INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue VIII, August 2023

Hazard and Operability Study (HAZOP) and Risk Analysis of Boiler Section of Egbin Power Plant Lagos

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DOI: **https://doi.org/10.51583/IJLTEMAS.2023.12808**

Received: 11 July 2023; Accepted: 15 August 2023; Published: 16 September 2023

Abstract: In this paper, the Hazard and Operability Analysis HAZOP) studies carried out on the boiler section of Egbin Power Plantto validate the hazard and safe operations of the plant are presented. The aim is to identify all the corrective measures to improve safety and to provide refresher training for the operating personnel as well as to look at different scenarios that may come up as production is going on. The methodology used in carrying out the Hazard and Operability Studies was by using a well-structured and systematic method such as the combination of relevant keywords and parameters/variables like flow, temperature, pressure, level, etc. which resulted in deviations. These deviations were caused byequipment malfunctions, operational problems, and other factor. These resulted in consequences thatlead to low power output. The consequences of any action are the risks that should be avoided for the plant to continue to run. To overcome these problems, a tentativeactionwas provided which would make the operator take immediate action to mitigate the problems while maintenance would be carried out to avoid plant shutdown.

Keywords: Hazop, consequences, deviations, equipment malfunction, power plant, primary keyword, secondary keyword.

I. Introduction

Egbin thermal station is a steam turbine plant comprising of six 220MW independent boiler turbine units. The first unit of the plant was commissioned in July 1985, while the last unit was commissioned in September 1986.The station is of reheat type with a high intermediate low-pressure impulse reaction turbine and a hydrogen-cooled generator. Egbin thermal station is the single largest installed electricity generation plant in Nigeria. It has an installed capacity of 1320 MW and generating capacity of 6.8 TWh. Egbin Power PLC was incorporated on November 8th, 2005 to own all of the assets of the power station. The power plant is the largest so far in Nigeria [Adelaja et al., 2007]. Today the company has been privatized.

Hazard and Operability Studies

A HAZOP study is a form of design review that looks at how the plant will cope with abnormal situations, rather than how it will perform under normal conditions (Macdonald and Mackay, 2004.) The study involves consideration of each process line and vessel, examining for each the possible causes and consequences of a whole range of process abnormalities. While some of the postulated abnormalities may not apply to a particular process line, they are all probable with the objective of identifying any significant route to a process upset, operating problems, or hazardous incident. It is a thorough but qualitative approach to risk minimization (NIST, 2008-2023 report))

HAZOP was first used in the chemical process industry(Kletz, 1999). The system was adopted in the petroleum industry and later extended to the food industry, water industry, nuclear power plants Wikipedia).

Definitions:

Hazard - any operation that could possibly cause a catastrophic release of toxic, flammable or explosive chemicals or any action that could result in injury to persons(Gillett, Crowl, & Lee, 2017).

Operability - any operation inside the design envelope that would cause a shutdown that could possibly lead to a violation of environmental, health or safety regulations or negatively impact on the profitability(Smidts & Van den Bosch, 2007).

The technique of Hazard and Operability Studies, or in more common terms HAZOPS, has been used and developed over approximately four decades for 'identifying potential hazards and operability problems' caused by 'deviations from the design intent' of both new and existing process plants. [Lawley, 1974]

A HAZOP study identifies hazards and operability problems. The concept involves investigating how the plant might deviate from the design intent. If, in the process of identifying problems during a HAZOP study, a solution becomes apparent, it is recorded as part of the HAZOP result. However, care must be taken to avoid trying to find solutions which are not so apparent, because the prime objective for the HAZOP is problem identification [Crawley and Tyler, 2003]. HAZOP study was developed to supplement

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experience-based practices when a new design or technology is involved. Its use has however expanded to almost all phases of process life. HAZOP is based on the principle that several experts with different backgrounds can interact and identify more problems when working together than when working separately and combining their results.

The objective of this research is to identify operational hazardous problems of the Egbin power station by carrying out HAZOP study specifically on the boiler section which is the life wire of the power station and to see how this affects the capacity for optimum generation of power, so as to serve as a guide or reference for the new power plants being established now.

II. Operational Problems of Egbin Power Station

Operational problems identified in Egbin power plant during the course of this work can be classified into the following:

Materials: Lack of required spare parts, non-constant gas supply. The gas supply problems can be classified as follows:

(a). External low gas supply pressure problem.

(b). Pigging operation. Problems during pigging operations in1992, led to a rush of gas condensate from the Nigeria Gas Company metering station which resulted in furnace explosion of Unit 4 of the plant and a total cut off of gas supply to the plant for 14 days.

(c). The total amount of gas that was supposed to go to the power station was shared with another independent power station recently established in Lagos, (Applied Energy Services (AES)); a gas turbine with capacity of 290 MW. AES is the first NIPP (national independent power plant) project in Lagos State of Nigeria.

