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Design Issues and Considerations of a Self-Diagonizing and Optimizing Features of Industrial Process Control

Dr. Ugochukwu. Kamalu[1], Frederick Etumnu[2]
Senior Lecturer[1], ME Student[2]
Department of Electrical and Electronic Engineering
University of Portharcourt, Nigeria

Abstract:
Industrial process control designs has gone from the mere local control designs to a more advanced control levels of designs in recent times. Some of the key features that are incorporated in these advanced industrial process control design systems are self-diagnostic and optimizing features. This paper focuses on the design and features of a Shell Multivariable Optimizing Controller (SMOC); a self-optimizing controller used in a distillation column of an industrial process control plants. Also, the design and features of a SMART transmitter, a self-diagnostic Safety Instrumented System (SIS) tool, was also investigated in this work.

Keywords: Self, diagnostic, self-optimizing, transmitter, controller, process, control, industrial

I. INTRODUCTION

These days, the strategies and technologies employed in most industrial process control systems are very sophisticated and advanced. A number of the designed systems and equipment used in the advanced process control require very little or no human intervention; they perform a number of tasks like diagnosis, calibrations, optimization, prediction and checks all by themselves – they are more or less self-driven systems. In this paper, a searchlight would be beamed specifically on industrial process control systems with self-diagnostic and self-optimizing capabilities. A self-optimizing industrial process control system have the ability to endogenously modify themselves to meet some set objectives of the process control system irrespective of changes or disturbances within the system. This means that the system would most likely have features that allow it to detect, and make modification in response to changes within the process control system [1]. More so, self-optimizing system models have the capability to significantly improve the plant performance. This is as a result of the effective control scheme it incorporates [2] [3]. An important focus of self-optimizing process control systems is to minimize losses in the process irrespective of the disturbances that may be imminent within the processes [4]. If a process control system has a constant set point for the controlled variable and yet achieve an acceptable loss within the system, such a system could be said to be a self-optimizing system [5]. A self-optimizing industrial process control system like the Shell Multivariable Optimizing Controller (SMOC) system is an intelligent system that does respond autonomously as the process condition changes. It is very flexible and robust to learn, adapt their behavior to varying conditions and then optimize as the situations demand [6] [7]. On the other hand, self-diagnosis, a term that was somewhat borrowed from traditional medical science which imply checking, identifying or diagnosing a medical condition, is now been applied in engineering and science for identification of faults and anomalies in systems [8]. The industrial process control instrument with self-diagnostic capability this work is looking at is a SMART transmitter, an intelligent device which is able to report failures and inconsistencies within the process for prompt action or corrective measures to be taken [9]. The SMART transmitter, being a microprocessor-based instrument, makes use of internal algorithm for self-diagnosis of possible anomalies and failures within the process device or equipment. It has the abilities to log and plots set points and key variables over a period of time [10]. The essence of incorporating these self-diagnosing and optimizing features is to bring about improvement in the performances of the industrial process control systems so as to enhance or ensure optimum and consistent production and reduction in wastes within the process industries [11].

II. DESIGN ISSUES AND CONSIDERATION

These include the specific strategies and consideration or challenges encountered during the planning, design, implementation of the self-diagnostic and optimizing controller. Successful implementation of the system design, involves adequate planning of the structure and selection of suitable components and parameters. The issue surrounding the design of self-diagonizing and optimizing features of industrial process control are both with hardware and software. The general considerations followed in such designs should always be outlined. Every design has a specific task it intends to accomplish. This has to do with the functional and non-functional requirements. Design specification varies for different applications of the process control system. A general overview of some of the design specifications are as follows:

i) Functional requirements: This should specify all the functions the design system is expected to do

ii) Nonfunctional requirement: It should outline the scope of the design which should highlight what it should not do.

iii) Operational Environment: The environment should be specified. This includes stating if it is in the sea, airy area, dusty and so on.

iv) Tools/Equipment required for the design
v) Software to be used in the design
vi) Parameter estimation and optimization
vii) Design approach to be used
viii) All the expected faults in the system
ix) Checks, test and troubleshooting procedure
x) Recalibration/Reset to optimum value
xi) Hardware equipment selection technical considerations.

