**CHAPTER ONE**

**1.0 INTRODUCTION**

**1.01 GENERAL OVER VIEW OF THE PLANT:**

Egbin thermal station is a steam turbine plant comprising of six 220MW independent boiler and turbine units. It commenced operation in 1985 with two 220MW steam turbine. Each having its own dual gas/oil fired boilers. Two additional and similar 2220MW units were commissioned in 1986 and a further two in 1987 bringing the total installed capacity to 1320MW.

Egbin power plant is of reheat type with high intermediate low pressure impulse reaction turbine and hydrogen cooled generator. It is the is largest installed electricity generating plant Nigeria owned by the Federal Government of Nigeria under the national electric power authority now known as power holding company of Nigeria (PHCN). They are responsible for the generating, transmission and distribution of electricity in some major parts of the Country.

The power plant boiler as the major system of concern has the capacity of producing steam at 705metric ton/hr at full load. When filled to half of its volume with deminerized or treated water pumped with the aid of the boiler feed pump. The furnace lined with radiant tubes provides the tube wall with the required heat to produce steam which is superheated and piped to the turbine to effect the turbine torque with rotary motion for the production of electricity.

The power plant steam generator is subjected to low productivity, system faults or even hazard because of various conditions such as misoperation, equipment quality change, and external disturbances which might probably spread to a wide range. Thus, it is of great importance to find the possible root cause and consequences according to the current system promptly.

**1.02 SIGNED DIRECTED GRAPH (SDG)**

The signed directed graph (SDG) model is a kind of qualitative graphical models to describe the process variables and their cause-effect relations in continuous systems, denoting the process variables as nodes while causal relations as directed arcs. The signs of nodes and arc correspond to variable deviations and causal directions individually. SDG is composed of nodes, edges and signs. Nodes in a digraph correspond to state variables, failure origins and alarm conditions; and directed arcs between the nodes show the cause-effect relationship between these variables. Each node can take a value of (0), (+), and (-), representing that the corresponding variable is at its normal steady state value, above or below the nominal steady state value, respectively. Arcs take values (+), or (-), indicating that the cause and effect change is in the same direction or the opposite direction. An SDG model shows the pathways of causality for fault propagation. Sometimes, the directed edge with sign “+” is replaced by a solid directed line, the one with sign “−” is replaced by a dotted directed line. It should be mentioned that there are loops in SDG generated from chemical process. When multiplying the sign of each edge within the loop, the influence type of a loop is obtained. The loop with negative result is called negative loop, and that with positive result is called a positive loop. Unlike quantitative approaches, which require a rigorous process model and extensive measurements to collect process data for parameter estimation, an SDG-based approach requires only a minimum of process data to perform a quick diagnosis.

**1.03 FAULT DETECTION AND DIAGNOSIS:**

Fault in chemical process is used to identify whether process (measured or unmeasured) variable individually or collectively are within the normal range, while diagnosis on the other hand refers to determination of the equipment or portion of it that is causing the fault, that is the portion of the fault origin or root cause.

Generally, fault may be grouped as external disturbance from the environment equipment failure and malfunctioning of the sensor or actuator.

The major purpose of fault detections is to determine the existence of fault, while diagnosis is to determine the fault origin or root cause.

**1.04CHARACTERISTIC OF GOOD FAULT DIAGNOSIS SYSTEM**

For a diagnostic system to perform it desired function effectively and efficiently, the following criteria must be considered through all these attributes will not usually be met by any single technique. It serves the bench marks or yard stick for my diagnosis system.

1. Isolability: this is the ability of a fault diagnosis system to distinguish or differentiate faults from each other.
2. Early detection and diagram: this another important desirable attributes of a diagnosis system that is closely related to sensitivity. It involves the ability of the system to detect fault and locate fault origin as soon as it occurs.
3. Robustness: this is the most critical requirement by fault detection and diagnosis system. It requires that the diagnostic system should not fail in case of various noise and uncertainties during operation
4. Novelty identifiability: it is expected that a diagnostic system should be able to decide whether the process is functioning normally or abnormally and if abnormal, whether the cause is known-malfunction or unknown as novelty identifiability.
5. Explanation facility: this require that a diagnosis system should provide explanation and information on how the fault originated and propagated to the current situation
6. Modelling requirement: this demands that the amount of modeling required for the development of a diagnostic classifier should be fast and can be easily developed and also the modeling effort should be minimal as possible.
7. Multiple fault identifiable: this is the ability of the system to identify multiple faults occurring at a time

Adaptability: the system should also be adaptable to environmental changes

1. Storage and computation requirement: this demand that the diagnostic algorithm and implementation should be computationally less complex but might entail high storage requirement
2. Classification error estimation: this is an important requirement for a diagnostic system in building users confidence on its reliability

**1.05 MOTIVATION**

The overall performance and economic benefit of Egbin power plant has not been encouraging over the years, as a result of abnormal situation in the process plant The abnormal situation happen when process deviate significantly from their normal operation ranges, usually due to sensor drifts, equipment failure, change in process parameter or operator’s error. Consequently, if these faults and failure are ignored ,there may be serious consequences such as fire or explosion and even, when there is no emergencies, it tend to lower the product quality ,and other significant lost .

