TABLE-I: SUMMARY OF INDEPENDENT REVIEW PROCESS FOR PRE-DEVELOPED SYSTEM (PDS)

Sr. No	Life cycle phases	Independent Review stages	Input documents	Output Deliverables
1.	Requirements phase	System Requirements Review	SR document along with traceability matrix with PSAR/DBI/DN/SOP	Verification Report (VR) on SR
2.	Procurement Phase			
	Evaluation Phase	Product Evaluation Review	Product Specification Compliance(PSC) Fitness for Purpose (FFP)	RR on PSC, FFP
			Previous design, development documents and reports on the exiting PDS	Audit Report (AR) on previous design and development documents & reports
	Configuration & Customization phase	Configuration Review	Configuration Management Plan during Development/ Manufacturing (CMP-D/M), System Verification and Validation Plan (SVVP) Verification Plan for Application Software (VP-ASW) System Architecture Design (SAD) System Validation Procedure (SVP) System Safety Analysis report (SSAR) Hardware Reliability Analysis (HRA)	RR on CMP-D/M, VR on SVVP VR on VP-ASW, SAD, SVP RR on SSAR, HRA
		Customization Review	Application programming requirements (APR) Application Program (AP) System Build (SB) User Documentation (UD)	VR on APR VR on AP RR on SB, UD
		System Validation at factory on standalone system in simulated environment.	SVP-F (Part of SVP) SB UD	SVR-F
3.	Deployment phase	System Validation at Site system integrated with field I/O and other digital I&C systems in actual environment.	SVP-S (Part of SVP) SB UD CMP-OM document	SVR-S RR on CMP-OM

IV&V ACTIVITIES AND CHALLENGES FOR PDS AT NPCIL

Since 2003, NPCIL has deployed more than 150 numbers of the safety and safety related digital pre-developed systems at the various projects/plants after successful completion of the V&V activities on each of the system. There were various anomalies detected and corrected for the safety and safety related functions. The supplementary validations have also been completed after correction or change modification. Implementation of IV&V process was a new challenge and a learning process at NPCIL due to change of the culture. The following are the major challenges in the IV&V review process of the PDS:

- The system integrators or vendors are not fully aware the overall requirements of the V&V process and therefore they are not able to compliance this process in time due to lack of resources and efforts. However, it was observed that the original equipment manufacturers (OEM) followed V&V process concurrently in line with product development life cycle for the digital I&C systems or subsystems deployed in safety or safety critical applications. But all the deliverables of this process are not made available to the local vendors or system integrators due to many factors like IPR, commercial issues, etc. Therefore there is need for familiarization of this process to the potential vendors and system integrators to know the overall requirements in line with the project schedule.
- All the design and development documents with their corresponding reports on the basic product are not made available for the audit.
- The applicable deign documents with the required information on the PDS are not available.
- The project wise incremental changes/ modifications in the basic hardware and software are not available
- The source codes are not made available for formal verification and validation due to intellectual property (IPR) issues.
- End user licenses are not provided specially for software development and testing tools.
- Many times the system requirements is incomplete/ambiguous for deployment of the CBS then a vendor driven design is imposed
- Change Management procedure is not followed
- There are embedded or programmable controller based subsystems with in a main system which are discovered at later stage and skipped from the review stages
- IV&V process system hardware versus software
- Non-availability of transparent feedback mechanism for tracking the implementations of V&V suggestion/recommendation on the system and design documentation.
- In phase or concurrent IV&V process for new projects
- Requirements of the certifications on the software development and testing tools used for review, static and dynamic analysis of software codes
- Lack of resources and expertise for smooth implementation of the V&V process.
- There are multiple make and models for the identical application and therefore this need to mobilize different resources and expertise.

CONCLUSION:

Independent verification and validation process is the integrated part of the engineering process and it provides an objective assessment for the product and process throughout the system development life cycle. Once the product is build correctly, completely and demonstrated the safety, reliability, functional and performance requirements than

- The both the organizations (NPCIL and the vendor) have documented evidence that the finish product meets all stated requirements for the hardware & software.
- The organization has minimized the project execution time and in turn saved the money
- The user is able to use the hardware & software productively within the organization.
- Build up the confidence level of the user
- The product is qualified by the IV&V process of the NPCIL.

ACRONYMS

AERB	Atomic Energy Regulatory Board
AR	Audit Report
DBI	Design Basis Instructions
DN	Design Note
I&C	Instrument and Control
IT	Information Technology
IV&V	Independent Verification and Validation
LWR	Light Water Reactor
NDS	Newly developed Systems
NPP	Nuclear Power Plant
OEM	Original Equipment Manufacturer
O&M	Operation and Maintenance
PDS	Pre Developed Systems
PHWR	Pressurized Heavy Water Reactor
RR	Review Report
SQA	Software Quality Assurance
SVR	System Validation Report
V&V	Verification and Validation
VR	Verification Report

REFERENCES

[1] AERB Safety Guide AERB-SG-D-25: Computer Based Systems of PHWR

[2] Engineering Procedures for Computer based digital I&C systems (NPCIL internal documents)

[3] Procedure for Independent Verification and Validation of digital I&C systems (NPCIL internal document)

[4] IEC 60880 NPP – I&C systems important to safety – Software aspects for computer-based systems performing category A functions

[5] IEC 62138 NPP – I&C important for Safety – Software aspects for Computer –based systems performing category B or C functions

BIOGRAPHIES

Sh. Harish Rajput graduated in Electrical Engineering from Jabalpur Engineering College in the year 1985. He joined Department of Atomic Energy through BARC Training school in 1986. Since joining the NPCIL, he has worked in the various fields like reactor operation, I&C maintenance, IT & Communication, I&C design groups, software quality assurance groups and contributed excellent works in each field. At present he is working as "Additional Chief Engineer" in Software Quality Assurance Group. He is associated with verification and validation of the safety and safety related computer based digital I&C systems in Indian PHWR plants and Russian Light Water Reactors. He was conferred with "Group achievement award for the year 2007" by NPCIL.

OPERATING EXPERIENCES WITH PROGRAMMABLE LOGIC CONTROLLER (PLC) SYSTEM IN INDIAN NUCLEAR POWER PLANTS.

Vinay Soni, A.V Ughade, K.K. Chandra, C.P. Shrivastwa,
(vsoni@npcil.co.in, avughade@npcil.co.in, kkchandra@npcil.co.in, cpshrivastwa@npcil.co.in)
Nuclear Power Corporation of India Ltd, Mumbai.

ABSTRACT

Programmable Logic Controllers (PLC) was introduced for the first time in new generation standard 220MWe Nuclear Power Plants (NPPs) that replaces a large number of relay based logics used in safety related and non safety applications. The introduction of PLC decouples the design activity from construction activity thus allowing both the activities to progress independently. This also offers other benefits e.g. debugging, data logging, automatic self diagnosis, fault tolerance, hot repair etc. The experience on the deployment of PLC system which is computer-based has brought out various implementation issues. The objective of this paper is to highlight the challenges faced, the solutions emerged and improvement carried out based on operational feedback of NPPs.

KEYWORDS: PLC, Token Bus.

INTRODUCTION

Main function of Programmable Logic Controllers (PLC) in Indian NPP is automatic ON-OFF control of various pumps, fans & valves, dampers, controlling sequence of operation of machines and doors, implementing various interlocks, driving indicating lamps etc. They are mainly used for;

I. Control of various process interlocks and control functions (Station-PLC)

II. Control of Main and Emergency airlocks (Airlock PLC)

III. Dryer control (Dryer PLC)

IV. Emergency transfer of load on class-IV failure (EMTR PLC).

Systems in Indian NPPs are categorized into four safety classes - Safety Critical (IA), Safety Related (IB, IC) and Not Important to Nuclear Safety (NINS) - based on their significance to nuclear safety. PLCs are used in IB, IC and NINS applications.

PLC ARCHITECTURE:

Two kinds of internal architecture are employed in PLC implementation:-

I. Dual processor hot standby where each PLC has two redundant processors controlling common I/Os and

II. Dual computer hot standby where each PLC has single processor but one PLC is standby to other PLC.

A number of such PLCs are connected through dual redundant token bus, forming networks, and exchange data and information necessary for generation of outputs. In each network an engineering work station is provided which serves as an operator interface. Each network also includes one Gateway for communicating information on inputs, diagnostics messages on PLC health to Computerized Operator Information System – a computer based system for centralized display and logging of information. Typical diagram of PLCs with dual redundant network is shown in Figure-1.

The access protocol used is Token Bus Control (TBC) as per IEEE-802.4 standard [1]. In line with C&I philosophy PLCs are organized into two redundant groups. Redundant loads like pumps, valves etc are connected to two redundant groups of PLCs to take care of single PLC failure.

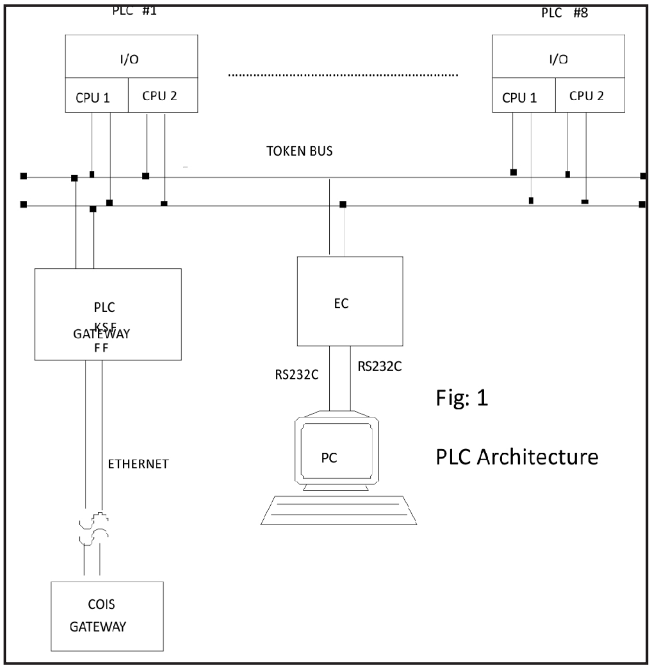

Fig: 1

PLC Architecture

CHALLENGES ASSOCIATED WITH PLCs:

A. PERFORMANCE

(a) Spurious ground fault indication in 48 V DC control power supply

This was attributed to high off-state current of FIT (Finite Impulse Test) modules. It has been addressed by using low off state current FIT modules having leakage current of about 1 microampere, by reducing FIT frequency and by providing dedicated built-in field input interrogation power supply.

(b) PLCs going Out of network

Communication related problems like Send Message Errors, CPUs going out of network etc. were observed in PLCs. These problems were observed in all the plants but their impact was significant in NPPs where LAN was also used for sharing control signals among the PLC nodes (i.e. information required for generating outputs used in controlling various equipments) thus failure of LAN was resulting to process disturbances.

The problem was attributed to;

- Longer length of LAN cable
- Weak signal strength
- Improper Grounding of LAN cable shields

The relation between the no. of nodes and the maximum permissible cable length for satisfactory operation LAN as indicated in the supplier's manual [2] is shown in figure-2. In initial NPPs, no. of nodes on LAN was 22 and the length of LAN cable was around 400 meters. This was almost nearing the boundary condition (500 meters). Also due to the improper laying of cable (i.e. not maintaining the minimum bending radius) and improper grounding of the cable shield the minimum signal strength of 10 dBmV, as recommended in IEEE-802.4 [1], at the receiving end of PLC require for satisfactory operation was not available during LAN disturbances.

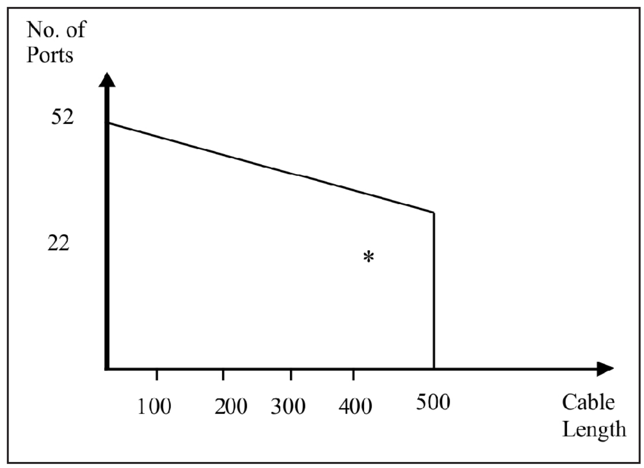

Figure: 2 Relation between no. of nodes and length of LAN cable

Above problems were resolved by incorporating following modifications;

- LAN network is split into number of smaller networks which results in lesser attenuation and more signal availability at receiving end.
- EMI/RFI is addressed by laying trunk cables in metallic conduits.
- Maintaining the bending radius of trunk cable > 7 inches and taking adequate precaution while laying the cable to avoid over stretching and crushing of trunk cables thus preventing the change in characteristics impedance of trunk

cable.

- Proper termination of LAN cable is made to reduce reflection.
- Multipoint grounding (suitable for high frequency) of LAN cable shield.

Moreover to avoid the disturbance on loads due to communication failure, each PLC is provided with all the inputs, in hardware form, necessary for generation of outputs used in control purpose. The use of LAN is restricted to information function only.

After carrying out the above modifications, the LAN parameters like signal attenuation, peak & average noise and return loss were measured and following are the results

LAN Parameters	Before modification (Kaiga-2)	After modification & with multipoint grounding (Kaiga-2)	
Signal attenuation	36.13 dB	4.98 dB	
Noise	Peak	+4 dBmV	-10 dBmV
	Average	-19 dBmV	-20 dBmV
Return Loss		-30.01 dB	-31.82 dB

(c) Halting of CPU

Problem of one CPU halting was observed in PLCs where dual processor hot standby configuration is employed. The problem was analyzed and attributed to loss of synchronization between two running CPUs. Because of this, each CPU considered other CPU faulty and tried to acquire the bus leading to bus contention and subsequent halting of one CPU. Loss of synchronization between the running CPUs occurred due to elongation of cycle time of PLC. This was caused by unbounded time involved in semaphore lock acquisition while communicating to token bus controller as no timeout was possible because of high priority of communication task.

To address the CPU halting problem, PLC software is modified to implement the fixed period of execution for the scan task so that the communication task can be kept at lower priority. Thus any communication problem will not lead to loss of synchronization between the redundant CPUs and subsequent halting of CPUs can be avoided. This modified software is tested on 4 PLC token bus network and installed in PLC system at site. The performance of the modified software is satisfactory.

d) AC-DC Switch Mode Power Supply

Redundant AC-DC SMPS was used for feeding power supply to PLC as shown in Fig.3

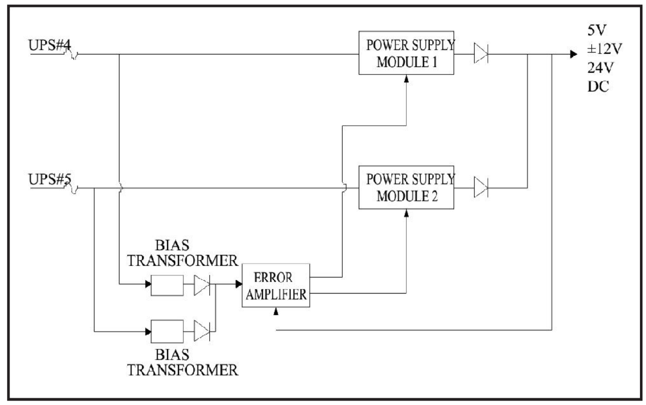

Fig.3 Current Sharing Mode Power Supply

In the above scheme there was a common error amplifier which was used for common feedback to both modules running in

parallel for equal load current sharing. Power supply to this common error amplifier was derived from diode paralleled bias transformers. After review of current sharing mode power supply, it was found that failure of common error amplifier would lead to failure of both modules running in parallel.

To avoid this, DC to DC SMPS is used in place of AC to DC SMPS and also independent error amplifier is used to ensure current sharing. Source power supply to DC to DC SMPS is taken from intermediate DC bus of UPS which has a battery back-up. So source power supply to DC to DC SMPS can be considered as class-I power supply. Failure of any UPS will not lead to unavailability source power supply to DC to DC SMPS.

B. OBSOLESCENCE

We are facing difficulties to maintain the PLC due to paucity of spares. Also suppliers expressed their inability to supply the spares for following hardware boards.

1. TBC VME } Used in Token Bus
2. TBC MODEM }
3. RT-20 - used as the main processor for the PLC

To overcome obsolescence of TBC VME and TBC MODEM cards, necessary design modification in PLC is carried out to replace token bus with dual Ethernet LAN. This Ethernet LAN was tested and subsequently retrofitted in EMTR PLC and Airlock PLCs. Performance of these retrofitted is reported to be satisfactory. Based on this performance, the implementation of Ethernet network is being considered for other PLCs also.

CONCLUSION

PLC system is running satisfactorily after carrying out all the above modifications in the existing operating NPPs. Important LAN parameters like Signal strength at each drop point, signal attenuation, noise and return loss are measured at every Bi-annual Shut down to predict LAN behaviors and identifying deterioration at any point of time by comparing the LAN parameters with reference readings. Also up-gradation of Token Bus with Ethernet LAN is being taken up to address obsolescence issues.

