POLITEHNICA UNIVERSITY OF BUCHAREST

ETTI-B DOCTORAL SCHOOL

- Summary of the doctoral thesis -

OPTIMIZED TECHNIQUES FOR INSURING PREDICTIVE MAINTENANCE FOR ELECTRONIC SYSTEMS AND MANUFACTURING PROCESSES THERE OF

PhD student: **Eng. George - Robert Şşman**

Scientific supervisor, **Prof. Univ. Dr. ing. Nicu BIZON**

Thanks

Now, at the end of the doctoral internship, I feel deeply marked by the feelings of happiness and fulfillment that come from the professional and personal satisfaction of the completed studies.

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CHAPTER 1
INTRODUCTION

1.1 Presentation of the field of the doctoral thesis

a) The structure of the work

The research activities carried out to meet the specific objectives proposed were materialized in the present work, which we have structured in 6 chapters, briefly presented below.

Chapter I presents the current state of research and development in the field of predictive maintenance of electronic equipment.

Chapter II presents techniques and equipment used in the field of predictive maintenance based on time analysis and / or, in frequency, concepts of artificial intelligence and fuzzy logic applied in the same field of predictive maintenance.

Chapter III refers to mathematical methods and tools for processing the data acquired during the operating processes of the systems, monitored with the help of electronic equipment. There are presented classical methods of data analysis, but also advanced methods of data processing based on techniques recently proposed in the specialized literature. Some of these advanced methods have been practically implemented on a power source used in telecommunications.

Chapter IV is dedicated to advanced process control and monitoring systems. The author's contributions are also highlighted in the design of early fault detection systems, in the use of IO-Link technology with software interface for defect identification, in the design of industrial systems based on PLCs, but also in the analysis of the data regarding the maintenance of electronic telecommunication systems.

Chapter V deals with the concepts of virtual metrology and the sequential RUN - TO - RUN type control applied in performing the predictive maintenance. The author proposed a real-time metrological system with integrated predictive maintenance functions based on the concept of virtual metrology.

Chapter VI concludes the theoretical and applicative approach of the thesis, highlighting possible development trends in the field of predictive maintenance.

The final part of the paper includes specialized bibliography, which also includes the author's publications.

1.2. Objectives proposed in the paper

The main objective of this paper is to analyze the electronic systems and the specific manufacturing processes, from the point of view of their predictive maintenance, by using specific performance indicators.

The analysis focuses on predictive maintenance techniques that can ensure optimal functioning of electronic equipment used in telecommunications systems. The specialized studies, as well as the experimental research carried out by me during the doctoral period, highlighted the necessity of using the modern techniques of predictive maintenance, techniques that lead to the prolongation of life of the electronic equipment. In case of special operating conditions it is necessary to develop customized predictive maintenance solutions for these equipments.

The main objectives of this paper are the following:

O1: Analysis of predictive maintenance applied to electronic systems and their specific manufacturing processes by using specific performance indicators.

O2. Design and implementation of software solutions for interfacing diagnostic systems with electronic equipment monitored online in the running process.

The results obtained from research conducted in the thesis are reported in Chapter VI in strong correlation with the following specific objectives:

- OS1. Analysis and systematization of the maintenance techniques used in the field of electronic equipment, highlighting the specific advantages of using each maintenance technique;
- OS2. Processing of the data acquired from real systems of maintenance assurance for the electronic equipment analyzed in the case studies presented in the paper;
- OS3. Design and implementation of software solutions (software algorithms and graphical interfaces), realized in different programming languages, dedicated to the electronic equipment diagnostic systems in the operating process;
- OS4. Design and implementation of graphical interfaces for remote monitoring of electronic equipment;
- OS5. Development of optimized software solutions based on classical concepts, respectively on computational intelligence, to identify the potential causes of electronic equipment failure.

- OS6. Validation of the proposed mathematical models and methods for performing predictive maintenance by comparison with the basic ones proposed in the specialized literature;
- OS7. Validation by simulation and / or experimentation of software algorithms and graphical interfaces developed

1.4. The current state of the field of electronic equipment maintenance

1.4.1. a) The concept of maintenance

The development of a new system or equipment starts with defining the operational requirements, following the development of the maintenance concept, which provides a common basis for defining the maintenance and logistics requirements folded on the requirements of the project to meet the operational needs imposed.

The development of the maintenance concept is one of the most important stages in the system development cycle, because maintenance planning and maintenance logistics can be carried out from this design phase, as these activities can be separated from the technical maintenance activities.

The maintenance concept describes a logistics plan for the maintenance of the equipment systems in an operational environment depending on:

- the criteria for choosing the model and the maintenance levels;

- policy and requirements regarding fundamental maintenance logistics (structure of this logistics);

- the criteria regarding the control and test equipment (they can be integrated automatically or used when a control request appears) [2].

Predictive maintenance is "the means of improving and increasing productivity, product quality and total efficiency of manufacturing and production systems" [4].

This type of maintenance is based on the programming of the activities according to the operating parameters of the electronic equipment or components. At the same time, predictive maintenance involves a whole logistics system. [5].

1.4.3. Management models for the implementation of predictive maintenance

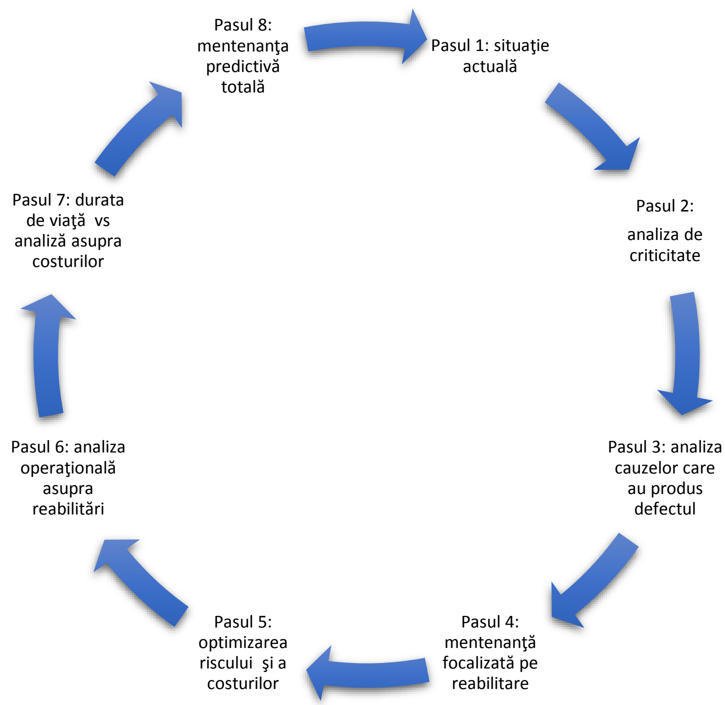

Figure 1.7. Model for the implementation of a predictive maintenance plan

1.4.6. Equipment based on predictive maintenance reliability

Reliability represents the ability of a technical system (electronic equipment, element, apparatus or assembly) to function without fail within a given time and under given conditions, fulfilling the function assigned to it under the conditions established by the human factor. In order to benefit from the high reliability of the electronic equipment, the operating elements of the equipment to be manufactured for maximum efficiency in use must be considered from the design stage.