However the use of signed directed graph (SDG) serves to detect and diagnose such abnormalities and by applying quality and equipment maintenance, the fault or failure could be remarkably improved.

**1.06 ECONOMIC IMPORTANCE**

Constant supply of steam produced by steam generator is necessary for the smooth and effective running of the Egbin turbine. And to achieve this there is a great need to ensure normal operation range, operator safety, and preventing damage of the production facilities.

Signed Directed Graph (SDG) based approach with process knowledge can fulfill the requirement of early detection and accurate diagnosis of process fault in the steam generator of Egbin power plant .This abnormalities if not checked would tend to lower plant productivity or lead to serious consequences such as fire, explosion or other significant lost which may be caused by abnormal situation in the process plant

**1.07 OBJECTIVE AND SCOPE**

The objective of this project is to use sign directed graph as a technique of fault detection and diagnosis (FDD) in Egbin steam generator (boiler). This entail modeling of effective and efficient sign directed graph through operation data process knowledge and experience of the operator under no control basis and application to the 705metric ton/hr steam generating capacity boiler of Egbin power plant

**1.08 LIMITATION**

One of the major constrain encountered in this project was inadequate time. This is because the basis of SDG used in this research work, centers on having adequate information about operational data, process knowledge and the experience of the operator, which may not be likely be achieved within the time frame of this project

The complexity of the control aspect of signed directed graph is another area that calls for further research work and will not be included in this project.

Other SDG oriented constraints include optimum sensor location which is necessary for accurate faults detectability and identifiability, and improvement on spurious result all needed to be addressed properly.

**CHAPTER TWO**

**2.0 LITERATURE REVIEW:**

**2.01 EGBIN PLANT OVERVIEW**

Egbin power plant is located at Ijede area of Ikorodu in Lagos Nigeria. Egbin steam generator is dual fired (gas and heavy oil) system with modern control equipment, single reheat, and six stages regenerative feed heating.

The plant was constructed under the joint Japanese/French financing on a turnkey contract basis and most of the equipment were supplied by the Japanese. The overall cost of the plant was US$1Billion with an expected life of 30years, based on the fact that the steam generator should run mainly on natural gas which does not give serious boiler slag and ash problem.(A.O.Adelaja ,O.Y. Ogumula and E.O.Williams).

The natural gas used in the steam generator burner is supplied from Nigerian gas company (NGC) through the escravos –lagos pipeline en route to Egbin gas station. The cooling and feed water is pumped from lagoon into the water treatment plant en route to condenser and boiler drum respectively.

**2.02 EGBIN POWER PLANT HAZOP:**

Hazard and operability study of Egbin power plant boiler have been studied by B.Q. Adetutu ( 7 ) this is an effort to improved the performance of the plant and where there is malfunction equipment failure or misoperation, use HAZOP analysis to ensure that the steam generator (boiler) meet up with the optimum capacity with which it was designed

**2.03 USE OF SDG IN CHEMICAL PROCESS:**

The use of signed directed graph in chemical process was first proposed by Iri et al in 1979 in the work carried out attempt was made to apply graph theory to distinguish diagnosis system failure. Influence of the system element are represented by a signed digraph model and the pattern on the model was introduce to represent symptoms of the system under abnormal situation

The origin of the system failure can be located at the maximal strongly connected component in the cause –effect graph.

In the following year, Umeda et al. developed a method for cause and effect analysis of a processing system based on SDG .Variation on the SDG involving multiple time stages and delay time have been addressed .method for obtaining an SDG from differential equation and algebraic equation were also presented in the same article .a diagnosis. A diagnostic algorithm presented later by Kokowa et al incorporated delay gain and fault propagation probability into the digraph. The method only applied to process without feedback. Siozaki and his co-worker also extended the idea of SDG into five range pattern (0, +, +? \_,\_?)Instead of three pattern (0, +, \_).where +, +? and \_, \_? also denoted gray zones, where it is not clear whether values of state variables are normal or not so the accuracy and speed on search could be improve.

The SDG approach usually utilizes the qualitative influence between process variables and dept first search was mainly used online to determine the fault propagation path and possible fault origin candidate .the online search proceeds from the affected nodes back to the cause node, which makes the diagnosis time longer when the system becomes bigger. Instead of backward fault diagnosis Kramer and palowitch introduced a rule- based method using SDGs for fault diagnosis .The problem of poor diagnosis resolution and sensitivity to alarm thresholds were discussed using a rule based approach. The processing time was notably reduced. However the method has problem in dealing with noisy data and with a compensatory response (CR –meaning the return to its original values) or inverse response (IR –meaning their final qualitative value are opposite the initial values) CR/IR occur when nodes under consideration exhibits conflicting behavior due to multiplying feedback path from the root nodes or when a node is in a negative feedback (control or non control) loop. The corresponding variable are called compensatory variable (CV) and inverse (IV).whenever a CR/IV is exhibited earlier method failed to characterize the ultimate steady state response .To overcome these problem, Oyelele and Kramer introduced steady state qualitative simulation . The main goal was to improves diagnosis resolution without loss of completeness .additional arc are drawn and extended SDG (ESDG)was developed to propagate the effect across IVs and CVs .The use of non causal and causal redundant equation to eliminates spurious solution was first proposed. Chang and Yu proposed another algorithm to overcome several problems associated with SDG. SDG model were here simplified based on “common sense” and a systematic procedure for rule development based on the SDG have been studied by L. Wang. In 1994 Wilcox and himmelblau developed an enhanced SDG approach called the possible cause and effect graph (PCEG) methodology .PCEG inherit a number of properties from SDG such as easy construction, completeness, dealing with cycle system (system with loop) Moreover it overcome some of the drawback of the original SDG methodology .PCEG successfully reduces the search space by providing more accurate information