Human: Shortage of required number of personnel (staff)is another contributing factor to operational problems. Lack of qualified maintenance engineers, lack of training for the maintenance personnel in form of seminars and workshops in the operations of the plant are all human problems.

Organisational: These include poor record keeping of data, lack of maintenance culture i.e., lack of inspection of the power unit every 30 days (for repair and cleaning of parts) and lack of plant over-hauling maintenance every 3 years (for changing of auxilliary parts of the power unit as required were identified as part of organisational problems. [Adelaja et al., 2007]

Major plant components [Egbin Power Plant Operational Manual]

(i) Steam Generator is the radiant type, natural circulation with single reheat and duct firing.

(ii) Steam Turbine is the impulse type with two casings, and tandem compound double flow reheat condensing tube. Maximum continuous rating is 200MW, speed 3000rpm. Initial steam pressure = 12500 kPa, initial steam temperature 538 ºC. Exhaust steam pressure 8.5 kPa, number of stages is 3, these are: high pressure, intermediate pressure, and low pressure. It also has 3 low pressure and 2 high pressure heaters with 1 deaerator.

(iii) Condenser is a surface type, cooling water is from lagoon water, number of passes is 2, condensing surface is 10630m^2, number of tubes- 12,142.

Operations of the plant

The plant consists of three main parts, which are the steam generator, turbine and generator section for the production ofelectricity.

Boiler Section

The steam generator which is used to produce steam consists of the following:

- Boiler: This consists of a furnace with all pressure parts (drum, downcomers, water walls, headers, etc). Valves mountings, refractory insulation and outer casing, hangers, supports and steel work.
- Super heaters: reheaters, economiser, burners, vents, drains, flash tanks, and blow down tank.

The turbine consists of the stator and the rotor, which convert chemical energy to mechanical energy and it is in three stages namely: high pressure, intermediate pressure and low-pressure turbine.

The generator converts mechanical energy to electrical energy

Steam is generated in the boiler by filling up the drum to half its level with de-mineralized water which was treated from well water and stored in de-mineralized water tank. The boiler filling pump is used to pump the water from the de-mineralized water tank to the drum in the boiler. The drum pressure is about 13490kPa and temperature of 334ºC at full load (220MW).

Before heat can be generated, three things must be present in the burner, the fuel (natural gas), the air and the igniter. Forced Draft Fan (FDF) is used to extract air from the surrounding with a discharge temperature of 107.19℃ and passes through the gas air heater which increases the temperature of the air, in the presence of these three parameters, the burner is started from a panel which causes combustion of fuel to take place, and the heat generated from the combustion heats up the water in the drum , the steam generated then passes through the primary and secondary super heaters to increase the temperature of the steam to about 538 ℃ and a pressure of 12910kPa. This steam is then piped to the high-pressure turbine to turn the rotor. At this point the temperature and pressure of the steam leaving this point is reduced to about 351℃ and 690 kPa respectively.

This steam is then channelled back to the reheater which increases the temperature and the pressure of the steam to about 541C and 3130kPa respectively, before being channelled to the intermediate pressure turbine to turn the rotor. The steam leaving this point then goes to the low-pressure turbine to turn the rotor. Since the low-pressure turbine is placed on a condenser unit, the used steam leaving this junction is then condensed back to water by allowing this steam to exchange heat with circulating cooling water in a shell and tube heat exchanger. The condensed and cooled steam which is now water, is stored in a hot well for recirculation and is used as a make up in the drum.

For continous action of the process, condensate extraction pump (CEP) pumps the water from the hot well with a discharge pressure of 920kPa and temperature of 44.3℃. It is then passed through the steam jet air ejector to remove any air from the water. It also passes through the gland condenser for further condensation. To increase the pressure and temperature of the steam, a condensate booster pumps (CBP) is used to accomplished this action. The CBP pumps the water to the low-pressure heater (LP) which are three in number to increase the temperature of the water, before it goes to the deaerator which also removes air from the water, and also serves as $_o$heat exchanger and storage tank. At Egbin Power Plant the Deaerator is at the sixth floor while the boiler feed that increases the temperature from 170.5℃ to 173.0 ℃ and pressure from 1030kPa to 14800kPa. This great increase in the pressure is caused by gravity of the water from the sixth floor to the first floor.

After gaining heat from the heater, water is then moved to the economizer which also serves as heat exchanger, to increase temperature from 237℃ to 264 ℃ and reduced pressure from 13760kPa to 13490kPa.

All these actions are to ensure that the pressure and temperature of recycled water is close to that of the drum, in order to avoid thermal expansion which could lead to boiler drum explosion.