The term reliability comes from the French language "fiabilité". It refers to the study of system failures, the trait of being reliable (operating safety).

If by the quality of a product we understand the degree or the level by which it meets the needs at a given moment, then the reliability of the equipment means the use of the product at the designed parameters, its safe and continuous operation, under certain conditions, for a given period of time.

All these things are possible by performing predictive maintenance and observing the maintenance plan.

The reliability of an equipment can also be described by the numerical characteristics of a random parameter. These features are:

- average
- the average quadratic deviation
- dispersion

The average time of good functioning of an electronic equipment for which predictive maintenance is performed according to the works plan is defined using the relation:

$$m = \int_0^\infty t \times f(t)dt, t \in (0, \infty) \quad (1.1)$$

$$m = \int_0^\infty R(t)dt \quad (1.2)$$

The specific performance indicators are determined by the average time of good functioning of an electronic equipment, which in the specialized works is differentiated by the following indicators:

- MTBF - represents Mean Time Between Failures - the average running time between failures;

- MTTF - represents Mean Time To Failures - the average operating time until failure, for equipment that is not performing the predictive maintenance according to the plan;

- MTTFF - represents Mean Time To First Failures - the average running time until the first failure.

The reliability of electronic equipment can also be characterized by an indicator of reliability assessment when the equipment is put into operation. This reliability indicator can be calculated experimentally, by extractingsome samples of electronic components from the factory: capacitors, integrators, relays, etc.

The reliability of a complex system can be increased in two ways:

- simplification of the system structure and the use of higher quality components;
- implementation of the concept of fault tolerance.

CHAPTER 2

ELECTRONIC TECHNOLOGIES AND EQUIPMENT FOR THE MAINTENANCE OF PREVENTIVE MAINTENANCE

2.5.1. SIMOCOD type equipment with integrated diagnostics and monitoring management

The use of equipment for predictive maintenance has seen a significant increase in the last period, although, at present, the technology is quite expensive and the installation process can be a long one.

Objective

The objective of this case study is to highlight the diagnostic mode of an asynchronous three-phase motor using a SIMOCOD type diagnosis and monitoring module.

Obtained results

The data recorded with this module was acquired from the field, with the help of sensors, such as: temperature sensor, speed sensor, electric phase monitoring sensor.

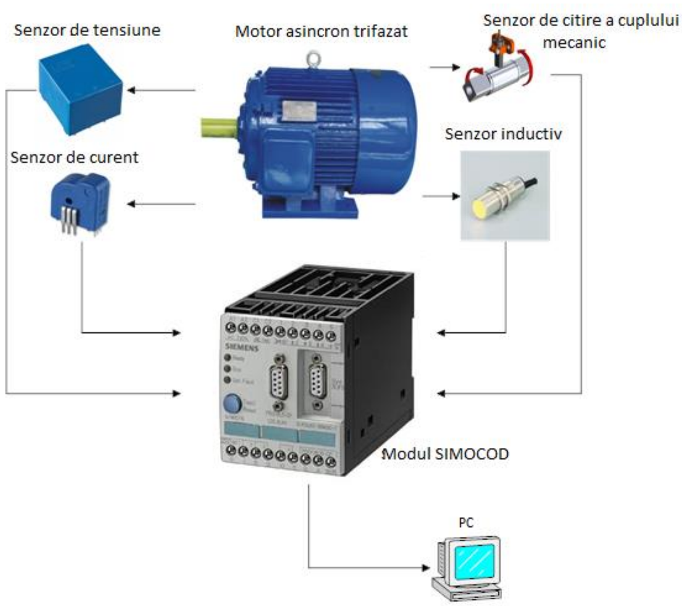

Figure 2.15. Block diagram of a DC system with permanent magnets using SIMOCOD mode [43]

Figure 2.15 shows a block diagram of an electric motor diagnostics system, using a SIMOCOD module. This scheme comprises speed, torque, current and inductive sensors, with which data on the functional parameters of the engine are acquired . This data is transmitted to the SIMOCOD module using the PROFIBUS, Ethernet or IO-Link communication protocols . [43]

[44]. The only use of this application is the prevention of damage to the components by setting certain nominal parameters of engine operation [44].

The monitoring of the working mode of a three-phase motor is done using the interface presented in figure 2.16. In this figure the operating mode of the engine is presented, being able to observe as a percentage the load level of each phase. The information is presented numerically and graphically. Any imbalance between electrical phases provides information that could prevent a fault from occurring [43].

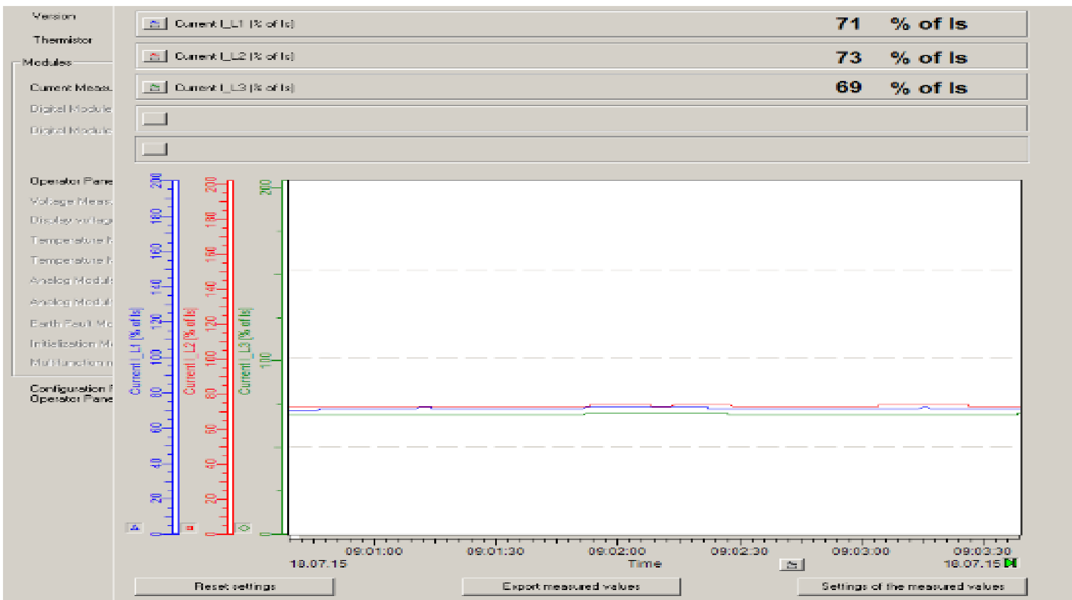

Figure 2.16. Interface dedicated to monitoring a three - phase asynchronous motor [43]

To perform the preventive maintenance applied to an electric motor, the SIMOCOD module, through custom interfaces, allows the setting of the nominal operating parameters of the monitored equipment. Such custom interfaces are presented in Figure 2.17 .

By configuring the SIMOCOD module we can set values for the following parameters:

- ✓ working temperature at which the engine stops;
- ✓ monitoring the ground connection of the motor;
- ✓ absence of an electric phase.
- ✓ type of engine start: star and / or triangle;
- ✓ engine operating speed and accelerator ramp for the converter [45].

