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Review of Control Room Instrumentation Required for Safe Operation of Modern Utility Steam Generators

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REVIEW OF CONTROL ROOM INSTRUMENTATION REQUIRED FOR SAFE OPERATION OF MODERN UTILITY STEAM GENERATORS

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INTRODUCTION

If we are to avoid a devastating economic depression as well as massive blackouts caused by electric power shortages, we must not only replace fossil fired units as they reach 30 years service, but also provide for a 3% growth rate. The latest estimates of electric generating requirements through 1990 show that we should be building at the rate of 800 megawatts installed capacity every 16 days.[1]

Government restrictions and the reduced rate of increase in the demand for electricity have delayed needed construction. This lull in activity has allowed time for evaluation of existing equipment and development of design specifications for future installations.

An important aspect of this progress is the selection of controls and instrumentation which will enhance safe and reliable operation. The complexity of controls, the quantity of monitored variables and the cost of conventional control and instrumentation equipment have grown significantly; however, modern micro-electronics can provide dramatic increases in data acquisition and controls capability without increasing costs.

In this paper, we shall examine instrumentation needs of modern steam generators, review case histories, state of the art and future trends.

PROCESS MONITORING INSTRUMENTATION

This discussion deals with the instrumentation located in the control room of a modern large steam generator. From this nerve center the operator should be able to monitor and control all important parameters; therefore, if sufficient instrumentation is not provided, the operator may be unaware of abnormalities perhaps resulting in fires, explosions and other accidents. Also, without adequate recording and/or logging instrumentation it may be impossible to reconstruct events in order to prevent their recurrence.

Coal systems are much more complex and under certain conditions, more hazardous than oil or gas firing systems, and the proper handling of this fuel requires that special additional information be available for control and monitoring by the operator. Apart from the need for a greater quantity of information, it is difficult to accurately sense most flows, levels and temperatures in coal systems. Therefore, extra effort must be expended in the design of the monitoring instruments to provide information of high quality and offset the inherent process limitations.

Along with the hazards of handling the coal air mixture, there are hazards and difficulties in the storage, conveying, feeding and metering of the coal and in disposing of ash and flue gas contaminants. Most of the coal equipment is difficult to automate because it handles bulk material and during wet and cold weather it may require manual intervention to maintain the uninterrupted flow of material.[2]

Based on their specific equipment knowledge and experience, the manufacturers of the firing systems and steam generators are best qualified to specify the required instrumentation and each should list recommended control room instruments. The customer or his engineering representatives should use this type of list as the minimum basis for instrument procurement and should not subtract from it without consulting with the equipment manufacturer.

The manufacturer's requirements list should contain recorder points, indicators, alarms and trips for each of the fuels being fired and all other boiler systems. Figure 1 shows a manufacturer's typical recommended instrumentation list for a coal pulverizer system.

RECORDER POINTS

Mill Primary Air Mass Flow	Eng. Units
Primary Air Temperature (At P.A. Venturi)	0-700° F
Mill Inlet Temperature	0-700° F
Mill Outlet Temperature	0-700° F
Classifier Outlet Temperature	0-700° F
Primary Air Temperature (Before H.A. Damper)	0-800° F
Tempering Air Temperature	-10° to 150° F
Mill Sound Level	As Required
Mill Motor Power	As Required

INDICATORS

Mill End Differential Pressure	0-12" WG
Classifier to Furnace Diff. Pressure	0-30" WG
Mill Seal Air Diff. Pressure	0-30" WG
Mill Outlet Pressure	0-30" WG
Classifier Differential Pressure	0-10" WG
Seal Air Fan Manifold Pressure	0-90" WG
P.A. Fan Inlet Press. (Hot P.A. Fan)	0-10" WG
P.A. Manifold Pressure (Cold P.A. Fan)	0-100" WG
P.A. Fan Discharge Pressure (Hot and Cold P.A. Fan)	0-70" WG
Seal Air Flow	Local Indicator
Primary Air Fan Discharge Temperature (Cold P.A. Fan)	0-150° F
Primary Air Fan Discharge Temperature (Hot P.A. Fan)	0-700° F
Feeder Feed Rate	As Required
Hot Air Damper Position	
Tempering Air Damper Position	
Rating Damper Position	
Seal Air Damper Position	

INDICATORS, Continued

By-pass Air Damper Position (Transmitted Pos)
Mill Level (Pneumatic Probes)
Mill Motor Amps
Mill Sound Level
Mill Motor KW
Primary Air Fan Motor Amps
Crusher-Dryer Motor Amps