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**2.04 ATTEMPTES TO ADD QUALITATIVE INFORMATION**

Due to the qualitative nature of pure SDG models, their low diagnosis resolution restricts their usage. Since the 1990's, the use of fuzzy logic and fuzzy set theory to improve the diagnosis resolution in SDG model-based approaches has been discussed by some researchers. Quantitative information has also been added to the SDG, for better understanding of the dynamic system and spurious fault candidates were reduced dramatically.

The use of fuzzy set theory to help address the problem of alarm threshold sensitivity was discussed by Han et al. In their approach, after the strongly connected components which are the possible fault origins are located, fuzzy logic is introduced. Based on their membership degree, variables are sequentially arranged and the most probable fault origins are located. This approach was shown to improve the accuracy of diagnosis resolution. Shih and Lee discussed the removal of spurious solutions using fuzzy logic principles with SDGs, and the Fuzzy Cause-Effect Digraph was proposed. The spurious interpretations attributed to system CR and IR from backward loops and forward paths in the process have been eliminated. Furthermore, this method also can estimate the state of the unmeasured variables, to explain fault propagation paths and to ascertain origins. The combined use of SDGs and fuzzy reasoning for fault diagnosis was also discussed by Tarifa and Scenna. An SDG is used to model the process to be supervised, and an IF-THEN rule base is compiled, one rule for each potential fault. Fuzzy logic is used in the evaluation to overcome the problems caused by noisy data, CR, IR, and model limitations. The fault whose rule has the highest value of certainty should be the first one considered by the operator. Application to a multi-stage flash desalination plant has been performed using this approach.

The literature on combining fuzzy logic and qualitative models looks at improving the representational scope of qualitative models by increasing the granularity through the use of fuzzy representations of real-valued functions. For that reason, Venkatasubramanian et al. believe that these hybrid approaches seem to hold promise.

**2.05** **RECENT ACTIVITY**

SDG based diagnosis approaches have been thoroughly studied by Professor Venkatasubramanian of Purdue University, USA and some of his students. More systematical theory and more comprehensive applications have been developed. The scope ranges from SDG-based fault diagnosis, sensor location determination, operator training, to hazard and operability (HAZOP) analysis, and from single SDG-based methods to hybrid methods. Single fault diagnosis has been studied as well as multiple fault diagnosis. In recent years, Maurya et al. have also presented several significant papers regarding fault diagnosis using SDGs.From their view, SDG-based analysis is based on shallow knowledge (gained from experience) and intuition. Maurya et al., based on earlier contributions of Mylaraswamyet al. have proposed a comprehensive and systematic framework for the development and analysis of SDG-based models and proved feasibility and correctness. Attention also has been paid to the conceptual relationship between the analysis of graph models and the underlying mathematical description of the process. Control loops and flow sheet analysis were, for the first time, discussed thoroughly. The elimination of spurious solutions was achieved by using causal and non causal redundant equations. Analysis of inverse and compensatory response was also thoroughly discussed. The application of fault diagnosis was proved for small examples as well as a flow-sheet size chemical process in this serial work, and the results are quite promising. These papers are important contributions to the literature. Some aspects are touched for the first time, for example, a systematic and proven analysis methodology of SDG model is given, and control loops within the SDG framework have been comprehensively addressed. Though the approach proposed is systematical, comprehensive and more objective (all the analysis is based on the manipulation of mathematical equations), the requirements for development is complicated for complex processes. It requires more detailed and precise mathematical equations, which are not easy to get in practice, and the algebraic manipulation for redundant equations is difficult.

After more than 25 years of development, SDG-based approaches are becoming more and more mature. Different approaches have been proposed to deal with different problems, or combined with other approaches to fulfill different requirements. They all showed promise for the various problems solved.

**2.06 DEVELOPMENT OF DIAGNOSTIC SYSTEM FOR EGBIN POWER PLANT BOILER**

An efficient and effective diagnostic method based on SDG approach is established in this project, to identify possible causes of process disturbances and fault in the boiler. This is centered on compiling an expert system rule base, using all the known process knowledge to increase the diagnostic resolution.

In order to develop the desired diagnostic system two stages are considered. The first stage is the preliminary studies and modeling rule­-base expert system which is done off-line. The second stage deals with the simulation of the rule-base system developed in the first stage, this is carried out on-line.

In the off-line stage, SDG is used to model the process to be monitored. For each potential fault, possible fault pattern are propagated from the graphic model and system simulation and process knowledge are combined to determine all possible qualitative pattern for each potential fault and compiled into IF-THEN rules, one rule for each potential fault.

The composed rule-base expert system is used for on-line diagnosis which is operated together with the monitored process.

The FDI system runs all the time during operation and operation state (start-up, shut-down, or operational changes) is also an input to FDI system.