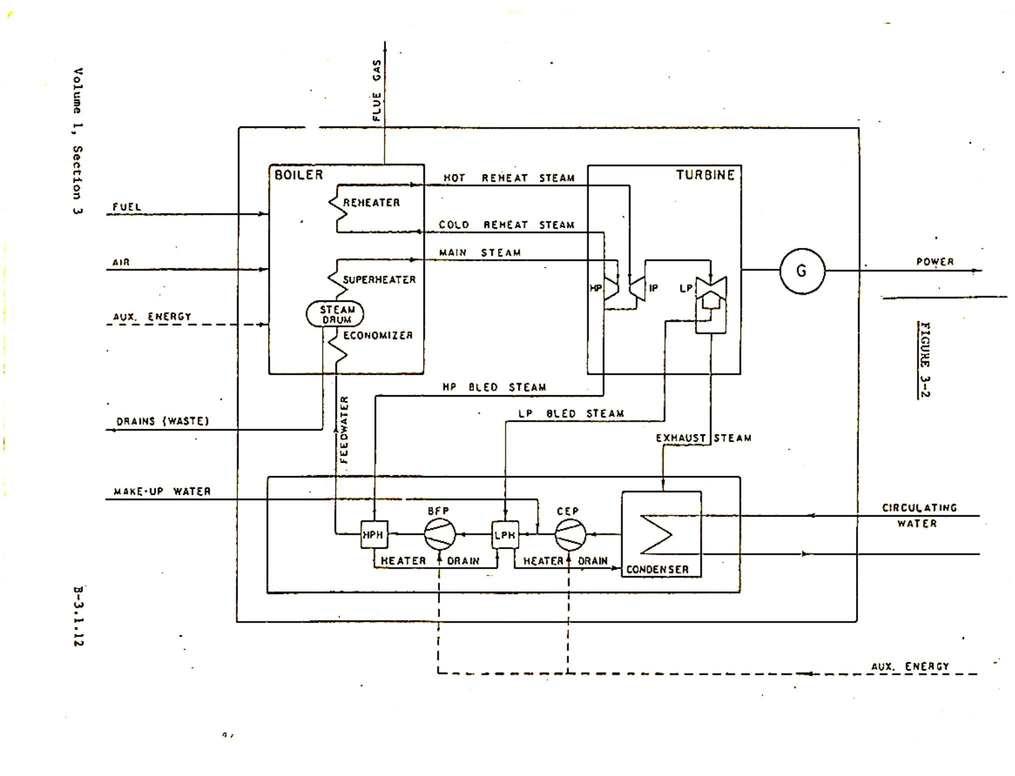

Fig 1: General overview of the plant: Source: Egbin Power Plant Operational Manual

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III. Methodology

In this work, the HAZOP study process involves the use of relevant keywords or guide words combinations and then some essential questions suitable for a specific application are devised on the guide words to the equipment in question in an effort to uncover potential problems. The results are recorded in column format under the following headings:

key word	deviation	possibe causes	Consequence	action required

Resources available to carry out the work

- Process flow diagram of the power plant, in particular, the boiler plant
- Operation data of the power plant
- Personnel from the power plant that will supply important information from the plant
- Operational manual of the plant
- Environmental and Safety Handbook on the plant

Definition of terms

Keyword: These are simple words which are used to qualify or quantify the intention in order to guide and stimulate the brainstorming process and so discover deviations.The keywords are used to ensure that the design is explored in every conceivable way.

Deviation: The keyword combination being applied (e.g. Flow/No).

Possible Causes: Potential causes which would result in the deviation occurring. (e.g. Boiler Feed pump failure, discharge valve fails to open).

There are primary keywords which focus attention upon a particular aspect of the design intent or an associated process condition or parameter, example, flow, pressure, level, temperature, composition, mix etc There are operational words such as isolate, inspect, vent, drain, purge, maintain, shutdown, start-up etc. There is also secondary keyword that, when combined with a primary keyward, suggest possible deviations as shown in the table below

Table 1.0 Some Secondary Keywords and their Meaning

Words	Meaning
No	The design intent does not occur (example, (Flow/No)), or the operational aspect is not achievable, example (Isolate/No).
Less	A quantity decrease in the design intent occurs (example Pressure/Less)
More	A quantity increase in the design intent occurs (example, Temperature/More)
Reverse	The opposite of the design intent occurs (example, Flow/Reverse
Also	The design intent is completely realised, but in addition some other related activity occurs (example, Flow/Also indicating contamination in a product, or Level/Also meaning material in a tank or vessel that should not be there)
Other	The activity occurs, but not in the way intended (example, Flow/other, could indicate a leak or product flowing where it should not, or composition/Other, might suggest unexpected proportions in a feedstock.
Fluctuation	The design intent is achieved only part of the time (example, an air-lock in a pipeline might result in Flow/Fluctuation)
Early	Usually used when studying sequential operations, this would indicate that a step is started at the wrong time or done out of sequence.

