METHODOLOGY FOR DESIGNING SUPERVISORY SYSTEMS: CASE STUDY OF A COUNTING SYSTEM OF NATURAL GAS

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Abstract: *After a presentation of the functionality of a supervisory system for complex processes, we present the concepts of SCADA (supervisory control and data acquisition) systems. A methodology for designing supervisory production systems has been presented. This methodology is based on a functional analysis technique SADT (Structured Analysis and Design Technique) and has been applied on an example of a SCADA system of a thermal power plant (TPP). This technique allows a functional description of a SCADA system. An application of supervision of a counting system of the natural gas of a TPP is presented.*

Key-words: *Supervisory systems; SCADA; Functional Analysis; Thermal power plan; Natural gas.*

1. Introduction

Today, the supervision of production systems is more and more complex to perform, not only because of the number of variables always more numerous to monitor but also because of the numerous interrelations existing between them, very difficult to interpret when the process is highly automated.

The challenge of the future years is based on the design of support systems which let an active part to the supervisory operators by supplying tools and information allowing them to understand the running of production equipment. Indeed, the traditional supervisory systems present many already known problems. First, whereas sometimes the operator is saturated by an information overload, some other times the information under load does not permit them to update their mental model of the supervised process.

Moreover, the supervisory operator has a tendency to wait for the alarm to act, instead of trying to foresee or anticipate abnormal states of the system. So, to avoid these perverse effects and to make operator's work more active, the design of future supervisory systems has to be human centered in order to optimize Man-Machine interactions.

It seems in fact important to supply the means to this operator to perform his own evaluation of the process state. To reach this objective, Functional Analysis seems to be a promising research method [1]. In fact, allowing the running of the production equipment to be understood, these techniques permit designers to determine the good information to display through the supervisory interfaces dedicated to each kind of supervisory task (monitoring, diagnosis, action, etc.). In addition, Functional Analysis techniques could be a good help to design support systems such as alarm filtering systems.

By means of a significant example, the objective of this paper is to show interests of the use of Functional Analysis techniques such as SADT (Structured Analysis and Design Technique) for the design of supervisory systems. An example of a SCADA system of a thermal power plant is presented. The next section briefly describes the characteristics of a SCADA system and the problems linked to its design. Next, the interests of using SADT in the design steps are developed. In Section 3, after presenting concepts of SADT, this technique is applied to a SCADA system of a thermal power plant. The last section presents a discussion about the advantages and inconveniences of the Functional Analysis technique used.

2. Functionality of a supervisory system

Supervision consists of commanding a process and supervising its working [2]. To achieve this goal, the supervisory system of a process must collect, supervise and record important sources of data linked to the process, to detect the possible loss of functions and alert the human operator.

The main objective of a supervisory system is to give the means to the human operator to control and to command a highly automated process. So, the supervision of industrial processes includes a set of tasks aimed at controlling a process and supervising its operation.

A supervised system is composed of the following parts:

- The Man-Machine Interfaces (MMI), displaying information thanks to the information synthesis system.
- The supervisory tools, supplying services thanks to the automatic supervisory system and the decision support systems.
- The control/command part, interface between the MMI, the supervisory tools and the process.
- The process is also called production system or operative part, performing the physical work on the input product flow.

A supervisory system has to give to the human operator:

- A global view of the installation and its operation. The operator must access this pertinent information, without much reasoning.
- Information concerning the evolution of the process state.
- Information which permits results of operator's actions to be controlled quickly.
- The means to drive away into the different levels of process abstraction.
- Good alarms; i.e. well defined, well commented and specific to the different running modes.

According to the point of view proposed by Lambert [3], an automatic supervisory system is a traditional supervisory system, that is to say, a system which provides a hierarchical list of alarms generated by a simple comparison with regard to thresholds. The information synthesis system manages the presentation of information via any support (synoptic, console, panel, etc.) to the human operator.

3. Presentation of SCADA systems

SCADA is the acronym for "supervisory control and data acquisition." SCADA systems are widely used in industry for supervisory control and data acquisition of industrial processes. The process can be industrial, infrastructure or facility [4-7].

SCADA system is used to observe and supervise the shop floor equipments in various industrial automation applications [8-10]. SCADA software, working on DOS and UNIX operating systems used in the 1980s, was an alarm-based program, which has a fairly simple visual interface.