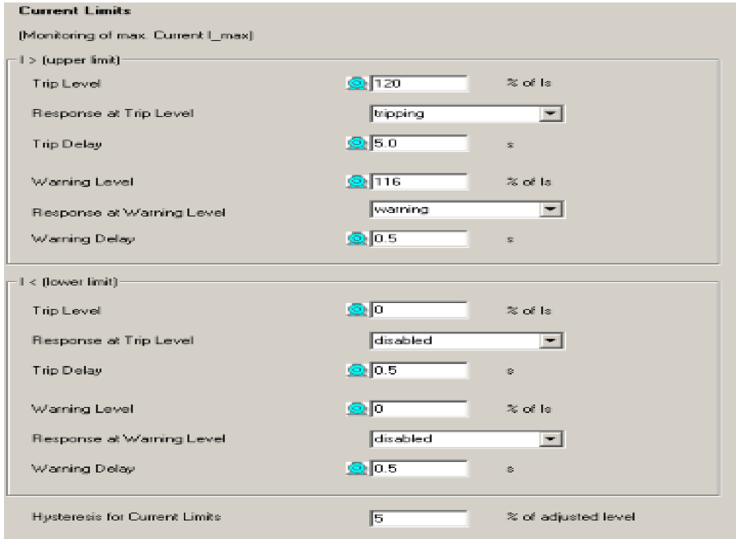

Figure 2.17.Interface for setting the working parameters of a three-phase motor [43]

Theprogramming software of the SIMOCOD module allows us to create maintenance pages in which we can introduce, in addition to the main functions monitored, the vital functions and a series of parameters that must be permanently monitored, such as: the degree of load of the engine, the consumed current, the direction of rotation of the engine, the state of communication with the DCS (Digital Control System) sensors used in the operation of the monitored equipment (temperature sensor, vibration sensor, optical sensors). All these sensors are incorporated in the monitored system and can lead to the detection of an issue of the entire system. [43] [44].

In the software submenu of the SIMOCOD module there is the possibility of creating new parameters that must be checked before starting the engine. These tests provide information on the state of the motor, the communication channel with DCS, the working mode (online or local), the status of all the sensors involved in starting the equipment. An interface that uses such functions is shown in Figure 2.19 [43].

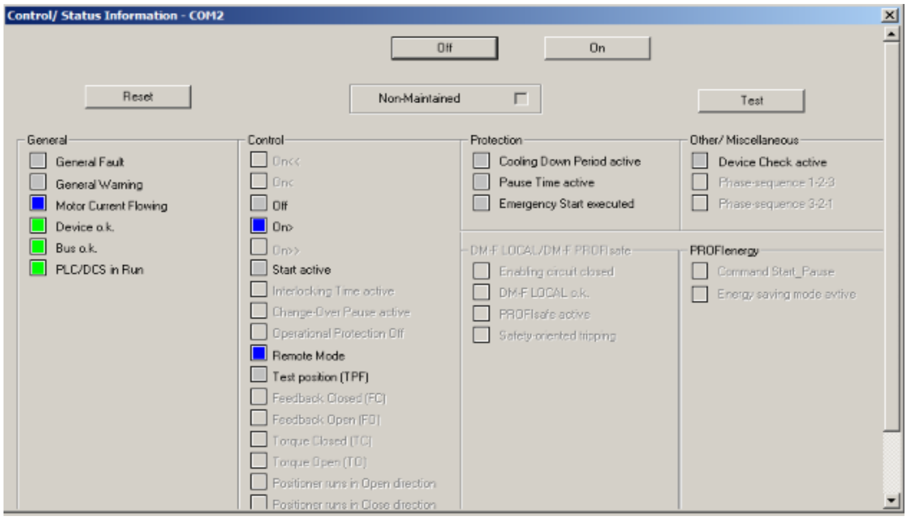

Figure 2.19. Interface for sensor initialization and motor check before starting [43]

Conclusions

Following the results obtained in the case study, it can be observed that the introduction and development of maintenance systems based on the modules with integrated management improves the functioning of the electronic equipment monitored with these modules. By conducting the case study with the SIMOCOD type module, I wanted to highlight the importance of observing the general conditions for starting and operating electronic equipment [43].

CHAPTER 3.

METHODS AND TOOLS APPLIED TO THE MAINTENANCE OF ELECTRONIC EQUIPMENT FOR DATA ACQUISITION AND ANALYSIS

3.1.1. Pareto Diagram. Case study on the maintenance of a power station used in telecommunications equipment

The following is a case study on a power station used in telecommunications equipment using analysis based on the Pareto chart .

The studied power station is composed of the following elements (subassemblies):

- 2 AC-DC converters (rectifiers);
- 1 controller;
- 1 Ethernet card;
- 2 groups of batteries.

Objective

The main objective of this case study is the application of the Pareto method by monitoring the functionality of the power station for a fixed period of time. The role of monitoring is to identify the main flaws in order to apply the Pareto method.

Obtained results

The monitoring of the functionality of the power station was carried out between 10.12.2015 - 10.02.2016, and the number of monitored stations was 9 units. This monitoring was performed remotely (remote), with the help of a dedicated application for this equipment. When a fault was reported, a hardware (hardware) local analysis was performed. The events were centralized in the form of a table, in excel, all the defects that appearedbeing marked according to table 5 [49].

Table 5. Recording of monitored data [49]

No. crt	date	part	The component that caused the shutdown
1	10/12/2015	Rectifier	Fan
2	10/12/2015	IFIP	An oxidized ethernet card port pin
3	12/12/2015	Rectifier	Filter capacitor
5	15/12/2015	controller	DC converter monitoring board
6	12/17/2015	controller	Local display
7	12/19/2015	Rectifier	Communication cable between Controller and rectifier
8	12/19/2015	controller	Condenser on the remote communication PCB
9	12/24/2015	Rectifier	Rectifier temperature sensor
10	25/12/2015	Battery	1 battery in a group is discharged below the minimum allowed level
11	12/28/2015	Rectifier	Fan
12	31.12.2015	controller	Condenser on the remote communication PCB
13	01/02/2016	controller	Eprom
14	01/02/2016	Rectifier	Filter capacitor
15	01/05/2016	Battery	Temperature reading sensor connected to battery groups
16	10/01/2016	Rectifier	Filter capacitor
17	01/13/2016	controller	Internal fan controller 's
18	01/18/2016	controller	Communication cable between Controller and rectifier
19	01/21/2016	controller	Voltage monitor
20	01/23/2016	Rectifier	Fan

21	01/26/2016	controller	Condenser on the remote communication PCB
22	30/01/2016	Rectifier	Eprom inter
2. 3	02/05/2016	Rectifier	fan
24	02/07/2016	IFIP	An oxidized ethernet card port pin
25	10/01/2016	Rectifier	Filter capacitor

Following the analysis of the data presented in table 5, table 6. was performed. This table presents a centralization of the frequencies of occurrence of faults. Subsequently, for easy interpretation, a diagram is made according to figure 3.1.