ACKNOWLEDGEMENT

We acknowledge the support of Shri Md. Arifuddin and his Team at ECIL, Hyderabad for their help and support in identifying the reasons and implementing the solutions.

ACRONYMS

PLC Programmable Logic Controller

TBC Token Bus Control

NPP Nuclear Power Plant

LAN Local Area Network

REFERENCE

1. IEEE-802.4: - Standard for Token Bus LAN

2. RELCOM Carrier Band Network Handbook

BIOGRAPHIES

Shri Vinay Soni graduated in Electronics and Telecommunication Engineering from Bhilai Institute of technology, Durg. He joined Department of Atomic Energy in year 2005. During his career he has been associated with Design, Engineering and Procurement of various C&I Systems. At present he is working as an Executive Engineer in Reactor Protection Group.

Shri A.V.Ughade graduated in Electronics Engineering from VNIT, Nagpur. He joined Department of Atomic Energy in year 1988. During his career he has been associated with Design, Engineering and Procurement of various C&I Systems. At present he is working as an Additional Chief Engineer in Reactor Protection Group.

Shri K.K.Chandra graduated in Electronics Engineering from Jadavpur University Calcutta. He Joined Department of Atomic Energy in 1984. During his career he has been associated with Design, Engineering and Procurement of various C&I Systems. He was also associated with formulation of AERB Safety Guide for Indian PHWR -AERB/NPP-PHWR/SG/D-25. At present he is working as Additional Chief Engineer in Station Control Group .

Shri C.P.Shrivastwa graduated from BCE, Bhagalpur. He joined Department of Atomic Energy in year 1980. During his career he has been associated with Design, Engineering and Procurement of various C&I Systems. At present he is heading Station Control Section.

System Reliability Estimation and Updation

Lalit Kumar Singh#1, Ajita Srivastava#2, S.K.Goswami#3, Agilandaeswari K.#4, M. Bharath Kumar.#5

#Nuclear Power Corporation of India Ltd.

Mumbai, India

1 lksingh@npcil.co.in 2 ajitas@npcil.co.in 3 skgoswami@npcil.co.in 4 agilakaruna@npcil.co.in 5 mbharathkumar@npcil.co.in

Abstract

n approach for reliability modelling of a system based on Bayesian Network is proposed, aiming at the limitations of traditional reliability analysis theory. We developed a general methodology for modelling reliability of complex systems based on Bayesian network. A reliability structure represented as a Fault Tree Diagram is transformed to Bayesian network representation by which the reliability of the system can be obtained using probability propagation techniques. Some advantages of Bayesian network over Fault Tree method are shown. More importantly, we have shown the impact of a subsystem's reliability change on all other subsystems and system. We present Emergency Core Cooling System of Nuclear Power Plant as a case study to demonstrate our approach.

Keywords

System reliability, Reliability estimation, Bayesian network

I. INTRODUCTION

Systems installed in Nuclear Power Plants, Medical domains, etc have very high reliability requirements. For this, there are statistical technique that can predict the reliability of a complex system based on its structure and the reliability of each component. Some traditions technique for reliability analysis have several important limitations and are based on unrealistic assumptions like all the failures are independent and the rate of failure is constant. Also, much expertise is needed to build the reliability model. Further, due to the approximations in the computational model and the limited statistical data on the input variables, there may be uncertainty in this computation. So we have used the Baye's theory which is used for probabilistic updating.

Works on system safety and Bayesian Networks were developed in [1] and the works presented by Boudali and Dugan [2]. In the paper [3] the authors describe the stochastic modelling techniques such as Fault Trees and Petri Net. This paper focuses on the situations where new information on component or system performance may have become available through testing or inspection after analysis, and explores techniques to update the prior reliability prediction using this information. To update system level reliability prediction, many approaches have been proposed [4-5]. In these approaches, the system is viewed through a single limit state. Marz and Waller [7] winded up, concluding that system test data usually provide no information on component performance as is a system test passes, it does not mean that all the components in the system were successful and vice versa as it depends on the configuration of the system.

Bayesian networks have been applied mostly in the field of Artificial intelligence and now have gain popularity in the field of engineering decision strategy [8]. However so far, as par our knowledge it has not been used in the reliability analysis of Nuclear Power Plant structures

We therefore investigate the difficulties in the application of Bayesian network in one of the system of Nuclear Power Plant, known as Emergency Core Cooling System (taken as case study).

The layout of the paper is as follows:

Sections 2 describes Bayesian Networks. In section 3, we describe a brief description of Emergency Core Cooling System, which is a safety system of Nuclear Power Plant. In section 4. We describe our approach based on Bayesian Network to estimate the reliability of the system, considering the parallel and series subsystems. In section 5, we describe the method to update the reliability of all the subsystems/components and system followed by change in reliability of any subsystems/

system. Finally section 6 concludes the paper.

II. BAYESIAN NETWORKS

A Bayesian network B is an annotated acyclic graph that represents a joint probability distribution over a set of random variables V. The network is defined by a pair where G is the DAG whose nodes represents random variables, and whose edges represent the direct dependencies between these variables. The graph G encodes independence assumptions, by which each variable is independent of its nondescendents given its parents in G. The second component denotes the set of parameters of the network. This set contains the parameter for each realization of conditioned on , the set of parents of in G. Accordingly, B defines a unique joint probability distribution over V, namely

$$P_B(X) = P_B(X_1, X_2, \dots, X_n) = \prod_{i=1}^{n} P_B(X_i | \pi_i)$$

$$= \prod_{i=1}^{n} \theta_{x_i|\pi_i} \dots\dots\dots\dots\dots (1)$$

For simplicity of representation we omit the subscript B henceforth. If has no parents, its local probability distribution is said to be unconditional, otherwise it is conditional. If the variable represented by a node is observed, then the node is said to be an evidence node, otherwise the node is said to be hidden or latent.

The main advantages of Bayesian networks are:

i. the factorization implied by (1)

ii. the fact that conditionally independence relations can be inferred directly from the graph G.

The marginal probability of is (suppressing B):

$$P(X_i) = \sum_{X \notin X_i} P(X) \dots\dots\dots\dots\dots (2)$$

Assume an event E has occurred, we have:

$$P(X|E) = \frac{P(X,E)}{P(E)} = \frac{P(X,E)}{\sum_X P(X,E)} \dots\dots\dots\dots (3)$$

To compare it with Fault Tree analysis, Fault trees allows duplicating nodes for common cause analysis, which can be validated by considering the example of Fault tree, given in Figure1. The corresponding BN is illustrated in Figure2. Here A is a subsystem or component failure of a system. Let failure is denoted by 1 and pass is denoted by 0. In Fault Tree F is a duplicate node while this duplicate node has been eliminated in the corresponding Bayesian Network, shown in Figure2.

So, the joint probability of the Bayesian network, given in Figure2 is:

$$P(X) = P(H)P(I)P(F)P(E|H,I,F)P(D)P(B|D,E)$$
$$\times P(G)P(C|F,G)P(A|B,C)$$

......................(4)

The subsystem failure probability is

$$P(A=1) = \sum_{A=0}^{1}\sum_{B=0}^{1}\dots\sum_{I=0}^{1} \begin{matrix} P(H)P(I)P(F)P(E|H,I,F)P(D)P(B|D,E) \\ \times P(G)P(C|F,G)P(A=1|B,C) \end{matrix} \dots\dots\dots\dots (5)$$

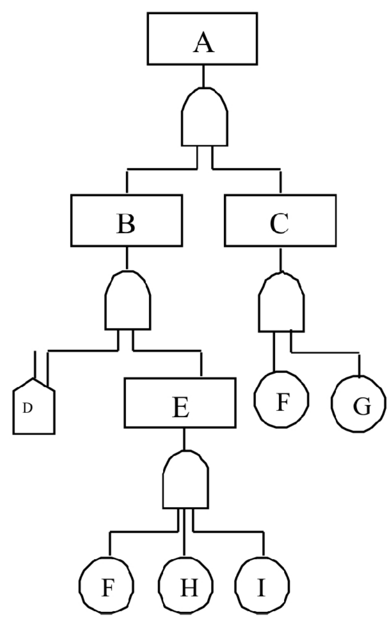

Figure1. Fault Tree

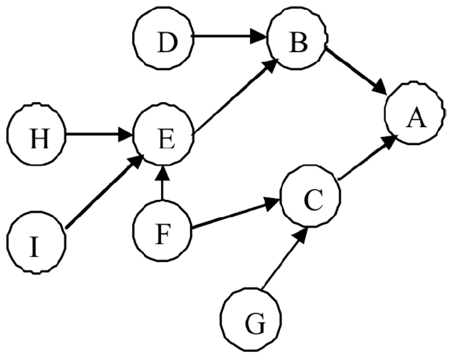

Figure2. Bayesian Network of Figure1

Therefore in case of subsystem failure, the marginal probability of all the nodes in the network can be updated as:

$$P(X|A=1) = \frac{P(X, A=1)}{P(A=1)} \ldots\ldots\ldots\ldots..(6)$$

In case of Fault tree system reliability analysis, when system level test data are available, we can only determine the posterior probability of system failure by using Bayes' theorem and updating the component performance statistics is not possible because we treat a single component only [7].

III. EMERGENGY CORE COOLING SYSTEM

Emergency Core Cooling System (ECCS) is one of the special safety systems that are provided to limit radioactivity release should a serious breach in PHT system pressure boundary occur. To limit radioactivity there are three barriers:

i. the fuel sheath

ii. the PHT system boundary

iii. the containment structure

ECCS is designed to protect fuel sheath by removing decay heat from the fuel following loss of coolant accident (LOCA) in PHT pressure boundary covering all range of break sizes. The system provides coolant make up flow to, and long term core decay heat removal from the failed PHT circuit. However, a separate leak handling system involving primary feed system, has been provided to handle effectively leaks up to about 9.5 Kg/sec, which is within the capacity of primary pressurizing pumps, without invoking ECCS. ECCS contains several valves and pumps which operates as per the designed logic to inject the water or heavy water into the core to mitigate the consequences of LOCA.

IV. SERIES AND PARALLEL SYSTEM TAKING ECCS AS A CASE STUDY

Consider a series system, taking top event as ECCS failure; the fault tree of which is given in Figure 3.

A and B are two basic events defined as:

A	B
Pump1	Pump2

Table1. Basic events for ECCS status

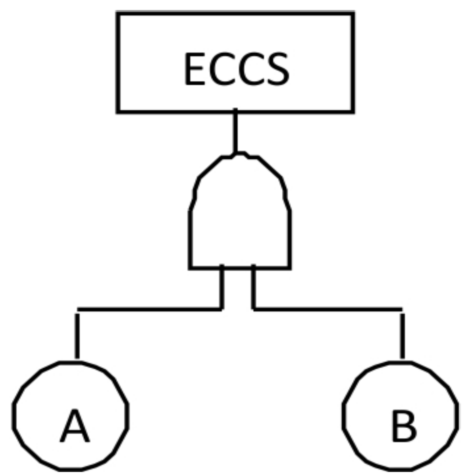

Figure3. Fault Tree of ECCS

There are many basic events, responsible for failure or success of the ECCS system but just for simplicity to illustrate our approach, we consider only two. Now it is easy to represent this fault tree into BN and is shown in Figure 4. Here C represents ECCS.

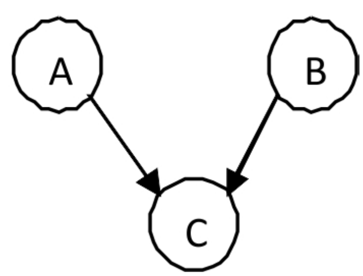

Figure4. BN of figure3

It means that ECCS function will fail if any one of the two events A and B fails, shown in Table1.

A	B	P(C=1| A, B)
0	0	0
0	1	1
1	0	1
1	1	1

Table1. Probability of C failure given A & B in case of series system

Figure 4 infers that A and B are independent. However, in this case, there is dependence between the failures of bar A and bar B. The dependence could be the statistical correlation between the states of A and B due to the common random variables in their limit states. Therefore,

$$P(AB) \neq P(A)P(B) \dots\dots\dots\dots\dots\dots..(7)$$

Let

$$P(X = 1) = P(X)$$
$$P(X = 0) = P(\bar{X})$$

ECCS system failure probability can be computed from Table1 as:

$$P(C) = 1 \times P(A)P(B) + 1 \times P(A)P(\bar{B}) + 1 \times P(\bar{A})P(B) + 0 \times P(\bar{A})P(\bar{B})$$

$$= P(A) + P(B)[1 - P(A)]$$
$$= P(A) + P(B) - P(A)P(B) \dots\dots\dots\dots\dots\dots(8)$$

This equation is only correct when A and B are independent which is not true, hence modification is need to construct the BN. For this we make two modifications: consider all the input random variables as root nodes. For example considering is strength of node i and the applied load is . In this case the failure probability:

$$P(i) = f(S_i, \omega) \dots\dots\dots\dots\dots\dots..(9)$$

Then we construct BN in case of correlated and uncorrelated variables as shown in Figure5(a) and 5(b) respectively.

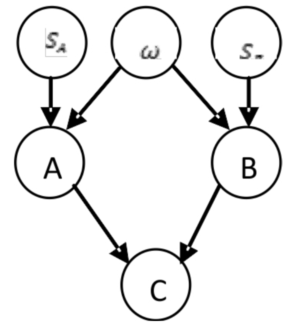

Figure5a.Modified BN (not correlated variables)

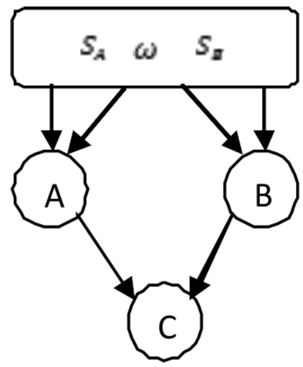

Figure5b. Modified BN (correlated variables)

Now let us try to model the parallel system using BN. In this case any one pump is sufficient to function ECCS. So both the pumps are required to be failed for ECCS failure as shown in fault tree diagram in Figure 6. Here A and B represents the two pumps. In this case sequential dependence between A and B also needs to be incorporated, which means that failure of A can change the failure distribution of B and viceversa. But BN does not allow cycles, but BN still can be created like figure5, by incorporating additional information on sequential failure probabilities as shown in Table2.

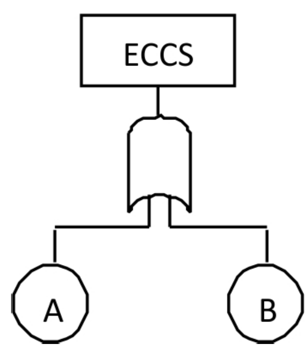

Figure6. Fault Tree of ECCS

A	B	P(C=1| A, B)
0	0	0
0	1	P(|B=1, A=0)
1	0	P(|A=1, B=0)
1	1	1

Table2. Probability of C failure given A & B in case of parallel system

A_B : updated state of A after B fails

B_A: updated state of B after A fails

P(C=1|A=1, B=0) = P(B_A=1 |A=1, B=0) : Probability that C=1 will occur given A fails first is equal to failure probability of B given A fails first, since C=1 is defined when both A and B fail.

Hence, this approach allows modeling both types of dependence: statistical and sequential

So, the probability of ECCS function failure for series system (Figure 3), using equation 1 & 2, is given as:

$$P(C=1) = \sum_{A=0}^{1}\sum_{B=0}^{1}\int_{s_A}\int_{s_B}\int_{\omega} P(C=1|A,B)P(A|s_A,\omega) \times P(B|s_B,\omega)\, f(s_A) f(s_B) f(\omega)\, ds_A ds_B d\omega \ldots\ldots\ldots (10)$$

I : pdf of input random variables.

If these random variables are correlated, **I** needs to be replaced by their joint pdf. For clarification if suppose in case of series system, each node A and B takes half load, then following conditional probabilities can be used in equation:

$$P\left(A=1\middle|s_A \le \frac{\omega}{2}\right)=1,$$

$$P\left(A=0\middle|s_A \ge \frac{\omega}{2}\right)=1$$

And

$$P\left(B=1\middle|s_B \le \frac{\omega}{2}\right)=1,$$

$$P\left(B=0\middle|s_B \ge \frac{\omega}{2}\right)=1$$

....(11)

The equation 10 can be solved using multi-normal integration or Monte Carlo simulation without complete numerical integration.

$$A_B = 1 \Rightarrow s_A \le \omega$$

$$B_A = 1 \Rightarrow s_B \le \omega$$

....(12)

Similarly in case of parallel system when one Pump A fails, other pump B can take the full load. We need to consider .