The SCADA system usually consists of the following subsystems:

- A Man-Machine Interface (MMI) is the apparatus which presents process data to a human operator, and through this, the human operator, monitors and controls the process.
- A supervisory system, acquiring data on the process and sending commands to the process.
- Remote Terminal Units (RTUs) connecting to sensors in the process, converting sensor signals to digital data and sending digital data to the supervisory system.
- Communication infrastructure connecting the supervisory system to the RTUs.

In fact, most control actions are performed automatically by RTU or by programmable logic controllers (PLC). Host control functions are usually restricted to basic overriding or supervisory level intervention. For example, a PLC may control the flow of cooling water through part of an industrial process, but the SCADA system may allow operators to change the set points for the flow, and enable alarm conditions, such as loss of flow and high temperature, to be displayed and recorded. The feedback control loop passes through the RTU or PLC, while the SCADA system monitors the overall performance of the loop.

With the advances of electronic and software technologies, the supervisory control and data acquisition systems are widely used in industrial plant automation [11-14]. It provides an efficient tool to monitor and control equipment in manufacturing processes on-line. The SCADA automation system always includes several functions, e.g., signal sensing, control, human machine interface, management, and networking.

4. Review of SADT method

The SADT method [15] represent attempts to apply the concept of focus groups specifically to information systems planning, eliciting data from groups of stakeholders or organizational teams. SADT is characterized by the use of predetermined roles for group/team members and the use of graphically structured diagrams. It enables capturing of proposed system's functions and data flows among the functions.

SADT, which was designed by Ross in the 1970s, was originally destined for software engineering but rapidly other areas of application were found, such as aeronautic, production management, etc.

SADT is a standard tool used in designing computer integrated manufacturing systems, including flexible manufacturing systems [16]. Although SADT does not need any specific supporting tools, several computer programs implementing SADT methodology have been developed. One of them is Design: IDEF, which implements IDEF0 method. SADT: IDEF0

represents activity oriented modelling approach (Figure.1). IDEF0 representation of a manufacturing system consists of an ordered set of boxes representing activities performed by the system. The activity may be a decision-making, information conversion, or material conversion activity. The inputs are those items which are transformed by the activity; the output is the result of the activity. The conditions and rules describing the manner in which the activity is performed are represented by control arrows. The mechanism represents resources (machines, computers, operators, etc.) used when performing the activity.
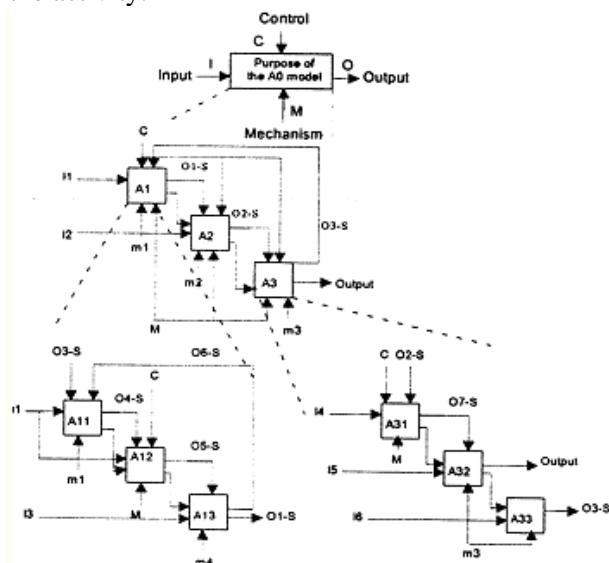

Fig. 1. Top-down, modular and hierarchical decomposition of SADT method.

The boxes called ICOM's input-control-output-mechanisms are hierarchically decomposed. At the top of the hierarchy, the overall purpose of the system is shown, which is then decomposed into components-subactivities. The decomposition process continues until there is sufficient detail to serve the purpose of the model builder. SADT: IDEF0 models ensure consistency of the overall modelled system at each level of the decomposition. Unfortunately, they are static, i.e. they exclusively represent system activities and their interrelationships, but they do not show directly logical and time dependencies between them. SADT defines an activation as the way a function operates when it is 'triggered' by the arrival of some of its controls and inputs to generate some of its outputs. Thus, for any particular activation, not all possible controls and inputs are used and not all possible outputs are produced. Activation rules are made up of a box number, a unique activation identifier, preconditions and postconditions.

