding a SDI-12 interface to an individual sensor adds to the cost of the sensor. However, interfaces are also available that can accept input from a number of sensors with similar analogue output, convert their output values to a digital value (numeric value) and then transmit it over a standard SDI-12 bus. This approach allows conventional sensors to be connected to a SDI-12 bus network.


*Figure 4: A SDI-12 Interface for connecting 8 vibrating wire sensors to a SDI-12 bus cable.*

## WIRELESS LINKS

Wireless links are becoming very popular for connecting sensors to the central DAS or host computer. Wireless links as the name implies eliminates all cabling between the individual sensors and the central DAS. There are many different types of wireless links but no one type of link is suitable for all situations found in the field. A knowledge of the advantages, disadvantages and limitations of each type of wireless link is essential for designing an economical and reliable wireless sensor instrumentation network.

The theory and practice of wireless links is a vast subject and research is currently on for development and standardization of very sophisticated wireless sensor networks. Here we will only discuss the most common solutions currently being adopted in safety instrumentation networks.

The use of radio frequency spectrum for establishing a wireless link is tightly controlled by respective national governments and generally requires a license from the national radio frequency regulatory body. Only a very small fraction of the total available spectrum is earmarked as free for unlicensed use. Even these frequencies vary from country to country; so a knowledge of local regulation regarding use of radio frequencies is a must before choosing a particular type of wireless link. However, in general the 2.4 GHz and 5 GHz bands are free for unlicensed use in most countries. In some countries the use of certain frequencies in the 800 to 900 MHz range is also allowed without requiring a license.

Sensors and Data collection units that operate at 2.4 or 5 GHz require a near line of sight access between the two communicating devices. Except for small obstructions any significant obstruction that comes between the two communicating devices can render the wireless link unusable.

Wireless links operating at 800 to 900 MHz band are more tolerant towards in line obstructions and the radio signals between the two communicating devices can to some extent travel around the obstruction provided it is not very large.

A bluetooth standard wireless link operates at 2.4 GHz and is generally used for very short distance communication of up to 10 metres but the link can be used for distances up to 100 metres using higher power. The higher power Bluetooth link is used for link distance above 10 metres. For example the data from a difficult to reach borehole extensometer / anchor bolt load cell combination installed at the crown of a large tunnel or underground chamber can be accessed from the base or floor wirelessly using Bluetooth wireless link.

Large instrumentation project sites generally have a large number of sensors spread over a wide area that need to be connected to a central DAS. Connecting all the sensors to the central DAS using copper cables may not be a viable solution due to many factors. However, the distance between most of sensors and the DAS may often be beyond the range of low power wireless links or near line of sight location may not be possible for all sensor locations. A similar situation is also found in tunnel instrumentation as the sensors are spread out over a large linear distance from the face of the tunnel. A curved tunnel section introduces more problems in using low power point to point wireless links.

Digital sensors equipped with ZigBee RF modems allow what is known as mesh networking. The ZigBee modems allow each sensor to get data from its neighbour farther away from the DAS and relay them to another neighbour that is more nearer to the central DAS. The communication links established between the sensors themselves make up what is commonly known as a mesh network. Mesh networks are only suitable for low data transfer rates and the ZigBee modems are increasingly being designed for lower power consumption. This makes the ZigBee mesh networking a good candidate for use in civil engineering instrumentation projects.

In some projects the sensors may be spread out over many square kilometers area. Typical examples are ground water monitoring, surface settlement and building monitoring over metro or sewage tunneling activity in urban areas, rainfall monitoring around dam catchment areas etc. The above wireless technologies are not suitable for such applications due to the very long distances between the sensors and the central DAS.

For covering very long distances or wide areas, GSM/GPRS modems are used either with individual digital sensors or more commonly with a small DAS that caters to a cluster of sensors deployed at the same location. GSM/GPRS modems leverage commercial cellular phone service provider's network and the internet to relay sensor data to a central DAS or host computer connected to the internet. For using the GSM/GPRS modems it is essential that the sensor location is covered by a cellular service network provider. Using GSM/GPRS modems sensor data can be transmitted to a DAS or host computer even at the other end of the world.

Caution should be exercised when using GSM/GPRS data links for relaying time critical or hazard warning data. Often during an emergency like a natural or a manmade disaster the cellular phone system gets overloaded with massive volume of calls which renders the phone network temporary non-functional. Such a situation will not allow critical data to be passed on to the recipient in time to prevent either immense damage or even loss of life.

## DISTRIBUTION OF PROCESSED DATA OVER INTERNET

A civil engineering project during the construction phase will have many stake holders who would be interested in the safety and optimum construction status of the project. Typical stake holders would be the project owners, designers or consultants, contractors and site engineering and safety monitoring personnel. For large projects the stake holder's empowered personnel may have offices located hundreds of kilometers away from the actual project site. Consequently there is a need to provide all the stake holders with near real time access to data from safety monitoring instrumentation network irrespective of their actual location. In view of this, another important function of safety instrumentation network that is becoming an essential part of project contracts is providing means for alerting authorized personnel about development of potential hazardous development in near real time so that remedial actions can be started without delay.

A few geotechnical instrument manufacturers and geotechnical instrumentation service providers are now providing proprietary software that can be hosted on servers connected to the internet. The software is capable of collecting data from the various sensors and dataloggers deployed in a project over conventional copper cables, optical fibre cables, or various types of RF links according to a preset schedule. The collected data is added to a database. The software can present the collected data as a set of meaningful graphs or tables in a format appropriate to the parameter or parameters being monitored on demand by the various users from different locations around the world over the internet.


If different alarm thresholds are defined for the logged parameters, the software can also issue an alert to authorized personnel through e-mail or SMS (Short Messaging Service) about any

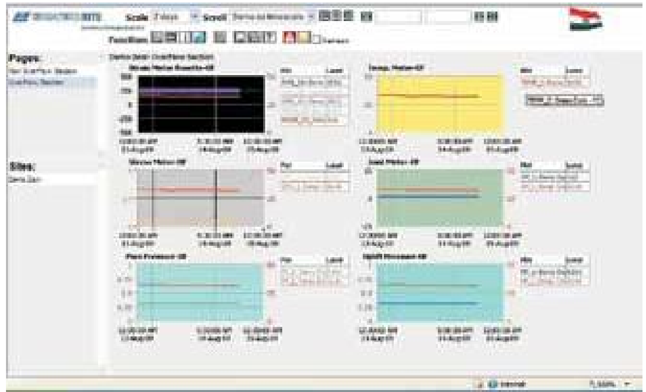


*Figure 5: Screen shots from a web based data monitoring service showing login screen (previous page) and a graph page (above).*

parameter or a set of parameters exceeding the preset alarm thresholds. Most software will allow setting up of up to 2 alarm levels corresponding to a general alert that the parameter has exceeded a preset alert level that demands immediate remedial action or the parameter has exceed the safe limits specified by the designer and further work should be stopped.

For those users who are unable to setup and maintain their own data servers some instrumentation service providers also provide hosting services where the monitoring and reporting software is hosted on the service providers servers. These servers are high reliability servers, with redundant power supplies for high availability and have sufficient internet bandwidth for meeting the project requirement. Leasing of hosting services for the monitoring and reporting software is an advantage for smaller project owners or contractors who need not dedicate personnel and resources for maintaining the high availability severs which in itself requires a degree of sophistication best left to experts.

## CONCLUSION

This paper highlights some of the advancement and recent trends taking place in the areas of sensor technology, data transmission, data recording and presentation in field instrumentation employed for safety monitoring of geotechnical and structural engineering projects.

Keeping a watch and adopting new sensor technologies can increase accuracy of measurements with reduced costs. Using digital sensors allows many benefits like calibrated outputs, non degrading accuracy and easy transmission of data over long distances to a remote host computer.

The use of mobile phone as a data collection device, if provided by the instrumentation manufacturer, can like the Swiss Army knife allow the field engineer to carry the equivalent of a phone, camera, location tracking, web browser, training and user manuals, video recorder and playback, and a host of readout units in a single compact palm held device.

The use of an appropriate bus technology for transmission of sensor data over copper cables to the central DAS will result in substantial reduction in cabling as well as total project cost. For this an understanding of the advantages and limitations of the different available bus technologies is a must.

Wireless links eliminate the need to connect the installed sensors and the central host computer with cables. In some situations wireless links would be the only solution as laying of cables may not be feasible. An understanding of advantages and limitations of different wireless links will help in choosing the most optimum solution for a particular project.

Adopting a web based data access service will allow all stake holders to have access to safety instrumentation network data and analysis in near real time from anywhere in the world. The system will also allow authorized personnel with authority to initiate suitable remedial action to be alerted to potentially hazardous developments that can give rise to a catastrophe over time. Timely alerts can prevent loss of human life, time and money due to catastrophic failures.

# Two-axis Solar Tracking System

S.P.S. Pundir, Rakesh Swami, Vishal Singh


## ABSTRACT:

Solar tracker systems are used in radiation measurement station and also for focusing PV module towards sun to harness more solar energy. A two axis solar tracker utilise two numbers of drives, independently controlled to move the mechanical assembly in zenith and azimuth direction. A micro-controller based two axis solar tracker has been developed in-house and put in service for carrying pyroheliometer at NETRA solar measuring station. Its algorithm results have been verified with standard tracker available with NETRA radiation station.



## KEY WORDS:

Solar tracker, Longitude, Latitude, Declination angle, Hour angle, Zenith angle, Azimuth angle


## 1. INTRODUCTION

Solar energy is the energy extracted from the rays issued from the sun in the form of heat and electricity. This energy is essential for all life on Earth. It is a renewable resource that is clean, economical, and less pollution compared to other resources and energy [1]. Therefore, efforts are being made all over the world to tap this vast source of energy.

Solar energy, though found in abundance, is difficult to harness as available solar energy is available in large frequency spectrum, and is affected by seasonal and daily movement of sun with respect to earth due to earth's revolution and rotation. Technologies available in market for tapping solar power are solar thermal and solar PV. In order to efficiently tap the solar energy through these two technologies, the effect of sun-earth relative movement is to be mitigated through solar tracking. A solar tracker is devices that orient various payloads toward the sun direction. Position of sun at any location of earth can be established with two angles i.e. zenith angle and azimuth angle and with their help solar tracker can align its pay loads in sun's direction. A solar tracker has been developed which works by calculating solar angles through empirical formulas and can track sun at any place on earth round the year.

## 2. SOLAR ANGLES CONCEPT

In order to track the sun on a plane of the Earth surface, the relative position of the Sun on the celestial sphere to a point on Earth has to be established which keeps on changing with time in a day and with number of day in a year. The position of the Sun at a point on Earth is given by the solar zenith angle θ and by azimuth angle Φ. These two angles are calculated with the inputs of geographical location of place, number of day in year and the local time. Following are the key points related to establish the sun position at a point.