**CHAPTER THREE**

**3.0 METHODOLOGY:**

**3.01MAJOR COMPONENT OF EGBIN STEAM GENERATOR:**

The steam generator, which its major function is to produce steam consist of the following units

* The boiler: this consist of the drum, downcomer, water wall, safety valve, vents, drain, blowdown, flash tank, e.t.c
* The furnaces consist of the burner, refractory, insulation and casing. The furnace chamber contain the following device s installed strategically for effective heat regeneration

1. Superheater
2. Reheater
3. Economizer
4. Air preheater



FIGURE 1.0 SCHEMATIC DIAGRAM OF STEAM GENERATOR (BOILOER)

**3.02 OPERTION PRINCIPLE OF THE STEAM GENERATOR**

Egbin steam generator is a fire-tube boiler type with radiant tubes natural circulation, single reheat duct firing. The steam generator has capacity of producing 705metric ton/hr of steam.

The boiler feed pump (BFP) supplies the drum with treated water from water treatment plant at the flow rate of 62750kg/hr and temperature of 204oC to the half capacity of the boiler drum. The water in the drum, through natural circulation flow through radiant tubes installed in the furnace chamber

The furnace provides the platform through which the fuel oil/natural gas undergoes combustion in the present of preheated air and ignition source, to produce combustion product or flue gases.

Flue gases or combustion product passes through the furnace chamber transferring heat to the radiant tubes containing natural circulating water, superheater, reheater, economizer, air-preheater, gas collector and then ejected through the stack.

The superheated steam under controlled temperature of the attemerator is piped to the high pressure turbine to turn the rotor, and by this action the temperature and the pressure of the steam leaving the high pressure turbine reduces to 351oC and 690kpa respectively this steam is then channel back to the reheater which increases the temperature and pressure to about 541oC and 3130kpa, and then channel to intermediate pressure turbine to also turn the rotor and finally to the low pressure turbine where it also perform the same function.

The steam leaving the low pressure turbine is condensed and with the aid of condensate extraction pump returned to the boiler drum completing the continuous process of the water-steam path.

**3.03 STEAM GENERATOR SUB-UNIT FOR SDG:**

The steam generator can be separated in to the following sub-units for the purpose of developing each unit signed directed graph. The sub-units considered in this system are as follows:

* The water-steam path or circuit: this is a system of series of connected element for the transportation of water, steam-water mixture and superheated steam. The water circuit includes the following element economizer, furnace tube wall, reheater, airpreheater and steam superheaters.
* The gas path: this involves a complex of elements in which the combustion product flow from the furnace into the atmosphere, it begins in the boiler furnace and passes through the superheater economizer, air pre-heater ash collector, and stack .the air and gas path are connected in series forming what is called the gas-air path The transition from one to another take place in the furnace space. Air is transported by the blower and the corresponded air part in the portion between the blower ad the furnace is at pressure higher than the atmospheric.

Combustion products are transported by the induced draft fan arranged downstream of the boiler and of the furnace and all gas ducts are at a pressure below atmospheric. This is what is called balance draft scheme. The transport of air to the furnace and of combustion product can be ensured by the forced draft fans.

* The air path: include a combination of element for suction of atmospheric air, it’s preheating, transport, and supply into the furnace the air part composes of a cooled air duct, air heater, hot air duct and the burner.
* Fuel path: a combination of element which is transported and delivered to the boiler furnace for the combustion, in the case of gas and fuel oil-fired furnace, the condition of combustion of natural gas and fuel oil have much in common and therefore both fuel can be burn in the furnace of the same design. Here the furnaces are designed primarily for fuel oil with natural gas as the auxiliary fuel.

**3.04 SENSOR LOCATION:**

Sensor location is an important part of SDG development which requires optimization criterion with constraints imposed by issues of detectability and identifiability in order to improve fault diagnosis reliability.

Measuring fault detection qualities related to sensor location require that all fault should be detected as soon as they occur, with each faults differentiated from each other based on sensor reading.

In this project all sensor are assumed to be effective, i.e. they show whether they process variable are normal or abnormal in other word the sensor fault are not considered

Fault under consideration plays a vital role in sensor location as different fault have different behavior. So sensor must be located at strategic point to enhance reachability of the diagnosis system

|  |  |  |  |
| --- | --- | --- | --- |
|  | FAULTS | POSSIBLE CAUSE | CONSEQUENCES |
| 1 | Lack of water in the drum   * Boiler feed pump failure * Low flow rate inlet feed water | * Malfunctioning of BFP * Discharge valve fails open * Manufacturing of economizer outlet valve | * Flow rate of inlet water level of water in drum decreases. * Increases in boiler drum temp, pressure which may lead to boiler drum explosion. |
| 2 | Full of water in the drum   * More flow rate of inlet feed water. | * Manufacturing of BFP. | * Carryover of wet steam to the turbine, resulting from decrease in temp pressure |
| 3 | Burner capacity low | * Less number of burners working. * Tripping of burners | * Reduces generating capacity less than 55Mw * Decreases in temp of the boiler, pressure * Increase in oxygen percent of the flow gas. |
| 4 | Burner capacity high | * Excess, burning at a particular load. | * Destroy the walls tubes due to overheating (tube wall temp increase). * Increase in drum temp and pressure, which may lead to drum explosion. * Decrease in oxygen percent flow gas. |
| 5 | Malfunction of the main steam (throttling valve)   * Steam flow rate to turbine inlet low | * Malfunction of the main­­-steam valve (throttle valve) * Decrease in boiler drum pressure as a result of decrease in hearth temperature. | * Decrease in turbine torque. * Increase in pressure and level of water in the drum. |
| 6 | Forced draft fan failure | * Fan failure * Malfunction of wind box | * Low hearth temp as a result of incomplete combustion * Increase in pressure of the hearth, percent of oxygen in effluent smoke. |