So,

$$\begin{aligned} P(C=1) = P(C=1|A=1,B=1) & \\ \times P(A=1,B=1) & \\ + P(C=1|A=0,B=1) & \\ \times P(A=0,B=1) & \\ + P(C=1|A=1,B=0) & \\ \times P(A=1,B=0) & \\ + P(C=1|A=0,B=0) & \\ \times P(A=0,B=0) & \end{aligned}$$

$$= P\left(s_A \le \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) + P\left(s_A \le \omega \middle| s_A \ge \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) \times P\left(s_A \ge \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) + P\left(s_B \le \omega \middle| s_A \le \frac{\omega}{2} \cap s_B \ge \frac{\omega}{2}\right) \times P\left(s_A \le \frac{\omega}{2} \cap s_B \ge \frac{\omega}{2}\right)$$

$$= P\left(s_A \le \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) + P\left(s_A \le \omega \cap s_A \ge \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) + P\left(s_B \le \omega \cap s_A \le \frac{\omega}{2} \cap s_B \ge \frac{\omega}{2}\right)$$

....(13)

Failure probability using Fault Tree approach is given by considering the same failure sequence:

$$A \rightarrow B \equiv s_A \le \frac{\omega}{2} \cap s_B \le \omega$$

$$B \rightarrow A \equiv s_B \le \frac{\omega}{2} \cap s_A \le \omega$$

Hence

$$P(C=1) = P(A \rightarrow B) \cup P(B \rightarrow A)$$

$$= P[\left(s_A \le \frac{\omega}{2} \cap s_B \le \omega\right) \cup \left(s_B \le \frac{\omega}{2} \cap s_A \le \omega\right)]$$

$$= P[(s_A \le \tfrac{\omega}{2} \cap \left(s_B \le \tfrac{\omega}{2} \cup \left(\tfrac{\omega}{2} \le s_B \cap s_B \le \omega\right)\right)) \cup (s_B \le \tfrac{\omega}{2} \cap \left(s_A \le \tfrac{\omega}{2} \cup \left(\tfrac{\omega}{2} \le s_A \cap s_A \le \omega\right)\right))]$$

$$= P\left[\left(s_A \le \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) \cup \left(s_A \le \frac{\omega}{2} \cap \frac{\omega}{2} \le s_B \cap s_B \le \omega\right) \cup \left(s_B \le \frac{\omega}{2} \cap \frac{\omega}{2} \le s_A \cap s_A \le \omega\right)\right] \dots\dots\dots\dots (14)$$

These three events are mutually exclusive, so

$$P(C=1) = P\left(s_A \le \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) + P\left(s_A \le \frac{\omega}{2} \cap \frac{\omega}{2} \le s_B \cap s_B \le \omega\right) + P\left(s_B \le \frac{\omega}{2} \cap \frac{\omega}{2} \le s_A \cap s_A \le \omega\right) \dots\dots\dots (15)$$

Equation 13 and 14 are identical

V. RELIABILITY UPDATION

If the ECCS failure is observed, in case of series system; failure probability of A and B and probability distribution of random variables can be updated as:

$$P(A=1|C=1) = \frac{P(A=1, C=1)}{P(C=1)} = \frac{P(A=1)}{P(C=1)} = \frac{P(s_A \le \frac{\omega}{2})}{P(C=1)}$$

$$P(B=1|C=1) = \frac{P(B=1, C=1)}{P(C=1)} = \frac{P(B=1)}{P(C=1)} = \frac{P(s_A \le \frac{\omega}{2})}{P(C=1)}$$

$$f(s_A|C=1) = \frac{dF(s_A|C=1)}{ds_A} = \frac{d}{ds_A}\left(\frac{P(s_A \le s_A, C=1}{P(C=1)}\right)$$

P(C = 1) can be calculated from equation 10. Similarly distribution of other variables can be found out. If B failure is observed, other nodes can be updated as:

$$P(A=1, B=1) = \frac{P(A=1, B=1)}{P(B=1)}$$

$$f(s_B|B=1) = \frac{dF(s_B|C=1)}{ds_B} = \frac{d}{ds_B}\left(\frac{P(s_B \le s_B, B=1}{P(B=1)}\right)$$

$$P(C=1, B=1) = \frac{P(C=1, B=1)}{P(B=1)} = \frac{P(B=1)}{P(B=1)} = 1$$

Similarly for parallel system

$$P(C=1, B=1) = \frac{P(C=1, B=1)}{P(B=1)} = \frac{P(C=1|A=0, B=1) \times P(A=0, B=1)}{P(B=1)} + \frac{P(C=1|A=1, B=1) \times P(A=1, B=1)}{P(B=1)}$$

$$= \frac{P\left(s_A \le \omega \cap s_A \ge \frac{\omega}{2} \cap s_B \le \frac{\omega}{2}\right) + P(s_A \le \frac{\omega}{2} \cap s_B \le \frac{\omega}{2})}{P(s_B \le \frac{\omega}{2})}$$

All the joint probabilities, mentioned in the above equations may be obtained by Monte Carlo simulation.

VI. CONCLUSION

In this paper, an approach to find the reliability of the system has been shown using Bayesian Networks. We demonstrated our approach taking a safety critical system of Nuclear Power Plant, known as Emergency Core Cooling System. A brief description of the system has been specified. A comparative study between the Fault Tree and Bayesian approach has been shown. We have also shown the approach to predict the reliability of the component if its associated component's reliability gets changed.

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Automation in Thermal Power Plant

REAL TIME MEASUREMENT OF CARBON IN FLY ASH FOR COAL FIRED BOILERS IN POWER PLANTS

Anup Shukla,ABB Limited

ABSTRACT

The new non extractive microwave type technology for the online real time basis measurement of unburnt carbon in a power plant and its relevance to Indian power plant combustion optimization and early diagnosis of abnormal conditions upstream to the boiler. Reduction of excess air,Carbon in fly ash.

Key words

CIA=Carbon in ash,Resonant cavity, LOI=Loss Of Ignition

INTRODUCTION

The presence of unburned Carbon in boiler fly ash has important economic and environmental consequences to the to the operator of a coal-fired boiler installation .The paper covers the information related with new Non extractive type Microwave based measurement technology and its advantages over current methodologies of the measurement of Carbon in fly ash.

Its presence is a measure of inefficient fuel utilization which means that more fuel must be burned in order to obtain a given output and which in turn directly increases the cost of electrical power generation. Furthermore, inefficient fuel utilization by virtue of requiring more fuel to be burned in order to produce a given output increases the presence of NOx emissions which is the basis for environmental concerns .Thus knowledge of the carbon content of Boiler Fly ash is an important element in establishing a low NOx boiler emission strategy .In addition low carbon fly ash can be a potential source of income to the operator of a pulverized coal fired boiler in that fly ash can be employed as a building material if the carbon content in the fly ash is sufficiently low. Fly ash with high carbon content is unsuitable as a building material and normally requires the use of expensive waste disposal methods.

The presence of unburned carbon in flyash has been shown to be a function of furnace design,coal quality,the ability of the pulverizer to grind the coal and heat release rate.Boilers are designed to take these factors into the consideration.However following the Clean air act amendment of 1999 and installation of low NOx burners Higher carbon in ash level was the result of these changes.

There is a need to have a real time and accurate measurement of CIA for the on line performance optimization of combustion .

Presently most power plants monitor the CIA level by manually obtaining sample from precipitator ash hoppers or flue gas stream and sending the sample to the laboratory for analysis.Depending upon the laboratory analysis procedure employed,the results of analysis may not be available up to 24 hours.This rather long delay in response may hinder the process of combustion optimization.Another problem associated with manual sampling is difficulty in assuring that the sample analyzed is representive of the specific boiler charectistics.

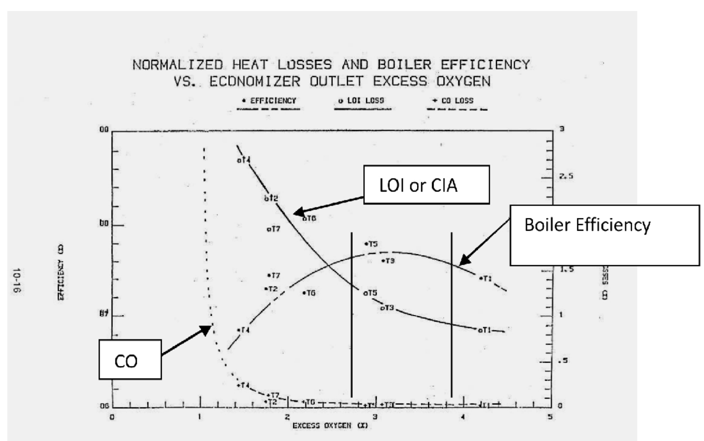


FIGURE 6: CO vs LOI

The above curve shows the relation ship of LOI/CIA with combustion efficiency and response.The curve has been taken from slide presentation by Land Combustion at EPRI conference in 1994.The curve depicts that beyond a point, CO value is (almost flat) insensitive to combustion effeciency variations whereas LOI/CIA curve is very sensitive and can help the user to achieve further efficiency by tweaking excess air(O2) by keeping the efficiency closer to its maxima point.This curve gives the relevance of LOI/CIA measurement on real time basis for Combustion optimization.

Technology Issues and Factors-

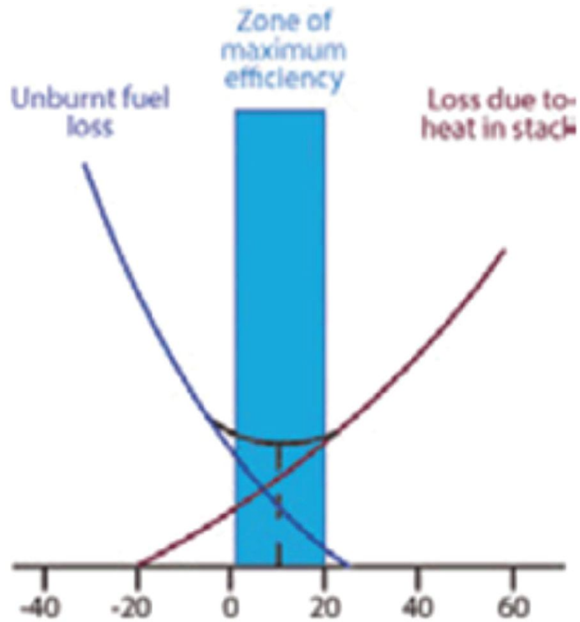
The current methods of measuring the carbon content in boiler flyash are deficient in several regards which as follows:

Firstly these methods are typically extractive in nature in that a specified quantity of fly ash must be captured in order to analyze its Carbon content.This is a time consuming process which yields a sample that is representative of only one location within the flue gas stream.Infact,unknown temperature gradients across the flue gas stream will cause concomitant gradients in theCarbon content of the flyash.

Secondly ,these methods require the expense associated with employing additional analytical equipment and entail a lengthy time delay between in sampling and final analysis of carbon content.As a consequnce of delay in sampling and final analysis this method is not useful for real time optimization and control of low NOx optimization.

Thirdly,The ash content in coal is very high in order of 30 to40%.This contribute to ash load in the furnace duct and the hopper fly ash which essentially gives low carbon content in ash in hopper.For combustionabsolute carbon in flue does reveal the correct picture of combustion and therefore absolute carbon measurement is a must and requires efficient measurement in duct immediate after combustion.The effective measuremant of LOI/CIA in flue will give us to identify correct operating value of boiler.Furthermore as the Indian coal contains so much ash in it will assist the operator if he tunes his boiler to the carbon concentration in the flue gas .As its variability will be smaller than that of the ash concentration as read by the dust probes.

Our feedback from various power plants in India is that the power station operators cannot increase the excess air to reduce the CIA below 1%. This suggests that the plants may be running with too much excess air and heating up the atmosphere. Instead the boiler operator could perhaps reduce the excess air, allow the CIA percentage raise slightly but in so doing lower the heat loss through the stack and reduce the coal consumption of the power station. Because of the real time nature of the measurement the operator would know immediately the effect of his adjustments both positive and negative. He would no longer be operating blind.

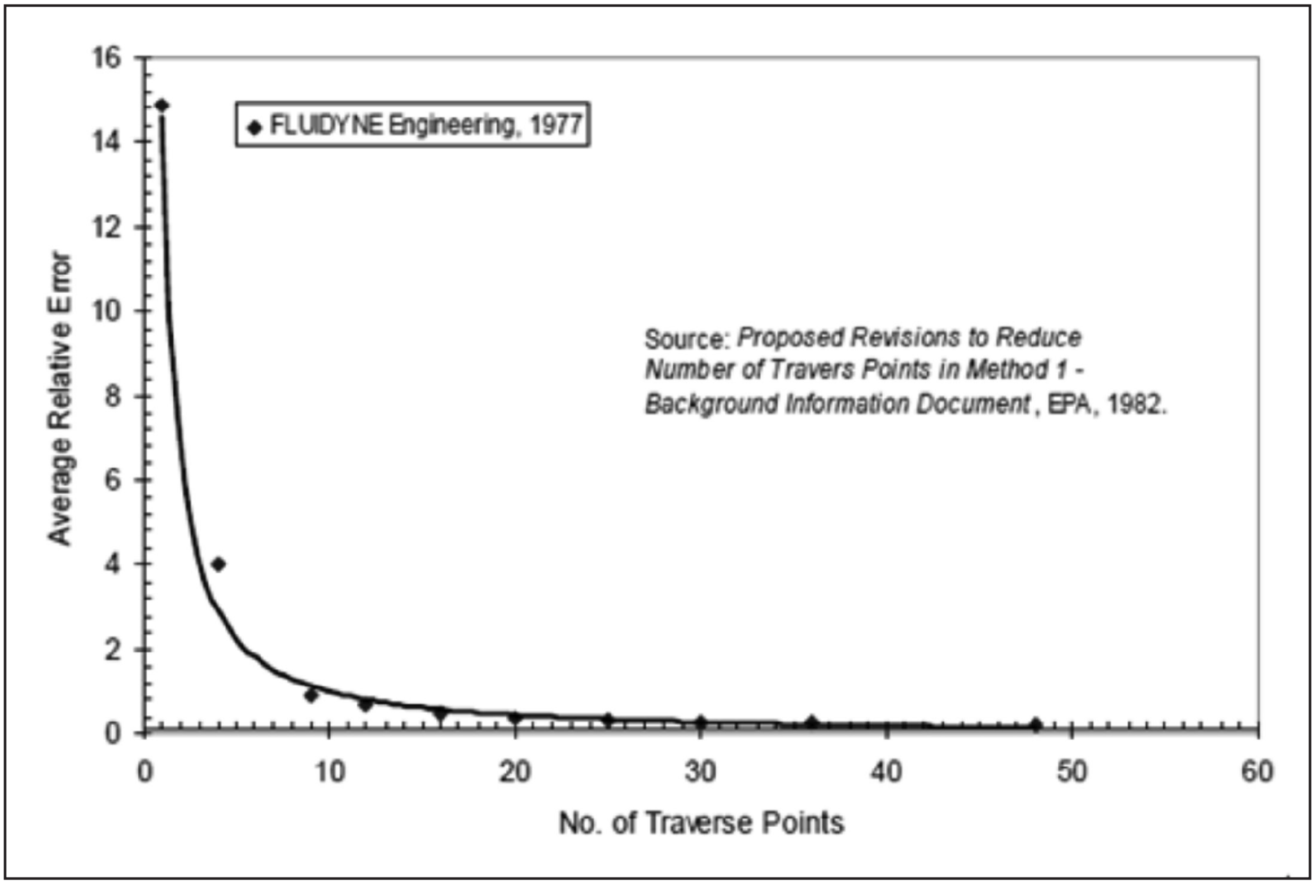


Extractive and Non- extractive measurement

Carbon in ash measurement comes in two broad catagories extractive type and Non extractive type.

Extractive types are those where in ash sample is taken out and analysis is done whereas non extractive type measure carbon directly on the flue gas stream and can handle the temperature of the flue gas. Fly ash sample is not required for non extractive type measurement hence the results are faster , dynamic and useful for control and optimization .

The insitu and sampling type system require multipoint sampling to arrive at realiable measurement of carbon in ash in a generation unit. A typical relative error with number of traverse points for sampling type measurement is shown below-



It is interesting to note that traverse point more than 20 points are requiredto get a relative accurate measurement of CIA/LOI.

Non-extractive Microwave type measurement of carbon in flue gas adresses these difficiencies through utilization of the resonant cavity across the duct.Since the measurement is real time it is useful as a feedback input to boiler control system seeking to optimize fule utilization and reduce NOx emissions. More so the measurements are based upon a volume inspection and as such representative of volumetric avereage, they are less susceptible to the presence of gradients in carbon contents in fly ash

The solution to the above requirement-

A system including a resonant cavity for measuring in situ and in real time the Carbon content of the fly ash produced from the combustion process occuring within a pulverized coal fired steam generator.The resonant cavity basically includes an intelligence section,atransmitting section,a cavity section and areceiving section.When the system ,including the resonant cavity, is so employed that the measurements gained therefrom can be utilized either by an operator or as input to a boiler control system or both in order that corrective action may be implemented when such is required. Furthermore,due to multiple reflections of the electromagnetic radiations within resonant cavity,measurement is possible even in the presence of extremly dilute fly ash i.e. relativelysmall fly ash present in the flue gas stream

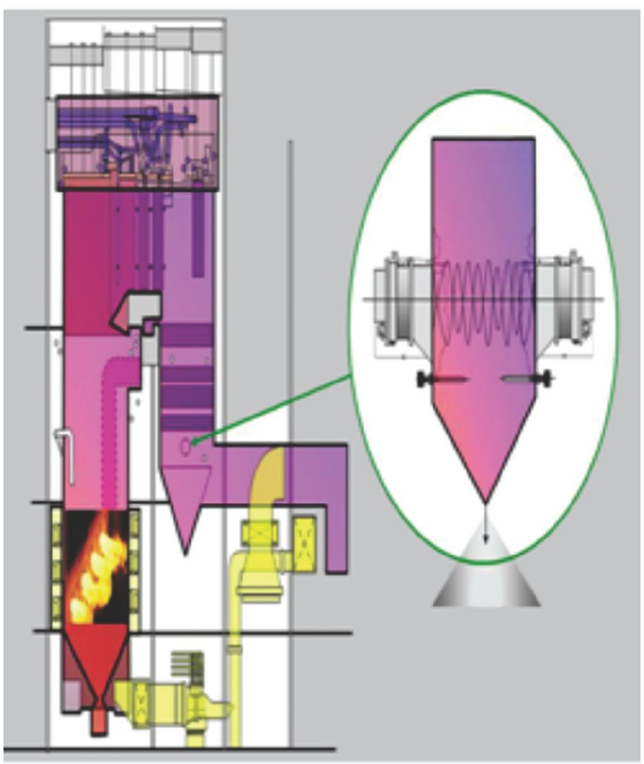
Resonant cavity-Theoretical Explanation

The simplest resonant cavity is the Fabry-Perot Etalon as explained in chapter four of Optical Electronics by A.yariv,4th edition,Saunders College Publishing,1991.