Cause: Potential causes that would result in the deviation occurring example, strainer S1 blockage due to impurities in dosing tank T1 might be the cause of Flow/No.

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Consequence: The consequence which would arise, both from the effect of the deviation (e.g."overspeeding of the turbine rotor which could lead to turbine tripping.").

Action required: Where a credible cause results in a negative consequence, it must be decided whether some action should be taken. It is at this stage that consequences are considered. If it is deemed that the protective measures are adequate, then no action needs be taken, and words to that effect are recorded in the action column.

Actions fall into two groups:

(i) actions that remove the cause.

(ii) actions that mitigate or eliminate the consequence.

Whereas the former is to be preferred, it is not always possible, especially when dealing with equipment malfunction. However, removing the cause first is always taken into cnsideration, and only where necessary, mitigate the consequences. [Lawley,1974]

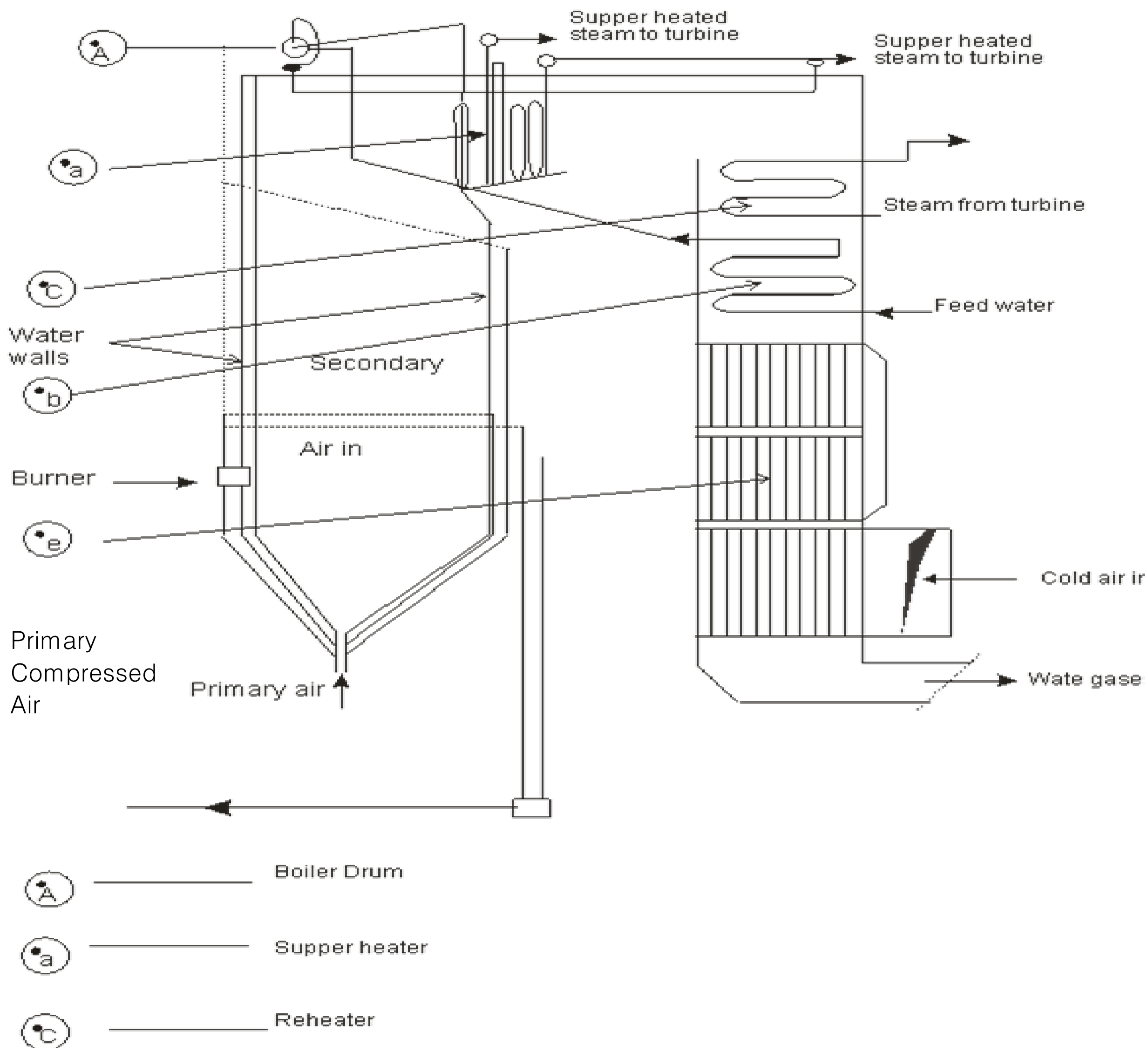

Figure 2. Schematic diagram of the boiler

Assumption: This technique assumes a good level of general management competence in accordance with good engineering practice

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Recording: Each step of HAZOP is recorded which includes a copy of the data (which includes, flowsheet, process and instrumentation diagrams, running instructions models etc.). A copy of what has been produced during HAZOP study.