TABLE 1.0 BOLIER PROBABLE FAULT, CAUSES AND CONSEQUENCES

|  |  |  |  |
| --- | --- | --- | --- |
| MEASURED NODES | | | |
| Nodes | Parameter/Units | Values | |
| PA | Feed water pressure | 13,970Kpa | |
| FA | Feed water flow rate | 665,100kg/hr | |
| FC | Over heated steam flow rate | 64,750kg/hr | |
| FB | Cooling water flow rate | 18,475kg/hr | |
| TA | Temperature of the overheated steam | 335oC | |
| PC | Boiler drum pressure | 136,80Kpa | |
| PB | Superheated steam pressure | 12,990Kpa | |
| TB | Hearth temperature | 1,297 oC | |
| FD | Flow rate of air | 825,400Kg/h | |
| OA | Oxygen percent in flue gas | 6.8% | |
| FE | Flow rate of fuel oil | 548,310m3/h | |
| PE | Pressure of the hearth | 1130Kpa | |
| UNMEASURED NODES | | | |
| VB | Inlet water valve | |  |
| LA | Water level at top steam drum | |  |
| VC | Main steam (throttle) valve | |  |
| RD | Turbine torque | |  |
| VA | Cooling water valve | |  |
|  |  | |  |
| FF | Flow rate of auxiliary fuel | |  |
| FG | Flow rate | |  |
| CA | Draught fan baffle | |  |
| PD | Pressure of the effluent at the exist | |  |

TABLE 1.1 BOILER PROCESS VARIABLES (MEASURED AND UNMEASURED) WITH THEIR CORRESPONDING VALUES

**3.05 MODELLING OF BOILER SDG:**

The control of SDG was not considered in this research work. This is as a result of its complexity which may be seen as a new area further of research. Hence the SDG model for boiler was extracted from system topology which includes process knowledge, plant operation

data, and /or operator experience. Mathematical model can also be written base on material balance and energy balance

Water-steam path:

The basic steps in developing boiler SDG after the analysis of the steam generating process, is to develop SDG for each sub unit (water-steam path and fuel-air path) and then combining the sub-unit SDG forming the main boiler SDG of the entire system.

Water- steam path sub unit variables comprises of nodes denoted as PA, VB, LA, FA, FC, FB, VB, TA, PC, PB, VC, and RA . This is shown in table1.1 with it meaning and values. The arc connecting all nodes in this loop where determined by the interrelationship between the nodes as discuss in the previous chapter.

The solid lines ( ) positive arc means that increase in starting nodes will lead to increase in the end node.

While dash line ( ) negative arc means that increase in starting node will lead to decrease in end nodes and decrease the starting node will lead to increase in the end nodes. This notation will be used throughout this project work.

Material flow diagraph was setup by connectivity information between entities of the water-steam sub-unit system as shown in figure 1.1 below

FIGURE 1.1 WATER-STEAM SUB-UNIT SDG MODEL

Fuel –air-burner path

The sub-unit process variables for the fuel-air –burner path are represented by TA,FF,FE,OA,FG,FD,CA,PE,and PD.The digraph of causal influence which is graphically representation of material and energy flow is shown in figure1.2

FIGURE 1.2 FUEL-AIR –BURNER SUB-UNIT SDG MODEL

**3.06 MAIN BOILER SYSTEM DIGRAPH**

The main boiler system digraph is developed by combining the sub- unit SDG of the water-steam path and fuel-air –burner path .this can be achieved by connecting any common variables relating the sub-units

FIGURE 1.3 MAIN BOILER SYSTEM DIGRAPH

**3.07 CONSISTENCY TEST**

Having developed main boiler SDG, the next step is to check the consistent paths through which faults can be propagated, this is done by using the truth value table explained in appendix . In consistency test, the node whose sign are zero are not considered as valid nodes for fault propagation and these nodes are considered normal operation state.

**CHAPTER FOUR**

**4.0 IMPLEMENTATION AND SIMULATION**

**4.01 FAULT ANALYSIS AND DEVELOPMENT OF PATTERN:**

SDG for each fault considered can be reduce from the original SDG model shown in the figure1.3.

This is according to the single fault assumption which state that there can be only one fault origin in each case and based on this assumption other fault origin are deleted from the main SDG. It is also assumed that measurement in each node is rapid and as a result variable nodes are lumped with their corresponding sensors. In other words all fault variable used for fault propagation are sensor values.

Fault propagation from the fault origin or root to the node representing any system variable in the reduce SDG takes the shortest consistent path along the loop.

Total of six faults have been selected and studied in this project each of which is examined. The elements of the pattern for the fault diagnosis correspond to the twelve measured variable from the SDG model of the main boiler system. And may be represented as follows

PA, FA, FC, FB, TA, PC, PB, TB, FD, OA, FE, PE.

