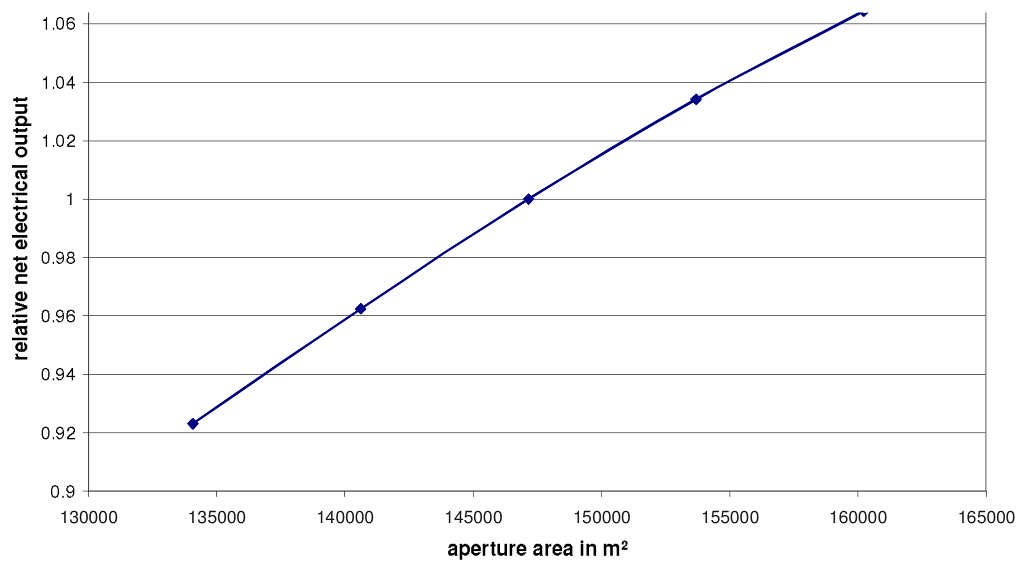
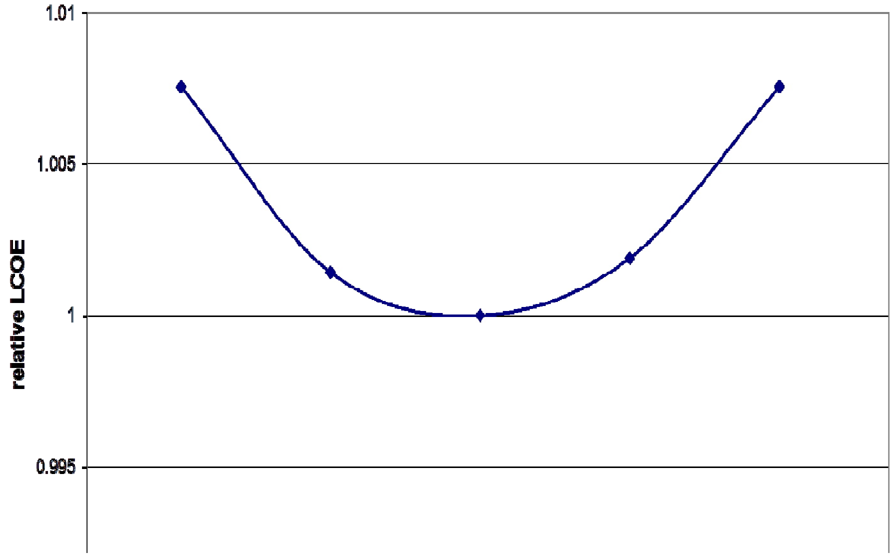


But this increased power comes at the cost of an increased Capex and an increased dumping of steam (since power block capacity is fixed). The reverse is also true. A decrease in the field size, decreases the Capex and Steam dumping but also increases the number of part load hours that in turn reduce the efficiency and hence the power output of the plant. The relation of field size and electric output is shown in the graph above.

As said earlier, the ultimate aim is to minimize the cost of production. So the next step is to calculate the Levelized Cost of Electricity (LCOE) by adding the financial parameters of the project to these technical parameters. Some of the simulators have an in-built financial modelling capability, while some others have an interface for an external financial modelling tool. In any case, the LCOE for the base solar field size is calculated. This base size is same as the approximate field size that was determined in the second step. The dependencies like the part load efficiency and others are nonlinear in nature and therefore for a fixed power block size, an LCOE-optimal solar field size exists. The approximate field size determined earlier may not be the best size for a minimum LCOE. Therefore a few values of solar field size (both smaller and larger than the base size) are considered and for each size, LCOE is calculated. The graph that is obtained is a bell shaped curve like the one shown below. The bottom most point here is the minimum LCOE and the solar field size corresponding to this point is taken as the optimum solar field size on which the plant is built.

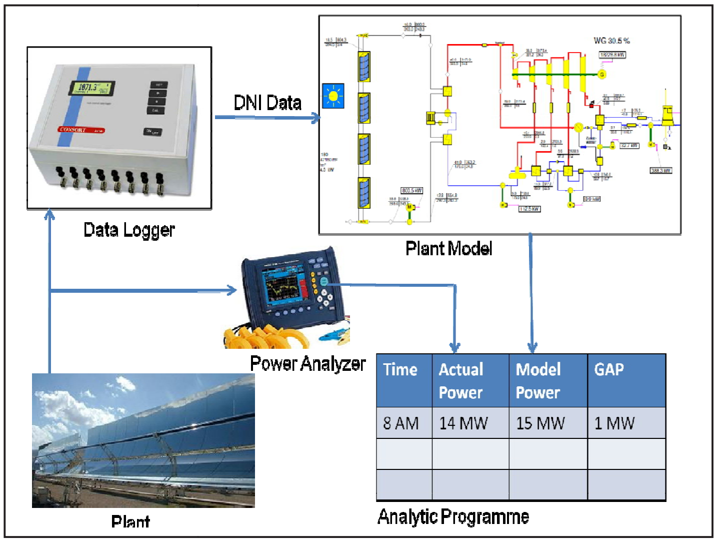


Calculation of field size and storage for minimum LCOE (MVIS)

When thermal storage is a part of the plant, the optimization of storage size also becomes an issue along with the optimization of solar field size. In order to consider the storage, Multi Variable Iterative Simulation is done. For this, first a value of storage is fixed say 3 hours and iteration for different solar field sizes leading to different LCOE are done. The storage size is then changed and the process is repeated. This is done for the entire range of storage sizes that are to be explored. Finally, the Storage hours and the field size is fixed based on the absolute minimum out of all the above results.

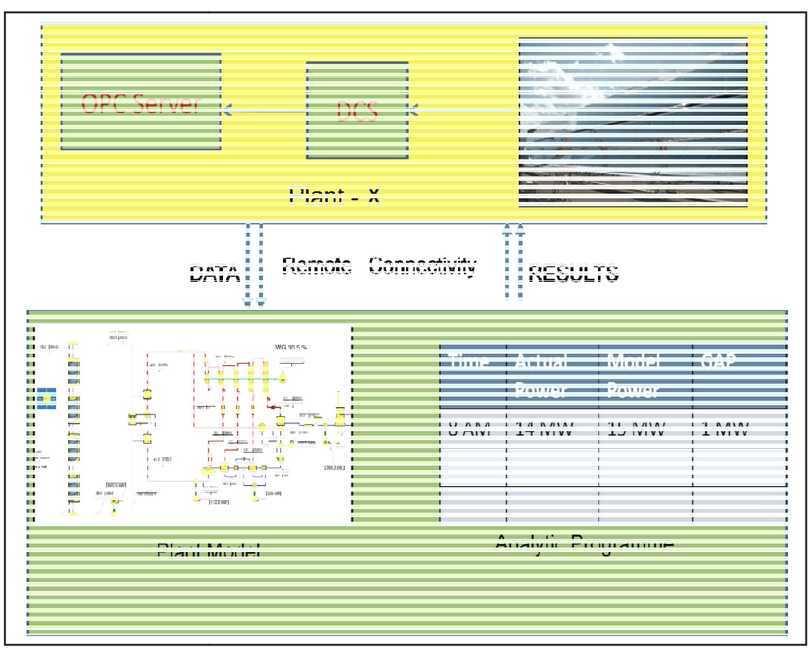
USE OF SIMULATIONS DURING PG TESTING AND REGULAR PERFORMANCE MONITORING OF A CSP PLANT

For CSP plants, performance guarantee testing is a more challenging task than conventional power plants because the fuel (DNI) is not controllable. Therefore one of the methods to check its performance is to compare the actual generation of the plant with the production of the simulated model wherein actual DNI data is used. Project developers, technology suppliers and the O&M contractors have the possibility of installing simulation tools at the site during the testing period. For doing the PG testing, a simulation model is continuously fed with the DNI and other relevant data online at the site. Based on this data, the model computes the power that the plant should generate. It then does a gap analysis between the expected power and the actual power that is being produced. A typical arrangement for such a PG test is shown in the block diagram below.



SIMULATION FOR DAILY PERFORMANCE MONITORING OF A SOLAR THERMAL PLANT

A similar arrangement as above can be used for regular performance monitoring of the plant also. The only difference is that in this case the simulator gets data from the control system of the plant rather than the special instruments used during the PG test as shown below.

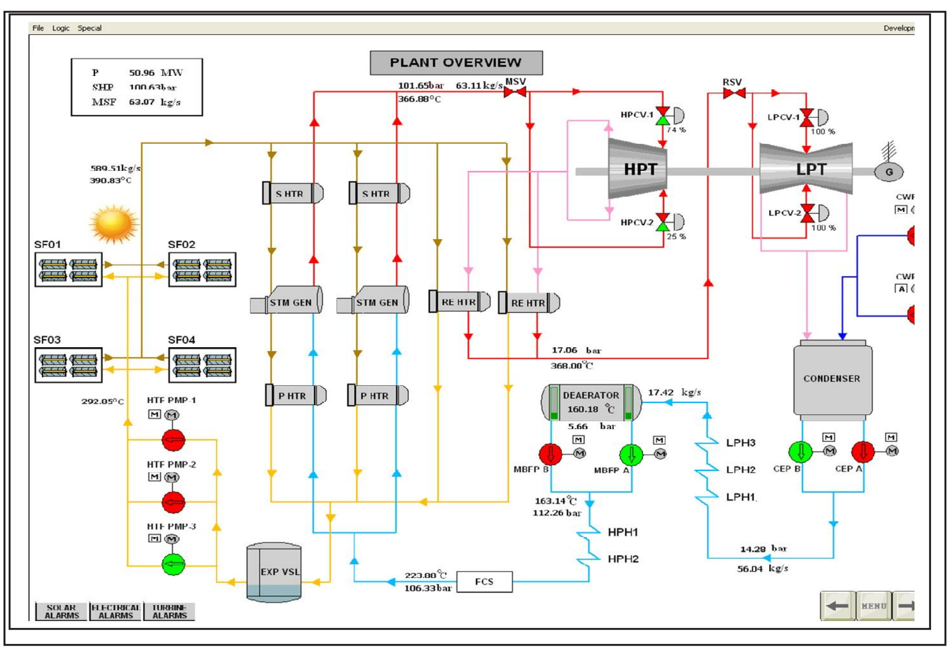


DYNAMIC SIMULATION OF A SOLAR THERMAL PLANT OPERATION

As said earlier, a dynamic simulator replicates the plant behaviour completely. Therefore it can act as a running plant for any type of study or any training to be conducted. So dynamic simulators find two important applications in solar thermal power plants, operator training and simulation studies for engineering analysis. Both of them are very relevant in India, given the nascent stage of CSP in India.