## 2.1. LONGITUDE

Longitude is the angular distance measured from the prime meridian through Greenwich, England, west or east to a point on the earth's surface. Any location west of the prime meridian is positive and east is negative.

## 2.2. LATITUDE

The Latitude is the angular distance measured along a meridian from the equator, North or South, to a point on the earth's surface. Any location towards the North is considered having positive latitude and towards the South as negative latitude. The North and the South poles are +90 and -90 respectively. Latitude values are important as they define the relationships with the sun.

## 2.3. JULIAN DATE

Julian date is the number of days from the first day of the year. January 1 has a Julian Day of 1, December 31 has a Julian day of 365, except in leap years when it has a Julian Day of 366.

## 2.4. SOLAR DECLINATION ANGLE

The angle between the earth-sun line and the equatorial plane is called the declination angle. Declination changes with the date and is independent of the location. The declination is maximum (23.45) on the summer/winter solstice and 0 on the equinoxes [2]. It is mathematically given as:

*Declination angle = 23.45*sin [(360/365)*(284+A* [1]

Here, A is the Julian date.

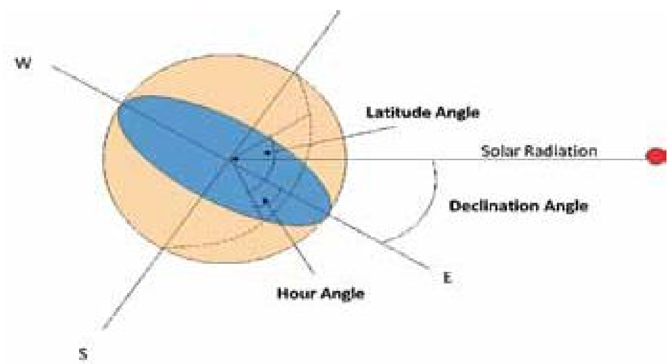



*Figure 1: Representation of Various Angles*

**2.5. TRUE SOLAR TIME (TST):** is given by the daily apparent motion of the true, or observed, Sun. It is based on the apparent solar day, which is the interval between two successive returns of the Sun to the local meridian.TST differs from the mean solar time (MST) by the amount of equation of time [3] which have seasonal variation of up to 16 minutes. This variation is because of following reasons.

1. First, Earth's orbit is an ellipse, not a circle, so the Earth moves faster when it is nearest the Sun (perihelion) and slower when it is farthest from the Sun (aphelion).

2. Due to Earth's axial tilt (known as the obliquity of the ecliptic), the Sun's annual motion is along a great circle (the ecliptic) that is tilted to Earth's celestial equator. When the Sun crosses the equator at both equinoxes, the Sun's daily shift (relative to the background stars) is at an angle to the equator, so the projection of this shift onto the equator is less than its average for the year; when the Sun is farthest from the equator at both solstices, the Sun's shift in position from one day to the next is parallel to the equator, so the projection onto the equator of this shift is larger than the average for the year [4].

True solar time (TST) can represented as

*TST = MST + equation of time* [2]

*Equation of time = 0.0172+0.4281cosB-7.3515sinB-3.3495cos2B-9.3619sin2B* [3]

*MST = GMT + local longitude*24/360* [4]

Here,

MST is Mean Solar Time,

LST is Local Standard Time,

GMT is Greenwich Mean Time,

## 2.6 HOUR ANGLE:

The Hour Angle is the angular distance that the earth has rotated in a day. It is equal to 15 degrees multiplied by the number of hours from local solar noon. This is based on the nominal time, 24 hours, required for the earth to rotate once i.e. 360 degrees.

*Hour Angle = 15 * (TST -12)* [5]

## 2.7 SOLAR ZENITH ANGLE

Zenith Angle is the angle between the local zenith and the line of sight to the sun. It can be calculated as

*zenith angle =* $\cos^{-1}$*[sin(latitude) . sin(Solar declination angle) + cos(latitude). cos(Solar declination angle) . cos(Hou angle)]* [6]

90° complement of zenith is known as altitude angle.

## 2.8 SOLAR AZIMUTH ANGLE

Solar azimuth angle is angle of Sun projection on earth from due north in clockwise direction. It can be calculated as

$$\text{azimuth angle} = \pi + \tan^{-1}\left[\frac{\sin(\text{Hour angle}).\cos(\text{Solar declination angle})}{(\cos(\text{Solar declination angle}).\cos(\text{Hour angle}).\sin(\text{latitude}) - \cos(\text{latitude}).\sin(\text{Solar declination angle}))}\right]$$

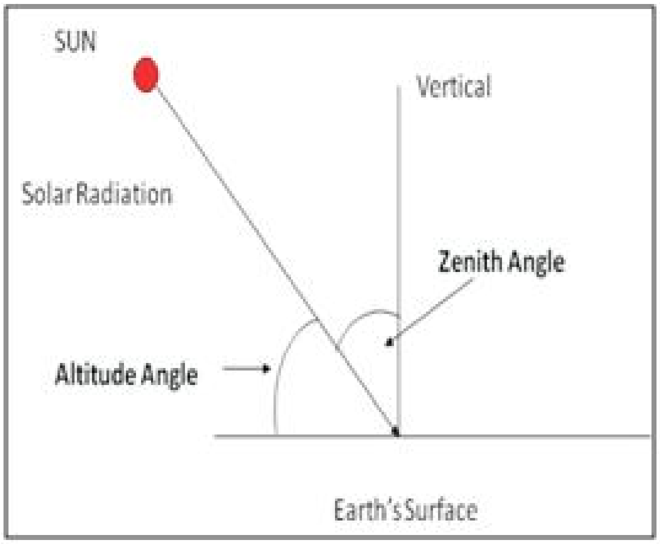



*Figure 2: Zenith angle*

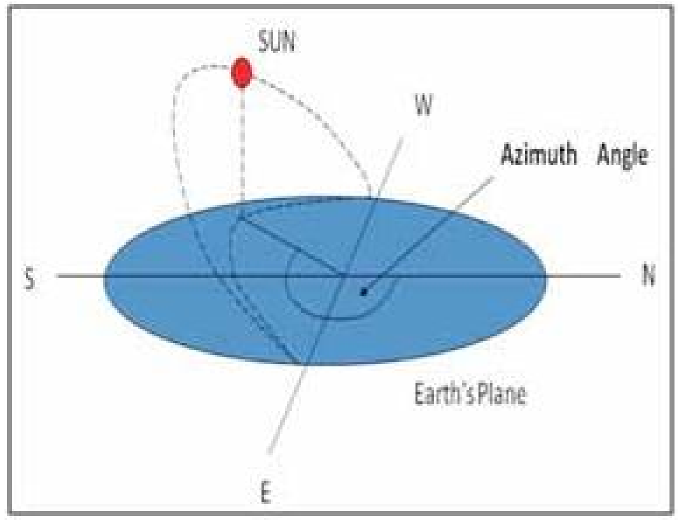



*Figure 2: Zenith angle*

3. SOLAR TRACKING TECHNIQUES:

A solar tracker is a device that orients various payloads such as radiation measurement assembly or PV module toward the sun direction. There are many forms of solar tracking system currently available; vary mainly in the method of implementing the designs. The two general forms of tracking used are fixed control algorithms and dynamic tracking. The difference between two methods is the manner in which path of the sun is tracked.

In fixed control algorithm system, path of the sun is determined by an algorithm that calculates the position of sun entire period by given time, day, month and year. On the other hand, in dynamic tracking system, actively searches for the sun's position by sensors feedback mounted on it. Both tracking methods have a control system which consist DC motor, stepper motors or servo motors, which are directed by a control circuit, either digital or analog.

Two-axis solar tracker will track both zenith and azimuth position of the sun by employing two no. of stepper motors with suitable gear ratio and driving circuit controlled by microcontroller unit.

4. NETRA INITIATIVE IN SOLAR TRACKING:

NETRA is actively involved in solar research areas like solar PV, solar thermal etc. It has a solar radiation measurement station consists of various equipments i.e. pyroheliometer, solar trackers etc.

In line with ongoing research activities NETRA has developed an in-house two axis solar tracker. It is based on fixed control algorithm using equations mentioned in section 2 of this paper. Presently

it put in service at NETRA solar radiation measurement station. This solar tracker can track the Sun's apparent motion exactly anywhere in the world after altering local geographical coordinates and time. Main circuitry of solar tracker is shown in figure 4.

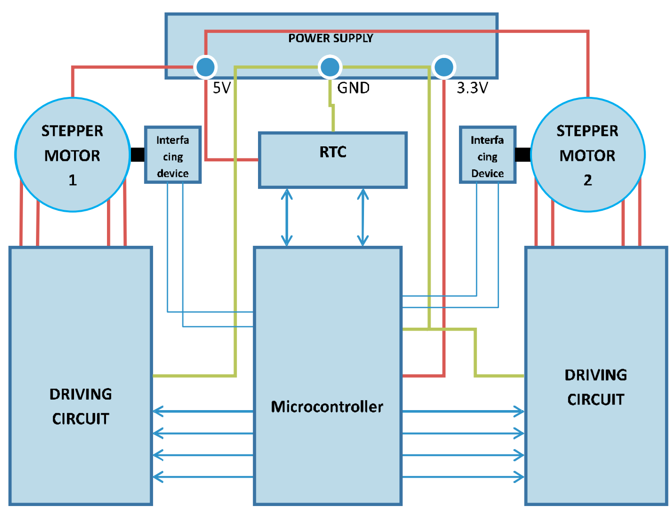



*Figure 4: Circuitry of Solar Tracker*

Developed Solar tracker concept can be extended to carry PV modules to harness more solar energy and also in heliostat for natural lighting/solar tower. For these applications detailed mechanical designing and software development are in progress at NETRA.

## 5. CONCLUSION:

A cost effective, micro-controller based two axis solar tracker can be developed and deployed for a given payload in-house. Solar tracker mechanisms are very useful to tilt PV module towards sun direction to harness more solar energy, reported up-to 30%.The same solar concept can be extended to develop solar natural light and heliostat.

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2) http://www.usc.edu/dept/architecture/mbs/tools/vrsolar/Help/solarconcepts.html#Declination
3) http://en.wikipedia.org/wiki/Equation_of_time
4) http://en.wikipedia.org/wiki/Solar_time
5) http://en.wikipedia.org/wiki/Algorithm

# SOLAR THERMAL POWER PLANTS - AN OVERVIEW OF AUTOMATION

**NR Kamath, Ramesh Kasinatha**

ABB Ltd Bangalore

ABSTRACT

The paper presents an overview of Automation for concentrating solar power (CSP) parabolic trough Power Plants.