Table 2.0 Some Necessary Guide words

Guide word	Deviation from Design intention	Remarks
NONE		
No part of the intended result is achieved No operation, damage and nothing else happens wrong process routing		
Reverse Opposite (logical operator) Backflow		
More of Quantitative increase Flow, pressure, temp. Concentration, level,		
Less of Quantitative decrease See More of		
Part of Qualitative decrease Number of components in a mixture, phase change, specifications		

IV. HAZOP Result

HAZOP Study: BOILER DRUM OUTLET -- SUPERHEATER INLET (NODE 1)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No flow	(i) Boiler Feed pump (BFP) failure. (ii) Discharge valve fails to open.	(i) Low generation at that particular time. (ii) Reverse rotation of BFP. (iii) valve overheat.	(i) provision of make-up water to assist the flow of water from the hot well. (ii) Start the pump manually, thereby checking for leakages and carrying out maintenance on the pump.
MORE OF	More Flow	(i) If CEP, CBP and BFP are running at low load less than 55MW. (ii) If BFP discharge is more than 647,504 kg/h.	(i) Banging sound along the line of flow which could lead to high vibration.	(i) Stop CBP and reducing BFP flow.
	More Temperat-ure	(i) Excess burning at a particular Load (MW). (ii) If inlet temperature of the steam is more than 486 ^{0}C.	(i) Destroys the drum waterwall tubes due to overheating of the tubes (downcomers and tube risers), and could lead to drum explosion.	(i) Install water spray on the Primary and Secondary Superheaters.
	More Pressure	(i) Allowing more discharge at the BFP. (ii) If the inlet pressure of the steam is more than 14,320 kPa.	(i) carry over of wet steam to the High Pressure turbine, and can lead to turbine blade corrosion.	(i) Installation of safety relief valve to vent off the excess pressure.
LESS OF	Less Flow	(i) Low BFP discharge. (ii) Tripping of BFP and CEP. (ii) If BFP discharge is less than 647,504 kg/h.	(i) High temperature at the drum to the turbine.	(i) Start up the CBP to assist the flow of water. (ii) Increasing BFP flow.
	Less Temperat-e	(i) Less number of burners working. (ii) Tripping off of burners. (iii) If the inlet steam temperature is less than 486 ^{0}C.	(i) Reduce generation capacity less than 55MW.	(i) Starting more burners to add more heat thereby raising the temperature.

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	Less Pressure	(i) Allowing more discharge at the BFP. (ii) If the inlet pressure of the steam is less than 14,320 kPa.	(i) Leads to low generation.	(i) Start up the CBP to assist the flow of water. (ii) Increasing BFP flow.
OTHER	Maintenann	(i) Equipment failure.	(i) Main unit stops.	(i) Ensure all equipments are working at high capacity, and they should be made of the right materials. e.g., pipes, etc.

HAZOP Study: SUPERHEATER OUTLET—HIGH PRESSURE TURBINE INLET (NODE 2)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No flow	(i) Operator error (ii) Malfunctioning of main stop valve .	(i) Loss of unit / generation.	(i) The main stop valve should be opened manually before 15 seconds.
MORE OF	More Flow	(i) If CEP, CBP and BFP are running at low load less than 55MW. (ii) If BFP discharge is more than 647,504 kg/h.	(i) Overspeeding of the turbine rotor which could lead to turbine tripping.	(i) Stop CBP and reducing BFP flow.
	More Temperature	(i) Excess burning at a particular Load (MW). (ii) If inlet temperature of the steam is more than 541 ^{0}C.	(i) Damage to the superheaters because they are made of tubes.	(i) Install water spray on the Primary and Secondary Superheaters.
	More Pressure	(i) Allowing more discharge at the BFP. (ii) If the inlet pressure of the steam is more than 12,500 kPa.	(i) carry over of wet steam to the high pressure turbine and can lead to turbine blade corrosion.	(i) Installation of safety relief valve to vent off the excess pressure.
LESS OF	Less Flow	(i) Low BFP discharge. (ii) Tripping of BFP and CEP. (iii) If BFP discharge is less than 647,504 kg/h.	(i) High temperature at the drum to the turbine.	(i) Start up the CBP to assist the flow of water. (ii) Increase BFP flow.
	Less Temp.	(i) Less number of burners working. (ii) Tripping of burners. (ii) If inlet temperature of the steam is less than 541 ^{0}C.	(i) Reduce generation capacity less than 55 MW.	(i) Starting more burners to add more heat thereby raising the temperature.
	Less Pressure	(ii) If the inlet pressure of the steam is more than 12,500 kPa.	(i) Leads to low generation.	(i) As stated for less flow.