ALARMS

Mill Level High
Mill Motor KW Low
Mill Sonics High
Mill End Diff. Press. High
Mill Seal Air Diff. Press. High
Mill Seal Air Diff. Press. Low
Seal Air Fan Rotor Diff. Low
P.A. Manifold Press. Low (Cold P.A. Fan)
Mill Inlet Temp. High
Mill Outlet Temp. Low
Classifier Outlet Temp. High
Mill Bearing Temp. High (Gear Drive)
Mill Bearing Temp. High (Chain Drive)
Chain Oil Temp. High (Chain Drive)
Mill Motor Bearing Temp. High
Mill Motor Stator Temp. High
Mill Outlet Temp. High
"No Coal Feed" Alarm
High Axial Mill Displacement
Low Oil Flow to Chain Alarm
Low Primary Air Mass Flow
High Gear Reducer Temperature

Figure 1 Typical Instruments and Ranges for Ball Tube Mills

INSTRUMENTATION SELECTION

Instrumentation to monitor steam generators has evolved slowly. For utility boiler operation the most important features are safety and reliability, and utilities understandably do not adopt new instruments readily. New types must be well proven, and pneumatic as well as electromagnetic systems are still used.

Analog meters are being gradually replaced by digital displays, alphanumeric hard copy printers and cathode ray tubes. Their outputs have advantages of accuracy and speed of reading, but trends are more difficult to discern and it is difficult to determine deviations quickly. The designer should be aware of the dangers encountered when digital readouts are substituted for the traditional large size indicators or pen recorders. Digital readouts present only one piece of information, an absolute value. Analog conventional display presents, in addition to an absolute value, the deviation from the normal value that tells the operators at a glance whether the equipment is operating within safe limits.

As computer systems have been added to the instrumentation of boilers, one mistake designers have made is to remove very important trending information. Trending data has been traditionally portrayed in visual, analog form on circular or strip chart recorders, round dial or vertical scale indicators. Now much of the operator's information appears on CRT displays, in the form of printed word or code, or on typed hard copy lines of a printer. The operator's decision during rapid transients or emergencies must be deduced from what he remembers reading earlier, comparison of printed records widely spaced on a page, or a simple go/no-go alarm. Access to multitudinous amounts of digital data does not replace the pictorial, and immediate full view record of the circular or strip chart which tells him where he was, where he has been, and where he is headed.

The power plant operator must have constant trend information of certain critical data such as boiler water level, boiler steam pressure, boiler steam flow, air flow, steam temperature, pulverizer temperatures, etc., so that deviations or trends in these values can be evaluated and interpreted and appropriate action can be taken in the event of a system failure.

A computer can be an excellent back-up and a system can be devised by the use of real time microprocessor based computers with relatively large memories, where a much wider spectrum of data can be stored and periodically updated. On a system trip or other malfunction, the data can be made to remain in storage and printed in digital form or analog plot for analysis of the conditions before and after the accident.

We might finally caution that the use of computer display techniques may tend to dangerously take the operators away from the close personal association with the boiler. Care should be taken by the instrumentation designer to keep the operator involved and hold his interest so that he is able to react with confidence and effectiveness when the emergency arises.

BURNER MANAGEMENT SYSTEMS

Burner Management systems (BMS) include not only the logic related to boiler furnace safety, boiler purge, master fuel trip and flame safeguard, but also complex sequencing systems for the automatic start-up and shut-down of firing equipment, load run backs, pulverizer inerting system operation, etc. The following comments are related to the engineering of the BMS systems:

a) When engineering these systems it is imperative that the boiler manufacturer be involved and participate in the design of the logic system, otherwise the control vendor or the engineering consultants may not be aware of changes in the design of the equipment or in the method of operation which may require changes in the logic. A change which is easily made in the design stage or in the shop may become prohibitive in the field. Ideally, the boiler manufacturer should be responsible for furnishing the BMS systems.

b) There is a tendency to increase the logic complexity and remove the operator's responsibility to the point where there is insufficient flexibility for operating under unusual circumstances. Increasing the number of interlocks and permissives is not a substitute for experienced, well trained operators.

c) There is so much concern for avoiding nuisance trips that the design, at times, may lack major safety features. It should be understood that compliance with the National Fire Protection Association (NFPA) standards provides only the minimum accepted protection. Not tripping on low air flow, very low drum level, etc., or designing under the "power to trip" concept without understanding its limitations and without making provisions for proper back-up has resulted in serious damage or nearly so, as can be seen in the examples of the next section.