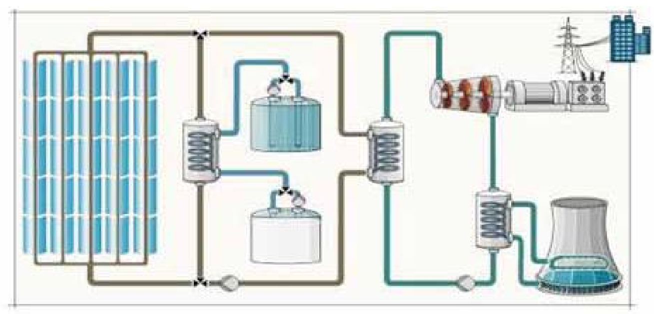
INTRODUCTION

This solar thermal power plant uses solar energy to generate heat that is then converted into electricity. Parabolic trough power plants consist of a huge field (called solar field) of trough-shaped parabolic mirrors that concentrate sunlight onto specially coated absorber tubes (receivers) located along the focal line. Concentrated solar radiation is converted into heat inside the specially coated receivers. Then, a special heat transfer fluid flows through the receivers, is then pumped to the main power plant generator. The steam generated is then used to operate a turbine which generates electricity in the same way as in conventional power plants. One of the most interesting technological features is that it is possible to make electricity from the sun even by night, for this purpose, liquid salt tanks for thermal storage are used.

CSP technology is based on solar radiation concentration to produce steam or hot air which could then be used on conventional electric plants.

- The main components are
- Concentrator: Different optics elements as mirrors, concentrate the sun on a point or a line where the receiver is located.
- Receiver: The receiver collects the concentrated sun rays and transfers the energy to a heat transfer fluid.
- Heat Exchanger: At the evaporator the heat transfer fluid transfers heat the water that becomes steam
- Turbine and Generator: To convert the steam into electrical power

**CSP Parabolic Trough & TES Functional Layout**

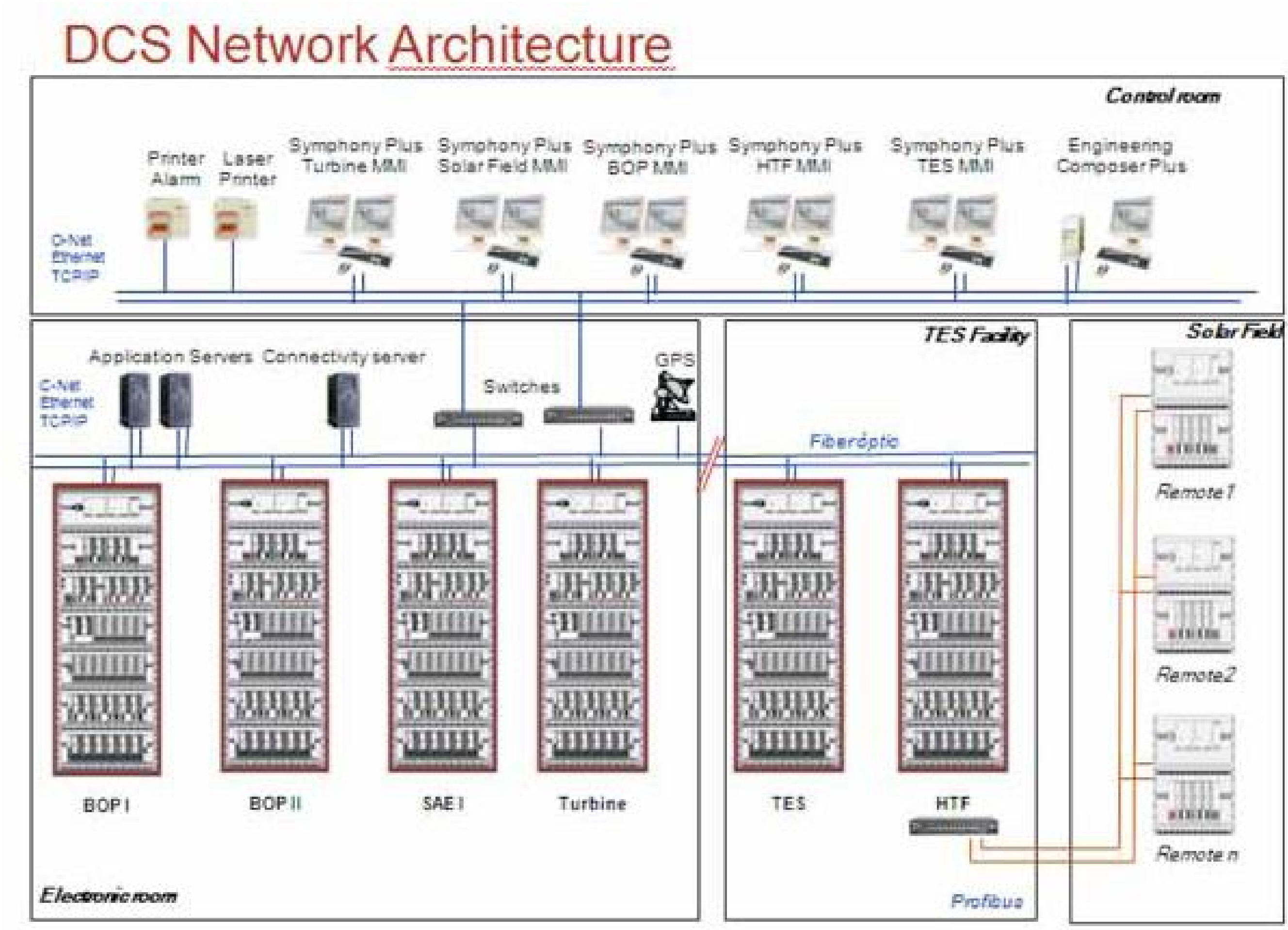


Solar field TES BOP Turbine island

## CONTROL SYSTEM

The DCS Control System solution is based on the extremely reliable families of controllers, communication interfaces and I/O modules that match these challenging requirements in solar power generation. Controllers provide a full range of controls, scalability, and fault tolerant redundancy options. The I/O signals are interfaced via mod-bus communications. This provides remote and local installations in a small footprint, provided by standard cabinets with rail mounting, covering the fully broad range of I/O types. Systems covers hundreds of parabolic troughs, dishes or collectors in the solar field to control systems for thermal storage tanks, Turbine Auxiliaries , BOP area for the power block, electrical equipment that feeds the power reliably into the local power grid and Optimization solutions.

The Man-Machine Interface is based on the latest Symphony Plus Operations, that represents the most advanced full-featured information platform for plant management and control. S+ embraces the use of context sensitive aspect menus to provide integrated information sharing, intuitive navigation, and efficient engineering.




Application Concept is driven by the need to maintain Plant under Automated Process Control & Monitoring with minimum operator requirements, The DCS fulfills the requirements of simple system architecture, Scalable control platform to automate all areas within the plant, Seamless integration of all plant devices and systems, automation of electrical, business and maintenance with Secure and reliable control environment to prevent unauthorized access

## CONTROL AREAS, DIRECT CONTROL

The controls covered are;

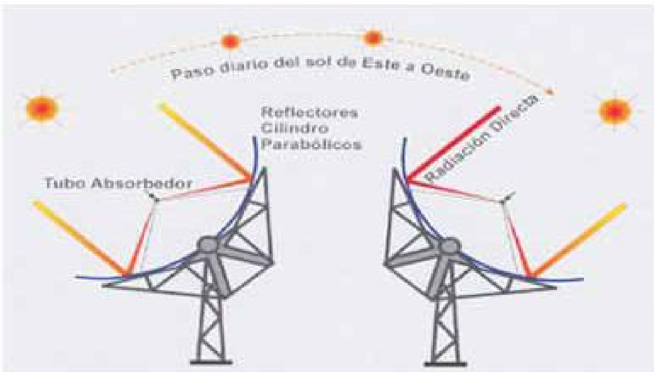
- Solar Field Control
- Heat Transfer Fluid Control
- Thermal Energy Storage -TES
- Balance of Plant Control:
- Feedwater pumps & water auxiliaries
- Cooling systems
- Water steam cycle control
- Condensate systems
- Electrical systems
- Auxiliary systems

## INDIRECT CONTROL- MONITORED SYSTEMS

The controls covered are typically;

- Turbine control
- Water treatment systems
- Instrumentation compresed air systems
- Black start / diesel genset
- Auxiliary HTF boiler
- Nitrogen systems
- Electrical protection systems

## SOLAR FIELD CONTROL SYSTEM

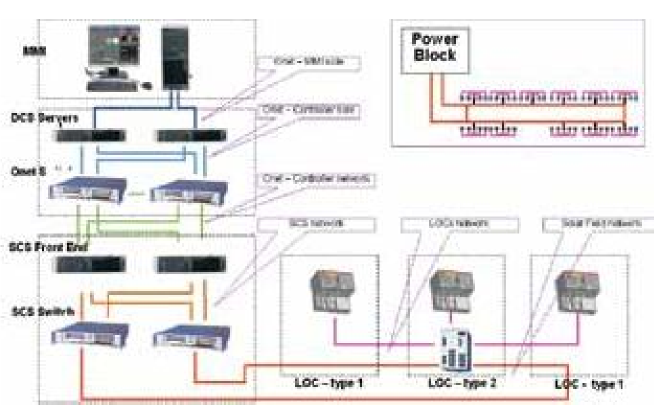



**The Control Systems carries out Positioning** and **Control** of Solar Mirrors to concentrate sun radiation in a Collector and heat HTF, Key features are , Operation on **Autonomous** mode, **Continuous Sun** Tracking, Maximize the **performance** of Solar Field keeping the operation and installation safe. The field components are designed to perform in **Extreme** environmental conditions, and designed for ease to configure and maintain.

The SCS uses proven standard NREL - SPA Solar Algorithm. Carries out powerful calculations of trigonometric functions with resolution of 3 x 10E-4 degrees for solar vector.

The SCS system manages communications with the solar field and also serves as an interface between the DCS and both the operator station of the solar field and the LOCs. The SCS optimizes and manages status data of every controller of the solar field in real-time and sends its historical storage to the operator station of the solar field.