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OTHER	Maintenancee	(i) Equipment failure.	(i) Main unit stops.	(i) Ensure all equipments are working at high capacity, and they should be made of the right materials. e.g., pipes, etc.

HAZOP Study: HIGH PRESSURE TURBINE OUTLET – REHEATER INLET (NODE 3)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No flow	(i) Boiler Feed pump failure. (ii) Discharge valve fails to open.	(i) Boiler tube metal temperature goes high.	(i) Add external steam to the reheater to reduce temperature and increase flow.
MORE OF	More Flow	(i) If the discharge valve opening does not correspond to the what is on the gauge. (ii) If BFP discharge is more than 630,572 kg/h.	(i) Low temperature of the steam. (ii) In-balance in flow process resulting into power surge. (iii) wear of reheater tubes.	(i) Taking out the one that is malfunctioning by replacing it with the standby.
	More Temperature	(i) Running of more temperature burner than pressure burner. (ii) Malfunctioning of the Reheat Master. (ii) If inlet temperature of the steam is more than 374 ^{0}C.	(i) Causes thermal stress on the tubes which cause the material of construction to be weakened or temperature rising above 580 ^{0}C.	(i) Opening the heater spray to reduce the temperature of the steam.
	More Pressure	(i) If the inlet pressure of the steam is more than 3,780 kPa.	(i) Rupture the reheater tubes.	(i) Regular calibration of pumps and discharge valves. (ii) Frequent checks on safety relief valves relative to the pressure they hold.
LESS OF	Less Flow	(i) Boiler feed pump failure. (ii) Discharge valve fails to open.	(i) Boiler tube metal temperature high. (ii) Loss of unit.	(i) Check for pump availability relative to their maximum rating. (ii) Carrying out preventive maintenance of pump and valves.
	Less Temperature	(i) Loss of lagging material along the pipeline. (ii) If inlet temperature of the steam is less than 374 ^{0}C.	(i) The reheater will not be able to increase the temperature to desirable limit required by the intermediate pressure turbine.	(i) Re-lagging of the pipes.
	Less Pressure	(i) If the inlet pressure of the steam is more than 3,780 kPa.	(i) Cavitation, by sucking in external material when there is no steam to pump.	(i) Increasing the pressure by increasing the firing rate of the burners at the lower level.
OTHER	Maintenance	(i) Equipment failure.	(i) Main unit stops.	(i) Ensure all equipments are working at high capacity, and they should be made of the right materials. e.g., pipes, etc.

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HAZOP Study: REHEATER OUTLET – INTERMEDIATE PRESSURE TURBINE INLET (NODE 4)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No flow	(i) Boiler Feed pump failure. (ii) Discharge valve fails to open.	(i) Low generation at that particular time. (ii) Reverse rotation of BFP. (iii) Valve overheat.	(i) provision of make-up water to assist the flow of water from the hot well. (ii) Stop the pump manually, thereby checking for leakages and carrying out maintenance on the pump.
MORE OF	More Flow	(i) If CEP, CBP and BFP are running at low load less than 55MW. (ii) If BFP discharge is more than 579,724 kg/h.	(i) Banging sound along the line of flow which could lead to high vibration.	(i) Stop CBP and reducing BFP flow.
	More Temperature	(i) Excess burning at a particular load (MW). (ii) If inlet temperature of the steam is more than 541 ^{0}C.	(i) Weakening of pipe carrying the steam thereby weakening the materials of construction. (ii) Cause expansion in the turbine blades and shell which causes both of them to come in contact with each other and could lead to wear and tear.	(i) Reduce firing at the upper level burners. (ii) Regular checks on thermo probe.
	More Pressure	(i) If the inlet pressure of the steam is more than 3,780 kPa.	(i) Breaking of turbine blades, buckets.	(i) Reducing the pressure by reducing the firing rate of the burners at the lower level.
LESS OF	Less Flow	(i) If CEP, CBP and BFP are running at low load less than 55MW. (ii) If BFP discharge is less than 579,724 kg/h.	(i) Boiler tube metal temperature high. (ii) Loss of unit.	(i) Check for pump availability relative to their maximum rating. (ii) Carrying out preventive maintenance of pump and valves.
	Less Temperature	(i) If inlet temperature of the steam is less than 541 ^{0}C. (ii) Loss of lagging material along the pipeline.	(i) The reheater will not be able to increase the temperature to desirable limit required by the intermediate pressure turbine.	(i) The reheater will not be able to increase the temperature to desirable limit required by the Intermediate Pressure Turbine.
	Less Pressure	(i) If the inlet pressure of the steam is less than 3,780 kPa.	(i) Cavitation, by sucking in external material when there is no steam to pump.	(i) Increasing the pressure by increasing the firing rate of the burners at the lower level.
OTHER	Maintenance	(i) Equipment failure.	(i) Main unit stops.	(i) Ensure all equipments are working at high capacity, and they should be made of right materials. e.g, pipes, e.t.c

