Steam Power Plant Instrumentation: A Case Study of Sapele Power Station

P. A. Ondachi

Department of Mechanical Engineering, Baze University, Abuja, Nigeria

***Abstract*:-This paper presents the installation and functional status of the instrumentation and controls for boiler and turbine plants of Sapele Steam Power Station in Nigeria which has been in operation since 1978.The level of sophistication, adequacy of measurement points, and functional condition of instrumentation systems for Sapele steam power station have been studied in this work. Also investigated was the availability of facilities for instrument maintenance and calibration. The level of sophistication of the instrumentation system for the simple and medium capacity Sapele station was found to be appropriately modest. In terms of sufficiency, measurement points installed on the plant were considered inadequate for the purpose of plant performance analysis. Most of the instruments on the plant were found to be in poor working condition, especially on the boiler plants. The implication of the findings is that accurate plant performance indicators cannot be readily calculated for the Sapele station because provision had not been made to measure all relevant thermodynamic process parameters. Results from the survey also indicate that general overhaul of the plant appears to be overdue.**

Key Words: **Sapele Power Plant, Instrumentation, Basic loop, Performance evaluation, Efficiency, Case study, Measurements, Boiler, Turbo-generator, Obsolescence.**

I. INTRODUCTION

Various activities, be they industrial or general utility, require some form of measurements of the key process parameters. These measurements may be quantitative or qualitative; of the highest accuracy and precision, or rudimentary. The measurements, therefore require appropriate instrumentation schemes and the data derived being used for any or a combination of such purposes as operation, control, safety, performance evaluation, quality assurance and plant history.

The focus of this present study is the assessment of the instrumentation schemes for comprehensive plant performance analysis (emphasis being placed on boiler, turbine and their associated auxiliary plants). Parameters of major interest which are desired to be measured and for which their instrumentation schemes are to be evaluated include pressure, temperature, flow rate, voltage, current, power generated and chemical analyses of the principal flow circuits of the power plant such as the fuel (oil or gas), combustion air, flue gases, feed water, condenser cooling water and lubrication oil. Also of interest are turbine mechanical conditions such as speed and vibration levels.

Historically, power stations at the beginning of the 20th century only required few measurement points for pressure, temperature, vacuum, speed, voltage and current, when plant operation and control were purely manual[1]. However, the level of instrumentation has grown to amazing complexity in modern times. This growth in sophistication of instruments and instrumentation has had to keep pace with developments in increasing unit sizes, pressure levels, and complexity of power plants themselves, as dictated by economic considerations. As power plants have increased in unit sizes and complexity, their requirements for safe, correct and efficient operation have also had to be satisfied by increased levels of remote and automatic controls. These requirements in themselves have also called for additional instrumentation [1].

The measurement of thermodynamic conditions of the working fluid at various relevant points of the plant allows for evaluation of technical performance of the different plant items which will give integrated system performance indication in terms of efficiency. Accurate and precise knowledge of equipment performance allows for systematic planning of plant performance improvement schemes and the accurate determination of operating costs that are optimal. Measurements for performance evaluation require to be accurate and to be recorded continuously for reference purpose.

1.1 Boiler Plant Measurements

The type and number of measurements taken on a boiler plant generally depend on the size and complexity of the plant, type of fuel burnt, energy level of steam used, reheat system (if applicable), once-through boiler or conventional design and similar other considerations [1, 2]. However, the principles employed in the design and installation of instrumentation schemes for all plants are basically the same, notwithstanding the type of plant design.

For a boiler running on natural gas as fuel, for example, the flow rate, pressure, temperature and chemical composition of the gas will be measured, all for the purpose of fuel inlet control and calculation of calorific values, which will be necessary for computation of performance ratios[3]. The air to the burners will have its flow rate, pressure and temperature measured, for the control of efficient combustion process. This knowledge of air flow will be used in boiler management and for performance evaluation.