Table 6 Centralization of data according to the frequency of occurrence of defects [49]

No. crt	part	No accidental stops
1	Rectifier	11
2	controller	9
3	IFIP	2
4	Battery	2

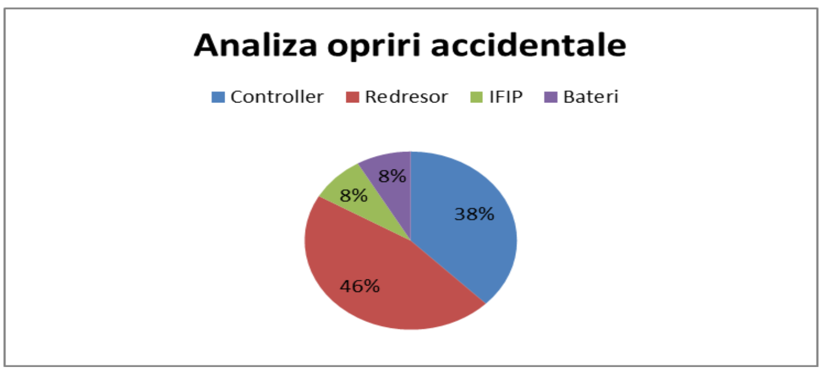

Figure 3.1. Pareto analysis on accidental stops [49]

After analyzing the data recorded in table 5, it turns out that the equipment with the most accidental stops is the rectifier. In order to be able to identify the defects, the components that lead to the failure of this equipment are extracted from the recorded data. Thus, we find separately, table 7. Based on the data in table 7, a new Pareto diagram is created, according to figures 3.2 [49] [50].

Table 7. Analysis of defective rectifier components [49]

No. crt	part	The component that caused the shutdown	No stopping
1	Rectifier	Filter capacitor	4
2	Rectifier	Internal eprom	1
3	Rectifier	Communication cable	1
4	Rectifier	Fan	4
5	Rectifier	Temperature sensor	1

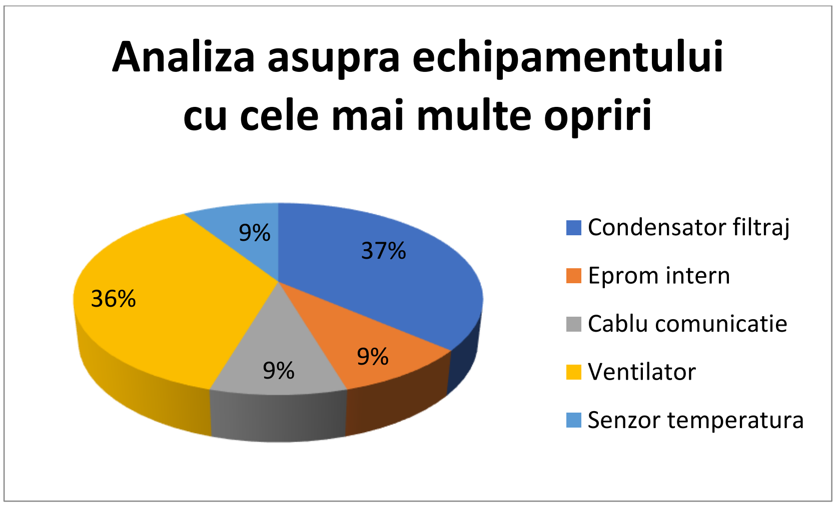

Figure 3.2. Analysis on the equipment with the most stops [49]

Conclusions

Following the Pareto analysis it turns out that vital for the power station is the rectifier subassembly (module). It presented, according to the recorded and studied data, most accidental stops. From the analysis of the causes of the defects it appears that the preventive maintenance actions to be carried out are the following:

- cleaning the fans;
- lubrication of the bearings from the fan;
- adjusting the thresholds of the nominal voltages of the rectifiers;
- installation of a protection relay (surveillance of the balance of the electrical phases) to avoid the destruction of the filter capacitors;

- the verification of the communication cables and the realization of a communication route through a safe environment without disturbances; [50].

3.2.2. Fuzzy graphics

A decision problem cannot always be formulated from the beginning in a classical mathematical language.

Frequently, in formulating the decision problem, interference is encountered between natural language and artificial language. The theory of fuzzy sets allows a proper processing of vague information through linguistic variables [58].

Case study applied to the power station

Objective

To perform the predictive maintenance of an energy supply source by analyzing the data acquired from this source, we implement the following method using Fuzzy Graphs (FG) .

Obtained results

Thesets used as nodes of FG are as follows:

The subsystems set - S = $\{S_1, S_2, S_3, S_4\}$;

The set of levels of risk of failure - R = $\{R_1, R_2, R_3\}$;

The set of components - C = $\{C_1, C_2, C_3, C_4, C_5\}$.

In this analysis, 4 subsystems were considered, as specified in the following table. In these 4 subsystems there are faults, mainly due to the 5 components identified and presented in the table. The risk of failure is divided into 3 levels [49].

Nr crt	Mulţimi	Elementele mulţimii	Definiţia elementelor
1	S – subsistem	S_1	Redresor
		S_2	Controler
		S_3	Cartela IFIP
		S_4	Grup acumulatori
2	R – nivele de risc de defectare	R_1	Risc scazut
		R_2	Risc mediu

		R_3	Risc mare
3	C – componente	C_1	Ventilatoare
		C_2	Condensator comunicatie PCB
		C_3	Cablu comunicatie
		C_4	Condensator de filtraj
		C_5	Eprom

Table 8. Defining the nodes in the fuzzy graph

Based on the possibility of defects, the arithmetic mean between the two relations $R_{ij}$and $R_{ji}$is realized. Thus the fuzzy sets are extracted to identify the components that can produce defects $\tilde{R}_i$, i = 1,2,3,4:

$$\tilde{R}_1 = \left\{\frac{1}{C_1}, \frac{0.5}{C_2}, \frac{0.4}{C_3}, \frac{0.4}{C_4}, \frac{0.7}{C_5}\right\}; \tag{3.20.a}$$

$$\tilde{R}_2 = \left\{\frac{0.7}{C_1}, \frac{0.9}{C_2}, \frac{0.3}{C_3}, \frac{0.5}{C_4}, \frac{0.25}{C_5}\right\}; \tag{3.20.b}$$

$$\tilde{R}_3 = \left\{\frac{0.4}{C_1}, \frac{0.4}{C_2}, \frac{0.8}{C_3}, \frac{0.55}{C_4}, \frac{0.15}{C_5}\right\}; \tag{3.20.c}$$

$$\tilde{R}_4 = \left\{\frac{0.4}{C_1}, \frac{0.5}{C_2}, \frac{0.7}{C_3}, \frac{0.7}{C_4}, \frac{0.45}{C_5}\right\} \tag{3.20.d}$$

Following the data processing results the FTN of figure 3.7. Figure 3.8 shows the α cut level. Values for this FTN are α□∈□{0.55, 0.6, 0.85, 1}. The following table gives the association relations between sets S and C.