Malfunction of boiler feed pump flow rate reduced SDG for malfunction of the boiler feed flow rate was shown in figure1.4 there are two different fault that can emanate from the BPF flow rate.

They are:

Fault 1: high BFP flow rate denoted as FA (+)

Fault 2: low BFP flow rate denoted as FA (-)

FIGURE 1.4 REDUCED SDG FOR MALFUNCTION OF BOILER FEED PUMP FLOW RATE

* Fault 1: high BFP flow rate FA (+)

Considering fault 1 high flow rate of the boiler feed pump FA (+) the root node or fault origin takes signed values FA (+) = +1

* Propagation of this fault along the shortest consistent path from

FA  LA

As represented in the reduced SDG in figure1.4 makes LA = +1

The propagation of FA (+) along the shortest consistent path from

FA FC

Make FC = +1

* The propagation path from FA to PC takes

FA (+) FC (+) PC (-)

Which makes PC = -1

* Of Propagation path of FA to PB takes

FA (+) FC (+) PC (-) PB (-)

Which makes PB = -1

However, other process variables not shown in the reduced SDG of BFP fault in figure1.4 are not reachable consequently they are assumed to be normal taking the pattern for high flow rate of BFP is given as

0, +, +, 0, 0, -1, -1, 0, 0, 0, 0, 0

* Fault 2: low flow rate of the boiler feed pump FA (-)

The fault origin here takes signed values FA (-) = -1 the pattern for low flow rate of the FA (-) takes opposite sign to that of the high flow rate FA (+) above and it is given by

0, -, -, 0, 0, +, +, 0, 0, 0, 0, 0

* Fault 3: malfunction of the main steam valve.

FIGURE 1.5 REDUCED SDG FOR MALFUNTION OF THE MAIN STEAM VALVE

The reduced SDG for the malfunctioning of the main steam valve is shown in figure1.5 the steam valve stuck disturbances is represented as VC (-). This makes the stuck valve fault takes signed valve.

VC (-) = -1

* Propagation along the shortest consistent path is given below
* From VC to FC takes

VC (-) FC (-)

Which makes FC (-) = -1

* From VC to PC takes

VC (-) FC (-) PC (+)

Which makes PC (+) = +1

* VC to PB takes

VC (-) FC (-) PC (+) PB (+)

Which makes PB = +1

All other measured variable are not reachable in the stuck value malfunction and are considered normal, taking values of zero. The pattern for stuck values disturbance is given by

0, 0, -, 0, 0, +, +, 0, 0, 0, 0, 0

Malfunction of burner capacity

FIGURE 1.6 REDUCED SDG FOR THE MALFUNFUNTION OF BURNER CAPACITY

Reduced SDG model for the malfunctioning of burner capacity is given in figure1.6

There are two type of fault that may result in malfunctioning of burner capacity, they are as follows:

Fault 4: burner capacity high

Fault 5: burner capacity low

* For fault 4: burner capacity high

The disturbance caused by high capacity is represented by FA (+). The signed value for high burner capacity TA (+) = +1

The propagation from this fault origin along the shortest consistent path or arc is as follows:

* From TB(+) to OA takes

TB (+) OA (-) which makes

OA (-) = -1

* TB to TA takes

TB (+) TA (+) which makes

TA (+) = +1

* TB to PC takes

TB (+) PC (+)

Which makes PC (+) = +1

* TB (+) PC (+) PB (+)

Which makes PB (+) = +1

TB to takes

TB (+) PC (+) FC (+)

Which makes FC (+) = +1

Other variable are not reachable from the reduced SDG, and as a result takes zero (0)

Pattern for high burner capacity is given as

0, 0, +, 0, +, +, +, +, 0, -, 0, 0

* Fault 5: burner capacity low

Disturbance cause by low burner capacity is represented by TB (-), and the signed values is given by TB (-) = -1 the fault pattern of the TB (-) are opposite of the pattern of TB (+) discussed above. So the fault pattern of TB (-) is given by

0, 0, -, 0, -, -, -, -, 0, +, 0, 0

* Fault 6: malfunction of forced draft fan

FIGURE 1.7 REDUCED SDG FOR THE MALFUNCTION OF FORCED DRAFT FAN

The required SDG for the disturbance of forced draft fan is given in figure1.7 the fault origin is represented by CA (-), and the signed value is given by

CA (-) = -1

Propagation along the consistent and shortest arc is given below

* From CA (-) to FA takes
* CA (-) FA (-) which makes

FA (-) = -1

* CA (-) to OA takes

CA (-) FA (-) OA (-)

Which makes OA = -1

* CA (-) to TB takes

CA (-) FA (-) TB (-)

Which makes TB (-) = -1

* CA (-) to TA takes

CA (-) FA (-) TB (-) TA (-)

Which makes TA (-) = -1

CA (-) to PC takes

* CA (-) FA (-) TB (-) TA (-) PC (-)

Which make PC (-) = -1

CA (-) to PB takes

CA (-) FA (-) TB (-) TA (-) PB (-)

Which makes PB (-) = -1

* CA (-) to FC takes

CA (-) FA (-) TB (-) TA (-) FC (-)