The temperature and chemical analysis of combustion gases is measured at various points of the gas circuit together with measurement of excess oxygen at chimney outlet. All these will be required for the evaluation of boiler performance[3].On the steam and water circuits, temperature and pressure are measured at various points while steam flow is measured at a point close to the high pressure turbine stop valve. Feed water is sampled at the boiler drum for the measurement of conductivity, dissolved oxygen and suspended particles. Metal temperatures are also taken for boiler drum, superheater and reheater tubes in order to monitor and control thermal cycling, all for the purpose of plant safety [4].All critical measurements such as steam temperature, pressure and flow, metal temperatures, etc., are also continuously recorded to provide history of equipment performance [2, 5].

1.2 Turbo-generator Plant Measurements

Several measurements are also taken on the turbine plant for the purpose of efficient operation and control.

The main steam for expansion in the turbine will have its pressure, temperature and flow rate measured before the turbine stop valve. The exhaust from the h. p. turbine will also have its thermodynamic properties measured. This is also done for the hot inlet steam from the reheater to intermediate pressure turbine (I. P.). Pressure and temperature for all steam extractions for feed heating are also measured. Drains from all feed heaters have their flow rates and temperatures measured together with the feed water temperature before and after each heater. Feed water flow rate is measured before the economizer.

Provisions are also normally made for the measurement, indication and recording of turbine speed, eccentricity, vibration, generator voltage, current and power output[1, 2].

1.3 The Basic Instrumentation Loop

The level of automation and centralization of operations required in a steam power station is only made possible by the appropriate integration, into functional loops, of various instruments. These include primary elements such as temperature or pressure sensors, signal conditioners such as transmitters, amplifiers, converters and summators. Other instruments necessary in the loop are indicators, recorders, relays and controllers to ensure the maintenance of the desired operating conditions[6]. Alarms and annunciators are normally tied into the appropriate loop to give indication of abnormal plant condition.

Other items of instrumentation which may be optional for small capacity units but essential to larger ones are micro-processor based special purpose computers such as data loggers for automatic logging of plant process data which will be very useful for plant performance calculations; alarm scanner to give historical record of unit alarms; sequence of events recorder to provide printed record of sequence of plant equipment tripping and starting.

An instrumentation loop is always arranged such that outputs from the primary devices feed into transmitters where the signals are amplified and sent to the appropriate conditioner. From the conditioner, the signal goes to the indicator and any other instrument for purpose of operation, control or recording[2, 3 & 6].

1.4 Overview of Sapele Power Plant Instrumentation System

The station's instrumentation schemes may not be described as complex whereby involving the use of high-tech control computers. However, the sophistication of the system is at such a level that plant operation, control and monitoring are effected automatically [2].Necessary instruments and controls which will provide protection against unsafe plant conditions are also installed. Measuring instruments are available which furnish plant process data on which operation and control decisions may be based.

The instrumentation system design for all the six (6) units of the station are identical. Each unit has a control desk for the boiler and another for the turbo-generator. There is also a common services control panel for the entire steam plant. All these control desks are located in the central control room. There are also instrument panels for local indications at relevant points in the plant for each unit [2].

The start-up, operation and normal shut-down of each unit and their major auxiliary equipment are effected remotely from the control room. Instruments such as analogue indicators, recorders, controllers, status lights and alarm annunciators are installed that ensure that each of the six units is supervised and operated safely from the control room. Additionally, for plant and personnel safety, instrumentation is available to trip the units in the event of failure of critical controls such as drum water level, fuel flow, grid system instability, etc.

This study was premised on the need to find the level of sophistication of installed instruments at the Sapele power plant as to confirm the adequacy of instrumentation for the purpose of evaluating the performance of major plant equipment; determine the functional condition of installed instruments and their accuracy and to determine availability of skilled manpower and facility for instrument maintenance.

II. METHOD

Research method employed involved on-site real time study and recording of process parameters of all relevant plant items. A period of two weeks was utilized for this purpose. For each principal plant item, an approach of observing and recording its key process parameters for a period of three (3) days was taken.

In the boiler and turbo-generator plants, parameters desired to be measured are shown in Table 1.