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HAZOP Study: NATURAL GAS TO THE BURNER (NODE 5)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No Flow	(i) None availability of natural gas from Nigerian Gas Company (NGC). (ii) Malfunctioning of natural gas Slam Shut Valve. (iii) Malfunctioning of burners and accessories.	(i) No firing. (ii) No generation.	(i) Making natural gas available from time to time. (ii) Carrying out maintenance on Slam Shut Valve. (iii) Carrying out maintenance on burners and accessories.
MORE OF	More Flow	(i) High pipeline flow rate above 548,310 m^3/h from NGC. (ii) Malfunctioning of natural gas Slam Shut Valve.	(i) Causes incomplete combustion in the furnace. (ii) Unit loss due to excess gas flow at fire (by the Master Fuel Trip)	(i) Add excess air to neutralize the excess gas. (ii) Recalibration of the gas flow control valve.
	More Temperature	The temperature of the natural gas is being controlled by NGC.		
	More Pressure	(i) High pipeline pressure above 2590 kPa from NGC. (ii) Malfunctioning of natural gas Slam Shut Valve.	(i) Carry over of condensate to the boiler furnace which could lead to boiler explosion.	(i) Shut down the plant manually.
LESS OF	Less Flow	(i) Low pipeline flow rate below 548,310 m^3/h from NGC. (ii) Malfunctioning of natural gas Slam Shut Valve.	(i) Causes incomplete combustion in the furnace.	(i) Increase pressure from NGC. (ii) Carrying out maintenance on slam shut valve
	Less Temperature	The temperature of the natural gas is being controlled by NGC.		
	Less Pressure	(i) Low pipeline pressure below 2,590 kPa from NGC.	(i) Low pressure at any level of the burner will trip the three burners at that level thereby tripping the unit / plant.	(i) Reduction of load / generation.
OTHER	Maintenance	(i) Equipment failure.	(i) Main unit stop.	(i) Ensure all equipments are working at high capacity, and they should be made of the right materials.of constructione.g., pipes, etc.

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HAZOP Study: FORCED DRAFT FAN INLET TO THE BURNER (NODE 6)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No Flow	(i) Fan failure.	(i) No primary air for initial light-off.	(i) Carrying out maintenance on the forced draft fan.
MORE OF	More Flow	(i) Fan failure. (i) If the air flow to the burner is more than 837,800 kg/h.	(i) Incomplete combustion (ii) Can lead to pipe wearing and also to explosion. (iii) Can extinguish fire and cause unit trip.	(i) Using excess air correction by reducing the volume of air.
	More Temperature	If the temp. of the air leaving the pre-heater is more than 271C (ii) Malfunction of the pre-heater	There would be thermal stress which could lead to explosion	Maintenance of the air pr-heater (ii) Changing of the pr-heater if required
	More Pressure	(i) Malfunctioning of the windbox (i) If the inlet pressure of the air is more than 108.31 kPa.	(i) Incomplete combustion. (ii) Can lead to pipe rupture and also lead to explosion.	(i) Using excess air correction by reducing the volume of air.
LESS OF	Less Flow	(i) Loss of Forced Draft Fan. (ii) If the air flow to the burner is less than 837,800 kg/h.	(i) Incomplete combustion	(i) Using excess air correction by increasing the volume of air.
	Less Temperature	If the temp. of the air leaving the pre-heater is more than 271C (ii) Mal-functioning of the pre-heater	There would be waste of energy because if the air is too cold, there would be additional fuel that will be burnt	Maintenance of the air pre-heater (ii) Chang the pre-heater if required
	Less Pressure	(i) Malfunctioning of the windbox. (i) If the inlet pressure of the air is more than 105.91 kPa.	(i) Incomplete combustion	(i) Using excess air correction by increasing the volume of air.
OTHER	Maintenance.	(i) Equipment failure.	(i) Main unit stop.	(i) Ensure all equipment are working at high capacity, and they should be made of right materials. e.g., pipes, etc.

HAZOP Study: ECONOMIZER INLET (NODE 7)

Keyword	Deviation	Possible Causes	Consequences	Action Required
NONE	No Flow	(i) High Pressure Heater failure. (ii) Loss of Boiler Feed Pump.	(i) No supply of feed water to the economizer	(ii) Maintenance of High Pressure Heater. (iii) Starting Boiler Feed Pump.