	α□= 0.7				α□= 0.8			α□= 0.9		α□= 1
S	S_4	S_3	S_2	S_1	S_3	S_2	S_1	S_2	S_1	S_1
C	C_3	C_3	C_1 ; C_2	C_1 ; C_5	C_3	C_2	C_1	C_2	C_1	C_1

Table 9. Defining sets of fuzzy graphs

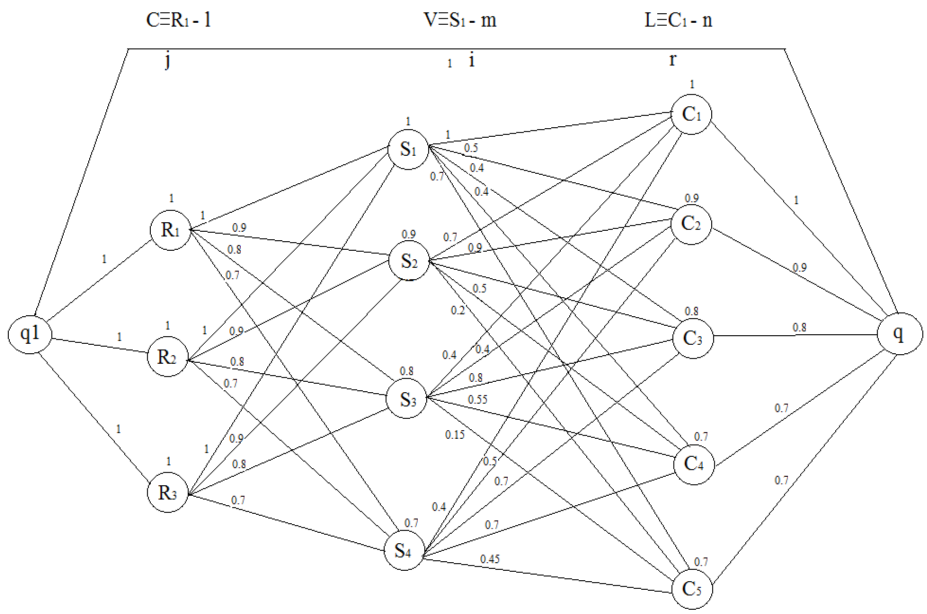

Figure 3.7. FTN for case study: a multi-attribute problem [49]

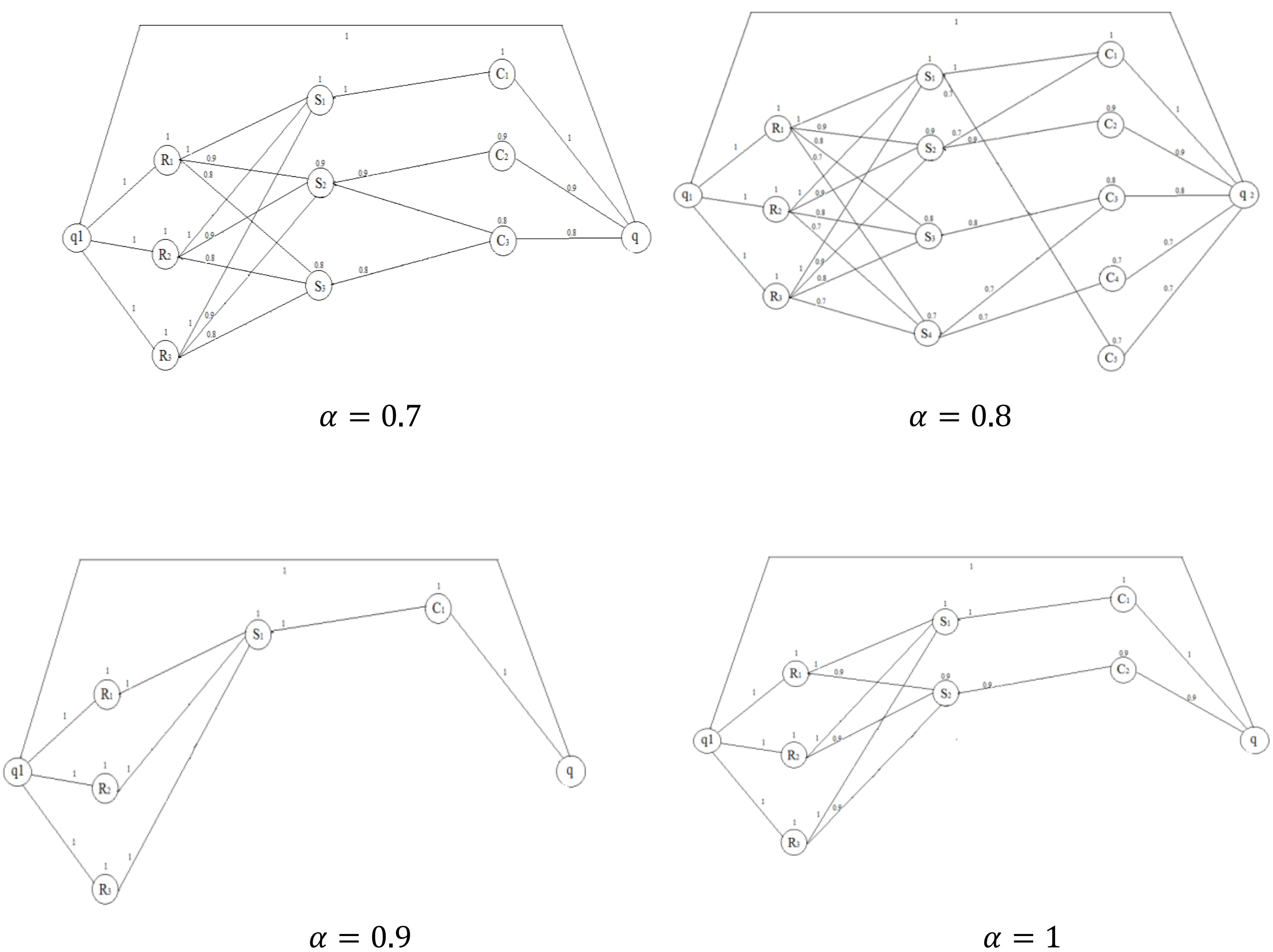

Figure 3.8. The α-level cuts in the FTN associated with the case study [49]

The complete relationship is associated:

$$\tilde{\Re}_{S\times C}=\left\{\frac{1}{(S_1,C_1)},\frac{0.9}{(S_2,C_2)},\frac{0.8}{(S_3,C_3)},\frac{0.7}{(S_1,C_5)},\frac{0.7}{(S_2,C_1)},\frac{0.7}{(S_4,C_3)},\frac{0.7}{(S_4,C_5)},\frac{0.7}{(S_1,C_1)},\frac{0.55}{(S_3,C_4)},\frac{0.5}{(S_1,C_2)}\right\}\cup$$

$$\cup\left\{\frac{0.5}{(S_2,C_4)},\frac{0.5}{(S_4,C_2)},\frac{0.45}{(S_4,C_5)},\frac{0.4}{(S_1,C_3)},\frac{0.4}{(S_1,C_4)},\frac{0.4}{(S_3,C_1)},\frac{0.4}{(S_3,C_2)},\frac{0.4}{(S_4,C_1)},\frac{0.3}{(S_2,C_3)},\frac{0.25}{(S_2,C_5)},\frac{0.15}{(S_3,C_5)}\right\} \quad (3.21)$$

The fuzzy affinity between sets S and C is:

$$\left\{\frac{1}{(S_1,C_1)},\frac{0.9}{(S_2,C_2)},\frac{0.8}{(S_3,C_3)},\frac{0.7}{(S_4,C_3)},\frac{0.7}{(S_4,C_5)}\right\} \quad (3.22)$$

Conclusions

The solution of the multi-attribute problem using the fuzzy graph method is $S^*=(S_4,S_3)$. Subsystems S_4 and S_3 (IFIP Card and Battery Group) have a low risk of failure, and subsystems S_1 and S_2 (Rectifier and Controller) have a high risk of failure (1 and 0.9 respectively). Consequently, remote diagnostic techniques can focus on these two subsystems, S_1 and S_2, identified as being more vulnerable to failure. [49] [60]

CHAPTER 4

ADVANCED CONTROL AND MONITORING SYSTEMS FOR ELECTRONIC EQUIPMENT INVOLVED IN MANUFACTURING PROCESSES

4.3. Systems for monitoring and analyzing the data recorded from electronic equipment involved in PLC-based manufacturing processes

Case study: performing predictive maintenance for an energy station

In this subchapter we conducted a case study on a power station used in telecommunications.