## A typical SCS structure is shown below

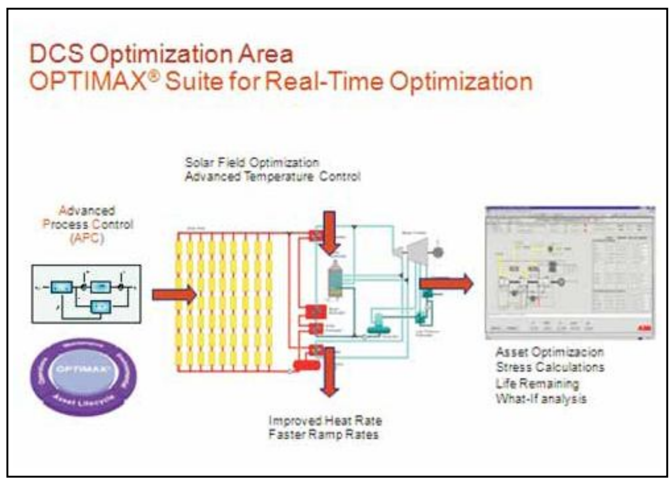



## LOC COMMUNICATIONS

The solar field of a 50W Power Plant unit is formed typically by 480 number of cylindrical parabolic collectors, divided in 4 no. of fields and each fields with 30 loops. Each loop is with 4 collectors. In each collector is allocated with a local controller (LOC) to control and monitoring collector position. Field network is based on Ethernet, SCS computer will be connected to the network, through which it will exchange information (via Modbus TCP) with the Solar Field.

## OPTIMIZATION

Covers Solar Field Optimization, Advanced Temperature Control, stress calculation etc to achieve improved heat rate and optimum Load Ramp rates and Asset Optimization and What–if analysis




## REFERENCE PLANTS

ANDASOL units 1 and 2 Solar Power Station The Andasol solar power stations will be Europe's first parabolic trough power plants. They are located in Andalucia, in the province of Granada, one of the sunniest regions n Spain. The Joint Venture SENER-ACS/Cobra group is responsible for constructing the power plants.

## PRESENTERS

**NR Kamath started** his career with BHEL in 1981. He worked in different areas like Steel Plant Automation, Generator Excitation & Protection Systems and design and commissioning of DCS Systems for Power Plants. Subsequently he handed Operation & Maintenance and Plant Management of Combined Cycle Power Plants and Utility Divisions in industries before joining ABB in

1996, He is presently Head - Engineering of DCS and C&I Systems for Power Generation applications

**Ramesh Kasinathan** started his career in 1991 with Thyssen Krupp where he was involved in Electrical & Automation Systems for Material handling Industry, before moving to GIPCL. In GIPCL, he was in charge of C&I maintenance for their Power Plants. Since 2007 is working with ABB in the Sales and Proposals for Automation Systems for Power Generation including Renewable Energy sector solutions.