For SADT diagrams or function boxes, we will consider two events to be representing the activation states of the activities. The first event represents the instant when the activity is triggered off, and the second event represents the ending instant [17-18].

This method has got several advantages:
- Large field of applications such as automation, software developments, management systems and so on.
- Facility and universality of the basic concepts.
- Existence of a set of procedures, advises and guidelines

We present, in an in exhaustive manner, some studies of the SADT method with an industrial character that have been presented in various researches:

Researchers, Santarek K. & al. [19], have described an approach to manufacturing systems design that allows automatic generation of controller logic from a high level system design specification. The high level system design specification was developed using SADT method and Design:IDEF software package. The interface is based on a number of transformation rules from an IDEF0 specification into a Petri net. A standard qualitative analysis and simulation of the Petri net is used to determine if the manufacturing system will operate in the desired manner.

Researchers, Ryan J. & al. [20], have proposed that a process modelling tool be developed specifically to support simulation requirements gathering. Then, a simulation process modelling tool called simulation activity diagrams is presented. In fact, many developments have taken place around supporting the model coding task of simulation, there are few tools available to assist in the requirements gathering phase of simulation. The authors have provided a selective review of some of the most important in relation to simulation. A conclusion from this review is that none of the tools available adequately supports the requirements gathering phase of simulation.

Researchers, Benard V. & al. [21], have developed and proposed the Safe-SADT method. This method allows the explicit formalization of functional interactions; the identification of the characteristic values affecting the dependability of complex systems, the quantification of the reliability, availability, maintainability, and safety parameters of the system's operational architecture, and validation of that operational architecture in terms of the dependability objectives, and constraints set down in the functional requirement specifications.

5. Presentation of a SCADA system of a thermal power plant

During the last few years, the Société Tunisienne de l'Electricité et du Gaz (S.T.E.G) has evolved in a difficult international conjuncture characterized by the increasing of the hydrocarbon's prices. In spite of this economic situation, the S.T.E.G has deployed many efforts in different domains of its activity that enabled it to record some remarkable results [22]. This is why the growth of 4.8% of the national production of electricity in 2007 enabled to the S.T.E.G to answer to the country evolution demand under the best conditions of continuity and security.

Among the production units of electricity of the S.T.E.G, we present an example of a thermal power plant (TPP) that consists on a system producing the electricity while using dry water steam to drag the alternator in rotation. This steam is generated in a furnace that transforms the chemical energy of the fuel (natural gas, heavy fuel-oil) in calorific energy.

In fact, a TPP is a power plant (Figure.2) in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser. The greatest variation in the design of TPPs is due to the different fuel sources. Some prefer to use the term energy center because such facilities convert forms of heat energy into electrical energy.

In TPPs, mechanical power is produced by a heat engine which transforms thermal energy, often from combustion of a fuel, into rotational energy. Most thermal power plants produce steam, and these are sometimes called steam power plants. TPPs are classified by the type of fuel and the type of prime mover installed [23].
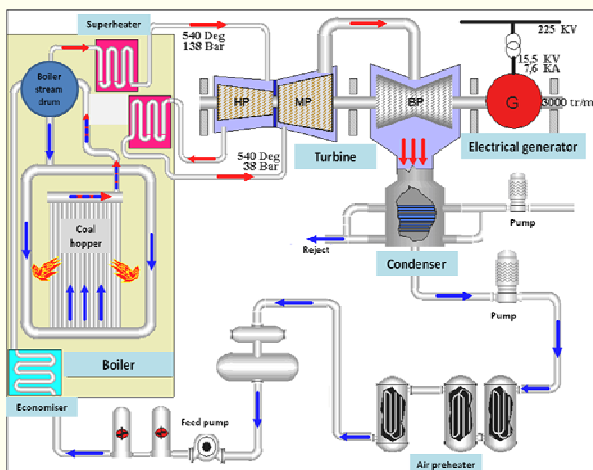
Fig. 2. Functionality of a thermal power plant.

The electric efficiency of a conventional TPP, considered as saleable energy produced at the plant busbars compared with the heating value of the fuel consumed, is typically 33 to 48% efficient, limited as all heat engines are by the laws of thermodynamics. The rest of the energy must leave the plant in the form of heat.