Objective

In the case study I want to implement a series of preventive measures to highlight the importance of predictive maintenance on the equipment studied.

Obtained results

For this purpose we made a series of signal acquisitions with the help of a data acquisition board.

When aquiring the signals we used the DAQ USB - 6211 procurement board from National Instruments. [75].

The software used to interpret and view the acquired data is Matlab.

In the case study we analyzed the influence of the capacities C40, C41 within the DC - DC converter used in the power station (figure 4.15) [50] [73] [78].

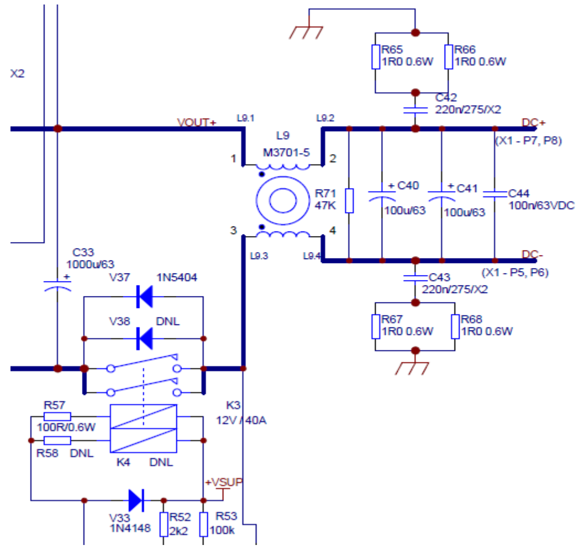

Figure 4.15. Electrical scheme for the power floor of the power station

The 2 capacities ensure the voltage filtering from the converter output. The converter provides us with a voltage in the range [54.5 ÷ 55] V at a current of 0.5 A.

Because the output voltage exceeds the value of the analog input voltage of the acquisition board, we interposed a signal formatting circuit, made from a resistive divider R1; R2 and a Zener PL8V2 diode [73] [78].

In the simulation presented in figure 4.18, the input voltage in the divider is in the range [0 ÷ 60] V, and the output voltage is shown in red.

In the experiment for the electric charge we used two H7 type bulbs connected in series, with the following characteristics: 24 V supply voltage, 70 W power [78].

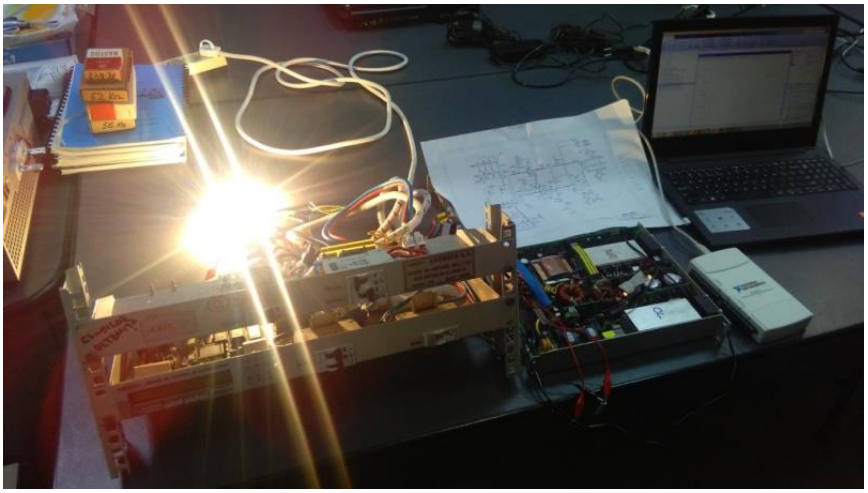

Figure 4.19.Mounting used in data acquisition from the power station [73]

For the monitored converter, they represented an electronic load that absorbed a current of 3A. The polarized electrolytic capacitors C40 and C41 had, in turn, the values of 1µF, 47µF and 100µF (at a nominal voltage of 63V).

No coupled load was detected, regardless of the value of the capacitor used. With the load coupled, the following average values of the voltage acquired for different capacitance values of capacitors C40, C41 [73] [78] resulted .

Capacitors value	**Medium voltage value [V]**	**Percentage of $_{nominal}$V [%]**	**Voltage difference from $_{nominal}$V [V]**
100uF capacitors	54.51012	100.00	0.00
47uF capacitors	53.82307	98,74	0.69
1uF capacitors	52.93794	97.12	1.57

For all the cases we exported the values resulting from the acquisition and we correlated all the graphs in Excel, showing the figures:

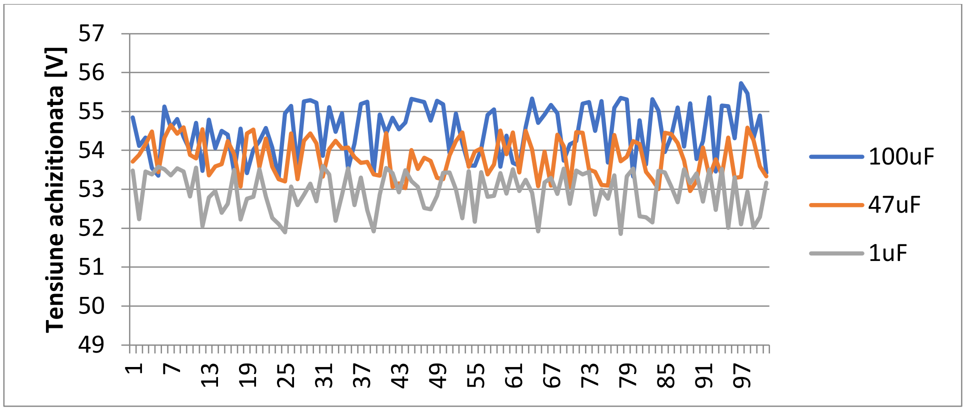

Figure 4.22.Acquisition of signals for different capacitor values (ZOOM) (gray - 1µ, red - 47µ blue - 100µ)

After analyzing the simulated results, we obtained a transfer factor (the ratio between the output voltage in the rectifier and the output voltage in the formatting circuit) of 7,199. After the practical realization of the circuit, the actual transfer factor is 7,676.

The value of the capacitive filter from the rectifier output is important when the load is high enough and the capacity is 50% less than the nominal value.

We simulated the component failure that has the highest rate of failure , namely the fan. Throughout the tests, I used an electric load that absorbs a current of 4A to observe the speed of overheating of the electrical components.

We made a series of infrared camera acquisitions to create a standard image database. After these acquisitions we reduced the fan speeds to observe the effects. This action resulted in the radiator overheating (see figs. 4.24, 4.25) [73] [78].