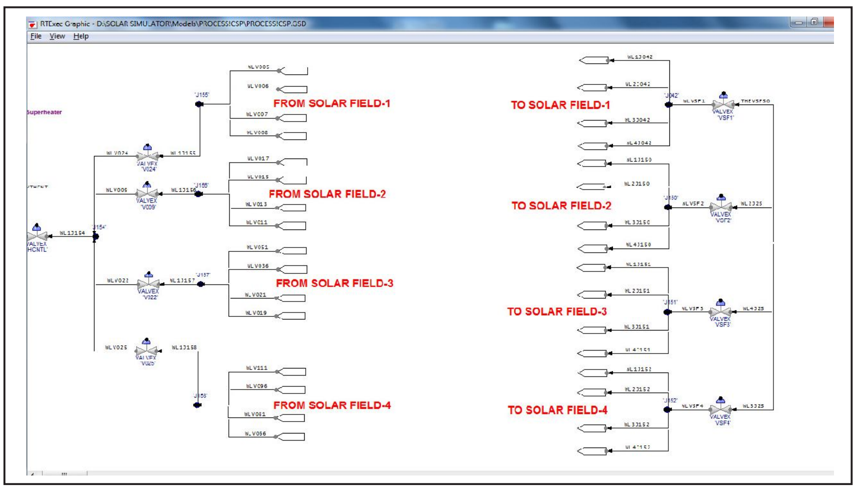
Dynamic simulation for training in CSP

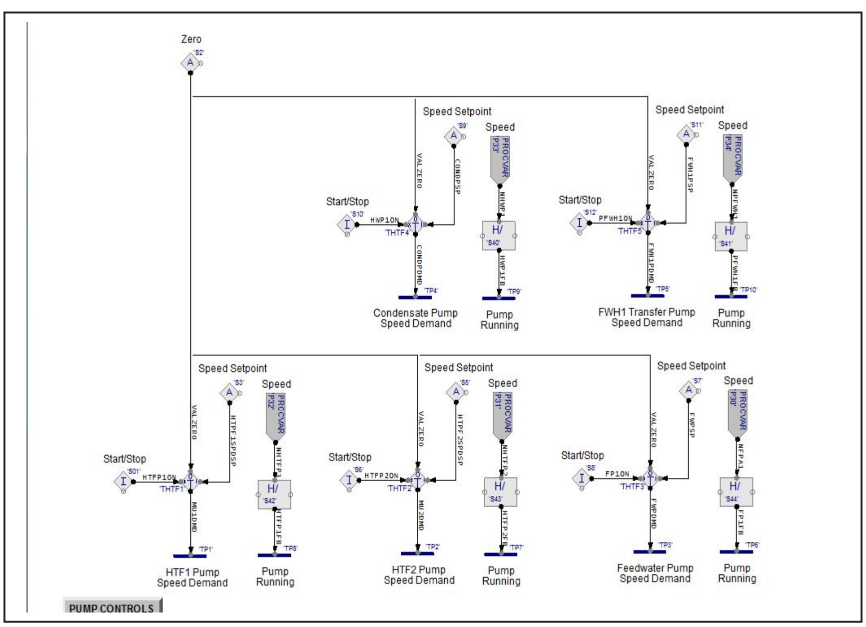
Just like other operator training simulators, a CSP plant simulator also consists of three distinct components. These are Process Model, Control Model and HMI. The process model as the name indicates models the plant equipment and the process. The simulation platforms available today have facilities to model all the components of the power block side. The solar side equipment modelling facilities might be under development. Steag has just added the equations for solar angle calculation, trough calculations and HTF circuit and has made a solar simulator using the toolkit from Trax Inc. The simulator is a generic simulator for a 50 MW parabolic trough plant. The plant that has been simulated is composed of 112 solar collector loops, divided into four solar fields of 28 loops each. Each loop has four collectors of 150m each. These loops can be operated in various modes viz solar tracking, complete defocus and specific position. The heating is based on a Heat Transfer Fluid that gets heated in the solar field and flows to a string of solar super heater, steam generator and a preheater. The heat from HTF is transferred to water steam cycle in these heat exchangers and the steam thus generated is sent to a turbine. The turbine has an HP and an LP stage with a single reheat. The figure below shows the overview of the generic plant that has been simulated.



Closed loop controls, interlocks and permissives etc. have been considered for all important equipment. Some important closed loop controls include heat transfer fluid outlet temperature, steam generator drum level, condenser hot well level and Turbine Electro hydraulic control system.

Complete plant startup and planned shutdown operations over a day can be performed. Several built in malfunctions and some custom malfunctions are programmed. Plant response during different conditions like cloudy, sunny day etc can also be observed. For observing plant behaviour under different DNI conditions, it is possible to use different DNI files. A couple of snapshots of the Steag generic simulator are given below:

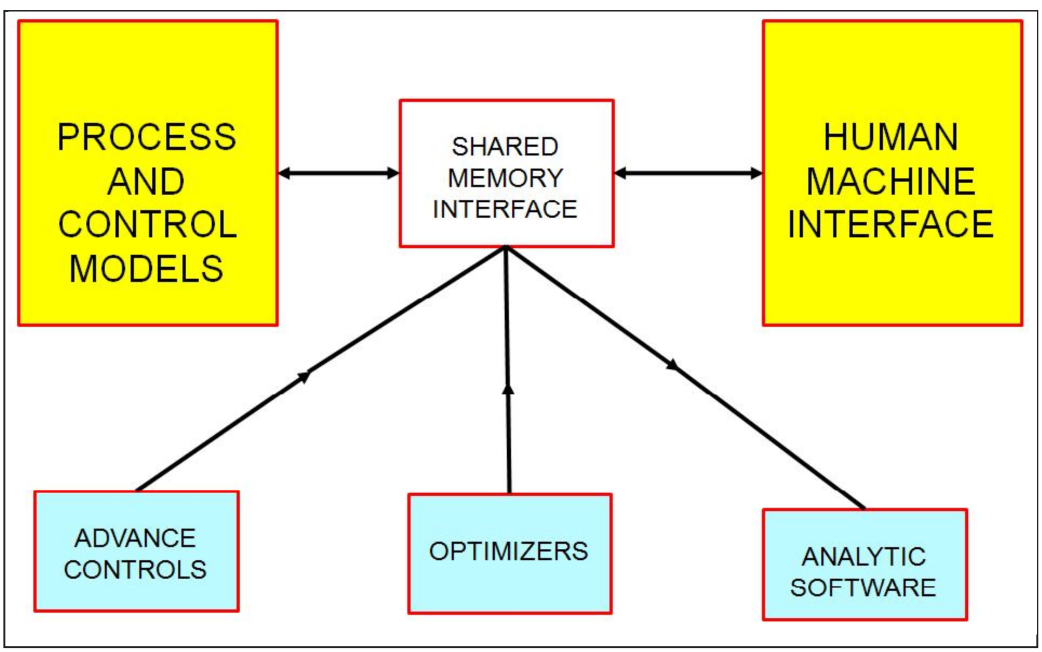




Dynamic simulation for Engineering studies in CSP

To be able to do engineering analysis by conducting simulation studies is a very important feature of a dynamic simulator. The simulators required for engineering analysis need to be more precise than the training simulators in terms of their fidelity to the plant. The simulator can be run under varying conditions e.g. different DNI patterns and variations of other parameters to establish the plant behaviour under specific conditions. As an example it is possible to study the start up time under various DNI conditions i.e. start up on a rainy day, start up on a clear day, start up during summers / winters etc. Another example is to study the effect of clouds on a running plant e.g. how long the plant can sustain (without tripping) when clouds of varying intensities interrupt the sunlight.

It is not only possible to study such effects but it is also possible to optimize the plant behaviour under these conditions. For example, the start up time can be optimized or the time for which the plant can sustain clouds could be maximized. Such optimization is possible if these conditions are simulated again and again and the plant is run with varying control strategies each time. The above is more useful if it is automatically done by an external software that is interfaced to the simulator. As shown in the figure below, it is possible to interface other software to a simulator by using a shared memory interface. This is not the only way, infact this is the way Steag has successfully interfaced other software to their own simulator. Other simulators may have different ways on interface. The purpose of this shared memory is to share data between the plant models and the HMI. Steag uses the same for interface of other software to the simulator. It is possible to interface advanced control software, optimizers and analytic softwares with simulators using this method.



Interface of Advanced controls and optimizers with simulators

Using the method as described above, it is possible to interface software such as optimizers and Advanced control software to do optimizations and related studies. With this interface, it is possible to write the setpoints generated by Advanced control software on the simulator fields and test the results.

With the application of a model predictive controller (MPC), it is possible to use the dynamic simulation model to predict the future behaviour with respect to changes in actuating variables. With this approach, it is also possible to do optimizations in order to Maximize produced energy, Minimize risk of shutdown during transients, Minimize time to start-up etc.

It is also possible to interface analytical softwares with simulator for analysis of important plant parameters. In this case the simulator is run under different conditions and the important process parameters flow to the analytic software and are stored in its database. These parameters are analysed either online or offline to make different types of analysis. One of the softwares that Steag has interface successfully with it's dynamic simulator is a software called Statistical process control which is also a product of Steag.

Short resume – **V.S.Sharma** (vs.sharma@steag.in : 9810007767)

V.S.Sharma has around Twenty Two years experience in industry during which he has been working in ***Solar Energy, Power industry and other Engineering Industries.*** He is a Mechanical engineer with M.Tech from Indian Institute of Technology Madras in India.

He is currently working as General Manager – Renewable Energy in Steag, where he is involved in modeling and dynamic simulations of Solar thermal systems. He lead a team that developed a 50 MW simulator for a Solar thermal plants. He has also been involved in various capacities in a number of solar projects that include work such as Feasibility studies, Detailed Project Reports, Technical due diligence studies, owners' engineering assignments and hybridization studies. He has provided training in Solar thermal simulation to a wide variety of participants. He has earlier worked in the field of process optimization software for various types of power plants.

Before joining Steag, he has been involved in conceptualization and development of Energy Benchmarking systems for cement industry in India.

Conference Title: POWAT 2013

Paper Title: Substation Automation System Essentials

Vaibhav Tare
L. Rajagopalan

Key words: Substation Automation, levels of SA – Process / Bay Station / Enterprise Level, IEC-61850, Intelligent Electronic Device, implementation challenges

INDUSTRY FOCUS AND SUBSTATION AUTOMATION

India's expanding infrastructure network calls for huge investments in deployment of SCADA systems in power distribution along with plans to SMART grid implementation on pilot basis. The "Substation Automation System (SAS)" forms the heart of SCADA systems to achieve the goals set by the electrical power transmission and distribution utilities for securing the real time, enterprise wide information, which will enable them to enhance reliability at the right time, better manage their assets and improved operations and maintenance.

Substation Automation System (SAS) provides valuable information, both operational and non-operational, to various user groups within the utility. This information is the *key* to improve reliability, gain operational efficiencies, enable predictive maintenance, life extensions and improved planning.

LEVELS OF SUBSTATION AUTOMATION SYSTEM (THE ARCHITECTURE)

The SAS architecture is based on the functionality requirements of the system (monitoring, protection and control). In general the SAS can be broken down into four levels.

Process Level (Level 0) is the lowest level that includes power system equipments such as CTs, PTs, circuit breakers, merging equipments etc.

Bay level (Level 1) is the intermediate level includes Intelligent Electronic Devices (IEDs), that perform the various protection, control and metering functions. The Bay Level also contains maintenance functions required for individual bays and is usually located closer to the switchgear.

Station Level (Level 2) is the next higher level that includes the IED integration and Substation Automation Applications. The station level provides an overview of the substation and is located in control room environment.

Enterprise level is the highest level (SCADA) where the desired information is extracted and presented to the intended users, who have applications to analyze this information. There are multiple data paths available to transfer the information from station level to the enterprise level.