III. The Significance of Self-Diagnosis and Optimization in Industrial Process Control

The introduction of Advance Process Control (APC) technology with self-diagnosing and optimizing features in industrial process control systems, have a number of advantages like increased throughput, reduction in quality give away and off-specs, increase in the production of more valuable products, reduction in energy cost, reduction in utility consumption and increase in safety performance of the system and so on [12]. The benefits are enormous and this is why most modern industrial process control facilities are employing these advanced technologies. Shell Multivariable Optimizing Controller (SMOC), is an example of such advanced technologies. It is a Model Predictive Controller (MPC) which uses the process model to predict the behaviour of the process so as to dynamically make predictions at a steady-state targets which yield great results at relatively low cost [13]. This model predictive control designs have been widely applied in most industrial process control in recent times due to the high performing index it has without expert intervention for long durations [14]. More so, self-diagnosis in industrial process control systems have a number of benefits as well. It has increased the availability and utilization of process plants due to earlier detection of possible failures or damages. It has made it possible to reschedule maintenance and process system overhaul plans ahead of time. This has contributed immensely to the high reliability figures that are recorded in these advanced industrial process control plants [10].

IV. Implementation of SMOC on A Distillation Column

Yokagawa Electric Corporation [12] implemented a design of a self-optimizing controller otherwise known as SMOC on a distillation column shown in Figure 1. It is a depropanizer column with a reboiler at the bottom which provide the required heat for the distillation process. The heavy bottom product is propane while the lighter hydrocarbons (Ethane, methane, etc.) go out as the top products. The arrangement has a reflux drum which is provided at the top section on the column for proper stripping and separation of the hydrocarbon constituents. There are a number of independent controllers and analysers like the Level Controller (LC), the Pressure Controller (PC), the Flow Transmitter (FT), Temperature Indicator (TI), and Quality Analyser (QR) shown in Figure 1 which monitors and ensure the produced products and processes are of the required specifications and qualities. The single input and single output controllers working independently makes it very difficult to optimize the whole process. This is where the use of an Exasmoc, (SMOC) comes into play. SMOC helps to self-optimize the process and ensure that losses and disturbances which can negatively affect optimization are handled efficiently. As seen from Figure 1, The signals from the QR on the reflux and the bottom product, the PC on the column, the FT feed into the column, and TI variables goes into the Exasmoc (SMOC) which in turn manipulate the reflux flow into the column and the flow on the reboiler online to either increase or reduce the heating fluid depending on what is needed with the objective to self-optimize the process system. The SMOC, being a multivariable controller interact with a great percentage of the process and then takes informed decision all by itself in line with its internal algorithm. The SMOC system considers the disturbances within the process system and acts as required. Figure 2 shows a transfer function model of the distillation column. The transfer function model makes it easy to tune the self-optimizing SMOC controller for optimum efficiency. Each of the six transfer function blocks can be tuned to achieve the desired result.

V. THE DESIGN OF SMOC: A SELF-OPTIMIZING CONTROLLER

The design of the SMOC controller is done using software tools known as PC-SMOC, AIDA and Exasmoc. The design is done offline before it is then integrated into the industrial process control system for self-optimizing of the process system.