Which makes FC (-) = -1

Hence the disturbance pattern for CA (-) is given by

0, 0, -, 0, -, -, -, -, -, -, 0, -

**4.02 FAULTS PATTERN SUMMARY**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | FA(+) | FA(-) | VC(-) | TB(+) | TB(-) | CA(-) |
| PA | 0 | 0 | 0 | 0 | 0 | 0 |
| FA | +1 | -1 | 0 | 0 | 0 | 0 |
| FC | +1 | -1 | -1 | +1 | -1 | -1 |
| FB | 0 | 0 | 0 | 0 | 0 | 0 |
| TA | 0 | 0 | 0 | +1 | -1 | -1 |
| PC | -1 | +1 | +1 | +1 | -1 | 1 |
| PB | -1 | +1 | +1 | +1 | -1 | -1 |
| TB | 0 | 0 | 0 | +1 | -1 | -1 |
| FD | 0 | 0 | 0 | 0 | 0 | -1 |
| OA | 0 | 0 | 0 | -1 | +1 | -1 |
| FE | 0 | 0 | 0 | 0 | 0 | 0 |
| PE | 0 | 0 | 0 | 0 | 0 | -1 |

TABLE 1.2 FAULTS PATTERN SUMMARY

Summary of all the six (6) examine fault are shown in the table above. The patterns were tested by simulating the boiler system and then compiled into IF-THEN rule base. The pattern table comprises of fault by propagation through signed directed graph

The first row represents the faults whose qualitative state composes the pattern while the first column represents the measured variables used in fault propagation.

**4.03 MODEL SIMULATION RESULT**

Simulation model built with java, and with simulation code shown in appendix is used for the on-line diagnosis. Six (6) faults and disturbances were selected examined

Threshold of 5%of the normal value of the selected measured nodes were choose. Table shows the value of measured variables and their corresponding threshold for the boiler system.

|  |  |  |  |
| --- | --- | --- | --- |
| Nodes | Minimum | Maximum | ± Range |
| PA | 13271.5 | 14668.5 | 689.5 |
| FA | 631845 | 698355 | 33255 |
| FC | 615128.5 | 679879.2 | 32375.5 |
| FB | 17551.25 | 19398.25 | 923.75 |
| TA | 318.25 | 351.75 | 16.75 |
| PC | 12996 | 136364 | 684 |
| PB | 12345 | 136185 | 645 |
| TB | 1232.15 | 136185 | 64.85 |
| FD | 784130 | 866670 | 41270 |
| OA | 6.46 | 7.14 | 0.34 |
| FE | 520.894.5 | 575725.5 | 27415.5 |
| PE | 1073.5 | 1186.5 | 56.5 |

TABLE 1.3 MEASURED VARIABLES WITH THEIR CORRESPONDING THRESHOLD OF 5%

In on-line fault diagnosis, measurements are first processed .then compared with the nominal steady state values. Process data is then transformed into qualitative values either (0), (-), (+).

The second step is the input of expert system rules compiled from qualitative information corresponding to the data. And the third step is the pattern matching and on-line diagnosis of the fault origin .when fault occur the corresponding system variables will change from zero (0) to either (-1),or (+),then pattern values collected are compared with the knowledge base ,the fault for which the pattern matches will be fault pattern and the initial node of propagation of the fault pattern will be displayed as the fault origin. Simulation result for each of the six (6) selected faults and disturbances are shown in figure below.

In each of the simulation result the fault was introduced at 2 hours. The symbol shows high values of the measured variables,while and O stand for low and normal values of measured variables of the operating state respectively.

TIME/HOURS

FAULTT

1

2

3

4

5

6

FA

VC

TB

CA

FIGURE: HIGH FLOW RATE OF FEED WATER FAULT FA (+)

FIGURE: LOW FLOW RATE OF FEED WATER FAULT FA (-)

TIME/HOURS

FAULTT

1

2

3

4

5

6

FA

VC

TB

CA

FIGURE: MAIN STEAM VALVE STUCK FAULT VC (-)

TIME/HOURS

FAULTT

1

2

3

4

5

6

FA

VC

TB

CA

FIGURE: HIGH HEARTH TEMPERATURE FAULT TB (+)

TIME/HOURS

FAULTT

1

2

3

4

5

6

FA

VC

TB

CA

FIGURE: LOW HEARTH TEMPERATURE FAULT TB (-)

TIME/HOURS

FAULTT

1

2

3

4

5

6

FA

VC

TB

CA

FIGURE: FORCED DRAFT FAN FAILURE CA (-)

TIME/HOURS

FAULTT

1

2

3

4

5

6

FA

VC

TB

CA

**CHAPTER FIVE**

**5.0 CONCLUSSION**

Signed digraph diagnostic system has been applied to Egbin power plant steam generator in this research work. The simulation results for the boiler model showed that the algorithm is effective and efficient. The entire six (6) considered fault tested using the diagnostic method were correctly detected and diagnosed as they occur. This is one of the major attributes of effective and efficient fault detection and diagnosis techniques and it is as a result of its in-depth analysis of abnormal situation and its ability to present a complete picture of possible fault hypothesis in a process.

However ,the robustness of this diagnostic technique was not ascertained ,owning to the fact that the characteristics of quick detection makes the method more sensitive and prone to noise which may lead to false alarm .

Generally the result of the diagnostic technique using signed diagraph with application to Egbin power plant boiler showed promise for various fault examine but can be combined with other approaches like HAZOP Fuzzy Logic and Neural Network to fulfill different requirements.