Since the efficiency of the plant is fundamentally limited by the ratio of the absolute temperatures of the steam at turbine input and output, efficiency improvements require use of higher temperature, and therefore higher pressure, steam [24].

An example of a SCADA system of a TPP is presented (Figure 3). The stations belong to a superior network Ethernet (10 Mb/s). Principally, this network enables to exchange files between the stations. It enables to avoid the overload of the Node bus network.
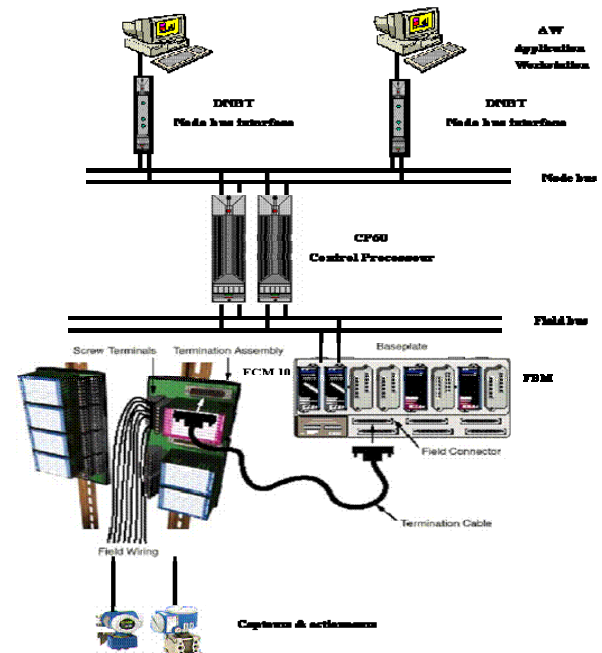
Fig. 3. Architecture of a SCADA system.

Legend:
I/A: Intelligent / Automation
FBM: Field bus modules
FCM: Field Bus Communication Module
AW: Application work station
WP: Work station Processor
CP60: Control Process60
DNBT: Dual Node bus 10Base-T Interface

6. Application of SADT method

Based on the description of the SCADA system, a corresponding SADT model of actigrams type has been built. An important point must be noticed: the point of view of the analysis is that of a person without concrete experience on

the SCADA system of a TPP, i.e. only through a bookish knowledge, whose objective is the use of the final models for the design of supervisory displays (monitoring, diagnosis displays, etc.).

So, this SADT model is composed exclusively of actigrams (Figures 4-5). It starts with the main function 'To supervise the signals of a thermal power plant' (Figure.4). Then, this function is broken into sub-functions and this process is developed until the last decomposition level has been reached (levels A1, A2 and A3).

Recall that the techniques such as SADT are semi-formal. By consequence, for the same subject, different correct models can be built without having to know with certitude which model is the good or, at least, the best. In fact, this kind of model allows lets users sufficient freedom in its construction and so the subjective factor introduces a supplementary dimension for its validation. That is why the validation step on the whole necessitates the confrontation of different points of views.