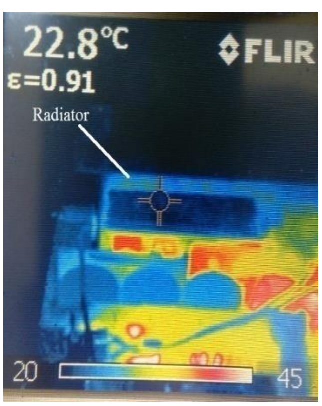

Figure 4.24. Radiator at normal temperature [78]

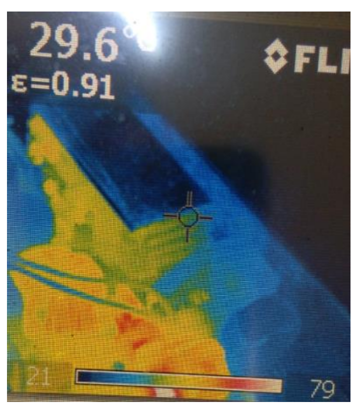

Figure 4.25. Overheating radiator with reduced fan speeds [78]

When the fans were completely switched off, in addition to the radiator overheating, the transistor overheating within the rectifier auxiliary source was observed.

If in the standard photographs it had an average temperature of ~ 20 ° C, with the lack of ventilation the transistor temperatures went up to 80 ° C (see fig. 4.26, fig. 4.27) [73] [78] .

Figure 4.26. Temperature value of transistor with reduced cooling fan speeds [78]

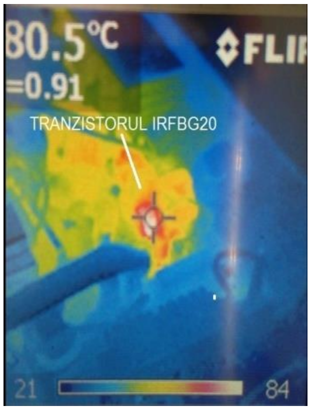

Figure 4.27. Temperature value of transistor with fan completely off [78]

In addition to the potential damage to this transistor, a number of problems may also occur with the circuit board (PCB) bonding to it.

Conclusions

With the results obtained in the case study we were able to identify a series of electronic components within the power station that correlated with certain phenomena such as: overheating, too high electrical load at start up leading to the appearance of defects.

The over voltage test carried out resulted in the loss of capacity or the total destruction of the filter capacitors.

In the overheating test we could see that the IRFGB 20 transistor fails, and we find a series of defects:

- the control pulse generation for the transistors in the power factor adjustment stage is no longer calibrated.
- generation of control pulses for the DC - DC conversion stage transistors no longer takes place [73] [76] [78].

CHAPTER 5
PREDICTIVE MAINTENANCE BASED ON THE CONCEPT OF VIRTUAL METROLOGY

5. 5. Case study: virtual metrology implemented using a PLC

Objective

In the next case study, software interfaces used in the industry for monitoring the electronic equipment involved in the manufacturing process are presented. These interfaces have the role of verifying the operating parameters.

Obtained results

Depending on the number of equipment we want to monitor, individual tabs can be created in the maintenance pages.

Figure 5.6 shows an interface in which several electronic equipments that make up a subsystem are declared . Each compartment has an exact and fixed position in the equipment assembly involved in the manufacturing process. Incorrect allocation of one compartment to another position can lead to major damage to the industrial system. By querying the position sensors in the industrial system with the help of the interface, it is confirmed that the equipment is in the position corresponding to the operating stage. Also, this query automatically checks the communication between the equipment and the control room, the operation of the action buttons and the power supply of the equipment called, in this case, "compartment" [80].

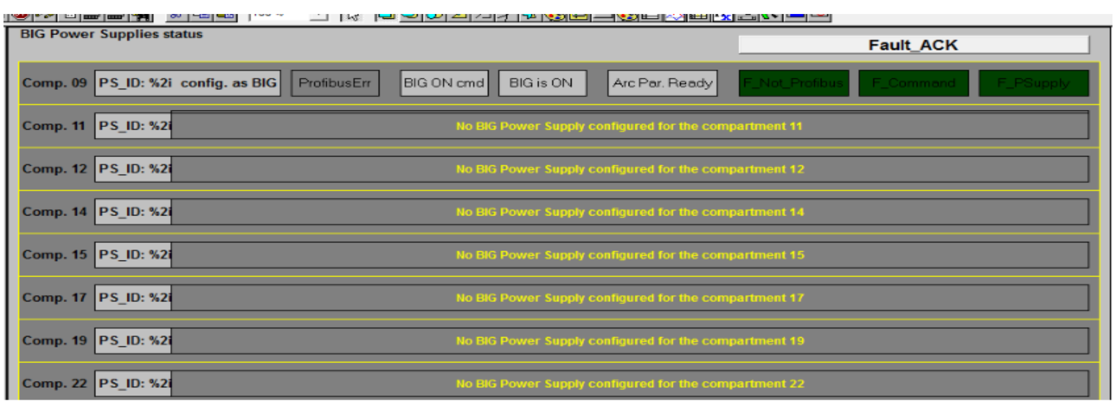

Figure 5.6 Software interface for querying the electronic equipment system involved in the technological process [80]

From the point of view of virtual metrology, with the help of this software program, a series of values of the parameters of the equipment are obtained. The "compartment", as we called it earlier, consists of a series of mini electronic equipment. Each compartment contains a pressure, temperature, position sensor and communication interrogator (Figure 5.7) [80].

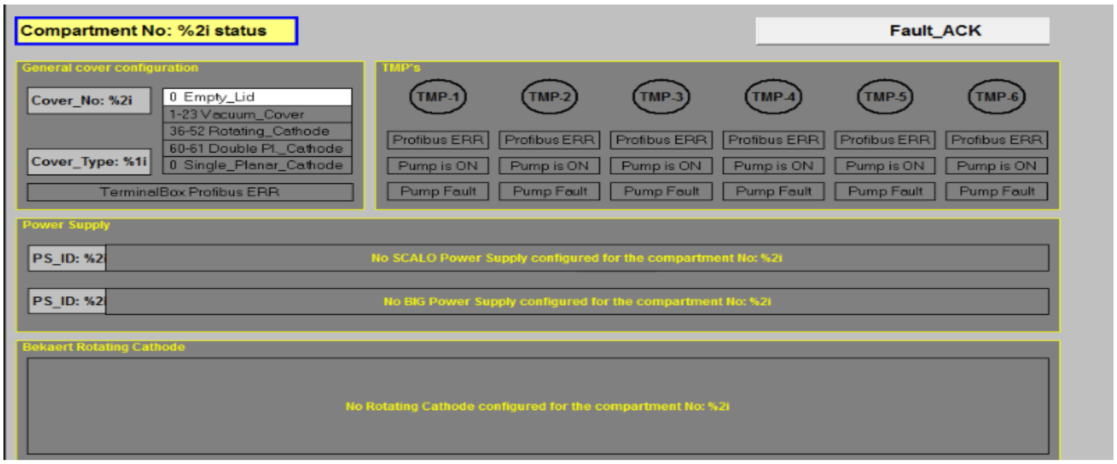

Figure 5.7.Checking the parameters of the equipment located in the subsystem[80]

Conclusions

Any error is reported in the software interface and centralized in DCS. It can be observed that there is a "Fault-ACK" button which represents the alarm detection and which, by its action, leads to the continuation of the technological process, if the alarm does not jeopardize the operation of the equipment or cannot lead to the appearance of the system's fault status [80].