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MORE OF	More Flow	(i) Two Boiler Feed Pumps working at 50% maximum continuous rating (MCR). (ii) If BFP discharge is more than 627,504 kg/h.	(i) High quantity of dissolved-oxygen going to the economizer.	(i) Stopping one Boiler Feed Pump.
	More Temperature	(i) Malfunctioning of high pressure heater. if inlet temperature of the feed water is more than 236.6 ℃.	(i) High temperature at the economizer which if allow ed to go the boiler drum would cause thermal expansion at the drum and this will result in boiler drum explosion.	(i) By by-passing the high-pressure heater to another one.
	More Pressure	(i) If the inlet pressure of the feed water is more than 13,740 kPa. (ii) Boiler feed pump (BFP) failure.	(i) Can break the baffles in the economizer.	(i) Decreasing the BFP flow (ii) Stop the pump manually, and check for leakages and carrying out maintenance on the pump.
LESS OF	Less Flow	(i) If BFP discharge is less than 627,504 kg/h. (ii) Boiler Feed pump (BFP) failure	(i)Tripping of the unit at maximum higher load. (ii) Lead to load run back.	(i) Increasing the BFP flow (ii) Stop the pump manually, thereby checking for leakages and carrying out maintenance on the pump.
	Less Temperature	(i) Malfunctioning of High Pressure Heater. (ii) If inlet temperature of the feed water is less than 236.6 ^{0}C.	(i) Wasting of energy to increase the temperature. (ii) Low generation.	(i) Increase the temperature of the auxiliary steam.
	Less Pressure	(i) If the inlet pressure of feed water is less than 13,740 kPa. (ii) Boiler Feed pump (BFP) failure. (iii) leakage along the pipelines.	(i) Low generation. (ii) Load run back.	(i) Increasing the BFP flow (ii) Stop the pump manually, and check for leakages and carrying out maintenance on the pump.
OTHER	Maintenance	(i) Equipment failure.	(i) Main unit stop.	(i) Ensure all equipment are working at high capacity, and they should be made of right materials. E.g., pipes, etc.

HAZOP Study: ECONOMIZER OUTLET – BOILER DRUM INLET (NODE 8)

Keyword	**Deviation**	**Possible Causes**	**Consequences**	**Action Required**
NONE	No Flow	(i) Malfunctioning of Economizer outlet valve which is manually operated. (ii) Tripping of Boiler Feed pump.	(i) Boiler drum temperature will rise and can cause boiler drum explosion.	(i) Shut down the unit/plant by closing the main stop valve, so that the remaining steam on the line will not flow to the turbine.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue VIII, August 2023

MORE OF	More Flow	(i) Malfunctioning of Boiler Feed Pump discharge because it run automatically. (ii) If BFP discharge is more than 676,592 kg/h.	(i) Carry over of wet steam to the turbine.	(i) Control the Boiler Feed Pump manually.
	More Temperature	(i) Malfunctioning of High Pressure Heater. if inlet temperature of the feed water is more than 283 ^{0}C.	(i) It damage	(i) Shutting down one of the high-pressure heater. (ii) Carrying out maintenance on high pressure heater.
	More Pressure	(i) If the inlet pressure of the feed water is more than 13,680 kPa. (ii) Boiler Feed pump (BFP) failure.	(i) Over pressurization of the boiler drum giving rise to breakage of baffles, and also the frequent occurrence of this will lead to safety valve spring damage.	(i) Decreasing the BFP flow. (ii) Stop the pump manually, thereby checking for leakages and carrying out maintenance on the pump.
LESS OF	Less Flow	(i) Malfunctioning of Boiler Feed Pump discharge because it run automatically.	(i) Could cause improper distribution of heat in the boiler tube which cause pigging.	(i) Control the Boiler Feed Pump manually.
	Less Temperature	(i) Malfunctioning of Economizer due to the fact that there is no proper utilization of dissolved-oxygen which also takes out heat from the steam.	(i) Carry over of wet steam to the turbine.	(i) Increase firing by turning on more burners.
	Less Pressure	(i) If the inlet pressure of the feed water is less than 13,680 kPa	(i) Low generation. (ii) Loss of unit.	(i) Increasing the BFP flow. (ii) Stop the pump manually, thereby checking for leakages and carrying out maintenance on the pump.
OTHER	Maintenance	(i) Equipment failure.	(i) Main unit stop.	(i) Ensure all equipments are working at high capacity, and they should be made of right materials.of construction e.g., pipes, etc.

V. Conclusion

In the Hazop study carried out, it can be concluded that the major equipment in the boiler section is the Boiler Feed Pump which determines the pressure and flowrate entering each equipment, therefore maitenance should be carried out on this equipment frequently, and also there should be provision for replacement of any of the equipment that is damaged. The equipment should also have spares.

From the study carried out, it was identified that, for the power plant to run optimally, gas supply should be frequent and enough at all times.

The plant was designed to operate for 30 years, therefore, modernization should take place.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue VIII, August 2023

Finally, if the action required in the hazop result can be employed in this plant, it will go a long way to improve the maintenance of the equipments which also would improve the generation capacity of the plant.This result can also be employed by other existing power plantsand also new ones.

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