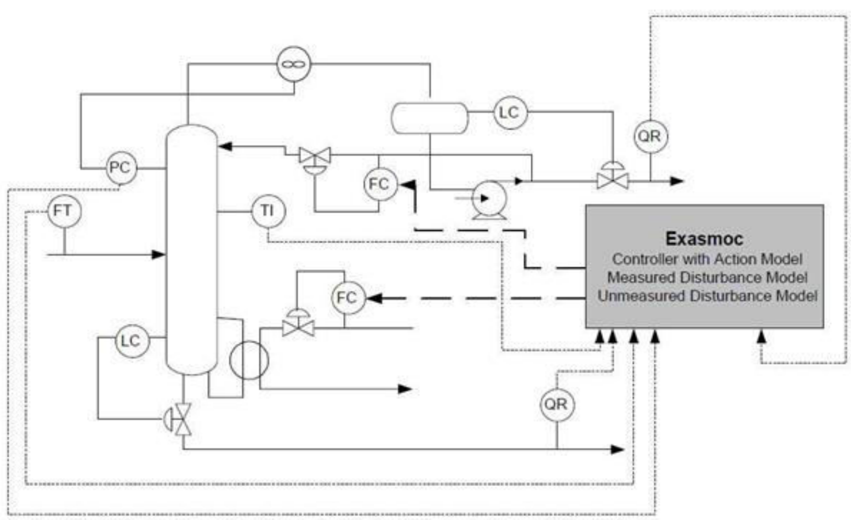


Figure.1. A distillation column with a self-optimizing controller feature [12]

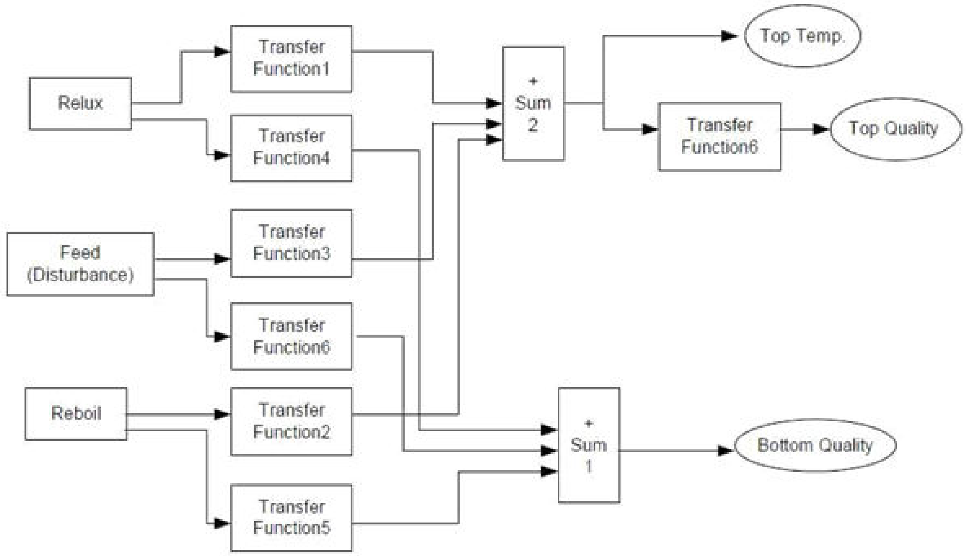


Figure.2. The transfer function model of the distillation column [12]

A PC-SMOC is an offline suite used for designing, simulating and tunning the SMOC optimizing controller before launching it on to an online platform. The PC-SMOC could be used in conjuction with Advanced Identification Data Analysis (AIDA). AIDA is a packaged that helps or is used to design emperical process model from various process variables that interact [10]. Both the PC-SMOC and AIDA are window based offline packages used for modelling of the self-optimizing controller. AIDA is a user-friendly software with graphic builders that has been designed to be robust is handling disturbances and noise that is typical in a live plant [15]. SMOC uses what is known as "Grey Box Model" design when designing a process plant. It is called "grey box" because something about the process is known. SMOC does not actually model the whole process, rather it concentrate on the key variables which can help to optimize the process. Figure 3 shows a block diagram of a grey box model which is unlike the black box model where the design engineer may not know about the process [16]. Each of the blocks in Figure 3 represent various variables whose transfer function can be tuned to optimize the entire process. This model design allows designers to model block by block to achieve the set objectives of the process. It looks like a process flow diagram [12].