Table 1: List of Plant items and Process Parameters Measured

S/N	PLANT ITEM	PROCESS PARAMETER
1.	Combustion Air System	(a) Air heater temperature inlet (b) Air heater temperature outlet (c) Air heater differential pressure (d) Forced draft fan discharge pressure (e) Air flow rate
2	Fuel Control System (Natural Gas)	(a) Temperature (°C) – Burner inlet (b) Pressure (bar) – Burner inlet (c) Flow to Burner (x 1000 m^3/h)
3	Material Safety System	METAL TEMPERATURE (°C) (a) Drum – Water space - Steam space (b) Final super heater (c) Primary super heater (d) H. P. Casing (e) H. P. drain & stop valve
4	Main Steam System -	(a) Temperature (°C) - After primary superheater - After final superheater - H. P. stop valve - H. P. exhaust - L. P. inlet - L. P. exhaust - Condenser inlet (b) Main steam flow (x 1000 m^3 /h) (c) Main steam pressure (bar) - Drum - After final superheater H. P. Stop valve Wheel chamber H. P. turbine exhaust Bled steam to feed heaters L. P. inlet Deaerator Condenser vacuum (mmH_2O)
5	Feed Water System	(a) Temperature (°C) Economizer inlet Economizer outlet Condensate temperature before extraction pump Condensate temperature before and after feed heaters (b) Pressure (bar) – Economizer outlet (c) Flow rate (m^3 /h)
6	Flue Gas System	(a) Temperature (°C) - Main air heater inlet - Main air heater outlet (b) Analysis - Dust density - Smoke density - Combustibles - Oxygen
7	Condenser Cooling Water System	- Flow rate (m^3 /h) - Inlet temperature °C - Outlet temperature °C
8	Turbine Supervisory System	- Absolute expansion (µm) - Differential expansion (µm) - Bearing vibration (µm) - Eccentricity (%) - Speed (rpm) - Power generated (MW)

III. RESULTS

From the consideration of identical design of the six units and their instrumentation systems, description and process data for Unit 6 given below are representative of the entire plant.

Tables 2 and 3 contain values of operating parameters as taken from Unit 6. These tables also show the many plant parameters deemed necessary for performance evaluation such as calculation of efficiency of key components, but for which provisions were not made for the measurement at plant installation phase. This, therefore, means that efficiencies cannot be determined for all relevant plant items even though overall station efficiency may be calculated from knowledge of total fuel consumed and power sent out to the grid [3]. Hence, even where it may be conceded that the instrumentation systems installed are sufficient for purposes such as operation, control and safety, the assertion here is that the instrumentation scheme for the station is inadequate from the point of view described above.

Table 2: Boiler Plant Operating Parameters (Unit 6 – Sapele Power Station)

PROCESS PARAMETERS	READINGS					
	DAY 1		DAY 2		DAY 3	
	A	B	A	B	A	B
1. COMBUSTION AIR						
(a) Temperature (^oC)						
Air heater inlet	31.0	31.0	30.7	31.0	31.0	31.5
Air heater outlet	515*	516*	515*	515*	515*	515*
(b) Differential pressure across air heater (mm H_2O)	115	X	110	X	116	X
(c) Forced draft fan discharge pressure (mm H_2O)	800	X	820	X	815	X
(d) Air flow rate (x 1000 m^3/h)	40	X	40	X	35	X
2. FUEL (NATURAL GAS)						
(a) Temperature ^oC – Burner inlet	--	X	--	X	--	X
(b) Pressure (bar) – Burner inlet	6.0	X	5.8	X	6.0	X
(c) Flow to Burner (x 1000 m^3/h)	28	X	26	X	24	X
3. METAL TEMPERATURE (^oC)						
(a) Drum – Water space	300	305	300	302	300	300
--Steam space	400	398	402	405	400	400
(b) Final super heater	600	-	590	-	595	-
(c) Primary super heater	260*	400*	160*	402*	200*	400*
4. MAIN STEAM						
(a) Temperature (^oC)						
- After primary superheater	380	380	380	380	381	380
- After final superheater	520	480*	518	450*	518	445*
(b) Main steam flow (x 1000 m^3 /h)	-	X	-	X	-	X
(c) Main steam pressure (bar)						
- Drum	98	X	100	X	98	X
- After final superheater	-	X	-	X	-	X
5. FEED WATER						
Temperature (^oC)						
- Economizer inlet	150	X	150	X	151	X
- Economizer outlet	270	X	280	X	282	X
Pressure (bar) – Economizer outlet	100	X	105	X	500*	X
Flow rate (m^3 /h)	500	X	505	X	500	X
6. FLUE GASES						
(a). Temperature (^oC)						
- Main air heater inlet	-	-	-	-	-	-
- Main air heater outlet	-	-	-	-	-	-
(b). Analysis						
- Dust density	-	-	-	-	-	-
- Smoke density	-	-	-	-	-	-
- Combustibles	-	-	-	-	-	-
- Oxygen	-	-	-	-	-	-