As to the SADT technique, users can follow rules or recommendations to the level of the coherency of the model, such as distinction between the different types of interfaces, numeration of boxes and diagrams, minimal and maximal numbers of boxes by diagram, etc. One intends, by coherency application of the heritage rule i.e. when data are placed at a N decomposition level, it is explicitly or implicitly present at the inferior levels. However, a complementary mean to check coherency of actigrams is a confrontation between actigrams and datagrams, which is not possible in our case.
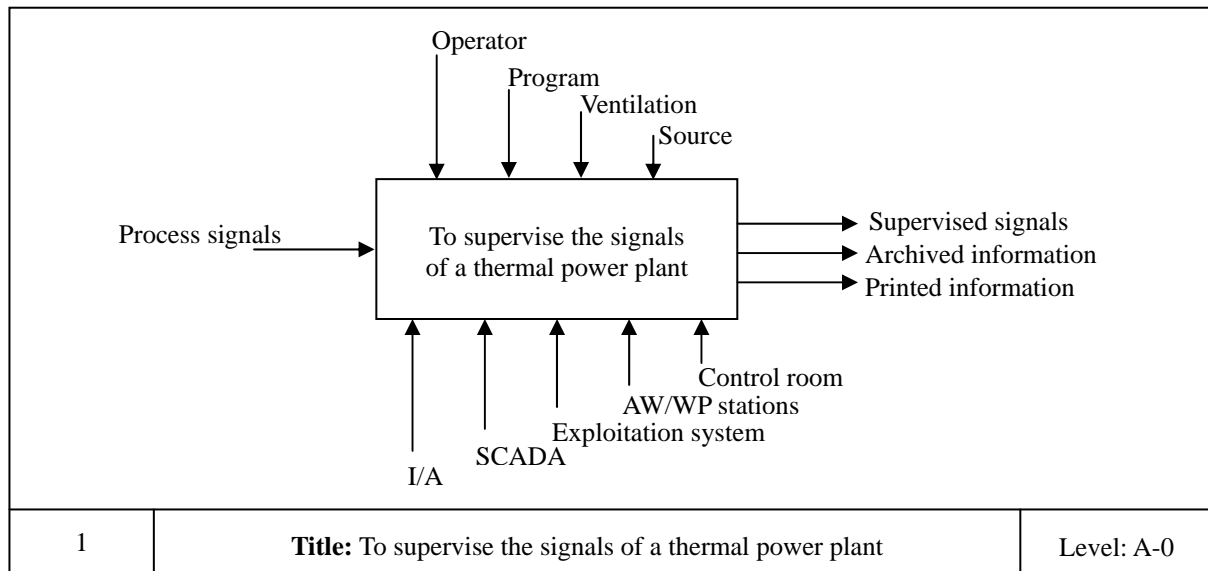

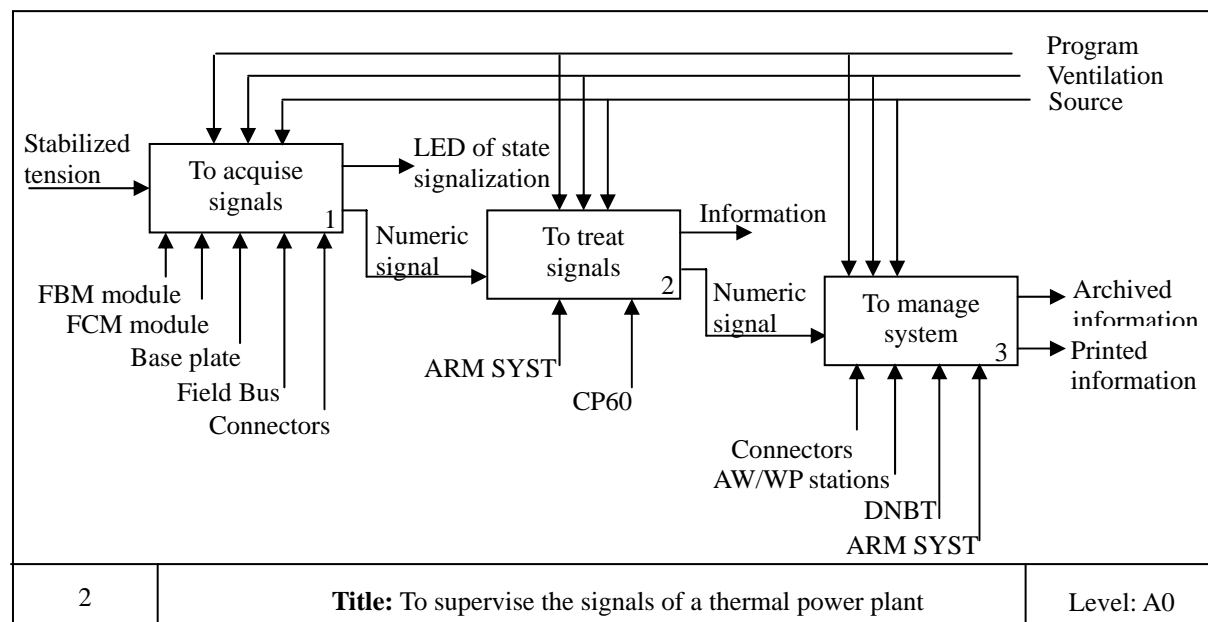Fig. 4. A-0 level of the SADT model.

Fig. 5. A0 level of the SADT model.