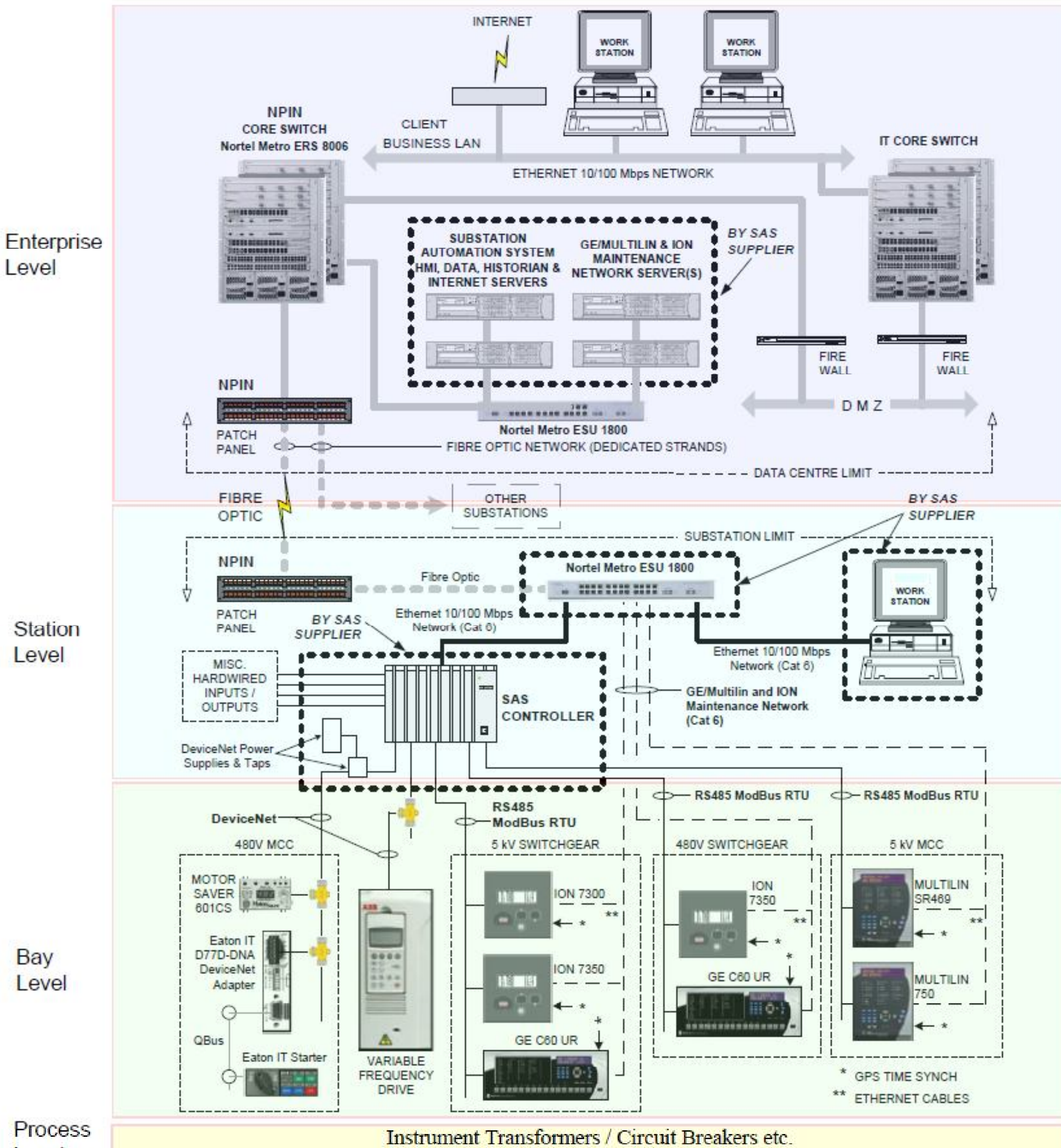


Figure -1

Substation Automation System architecture (typical)

ELEMENTS OF SUBSTATION AUTOMATION SYSTEM

The substation automation system comprises of many sub components, the major elements are described here briefly.

- *Intelligent Electronic Device (IED)* is any device incorporating one or more processors with the capability of receiving or sending data / control from or to an external source (for example, electronic multifunction meters, digital relays, controllers). IEDs are the key elements of substation automation. The capability of IEDs to integrate various functions (control, metering, protection and data acquisition) into a single device not only reduces the capital and operating costs, panel and room space but eliminates redundant devices also. Selection of an IED for a particular function normally depends on requirements like availability, performance, supported communication protocols, cost, state of the art of the technology and utility's philosophy.

- *SAS Controller* is normally a PLC or RTU based device which polls each of the IEDs for the analog values and status signals for monitoring of the substation. This SAS controller also has hardwired input / output for protecting and controlling the primary equipment and the grid. It also acts as a data concentrator for the overall utility SCADA (Supervisory Control and Data Acquisition) system. Apart from these application functions the SAS controller also manages the functions related to the SAS itself, for example managing the communication. A station computer also accompanies the SAS controller and acts as a server for control and monitoring of the substation.

- *User Interface HMI* provides the user with a view of all the essential activities to be performed in efficient and hierarchical displays. An intuitive design of HMI uses standard symbol library to represent substation power equipment on graphical displays. The use of standard library ensures effective use of the system and minimizes confusion. The HMI is deployed in a personal computer and acts as a client to the station computer.

- *Utility SCADA* is at the enterprise level of the substation automation system. The SCADA collects all the instantaneous analog values and status inputs like volts, amperes, KW, KVAR, circuit breaker open / close status, switch positions etc. via communication link from the SAS controller or the station computer. This data is time critical and is used for monitoring and control of the substation.

- *Utility Data Center* is also at the enterprise level of the substation automation system and collects all the non-operational data like event summaries, in addition to the SCADA data. The data center enables the client server architecture, where in the need to wait for access through a single line of communication is eliminated. It also provides the users with up to date information over the corporate WAN (Wide Area Network). Size of the data center depends on the number of users, type of data needed, nature of the application and frequency of the data update required for each user.

- *Communication* is the most important element of the substation automation system for successful integration of various parts of the electric utility enterprise. The communication system plays an important role in the real time mission critical operation of substation automation system. The key requirements of communication system include but are not limited to:

- ✓ High speed IED to IED communication
- ✓ Networkable throughout the enterprise
- ✓ High availability
- ✓ High reliability
- ✓ Standards based
- ✓ Multi vendor interoperability
- ✓ Support for file transfer
- ✓ Automatic detection and configuration (plug and play)
- ✓ Support for security

There are several factors to consider while choosing the right protocol for the substation automation system application. Consideration must be given to the part of the system for which the communication protocol is to be selected, for example whether the protocol is required for communication between SCADA master station to the SAS controller or the protocol is required for the communication between an IED to the SAS controller or it is the substation maintenance LAN.

It is also important to think about the future while selecting the communication protocol as various protocols are under different phases of technological development. It must be ensured that the manufacturer continuously support their products for the life time of the substation automation system.

Over the years many communication protocols have been developed for the various parts of the substation automation system, for example, DNP, UCA, MMS, Profinet, Device net, OPC-DA, Ethernet IP, Modbus RTU etc. However now a days many utilities are moving towards IEC-61850, which is a comprehensive standard for all communication functions in utility applications. It is a non proprietary standard with multi vendor interoperability. It realizes highly flexible configuration of communication networks and can greatly simplify substation automation architecture.

SUBSTATION AUTOMATION CHALLENGES

As the substation automation system comprises of many sub components, the integration of these components poses technical issues for design and implementation of Substation Automation System. Some of the technical issues are discussed here briefly

- Meeting the performance requirements (selecting the right IEDs):
  Performance requirements like response time, safety and reliability guide the allocation of logical nodes and their related functions to devices and strongly influence the architecture of the substation automation system. A compromise has to be made between the performance and cost of the device while selecting the IED.

- Selecting the right protocol and the network topology:
  As described earlier there are many constraints in selecting the right protocol for the various communication needs of the substation automation system, it is essential to give a thought on the various communication network topologies possible with the selected devices. Each network topology (bus, ring, star) has its own limitation and constraints.

- Technological advances:
  The timing of the installation plays an important role while designing the system as in some application areas the technology is changing so quickly that it is difficult to keep up on a continuous basis will all the technological advances in all the areas.

- Cyber Security:
  The substations are very important part of a country's infrastructure and must be protected from cyber attacks. Appropriate use of firewalls, DMZ, conduits, Defense in Depth security policies to counter denial of service and other attacks per recommendations of international standards such as ANSI/ISA 99 and IEC/ISA 62443 are essential.

CONCLUSION

With the use of substation automation system the utilities can achieve their goals of minimum down time and improved power quality. The implementation of automation system is costly; however the savings achieved in the operation and maintenance costs are far more than the initial installation costs. Although there are some challenges with the system, the industry is making all efforts to mitigate and overcome these challenges and provide cost effective solutions to the utilities and help them build the Smart Grid.

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New technology along with current Vibration Monitoring for Power Plant Rotary Machines

Mukesh Vyas
Forbes Marshall P Ltd Pune

Introduction - Vibration Monitoring in Power Plants

Vibration is a very key parameter for Critical Rotating machines such as Turbine, Generators and other secondary critical machines in Power Plant.

Machinery Vibration Monitoring in power plant is effective measuring tool in reducing overall operating costs. Monitoring Vibration levels over time allows the plant engineer to predict problems before serious damage occurs. When Rotating machine problems discovered early, the plant engineer will have schedule maintenance and reduce down time in a cost effective manner. We can do analysis of fault in early by using on line real time analysis & diagnostic software, which will tell specific cause and location of problem in machine. If we select right Vibration Monitoring system and software for Power plant rotary machines, over all down time will be reduce with proper planning in advance.

Today's scenario with global competition & pressure, every plant want to have 95% up time, hence maintenance planners are moving from Reactive Maintenance to Proactive maintenance.

Key Words :

Turbine Vibration Monitoring , Remote Vibration Monitoring , API670 , Winding Vibration Monitoring , Vibration Analysis & Diagnosis Software

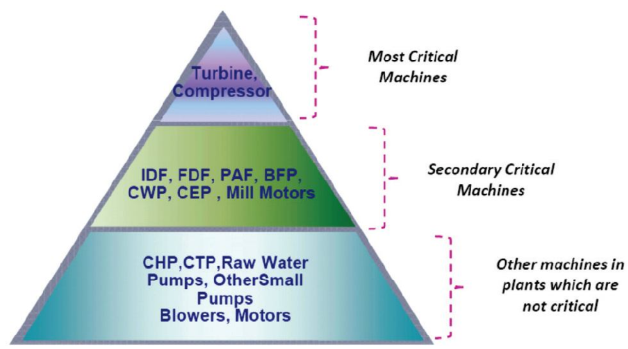
Trends of Vibration Monitoring in Power Plants

Vibration monitoring in power plants rotary machines are divided in following three categories based on cost of machines , safety and cost of damages and losses in plants in case these machines fails or have unplanned shut down:

1) Critical Machines : Turbine & Generators

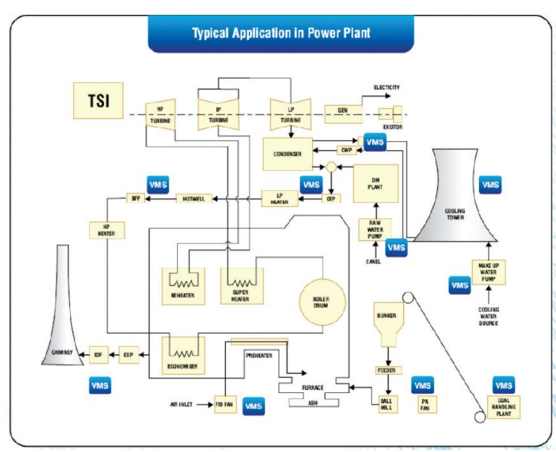
2) Secondary Critical Machines : Pumps – Boiler Feed Pump , Condensate Extraction Pump, Cooling Wanter Pump. Fans – Induced Draft Fan , Pulverized Air Fan, Forced Draft Fan & Mill Motors.

3) Balance of Plant Machines : Cooling Tower Fans , Coal Handling Crushers , Make up Water Pumps, Raw Water Pumps & Other compressors & pumps.



Typical Lay out of Power Plants and Rotary machines in the plants

Typical Lay out of Power Plant which Explains that where all we need Vibration Monitoring and How critical is each machine if there is shut down.



Current Monitoring System & New Technologies

A – Turbine & Generators :

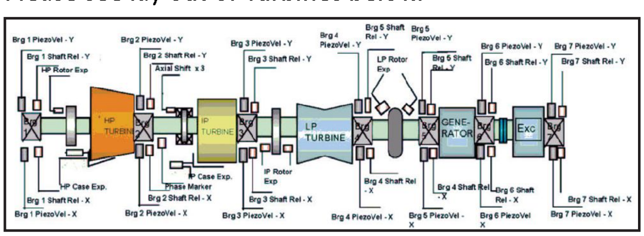
For On Line Vibration Monitoring of Turbine & Generator which is called Turbine Supervisory System (TSI / TSS), following parameters are measured:

1. Relative shaft vibration by installing two nos (X & Y - 45 Deg from Centre) non contact eddy current sensors at each bearings.
2. Bearing Vibration are measuring measurement done by using Contact Type Velocity sensors if required two nos per bearing (X & Y – 90 Deg C from Centre).
3. Absolute Shaft Vibration by taking inputs of shaft and casing vibration sensors.
4. Case Expansion
5. Differential Expansion
6. Axial shift
7. Phase Markers

Sensors used are Eddy Current Sensors as per API 670 , Piezo Velocity Sensors & LVDT Sensors are used. From Sensors field cable will be laid and connected to Monitors which are installed inside Control Panel in Control room.

Monitoring system is used as per API 670 with 19" Rack with redundant power supply, redundant communication , analysis output function , hot standby modules and other required features mentioned in API

Please see lay out of Turbines below.



New Technology in Turbine Supervisory System

1.Generator End Winding Vibration Monitoring:

Generator end-windings experience mechanical vibration during operation. The frequency of this vibration is twice the electrical synchronous frequency of the generator. High vibration can lead to loosening of entire end- winding support system, wear of insulation material, rupture of coil, and fatigue cracking of conductors, all of which require extensive out-of-service repairs.