## ISA Members Details

| S.No. | Mem ID | Name | company Name | Cont.no. | E-mail ID | Designation |
|---|---|---|---|---|---|---|
| 1 | 33044438 | Apaar Bhatnagar | IOCL | 9871399610 | apaar_b@yahoo.com | Sr. Pr. Engineer |
| 2 | 32929694 | Arun Gupta | Indure | 9818102784 | arung@indure.com | Sr. Engineer |
| 3 | 33148417 | Ashok Kumar Panda | Lancogroup | 9717493280 | ashok.panda@lancogroup.com | HOD(C&I) |
| 4 | 33173206 | Amit Kaul | Pyro Electric | 9313046256 | amitkaul@pyro-electric.in | GM |
| 5 | 32941225 | Amar S. Sindhu | Forbes Marshall | 9810110794 | asandhu@forbesmarshall.com | GM(Inst.) |
| 6 | 33132512 | A K Nehra | Belz Instruments | 9810197068 | aknehra@gmail.com | CEO |
| 7 | 33191532 | Avneesh Srivastava | Student | 9873244620 | avneesh.codeworks@gmail.com | Student |
| 8 | 33129446 | Arshad Zia | E&H | 9717593000 | arshad.zia@in.endress.com | Regional Manager |
| 9 | | Arun Kumar Nayal | Coperion | 9810475310 | arun.nayal@gmail.com | AGM(E&I) |
| 10 | 33214914 | Anil Kumar singh | Iffco | 9650600940 | singhak@iffco.in | Sr. E.D. |
| 11 | 33199163 | Ashutosh Sharma | Jasubhai | 9971224433 | ashutosh@jengg.com | Gen. Manager |
| 12 | 33214924 | Anad Prakash Singhal | Ambit Switchgear | 9873145711 | singhal@ambit.in | Director |
| 13 | 33211650 | Alok Katiyar | Bechtel | 9868323042 | akatiyar@bechtel.com | Lead Engineer |
| 14 | 33211666 | Abhishek Chatterjee | Student | 9873079109 | abhishek.chatterjee081012ece@gmail.com | Student |
| 15 | | Alok Kumar Agarwal | L & T | 9911998292 | alokkumar_agarwal@lntenc.com | AGM(CS) |
| 16 | 32929700 | Aloke Mandal | TPS | 9810629406 | aloke.mandal@rediffmail.com | DGM |
| 17 | 33026901 | Ashish Hemant Pendse | SSP Fittings | 9422007860 | ap@sspfittings.com | Regional Manager |
| 18 | 33216367 | Amit Shukla | Supreme Technology | 9818166449 | as@supremetechnology.co.in | Partner |
| 19 | 33211564 | Ajay Sahai | Macawber Beekay | 9873349702 | ajay.sahai@mbl.in | Director |
| 20 | 32929705 | Alok Chandna | Schneider | 9811432026 | alokchandna@hotmail.com | GM |
| 21 | 32946374 | Ajay Raina | Invensys | 9871463555 | aj.raina@yahoo.com | Director - Sales |
| 22 | 33173214 | Anuja Thukral | Phoenix | 9310221033 | anuja.thukral@gmail.com | Product Manager |
| 23 | 32986104 | Amit Pratap Talesara | Pyrotech | 9314468725 | amit@pyrotechindia.com | Managing Director |
| 24 | 32930460 | Anil Mahajan | Instrument Ltd | 9810035733 | icvld@sify.com | AGM(MKTG-PU.) |
| 25 | 33189103 | Ashwani Goel | Goel Clinic | | goel.ashwini@gmail.com | Director |
| 26 | 33178524 | Anil Soni | Emerson Process | 9582289180 | anil.soni@emerson.com | Manager |
| 27 | 33148418 | Avijit Chatterjee | Toshiba | 9871108982 | avijit.c@ttps.toshiba-india.com | DGM |
| 28 | 33158320 | Arundhati Bhattacharya | NTPC | 9650992956 | arundhatib@ntpceoc.co.in | HOD(C&I) |
| 29 | | Aman Singhal | NTPC | 9650996965 | amansinghal@ntpceoc.co.in | Design Engineer |
| 30 | 33179999 | Anisha B Singhal | BHEL | 9810253264 | anishabsinghal@bhelpem.co.in | Sr. Manager (C&I) |
| 31 | 33180000 | Arun Karkara | BHEL | 9818699071 | akarkara@bhelpem.co.in | AGM (C&I) |
| 32 | 33195628 | Arvind Kumar | Deptt. Of Sc. & Tech. | 9811307210 | arvind.kumar71@nic.in | Scientist |
| 33 | 33129467 | Arun Praksh | Power Machines | 9871197122 | arunprakash@power-machines.com | Sr. Project Manager |
| 34 | 33154173 | Ambrish Gupta | Siemens Ltd | 9910233222 | ambrish.gupta@siemens.com | Manager |
| 35 | | Anup Kumar | Fluor Daniel | 9810112409 | anupk99@gmail.com | Lead Engineer |
| 36 | 33137153 | Arun Kumar S | IOCL | 9811034739 | arun.chuvuk@gmail.com | Engineer (Inst.) |
| 37 | 33134807 | Amit Agarwal | Metso | 9711955581 | amit.agrawal@metso.com | GM |
| 38 | 33191537 | Avtar Singh | Modern electronics | 9915081959 | avvtar@rediffmail.com | Technical Advisor(Automation) |
| 39 | 33194318 | Ashish Pathak | IOCL | 9899690981 | ashishpathak18@yahoo.co.in | Project Engineer |
| 40 | 33129424 | Akash Sharma | Provibtech | 9910901033 | asharma@provibtech.com | Country Manager |
| 41 | 33158318 | Anil Varshney | Indure | 9810998160 | avarshney@indure.com | Vice President |
| 42 | 33156301 | A K Bansal | Power Machines | 9810969411 | akbansal@power-machines.com | Sr. Pr. Manager |
| 43 | 33195619 | Alok Gupta | Cadtech | 9350291928 | alok.gupta@cadtechindia.com | Business Manager |
| 44 | 32247966 | Alok Shrivastava | NTPC | 9650992518 | alok@ntpceoc.co.in | CDE |
| 45 | 33148415 | Ashok R Yadav | BGR Energy | 9212201383 | aashok3@gmail.com | Sr. Manager |
| 46 | 32252220 | Amit Garg | Indure | 9818365750 | amitgarg@indure.com | General Manager |
| 47 | 33173213 | Anant K Ghadigankar | Thermo Fisher | 9811555095 | anant.ghadigaonkar@thermofisher.com | Regional Sales Manager |
| 48 | 33191658 | Amit Kulshreshtha | NTPC | 9650992138 | kulshreshtha.amit@gmail.com | |
| 49 | 33211672 | Archana Rawat | Flour India | 9810402965 | archana.rawat@fluor.com | Engineer |
| 50 | 33191651 | Ajay Mahajan | Wintech | 9873350470 | ajay@weplindia.com | M. Director |
| 51 | 33212639 | Arnab Mitramustaphi | SK E&C | 9654542270 | arnabmitramustaphi@gmail.com | Engineer |
| 52 | 33187317 | Ajay Pratap Singh | Akansha Enterprises | 9650359011 | aps@engineer.com | Senior Manager |
| 53 | 33212652 | Anil Gupta | KEI Ind. | 9810004410 | anilgupta@kei-ind.com | CMD |
| 54 | 32970471 | Aman Sagar | Triveni | 9910555211 | aman.sagar@projects.trivenigroup.com, aman_sagar44@yahoo.com | Project Manager |
| 55 | 33194323 | Ashok Kumar | IOCL | 9873234937 | bhattiak@iocl.co.in | Project Engineer |
| 56 | 32970519 | Abhijit Kumar Bhowmik | IOCL | 9818391654 | bhowmika@iocl.co.in | Chief Pr. Manager |
| 57 | 04004742 | Amitava Sengupta | Retired | 9810236850 | amitava_juthika@yahoo.com | Advisor |
| 58 | 33212656 | Arun Kumar | Alstom | 9899819319 | kumar.arun@power.alstom.com | Sr. Manager |
| 59 | 33126388 | Anand Subramanium | Alstom | 9810236867 | kasubbu16@yahoo.co.in | GM(Sales) |
| 60 | 32247401 | Anil Chaudhary | Elcon Systems | 9310016949 | anil@elconsys.in | Managing Director |
| 61 | 32972095 | Anil Mishra | Cadtech | 9810321115 | anil.mishra@cadtechindia.com | General Manager |
| 62 | 32978450 | Anu Acharya | Engineers India | 9818682191 | a.acharya@eil.co.in | Manager |
| 63 | 33076159 | Arun Bandyopadhyay | GS Engineering | 9873462074 | bandyopadhyayarun@hotmail.com | Principal Engineer |
| 64 | 33214917 | Abhishek Goyal | Student | 9818953439 | abhishekgoyl@gmail.com | Student |
| 65 | 31993534 | Asheet Pall | VSPL | 9910123969 | apall_in@yahoo.com | Vice President |
| 66 | 33042943 | Ashish Manchanda | Phoenix | 9350043430 | AManchanda@phoenixcontact.co.in | Vice President |
| 67 | 33195627 | Abhishek Baid | Hulasi Metals | 9314503083 | abaid@hulasi.com | Director |
| 68 | 33211661 | Avanish Prakash | Bechtel | 9968176163 | avanishprakash@gmail.com | |
| 69 | 32930444 | Amalendu Kumar | IOCL | 9431802456 | kumara3@iocl.co.in | GM |
| 70 | 33150575 | Anindya Ray | NTPC | 9818833274 | anindyaray@ntpceoc.co.in | DGM |
| 71 | 32899583 | A .Chakrabarty | IOCL | 9810629360 | chakrabartya@iocl.co.in | Chief Pr. Manager |
| 72 | 33071014 | Atanu Ghosal | Haldar Topse | 9717489729 | atgh@topsoe.in | Deputy Chief Engineer |
| 73 | 33218564 | Aditi Bhatia | Student | 9896916262 | aditi.13aries@gmail.com | Student |
| 74 | 33218560 | Ankit Saini | Student | 9896105135 | ankit.saini@gmail.com | Student |
| 75 | 33218558 | Baishakhi Bhattacharya | Student | 9810836491 | shudha.b@gmail.com | Student |
| 76 | 32154953 | B.M.Sundriyal | Lastec DRDO | 9891045308 | sundriyalbm@yahoo.co.in | Engineer (C&I) |
| 77 | 33216366 | B Ahirwal | CIMFR | 9431158946 | ahirwalcmri@yahoo.co.uk | Sr. Scientist |
| 78 | 33126391 | B S Chauhan | Unitech Machines | 9313485794 | chauhanbs20@yahoo.co.in | Sr. Manager |
| 79 | 33195635 | B M Maheshwari | Temflo Systems | 9891094949 | bmmaheshwari@temflo.co.in | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 80 | 33086883 | Basavaraju Venkata Raju | IOCL | 9999688635 | rajubv@iocl.co.in | Sr. Pr. Manager |
| 81 | | Biswa Mukherjee | Invensys | 9818655038 | biswa.mukherjee@invensys.com | Associate Director- Sales |
| 82 | 33117794 | B S Negi | Unitop Instruments | 9999894192 | unitop23@yahoo.co.in | Properitor |
| 83 | 20061641 | B M Mishra | Ex-IOCL | 9435039600 | bmmishra1950@gmail.com | DGM(inst) |
| 84 | 04059307 | B S Agarwal | Jagian Pvt. Ltd. | 0145-2695220 | jagian@sancharnet.in | |
| 85 | 33194321 | Balkrishna Maurya | IOCL | 9999554316 | mauryab@iocl.co.in | Project Engineer |
| 86 | 33117794 | B M Nayyar | Macawber Beekay | 9911947550 | bmnayyar123@yahoo.com | Sr.Consultant (C&I) |
| 87 | 33191607 | Bhowmick Upendra Shah | Rotex Automation | 9820090783 | bushah@rotexindia.com | Director |
| 88 | 33218588 | Ashok Kumar Syal | Group Littlesilver | 9810629532 | aksyal@littlesilver.net | ED |
| 89 | 32941234 | B.K.Verma | Magnetrol | 9810613812 | bkvarma@magnetrolindia.com | Country Manager |
| 90 | 33212643 | Chandra Shekhar Choudhury | SK E&C | 9899828715 | cschoudhury1983@gmail.com | Engineer |
| 91 | 31995969 | C V Murthy | VSPL | 8800754105 | murtycv@gmail.com | President |
| 92 | | Chattar Singh | Engineers India | 9871610956 | chattar.singh@eil.co.in | Dy. Manager(Inst) |
| 93 | 33187332 | C Saroj | NTPC | 9650991368 | csaroj@ntpceoc.co.in | General Manager |
| 94 | 33214918 | D K Srivastava | Iffco | 9871378085 | dksrivastava@iffco.in | DGM(Project) |
| 95 | 33129438 | Dayanand Arya | Adroit | 9811171251 | darya@adroitcontrol.com | Director |
| 96 | 33158323 | Digvijay Tanwar | EPS Instrumentation | 9810731116 | eps@epsinst.com | Director (Inst.) |
| 97 | 32930461 | Dadi E. Mistry | Rockwell | 9810152127 | dadimistry@vsnl.net | Director |
| 98 | 32932739 | Debendra Mohanty | Bechtel | 9911330882 | dpmohant@bechtel.com | Chief Engineer |
| 99 | 33195621 | Davendra Gurudeva Tiwari | AAR-Tech Engineering | 9313030160 | aartech.engg@gmail.com | GM |
| 100 | 33191667 | D J Roy | Millennium Instruments Ltd, | 9871052200 | dr61@in.com | DGM |
| 101 | 33191664 | Dheeraj Kumar Jain | E & H | 8875891234 | jain.dheeraj5@gmail.com | Sr. Engineer |
| 102 | 33216363 | Dipak Nath | DSCL | 9829448866 | dipaknath3@sify.com | Senior C.E. |
| 103 | 33191542 | Deepak | NTPC | 9650990845 | deepak@ntpceoc.co.in | STA- D(T) |
| 104 | 32982238 | Dushyant Goyal | | 9970050356 | dushyantgoyal@gmail.com | |
| 105 | 33211537 | Dipin Thapar | Yokogawa | 9212058140 | dipin.thapar@in.yokogawa.com | Dy. Manager |
| 106 | 33047333 | Dharmender Singhal | Haldar Topse | 9999387604 | dhsi@topsoe.in | General Manager |
| 107 | 32936951 | E S. Ranganathan | GAIL | 9810620335 | ranganathan@gail.co.in | GM |
| 108 | 33136113 | Girishkant R Gupta | Cairn Energy | 9717098033 | ggirishkant@gmail.com | Manager - Inst. |
| 109 | 32156520 | G.S.Chaturvedi | Reliance Energy | 9313892388 | Gaurishankar.Chaturvedi@relianceada.com | Add. Vice President |
| 110 | 33156411 | Gautam Sarkar | Evonik | 9810980276 | gsarkar18@gmail.com | General Manager |
| 111 | 33218724 | Gaurav anand | Meggitt | 9900002390 | gaurav.anand@meggitt.com | Manager Sales |
| 112 | 33138974 | Gaurav Kumar | Bechtel | 9990072782 | pandit1010@gmail.com | Engineer |
| 113 | | Gaurav Batra | Student | 7206775163 | gauravbatra19@gmail.com | Student |
| 114 | 33109411 | G Ravishankar | Technip | 9871766528 | gravishankar@technip.com | Principal Engineer |
| 115 | 32941218 | Grindra Sinha | Toshbro Controls | 9910054693 | sinhag@toshbrocontrols.com | Sr. Manager |
| 116 | 33173210 | Gaurav Singh | Aryans Global Infra | 9582901901 | singhgaur@gmail.com | Managing Director |
| 117 | | G K Sharma | Millennium Instruments Ltd, | 9811284582 | gks@miepl.com | Managing Director |
| 118 | 32960796 | H K. Verma | IIT Roorkee | 01332-285588 | hkvfee@iitr.ernet.in | Professor -EE |
| 119 | 32969459 | Haribabu Bollipalli | Shree Renuka Sugar | 9933308949 | haribabu.b@rediffmail.com | Sr.Manager - Inst. |
| 120 | 33211665 | Himanshu Gupta | Lapp India | 9830065889 | lappcal4@lappindia.com | National Manager |
| 121 | 33123415 | H K Gupta | Howe India Pvt.Ltd. | 9717706444 | hkgupta1954@gmail.com | Sr. Principal Engineer |
| 122 | 32262947 | Hemant Kumar Pant | Ashcroft | 9350810818 | hemant.pant@ashcroftindia.com | Regional Manager |
| 123 | 33114457 | Harsh Bhardwaj | WAGO & CONTROLS (INDIA) LTD | 9810360092 | harsh@wagoindia.com | Project Manager |
| 124 | 33173215 | Harish Ahuja | ABB | 9810484485 | harish.ahuja@in.abb.com | Asst. Vice President |
| 125 | 33134820 | Hemant Agarwal | Delta | 9810155119 | hemant.agarwal@delta.co.th | Head Sales |
| 126 | 32910791 | Harvinder Singh Kalsi | Woodward | 9811771819 | hkkalsi@woodward.com | Head- Engr. Services |
| 127 | 33117789 | Hamesh Kumar Varshney | NTPC | 9650991485 | hemeshv@yahoo.co.in | Chief Design Engineer |
| 128 | 33152567 | I N Chowdhury | NTPC | 9650992875 | inchowdhury@ntpceoc.co.in | |
| 129 | 20313494 | Janmejaya Mahapatra | Avantha Power | 9717005276 | janmejaya.mahapatra@avanthapower.com | Head(Inst.) |
| 130 | 33211545 | Jagjeet Singh | Energo Enfineering | 9810088131 | singh.jagjeets@gmail.com | General Manager |
| 131 | 32253767 | J S Chandok | NTPC | 9650992930 | jschandok@gmail.com | Sr. Manager |
| 132 | 33187318 | Jai Prakash Srivastava | NTPC | 9650992657 | jpsrivastava@ntpc.co.in, | General Manager |
| 133 | 33195622 | Jitender Mehta | Protech | 9717393822 | jitendermeht@gmail.com | Director |
| 134 | 20077695 | J. K. Dhar | Punj Loyd | 011-26200123 | jkdhar@gmail.com | Ex. Director |
| 135 | 04121199 | Jagannath Mohapatra | IBPIL | 9717212999 | jagannathmohapatra6@gmail.com | GM(ERP) |
| 136 | 33142845 | Kalyan Mukhopadhyay | NTPC | 9650992923 | mkalyan@ntpceoc.co.in | DGM(R&M) |
| 137 | 33214925 | K S Bisht | L & T | 9582252384 | bishtks@Intebg.com | DGM |
| 138 | 33218739 | Krishna Kumar Singh | IOCL | 9868964927 | singhkk2@iocrd.co.in | Technical Officer |
| 139 | 33218577 | Krishna Murthy Prasad | Environment SA | 9930697410 | prasad@environnement-sa.com | Director |
| 140 | 32943742 | K Srinath | Rockwell | 9711008651 | ksrinath68@yahoo.com | GM- Marketing |
| 141 | 33180002 | K R Bhardwaj | BHEL | 9818673045 | krbhardwaj@bhelpem.co.in | AGM(C&I) |
| 142 | 32252299 | Kasina Chandramouli | NTPC | 9425222148 | kaicyem@gmail.com | Sr. Suppt. |
| 143 | 33138970 | Kapil Maggo | Northern Electric | 9811197892 | northernelectricals@gmail.com | Director |
| 144 | 33212658 | Kali Dass | Belden Cables | 9818044928 | kali.dass@belden.com | Manager - Sales |
| 145 | 33211669 | Kamal Malhotra | Higher Education | 9560466006 | kamalangel69@hotmail.com | Deputy Director |
| 146 | 33211538 | Kuldeep Moza | Yokogawa | 9810629466 | kuldeep.moza@in.yokogawa.com | |
| 147 | 33150573 | K Chakradhar | NTPC | 9650992541 | kchakradhar@ntpceoc.co.in | Chief Design Engr. |
| 148 | 33199167 | Kalpesh Gupta | Nortech Ferro Alloys | 9936408866 | kalpnesh@evoindia.com | |
| 149 | 33129444 | K P Singh | Reckers Controls | 9212728001 | kp@reckersreckers.com | Director |
| 150 | 33188883 | Karthik Nimmagadda | L&T Gulf | | karthik.nittrichy@gmail.com | Engineer(C&I) |
| 151 | 32936940 | Kuldip Pahuja | Eurotherm | 9810661828 | Kuldip.pahuja@invensys.com | |
| 152 | 32214510 | L Rajagopalan | Flour India | 011-22715818 | l.rajagopalan@fluor.com | Senior Lead Engineer |
| 153 | 33218590 | L J Swaminathan | Meggitt | 9731577119 | lj.swaminathan@meggitt.com | Country Manager |