List of actigrams:

A-0: To supervise the signals of a TPP
A-0: To supervise the signals of a TPP
  A1: To acquise signals
    A11: To connect signals
    A12: To filter signals
    A13: To convert signals
    A14: To stock data
  A2: To treat signals
    A21: To connect signals
    A22: To control
    A23: To treat signals
    A24: To transfer signals
  A3: To manage system
    A31: To acquise data
    A32: To control & treat data
    A33: To stock data
    A34: To exit data

For the SADT box, there is the function (verb to infinitive) and around this box, the associated data are specified of which the nature (input, output, control or mechanism) appears directly.

The possible uses for the SADT model are the design of a monitoring display and a diagnosis display. For the design of a monitoring display, the A0 level of this model (Figure.4) supplies a global view of the system. Indeed, information relative to each function represented through this level should appear in a monitoring display.

For the design of hierarchical diagnosis displays, each actigram of the SADT model constitutes a vision at a given abstraction level. So, each of these actigrams gives a less or more detailed vision. In function of the objectives defined by the designer for each display, a particular actigram can supply the required information.

Finally, this application of Functional Analysis technique on a thermal power plant shows briefly the interests of the SADT method in the design of supervisory systems.

7. Supervision of the natural gas (NG)

The different generation sources in the Tunisian electrical system are: hydroelectric, co-generation, renewable (biomass, solar and wind), NG thermal power, and others including diesel, oil and coal. The decision to invest in power generation projects, especially in NG thermal power generation, involves a series of issues and challenges. In fact, the real need for thermal power capacity is determined by the combination of energy supply and demand curves.

NG is the fastest growing primary energy source in the world. It is the more used one of fuels in the TPPs because it is more manageable, own that coal or the heavy fuel-oil; on the other hand it presents dangers and the bigger explosion risks. The exploitation of the NG requires a structure, of equipments, of instruments and an automatic control.

The TPP is nourished in NG from the Tunisian network of distribution. In fact, the gas undergoes several operations of preparation (Figure 6) before being introduced in the steam generator, it must be filtered, rehash, relaxed and counted.
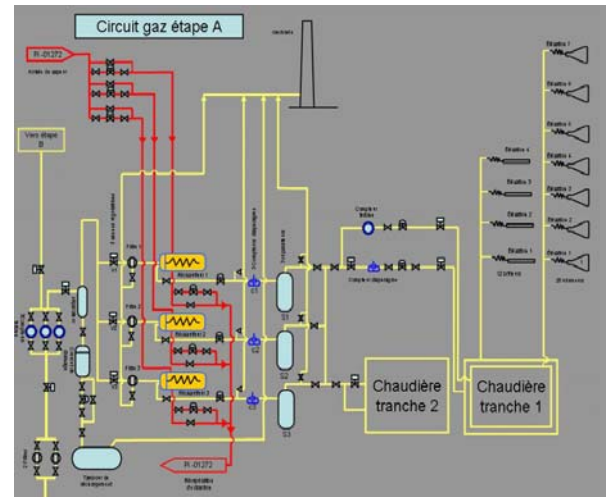

Fig. 6. System of the NG of a TPP.

The pressure of the NG nourishing burners and lighters vary according to the rate of combustion asked of 1.5 to 2.2 bars, gas arrives to the TPP to a pressure understood between 15 and 20 bars. It is therefore necessary to loosen it in order to have a neighboring pressure of 4 bars before the regulating floodgate. A second distinct détente for each steam generator adjusting the pressure of the order of 2 bars has the uphill of the regulating floodgate of NG debit.

The détente of gas can provoke, according to types of regulator and the conception of détente stations, of noises that are transmitted and amplified sometimes by pipelines, can reach some inadmissible levels for the man and for the good holding of the material. In the critical cases, one decreases the importance of this phenomenon while immediately choking noises in mufflers rooms after regulators. By the use of classic heating device to water or steam-powered nourished by stations of water or generators of steam of the power station. A regulation of arrival of the calorific flux (fluid of heating) is necessary in order to maintain a temperature understood between 15°C and 20°C after détente. This temperature corresponds to the one of the numbering.

A separator, placed in head of the station, assures a first elimination of foulness can be transported by the NG generally the separator is

slim of a decantation pot. Filters assure the final operation. These filters have an important role in beginning of exploitation. Dusts and oxide of iron contents in pipelines of gas are progressively driven toward the primary détente station.