A Fibre Optic Vibration System is used to measure the vibration of high voltage generator end-windings where conventional hardwired transducers cannot be safely mounted. Its is helpful to anticipate generator end-winding vibration problems, predict future maintenance needs, extend intervals between inspections, and minimize maintenance downtime.

A typical fibre optic accelerometer is shown in Fig. Its unibody design consist of a small size sensor head of non-conducting material, a fibre optic cable, and a feed through connector with built-in optoelectronic circuitry. It is sensitive to vibration in a single axis. The sensor head is located at the end of a two-strand, multimode, optical fibre glass cable. One fibre carries the light generated by the conditioning electronics for illumination; the sensor head returns an optical signal of variable intensity through the second fibre. The electrical isolation of the optical circuit allows the sensor to be mounted directly to the stator coil ends. Sensors

In the conditioning electronics, the optical signal is converted to an electrical signal by optoelectronic circuitry, processed and amplified to an acceptable level. The resultant measured signal is a calibrated analogue signal of 100 mV/g proportional to vibration acceleration which can be further processed by a Vibration Monitor. A specially designed software provides signal processing, display and data storage. In addition, vibration velocity and displacement are processed. After Fast Fourier Transform (FFT), the measured signals are displayed as amplitude-frequency spectrum.

2. Vibration Monitoring Unit with complete features and functions

Typical Vibration Monitoring rack is having following points :

1) Redundant Communication to DCS by giving two Modbus output from one module . This is now upgraded by giving two separate module giving two separate out put as a true redundant to DCS.

) Analysis function is done by single module in whole rack or more than twelve channel module in the rack, if this card fail then more channels are getting affected. Now latest generation monitoring system is having each four channel module is having optional built in analysis function and single key phasor input too for accommodating more machines hence if there is any issue in module only four channel get affected.

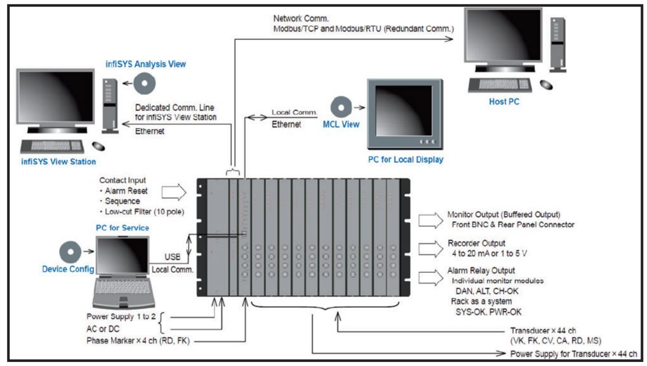
3) Current Monitoring system is having 02 buffer raw signal out put by which portable unit at BNC and rear buffer out put too will be available for further integration.

4) Current monitoring system is having universal monitoring module for Relative Shaft , Bearing Vibration , Axial Shift , Case Expansion , Diffential expansion and so on is done by single module by software. This will minimize the spare part inventory.

5) Current trend also seen that LCD Display are not required since digital interface is already connected to DCS.

6) API 670 Recommend to have trip signals from Vibration Monitor Racks and not via DCS which is not been followed in many ways and avoided some how. This is important points to bring critical and secondary critical machine trips via direct API 670 Monitoring .

Typical Example :



B. Secondary Critical Machines & C. Balance of Plant Machine :

For On line Monitoring Pump , Fans , Motors ,we use Contact type velocity or Accelerometer in X & Y Direction i.e. 90 Deg apart from each other to measure horizontal & vertical vibrations & phase marker sensors are used in case analysis is required.

From field JB the cable will be laid to Monitors which are located in control room.

Option 1 – API 670 Monitoring System

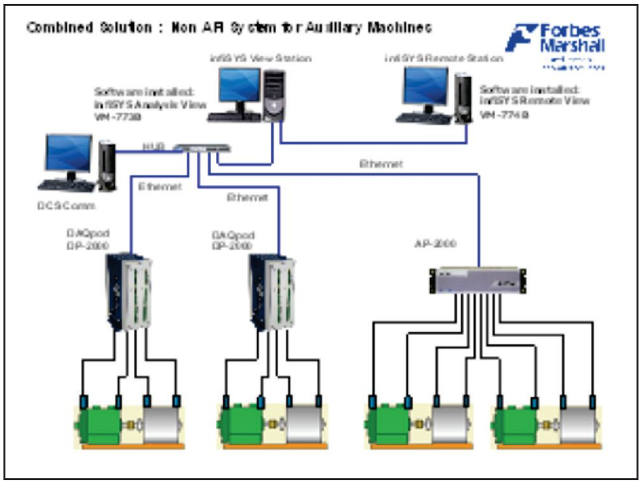
19 " Rack based monitoring system similar to main turbine and generator. All functions are as per API 670 designed standards.

Option 2 - New Technology Non API 670 Monitoring System

Since Non critical or Secondary Critical machines are having Roller Bearings which is having pattern of failures and not sudden damages unless there is an accident. In this case Operator or maintenance team have time and no need to shut down machine instantly.

Based on above assumption relay output and 4-20mA not required. If monitoring system have Modbus output to DCS and Analysis output port to Analysis & Diagnosis Software will be much simpler and advanced. Analysis & Diagnosis software will communicate with DCS on both ways by using OPC Client functions. This will remove many things in monitoring hardware and optimize the whole system. Of course this system will be 19" Rack system with Redundant Power supply.

Typical Lay Out :



Option 3 : Field Mount Transmitter giving Modbus & 4-20 mA output : Cost Effetive Solution for Machine Protection & Monitoring.

This is very simple solution to have on line Vibration Transmitter near to the machine which will give :

1) Local Display with 2 Channel input.
2) BNC Buffer output.
3) Two Relay output per channel
4) Isolated 4-20 mA output
5) Modbus output
6) IP 65 compliance
7) Wireless output optional

C. Analysis & Diagnostics of Power Plant Machines.

Analysis & Diagnostic system will take the sensor signals and give FFT wave form along with all other waveform and also predict why the machine vibration is high with probable cause to take quick action.

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

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

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

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

D. Remote Vibration Monitoring for Expert help to multiple plants :

In India there are very large power plant producers are having multiple plants and operating at multiple locations in India. There are limited Vibration and machine experts are available in any company and it is therefore important that they guide this plants by remotely to avoid shutdown. In this case it is possible to see machine vibration analysis remotely any where globally by machine OEMs and Vibration experts to guide the plant remotely to avod major damages before it goes out of hand. Refer above details on Remote Vibration Monitoring with Remote View software.

Conclusion :

1. It is important in power plant to decide right philosophy based on importance of machines with right size & right cost solution.
2. Traditional systems are very important and it is

necessary for critical machines.

3. For Secondary critical machines globally plant users are migrating to simple system with analysis & diagnosis package .

4. New Technology such and gen end winding , BOP Monitoring and Remote Monitoring will be very-very useful in coming days to adopt.

Biographic:

Mukesh Vyas is born at Banswara, Rajasthan and completed Diploma in Engineering , Degree in Engineering, MBA from NMIMS and other management qualification. At present he is working as a Business Unit Head for India at Forbes Marshall P Ltd Pune for Shinkawa Vibration Monitoring system . The total experience he carries is 21 years and presented multiple papaers at ISA and other bodies and received awards from Forbes Marshall management and Shinkawa Japan for excellent contribution in VMS Product range for Indian Market.

Nuclear Power Plant

DESIGN OF AN ELECTROMAGNETICALLY SHIELDED ELECTRONICS CABINET FOR INDIAN NPPs

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ABSTRACT

This paper discusses about the causes of electromagnetic interference, its effects, and remedies. As a case study the design of electronics cabinet used for housing the electronics in the electromagnetic environment of Indian Nuclear Power Plants (NPPs) is also discussed.

KEYWORDS

Electronic Cabinet, Electromagnetic Interference, Radio Frequency Interference, Electromagnetic Compatibility, Shielding Effectiveness,

ENVIRONMENT IN NUCLEAR POWER PLANTS IN INDIA

In a nuclear power plant, instruments are subjected to varying operating environment due to effect of temperature, pressure, humidity, electromagnetic interference (EMI), vibration, radiation etc. All these factors affect the operation of instruments and instruments must be designed to withstand these conditions. In this paper we are going to discuss the Electro-magnetic Compatibility (EMC) aspect of the C&I Design in Nuclear Power Plants.

ELECTROMAGNETIC INTERFERENCE

All electronics emit magnetic and electrical energy, if this energy unintentionally interacts with another device and causes it to malfunction, then it is considered interference. Most EMI is caused by frequencies that fall between 1 kilohertz and 10 gigahertz. Common sources of interference in a plant include motors, appliances, mobile phones, radar transmitters, static electricity, and lightning. Integrated circuits are also source of EMI, they couple their energy to larger objects such as heat sinks, PCBs and cables to radiate.

Devices that are vulnerable to interference, such as computers, microprocessors, electronic devices, measuring instruments etc. must be shielded to protect them from the effects of EMI.

EMC DESIGN FUNDAMENTALS

The fundamentals of design for EMC complied systems are quite different from those used for individual EMC complied equipment.

In a system, the RF environments plays a major role, and control techniques such as grounding, bonding, shielding, filtering, and cable/wiring design are used for carrying out successful EMC design.

GROUNDING

Equipment grounding depends upon the operating frequencies involved. Single-point grounding (SPG) is used for all low-frequency circuits. This is primarily done to prevent low-frequency common impedance coupling (ground loops).

Multi-point Grounding (MPG) is used for high-frequency circuits. This reduces common impedance coupling and prevents the equipment and subsystem boxes and cable shields from acting like antennas. Sometimes it's necessary to use a hybrid of SPG and MPGs.

BONDING

Good electrical bonding is used to create an equipotent plane, which minimizes potential differences between various equipment and subsystems.

Bonding of faying surfaces is done via bare metal-to-metal contact of similar materials fastened by, welding/ soldering, riveting, or bolting. All anodic film, grease, paint, lacquer, or other high-resistance coatings are removed from the faying surfaces. Scrapers, abrasives, or chemical cleaning methods are used to get to a clean, smooth bonding surface.

SHIELDING

Shielding is used to reduce unwanted signals internal or external to the shield.

The magnetic fields are predominant at frequencies below approximately 150 KHz; hence maximum shielding effectiveness is determined by the material and its thickness. For static or slowly varying magnetic fields below 100 kHz, the Faraday shielding is ineffective. Shields made of high magnetic permeability metal alloys can be used, such as sheets of Permalloy and Mu-Metal, or with nanocrystalline grain structure ferromagnetic metal coatings. The best shape for magnetic shields is thus a closed container surrounding the shielded volume.

Above 150 kHz where the electric and plane wave fields are predominant, any conductive material can provide greater than 150 dB attenuation, and thickness is not that important.

Shielding works by reflecting and absorbing incident RF energy. As such, the location of the RF source also affects the shielding. If the RF source is external to the shield, then the RF energy reflected from the enclosure adds to the shielding effectiveness. If the RF source is internal to the shield, the reflected energy is always inside the enclosure and does not add fully to the overall shielding effectiveness.

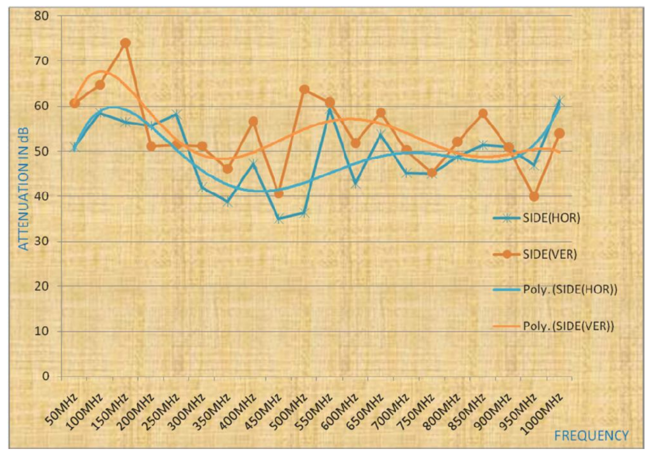
EMI ATTENUATION

Attenuation is one of the principal indicators for measuring the effectiveness of EMI shielding. It refers to the difference between an electromagnetic signal's intensity before and after shielding. Attenuation is marked in decibels (dB) that correspond to the ratio between field strength with and without the presence of a protective medium. The decrease in a signal's intensity, or amplitude, is usually exponential with distance, while the decibel range falls along a logarithmic scale. In practical systems a certain amount of shielding is required to minimise emissions and immunity problems.