This consists of two parallel,plane reflectors,or mirrors,located a fixed distance apart,between which there may exist a vacuum or some medium.Within the etalon,electromagnetic radiation,originating from an external source,is repeatedly reflected back and forth between the mirrors.At certain frequencies,fq,of the electromagnetic radiation,resonance occurs within cavity.This is marked by periodic sharp peaks in the intensity,I,of the radiation transmitted by the cavity.

The amplitude of the peak is reduced proportionaly on account of the carbon present in the flue gas.The algorithm in supporting electronics is able to convert the measurement in a standard 4-20 ma DC signal on real time basis.

The non-extractive type microwave cavity uses a high frequency of 94GHZ at which the interference of water vapour is eliminated.The concave mirrors/reflectros wave create a focused wave cavity.A variation of wave frequency of 100 MHZ over the above frequency fine tunes the wavelength as multiple of the distance between both reflectors across the duct to create a perfact resonance of microwave.



Summary-

The Real Time on line carbon in ash monitoring using non extractive type microwave resonantcavity method gives a very reliable and representative measurement.The multiple reflections and high frequency of microwave give correct measurement of carbon even in dilute ash or low carbon content.The frequency thus selected is sensitive to carbon only not even to the water vapor in the flue gas. It is a real time measurement with less than 1 minute update time and an accuracy of 1% absolute give a fast and accurate measurement.

The following advantages are envisaged in power plant if the wisdom of CIA is available on line-

- The soot blowing steam consumption can also be optimized by seeing the trend of CIA% variations during soot blowing .Due to the sootblowing the dust load temporarily increases in the duct which leads to reduce value of the carbon %.Once the dust is blown off and collected the carbon % starts recovering to original value on the fixed load and thus over consumption of steam can be avoided.The quick response of CIA value gives better optimization of steam consumption.

- Fast commissioning of boilers and its performance of load variations and mills performance can also be checked by seeing the real time trends of CIA.

- The Non extractive type measurement can be real time input and should be installed across the duct in burner back pass location.It is required one number per path of the flue gas and generally one no per generating unit is required.

- The real time accurate measurement can be additional input to close loop control circuits to further optimize the combution in a sustainable way and for good quality fly ash.

Alternative methods do require many sampling points to get avreaged accurate value of CIA following the numbers of traverse point recommendations in a power plant

About **Anup Shukla**- He is BSc, AMIE from Institution of Engineers India in Electronics and Telecommunication Engineering,MBA in Marketing, He has 25 years work experience in Instrumenatation by technical support and selling of Instruments with specialization on SWAS Analysers and combustion Analyzers..He is Asst Vice President Sales for Combustion products in India for ABB in India .Rightnow persuing establishing ABB Carbon in Ash monitor which is Real Time non extractive microwave type measurement of Carbon in flyash.The product claims to help the user to modify and correct their combution parameters and graduating with profitable and sustainable way of power generation. For more information he can be reached on**<anup.kr.shukla@in.abb.com>, Hand phone: +919810845978**

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SMALL, HIGH-SENSITIVITY SIMPLER SINGLE BEAM, NEW SERIES, INFRARED GAS ANALYZERS FOR WIDE RANGE OF APPLICATIONS

Sanjeev Kumar Gupta, Director,
Analyser Instrument Co. Pvt. Ltd., Kota

ABSTRACT

A small, high sensitivity infrared gas analyzer with a single beam has been developed, by creating a measuring section with higher sensitivity and employing sample switching (SSW), which achieves low range measurements that surpass the double beam measurement range. In this way smallest range measurements are now feasible with simpler design single beam infrared analysers.

There are two types of infrared gas analyzers: single beam types with a simple construction, and double beam types that have high sensitivity but are large and require complicated adjustments,

This Simple design single beam analyzer can be used in a wide range of applications from metal heat treatments and monitoring applications for biomass-/ waste-related generated fuels that require high range measurements, to low range exhaust gas monitoring and monitoring impurities in pure gases that require low range measurements.

1. Introduction

The NDIR Gas Analyzers have been used extensively in various industries for applications involving the measurement of gas concentrations, such as for combustion control, emissions gas monitoring and process control in various plants. In these applications, infrared gas analyzers are used to measure nitrogen oxides (NOx), sulfur dioxide (SO2), carbon monoxide (CO) and carbon dioxide (CO2) concentrations, and are used as environmental monitors to measure the combustion exhaust gases emitted from various industrial furnaces including garbage incinerators, boilers, steel production plants, cement production plants, and for the monitoring and control of gases inside furnaces.

With recent advances in control technology for combustion furnaces and incinerators and advances in techniques for removing toxic substances, the concentrations of NOR, SO2 and CO2 in exhaust gases are tending to decrease. Thus, the purpose of measurement, in addition to the conventional goal of controlling and monitoring exhaust gas, is often to prove that exhaust gas is not being emitted or is at low concentrations, and the ability to provide stable measurements of low concentrations of gas is increasingly sought.

To promote the widespread usage of gas analyzers , performance improvements, as well as standardization and simplification of the usage methods are needed.

This paper describes new type of gas analyzer that realizes high performance and ease of use.

2. Product Overview

The lineup of infrared gas analyzers include single-beam types having a simple construction, and double-beam types that have high sensitivity but are large and require complex adjustments. Figure 1 shows the structure of the measurement unit of a single-beam type, and Fig. 2 shows the structure of the measurement unit of a double-beam type.

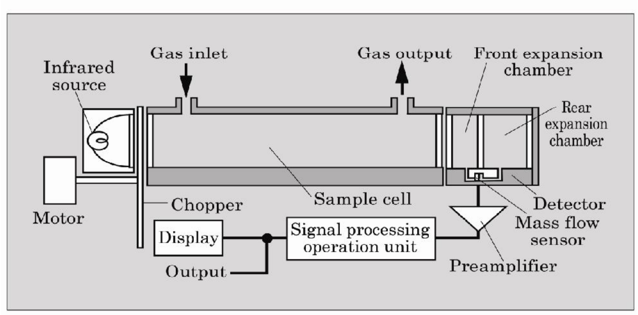


Fig.1 Configuration of single-beam type measurement unit

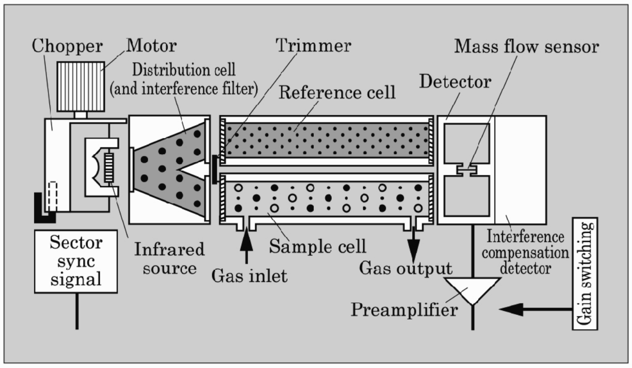


Fig. 2 Configuration of double-beam type measurement unit

A small high-sensitivity infrared single beam Gas Analyser has been developed which aim to achieve performance superior to that of the conventional double-beam type.

By increasing sensitivity of the measurement unit and adopting a method of sample switching, we have successfully developed an analyzer that achieves improved stability, is capable of measuring low concentrations and is easy to use. Additionally, component parts were made standardized so as to create a flexible product lineup able to support requirements for measurements ranging from low to high concentrations.

3. External Appearance and Specifications

Figure 3 shows the external appearance and Table 1 lists the main specifications of the whole new series. The series is provided as a general-purpose model that covers the conventional single-beam measurement range (0 to 200 ppm), a high-end model that covers the conventional double-beam range (0 to 50 ppm), and a low concentration model that enables measurement of even lower concentrations of 0 to 5 ppm.

4. Product Features

(1) Small-size, high sensitivity measurement

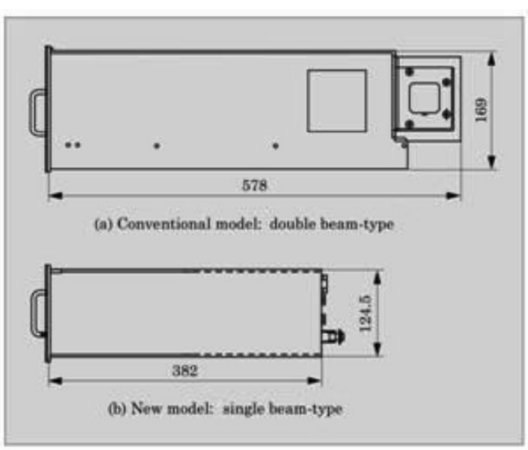
The thickness of the sensor film of the mass flow sensors used in the detectors of conventional infrared gas analyzers was reduced to improve detector sensitivity. Moreover, the smaller size and increased sensitivity of the measurement unit enabled the single-beam minimum measurement range (conventionally 0 to 200 ppm) to be reduced to 0 to 5 ppm, which is a 40-fold improvement.

With the smaller size of the measurement unit, even when equipped with a sample switching function (described below) is installed, the size remains the same as that of a conventional single-beam analyzer and the volume is less than one-half that of a conventional double-beam analyzer (see Fig. 4).

Table 1 Main specification of the New Series

Item	General Purpose	High End Model	Low Concentration Model
Measurement principles and measured components	NO, SO2, CO2, CH4 : Non – dispersive infrared absorption method O2: Selected from among magnetic, galvanic cell and custom zirconia methods		
Measurement method	Standard	Sample switching	
Range ratio	1 : 10 Max.		
Minimum measurement range	NO: 0 to 200 ppm SO2: 0 to 200 ppm CO2: 0 to 100 ppm CO : 0 to 200 ppm CH4: 0 to 500 ppm	NO: 0 to 50 ppm SO2: 0 to 50 ppm CO2: 0 to 50 ppm CO : 0 to 50 ppm	NO: 0 to 10 ppm SO2: 0 to 10 ppm CO2: 0 to 5 ppm CO : 0 to 5 ppm
	O2: 0 to 5 Vol % (in the case of magnetic or custom zirconia methods)		

Item	General Purpose	High End Model	Low Concentration Model
Minimum measurement range	NO: 0 to 200 ppm SO2: 0 to 200 ppm CO2: 0 to 100 ppm CO : 0 to 200 ppm CH4: 0 to 500 ppm	NO: 0 to 50 ppm SO2: 0 to 50 ppm CO2: 0 to 50 ppm CO : 0 to 50 ppm	NO: 0 to 10 ppm SO2: 0 to 10 ppm CO2: 0 to 5 ppm CO : 0 to 5 ppm
	O2: 0 to 5 Vol % (in the case of magnetic or custom zirconia methods)		
Warm-up time	4 Hours	2 Hours	
External I/ O	Analog output DC4 to 20 mA, 550 Ω or less , 12 points Analog input 0 to 1 V, 1 point Contact output 24 V DC, 1 A 15 points max. Contact input 12 to 24 V DC, 5 to 20 mA 9 points max		Same as the left, 4 points max Same as the left, 1 point Same as the left, 15 points max Same as the left, 6 points max.
Power Supply / power consumption	AC 100 to 240 V		
	50/ 60 Hz, approx, 100 VA	50/ 60 Hz, approx, 120 VA	50/ 60 Hz, approx, 100 VA
Dimension (mm)	483 (W) x 418 (D) x 132.5(H)		
Linearity	+/- 1.0% FS or less		
Repeatability	+/- 0.5% FS or less (0 to less than 200 ppm is +/- 1.0% FS or less)		
Drift (Zero point)	+/-2.0% or less per week (total of NO & SO2 drift for no more than 0 to 500 ppm is +/-2.0% FS or less per day)	+/- 0.5% Fs or less / week	
Drift (Span)	+/-2.0 % FS or less / week		
Response speed (90% response)	30 seconds or less		



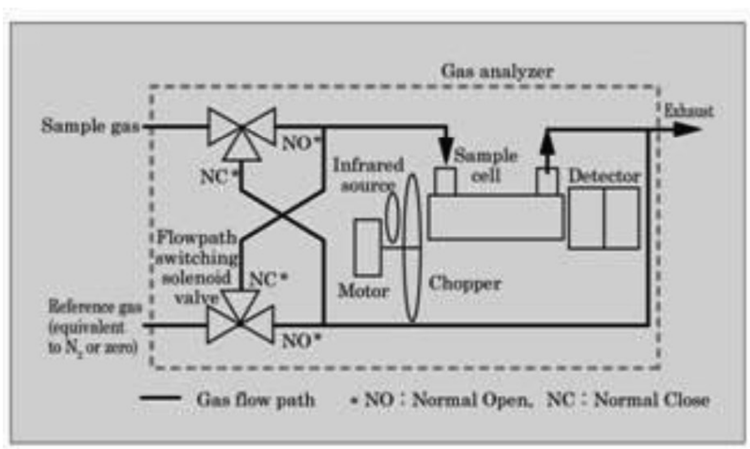


Fig.4 Comparison of conventional and new Models (side view drawings)

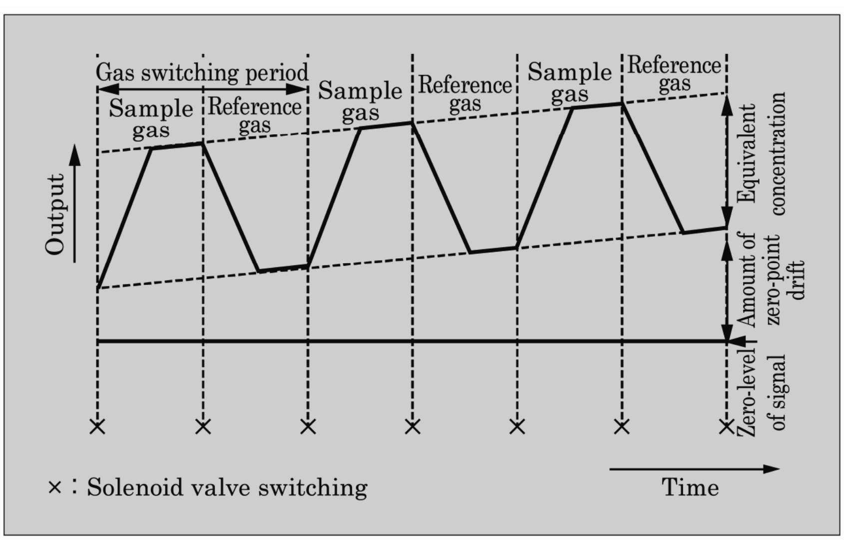
Fig.5 Configuration of Sample switching method

(2) Cancellation of zero point drift

Previously, low concentration measurements using a single-beam type analyzer incurred significant drifting of the zero-point due to the effect of ambient temperature changes, contamination inside the measurement cell and the like, and in order to maintain stability (refer to "Zero-point drift performance") measurements were limited to the range of 0 to 200 ppm. With the New series of products, however, a sample switching method is used and stable measurements can be obtained even when measuring low concentrations.

Figure 5 shows the configuration of the sample switching method.

In the sample switching method, a sample gas and a reference gas corresponding to a zero gas are switched at a certain period, introduced to the measurement unit, and alternatively measured to obtain measurements while continuously monitoring the zero-point. As a result, in principle, the drift of the zero-point is cancelled. Fig. 6 shows the mechanism for cancelling the zero-point drift. The measured values correspond to "concentration amounts," and even if the zero-point drifts, only the change in output is seen, and therefore the amount of drift is negligible. Consequently, stable measurements can be obtained even in the vicinity of the zero-point.



(3) Simple maintenance

Because a single-beam is used, there is no need for the optical balance adjustment that is required with the double-beam method. Additionally, the measurement unit has a simple structure that facilitates maintenance such as cell cleaning.

(4) New Product series that supports a wide range of measurements

The New series is suitable for a wide range of applications ranging from the monitoring of metal heat treatments and of the generation of fuel from biomass and waste where measurement of high concentrations of gas is required to the monitoring of low concentrations of exhaust gas, the monitoring of impurities in pure gas, and so on where measurement of low concentrations of gas is required.