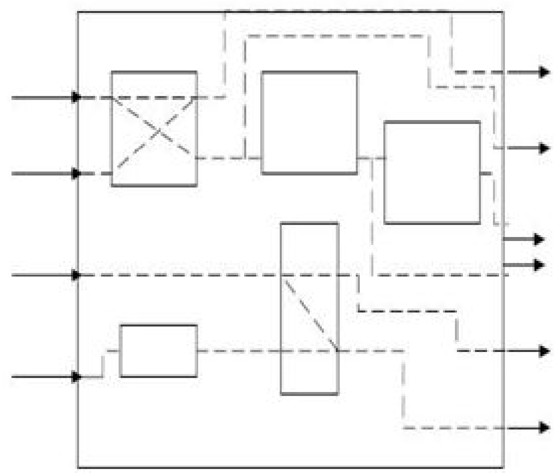


Figure. 3. The grey box model design [12]

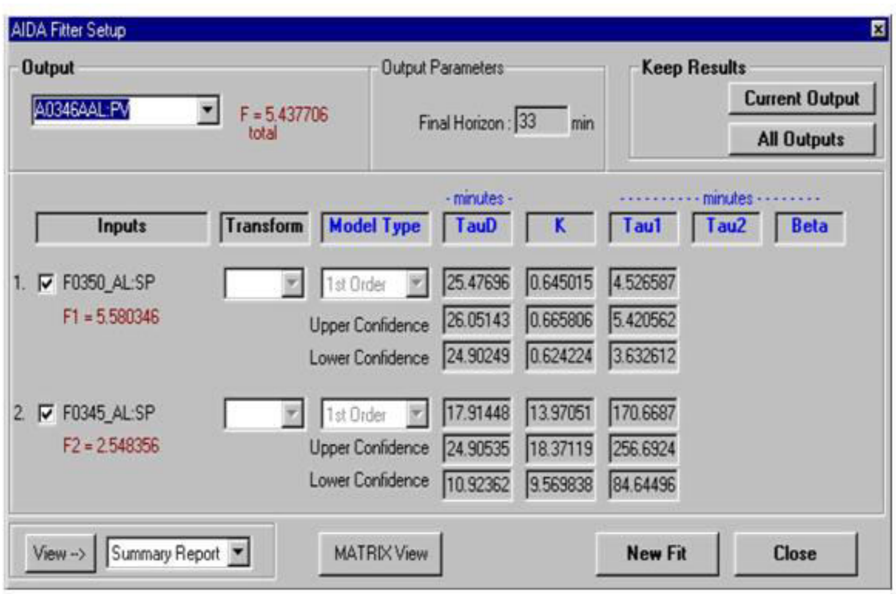


Figure.4. AIDA setup showing relationship between input and output variables [12]

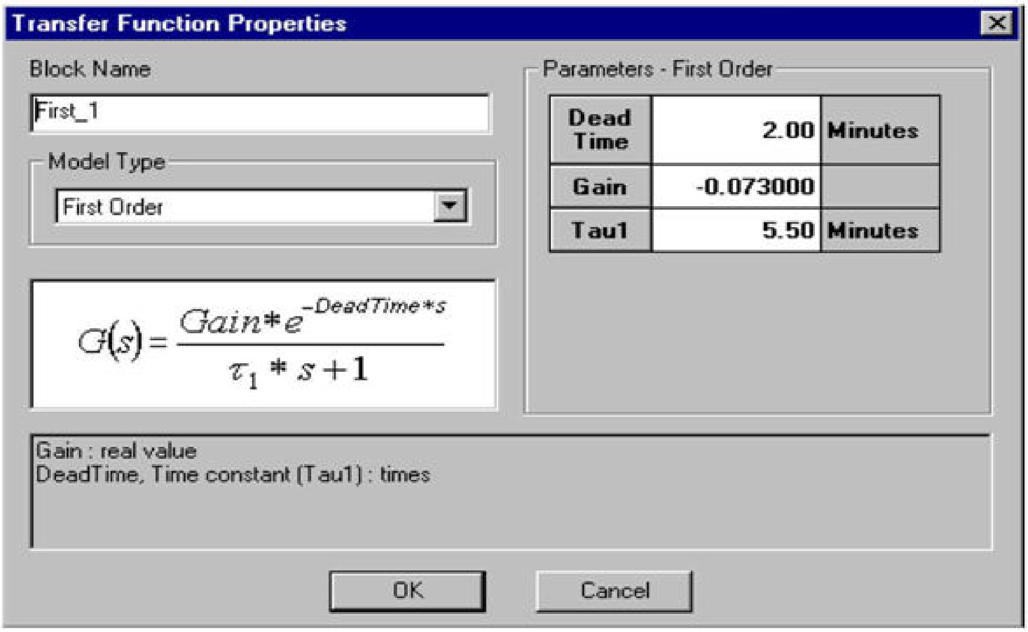


Figure.5. PC-SMOC graphic builder showing the transfer function properties [12]