- SE of the order of 20dB is the minimum worthwhile value
- SE of 50 to 60 dB is a typical average to cope with most problems
- For some test equipment and transmitters a SE of the order of 100dB may be necessary
- SE in excess of 120dB is very difficult to get in practice (state of the art)

SHIELDING REPRESENTATION

To explain the above in the shield attenuation diagram, the weakening of the fields by the housing is plotted against the frequency on a logarithmic scale.



Graph-I – Shielding Representation

- 20 dB shield attenuation corresponds to a weakening by the factor 10
- 40 dB shield attenuation corresponds to a weakening by the factor 100
- 60 dB shield attenuation corresponds to a weakening by the factor 1000 and so on.

FILTERING

System design combined with grounding, bonding, and shielding typically reduces the need for filters. But it may not eliminate them, especially if the problem is from RF energy being conducted on the systems interconnect wiring and cable.

A filter's advantage is its capability to attenuate a specific range of frequencies. These attenuate the higher frequency RF noise produced by circuits that create the system's intentional signals.

CABLE/WIRING DESIGN

EMI related to cable/wiring such as radiation coupling problems, crosstalk, and ground loops can be reduced by a systems-coordinated design effort.

a) Wires and cables are kept as short as possible and outgoing and return leads are always paired.

b) Reducing the coupling area also decreases inductive and capacitive crosstalk within the cable.

c) Segregate/isolate wiring based on signal-level classification

d) Segregation can be implemented within the cable by using multiple Shielded Twisted Pair (STP).

e) Use of shielded cable for problem circuits.

All above factors are considered while designing the C&I systems of the NPPs.

Large numbers of electronic cabinets are used to house the electronics devices, cards and modules in the NPPs. The development of electromagnetically shielded electronic cabinet is explained below as a case study.

ELECTRONIC CABINET FOR NPP

Fig-1 New cabinet design

Electronic Cabinets of 600 mm x 800 mm x 2200 mm (W x D x H) are used for housing Electronics Systems in Indian NPPs. Based on operating plant experience some malfunctions were observed in the plant which were attributable to EMI. Further in new 700 MWe plants with the introduction of new electronic module design it was felt prudent to redesign the electronic cabinets to take care of EMC aspects.

SPECIAL REQUIREMENTS OF CABINETS OF NPP

The Electronic Cabinets houses Computer Based Systems (CBS) characterized by high frequency, high density and low voltage electronic circuits. These circuits are prone to EMI due to adjacent sources of electrical noise equipment such as portable trans-receivers, Switched Mode Power Supplies (SMPS) etc. Also events such as inductive load switching, electrical faults, lightning surges, and static discharges produce high electrical noise. The electrical noise couples with sensitive equipment can cause malfunction.

Main requirement in new design of cabinets was to provide Shielding Effectiveness (SE) in various ranges as given below:

a) Size of cabinet- 800mm(W) x 900mm (D) x 2200mm (H)

b) Provision of cooling and lighting in cabinets – Two numbers of louvers are provided at the bottom of the front door for the entry of the cold air, and two numbers of exhaust fans are provided at the top of the cabinet for the exhaust of the hot air.

c) Cable entry from bottom- the bottom floor of the Control building is a cable gallery and hence the cable entry into the panel is from the bottom.

d) Cabinet shall provide Shielding from inside to outside (RE) and outside to inside (RS)

e) The front door of the cabinet shall be provided with see through glass for the viewing of the electronic module status, without opening of the door.

f) In the frequency ranges of 10 KHz to 100 MHz, 100MHz to 1GHz and 1GHz to 3GHz SE of cabinet shall be 60 dB, 50dB, and 35dB respectively

g) Applicable standard for testing of the SE of the cabinet is IEC-61587-3

BASIS FOR FREQUENCY RANGE

FREQUENCY RANGE 10 KHz-30 MHz

Based on EMI survey carried out by us at NPCIL's operating plants fields are also observed in the frequency range of 10 KHz to 30 MHz. Standard cabinet manufacturers in the market does not consider 10 KHz to 30 MHz frequency range for EMI/EMC protection since they are qualifying as per IEC-61587-3.Hence special care for attenuating this frequency range is required.

FREQUENCY RANGE 30 MHz-3GHz

New set of hardware modules designed by NPCIL has clock frequencies above 30 MHz range. Generally modules radiate / are susceptible at fundamental clock frequencies and their harmonics (+/-5%).

The Intentional transmission from Communication Devices: Walkie-Talkie, Bluetooth devices, etc is considered. Also 2G/3G/4G GSM mobile services in India operates between 900 to 2300MHz.

EMC Cabinets are used to provide shielding against radiations from inside (i.e. RE) as well as outside (i.e. RS). RE frequency range is from 30 MHz to 1000 MHz and RS frequency range is from 80 MHz to 3 GHz. Hence testing of EMC cabinets from 30 MHz to 3 GHz is essential to provide protection against both RE and RS.

Considering the above, frequency range of 30 MHz to 3GHz is selected.

BASIS FOR SE LIMITS

SE is the ability of an EM shield to reduce or attenuate external electromagnetic fields and external surface currents before they reach the interior of the shield and vice-versa.

Based on performance level-3 of IEC-61587-3 average Shielding Effectiveness (SE) is defined. After suitable modification of this requirement empty cabinet are tested and qualified as per Table given below:

Electric Field Attenuation Levels

Performance Level	Average Shielding Performance		
	Frequency Range		
	30MHz to 230MHz	230MHz to 1GHz	1GHz to 3GHz
3	60 dB	50 dB	35 dB

The range from 10 KHz to 30 MHz is neglected from EMC qualification point of view; however the readings are obtained for this range also. Based on these readings appropriate actions for qualification of cabinets is taken.

BASIS FOR SELECTING STANDARD FOR SE TESTING

IEC-61000-5-7, IEC-61587-3 and IEEE – 299 standards were studied w.r.t. the applicability to electromagnetically shielded cabinets.

a) IEC-61000-5-7 is applicable for enclosures of all dimensions, whereas IEC-61587-3 is applicable only for cabinet sizes up- to 900mm (D) x 1200mm (W) x 2200mm (H).

b) IEC-61000-5-7 covers the requirements for immunity to various types of electromagnetic disturbances, including lightning and high-altitude electromagnetic pulse (HEMP).

c) IEC-61000-5-7 covers the total frequency spectrum from 10 KHz to 40 GHz, whereas IEC-61587-3 covers frequency range from 30 MHz to 2GHz.

d) As per IEC-61000-5-7 readings shall be taken minimum @ every 1 % of the frequency, which is practically difficult (requires very large time) if the readings are to be taken manually. As per IEC-61587-3 frequency sweeps shall be in increments of not > 5 MHz.

e) IEC-61587-3 gives guidance for selecting the attenuation values in the various frequency ranges.

f) As per these standards, an enclosure will exhibit a higher SE after installation of components and modules than does the empty enclosure. Also an enclosure will exhibit a low SE after installing additional penetrations.

g) IEEE – 299 IEEE Standard Method for Measuring the Effectiveness of Electromagnetic Shielding Enclosures- The standard is applicable for Frequencies from 9 KHz to 18 GHz (Extendable down to 50 Hz and Up to 100 GHz). This standard applies to any enclosure having a smallest linear dimension =< 2 m. This standard is not applicable for NPCIL cabinet.

h) IEEE - P299.1 - IEEE Draft Standard Method for Measuring the Shielding Effectiveness of Enclosures and Boxes having all dimensions between 0.1 m and 2 m. This standard is in draft stage and not available to public hence not used.

IEC-61587-3-2006 is the latest available standard for shielding effectiveness for the cabinet and is used for testing of new design.

CABINET DESIGN FEATURES

In order to meet above requirement Cabinets were designed with following features:

a) **HIGH SHIELDING EFFECT-** A practically unbroken electro-conductive connection is achieved between the outer surfaces of the housing by fitting a conductive seal. The inner surfaces and the seal edges are kept unpainted. Corrosion protection is provided by the zinc plating.

b) **THE QUALITY OF HOUSING-** The integrity of the shielding is taken into account where cut-outs are made for inspection windows or climate control components (shielded panes, wire mesh, honeycomb cells).

c) Unpainted metal to metal contacts will be made along with conductive gaskets

d) Provision of conductive gaskets in doors and side covers

d) Minimum openings in enclosure

e) If a metal enclosure cannot be used, use of materials with good EMI attenuation e.g. plastic with conductive coating.

f) Wherever openings is required in the enclosure e.g. for door devices, louvers, locks, cables, etc. maximum diagonal or diameter of all opening is within 1/20th of wavelength of maximum frequency signal present inside cabinets. However, wherever openings bigger than this are required they are covered with a metal frame surrounding the aperture and earthed to the enclosure or a mesh with multiple holes.

g) Larger viewing openings provided with covered conductive see-thru glass.

h) EMC fan-and-filter units used. Honeycomb filters used for fan and louver opening shielding.

i) RFI suppressed LED illumination provided for the panel illumination

k) Shields in shielded control cables appropriately insulated before glanding.

VIEW OF CABINET

(External fields) **(Emitted fields)**

Fig-2 Shielding against interference fields

CHALLENGES FACED

1) Placing of see-thru glass of big size on the front door and to qualify the design for seismic & SE was a huge challenge. Prefabricated see-thru glass with conductive mesh in it was not available in such a big size. Special fabrication with sandwiching the conductive mesh in-between the two sheets of polycarbonate was done to achieve the desired result.

2) To cover the louvers and exhaust fan openings for EMC without affecting the ventilation inside the cabinet. Honeycomb filters with gaskets are used to take care of this factor.

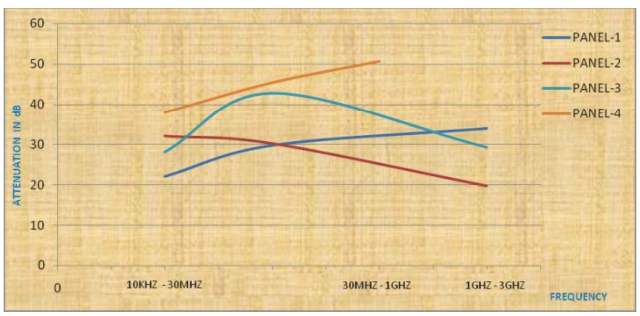
3) Ensuring the metal to metal contacts at the door openings. Four to five hinges, conductive gaskets, three/four point door locking arrangements were used to take care of this aspect.

4) Painting of the outer side of cabinet keeping the inside and all the overlapping edges unpainted.

INITIAL CABINET SE TESTING

NPCIL tested/studied 4 different EMC cabinets of known cabinet manufacturers. These cabinets are designed as per the NPCIL specification and design requirements. Salient features of these designs are:

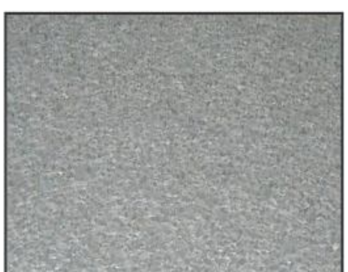
1. Panel-1- Double door on front, Zinc plated, no honeycomb
2. Panel-2- Double door on front with slotted see-thru glass, Zinc Plated, no honeycomb
3. Panel-3- 800mm x 900mm, zinc plated, with honeycomb, single front door
4. Panel-4- 800mm x 800mm, zinc plated, no see thru, no openings.



Graph-II – Initial cabinets test results

Panel-4 with no see-thru door, no openings and zinc plated gives the better results; it is the standard product of one of the manufacturer which is not designed as per NPCIL requirements.

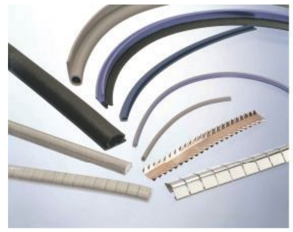
IMPROVEMENTS DONE AFTER INITIAL SE TESTING



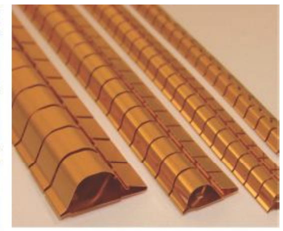
Aluzinc (AlZn) sheet

a. The cabinet is fabricated out of Aluzinc (AlZn) sheet to get the best possible conduction of the electromagnetic fields.

b. Providing the EMC gasket of good quality as well as the improving the workmanship to ensure throughout metal to metal contact.



Conductive Gaskets



Conductive fingers

Conductive mesh

c. Providing conductive mesh of appropriate density in the see-through window on front door.