The New series supports measurements ranging from low to high concentrations of furnace gas. Accordingly, the New series provides significant merits in terms of management and maintenance since the maintenance parts are standardized and there is no need to learn how to operate various types of analyzers.

In semiconductor and petrochemical plants, gas purification and supply equipment is installed for such gases as nitrogen, argon and oxygen. Devices are attached to this equipment for monitoring CO_2 and CO impurities contained within the supplied gas. These impurities affect the quality of products made in the plant and their manufacturing processes, and stable measurement of the purity levels is required. The targeted gases, CO and CO_2, are to be measured in the range of 0 to 5 ppm or to 10 ppm, and the new series of analyzers are suitable for this application.

Recently, attention has been focused on preventing global warming which is caused by greenhouse gases. Greenhouse gases include CO_2, CH_4 and the like. Infrared CO_2 meters are being used for the purpose of long-term observation of the global environment. The New series, with its excellent long-term stability, is well suited for the long-term continuous measurement of CO_2 in the atmosphere.

5. Conclusion

The New series of compact, high-sensitivity infrared gas analyzers use single infrared beam, improved sensitivity and zero-point drift cancellation to achieve the capability for measurement of low concentrations. Additionally, the handling of all the New series equipment has been standardized. The products introduced herein are suitable for use in a wide range of applications for combustion control and exhaust gas measurement in various plants.

In the future, we intend to develop gas analysis equipment optimized for these applications, such as by pre-treating the reference gas, and to advance the commercialization of explosion-proof products in order to expand the range of applications.

6. Biographies

Shri Sanjeev Kumar Gupta, was born in Kota in the year 1979. He Graduated in Mechanical Engineering from IIT New Delhi in 2002.

He joined Analyser Instrument Co. Pvt. Ltd. soon thereafter. In the Year 2006 he completed his MBA degree from Indian School of Business with specialization in finance & marketing. Currently he is CEO of Analyser Instrument Co. Pvt. Ltd. involved in design engineering, manufacturing, sales, installation & commissioning of Gas Analysis System in technical collaboration with Fuji Electric Co. Japan

Predictive Emissions Monitoring Systems (PEMS): A Novel and Cost-Effective Method for Continuous Compliance Monitoring of Source Emissions

Th. Eisenmann, CMC Solutions
L.L.C., 80637 Munich, Germany
Phone: +49-152-01537104, teisenmann@cmcsolutions.org

Key Words

PEMS, CEMS, Predictive, Emissions, Monitoring, Performance Specification 16, 40 CFR Part 60, 40 CFR Part 75, Subpart E, Quality Assurance

ABSTRACT

Predictive Emissions Monitoring (Systems) – PEM(S) are software-based data acquisition systems for monitoring emissions continuously by means of plant process data. A PEMS is interfaced with the plant process control system. It utilizes the inputs from the combustion or pollution control process to determine the emission rates of various pollutants that are regulated. A predictive emissions monitoring system does not need any gas analyzers.

By employing historical paired emissions and selected process data (e.g. load, fuel composition, flow, pressure and temperature data, environmental conditions, turbine and boiler settings or variables of the flue gas abatement system) a model is generated, which allows determining the actual plant emissions for compliance purposes. PEMS may be used as an alternative to C(ontinuous) E(missions) M(onitoring) S(ystems) for all gas or oil-fired plants (turbines, boilers, heaters etc.) for components like NOx, SO2, CO, O2, CO2, but also for NH3, H2S, HC, VOC.

These so-called empirical PEMS (in contrast to parametric PEMS) have been tested and evaluated with positive results within the frame of corresponding programs by the US Environmental Protection Agency (US EPA) in the last decade. Special emphasis has been put on quality assurance of the results. PEMS can be applied in lieu of CEMS according to title 40 C(ode) (of) F(ederal) R(egulations) Part 60[1] (especially Performance Specification 16[2]) and 40 CFR Part 75 (Subpart E)[3]. PEMS is used at multiple plant sites, particularly in the U.S., but also in the Middle East and partly in Asia. In Europe PEMS so far is common only in selected countries.

A strong motivation to replace CEMS with PEMS results from cost savings due to lower capital expenditures as well as much lower operational and maintenance cost. This motivation is based on the fact that PEMS can accomplish equal accuracy and quality of emissions data compared to CEMS.

1. INTRODUCTION

PEM(S) or Predictive Emissions Monitoring (Systems) can be considered as alternative to automatic monitoring devices (Continuous Emission Monitoring System – CEMS) for demonstrating regulatory compliance ofsource emissions. Just as CEMS, PEMS satisfy continuous determination of emissions according to prevailing regulations and quality assurance requirements. PEM exhibits similarities, but also differences to source measurements with gas analyzers. They feature, however, some distinct advantages, which will foster a widespread application in future with progressive replacement of analyzer based monitoring systems.

2. PEMSCLASSIFICATIONS

Predictive Emissions Monitoring Systems (PEMS) aresoftware-baseddata acquisition systems linked to theDistributed Control System (DCS) or Plant Information System (PI) of a power station or petrochemical plant. Usually, PEMS use a multitude of process parameters and their data from DCS or PI to determine emission concentrations and emission rates of regulated pollutants.Consequently, PEMS does not need gas analyzers and all the accessorial for continuous monitoring. Like probes, heated sample lines, protocol gases or shelters. The general configuration of CEMS and PEMS is shown in Fig. 1 & 2.

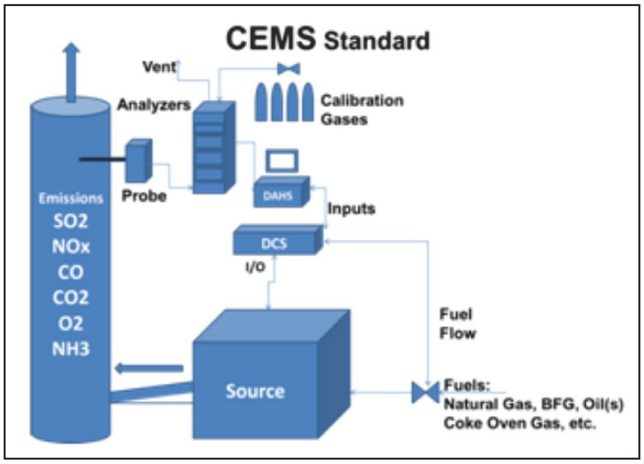


Fig. 1 Standard CEMS Configuration
DAHS: Data Acquisition and Handling System

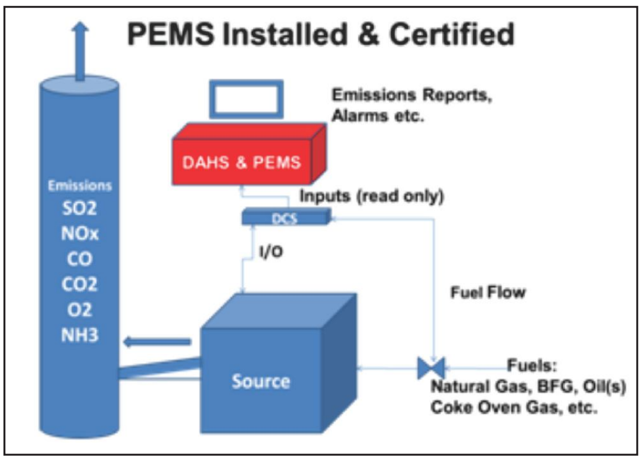


Fig. 2: Emissions Monitoring with PEMS and Data Acquisition (DAHS)

DCS: Distributed Control System

PEMS are anything but new, already in the 1970ies "First Principle" or parametric PEMS have been used. Since roughly the year 2000 the U.S. Environmental Protection Agency has tested empirical PEMS in extensive evaluation programs. Based on the positive results and experiences, PEMS have been certified and approved for compliance monitoring in lieu of CEMS since then.

PEM can refer to both parametric and empirical predictive emissions monitoring. Parametric and empirical systems share a common functional relationship with combustion and emissions. These approaches to emissions monitoring take input data from the process control system and generate emissions data without actually contacting the stack gas. Although parametric and empirical emission monitoring systems share a common functional block diagram, they provide dramatically different results.

Parametric systems utilize one to three key input parameters, are generally not very accurate and tend to over-predict the emissions. This includes the linear methods such as applying an emission factor which typically has a positive bias. Parametric systems require a few critical inputs that are used in formulaic calculations of the pollutant emission rate. A parametric formula is described for each pollutant, p, such that the emission rate, E, can be expressed as a function of up to three input parameters, I:

Parametric $E_p = f(I1)$ or $= f(I1, I2)$ or $= f(I1, I2, I3)$

Example $E_{NOx} = I1 \times K_{NOx}$ where $I1$ = heat input

As example, the NOx emission rate is defined as a linear function of heat input, when applying an emission factor (KNOx) to a low mass emitter. Parametric systems are not used on base-load gas turbines in U.S. emissions trading programs where continuous compliance monitoring is required. In the following, the acronym 'PEMS' is restricted to the empirical predictive type that can be used in U.S. compliance programs for continuous monitoring of all types of processes under existing federal regulations.Nevertheless, parametric PEMS[5] are very well suited for peak load plants or for monitoring of sources that are very difficult to access with conventional analyzers. The most prominent examples are flares in refineries or chemical plants. However, this method is called CPMS – Continuous Parametric Monitoring System to avoid confusion with PEMS for compliance.

EMPIRICALPREDICTIVE SYSTEMS

Modern empirical PEMS used since the end of the 1980ies achieve very high levels of accuracy and can maintain that accuracy over many years. Empirical approaches (such as neural network or statistical hybrid) require a historical dataset, collected prior to deployment containing emissions data from CEMS and time-synchronized process data available from the control system. A predictive formula is described for each pollutant, p, such that the emission rate, E, can be expressed as a function of n (greater than 3) input parameters and intermediate nodes, I[4]:, as:

Predictive	Ep	= f(I1, I2, I3, ... In)
Example	ENOx = f(I1, I2, I3, ... In) or	
(Neural	ENOx = I1 x w1 + I2 x w2 + I3 x w3 + In x wn	
Network)	where wn is the weight for the input or intermediate node n	

Empirical models use historical operating data correlated with emission data to predict the emission rates in real-time with accuracy demonstrated to be equivalent to CEMS (figure 3). Empirical systems unlike parametric and other theoretical predictive systems have demonstrated capability to even pass the strict requirements of 40 CFR Part 75, Subpart E[4] for certification.

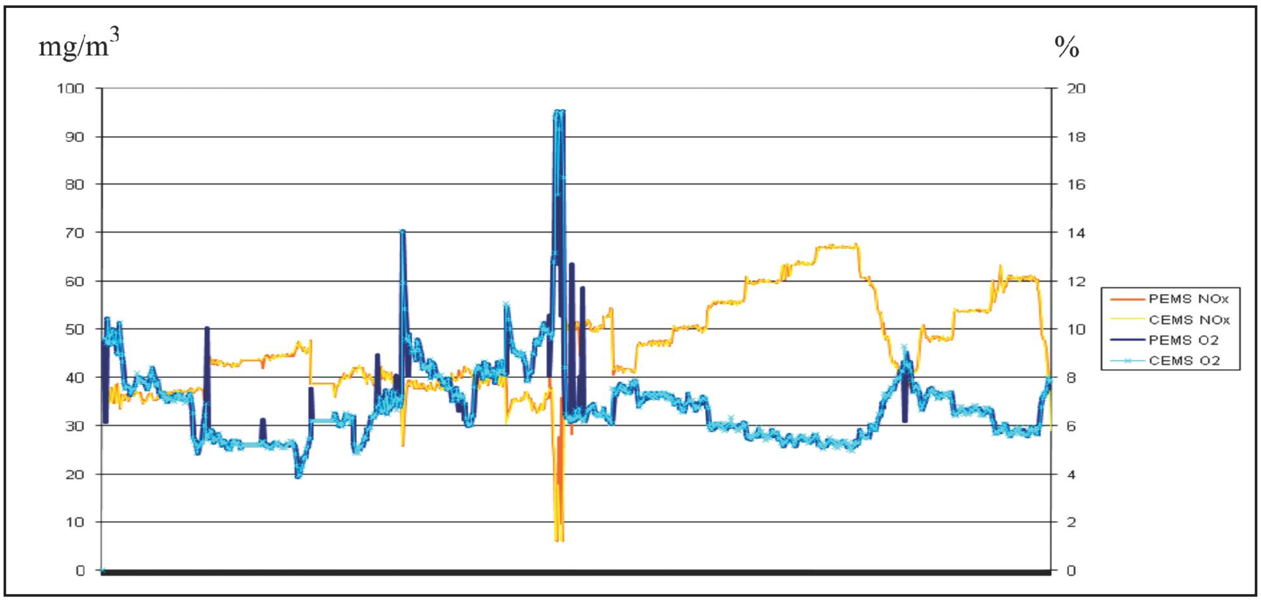


Figure 3 Comparison of PEMS / CEMS results for NOx und O2 (oil-fired boiler).

The data matrix resulting from above allows a precise determination of emissions, as long as the data of the selected process parameters remain within the model envelope, i.e. the data range for each process input that was included in the model. Another prerequisite is compliance to a strict quality assurance like laid down in Performance Specification PS-16[2].PS-16[2]stipulates the criteria for test and qualification of PEMS according to 40 CFR 60 – New Source Performance Standard (please see next chapter).

3. UNDERLYING REGULATIONS

PEM in the USA and countries basically following US Environmental Protection Agency (EPA) regulations is mainly used according 40 C(ode)F(ederal)R(regulation) Part 60[1]and 40 CFR Part 75 (Subpart E[3] Alternative Monitoring Methods).

Essential elements Part 60 or Part 75 are:

Part 60:

- New Source Performance Standard - NSPS, promulgated first 1971;
- There are subparts for each type of source with e.g. subpart D covering boilers, GG covering stationary gas turbines and J Petroleum Refineries;
- Applicable to Industrial Units >100 mmBTU (about 29 MW), in some case also to smaller sources (e.g. Subpart Dc covering small industrial boilers);

- Requires Continuous Monitoring of Primary Pollutants (NOx, SO2, CO, Opacity and VOC);
- PEMS permittedbased on Performance Specification (PS) 16[2];
- Quarterly Relative Accuracy Audits (RAAs) and annual Relative Accuracy Test Audits (RATA).

Part 75

- Originally published in January, 1993;
- The purpose was to establish Continuous Emission Monitoring (CEM) and reporting requirements under EPA's Acid Rain Program (ARP), which was instituted in 1990 under Title IV of the Clean Air Act;
- ARP regulates electric generating units (EGUs) that burn fossil fuels and that serve a generator > 25 megawatts;
- Part 75 requires continuous monitoring and reporting of SO2 mass emissions, CO2 mass emissions, NOx emission rate, and heat input;
- PEMS permitted based on subpart E (Alternative Monitoring Methods);
- For PEMS certification a side-by-side demonstration over 720 hours against Standard Reference Methods (SRM) or CEMS is inevitable (figure 3);
- Annualor semi-annual Relative Accuracy Test Audits (RATA) plus statistical data evaluation.

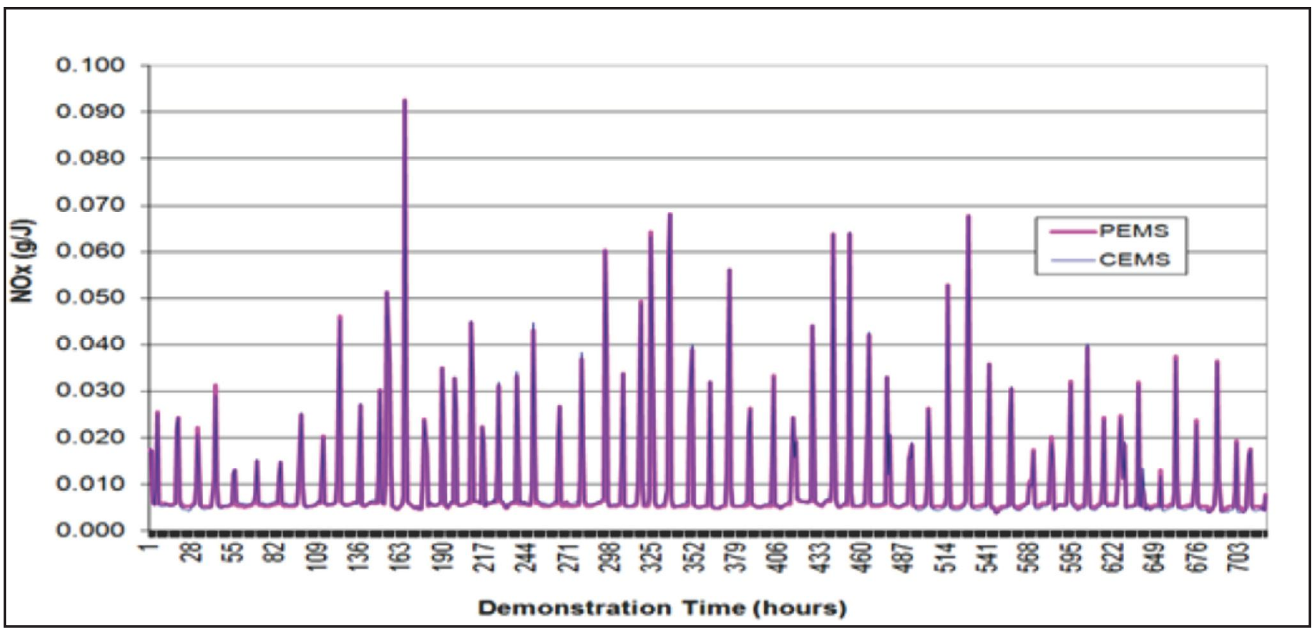


Figure 4 Time plot PEMS versus CEMS for NOx emitted by a peaking gas turbine. Comparison period 720 hours (Part 75 certification)

Comparable European directives are the Large Combustion Plant Directive LCPD (2001/80/EC)[6] andthe Waste Incineration Directive WID (2000/76/EC)[7].These directives are now condensed in thedirective 2010/75/EU on industrial emissions (integrated pollution prevention and control), effective January 06, 2011. For Europe, a new Working Group 37 within the European Committee for Standardization (CEN)has been established end of 2012 that shall draft a European PEMS Norm (EN) considering the standards EN14181[8] "Stationary source emissions - Quality assurance of automated measuring systems"and EN15267-3[9]"Air quality - Certification of automated measuring systems - Part 3: Performance criteria and test procedures for automated measuring systems for monitoring emissions from stationary sources". The norm needs to addresshow these standards can be applied to and fulfilled by PEM.