V. AIDA, PC-SMOC AND EXASMOC

Design suits and simulation results

Figure 4 shows the graphic builder design suit used to develop the self-optimizing controller. The inputs F1 and F2 transfer functions can be manipulated to give a desired output F. Considering the distillation column mentioned in Figure 1, the transfer functions as seen in Figure 2 can be inputted into the AIDA software to get a desired output such as the top quality, bottom quality and the top temperature. Figure 5 displays the PC-SMOC graphic builder showing the transfer function properties. Here the dead time, gain and the time constant properties can be varied to optimize the controller. Figure 6 shows the simulation result of the distillation column shown in Figure 1. The graphic representation of the each of the variables are displayed in the Figure 6 which is an erroneous model. In Figure 7, the self-optimizing controller tuned itself to correct the error or disturbance that was present in the simulated PC-SMOC erroneous model. From the Figure 7, it can be seen that the instability that was in Figure 6 was not in the Figure 7 as the model predictive optimizing controller have made the necessary adjustment based on the controller's set targets. One thing to note about the design of the self-optimizing controller using PC-SMOC is that once the designs have been tested and ran offline, its parameter can then be downloaded from the PC-SMOC to the Exasmoc (SMOC) which is the online package. If there is need to make or update anything, it is done offline on the PC-SMOC before it would be integrated online. The SMOC is window based and does not require any interface software or suite. They are just integrated into the Distributed Control System (DCS).

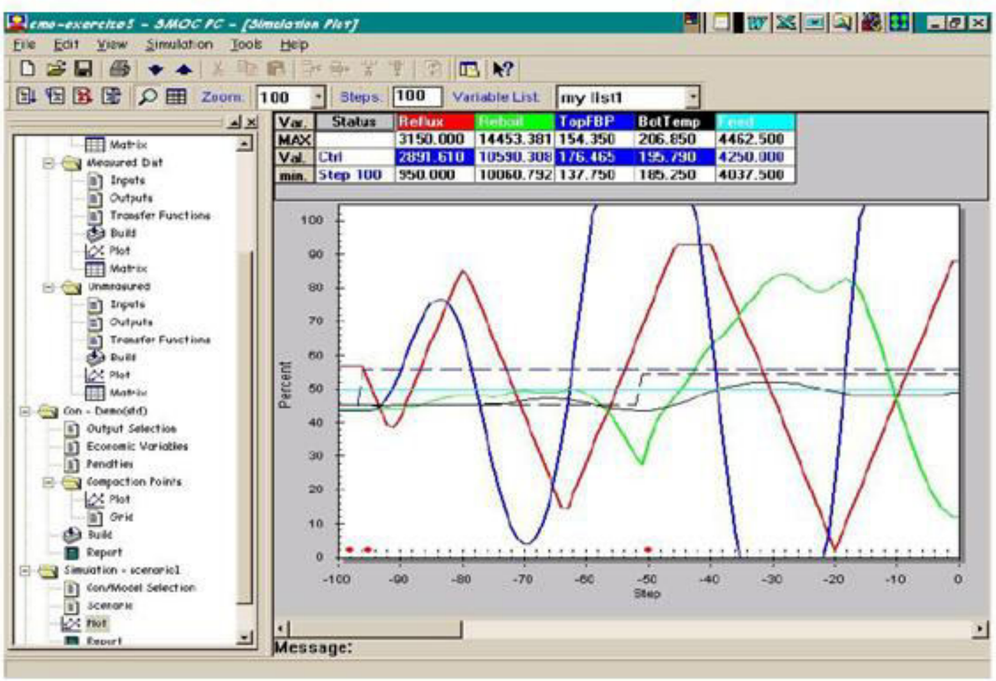


Figure .6. PC-SMOC simulation plot with erroneous model of the distillation column [12]