| | | | | | | |
|---|---|---|---|---|---|---|
| 154 | | Ujjwal Roy | Lahmeyer Intl. | 9818832603 | uroy@lahmeyer.in | Group GM |
| 155 | 33211668 | Mukesh Chaturvedi | Toshbro Controls | 8800384385 | chaturvedim@toshbrocontrols.com | Area Manager |
| 156 | 32930456 | Manish Goyal | AOL | 9928257802 | mgoyal@aol.in | General Manager |
| 157 | 33177034 | Mayank Kr. Saraogi | Paul Wurth | 9811689523 | mayank.saraogi@rediffmail.com | Deputy Manager |
| 158 | 32914624 | Mahendra Shah | ABB | 9810549706 | mahendra.shah@in.abb.com | Asst. Vice President |
| 159 | 33187331 | Meenu Singhal | Rockwell | 9811150530 | m.singhal@rediffmail.com, msinghal@ra.rockwell.com | Manager (Mktg. & Sale) |
| 160 | 33216369 | Krishan Kumar | Dembla | 9350581644 | northsales@dembla.com | Manager Sales |
| 161 | 33216370 | Manish Thirani | Dembla | 9350582707 | info@dembla.com | Regional Manager |
| 162 | 33191539 | Manoj Kumar Agarwal | Triveni | 9650315529 | manojhcst@yahoo.co.in | Dy. Manager |
| 163 | 33218727 | Milind B Kulkarni | Protego | 9967656642 | pipl@protego-india.com | MD |
| 164 | 33187327 | Mohit Kumar Rathi | Rockwell | 9711991467 | mohit_rathi1@rediffmail.com | Engineer - Contr. Sys, |
| 165 | 33218733 | Mamta Gupta | Technip | 9873487935 | magupta@technip.com | Engineer |
| 166 | 33080951 | Manish Kumar | Engineers India | 9810890933 | manish.kumar@eil.co.in | Dy. Manager(Inst) |
| 167 | 32196947 | Manish Saxena | Honeywell | 9818091508, 9868894481 | manish.saxena@honeywell.com, manish.honeywell@gmail.com | Manager |
| 168 | 32965943 | Manisha Gupta | Rockwell | 9811211176 | mgupta@ra.rockwell.com | Business Dev. Manager |
| 169 | 33211674 | Mayank Chauhan | Logic Ladder | 9891314129 | mchauhan@logicladder.com | Chief Executive Officer |
| 170 | 32247965 | M K Srivastava | NTPC | 9650991053 | mksrivastava@ntpceoc.co.in | DGM |
| 171 | 32046378 | M.P.Singh | JPVL | 9910900380 | mp1.singh@jalindia.co.in | VP (Engg) |
| 172 | 33146403 | N K Srivastava | NTPC | 9650991597 | nksrivastava@ntpceoc.co.in | GM |
| 173 | 35173217 | N Satish | BGR Energy | 9941921297 | sats25nov@gmail.com | GM |
| 174 | 33195630 | Naveen Sharma | Lancogroup | 9717897444 | naveen.sharma@lancogroup.com | ED |
| 175 | 33134714 | Naveen Kr. Vashisht | Rockwell | 9873161103 | nvashist@ra.rockwell.com | Mgr - Process. Solution |
| 176 | 33212642 | Nilesh Nandkumar Sable | SK E&C | 9999511232 | nilu_sable@yahoo.com | Engineer |
| 177 | 33194309 | Naresh Kumar Chellani | IOCL | 9999797851 | chellanin@iocl.co.in | Project Engineer |
| 178 | 33137800 | Narayan Subramanian | Crain India | | narayan36@yahoo.com | Sr. Manager (Ctrl Engr) |
| 179 | | Nikunj Garg | Student | 9034370710 | nikunjgarg06@gmail.com | Student |
| 180 | 04117201 | N K Pande | Pyrotech | 9811084854 | pande.nk@gmail.com | Managing Director |
| 181 | 04013686 | Nagender Pd. Saxena | | 0651 201103 | | Properitor |
| 182 | 33039885 | Narayana Dass | Bechtel | 9818659857 | narayanadass@yahoo.com | Sr. Engineer |
| 183 | 33195623 | Niraj Srivastava | Triveni | 9873724186 | niraj_46@yahoo.com | Project Engineer |
| 184 | 33187328 | Nitin Singla | Wissn Automation | 9310195951 | nitin@wissenautomation.com | Director |
| 185 | 33086888 | Narender Kumar Jain | Shiba Comp Pv | 9350695343 | nkjain@shibacomp.com | Director |
| 186 | 32954735 | Niraj Kumar | NTPC | 9650991711 | nirajkumar@ntpceoc.co.in | DGM(C&I) |
| 187 | | Namrata Raghuvansi | Amity University | 9910398144 | nraghuvanshi@amity.edu | Asst. Professor |
| 188 | 33123420 | N K Panchal | Pyrotech | 9312874737 | pmppl@pyrotechindia.com | Manager |
| 189 | 32927639 | N K Mallick | Bajaj Energy | 9910833294 | nkmallick@bajajenergy.com | Business Manager |
| 190 | | Nitin Sharma | L & T | 9911998149 | nitin_sharma@lntenc.com | AGM(CS) |
| 191 | 33212645 | Nilesh Joisar | Honeywell | 9560177559 | nilesh.joisar1@honeywell.com | Regional Head |
| 192 | 33191604 | Naveen Chopra | Triveni | 9818414160 | navinchopra1986@gmail.com | Engineer |
| 193 | 33191652 | Neeraj Kumar Gupta | Macawber Beekay | 9871395548 | neeraj.gupta@mbl.in | Dy. Mgr. |
| 194 | 33173208 | Neeraj Khanna | Toshiba | 9871018956 | neeraj.khanna@ttps.toshiba-india.com | DGM(C&I) |
| 195 | 33150587 | P S Chowdhury | NTPC | 9650992612 | pschowdhury@ntpceoc.co.in | CDE |
| 196 | 32243685 | P.Mahajan | Engineers India | 9818808231 | pm@eil.co.in | Director |
| 197 | 33137155 | Prateek Srivastav | NTPC | 9650992810 | prateek1508@rediffmail.com | Manager (QA & I) |
| 198 | 33209808 | Partha Sarath Mondal | Flour India | 9818240498 | Partha.S.Mondal@fluor.com | Engineer |
| 199 | 32156516 | P.Sengupta | NTPC | 9650992856 | pa.sengupta@gmail.com | GM |
| 200 | 33180004 | Pramendra Singh | United Controls | 9313550494 | pramendra_singh@yahoo.com | Partner |
| 201 | 32182907 | Pankaj Bhartiya | NTPC | 9650991208 | pankajbhartiya@yahoo.com | GM |
| 202 | 3319916 | Pankaj Sah | Doosan | 9818599317 | pankaj_sah02@yahoo.co.in | Gen. Manager |
| 203 | 33211660 | Priyanka Pande | Pyrotech | 9312751550 | pande.priyanka@pyrotechindia.com | Director |
| 204 | | Pankaj Verma | L & T Ltd. | 9911998275 | pankaj_verma@lntenc.com | AGM(CS) |
| 205 | 33047330 | Partha Pratim Saha | Samsung | 9811800682 | p.saha@samsung.com | Sr. Manager(C&I) |
| 206 | | Pankaj Verma | Dyanamic | 9899005407 | pankaj.verma@dipl.biz | Engineer |
| 207 | 33191653 | Pankajbhai P Patel | Ashcroft | 9327930503 | pankaj.patel@ashcroftindia.com | |
| 208 | 32180874 | Prabhat Kumar Saxena | Prosoft | 9810637873 | saxena@prosoft-technology.com | Country Manager |
| 209 | 33129449 | Parag Tyagi | Wissen Automation | 9310295951 | paraag@wissenautomation.com | Director |
| 210 | 32260379 | Pradeep Varma | NTPC | 011-29552514 | pv@ccipl.in | General Manager |
| 211 | 32986103 | Pratap Singh Talesara | Pyrotech | 0294-2492122 | pst@pyrotechindia.com | Managing Director |
| 212 | 33137157 | Prashant Pandurang Patil | NTPC | 9650992731 | pppatil@ntpceoc.co.in | Sr. Manager(Q&A) |
| 213 | 33136230 | P R Santosh | Areva | 9793051888 | prsantosh@gmail.com | Manager |
| 214 | | Parmeshwar Panwar | NTPC | 9650991774 | pipanwar@yahoo.co.in | Manager |
| 215 | 33134809 | P V Sreenivas | APGENCO | | pudpandu@yahoo.com | Divisional Engineer |
| 216 | 33211671 | Puneet Kumar Sharma | JPVL | 7838052625 | puneetkrsharma31@gmail.com | Engineer |
| 217 | 33214922 | Piyush C Tiwari | GE Fanuc | 9811413731 | piyush.c.tewari@ge.com | Business Dev. Manager |
| 218 | 33214920 | Piyush Mishra | Iffco | 9971156170 | piyush@iffco.in | DGM(Tech) |