The "power to trip" concept prevalent in the large utility boilers in the USA was developed to prevent nuisance trips on momentary loss of power. This concept is the opposite of the "fail-safe" or trip on loss of control power, prevalent in the industrial boiler field where it is often required by insurance standards.

Designers and users should be aware that the increase in availability brought about by using "power to trip" circuits must be accompanied with a very sound design. This design should include proper monitoring of the tripping circuits for power supply and tripping coil integrity as well as a reliable battery power back up. In spite of this, cases have occurred when internal short circuits, defective switches, or external fires have disabled the tripping circuits, making it impossible to trip the boiler using the emergency switches, sometimes at the worst possible moment. Close scrutiny of this design concept and development of systems which trip on loss of control power but are capable of overriding power interruptions of short duration, should be investigated and perhaps specified when feasible and reliable.

Case Histories

The following accidents resulted in serious damage to property, and are presented as an example of how proper control and instrumentation could have either prevented the occurrences or anticipated them with the consequent lessening of their impact.

a. On a large utility boiler fired by pulverized coal and equipped with a double ended ball tube mill, a fire developed in one of the two classifiers and resulted in a serious mill explosion. On a system of this kind, the coal/air mixture from each of the mill feeds a classifier. The exit temperature of each classifier is measured and the higher selected for control with cool tempering air. In this case, the high selected temperature was the only recorded and the evidence of an incipient fire in one of the classifiers was not noticed, because that classifier exit temperature was being kept at set point by increasing amounts of tempering air.

   This explosion might have been prevented if both classifier exit temperatures had been recorded. Then the considerable drop in temperature on the other classifier exit would have been noted, calling attention to the considerable unbalance of the mill "end to end" conditions.

b. Several years ago, on a utility boiler fired by natural gas, a leak developed in a gas line at the burner front. A burner deck fire ensued with considerable damage to equipment. When the operator depressed the boiler master fuel trip pushbutton, the main gas trip valve did not close, even after repeated attempts. Precious time was spent locating and closing a manual gas cock on the gas mains. This was the only way the boiler could be tripped. Later it was found that the fire had destroyed the wiring to the main gas trip valve at the burner front making it impossible to energize the trip solenoid coil.

   A "de-energize to trip" system could have prevented further damage; otherwise, adequate training to make operators aware of the design limitations and periodic operator drilling on fast contingency action could have sped up the manual tripping of the unit.

c. On a recent installation, a turbine trip should have caused an automatic boiler trip. Unfortunately, simultaneously a voltage surge caused the loss of control power to the plant interlock and burner management systems, making it impossible to trip the unit because of the inability to energize the tripping circuits. After repeated futile attempts to trip using the master fuel trip and individual motor stop pushbuttons, the operator had to manually pull the breakers of each mill and primary air fan as the only way to trip the boiler. Investigation showed that the backup power was a branch of the main plant bus and was also subjected to the voltage upset. Needless to say the plant has since installed a battery bank for backup control power.

d. Recently, three different power plants underwent serious damage to the furnace walls because of the lack of an input to energize the boiler trip circuits in the event of low water in the drum. In one case, the water level column isolating valves were left closed after maintenance and the false "normal" reading caused the operator to ignore the low water level alarms. In another case, out of three water level indicators, one was disabled, and the tubing of one of the legs of another was accidentally cut-off during maintenance making the indicator read high. Since that line also fed the feedwater control, the feedwater flow was automatically decreased. Although the remaining level indicator showed the loss of level, the operator decided not to trip the unit.

At the third power plant, debris from the packing of the isolation valves clogged the sensing lines to the drum, bottling up water in the column, producing an erroneous reading which the operator trusted more than the energized low level alarms.

In all three cases, had automatic tripping been provided, even with a time delay to prevent nuisance trips, expensive repairs may have been avoided.

RECENT DEVELOPMENTS

Gas Monitors

Stack gas monitors, especially infrared analyzers, are being applied in greater numbers for monitoring CO, O_2, SO_2 and oxides of nitrogen in large steam generators. CO monitors and opacity monitors are being used to reduce excess air, as early problems in these systems are being overcome. Control by CO increases efficiency and safety and reduces pollutants by fostering complete combustion. One company expects a spectral flame analyzer which monitors carbon monoxide and other gases in the combustion chamber to yield fuel savings of about 3% in a large installation.[3] Oxygen based combustion control, usually using in-situ zirconium oxide oxygen probes, is now widely and successfully utilized, although air infiltration into the system, gas stratification and damage to the sensors by heavy reducing atmospheres and thermal shock are still problems to be overcome.