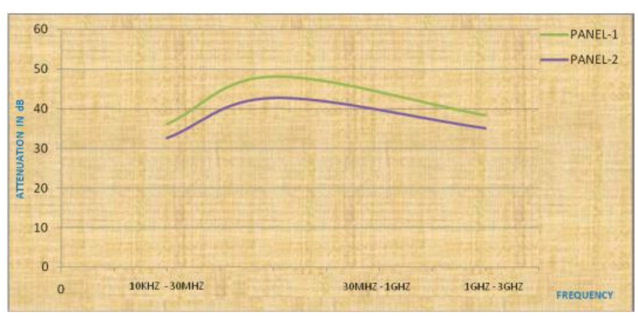
Conductive mesh

d. Providing the Honeycomb filter of appropriate thickness at louvers and exhaust fan openings.

TESTING AFTER IMPROVEMENTS

After the above improvements further testing was done.

1. Panel-1-1200mm x 1200mm x 2200mm, Aluzinc sheet, with honeycomb, double front door
2. Panel-2- 800mm x 900mm x 2200mm, Aluzinc sheet, with honeycomb, single front door



Graph-III – SE testing of the improved design

With the use of Aluzinc Sheet and honeycomb filters at all the openings, the SE improved. The study of the design is going on to see the scope of further improvements. These results are closer to the NPCIL requirements.

CONCLUSION

Above design of Cabinet is provided with 20mm honeycomb filters at all the openings, fabrication with aluzinc sheet, conductive mesh on the front see-thru door, ensured metal-to metal contact, conductive gaskets along all the openings and overlapping.

With this design a reasonable SE of has been achieved. Further improvement is in progress to achieve the desired SE.

ACRONYMS

EMC	Electro-Magnetic Compatibility
EMI	Electro- Magnetic Interference
NPP	Nuclear Power Plant
RE	Radiated Emission
RS	Radiated Susceptibility
SE	Shielding Effectiveness

ACKNOWLEDGMENTS

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BIOGRAPHIES

Sh. Virendrakumar Wankhede was born in Jalgaon, Maharashtra, India, in the year 1975. He graduated in Electronics Engineering and post graduated in HR and production management from the North Maharashtra Univ., Jalgaon. He has worked as Control Room Engineer for 5 years at various thermal power stations of Maharashtra State Electricity Board. Since June 2002, he is working as a Control Centre Designer with Nuclear Power Corporation of India limited. He has been given “Group achievement award for the year 2010” by NPCIL.

Sh. Neeraj Agrawal was born in Nainital, India in the year 1963. He graduated in Electrical engineering from Delhi College of Engineering in the year 1984. He joined Department of Atomic energy, in 1984 and obtained training in BARC Training school in Instrumentation. At present he is working as “Chief Engineer” in Nuclear Power Corporation of India Ltd. He is associated with design, engineering and procurement of I&C systems of Indian PHWR plants and imported Light water reactors. He was conferred with “Homi Bhabha Award” by BARC, “Special contribution award for the year 2006” and “Group achievement award for the year 2007" by NPCIL.

Sh. Anand Behre was born in Gwalior, India, in the year 1954. He graduated in Electrical engineering from Jabalpur Engineering College. He joined Department of Atomic Energy, in 1978. At present he is working as Associate Director, Control & Instrumentation in Nuclear Power Corporation of India Ltd. He is associated with design, engineering and procurement of C& I for Indian PHWRs

ENVIORNMENTAL QUALIFICATION OF INSTRUMENTS FOR USE IN NUCLEAR POWER PLANT

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ABSTRACT

Instruments and their associated cabling located in plant age due to various operating conditions. These must work as per their design intent in normal conditions and accident conditions even at the end of their life. Environmental qualification program of instruments for a nuclear power plant ensures above and hence plays a very vital role in ensuring safe operation. This paper discusses various aspects of qualification of instruments which is unique to Nuclear Power Plants.

KEYWORDS

Accelerated Thermal Ageing, Environmental Qualification, LOCA, LOCA chamber, Mission Time, MSLB, Qualified Life, Radiation, Safety Function, Safe Shutdown Earthquake (SSE)

INTRODUCTION

The systems and associated instruments used in the nuclear power plant have to perform under normal conditions and various anticipated operational transient conditions to ensure safety of the reactor. In addition to this, it is also required to perform its intended function, during and after an accident condition. These anticipated accidental conditions are called as design basis accidents and systems are provided to mitigate such a scenario by safely shutting down the reactor and ensuring long term core cooling.

These accident conditions can occur anytime during the operating life of the plant. Hence all systems and associated instrumentation must perform its design functions even at its end of life conditions. Hence degradation in performance of instruments due to aging plays an important role in deciding its qualified life.

Typically in a Nuclear Power Plant aging of instruments can take place due to following reasons:

a) Thermal Effect
b) Radiation Effect
c) Vibration Effect (non-seismic and operating basis earthquake)
d) EMI/EMC Effect
e) Usage (operating cycles)
f) Electrical loading and signals

In the eventuality of any accident these aged instruments are subjected to harsh environment conditions created due to:

a) Design Basis Accident like Loss Of Coolant Accident (LOCA) or Main Steam Line Break (MSLB) or SSE

b) Beyond Design Basis Accidents e.g. severe accidents

Design of the C&I systems must ensure that even with degradation due to above factors instrument is able to perform its intended safety function in above accident conditions.

ENVIRONMENTAL QUALIFICATION

Environmental qualification can be done either by type testing or by operating-experience or by analysis or by any combination of these. However in this paper qualification by testing is only discussed.

Environmental qualification can be broadly divided in to two categories

- Qualification for normal operating environment
- Qualification for accidental conditions

QUALIFICATION FOR NORMAL OPERATING ENVIRONMENT

During normal operating conditions also instruments are subjected to stresses. These stressors are temperature, pressure, humidity, radiation, vibrations etc.

Hence for qualifying these instruments for normal operating condition they are subjected to various tests simulating anticipated operating conditions including the storage conditions. Thus environmental tests like dry heat, damp heat, vibration and EMI/EMC test are carried out as type tests. These instruments are also qualified for tropical conditions. The maximum temperature, humidity and number of cycles for damp heat and temperature and duration for the dry heat tests are specified in the technical specification for all such items, depending on their location in the plant and associated operating environment.

Various standards used for qualification of instruments are:

a) Dry Heat: IS 9000-1994 Part–III / IEC-60068.2-Basic environmental testing procedures for electronic and electrical items: Part 3 Dry heat test

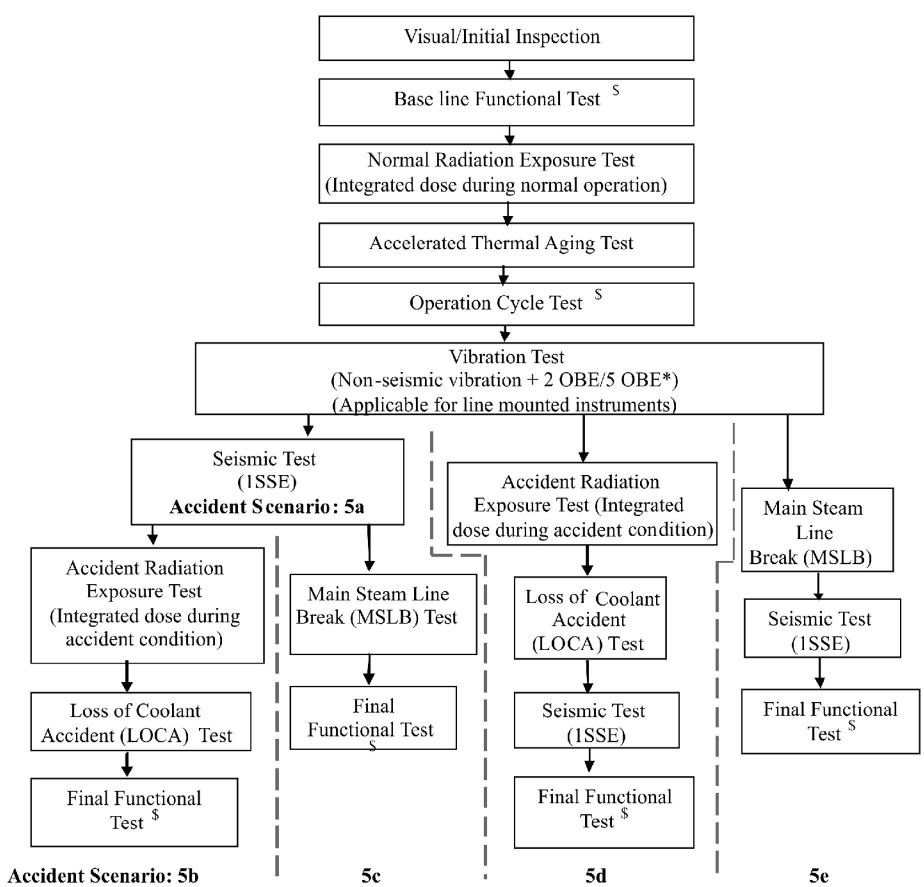
b) Damp Heat: IS 9000-1994 Part–V / IEC-60068.2-Basic environmental testing procedures for electronic and electrical items: Part 5 Damp heat (cyclic) test

c) EMI/EMC : PC-E-710: Engineering standard on electromagnetic compatibility qualification of C&I equipment (NPCIL's Document)

QUALIFICATION FOR AN ACCIDENTAL CONDITION

Before an instrument is qualified for accidental condition it must be aged for its qualified life. Primary objective of this aging is to ensure that the instrument can perform its safety function without experiencing common-cause failure before, during or after design basis accidents.

For qualification of instrument for various design basis accident, it is subjected to a test sequence which places the instrument to worst state of degradation. Generally test sequence as given in figure 1 is followed for qualification of the instruments.



Notes:

1) '$' Base line functional test and operation cycle test depends on type of instruments.

2) Input pressure fluctuation test, power supply variation test, power ON/OFF test are the typical operation cycle tests in case of transmitters.

3) '*' 2 OBE cycles for 20 years of qualified life and 5 OBE cycles for 40 years of qualified life.

4) Functional test are done after each tests to evaluate the performance of instrument.

5) Following five types of accident scenario are considered:

   a) SSE,
   b) SSE followed by LOCA,
   c) SSE followed by MSLB,
   d) LOCA followed by SSE,
   e) MSLB followed by SSE

6) During actual testing only one of the above accident scenarios will be considered for testing.

FIGURE-1: FLOW CHART FOR QUALIFYING THE INSTRUMENTS FOR AN ACCIDENT CONDITION

Some of the tests given in figure 1 are explained below:

RADIATION AGING TEST

This test consists of two main parts:

a) Normal Radiation Exposure Test

b) Accident Radiation Exposure Test

NORMAL RADIATION EXPOSURE TEST

Depending upon the qualified life of the instrument and its location in the plant, total dose (total integrated normal dose) the instrument will receive during normal operation in its life time is calculated.

The test instruments are subjected to gamma radiation with an equivalent dose equal to the total integrated normal dose. After irradiating the instrument, it is subjected to functional tests and its performance is compared with baseline functional tests.

ACCIDENT RADIATION EXPOSURE TEST

Depending upon the location of instrument in the plant and the design basis accident, total dose (total integrated accident dose) the instrument will receive during accident condition is calculated.

It is assumed that instrument will be subjected to accident condition after it is subjected to normal radiation exposure. Hence the instrument is additionally exposed to the total integrated accident dose postulated to occur during an accident.

In both these tests the dose rate is kept as low as possible. Normally it is kept below 1 Mrad/hr.

These two radiation exposure can be either combined or it can be given separately as explained in figure-1.

If the material of construction and components are properly selected failure of instrument during thermal aging test is not seen. Generally it is seen that mostly instruments containing electronic components fail during radiation aging test. Further since duration of thermal aging test is very long (generally 4 to 8 months), radiation aging test is done first.

ACCELERATED THERMAL AGING TEST

In order to simulate the deterioration due to temperature exposure during its normal service life, the equipment is subjected to accelerated thermal aging. In this test, instrument is kept at elevated temperature in a thermal chamber for a predetermined duration. During the test, based on manufacture's recommendation some of the elastomer parts (e. g. gaskets) of instruments are replaced at regular interval.

For non metallic materials, the time-temperature degradation process is described in a single temperature dependent reaction that follows the Arrhenius equation

$k = A \exp[-(Ea/kBT)]$ where

k = Reaction Rate

A = Frequency Factor (assumed constant)

Ea = Activation Energy

kB = Boltzmens Constant

T = Absolute Temperature

This equation is rearranged into the following form, which is more useful.

t2 = t1 exp Ea/kB [1/T2 - 1/T1]

t1 = Accelerated Aging Time

t2 = Qualified Service Duration

T1 = Accelerated Aging Temperature

T2 = Qualified Service Temperature.