| | | | | | | |
|---|---|---|---|---|---|---|
| 219 | 32156518 | Prasanjit Pal | NTPC | 9650991122 | prasenjit@ntpceoc.co.in | DGm & STA to Dir (Tech) |
| 220 | 33211662 | Ravi Shankar Kommu | Jindal Power | 9582252002 | ravishankar.kommu@jindalsteel.com | |
| 221 | 33211571 | Rahul Kapoor | IOT Design & Engr. | 9958833229 | rahul.ril@gmail.com | |
| 222 | 33194322 | Rohit Kumar | IOCL | 9958400466 | kumarrohit@iocl.co.in | Engineer |
| 223 | 33212651 | Rahul Sawhney | Syntronix | 9811871400 | rahul.sawhney@krutigroup.in | Director |
| 224 | 33214919 | Rajiv Kumar Gupta | Iffco | 9871371465 | guptark@iffco.in | DGM |
| 225 | 32941231 | R K Bassi | Vautomat | 9810005826 | vautomat@vautomatindia.com | Managing Director |
| 226 | 32191437 | R Priyamvada | Engineers India | 9312229961 | priyamvada.r@eil.co.in | HOD(C&I) |
| 227 | 32978454 | R.Shantidevi | Engineers India | 9868394027 | r.shantidevi@eil.co.in | |
| 228 | 32946375 | Rohit Gurudev Tiwari | AAR-Tech Engineering | 9312265257 | rohitgurudev@gmail.com | Managing Director |
| 229 | 33191675 | Rana Gupta | Cadtech | 9810903795 | rana.gupta@cadtechindia.com | Business Manager |
| 230 | 33136588 | Rajeev Prasad | | 9470591629 | rajeevprasad@gmail.com | Supretending Engineer |
| 231 | | Ravi K Tata | Bechtel | 0124-4098668 | rktata@gmail.com | Eng Group Survr. |
| 232 | 32978458 | Rafat Salam | Engineers India | 9818287308 | rafat.salam@eil.co.in | |
| 233 | 32936954 | Rajeev Gupta | Engineers India | 9818686395 | rajeev.gupta@eil.co.in | Sr. Manager |
| 234 | 33086887 | Rajender Kumar Jain | Shiba Comp Pv | 011-27480025 | rkjain@shibacomp.com | Director |
| 235 | 33176758 | Ritesh Kumar Jaiswal | BHEL | 9910732251 | rkjaiswal@bhelpem.co.in | Deputy Manager(C&I) |
| 236 | 33218735 | Rina Biswas | Technip | 0120-4301208 | rbiswas@technip.com | Pr. Engineer |
| 237 | 33191671 | Rahul Srivastava | NTPC | 9650996124 | rahulsrivastava@ntpceoc.co.in | DGM |
| 238 | 32247969 | Rajeev Khanna | NTPC | 9650991951 | rajeev_khanna@ntpceoc.co.in | Chief Design Engineer |
| 239 | 32972094 | Rajiv Gupta | Engineers India | 9818341262 | rajiv.gupta@eil.co.in | Sr. Manager |
| 240 | 32182087 | Rajiv Prakash | Rockwin | 9810129687 | rajiv@rockwin.com | Managing Director |
| 241 | 33191605 | Rahul Manocha | Max Automation | 9873007035 | rahulmanocha@maxgroup.co.in | Director |
| 242 | 32205732 | Ram Gagandas Dhalwani | Desein | 9810977949 | rdhalwani@deseinindure.com | Director |
| 243 | 32941232 | Ravi Bhanot | Retired - Punj Lloyd | 9811436859 | ravibhanot@yahoo.com | Retired |
| 244 | 33218737 | Ravi Gupta | HPCL Mittal | 9999208877 | ravigupta@hmel.in | Manager- Inst. |
| 245 | 33094975 | R J Thomas | Technip | 9891168701 | rjthomas@technip.com | Group Leader- Inst |
| 246 | 33129458 | Rajeev Ranjan | Anuraj Automation | 9999798012 | rajeev@anurajautomation.com | Director |
| 247 | 33156300 | Rajkumar Sharma | Hi-Rel | 9958692373 | rk_sharma@hirel.net | DGM (Project Sales) |
| 248 | 33193138 | Rohit Malhotra | | 9711843850 | | |
| 249 | 33218578 | Rajesh Sharma | Group Littlesilver | 9811960784 | rsharma@littlesilver.net | Marketing Manager |
| 250 | 33211535 | Rajesh Gupta | Adroit | 9873417288 | rgupta@adroitcontrol.com | |
| 251 | 33218730 | Rajesh Koul | Technisys | 8130854437 | support@technisys.org | Director |
| 252 | 32240787 | Raja Sekhar Gudipaty | IOCL | 9899786321 | rs.gudipaty@gmail.com | Deputy Manager - Inst. |
| 253 | 33134817 | Rajan Vashisht | Delta | 9810332947 | rajan.vashist@delta.co.th | Head Sales |
| 254 | 32180883 | Ravinder Goyal | EIP Enviro | 9810181109 | eipenviro@gmail.com | Managing Director |
| 255 | 33177605 | Rajat Goyal | Student | 9810181109 | rajatgoyal06@gmail.com | Student |
| 256 | 33187321 | Rohit Singhal | Mitsubishi Electric | 9810886028 | rohit.singhal@asia.meap.com | |
| 257 | 33146407 | Rajesh Suri | Lancogroup | 9350889254, 9717098000 | surirajesh@rediffmail.com | |
| 258 | 33146408 | Radheyshyam Tiwari | ISA | 9313384543 | radheytiwari@gmail.com | |
| 259 | 32986108 | Radhakrishnan Sarangapani | NTPC | 9650992571 | sarangapani@ntpceoc.co.in | DGM |
| 260 | 33026902 | Rohit Bhardwaj | Ex-IOCL | 9873149991 | rohit_iocl@yahoo.co.in | ED |
| 261 | 33158319 | Rajesh Bhatla | Engineers India | 9971006770 | rajeshbhatla@yahoo.com | Sr. Manager |
| 262 | 33191064 | Rupendra Kumar Ojha | Messung Systems | 9811501276 | rupendra_ojha@yahoo.com | Area Manager |
| 263 | 33173211 | Rajesh Vijay | The Tinsley Group | 9810134932 | tinsley@ndf.vsnl.net.in | Manager |
| 264 | 33129463 | Rohit Dube | Delta | 9810380395 | rohit.dube@delta.co.th | |
| 265 | 32978456 | S Mahesh Kumar | Engineers India | 9868105971 | s.mahesh.kumar@eil.co.in | Dy. Mgr. |
| 266 | 33212649 | Sanjay Kr. Tripathi | PDIL | 9868358859 | sanjaykrtripathi@pdilin.com | DGM (Inst) |
| 267 | | Sarika Sharma | Provibtech | 9910800620 | sarika@provibtech.com | Dy. Manager - Mktg. |
| 268 | 33213747 | Shashi Shekhar | UOP India | 9899000868 | shashi.shekhar@uop.com | Engineer |
| 269 | 33212647 | Sameer Kumar Bhowmick | NTPC | 9650991324 | samir_bhowmick@yahoo.com | AGM |
| 270 | 3318005 | Subban Jayaprakash | Vetri Engineers | 0422-25310371 | sjp@vetriengineers.com | |
| 271 | | Sudhir Sharma | Schneider | 9818992435 | sudhir.sharma@schneider-electric.com | Senior Manager |
| 272 | 33211664 | Sameer Dubey | Bechtel | 9868785035 | sdubey@bechtel.com | Engineer |
| 273 | | Sisir Kumar Bardhan | IOCL | 7838000016 | bardhansk@yahoo.co.in | DGM(PJ) |
| 274 | 33150553 | Satya Prakash Jain | Bechtel | 9968007123 | spjain@bechtel.com | |
| 275 | 32914623 | Sudhir S Kulkarni | ABB | 9810506367 | sydhir.s.kulkarni@in.abb.com | Vice President |
| 276 | 33211574 | S K Katyal | MIL | 9818512010 | skkatyal@milcontrols.com | |
| 277 | 32158190 | S N Rasool | Cairn Energy | 8800399024 | shaik.rasool@cairnindia.com | Engineer |
| 278 | 33173212 | Sandeep Sharma | The Tinsley Group | 9871098284 | sandyind2000@rediffmail.com | DGM |
| 279 | 33026903 | Sambhu Nath Ray Chaudhuri | IOCL | 9437070278 | raychaudhurisn@iocl.co.in | DGM(inst) |
| 280 | 33177036 | Sanjay Das | PL Engineering | 9873118786 | sanjay.das@ple.co.in | Sr. Manager |
| 281 | 33187330 | Sourav Adhikari | JPVL | 9717894274 | sourav.adhikari@jalindia.co.in | Engineer |
| 282 | 33195626 | Sanjeev Grover | Provibtech | 9958899511 | groversanjeev@yahoo.com | Country Manager |
| 283 | 33187323 | S K Dhawan | Engineers India | 9818686181 | sk.dhawan51@yahoo.co.in | AGM |
| 284 | 33191606 | Sanjeev Gogia | Aaxis Nano Tech. | 9216754369 | info@aaxisnano.com | Director |
| 285 | 33218565 | Silk Smita | Student | 9355193454 | silksmita76@gmail.com | Student |
| 286 | 33211569 | Sunil Mishra | NTPC | 9650992743 | skmisra@ntpceoc.co.in | |
| 287 | 33117790 | S Sudershan Rao | Deptt. Of Sc. & Tech. | 9650011279 | ssrao46@gmail.com | Scientist |
| 288 | 33154171 | Shankar Kumar Chattopadhyay | Reliance | 9312777707 | sankar.chattopadhyay@relianceada.com | Vice Presiddent |
| 289 | 33134819 | Sanjay Sharma | J S Electric Works | 9818582299 | sanjay70987@yahoo.com | Director |
| 290 | 32185129 | S C Joshi | Rockwell | 9711986213 | scjoshi@vsnl.com | Market Dev. Manager |
| 291 | 33214927 | Swati Dhawan | Technip | 9818686181 | swati_dhawan@rediffmail.com | Sr. Engineer |
| 292 | 33212638 | Shobhit Mittal | SK E&C | 9873174256 | shobhit.mittal@gmail.com | Engineer |
| 293 | 32262946 | Sandeep Nigam | Hi-Tech System | 9810159557 | sandeep@hitech.in | |
| 294 | 32154992 | S S Verma | Tricon | 9810868068 | sureverma@hotmail.com | Managing Director |