The objective of the SCADA system of the TPP is to collect data instantaneously of their sites and to transform in signals and numeric impulse and to send them through the network of communication toward the main and secondary stations. Indeed, the received data by the SCADA system only present 20% of the existing data totality.

In this part, we present the different stages of our application related to the interfacing and the configuration of the counting system of the NG to SCADA system:

- Branching of counters gas lighter to the SCADA system;
- Programming of the general counting of the gas lighter;
- Configuration of a new tabular circuit of the NG containing the new information.

We choice the Input/output map, the programming and the necessary block. This operation is achieved by the algorithms standard called blocks provided by Foxboro.

The proposed solution is to make the counting of impulses by the SCADA system and to program blocks of hourly and daily numbering. These impulses are given out by the generator of meter impulses to turbine.

The meter to turbine of gas lighters is installed 7.5 ms of the steam at the level, the distance between this one and the SCADA system is appraised to 160m, the work of branching are done during the minor revision of the power station.

After these works of branching, we programmed the different blocks of counting of the volume gas lighters. An algorithm of numbering of the volume NG has been adopted. Indeed, the Block AIN does the reading of the raw value (0 to 65535 points) a way of entrance of a module FBM217 achieves then on a read data of conditioning functions (characterization, stake to the ladder, limitation), of filtering and alarm. The ACCUM block achieves the integration and delivers to OUT exit a quantity. The block COST permits to pilot one of exits all or nothing of a module of FBM E/S in fashion bistable or pulsionnel. Finally, the block MATH permits to achieve some arithmetic operations in definite chain in a program.

For the stage of configuration, we used the software ICC (Integrated Control Configuration). This software enables us to create and to configure programs residing in the CP60.

For the stage of different block programming (AIN, ACCUM, etc.), we identified the label, the compound and the address of the signal.

The interfacing consists in improving the counters and to conceive a new tabular of the circuit NG containing the new counters of gas lighters by the use of the software Fox Draw. We proceeded the following manner: creation of the of the meter gas lighter; test of meter working; configuration of the different alarm display; configuration of the meter overlay; test of the meter overlay. The new tabular is elaborated by the use of the software Fox-draw containing the new counters of the NG (Figure 5).
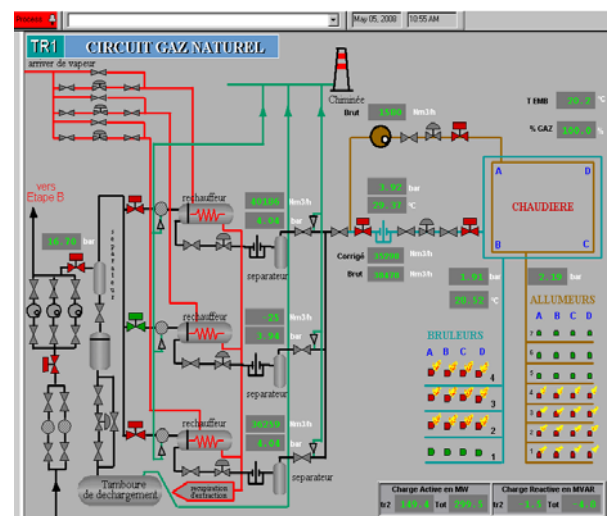

Fig. 7. New tabular of the NG of a TPP.

8. Conclusion

In this paper, an application of SADT method on a real system, a SCADA system of a thermal power plant generates a source of useful information for the design of a supervisory system (monitoring and diagnosis displays, definition of alarms, etc.). So, research into the application of Functional Analysis techniques for the design of a human centered supervisory system must be intensified in order to solve several difficulties and to improve their efficiency (tools to build the model, tools to check the validity of the model, etc.).

A supervisory system of the natural gas counting system of a TPP in Tunisia is presented. This application enables us the branching of counters of the natural gas of the TPP to a SCADA system. This application required the programming and the configuration of the counting system used in the TPP.

The difficulty of the design of a supervisory system lies in the capacity to represent both the

process faithfully and to provide for the designers usable information. In fact, a supervisory system must take into account the physiological and cognitive features of the supervisory operator because an inadequacy between the supplied information and the operator's information requirement is dangerous. To reach this objective, Functional Analysis techniques seem to be a promising way because the major advantage of these kinds of techniques is due to the concept of function and abstraction hierarchy which are familiar to the human operator. These techniques permit the complexity of a system to be overcome.

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