Value of activation energy depends on material of construction and this value generally ranges from 0.78 to 0.95.

Hence if ambient temperature is 450 C and the instrument is kept in thermal chamber at a temperature of 850 C then for qualifying this instrument for 10 years (activation energy is assumed to be 0.78) it has to be kept in thermal chamber for 152 days. As per NPCIL maintenance practice, after every 30 days of testing (equivalent to 2 years of normal operation) instrument is checked for its accuracy, and is recalibrated, if needed.

Figure-2: THERMAL CHAMBER
(NPCIL's R&D Lab at TMS)

TESTS FOR DESIGN BASIS ACCIDENTS

In a nuclear power plant, the major design basis accidents are Loss of Coolant Accident (LOCA), Main Steam Line Break (MSLB) conditions and seismic event.

A LOCA condition is the breach of the primary heat transport system due to which the high enthalpy, high-pressure heavy water escapes to the containment. This will result in instantaneous pressure and temperature rise in the primary containment. Some amount of rise in radiation also takes place. Subsequently the other parts of the containment that are normally accessible during reactor operation will also be subjected to these conditions but to a smaller extent. Under a Main Steam Line Break condition, the temperature and pressure inside the containment will increase substantially. However in PHWR plants there is no release of radiation under this type of accident.

LOCA QUALIFICATION TEST

The temperature and pressure conditions, expected during the LOCA are generated in a test chamber which is called as LOCA test chamber. Both the steam flow and temperature is critically controlled to ensure that these conditions are achieved and maintained in the chamber as close as possible to the LOCA test profile.

Pressure and temperature as seen by the instrument depends on its location in the plant.

In a typical 700 MWe PHWR plant, for an instrument located in accessible area of the Reactor building it will see the profile as given below:

a) 0-110 sec - 76oC at 0.73 kg/cm2 (g) pressure

b) 110-400 sec -73oC at 0.60 kg/cm2 (g) pressure

c) 400-800 sec -59oC at 0.46 kg/cm2 (g) pressure

d) 800-1700 sec-54oC at 0.31 kg/cm2 (g) pressure

e) 1700- 5500 sec-54oC at 0.17 kg/cm2 (g) pressure

f) Next 48 hrs-Moisture laden saturated air at 50oC

The above test profile is generated considering margins stipulated in IEEE-323 standard.

In the above test profile, along with steam temperature and water flow, air pressure in the chamber is also controlled for achieving the desired LOCA test profile.

Figure-3: LOCA TEST CHAMBER
(NPCIL's R&D Lab at TMS)

If the chamber does not have the facility to control the air flow, the test is conducted for a profile following a sequence as mentioned below:

a) Saturated steam at 117oC for first 550 sec

b) Saturated steam at 110oC for the next 550 sec

c) Saturated steam at 107oC for the next 1100 sec

d) Saturated steam at 105oC for the next 2800 sec

e) Moisture laden air at 50oC for the next 48 hrs

Maintaining 100% humidity, under this condition is also a requirement.

The instrument under test is monitored continuously, during the entire test by keeping it in energized condition. If the instrument is a motorized valve and is required to operate during the accident its operation is checked when the chamber achieves the peak temperature and pressure conditions. During and after the test if the deterioration in its performance is within the acceptable limits then only the test is declared as successful.

As seen from the typical pressure and temperature curves the entire safety related system components have to perform and do their intended function, under these two accidental conditions.

SEISMIC TEST

Seismic event can produce significant vibration levels which vary in intensity depending upon the location of the plant. Within a plant also vibration levels as seen by the instrument depends on its location within the plant.

For a typical 700 MWe project tentative values of these frequency and acceleration are given below:

Peak Acceleration Value: 3.5 g for SSE and 1.75 for OBE

Motion: Sinusoidal

Frequency range: 1 to 100 Hz

Test frequencies: 1 Hz, Hz, 1.26 Hz, 1.59 Hz, 2.0 Hz, 2.52 Hz, 3.75 Hz, 4.0 Hz, 5.04 Hz, 6.35 Hz, 8.0 Hz, 10.08 Hz, 12.67 Hz, 16.0 Hz, 20.16 Hz, 25.0 Hz, 32.0 Hz, 40.31 Hz, 50.8 Hz, 57.02 Hz, 64 Hz, 71.84 Hz, 80.63 Hz, 90.51 Hz, 100 Hz.

Test duration: 30 second at each frequency.

Test Axes: Tests are carried out in 2 orthogonal horizontal axes and vertical axis (one axis at a time).

Instruments are subjected to vibration tests on a shake table as per details given above. Instrument being qualified must demonstrate that it can perform its safety function during and after the time it is subjected to the forces resulting from one SSE. In addition the instrument must withstand the effect of number of OBEs prior to application of an SSE. In some cases instrument need not work during or after the seismic event but it must maintain its structural integrity during and after the SSE.

Figure-4: SEISMIC SHAKE TABLE
(Courtesy: CPRI, Bangalore)

MISSION TIME

Mission time is the period of time the equipment is required to remain functional to perform its intended duty, during an accident. For some of the systems in the plant, the mission time can be 2 months, which incidentally is the mission period of that system. For a differential pressure switch that senses the rise in reactor building pressure, to initiate the reactor trip the mission time is only few seconds. Hence this instrument is required to remain functional, under the accident condition for only few seconds.

The safety functions and mission time of each equipment or instrument, under the accident condition also play a vital role in the qualification aspect. If a motorized valve is required to open during the accident it shall be qualified to ensure its operation under that environment condition. If it has to remain in 'as -is' condition without any operation the qualification issue becomes less complicated. If a valve is required to throttle/operate number of times, the issue of qualification is much more complex.

Having explained the essence of both these parameters it has to be emphasized here that these two characteristics of each item are effectively used for the maximum advantage in the qualification program.

CHALLENGES

Environmental Qualification for all the critical instrumentation of a nuclear power station is very time consuming and a large amount of documentation has to be prepared. The thermal ageing test, due to restrictions on the maximum temperature that can be applied, takes very long time for completion. The facilities available in the country for such tests are also very limited. Maintaining the qualification in the plant over a period of time with proper surveillance in place is also a challenging job for the station. Non-availability of properly qualified instruments indigenously is also a problem to be tackled.

ACRONYMS

LOCA : Loss of coolant accident

MSLB : Main steam line break

Mrad : Mega rad

OBE : Operating Basis Earthquake

PHWR : Pressurised Heavy Water Plant

SSE : Safe shutdown earthquake

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BIOGRAPHIES

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Sh. Anand Behre was born in Gwalior, India, in the year 1954. He graduated in Electrical engineering from Jabalpur Engineering College. He joined Department of Atomic Energy, in 1978. At present he is working as "Associate Director (Control & Instrumentation)" in Nuclear Power Corporation of India Ltd. He is associated with design, engineering and procurement of C& I for Indian PHWRs.

INDEPENDENT VERIFICATION AND VALIDATION OF PRE-DEVELOPED COMPUTER BASED DIGITAL I&C SYSTEMS

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Abstract

Computer based digital systems (CBS) have been gradually introduced in Indian nuclear power plants. At present, many of these systems are used in safety and safety related applications mainly for control, protection and monitoring. These systems need to be demonstrated to be safe and reliable prior to deployment. Assessment of software in these systems is carried out rigorously to ensure that software is consistent, correct, complete and safe. The systems may be Newly Developed System (NDS), Certified Pre Developed System (PDS), commercially Off the Shelf Pre Developed System and their reviews pose different types of challenges. This paper details the Verification and Validation (V&V) process/methodology followed for PDS at NPCIL to ensure the correctness of requirements, design and implementation and deployment of these systems.

Keywords

Verification, Validation, Digital I&C, Newly Developed System (NDS), Pre-Developed System (PDS), Intellectual property (IPR)

INTRODUCTION:

Computer based digital I&C systems (CBSs) have been gradually introduced in Indian Nuclear Power Plants (NPPs) over last two decades. Narora Atomic Power Station was the first Indian NPP to deploy CBSs in control and monitoring applications. Kakrapar Atomic Power Station onwards, CBSs are being used in protection functions also. When the CBSs perform functions important to safety, these functions must be demonstrated to be safe and reliable with appropriate degree of confidence. The CBSs have different characteristics from other hardware based electronic control systems and therefore it is mandatory to follow a different approach to demonstrate their safety and reliability.

It is recognized that currently the Computer-Based digital I&C Systems are not amenable to quantitative assessment of reliability primarily due to present of software components in these systems. Therefore assessment of software in the Computer-Based Systems has to be based on evidence that the software is correct (with respect to specifications), safe and completely implemented as per the requirements. In other words, the software in these systems must be demonstrated to be safe and to have high level of integrity [1].

Integrity is assured using systematic, carefully controlled, fully documented and reviewable development process during the software development life cycle (SDLC), which is suitably interfaced with concurrently performed Verification & Validation (V&V) activities. Safety aspects of the system need to be demonstrated through reviews at each stage of development.

REGULATORY PROCESS:

In India, Atomic Energy Regulatory Board (AERB) is responsible for regulation/licensing during design, construction and operation of nuclear power plants. AERB has prepared and issued a safety guide on computer-based systems in Pressurized Heavy Water Reactors (AERB SG-D-25). This guide gives recommendations on:

1. Safety Case requirements for Computer-based Systems and

2. Design and Development process for Computer-based Systems

ENGINEERING PROCESS:

NPCIL has evolved Engineering procedures, which describes lifecycle processes during design, development/manufacturing, and deployment of digital I&C systems.

The life cycle of a digital I&C system consists of the following main phases:

- Requirements phase
- Execution phase for NDS/Procurement phase for PDS
- Deployment phase
- Operation and Maintenance phase

The life cycle of digital Computer Based I&C Systems (CBSs) consists of the entire stretch from defining the requirements through the development, deployment (installation and commissioning) to the operation and maintenance of the system. The prerequisite for entering the life cycle is the existence of a Preliminary Safety Analysis Report (PSAR), or a Statement of Purpose (SOP). In this document, the role of the computer-based system is defined vis-à-vis the rest of the plant. The system is discussed in the context of the plant operation and the conceptual requirements are stated in a plant-oriented fashion. The system's place in plant context, its connectivity to balance of plant, and its functional/ performance requirements are reviewed and accepted as part of the PSAR review process by AERB.

Depending upon the requirements, a system may be categorized as a NDS, Cert.-PDS or Comm.-PDS [2]. The IV & V review approach differs based on system category, safety classification, overall configuration and complexity of the system.

This paper describes the IV & V process/methodology for PDS and challenges followed at NPCIL.

IV &V REVIEW METHODOLOGY FOR PDS:

LIFE CYCLE OF PDS:

Life cycle for PDS is given in figure-2 and it comprises the following broad phases:

- Requirements Phase
- Procurement Phase
  - o Evaluation
  - o Execution
- Deployment Phase
- Operation and Maintenance Phase

In Requirements phase, the designer prepares the System Requirements (SR) based on the conceptual requirements stated in the PSAR/DBR/SOP. The SR document is reviewed for its consistency and completeness.

Procurement phase: The procurement phase consists of two parts viz (a) Evaluation and (b) Execution. In this phase tendering and procurement activities are carried out.

During evaluation, the suitability and quality of the selected system is evaluated concurrently with V&V review activities for PDS- Cert. or a PDS-Commercial. This includes the evaluation of manufacturing process of the existing product, product specifications, review of operating experience, the evaluation of design and development process that happened in the past. This ensures that the selected PDS is suitable for the desired application.

During execution, the system is manufactured as per the system requirements. Subsequently, software customization and hardware configuration is carried out to ensure that the PDS meet the system requirements. All the work products are reviewed concurrently by V&V agency for correctness, consistency and completeness.

At the end of the procurement phase, the system is subjected to validation tests at the manufacturer/ developer site to ensure that the PDS is meeting the system requirements. Any modifications in the system that arises during execution will require designer authorization. The system shall be revalidated after implementation of the required changes.

In Deployment Phase, the system is installed and commissioned at plant site. After the system is integrated with sensors, actuators and interfaced with other systems/subsystems at site, it is verified and validated to ensure that installed system meets all the functional and performance requirements.