Table 3: Turbine Plant Operating Parameters (Unit 6 – Sapele Power Station)

PROCESS PARAMETERS	READINGS					
	DAY 1		DAY 2		DAY 3	
	A	B	A	B	A	B
1. METAL TEMPERATURE (°C)						
H. P. Casing	455	457	456	455	455	455
H. P. drain & stop valve	470	468	470	470	470	467
2. MAIN STEAM						
(a). Temperature (°C)						
- H. P. stop valve	420	425	425	425	422	422
- H. P. exhaust	100	100	100	100	98	98
- L. P. inlet	X	X	X	X	X	X
- L. P. exhaust	X	X	X	X	X	X
- Condenser inlet	X	X	X	X	X	X
(b) Pressure (bar)						
- H. P. Stop valve	90	X	90	X	90	X
- Wheel chamber	45	X	42	X	42	X
- H. P. turbine exhaust	X	X	X	X	X	X
- Bled steam to feed heaters	X	X	X	X	X	X
- L. P. inlet	3.9	X	4.0	X	4.0	X
- Deaerator	3.1	X	3.2	X	3.1	X
- Condenser vacuum (mmH_2O)	60	X	58	X	50	X
(c) Steam flow rate	X	X	X	X	X	X
3. CONDENSATE (feed water from condensing unit)						
Temperature before extraction pump (°C)	14	X	14.5	X	14.0	X
Temperature before and after feed heaters °C	X	X	X	X	X	X
Condensate flow rate	X	X	X	X	X	X
4. DRAINS FROM FEED HEATERS						
Temperature (°C)	X	X	X	X	X	X
Flow rate (m^3 /h)	X	X	X	X	X	X
5. CONDENSER COOLING WATER						
- Flow rate (m^3 /h)	X	X	X	X	X	X
- Inlet temperature °C	-	X	-	X	-	X
- Outlet temperature °C	14.0*	X	14*	X	15*	X
6. TURBINE SUPERVISORY						
- Absolute expansion (μm)	45	45.4	46.0	45.0	46.0	46.0
- Differential expansion (μm)	43.0	44.0	42.0	42.5	43.0	43.0
- Bearing vibration (μm)	5.0	5.0	5.5	5.6	5.8	5.8
- Eccentricity (%)	0.0	0.0	0.0	0.0	0.0	0.0
- Speed (rpm)	3050	X	3050	X	3050	X
- Power generated (MW)	102	X	100	X	72	X

Key to Tables 2 & 3

(A) ---- No. 1 Instrument loop

(B) ---- No. 2 Instrument loop (Duplicated instruments)

(X) ----- Instrument not installed

(-) ------ Instrument not indicating

(*) ------ Indication judged unreliable

IV. DISCUSSION

The study of the instrumentation schemes for Sapele Steam Power Station was carried out under the broad objectives mentioned above. From Tables 2 and 3, clear positions can be taken in line with the study objectives as follows:

4.1 Level of Sophistication of the Instrumentation System:

The station is fully automated using analogue indicators and controllers, representative of technology available in the mid-70s when the plant was designed and constructed [1]. All measurements are made by remote sensing, the signals for the measured variables being appropriately processed through the use of transducers and transmitters.