**5.1 RECOMMENDATION**

Signed digraph technique as a useful fault diagnosis tool can be recommended for Egbin power plant boiler in order to keep the system performance as close as possible to optimal.

Further research work should be carried out on the improvement of some of the drawbacks of the signed directed graph based on the approach which majorly involves loss of diagnosis resolution because of is qualitative.

Other area which need improvement include control loop aspect of signed digraph which often leads to inverse and compensatory response (IR and CR).optimum sensor location and selection of proper threshold for each process variables must also be given reasonable consideration.

**5.2 REFERENCES**

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**APPENDIX A**

JAVA SIMULATION CODE

import javax.swing.\*;

import javax.swing.event.\*;

import javax.swing.border.\*;

import java.awt.\*;

import java.awt.event.\*;

import java.text.NumberFormat;

import java.lang.reflect.Array;

class Donatus {

public static void main(String args[]) {

System.out.println("Starting Donatus...");

final Sensor s1 = new Sensor(631845,698355,"PA");

final Sensor s2 = new Sensor(631845,698355,"FA");

final Sensor s3 = new Sensor(615128.5, 679879.2,"FC");

final Sensor s4 = new Sensor(17551.25, 19398.75,"FB");

final Sensor s5 = new Sensor(318.25, 351.75,"TA");

final Sensor s6 = new Sensor(12996, 14364,"PC");

final Sensor s7 = new Sensor(12345, 136356,"PB");

final Sensor s8 = new Sensor(1232.15, 1361.85,"TB");

final Sensor s9 = new Sensor(784130, 866670,"FD");

final Sensor s10 = new Sensor(6.46, 7.14,"OA");

final Sensor s11 = new Sensor(520894.5, 575725.5,"FE");

final Sensor s12 = new Sensor(1073.5, 1186.5,"PE");

final Sensor[] ss = {s1,s2,s3,s4,s5,s6,s7,s8,s9,s10,s11,s12};

JButton button\_1 = new JButton("RUN TEST");

final JLabel msg = new JLabel();

button\_1.addActionListener(new ActionListener(){

public void actionPerformed(ActionEvent e){

updateAll(ss);

printMessage(getPattern(ss),msg);

}

});

JPanel msg\_cv = new JPanel();

msg\_cv.setBackground(Color.black);

msg\_cv.add(msg, BorderLayout.CENTER);

// Create a frame to hold the application

JFrame fr = new JFrame("FirstGUI ...");

fr.setLayout(new GridLayout(14,1));

fr.getContentPane().add(s1);

fr.getContentPane().add(s2);

fr.getContentPane().add(s3);

fr.getContentPane().add(s4);

fr.getContentPane().add(s5);

fr.getContentPane().add(s6);

fr.getContentPane().add(s7);

fr.getContentPane().add(s8);

fr.getContentPane().add(s9);

fr.getContentPane().add(s10);

fr.getContentPane().add(s11);

fr.getContentPane().add(s12);

fr.getContentPane().add(button\_1);

fr.getContentPane().add(msg\_cv);

fr.pack();

fr.setVisible(true);

}

static void printMessage(String s,JLabel msg) {

String[] pattr = {

"0++00--00000",

"0--00++00000",

"00-00++00000",

"00+0++++0-00",

"00-0----0+00",

"00-0------0-"

};

String[] msgs ={

"High flow rate of the boiler feed pump!",

"Low flow rate of the boiler feed pump!",

"Malfunction of main stream valve!",

"Burner Capacity high ",

"Burner Capacity low!",

"Malfunction of Forced draft fan!"

};

boolean ok=false;

for(int i=0;i<6;i++){

if(s.equals(pattr[i])){

msg.setText(msgs[i]);

msg.setForeground(Color.RED);

System.out.println(s+"\t"+pattr[i]);

ok=true;

}

}

//System.out.println(s);

if(!ok){

msg.setText("No fault detected");

msg.setForeground(Color.GREEN);

}

}

static void updateAll(Sensor[] ss) {

for(int i=0;i<12;i++){

ss[i].updateIndicator();

}

}

//putting together the result from the method getTestResult

static String getPattern(Sensor[] ss) {

String out = "";

for(int i=0;i<12;i++){

out=out+ss[i].getTestResult();

}

return out;

}

}

**APPENDIX B**

**TRUTH TABLE**

A truth table is used to check the consistency of a branch or loop.a branch is said to be consistent if the initial and the immediate end node connecting both node match the sign on the branch between both nodes.

Considering two nodes A and B with either positive or negative arc .the consistency is checked by examining, if the sign of the starting node A and the immediate node B satisfy equation given below.

Sign (A→B) =sign (B) × sign (A)

The truth table given below is used for the simplification of the consistency test

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | A B | | | A B | | |
| + | 0 | \_ | + | 0 | \_ |
| + | T | T | F | F | T | T |
| 0 | F | T | F | F | T | F |
| \_ | F | T | T | T | T | F |

TABLE 1.4 TRUTH-TABLE FOR CONSISTENCY TEST

The letter T (True) in the truth table represents a consistent branch according to the measurement pattern of the initial and the final node.

At A=0 and B =0 implies fault does not exist also A=0 and B=0 is termed F (False) at steady state.