4. SUITABLE PLANTS AND POLLUTANTS

Basically, empirical PEMS are particularly suitable for monitoring emissions from all gas- and oil-fired boilers, heaters, turbines etc. With models based on historic emissions and process data (the model training data set), PEMS can determine besides the so-called „primary pollutants“ NOx, SO2, CO, also, but not limited CO2, O2, H2S, NH3 HC, VOC or formaldehyde. Restrictions exist for plants with solid fuels and large variability of fuel composition like can be found at waste incinerators. Such restrictions also apply to cement kilns, if they use co-firing of waste, tires or other solid fuels. Here, emissions are also largely influenced by the raw material composition. For coal fired plants, determination of SO2with variable sulfur content in the coal is problematic; this is even more the case for pollutants like mercury (Hg). For selective catalytic reduction (SCR), the emission concentration depends on the quality of the catalyst. Ageing of the catalyst can only be determined by monitoring the emission concentration in the flue gas (with a CEMS) and/or the reductant slip. A PEMS can however be used as backup for a CEMS for an SCR.

5. PROCESS PARAMETERS AND MODEL GENERATION

Suitable process parameters for PEMS modeling can be subclassified into three hierarchic groups:

A) Critical Parameters like

a. Fuel flow rates
b. Fuel composition and unit load (MW or heat output)
c. or other independent and critically important parameters
d. Pollution control parameters such as water or steam injection, ammonia injection rate, and scrubber differential pressure (DP)

B) Secondary Parameters like e.g.

a. Temperature, pressure, and flow near the combustion zone, inlet and exhaust conditions;
b. Damper positions, and other important, but not critical parameters
c. Fuel distribution
d. Vane angle
e. Compressor ratio and draft
f. etc.

C) Tertiary Parameters like e.g.

a. Other exhaust and inlet valve positions, control feedback signals, and other control settings or internal control parameters
b. Ambient humidity, temperature, and pressure
c. Bearing temperatures, amperage draws, and other associated process parameters
d. Some process discrete parameters
e. Parameters from ancillary and other plant processes such as feed dewatering systems fuel or inlet air conditioning equipment
f. etc.

For building a PEMS model, only critical parameters are indispensably necessary, these are recorded in power stations or other plant types anyhow.With respect to additional parameters, PEMS are flexible and typically a DCS provides far more process inputs than utilized. Hence, a plant operator is not in need to install any additional process sensors just for facilitating the use of PEMS. Out of the multitude of process parameters, those are selected that have the best correlation to emissions. In our experience, 10-25 process inputs are in most cases sufficient, because a larger number does not increase accuracy in a significant way.

The following steps have to be carried out to build a model and to approve PEMS:

1. Clarification, whether or not the concerned regulatory bodies will accept PEM as alternative for emissions monitoring. Preparation of alternative monitoring protocols;

2. First parameter selection and data collection for the model. The data pool for a PEM consists of historical emissions data from the source with

corresponding time-synchronized process data (model training data set). The period for such training data set depends on the source and the regulatory regime and can be between 2 and 30 days. Emissions data can be taken from historic measurements (intermittent or continuous) or they can be collected in a stack test campaign. Data shall be gathered during normal plant operation as well as during transitional stages and plant start-up and shut down. In any case, all emissions data have to be diligently quality assured;

3. Final determination of the best process inputs and the model levels. Again for a PEM model basically all parameters can be used that influence plant emissions;

4. Model generation for the specific source and implementation;

5. Verification / certification against standard reference methods (SRM): “Initial RATA test”. In the U.S. a report needs to be sent to the relevant regulatory agency or U.S. EPA for approval.

6. COMPARISON PEMS - CEMS

The following table summarizes substantial commonalities as well as differences of PEMS versus CEMS

Table 1 Substantial common features and differences of PEMS versus CEMS

Common Features	**CEMS / PEMS**	
Continuous	Both methods can be used for continuous emissions monitoring.	
Plant Types	For all oil- and gas-fired sources.	
Accuracy / Precision	Accuracy and precision are comparable provided that the same quality assurance is applied.	
Quality assurance of data	Securing data quality with procedures of EN14181 / EN 15267 (EU) as well as RATA / RAA (USA).	
Data Acquisition	For data representation and reporting of monitoring results, use of data acquisition and handling systems.	
Differences	**CEMS**	**PEMS**
Hardware	• Gas Analyzers • Accessories like probes, heated lines, racks, shelters etc. needed	• Standard server hardware with means for data back-up and securing data integrity
Application	CEMS more universally applicable: • Plants fired with solid fuels • Components like particulate matter and Hg	• Not suitable for solid fuels with large variability of composition • Coal-fired plants: Determination of SO2 restricted, especially if sulfur content varies significantly
Cost	• Capital cost: Approximately 50 % of a comparable CEMS. In case of model transferability or for ex-proof areas, cost difference may even be much higher	
	• Operations and maintenance: Approximately 10-20 % of CEMS cost	
	• Quality assurance: No cost difference	
Uptime / Drift	• PEMS: Less drift (only by drift of process sensors)	
	• PEMS: Larger uptime (typical 99.5 %+)	

7. Quality Assurance

PEMS is an analyzer! Consequently, Predictive Emission Monitoring Systems must abide by the same quality assurance (QA) schemes as analyzer based systems to guarantee equivalent results with equivalent accuracy and precision.According to PS-16 (2009)[2] the following QA elements have tobe conducted and incorporated in a QA plan beyond the initial PEMS certification test:

- Daily Sensor Evaluation Check. A sensor evaluation system must check the integrity of each PEMS input at least daily. We recommend doing this once per minute.
- Quarterly Relative Accuracy Audits (RAAs). In the first year of operation after the initial certification, a RAA has to be conducted consisting of at least three 30-minute portable analyzer or reference method (RM) determinations each quarter a RATA is not performed. The average of the 3 portable analyzer or RM determinations must not differ from the simultaneous PEMS average value by more than 10 percent of the analyzer or RM value or the test is failed. If a PEMS passes all quarterly RAAs in the first year and also passes the subsequent yearly RATA in the second year, one may elect to perform a single mid-year RAA in the second year in place of the quarterly RAAs. This option may be repeated, but only until the PEMS fails either a mid-year RAA or a yearly RATA. When such a failure occurs, one must resume quarterly RAAs in the quarter following the failure and continue conducting quarterly RAAs until the PEMS successfully passes both a year of quarterly RAAs and a subsequent RATA.
- Yearly Relative Accuracy Test Audit (RATA). Perform a minimum 9-run RATA at the normal operating level on a yearly basis in the quarter that the RAA is not performed.

For initial certification of a PEMS that is used for continual compliance standards, one must perform a minimum 27-run, 3-level (9 runs at each level, figure 5) relative accuracy test. Additionally, the data must be evaluated for bias and by F-test and correlation analysis. Conduct the specified number of RM tests at the low (minimum to 50 percent of maximum), mid (an intermediary level between the low and high levels), and high (80 percent to maximum) key parameter operating levels, as practicable. If these levels are not practicable, vary the key parameter range as much as possible over three levels.

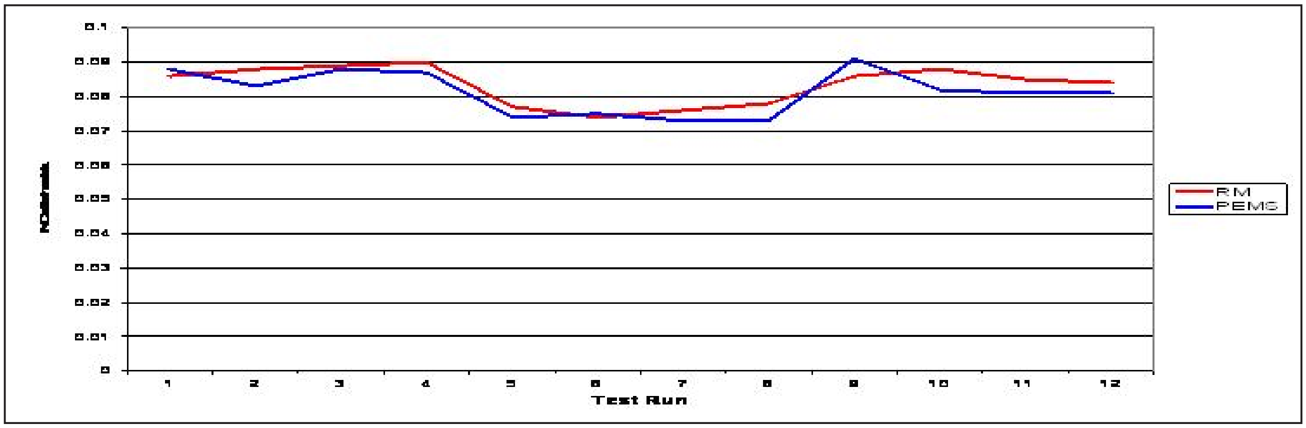
For countries following European regulations, a comparable PEMS QA can be conducted based on EN14181[8]with the QA elements QAL 2, QAL 3 und Annual Surveillance Test (AST).

Table 2:Overview of the most important QA measures for PEMS

PEMS is ananalyzer!	
Measure	**Frequency**
Sensor Validation	Minute, minimum daily
Zero & Span	Daily
RAA	Quarterly (see above)
RATA– AST (EN 14181)	Annual
EN14181 QAL 2	Initial calibration
EN14181 QAL 3	Periodic drift check at regular intervals
EN 14181AST	Annual

Very important is the continuous evaluation of those sensors, whose data is used as input for the model. This validation has to be done minimum daily. In practice, we recommend to use a validation system that does it once per minute in order to timely identify sensors that show abnormal behavior or fail. A particular advantage of PEMS in this connection is its resilience to input failures. Even if a few sensors fail or drift, the PEMS results remain valid as long as accuracy does not fall below a certain value according to the applicable regulation. This gives the operator more time to replace defective sensors without impairing data availability and monitoring uptime. In the 40 CFR Part 75 QA scheme, the effect of sensor failures on relative accuracy is investigated.

Figure 5 RATA: PEMS versus SRM (gas-fired boiler).Measurements at three different load levels.



8. PEMS COST

Using PEMS in lieu of CEMS - at least from the operator's point of view –is largely motivated by significantly lower capital cost and even more by the reduction of operation and maintenance expenditures. Asrule of thumb can be rated:

- PEMS procurement: 40-60 % cost compared to CEMS;
- PEMS operation and maintenance: approximately 10-20 % annual cost versus CEMS;
- CEMS / PEMS quality assurance: annual cost is at the same level for both if the same QA scheme is applied.

Table 3: Capital cost comparison PEMS – CEMS indetail

Initial Cost 3 Gases (CO, NOx, O2)	**PEMS versus CEMS Cost**
Base System PEMS with hardware / CEMS	40 – 70 %
Data Acquisition System (Part 60 DAS) Software	Same
DAHS Hardware	Same
Installation Cost: air, ac, shelter, electrical, mech. I/O	10-20 %
Ancillary Equipment: PEMS I/O interface standard OPC CEMS, probe, umbilical, etc.	0
System Training	50 %
Factory Acceptance	50 %
Totals (if in ex-proof zones, cost may differ 20 times!)	**50 -60 %**

Table 4: Comparison of main cost items PEMS versus CEMS in Detail

Operational and Maintenance O&M) - Annual	**PEMS versus CEMS Cost**
EPA Protocol Gases	0
Replacement Field Devices	0
PEMS / CEMS Spare Parts	5-10 %
Analyzer Repairs	0
Consumables & Spares:	0
Preventative Maintenance Activities	15-20 %
24/7 Service Contract as needed	
Totals	**10-15 %**

9. CONCLUSION AND OUTLOOK

In the USA and in countries basically following U.S. EPA regulations for monitoring source emissions, PEMS take on greater significance as alternative and replacement for CEMS. Decisive for accepting PEMS is equivalence of results obtained by stringent quality assurance procedures. This is the indispensable prerequisite to use PEMS in lieu of CEMS and to capitalize on lower cost benefits. Particularly in countries having implemented a limited environmental monitoring regime, an additional advantage is the lesserdemand for trained, skilled personnel, which typically lacks in such regions and can be utilized more effectively for plant operational tasks. Frequently, we hear that due to lack of staff CEMS operation cannot be warranted. PEMS only requires very low levels of interventions on-site, because many maintenance issues can be resolved by remote access. PEMS have demonstrated their quality and benefits in numerous installations in the U.S., in the Middle East and in parts of Asia. Subsequently, more and more countries would like to take advantage of PEMS benefits and PEMS will forge ahead also in Europe, where acceptance is still limited. Important is to understand that suitable sources and fuels are selected, because PEMS cannot replace CEMS for all types of plants. The following table 5 shall summarize the PEMS benefits:

Table 5: PEMS Benefits

Significantly lower capital expenditures
A fraction the operational and maintenance costs of a CEMS
Maintenance and repair costs virtually eliminated
If a particular parameter is missing, the model utilizes other available parameters for prediction
Resilient to input failures
Valid for normal operating conditions and during transitional states such as startup and shutdown.
Accuracy equal to a CEMS
Model can be setup and re-trained (as needed) by staff onsite or third party consultants.
PEMS can be used as diagnostic tool to determine the source of excess emissions. Thus, it can be instrumental in lowering emissions

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Thomas Eisenmann

L.L.C., 80637 Munich, Germany
Phone: +49-152-01537104,
teisenmann@cmcsolutions.org.

Unifying security and safety communication over IP infrastructure

Authors: Tom-Andre Tarlebø and Harald Kjølberg

Communication, Ethernet, integration, VoIP, IP, LAN, WAN, critical communication, safety and security, radio, public address, centralization / decentralization, IP extenders.

ABSRACT

Industrial Ethernet infrastructure is becoming increasingly widespread. This digital backbone shapes up to be a cost-effective platform, not only for traditional ITC applications, such as e-mail, WWW, data storage and –sharing but even for security, process monitoring and control, automation as well as surveillance and critical communication needs. In this scenario, the requirements regarding the security and solidity of the infrastructure become increasingly important. However, given a correct implementation, there are many benefits and synergies for those willing to look at integrating all safety and security communication and putting it on the IP backbone.

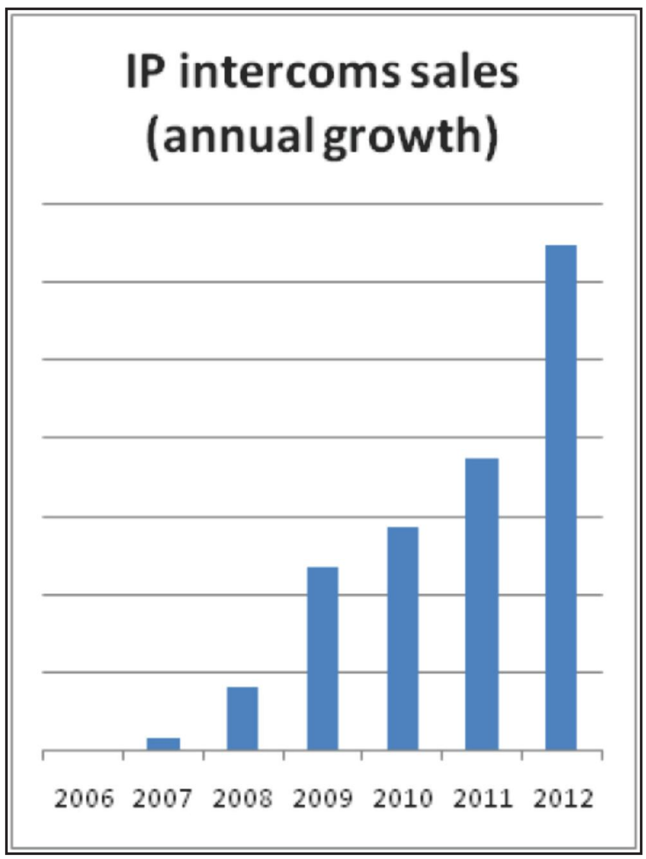
This paper describes the current trends and the possibilities we see for integrating security and safety communication on a common platform. From traditional communication, such as VHF and UHF radio, analogue telephone networks and analogue intercom systems to VoIP/SIP telephones, satellite links and IP-based Public address, they all integrate over IP. This paper looks at the benefits and synergies that were hard to imagine as little as a decade ago and how this will influence the future of critical safety and security communication.