| | | | | | | |
|---|---|---|---|---|---|---|
| 295 | 33209464 | Shafi Ahamed Syed | Flour India | 9818205563 | shafi.a.syed@fluor.com | Lead Engineer |
| 296 | 33132511 | S K Mittal | Desein | 9810095855 | smittal@deseinindure.com | Principal Engineer |
| 297 | 32252351 | Sameer Sharma | NTPC | 9868391186 | sameer@ntpceoc.co.in | Chief Design Engineer |
| 298 | 33142841 | Sumit Agrawal | United Controls | 9313550492 | sumitagrwal@yahoo.com | Engineers Partner |
| 299 | 33137158 | Shantanu Sinha | NTPC | 9650992323 | shantanusinha@ntpceoc.co.in | Engineer |
| 300 | 33137156 | Somnath Samanta | NTPC | 9650991148 | ssamanta@ntpceoc.co.in | DGM (Q&A) |
| 301 | 33195620 | Sachin Chadha | Rockwell | 9873588540 | schadha@ra.rockwell.com | Manager |
| 302 | 33212640 | Saidul Islam Mir | SK E&C | 8860825948 | saidul.mir@gmail.com | Engineer |
| 303 | 20243384 | Satyendra Kr Gupta | Analyser Instrument Co.Pvt.Ltd | 9414188611 | aicplindia@kappa.net.in | Managing Diretor |
| 304 | 33123422 | S C Gupta | World tech. Products | 9818998339 | scgupta@wtpindia.com | Director |
| 305 | 33156298 | Sanjay Tiwari | L & T | 9910799094 | stiwari@lntenc.com | |
| 306 | 04082289 | S. Venkataramanan | Aditya Birla | 9415394526 | venkataramanan.s@adityabirla.com | GM maintenance services |
| 307 | 33172515 | Sumit Pandey | Jindal Water | 9971862093 | omsumitam@gmail.com | Engr. Project |
| 308 | 32929692 | S.S.Garuryar | Polixel Security | 9811419253 | ssgaruryar@gmail.com | Vice President |
| 309 | 32899038 | Sachin Bhargava | Process & Machines Automation | 9829012029 | sachinbhargava@hotmail.com | CEO |
| 310 | 33150560 | Santanu Simlai | Reliance Energy | 9311601667 | santanu.simlai@relianceada.com | |
| 311 | 32247963 | S.Karthikeyan | Reliance | 9312847683 | karthik.srinivasan@relianceada.com | Asst. Vice President |
| 312 | 32899578 | Sandeep Gupta | Total Solution | 9868255848 | totalsolutions@vsnl.net, totalsolutionsco@yahoo.co.in | Director |
| 313 | 33070576 | Sandeep Sharma | Norgen | 9717693676 | ssharma@norgren.co.in | DGM |
| 314 | 33080949 | Sanjay Kumar Dutta | NTPC | 9650991363 | skdutta05@yahoo.co.in | DGM |
| 315 | 32927631 | Sanjeev Kumar Gupta | Analyser Instrument Co.Pvt.Ltd | 9772230061 | aicplindia@kappa.net.in | Director |
| 316 | 33117396 | Sunil Bhanot | | 9810691567 | bhanot_sunil@rediffmail.com | |
| 317 | 32156515 | S R Bhatnagar | Emerson Process | 9811159005 | sheel.bhatnagar@emerson.com | Sr.Director |
| 318 | 32183499 | Shyam Sunder Sharma | SRF Limited | 9910043656 | sssharma@srf.com | Chief Manager- Instr. |
| 319 | 33214095 | Satyaki Sen | Bechtel | 9650033552 | ssen1@bechtel.com | Engineer |
| 320 | 33180767 | Sudhanshu Shekhar | IOCL | 9896218062 | shekhars@iocl.co.in | Sr. Manager- Inst. |
| 321 | 33143882 | Stephen Titu | | 080-54100991 | nitram.st@gmail.com | |
| 322 | 32947350 | Sonia Madan | Engineers India | 9818686137 | sonia.madan@eil.co.in | Manager |
| 323 | 33194389 | Somnath Banerjee | IOCL | 9717993513 | banerjeesomnath@iocl.co.in | Project Engineer |
| 324 | 32101926 | Subhro Sengupta | Samsung | 9999333548 | subhro_sengupta@lntenc.com | Sr. DGM |
| 325 | 33199164 | Sunil Kumar Agarwal | Lohia Starlinger | 9936294131 | sra.1958@gmail.com | AGM |
| 326 | 33174907 | S S Pati | NTPC | 9650992894 | sspati@ntpceoc.co.in | Chief Design Engineer |
| 327 | 32198040 | Sunil Kumar Bhandari | Bechtel | 9810646044 | sxbhanda@bechtel.com | Engineer Supervisor |
| 328 | 32154998 | Subrata Neogi | Pentair Water | 9811787374 | subrataneogi@rediffmail.com | Vice President |
| 329 | 33068366 | Sumanta Basu | L & T - MHI | 9818199851 | sumanta_ntpc@yahoo.com | DGM- Eng |
| 330 | 33146690 | Soumitra Bhattacharya | NTPC | 9650991570 | soumitra@ntpceoc.co.in | DGM |
| 331 | 04007970 | S K Gupta | Ex-Wartsila Automation | 9414180307 | guptasurya_kant@hotmail.com | Sr. GM |
| 332 | 32978452 | Saikat Bhowal | Engineers India | 9818552550 | s.bhowal@eil.co.in | Manager |
| 333 | 33211649 | T D Bhatia | Continental Services | 9560314455 | tdbhatia2001@yahoo.co.in | Director |
| 334 | | Tarun Garg | NTPC | 9650998765 | tarungarg@ntpceoc.co.in | Design Engineer |
| 335 | 32928875 | Tiruchi Ganapathy Mohan | Engineers India | 9818738010 | mohantg@hotmail.com | AGM |
| 336 | 33123418 | Umang Gupta | Phoenix | 9999102388 | ugupta@phoenixcontact.co.in | Manager (Buseness Development |
| 337 | | Umesh Rai | Elcon Systems | 9313543557 | urai@elconsys.in | Business Manager |
| 338 | 33173700 | Umakant Parsad Singh | Reality Engineering | 9313348558 | msic@sify.com | Properitor |
| 339 | 33134811 | Vimal Bakshi | Reliable Instruments | 9818047375 | vimal_bakshi@rediffmail.com | |
| 340 | 33173216 | Vikas Singh | Gammon India | 9999600184 | vikassingh123@gmail.com | |
| 341 | 33195616 | Vipin Tomar | Siemens Ltd | 9871319696 | vipin.tomar@siemens.com | |
| 342 | 32965948 | Vivek Sheel Jain | IOCL | 9810874667 | jainvs1@iocl.co.in | Manager - Inst. |
| 343 | 32965946 | Vijay Kumar Dhiman | IOCL | 9873355145 | vijay_1219@yahoo.co.in | Senior Engineer |
| 344 | 33123421 | Vivek Gupta | World tech. Products | 9818998337 | vgupta@wtpindia.com | Director |
| 345 | 04100368 | V.Prakash | Rockwin | 9810046718 | vprakash@rockwin.com | Director |
| 346 | 33194307 | Vivek Sharma | IOCL | 9582215335 | sharmavivek@iocl.co.in | Project Engineer |
| 347 | 33194391 | Vijay Pai | IOCL | 9871600841 | paiv@iocl.co.in | DGM |
| 348 | 33211663 | V V Prakash | Bechtel | 9910298045 | vvprakas@bechtel.com | |
| 349 | 33195631 | Vijay K Anthwal | Temflo Systems | 9891777903 | vijay@temflo.co.in | |
| 350 | 33179508 | Vikrant Kumar | IOCL | 9729071204 | vikrantk@iocl.co.in | Dy.Manager-Inst. |
| 351 | 33211556 | Viswanathan Kumar | Reliance | 9312784983 | viswanathan.kumar@relianceada.com | |
| 352 | 33195633 | Varun Bansal | Tveen Techonology | 9958503900 | varun@tveen.in | Engineer |
| 353 | 33212646 | Varun Sawhney | Cords Cable | 9910009984 | vs@cordscable.com | Vice President - Mktg. |
| 354 | | Vinod Gogoriya | Gas Alarm India Pvt. Ltd | 9983345452 | vgogoriya@gmail.com | Business Manager |
| 355 | | Vikram Singh | Sintrol | 9811676061 | virkramvisu@gmail.com | Area Manager |
| 356 | 33212657 | Virat Joshi | Thyssenkrupp Indu. | 9971677456 | virat.joshi@thyssenkrupp.com | Engineer |
| 357 | 33191608 | Vijay Goel | NTPC | 9650991081 | vijaygoel@ntpc.co.in | Director |
| 358 | 32164639 | Vijay Prakash Johari | NTPC | 9868390631 | vpjohari@ntpceoc.co.in | Chief Design Engineer |
| 359 | 33194306 | Vinod Yeshwant Patil | IOCL | 9953001638 | vinodpatil2005@yahoo.com | Project Engineer |
| 360 | 33218574 | Vijay Sharma | Thermo Fisher | 9313202702 | vijay.sharma@thermo.com | Engineer |
| 361 | 33194311 | Vijay Kumar Kant | IOCL | 9999798169 | vkkant@yahoo.com | Project Engineer |
| 362 | | Vivek Bhausaheb Jagtap | BMH Tech. | 9420482495 | bmhtechnologies@gmail.com | Director |
| 363 | 32969453 | Yogendra Prasad Mehta | PDIL | 9811984175 | ypmehta2002@yahoo.com | Consultant |
| 364 | 33211670 | Yogendra Sharma | JPVL | 9540434969 | yogendra.sharma@jalindia.co.in | Field Engineer(C&I) |
| 365 | 33078290 | Yogendra Prasad | PDIL | 9810307748 | yprasad@pdilin.com | GM(Inspection) |
| 366 | 33191538 | Yamini rastogi | Triveni | 9990675531 | rastogi.yamini@gmail.com | Engineer |
| 367 | 32942309 | Yudhveer Singh | JPVL | 8800155370 | yudhveer.singh@jalindia.co.in | Engineer(C&I) |

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- Pyrotech Marketing & Projects Pvt. Ltd.
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E-mail: pmppl@pyrotechindia.com

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• Providing opportunities of higher education: Contributing for construction of engineering college (Institute of Technology, Korba) and setting up an Indian Institute of Information Technology (IIIT) in Chhattisgarh • Adopted 17 ITIs and 8 new ITIs under construction • Support for primary and secondary education and vocational training in the neighborhood villages • Set up Information Technology Centres and Disability Rehabilitation Centres for visually and physically handicapped • Support to specialised Eye Centers at Bhubaneswar, Mobile Health Clinics, DOTS Health Camps, free operations. • Infrastructure works like area lighting, water bodies and community information centers, construction of roads, drinking water facility and sanitation facilities in the neighbourhood villages • 48 schools being currently run in NTPC power projects benefitting about 40,000 students.

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