It has been known for many years that impending coal fires and explosions can be predicted by monitoring the level of CO in a closed area. Public Service, Indiana is the first utility in the United States known to have installed and placed a CO monitor in full operation.[4] This coal fire detection system appears to confirm that CO buildup in pulverizers, rather than rising mill outlet temperatures is a more reliable symptom of existing or impending pulverizer fires that may lead to explosions.

Using infrared analysis, the system monitors and charts the CO generated in each mill and gives a warning lead time of up to 1½ hours in advance of usual mill temperature increases. The success of this system will certainly lead to installation of similar equipment in other power plants.

Solid State Devices

Because of the increased accuracy and reliability of solid state devices, they have gradually been applied to the monitoring and control of steam generators. Typically, the instruments and controls for a boiler must be proven by at least two years of successful use in similar rugged applications.

There is a great deal of activity among sensor manufacturers to develop solid state sensors with ever increasing reliability, accuracy and repeatability. Developments in sensor technology will continue as the sensor, signal conditioner and analog digital device manufacturers try to keep up with computer advances. Computer accuracy is limited only by the number of bits, so any advances in sensor technology can be matched in the computer by increasing bit handling capability. The bit handling capability depends upon speed of the CPU, and serial/parallel architecture. The designer then has an economic decision whether to use a higher capacity computer, more accurate converters, or both.

By use of solid state devices, the mean time between failures (MTBF) has been increased several orders of magnitude over the MTBF for pneumatic or electromechanical devices. Even though a solid state system has thousands more memory or decision elements, the equipment can operate for many years experiencing very few failures and no fatigue. The solid state controls and instruments presently manufactured should have a potential life equal to the life span of the plant without excessive maintenance, repair or replacement.

With the higher costs of power plants and fuel, it is increasingly necessary to operate these plants at maximum efficiency. For continuous high efficiency operation the accuracy of the measuring instruments is vital and must be greater than the ±5% accuracy obtained a few years back with pneumatic instrumentation under actual power plant environmental conditions.

Today, with the new more accurate solid state transducers and analog-to-digital converters and with digital computers to process the inputs, we now have available the tools to monitor most parameters of steam generators to an accuracy approaching ±0.5%. Applying instruments with this accuracy, and incorporating the same accuracy into the control system, considerable fuel can be saved when it is recognized that a modern large steam generator may use in the order of two million tons of coal in a year. At this rate, an improvement of 1% in overall operating efficiency could save approximately 20 thousand tons of coal per year, or $800,000 per year assuming $40 per ton of coal.

With solid state devices there are no pivots to become worn, dirty, rusted; no bellows to leak, no moving pot wipers or windings to wear out or become dirty. Also, there are no commutators or brushes to wear out or get contaminated, no adjustment screws to become loose, no fragile tube filaments to open, grid wires to short, cathodes to lose emission or fragile meter jewels to crack.

In summary, we have eliminated almost 100% of the sources of mechanical troubles. Also in the process of developing solid state devices, engineers have had time to develop better methods of connecting circuits together, i.e., soldering, panel wiring, cabling, connectors, etc. They have also developed sophisticated test equipment for troubleshooting.

Diagnostic programs are used to determine any failures, and alternate redundant paths can be used. Because of the high speed of solid state equipment it is possible to run diagnostics during computer idle time, checking data buses as well as Central Processing Unit (CPU) and input/output (I/O) equipment.

Coaxial cable is used in I/O signal transmission where integrity of transmission must be preserved. Coaxial cable and low frequency carrier based transmission is beginning to gain the favor of the industry.

State of the Art Installation

The Pleasant Prairie Power Plant of the Wisconsin Electric Power Company is an example of forward thinking, state of the art, solid state instrumentation and control.[5] The steam generator used at this plant is a Riley Stoker Turbo® Furnace unit with a rated capacity of 2×10^6 Kg (4.4×10^6 pounds) of steam per hour at 1660°C/1660°C (955°F/955°F), which was specifically designed for daily cycling of steam demand. Training and experience have given the operators a great deal of confidence in the reliability of the CRT displays during both startup and operation. Redundant indicators and a set of selected strip chart recordings are provided for use at times when the computer system is inoperative to give the operator constant trending information. Details of this system are included in the referenced report. The following features provide maximum safety in operation of the steam generator:

1. For reliability there are many redundant items: One CPU out of three for two steam generators, one fixed head drum out of two and one moving head disc out of two. Out of two large core memories ($7 \times 32K$) one is redundant, and if some of core memory is lost it is possible to "bootstrap" around that core automatically.
2. The Master Control Panel is compact. By using CRT displays and miniature pushbutton/light combinations, the panel is less than one-half the size used for similar units. This feature contributes to safe operation in that the operator can see more instruments from a given position.