INTRODUCTION

With over 70 years as a manufacturer of products for safety and security communication (military, government agencies, airports, power-plants, ships, etc) and as a systems integrator we have experienced first-hand how the world of safety and security communication is transitioning to IP-based systems. This development has been rapid and markets/segments once considered as “conservative” have shown themselves to be among the most progressive. As the chart show, our sales of IP intercom have increased nearly 10-fold over the last 5 years. Today we see close to a 50/50 split between traditional and IP-based intercoms, with IP gaining ground every year.

Together with the increased use of Ethernet in industrial applications (factories, power-plants), we feel that this combination presents itself as a very attractive solution for this segment.

In this paper we will describe the development and trends with regards to Intercom, Public address, Radio and telephone communication and how we expect this to evolve. We will describe how IP integration affects the overall system architecture with regards to power distributionand safety. We will highlight some of the benefits with regards to flexibility, integration and maintenance and how cost is affected.



THE NEED FOR COMMUNICATION

Power plants, as most other industrial installations, have a diverse and widespread need for communication. Whether it is direct calls between operators in control-rooms, from control-room operators to service and maintenance crews, gate security, security personnel on foot, visitors from the public or even other sites, the requirements for direct communication are as diverse as the solutions applied. In addition there is a need for mass communication in the form of public address- and alarm systems.

Listed are some of the systems commonly used to address these requirements:

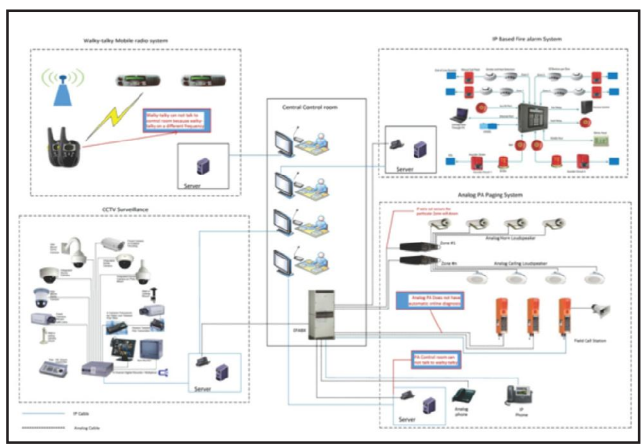
- Mobile radio systems (UHF/VHF/TETRA etc)
    - o Guards/security personnel
    - o Service and maintenance crews
    - o Vehicle operators
    - o Emergency response teams
- Intercom systems (analogue/digital/IP-based)
    - o Control-room operators
    - o Guard outposts
    - o Intra-site control-room communication
    - o Crane/machine operators
- Telephone systems (Landline/GSM/Satellite)
    - o Out-of-site communication
    - o Office communication
- Public Address systems (Analogue/Digital/IP-based)
    - o Control-room operators
    - o Security
- Alarm/evacuation systems
    - o Fire alarm
    - o Evacuation alarm
    - o Intrusion alarm

In addition most security systems today include video surveillance and access control. Together with voice communication these components form what is essentially a three-legged stool of security[1] . For modern security systems, each of these factors are equally important and missing either one dramatically reduces the efficiency of the system as a whole. Getting the three integrated on one platform reduces the load on the operators and even permits automation of tasks.

TRADITIONAL SYSTEMS

Traditional systems are to some extent becoming integrated but this is mainly donein the central dispatch or the control-room. Physically, these systems are placed in close proximity of each other to make them accessible for the operator. Messages or broadcasts that span from one system to the other are relayed through the operator. This practice not only puts a burden on the operators, it introduces the possibility of human error.

To reduce the work-load of the operators these systems may bemore or less integrated. However this is often done through proprietary interfaces and protocols, and incompatibilities have to be addressed with custom-made interfaces. This complicates expansion or replacement of components in the system as compatibility is not guaranteed, and new interfaces may have to be engineered as the need for other systems develop.



IP-BASED SYSTEMS

Traditionally IP-based systems have been centredon an

[1] http://www.securityinfowatch.com/article/10763077/audio-integration-security-a-three-legged-stool

IP-PABX, often SIP-based, from systems providers such as Cisco, Avaya, Alcatel, Lucentet.al. Edge-units (terminals) are provided from a wide range of manufacturers, and include a variety of devices; from simple desktop terminals to more advanced integrated systems providing video capabilities as well as audio. SIP-based ATEX-approved and industrial/rugged terminals are also becoming available in increasing numbers.

As such, the IP-based systems are very much apt for integration. Most systems offer inter-compatibility for both audio (e.g. over SIP for call initiation and control as well as standard audio codecs such as G.711 and G.722) and, to some extent, video (Onvif, H.263, H.264).

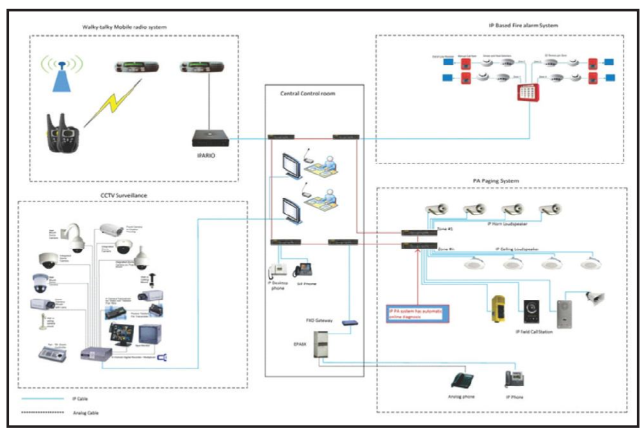
Traditionally there has been a marked separation between these systems and what is considered safety and security communication but this is changing. One of the main objections have been that these systems are business- or consumer-oriented and not tailored to the specific needs of industrial or safety/security communication. Features such as monitoring of input and outputs, error- and status reporting is still lacking in most of these solutions. However, intercom systems aimed at safety and security communication is continuing the transitioning to IP and these systems are becoming more widespread.

INTEGRATED SYSTEMS TODAY

As well integrated as pure IP-based systems get, there are still legacy systems in use that are hard to transition to an IP-backbone. In some cases the technology to replace older systems is not mature or cost-efficient yet. In other cases the systems that are required simply have no IP-based equivalent.Portable radio communication is one example of the former. In recent years digital radio systems such as TETRA and other digital radio systems have emerged. These are far more suited for IP integration than analogue UHF/VHF radio systems but their use is still limited. Main objections to the performance of TETRA as the public emergency network inNorway has been the maturity of the infrastructure as well as unit cost. As a result, several public emergency services (police, fire departments, hospitals) still use their traditional UHF/VHF radios in parallel with the new system. This means that a majority of the radio systems are dependent on the traditional switchboard/dispatch operator or custom systems for communication towards other systems.

Whether all systems will migrate to IP in time, or if it is even wise or cost-efficient to do so is too early to say. However, the interfaces for bringing these traditional systems together already exist.

- IP-based audio servers
- IP-based intercom devices
- IP-to-radio interfaces
- IP-capable PA amplifiers
- IP-based call- and alarm-panels
- IP-based amplified speakers
- Video management systems
- Building management systems (access control, HVAC, etc over OPC)



BENEFITS OF INTEGRATED COMMUNICATION SYSTEMS

The benefits of digital integrated systems are in general:

Increased safety and security

- **Centralized control, diagnostics and maintenance**

  Integration over IP lets the operator gather the various services on a common interface (e.g. a PC application). This not only increases situational awareness, it also helps reduce response time.

- **Decentralized redundancy**

The servers and the terminals may be placed at several locations. For the servers this can be particularly beneficial in the event of a catastrophic event such as natural disasters, fires or explosion. By separating the redundant systems spatially, the risk of a single event taking out the entire system is minimized.

Likewise, multiple terminals placed at separate locations allow for redundant control-rooms, even off-site, should evacuation of the facility be necessary.

- **Multi-site integration**

  Linking the various sites over a long distance connection (such as Fibre-Channel, Radio-link or suitably secure WAN connection) allows for better situational awareness, facilitates decentralized redundancy while reducing the man-hours in site.

- **Cross-system integration**

  Several systems today operate together through common protocols such as SIP (Audio), Onvif (Video), OPC (industrial automation) or proprietary interfaces. Combining functionality from different systems allow for e.g. combining and synchronizing audio and video from an area of interest, forwarding of relevant information, cross-system sharing of audio, video or data.

- **Conferencing capabilities**

  Bringing the various communication systems together on one platform, enables the operator to share audio, effectively conferencing over several previously incompatible systems. One example is the integration of guard radio UHF/VHF/TETRA with Intercom systems indoors, where proper radio coverage may be difficult to achieve. Other possibilities include forwarding of video and/or audio to emergency response teams located off-site as well as direct communication from central emergency management agencies to the staff on site.

Increased flexibility

- **Easy expansion of system**

  Expanding or rearranging the communication infrastructure is simplified through the use of one common backbone, the LAN. The use of structured cablingfacilitates repurposing existing cabling for other systems should the need arise. Adding additional servers for redundancy merely requires the server to be connected to the IP backbone, as opposed to each of the terminals as would have been required in a traditional system.

- **Changing core components**

  Exchanging a component only entails unplugging the old unit, transferring the configuration data and installing the new unit to the IP backbone as opposed to reconnecting each individual terminal, as is the case with analogue PABXes.

- **Mixing offerings from several manufacturers**

  As several of these systems have inter-operability with each other, the system may be comprised of several solutions from several manufacturers. This gives the client the possibility to choose the offering that is best suited to his needs.

- **Centralized/decentralized structure**

  One common control-room or several smaller? Or both? By tapping in to the IP backbone a terminal may be placed virtually anywhere. The same goes for servers and back-end equipment. In some cases it will be beneficial to gather all systems in one common location, whereas a more decentralized structure can be beneficial, especially if the facility is spread over several sites or a large area. The integration over the IP backbone permits any degree of centralization/ decentralization, enabling an optimal and cost-efficient use of the infrastructure.

Increased automation

- **Reduced load on operators**

  Whether through common or proprietary interfaces, integration of dissimilar systems enables a larger or lesser degree of automation. This reduces the load on the operator, whether it be a trivial, frequently occurring task or in an emergency situation.

- **Reduce chance of human error**

  Another consequence of this automation is that it reduces the risk of human error. In the event of an unwanted occurrence contaminating an area, an automated service could be initiating one or more of the following tasks: Physically sealing contaminated area, distributing pre-recoded voice messages both inside and outside the area, setting up communication towards emergency response agencies, regulating HVAC (Heating, Ventilation and Air Conditioning) systems to reduce contamination of adjacent areas, etc. The operator is thereby relieved to be able to get a better overview and assessment of the situation. In the event that the operator is unable to perform his duties such a system would function as a safety-net.

New and unique applications

- **Recording solutions (across all platforms)**

  Recording solutions for safety and security communication is seeing increased demand. For archival purposes, or even as legal evidence against an intruder or assailant. With an IP-based system this is far more accessible than with earlier systems. An added benefit is that all recording needs may be handled by a central recording and archival solution rather than several system specific solutions.

- **Video integration**

  Integrating surveillance video with audio and access control is a very powerful tool. Not only to improve the situational awareness, but also to communicate and direct the public directly from the control room. For emergency situations minutes or even seconds may be the fatal difference between a safe and successful evacuation and a tragic loss of lives. Being able to remotely assess the situation, and communicate, even before a rapid response team has arrived can potentially save lives.

- **Off-site monitoring**

  Through a suitably secure site-to-site connection, monitoring of less critical facilities can be done at a central surveillance facility. Either to relieve the crew on site or as backup should an unwanted situation occur.

- **Audio analysis**

  One particularly interesting technology that has emerged lately is the possibility for real-time automated audio analysis. An audio stream is fed to a computerized analysis suite that compares the audio one or more predefined audio profiles. Common profiles include: Gunshot (various types), breaking of glass, car alarms etc. The software may even trigger on human voice such as an infant crying or a scream of fear. It is even capable of distinguishing cheerful excitement from aggression. Coupled with video integration, this gives guards and surveillance crew a possibility to get images and audio from the situation as it is escalating.

- **Custom integration**

  Through standard and proprietary protocols and APIs some systems allow custom integration of the communication equipment. These custom interfaces may include computer based ("soft") building management- or control-room systems. The purpose is to unite the tools available to the operator on one unified and custom tailored interface to ease the workflow.

Financial benefits

- **Reuse of existing infrastructure**

  A structured cabling scheme is the most desirable and best suited for IP-based integration. Most modern facilities are wired with Category 5 or better cabling, meaning that much of the infrastructure is already present. Through Power-over-Ethernet (PoE) capable switches power distribution for IP-based units (up to 12.95 W per unit) is possible. Using networked audio amplifiers existing 100 V (or similar) public address systems may be integrated, reusing both existing cabling and speakers. Analogue telephone-systems (PABXes), radio systems (UHF/VHF/TETRA) may be integrated (with limited functionality) and reused or replaced with more modern solutions if desired.

- **Flexibility towards providers of systems and services**

  Ethernet or IP-based systems are already sharing a common distribution platform, but integrating dissimilar systems from a variety of manufacturers is not always possible. However, more and more providers of audio and video solutions are seeing the benefit in complying to open and public standards for integration towards other systems. This gives the user a great flexibility with regards to composing the offering that best suits the needs and budget of the project.

- **Automation**

  Increased automation reduces the need for man-hours, potentially saving considerable cost.

- **Future-proofing**

  As Ethernet is seeing widespread use, supplementing or replacing data buses commonly used today. CANBUS is seeing competition from Ethernet even in vehicles and PROFIBUS is turning towards PROFINET which is essentially an implementation of PROFIBUS over Ethernet infrastructure.

LIMITATIONS, VULNERABILITIES, WHAT TO CONSIDER WITH REGARDS TO THE IP-INFRASTRUCTURE

The main limitation for IP-based systems has traditionally been the dependence on Ethernet. Ethernet is inherently short-range (max 100 m between points recommended) and for several scenarios this will limit the useful application of these systems. There are solutions for overcoming this issue, such as Fibre-Channel, Wi-Fi-link, Ethernet extenders and DSL-modems, extending the useful range to several kilometres.

Another limitation of Ethernet is bandwidth. Most current Ethernet infrastructure is capable of a bandwidth of between 100 and 1000 Mbit/s. To avoid bandwidth intensive services “overloading” the infrastructure in an emergency situation, the IP backbone must be carefully dimensioned for the load it is likely to see. In addition actively using QoS to ensure a minimum bandwidth and a maximum latency for critical services should be considered.

Another concern regarding the use of Ethernet as a backbone is malicious intrusion, known as cyber-crime or “hacking” of systems. It ishighly recommendedto put core security and safety functions such as monitoring and automation, critical communication, surveillance and security on a LAN that is physically separate from non-critical services such as E-mail, WWW, VoIP etc. Both to address a possible lack of bandwidth, and to protect these services from intrusion by a malicious program.

Other security measures to be considered are:

- **VLAN**

  Virtual LANs is an effective way of placing more than one subnet on a single physical layer (Ethernet cable).

- **Firewalls**

  Firewalls should not only be considered as a last defence against the outside WAN. Proper implementation within the facility will let the various systems talk to each other while preventing an intruder access to these services even if he manages to get acces to the LAN at the facility.

- **VPN**

  Virtual private networks or “secure tunnels” are highly recommended if one intends to cross-link several sites over a WAN. Compared to Point-to-Point encryption, the VPN tunnel secures all communication between the nodes, making a MiTM-attack far more difficult.An added benefit is that dissimilar systems may use proprietary encryption which renders cross-system integration difficult or impossible.

THE FUTURE OF INTEGRATED COMMUNICATION

Looking forward, we expect to see even more solutions becoming available on the IP-backbone. With or without PoE power distribution.

Pure IP-based Public Address

Public address has traditionally been achieved using “zones” of 100V speaker loops. With a powered IP backbone each speaker could become a powered unit, uniquely addressable and independent of a central amplifier. Allocation of zones would be possible to do dynamically, as the use and needs of the facility changes. We foresee this decentralized form of PA to be introduced as a supplement to existing systems, mainly where the zones needed are too small to justify installation of a system based on a traditional 100V infrastructure. In time they might replace traditional PA all together.

Dynamic interfaces (touch screen)

Multi-functional control-surfaces are becoming increasingly widespread. Even in environments traditionally looked upon as being conservative or traditionalist. A prime example is the design of bridge environments for ships. Recently Ulstein yards, one of the world’s leading wharfs for high-tech vessels for offshore drilling operations released their concept *Ulstein Bridge Vision*[2]. This concept shows a drastic departure from the gauges, buttons, levers and switches traditionally associated with a ship’s bridge asit has moved all the functionality onto several unified information surfaces, including HUDs and LCD monitors. The user input is performed through a minimum of physical interfaces as well as touch surfaces capable of multi-touchand gestures[3,4]. The interface changes with the situation, providing the operator with the information relevant for the specific task at hand. The design is centred on the users needs, providing the information and functions when they are needed, emphasising important parameters while filtering out irrelevant information. This allows the operator to focus

Ulstein Bridge Vision concept

The Mobile control-room (tablet-like device).