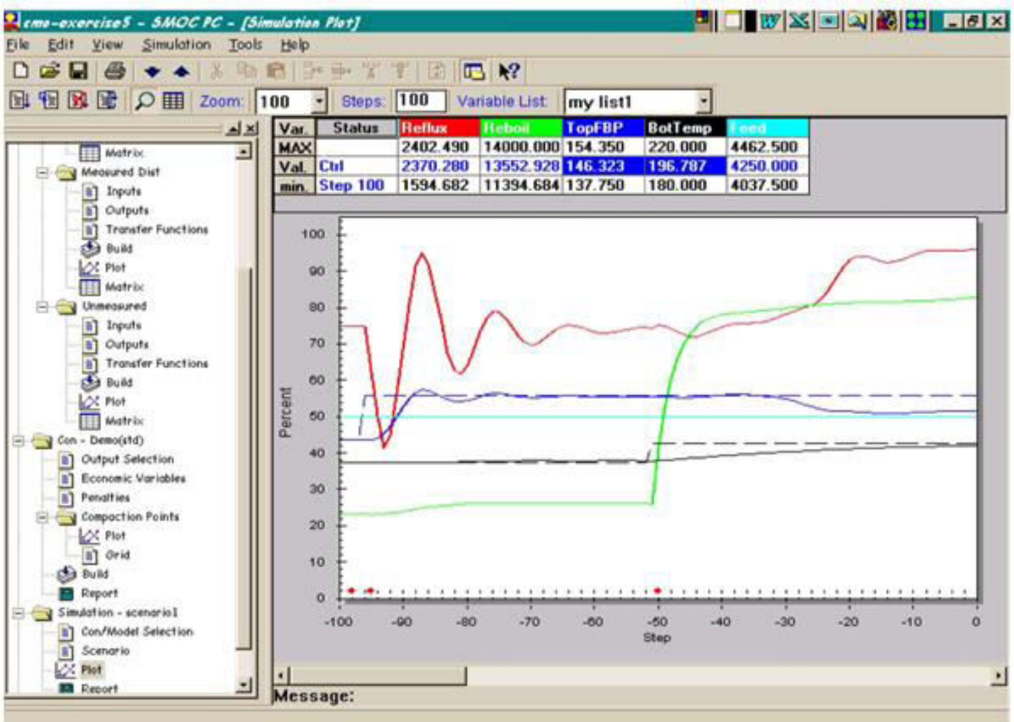


Figure.7. PC-SMOC simulation plot of the distillation column with observer model [12]

VI. SMART Transmitter with self- logs which send alerts when there is diagnostic features significant difference from the previous logged values [10].

Each of the transmitters (i.e. the level, temperature, flow and pressure transmitters) that is installed on the depropanizer distillation column in Figure 1, have Safety Instrumented System (SIS) function with self-diagnosing capabilities. The transmitters are said to be SMART because of the intelligence that makes them to self-diagnose online and report its findings to the DCS for action to be taken. Some of the faults the SMART transmitters do self-diagnose are set point deviation which is usually gotten from the systems raw data. Instability in the system performance is also seen as a fault. This is self-diagnosed via the system deviation histogram or plots. Changes in the characteristics of the process is also recorded as a fault. This is detected by cycle counter and cycle counter Apart from self-diagnosing the faults mentioned above, a key function of this SMART transmitter is the Safety Instrumented System (SIS) that it has that enables it to self-diagnose anomalies such as very high level, very high temperature, very high flow rate and very high pressure in the distillation column. They are designed to operate in a voting format like two-out-of-three-voting format (i.e. 2oo3). This means that, if two of the parallel installed transmitter senses or self-diagnose a high-high level for instance, the SIS is activated so as to safeguard the distillation column and the process from having an overflow due to the high-high level [17]. The transmitter sends signal to a final control element such as a valve to trip so as to protect the integrity of the process equipment. This self-diagnosis is done online to identify anomalies and faults that could pose a threat or cause process safety incidences and report or logs its results to allow for prompt action. Usually, the self-diagnostic property of the industrial process control system triggers the SIS to activate so as to adequately safeguard the industrial process system.