Considering that the installed 120 MW capacity, non-reheat units are relatively small and simple when compared to the 500 MW units that are now being commissioned in other regions of the world, the level of sophistication of the installed instrumentation schemes will be said to be appropriately modest[1].

4.2 Adequacy of Installed Instrumentation Scheme for Performance Studies:

In carrying out performance evaluation to compare with name plate specifications for rated output and efficiency values in order to plan for plant performance improvement, it is found that a multiplicity of plant thermodynamic and electrical process parameters will be required. Data will be required to evaluate performance of each item of plant such as forced draft fan, air heater, turbine cylinders, feed heaters, etc. With results of performance analyses, deviations from manufacturer's contractual guarantees after years of operation could then be determined and used as basis for the required maintenance work to keep the plant in good functional condition.

This survey revealed that measuring instruments for most operating parameters required for performance analysis (especially on turbo-generator plant) were not installed [1, 7]. Also, where it is expected that some critical measurement will be duplicated for the purpose of comparison and reliability, this was not the case. Therefore, the level of instrumentation of the plant is considered inadequate.

4.3 Condition of Installed Instruments

It was also a major objective of the study to assess the functional condition of the various instruments that were installed, with regards to accuracy of readings obtained from their respective indicators. It was found in this survey that many instruments, especially on the boiler plant, were faulty. As shown in Tables 2 and 3, most of the instruments gave zero indications when the unit was generating while others gave readings quite beyond the span of the indicator scales, implying that there were problems either with the primary elements, transducers or the electronic computing cards.

In arriving at conclusion on the condition of instruments, the principle of reliability by redundancy has been used. This principle states that where more than one instrument are installed to measure a given parameter, the instrument giving indications closest to expected values is more reliable [6]. The conditions of the installed instruments may be easily deduced from Tables 2 and 3. Also, due to the fact that most of the instruments have exceeded their expected life span of about 10 years [3, 6 & 8], it is not very surprising that many of them can no longer give accurate and reliable measurements.

The situation in which many instrumentation loops remain faulty, coupled with the fact that not all required instruments were installed in the first instance, may lead to unsafe and inefficient operation.

4.4 Availability of Skilled Manpower for Instrument Maintenance

The study revealed that Sapele Power Station has a very well organized instrument maintenance department under the leadership of a principal engineer. The department had in-house expertise in burner management and logics, turbine logics and controls, pneumatic control systems and instrument calibration. The field of instrumentation is an area of technology faced with rapid rate of obsolesce, therefore manpower will need to be trained frequently on new trends and equipment.

The instrument maintenance workshop is fairly adequately equipped with a lathe machine, a grinding wheel, dead weight tester, pneumatic precision calibrators, potentiometers, decade resistance boxes and other relevant tools that make the workshop compare well with recommend standards[1].

V. CONCLUSION

The place of appropriate instrumentation in order to achieve reliable, safe and efficient operation of power plants cannot be over emphasized. The Sapele plant is presently one of the few steam power stations in Nigeria. Under the broad objectives of the study it has been reported here that the level of sophistication of the instrumentation schemes was appropriately modest whereas in terms of requirements to carry out performance analysis, the number of measurement points for process parameters were inadequate as shown in Tables 2 and 3.

It is a serious concern that instrumentation systems that make up the "nervous system" of the plant have been allowed to be in poor non-functional state on many plant items of the Sapele Power Station. A cursory look through Tables 2 and 3 will show that values for operating process parameters such as main steam flow rate, steam temperature after final superheater, flue gas analysis and temperature after air heaters, etc., could not be obtained due to faulty instrumentation

While the staff strength for instrument maintenance appears adequate, attention should be paid to issues of regular specialized training so that expertise for maintenance of intricate instruments can be fully developed and domesticated in the plant.