3. The computer system, a Westinghouse Proteus 2500, has two major functions: Controlling the EHC (Electro hydraulic control) for the turbine-generator, and monitoring approximately 2500 data points for the two boiler units. Of particular interest is the EHC control which will control the turbine from turning gear to synchronization and on to demanded load point. A separate automatic system will perform the synchronizing.

   During turbine startup, the Proteus 2500 will perform turbine stress calculations based on the previous hour's data input. The calculated stresses will then be used by the Proteus 2500 to bring the unit on line as quickly and as safely as possible. Future development plans call for steam generator startup using a similar system which will calculate stresses in thick metal components, such as the steam drum, and thus allow maximum speed of ramping of the boiler load consistent with safety.

4. Presently, approximately 40 schematics for one unit and 90 for two units, ten of which are common, are available for CRT display.

5. Colored CRT's are used with red, orange and yellow to indicate urgency of alarms. An alarm which has returned to normal value but has not yet been cleared by the operator is displayed with a black background.

6. Data points are updated at a maximum frequency of once every five seconds and at a minimum frequency of once every 60 seconds, depending upon the data point.

   Field studies at this plant have determined that classifier exit temperatures, for example, should be updated every five to fifteen seconds in order to be effective in averting fires while a mill is being stripped.

7. Diagnostic programs are "bid" periodically to check out hardware, i.e., controller cards, bus, core memory, CPU, etc., and if there is a hardware failure in one component, the "auto bootstrap" will bring the equipment up around the defective hardware.

8. The Proteus 2500 is only used for data acquisition for the steam generators, while a solid state Foxboro analog system handles the control loops. A failure in a control loop will be detected by the computer and alarmed to the operator.

9. A complete alarm system initiated by deviations from set points, abnormal rate of change of variables and abnormal deviation between variables is included and the measured information is accumulated in the memory and periodically updated. On a failure or trip, plotted printouts of the measured variables, describing the conditions before and after the malfunction occurred, are available on demand.

Future Trends

It is encouraging to anticipate the instrumentation for safe operation of large steam generators of the future. We have a vast array of new components. Solid state equipment will predominate because of the superior characteristics enumerated above. However, because of the high price of fuel and lower costs per element of input, conversion, memory, logic, and output, the volume of data handled will be greatly increased. This will give tighter control of efficiency and provide safer operation.

The computer will be programmed to give most efficient dispatching instructions to all units of the net, continuously, with calculated and actual efficiency. Actual efficiency will be calculated from actual fuel input data and measured output energy and compared to efficiency calculated from heat balance. Any deviation above a pre-determined quantity will initiate a review of the preventive maintenance schedule.

The computer will schedule maintenance by the most efficient outage time for each unit.

The instruments and control system of the future will incorporate significant advances in architecture, and since hardware costs per function will continue to decrease, it will be increasingly cost effective to use higher level languages such as Fortran or Pascal, rather than assembly language. Multiple processor distributed systems including standard modular hardware will be common, and since the logic will be in the software, new custom systems will simply require changes to the standard software blocks. Using this philosophy, considerable repetitious design, now done by hand, will be done by the computer, taking proven systems in the form of programs, and modifying them where necessary to produce custom designed systems.

CONCLUSIONS

A great number of data and control points are used to monitor and control a modern large steam generator. The user should consult the steam generator manufacturer for a list of required instruments for safe operation. A review of computer systems indicates that it is not only feasible, but necessary, to use modern solid state microelectronics coupled with thorough study of the instrumentation design to give increased efficiency, reliability and safety to the operation of large steam generators.

Due to government restrictions, and to the reduced rate of increase in demand for electricity, the large steam generator manufacturing and instrumentation industries have been given the opportunity to review their designs. Time has been available to note deficiencies and to correct them in this interim period. However, this grace period is rapidly coming to an end. Increased knowledge and experience will be tested in the production of an increasing quantity of safe and reliable large steam generators in the future.

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