VII. DESIGN AND OPERATIONS OF THE SELF-DIAGNOSTIC SMART TRANSMITTER

The Self-diagnostic SMART transmitter is designed with sensor, logic solver and a final control element component as shown in Figure 8. The sensor interacts with the process and send its observation to a logic solver which is built with microprocessors to process the received information from the sensor and then send to the final control element to execute the safety or emergency shut down or trip action.

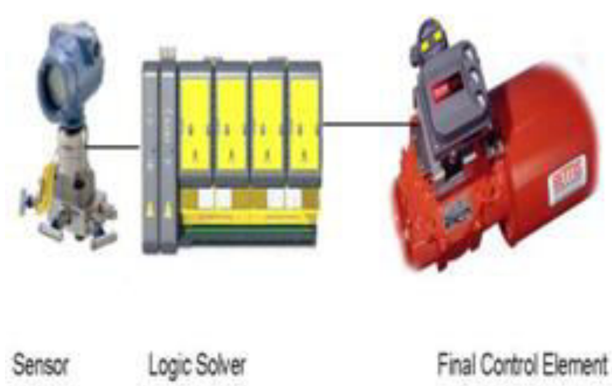
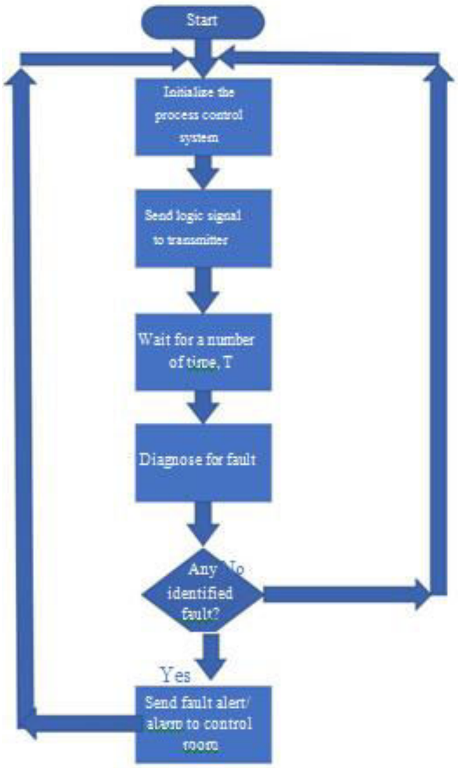


Figure.8. Components of a Safety Instrumented system with self-diagnostic feature [18].

For the operation or how the self-diagnostic system detects fault, the flow chart below illustrates that. When the process control system with the SIS is started, it first initializes itself. Then the logic solver sends the logic signal to a transmitter. The transmitter is sometimes incorporated with the logic solver or with the final control element (may be a valve). While the information is being processed, the fault is Flow chart showing how the self-diagnostic system detects fault



being self-diagnosed for a time T. A timestamp is set for the self-diagnosis. Once the time elapse, a decision is taken within the logical solver. If a fault is diagnosed, a fault alert is sent to the Distributed Control System (DCS) or a control room, however, if no fault is diagnosed after the set time, T, the process begins all over again and again in a continuous fashion.

VIII. CONCLUSION

Industrial process control system with self-optimizing and self-diagnostic features are very robust, reliable, safe and economic viable assets. This work investigated the design strategies of the systems. It was seen that with the use of software tools like the PC-SMOC, the AIDA and the Exasmoc window-based suits, the self-optimizing controller (SMOC) can be designed.The software packages make it easy to design, simulate and tune the self-optimizing controller both in the offline and online platforms. More so, the design and component structure of the SMART transmitter which is also a safety instrumented system was reviewed. A depropanizer distillation column was used as a case study for the implementation of the self-optimizing and self-diagnostic features.

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