In Operation and Maintenance phase, the system is taken into service to meet operational goals as per the design intent in the context of the plant. During operation period, need for modification may arise based on operational feedback or for any other reasons. The implementation of such modifications/changes is carried out as per Configuration Management Procedure–O&M (CMP-OM) and the modified system is revalidated before use

IV & V REVIEW PROCESS FOR PDS:

The IV&V review process for PDS consists of following main review stages:

- System Requirements Review
- Product Evaluation Review
- Configuration Review
- Customization Review
- System Validation
- Change/Modification Review

The IV&V review process for PDS is conducted concurrently with life cycle for PDS. The IV&V review process is initiated by submission of the Preliminary Safety Analysis Report (PSAR) and System Requirements (SR). The PSAR is considered as baseline document for the system review. Other design documents are reviewed for clarity, consistency, correctness and completeness and are verified against the preceding design document(s) for traceability [3].

The system documents are verified or reviewed at various stages and system validation is carried out at standalone system in simulated environment and integrated system in actual environment. The review at a stage may have several sub-stages. The basic review activity consist scrutiny of a document under review and submission of its verification or review report. The verification or review report brings out the anomalies found during the review or verification process (if any) and may recommend clearance of the document or its return to Designer for revision. In case of revision, the Designer re-submits the document for verification or review along with a compliance report that includes the cause for anomalies and rectification. After review of the revised document along with the compliance report, document verification or review report is issued.

All documents are reviewed using standard checklists. IV & V review reports and System Validation Report for a digital I&C system form part of its safety case to be submitted to the AERB. The summary of IV&V review process with deliverables for PDS is given in Table-1

The brief description of each review stage is given in the following sections

1.0 SYSTEM REQUIREMENTS REVIEW:

Requirements review is carried out to verify that SR covers all the design requirements of the pre developed digital I&C system as described in PSAR/ DBI/DN. It also verifies that all requirements like functional, performance, interface, safety and security requirements are unambiguous, correct, consistent, complete, traceable and verifiable.

2.0 PRODUCT EVALUATION REVIEW:

This review stage consists of the following sub stages:

i. Product Specification Compliances (PSC) review

ii. Fitness for the Purpose (FFP) review

iii. Audit of previous design, development documents and reports (original system)

The product specifications along with compliances with the SR are reviewed to confirm that specifications of the offered product are meeting all the requirements mentioned in the SR document. Deviations, if any, shall be clearly brought out and recorded with respect to functional, performance and safety requirements.

Fitness for the Purpose (FFP) is reviewed for the followings

- Organization level Quality Assurance Plans (QAP) of OEM
- Third party quality certifications on OEM
- Software development/production process
- Hardware manufacturing process
- Operating Experience Database/Operational history
- Customer certifications for satisfactory performance of the identical product

The correctness, consistency & completeness of the FFP is reviewed and observations are recorded in the review report and deficiencies, if any, are to be informed to the designer for correction.

The audit of the following design and development documents and their corresponding reports on the original/basic system is carried out to confirm that the proposed PDS is designed, developed and deployed as per the standard regulatory process for nuclear applications and have the adequate operating experience or the proposed PDS is proven to be reliable due to their standard design, manufacturing process, test reports/certifications and have adequate operating experience

i. Hardware Quality Assurance Plan (HQAP)

ii. Software Quality Assurance Plan (SQAP)

iii. Hardware Requirement Specification (HRS)

iv. Hardware Design Description (HDD)

v. Software Requirement Specification (SRS)

vi. Software Design Description (SDD)

vii. System Integration and Test Plan (SysITP)

viii. System Integration and Test Report (SysITR)

ix. System Validation Report (SVR)

x. Verification Report for HRS

xi. Verification Report for HDD

xii. Verification Report for SRS

xiii. Verification report for SDD

xiv. Verification Report for Source Code

xv. Evaluation Report on tools

xvi. Certification Report for Compliance of (a) General Design Criteria, (b) Safety Criteria and (c) Quality Policy

The audit observations are to be recorded in the audit report and deficiencies, if any, are to be informed to the manufacturer/developer through designer.

3.0 CONFIGURATION REVIEW:

This review stage consists of the following sub stages:

i. Verification Plan for Application Software (VP-ASW)

ii. Configuration Management Plan-Manufacturer (CMP-M)

iii. System Architectural Design (SAD)

iv. System Verification and Validation Plan (SVVP)

v. System Validation Procedure (SVP)

vi. System Safety Analysis Report (SSAR)

vii. Hardware Reliability Analysis (HRA)

Configuration Management Plan, System Verification and Validation Plan and Verification Plan for Application Software are reviewed and observations are recorded for correctness and completeness. Deficiencies, if any, are informed to the designer for correction and resubmission.

System Architectural design document is verified to ensure the compliance to the system requirements for consistency, correctness & completeness and observations are recorded. Deficiencies, if any, are informed to the designer for correction and resubmission.

System Validation Procedure (SVP) is reviewed for consistency and completeness along with the traceability matrix with SR document. All the observations are recorded for SVP and deficiencies, if any, are informed to the designer for correction and resubmission.

System Safety Analysis Report (SSAR) is reviewed for correct implementation of all the safety and safety related functions (IA, IB & IC systems), effect of single failure (IA & IB systems) and common cause failure (IA system only) on the safety of the equipment and plant. Hardware Reliability Analysis (HRA) document is reviewed to meet the quantitative reliability target or on demand failure probability as stated in system requirements (SR). This include the review of component and module/board level reliability data with their sources, reliability block diagrams, fault trees analysis, event trees analysis, maintainability prediction, method of reliability calculations, etc for the implemented safety functions. These documents are reviewed for consistency, correctness and completeness and the observations are recorded. Deficiencies, if any, are to be informed to the designer for correction and resubmission.

4.0 CUSTOMIZATION REVIEW:

This review stage consists of the following sub stages:

i. Application Programming Requirements (APR) / Software Customization (SC)

ii. Application Program (AP)

iii. System Build (SB)

iv. User Documentation (UD)

Application Programming Requirements (APR) or Software Customization (SC) is verified to ensure the compliance to the software related requirements for consistency and completeness and observations are recorded. Deficiencies, if any, are informed to the designer for correction and resubmission.

Application Program is verified for correct and complete implementation of the application software requirements. Deficiencies, if any, are informed to the designer for correction and resubmission.

System Build and User Documentation are verified for completeness, correctness and consistency and observations are recorded. Deficiencies, if any, are informed to the designer for correction and resubmission.

5.0. SYSTEM VALIDATION:

This stage consists of the following sub stages:

i. System Validation at manufacturer's premises

ii. System Validation at project site

For system validation at manufacturer's premises or factory, the standalone system is offered for validation after completion of QA activities and before shipment to site. The standalone system shall be subjected to validation in simulated environment by independent V&V team in coordination with the manufacturer, developer and system experts at manufacturer's premises / factory. Before system validation at factory, the V&V team check the manufacture's internal and external test reports/certifications to confirm the manufacturer's process compliance and known / pending deficiency for the completeness. System Validation Report- Factory (SVR-F) is prepared to record all the test results.

For system validation test at site, the system is offered after installation and commissioning at site. The system validation tests are carried out to confirm that the system has been re-assembled appropriately as per system build, system has been connected to field inputs, outputs and other CBS appropriately and system is functioning satisfactorily. Before system validation at site, the V&V team check the installation and commissioning report to confirm the offered system has been fully commissioned and there is no known / pending deficiency. System Validation Report-Site (SVR-S) is prepared for documenting the test results.

6.0 CHANGE/ MODIFICATION REVIEW:

The Configuration Management Procedure -O&M document is used for implementation of changes or corrections after deployment of the system. CMP-O&M is reviewed and observations are recorded for correctness and completeness. Deficiencies, if any, are informed to the user for correction and resubmission.

There may be certain changes/modifications during O&M phase of the system due to change of requirements based on operating experience in the field, errors observed during operation or obsolesce of the hardware/software components. All the changes/ modifications during the operation and maintenance phase are managed using configuration management procedure-O&M.

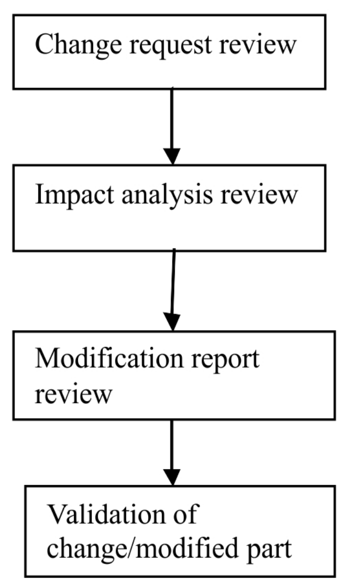

FIG-1: CHANGE/MODIFICATION REVIEW

The change/modification request, impact analysis, modification report are reviewed for correctness of the change implementation. The validation tests are carried out to ascertain the modification/changes. The impacts on the safety of the equipment or plant due to change/ modification are also reviewed.

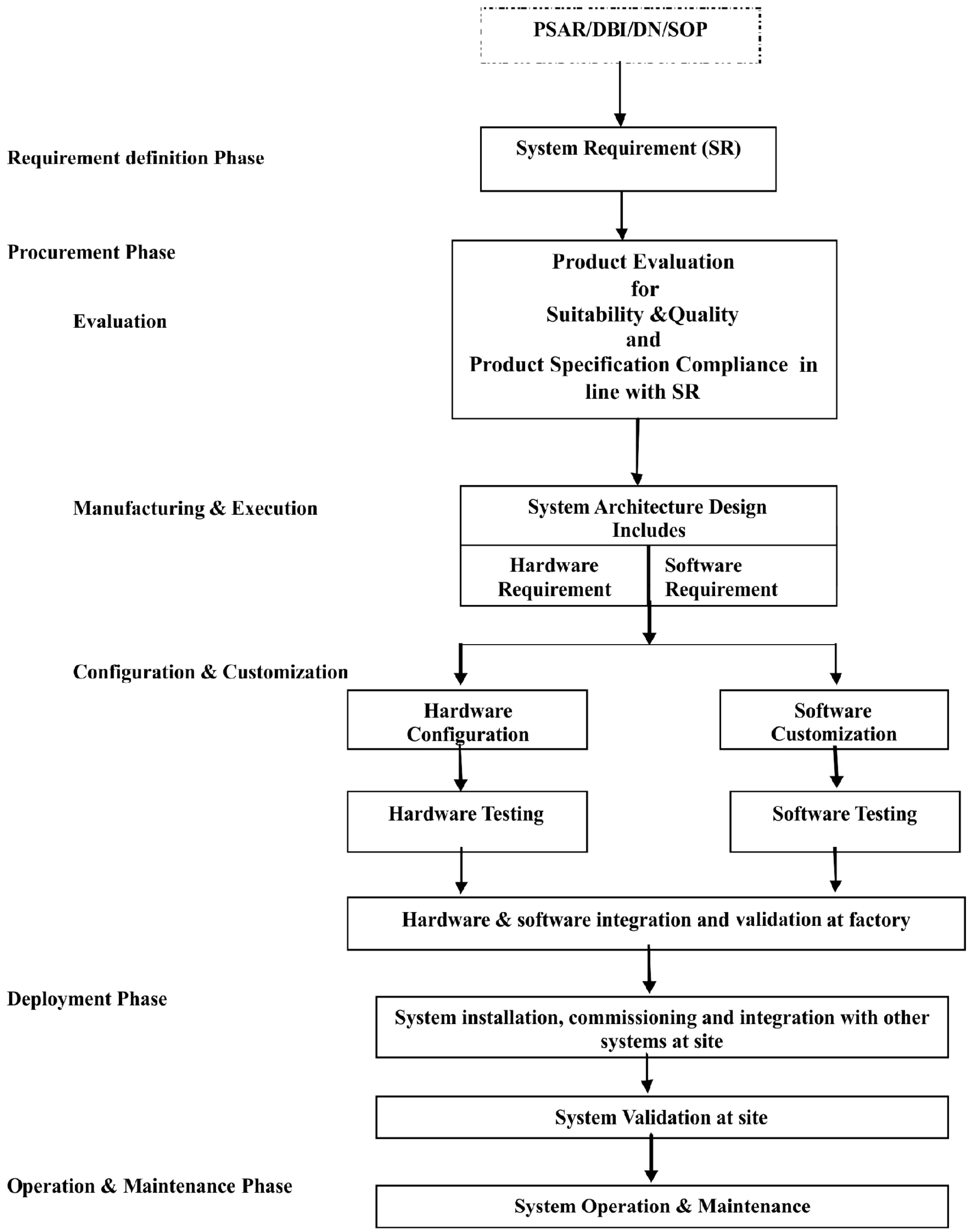

FIGURE-2: LIFE CYCLE FOR PRE-DEVELOPED SYSTEM (PDS)