Mobile networking has seen a huge increase since the introduction of the iPhone. With the emergence of the modern tablet (represented by Apple’s iPad), several manufacturers are bringing their offerings to market. A trending application is the use of a tablet as a mobile control-room for security personnel. Through the touch interface a supervisor can get an overview of the facility as or detailed information from an area or a service. He may easily access live video streams, perform PA announcements and set up conferences even while on the move. For wireless systems this requires a solid strategy with regards to network security.

User centreddesign and development.

The impact of the iPhone showed us the importance of user experience (UX) over the traditional feature-driven development. Users are expecting a more unified and tailored experience from their devices today than what

[2] http://www.ulstein.com/kunder/ulstein/mm.nsf/inpdocuments/D854ECEBEDA8C724C1257A6900471313/$file/ULSTEIN_BRIDGE_VISION_press_release_.pdf
[3] http://www.ulsteinlab.com/uploads/films_flv/UBV_The_Challenge_Caps.flv
[4] http://www.ulsteinlab.com/uploads/films_flv/ULSTEIN_BRIDGE_VISION.flv

they did 5 years ago. Since the introduction of the iPhone, solutions such as Android, Windows Phone 7/8 and Windows 8 have emerged in the wake of the UX revolution. The Ulstein Bridge Vision shows us that professional environments and applications are picking up on this trend as well.

Integration in total management systems.

With this evolution in mind we predict a move towards integrated total management systems. Whether it is a Video management system with audio and access-control capabilities, or an integrated security suite; providing the user with a common unified interface realizing the synergies of the separate systems is very much in-line with the UX-trend. This is, however, dependent on common standards for interoperability and that the manufacturers comply with these.

TOM-ANDRE TARLEBØ

Mr Tarlebø holds a Masters Degree (M.Sc) in Industrial Design Engineering from the Norwegian University of Science and Technology.Former Senior Product Designer for intercom devices, Mr Tarlebø is experienced with regards to the requirements and expectations of the industry as well as the trending technologies. His focus as a Product Manager by profession and Designer/ Engineer by education is the total user experience and the benefits to the users and operators as much as regulatory demands. Today he holds the position of Product Manager for StentofonIntercom at Zenitel Norway AS.

HARALD B. KJØLBERG

Mr Kjølberg holds a Masters Degree (M.Sc) in Electronic Engineering from the University Of Oslo, Norway. With experience as Hardware Designer, Head of Development and Product Manager, Mr. Kjølberg has extensive knowledge of integration between the systems involved in modern security and safety communication, both analogue and IP-based. For the last 2 years he has worked extensively towards IP-based PA systems and integration with older systems and infrastructure. Today he holds the position of Product Manager for Vingtor PA-solutions at Zenitel Norway AS.

ISA Delhi Section

Video Transmission over Ethernet For Industrial Security Applications

Tom Exley & Jaiprakash Vappala, ComNet Europe Ltd

ABSTRACT

Explore the of use of environmentally hardened fiber optic and copper-based transmission equipments for deployment in harsh out-of-plant operating environments utilized for the transmission of high quality video, audio, serial and Ethernet data, for CCTV surveillance, perimeter monitoring and data, for control in demanding mission-critical/extreme reliability applications, using a variety of network configurations and architectures.

KEY WORDS

Wavelength Division Multiplexing & Self-Healing Ring, Pass through PoE & Transient Protection

INTRODUCTION

The industrial automation and process control industry utilizes specialized communications and networking equipment designed to operate reliably in extremely difficult environments. Characterized by wide variations in operating temperature, high humidity, high levels of vibration and mechanical shock, voltage transient conditions, EMI/RFI, and exposure to airborne and particulate matter, these environments demand communications equipment that is specially designed for the task at hand, including highly robust design and construction, to ensure the network remains as reliable as possible. Equipments installed must be designed for deployment in harsh, out-of-plant environments, such as those encountered in petrochemical refineries, oil and gas pipelines, ITS/heavy and light railway/ transportation, mining, pulp and paper, discrete manufacturing (food & beverage production and processing, robotics, pharmaceutical production), and virtually all aspects of the industrial automation and process control.

The industrial security market has been witnessing the gradual transition to video, audio and data transmission over Ethernet. This change has impacted numerous other markets as well, including the transportation, factory automation/industrial control, and utility/ electric power transmission and distribution markets.

A key concern amongst petrochemical refining, distribution, and oil and natural gas exploration companies is the reliable and uninterrupted flow of product at all stages of the production process. Ethernet has been widely adopted as the networking technology of choice for nearly all SCADA (Supervisory Control and Data Acquisition) systems deployed in this market, for the control and monitoring of high-volume refining and pipeline/distribution applications.

Industrial Ethernet applications must mandate the requirement for security provisions to ensure that the network remains safe from any possible intrusion. The managed switches shall include SSH (Secure Shell), SSL (Secure Sockets Layer), to ensure the security of the network.

Wavelength-Division Multiplexing & Self Healing Ring

Prior to the introduction of video over IP (or Internet Protocol), a separate network of analog or digitally encoded video was typically utilized for hauling the video from the edge of the network back to the monitoring location. Audio for telephony or a communications intercom system; RS-232, RS-422, or RS-485 serial data, commonly used for CCTV camera pan-tilt-zoom (PTZ) control or the card access element of the system, was transmitted from the field devices back to the control center on other dedicated and parallel networks. The transmission media of choice was usually optical fiber for reasons of robustness and bandwidth.

Using a technique of wavelength-division multiplexing, sending signals of several different wavelengths of light into the fiber simultaneously, allowing multiplication in capacity in addition to making it possible to perform bidirectional communication.

A cost-effective system design to a challenging security-related application is a fiber optic drop-and-insert video and data transmission system designed for large-area perimeter surveillance and monitoring applications.

Shall be designed for use with the optical fiber typically configured as a true ring, the optical network shall also be configured in the easier-to-deploy linear add-drop topology and utilizes 10-bit digital encoding of baseband composite video for true broadcast quality video performance, and shall provide an easy to install platform for the video and control data to be inserted and extracted at multiple insert-and-drop (or monitoring) locations throughout the network.

Transmission distances of up to 48 km between nodes is available when the single-mode variant of this equipment is employed, making the self-healing ring system ideal for extremely wide area networks and related applications.

This technology would help in the judicious use of existing infrastructure of fiber in the plant by way of recycling and maximizing the use of fiber by using the same fiber for both Analog and IP video.

The optical technologies and system design approaches are still very viable solutions for hauling high-quality, full-motion video, audio, and data, and when optical fiber is employed as the communications media, extremely long transmission distances and electrically noisy environments are easily accommodated.

The difficulty of installing and maintaining two or more parallel and technically diverse networks, one for video, one for audio, and another for serial or other data, has motivated many users to consider the use of Ethernet as their preferred communications networking system. The relative ease of integration of the key components of the system onto a common platform has largely made Ethernet the networking solution of choice in the many markets, including the industrial security market.

With the advent of Ethernet, it now became practical and cost-effective to consolidate the video, audio, and data elements of a security communications subsystem onto a single network. Although in theory this should be the ideal platform for the typical local or wide area communications network utilized for industrial security and other surveillance applications, in practice several key and recurring issues are frequently encountered by the systems integrator and end-user responsible for the installation, maintenance, and operation of the system.

When analog video is to be deployed onto the network, a video encoder is required to convert the camera video output into an electrical signal that is compatible with transmission over an Ethernet-based network.

These encoders employ signal compression technology to reduce the bandwidth occupied by the video, so as to increase the number of potential video, audio, or data signals that may share the finite bandwidth available on the network.

Present video compression standards include MPEG-2, MPEG-4 and H.264, with MPEG-4 currently most widely used. The H.264 standard is newer and offers the advantage of enhanced video quality with the benefit of reduced bandwidth. MPEG-2 was originally developed for use by the commercial television broadcast industry, and although capable of superb video quality, its bandwidth requirements are large.

As such, it has not been widely accepted for use within those communications networks employing Ethernet. Regardless of the compression standard utilized, hardware decoders or decoding software compatible with the encoded video are required for viewing the video.

One major issue involves the relative lack of MPEG-4 or H.264 video encoders that are environmentally hardened when these devices are installed in an out-of-plant operating environment. In this kind of environment, issues such as ambient operating temperature, voltage transient protection, vibration, mechanical shock, and humidity with condensation must be considered to ensure that the video encoders or other field equipment are capable of providing long-term reliability and stable performance.

Hardware capable of withstanding the extended operating temperature range, humidity with condensation, and electrical voltage transients and noise encountered in an outdoor or out-of-plant environment are few and far between, and the equipment is costly as a result.

The MPEG-4 and H.264 video compression standards are suitable for transmission over Ethernet. As these standards rely upon video compression, the video in these standards is not transmitted in real time, and exhibits a certain amount of latency depending upon the compression standard utilized.

Some users may encounter potential legal issues with video transmission systems that are not real-time. Other users may have operator issues with the time lag or delay between executing a pan-tilt-zoom command, and the actual execution of the command as viewed on the CCTV monitor.

Full-motion 30 frames per second true broadcast-quality video with zero latency is not achievable considering the current state of Ethernet-based systems, and significant system bandwidth is required to achieve acceptable video quality.

The high system bandwidth requirement imposed by the video ultimately limits the total number of video channels and other signal sources that may be inserted onto the Ethernet platform. Many end-users have been disappointed with the video quality of their video-over-Ethernet system, especially when the video is viewed on highly revealing wall monitors. In addition, some video surveillance or monitoring applications mandate the use of high resolution cameras, and much of the resolution provided by these cameras may be lost when the video is compressed to MPEG-4 or H.264 and inserted onto the network. Although Ethernet is based upon the industry accepted IEEE 802.3 standard, and in theory any manufacturer's Ethernet equipment should be completely interoperable with any other manufacturer's equipment, in practice this is very frequently not the case.

Pass Through PoE

The pass through PoE eliminates the need for remote power to Powered device (PD), passing-through up to 30 watts of power per port to the powered device (PD). The IEEE 802.3-compliant Ethernet electrical interface of these Ethernet extenders also meets the requirements for IEEE 802.3af PoE power, passing through power to the PD.

It is an advanced and unique technology that extends Ethernet networks beyond the 100 meter limitation encountered when using COAX or UTP for IP Video and Ethernet-based applications. It is a cost-saving alternative that enables you to use existing COAX and UTP cables for significantly greater Ethernet transmission distances.

The system shall support 10 or 100Mbps Ethernet as well as Pass-through Power over Ethernet (PoE) over twisted pair cable (CAT5, UTP) or Coaxial cable. The device shall support transmission distances of up to 500m at 100 Mbps or 900m at 10 Mbps on twisted pair and 1500m on coaxial cable

PoE pass-through can be used to provide power redundancy for PoE IP cameras with previously installed power drops.

Protecting Copper Media transmission Equipment from the Effects of Lightning and Other Voltage Transient Events

With the advent of long-distance transmission of Ethernet data through copper media, such as CAT-5E/6E wiring, unshielded telephone-grade twisted pair (UTP), and coaxial cable, it has become necessary to consider the protection of the field and head-end equipment from voltage transient events, including lightning and other high-voltage conditions. Stray voltage conditions should be considered as well.

For the field or outdoor equipment, such as a CCTV camera, access control equipment, etc., the "45 degree cone of protection rule" should be rigorously observed. Ideally, the camera and housing should be located beneath an imaginary 45 degree angle drawn from the top of the supporting structure or building.

If it is not practical or possible to do this, a properly grounded lightning rod must be installed in the near-field of the camera, so as to attract lightning or other static discharges away from the equipment. Otherwise, the risk of a near or direct hit to the camera becomes significant, and no existing technology can protect delicate electronic equipment from a direct lightning hit.

As an example, unprotected parking-lot cameras installed on metallic support masts, or cameras mounted on metal-skinned buildings are particularly susceptible to lightning damage.

If the camera is mounted to a metallic structure, it becomes necessary to electrically and mechanically isolate the camera from the structure. This may be easily accomplished by the use of plastic or nylon screws, washers, and other non-metallic hardware, to effectively isolate the camera housing and its associated wiring away from the structure.

The camera and all related equipment must electrically float relative to ground on the structure. If there are grounding attachment points or connections (i.e. screws, nuts, etc.) on the camera, the camera housing, or any other equipment located in the field and related to the camera, they must be individually wired to the modem ground connection with a minimum of 12 gauge solid conductor (not stranded) wire, but do not connect any of this equipment to earth ground.

This single-point or star grounding practice is highly effective for protection against high voltage transients and low-voltage ground loops, and can eliminate troublesome video hum bars that otherwise may occur.

Standards

- RFC-2544 TCP/IP network bandwidth packet transmission standards
- IEEE 802.3af PoE,
- RFC: 768 UDP, 2068 HTTP, 793 TCP
- 791 IP, 1783 TFTP, 894 IP over Ethernet.
- NEMA TS-1/ TS-2 Environmentally hardened, to the requirements of for most out-of-plant applications

Reference: www.comnet.net

About **Tom Exley:** Holds a degree in Electrical and Electronics Engineering from Huddersfield University – UK. Tom has experience within the fiber industry for the last 15 years as field and technical sales and currently holds the position of senior technical sales manager at ComNet based at the EMEA/Asia HQ in Leeds UK.

About **Jaiprakash Vappala**: holds a Bachelors degree in Electrical & Electronics Engineering from Mangalore University. Gained work experience in Sales, selling Fire Alarm & Electronic Security products and solutions across India. Represented Group4, Tyco, CBC in over 18 Years of work experience as individual contributor, team member & leader, attended a one year executive programme on Strategic Management from IIM Kozhikode. Currently, responsible to develop the South Asia market, for a USA head quartered, Innovative manufacturer of fiber optic transmission and networking equipment, doing business as ComNet.

DEFENCE IN DEPTH: A MULTI LAYERED APPROACH TO CYBER SECURITY OF IACS (INDUSTRIAL AUTOMATION & CONTROL SYSTEMS)

R. Sarangapani
Additional General Manager
Project Engineering
(Control & Instrumentation)
NTPC Ltd
Engineering Office Complex,
Sec-24 Noida-201301

KEYWORDS

Industrial Automation & Controls (IACS), Intrusion Protection system(IPS), Stuxnet, Security Policies, DMZ, Security Audit.

ABSTRACT

Cyber security is becoming a very important concern for the whole community & the industry in particular. Until many years ago, the automation industry was keep out of the cyber threats loop, but with the connectivity of the automation systems to the business or enterprise network, these systems also have become vulnerable to cyber threats. To add to this, open architecture & commercial off the shelf(COTS) products in HMI have acted as catalysts to this changing scenario. The recent incidents comprising industrial control systems in various parts

of the world destroys the myth that there cannot be comprises in the core DCS controls.

This paper discusses the various methods & means of improving the cyber security status of any industrial installation with distributed control systems or programmable logic controllers (PLC)s. The main components of a IACS cyber security program are presented along with its importance in the overall security scenario. The standards related to cyber security are briefly touched and the areas addressed by these standards are described. In the end, issues of concern are raised along with suggestions to overcome these bottlenecks.

1.0 INTRODUCTION:

While technological changes have greatly changed the way of life, the power of information through cyber space perhaps is the greatest revolution in recent times & has greatly influenced our working. But as it has always been, this advantage has been misued & exploited by malicious actors creating the need for another specialized area of study termed as Çyber Security'.

2.0 CHANGES IN THE SCENARIO FOR DCS/PLC NETWORK:

When the distributed control systems replaced their previous generation of control systems (solid state or relay based systems or pneumatic control systems), these were dedicated for control of their respective processes. Real time Information was confined to the control room operators by & large & there was no interconnection between these DCS, nor there was a link to the desktop of the senior personnel of the plant for displaying on-the-fly real time information.

But the quest for real time information could not confine this in the control room for too long. Gradually, the heads of operation/

maintenance , the operation supervisors started to demand this information at their desktops & were provided the same, albeit through dedicated terminal of the DCS itself. This did not pose any vulnerability as the communication was wired & based on DCS proprietary protocols. Refer Figure 1.

Subsequently, three major changes took place. .i.e. Commercial off the shelf HMI products replaced the proprietary machines; commercial off the shelf operating systems entered the DCS HMI & the open communication protocols s were used both within DCS as well as in soft links to third party systems.

DCS systems becoming 'ópen', opened up a plethora of possibilities of software applications which needed real time information. These included plant performance optimization systems , management information systems, and asset monitoring systems. Hence, transfer of DCS data to third party systems became a standard norm.

Moreover, the reverse data transfer also started. i.e. the control room operator started getting real time information about various other related area of the plant. Eg, in a power plant, the offsite area information also started flowing into the main plant DCS vide a station wide Local Area Network (LAN) connecting various DCS and PLC's of the plant. Refer Figure 2.

Another area where technological advancements helped is remote support of the DCS for maintenance. No doubt, this is advantageous, but it posed a security challenge.

These scenario changes created a paradigm shift in the role of DCS for business support in various industries.