The issue of availability of relevant spare parts which has for some time attained critical importance in Nigerian industries generally, appears to be of urgent dimensions in this power station. The study revealed that quite often many required spare parts are not readily available when they are needed even for routine maintenance. This also explains the fact that at the time of this survey, five of the units were on prolonged outages due to one issue or the other, with the sixth only available on 50 % continuous maximum rating (CMR) for most periods.

VI. RECOMMENDATION

This study has focused on the measurements of essential process parameters and their related instrumentation systems at the Sapele Steam Power Station. The principal function of instrumentation which include operation, control, safety, performance evaluation and plant fault diagnosis and history have been high-lighted.

The modest analog systems installed on the Sapele Plant in the 1970s will have to be upgraded in the next plant statutory overhaul to solve the problem of obsolete instruments and bring the plant up to modern trends of efficient computerized instrumentation systems. Unlike most plant hard ware equipment such as piping, pumps, valves, and motors, the instrumentation and control equipment that controls all facets of plant operation reaches obsolescence long before the end of a plant's useful life[9, 10 & 11].

It is also expected that such overhaul will give opportunity to install adequate measuring points from the point of view of obtaining process data for calculation of plant performance ratios. The situation where relevant operational data cannot be obtained for the purpose of planning for plant improvement efforts is very uneconomical. The poor functional condition of the instruments observed may be a reflection of inadequate investment of resources into plant maintenance efforts and should be quickly addressed in order to avoid inefficient operations and unsafe conditions in the plant.

The challenge of specialized training of personnel already high-lighted, if implemented, will lead inevitably to reduction in operating costs since involvement of costly expatriates (with foreign exchange) in solving plant maintenance issues will be drastically curtailed.

ACKNOWLEDGEMENTS

Guidance received from late Professor L. A. Salami of the University of Benin, Benin City, Nigeria, is hereby gratefully appreciated. Also appreciated is the diligence exhibited by Dr. Chris BalaKatsina of the Federal University of Technology, Minna, in proofreading and giving very useful suggestions for the success of this paper. Supportive care from my wife and children is also gratefully recognized.

CONFLICTS OF INTEREST

Author has no conflict of interest relevant to this article.

REFERENCES

[1]. Central Electricity Generation Board (C. E. G. B.), (1971), London, U.K. Modern Power Station Practice, Vol. 6: Instrumentation, Controls and Testing, (Chapters 1 & 3)

[2]. Nalbandian H (2001) Instrumentation and control in coal-fired power plant. IEACR, London, UK, IEA Coal Research - The Clean Coal Centre Available: https://automationfederation.com/WorkArea/DownloadAsset.aspx?id=142459

[3]. National Electric Power Authority (N. E. P. A.), (1978), Lagos, Nigeria N.E.P.A. Maintenance Manual Vol. BM 37: Instrumentation & Control – Sapele Power Station, Nigeria, 1978.

[4]. Forbes Marshal, (2019) Boiler Efficiency: Introduction and Methods of Calculation, Available: https://www.forbesmarshall.com/fm_micro/news_room.aspx?Id=Boilers&nid=112

[5]. Central Electricity Generation Board (C. E. G. B.), (1971), London, U.K. Modern Power Station Practice, Vol. 5: Chemistry & Metallurgy, (Chapter 2)

[6]. National Electric Power Authority (N. E. P. A.), (1978), Lagos, Nigeria, Design Manual, Vol. BD 9: Instrumentation & Controls – Sapele Power Station,

[7]. Holman, J. P., (1980), New York, U.S., McGraw-Hill Book Company Experimental Methods for Engineers, 2nd Edition.

[8]. R. Jagan Mohan Rao, (2019). How to Create Instrument Loop Diagram Available: https://instrumentationtools.com

[9]. Rita Tatum, (2010) Determining and Stretching the Useful Life of Controls Available: www.facilitiesnet.com

[10]. Nick Kostora, (2016) HVAC System Life Cycles: How Long Should It Last? Available: www.achrnews.com

[11]. Ray DiSandro& Ray Torok (2005) Managing I & C Reliability and Obsolescence Available: https//pdfs.semanticscholar.org