CHAPTER 6

CONCLUSIONS, CONTRIBUTIONS, TRENDS

This chapter presents the results obtained, the original contributions, the list of original works and the possibilities for further development.

6.1.Results obtained and original contributions

Following the theoretical and applied research, the following contributions were presented, which are presented mainly in chapters 2,3,4 and 5.

The following is a table summarizing the contributions that are of particular relevance to the field addressed in the paper.

Specific objective	Results obtained	Results published in scientific papers
OS 1	Emphasys of applying concepts of virtual metrology in thepredictive maintenance equipment electronic theory and practice through case study in section 5.5.3 - Metrology virtual implemented using a PLC.	JEEECCS 2015 - Predictive maintenance of power industrial electronic equipment 1. Scientific report no.5 - Virtual metrology and sequential control (Run-to-Run) applied in predictive maintenance
OS 2	The making of case studies that are based on techniques of classical electronic equipment monitoring, Pareto analysis section 3.1.1.	ATEE 2017 - Monitoring parameters of electronic components to realize the maintenance of a power
	implementation of software interfaces for electronic equipment diagnostics .	
OS 3	implementation of software monitoring programs with integrated management equipment, section 4.2.	ECAI 2018 The importance of PLC in the predictive maintenance of electronic equipment
OS 4	software development for industrial environments in order to prevent the occurrence of accidental stops due to the equipment involved in the technological process .	ATEE 2017 - Monitoring parameters of electronics components to realization the maintenance of the power Scientific report no.4 - Advanced Systems Process Control
	Validation of the results obtained in chapter 4 by simulation and experimental application of the interfaces for monitoring, diagnosis and signaling of defects.	
OS 5	developing optimized software solutions based on classical concepts .	Scientific report no.3 - Mathematical methods and tools for the acquisition and analysis of data from monitored processes
	identification of the electronic components with the high rate of failure, section 3.2.2.	

OS 6	Application of fuzzy logic to highlight links between symptom - cause - effect.	ECAI 2015 - Predictive maintenance of electronics systems based on analysis with thermographic camera and fuzzy graphs
OS 7	Creation of databases containing defects recorded during the operation of the equipment tested.	IJTPE 2016 - Failure Risk Analysis Using Data from a Remote Monitored Power Station JEEECCS 2015 - Predictive maintenance of industrial power electronic equipment ICTPE 2016 - Remote diagnostics for power supply equipment used in telecommunications
	development of software interfaces for fast electronicequipment diagnostic of the components that are in the system, Section 4.3.	

6.2 List of original works

The results obtained by the author in the fields relevant to the doctoral thesis were disseminated by participating in conferences and sessions of scientific communications and by publishing articles which include the following :

Published in ISI WOS indexed conferences

1. **ECAI 2015 -** International Conference – 7th Edition Electronics, Computers and Artificial Intelligence June 25-June 27, 2015 **,** Bucharest, Romania .
Authors: Stanica Mirel Dorin, **Şşman** George Robert.
Paper : *Trends in computational intelligence applied in nuclear engineering for non-destructive examination techniques* ;
WOS: 000370971100039
2. **ECAI 2015 -** International Conference **– 9**th Edition Electronics, Computers and Artificial Intelligence June 25-June 27, 2017 **,** Bucharest, Romania.
Authors: **Şişman** George Robert, Bizon Nicu, Oproescu Michael.

Paper : *Predictive maintenance of electronics systems based on analysis with thermographic camera and fuzzy graphs* ;

WOS: 000425865900026

3. **ATEE 2017 -** THE 10th INTERNATIONAL SYMPOSIUM ON ADVANCED TOPICS IN ELECTRICAL ENGINEERING March 23-25, 2017 Bucharest, Romania.

Authors: **Şişman** George Robert , Oproescu Michael.

Paper: *Monitoring parameters of electronic components to realize the maintenance of a power supply0*

WOS: 000403399400162

4. **ECAI 2018 -** International Conference – 10th Edition Electronics, Computers and Artificial Intelligence June 28-June 30, 2018 **,** Iasi, Romania.

Authors **:** George George, Bizon Nicu, Oproescu Mihai.

Paper: *The importance of PLC in the predictive maintenance of electronic equipment*

WOS: 000467734100096

Published in SCOPUS indexed journals

5. **IJTPE 2015** - International Journal on "Technical and Physical Problems of Engineering" (IJTPE). Published by International Organization of IOTPE, December 2015, Issue 25, vol 7, no.4

Authors: **Şişman** George Robert , Oproescu Michael.

Paper: *Predictive maintenance at the electronic equipment - a brief review*

ISSN 2077-3528

6. **IJTPE 2016** - International Journal on "Technical and Physical Problems of Engineering" (IJTPE). Published by International Organization of IOTPE, September 2016, Issue 28, vol 8, number 3, pp 42-51.

Authors: Nicu Bizon, Oproescu Michael **Şişman** George Robert.

Paper: *Failure Risk Analysis Using Data from a Remote Monitored Power Station*

ISSN 2077-3528

Published in indexed journals in other international databases (Copernicus, Google Scholar etc.)

7. **JEEECCS 2015 -** Journal of Electrical Engineering, Electronics, Control and Computer Science - JEEECCS, 2015.
   Author: **Şişman** George Robert , Oproescu Michael.
   Paper: *Predictive maintenance of power industrial electronic equipment*

Published in international conferences

8. **ICTPE 2015** - 11th International Conference on "Technical and Physical Problems of Electrical Engineering" 10-12 September 2015, University of Pitesti & LUMINA - University of South-East Europe Bucharest, Romania.
   Authors: **Şişman** George Robert, Nicu Bizon, Oproescu Mihai
   Paper: *Predictive maintenance at the electronic equipment - a brief review*
9. **ICTPE 2016** - 12th International Conference on "Technical and Physical Problems of Electrical Engineering" 7-9 September 2016 ***University of the Basque Country*** Bilbao, Spain.
   Authors: **Şişman** George Robert, Bizon Nicu, Oproescu Mihai
   Paper: *On the remote diagnostic of the power source used in telecommunications*.
10. **ICTPE 2016** - 12th International Conference on "Technical and Physical Problems of Electrical Engineering" 7-9 September 2016 ***University of the Basque Country*** Bilbao, Spain.
    Authors: **Şişman** George Robert, Bizon Nicu, Oproescu Mihai
    Paper: *Predictive Maintenance Prioritization using Fuzzy Graphs*

6.3 Future development perspectives

Future research directions are closely related to the original ideas that were highlighted in the thesis. Development of new software solutions for monitoring electronic equipment. Transmitting the data recorded through various media and storing them in the cloud to prevent their alteration. Equipment interconnections for easier and faster monitoring.

Development of the monitoring segment of remote manufacturing processes based on Internet-based technology.

Realization of web interfaces with the ability to self-diagnose by classifying defects based on symptom-effect relationships.

The general trend is for online remote monitoring of electronic equipment, so research and development efforts are focused in this direction.

Scientific reports

1. **The scientific report no. 5** : *Virtual metrology and sequential control (Run-to-Run) applied in predictive maintenance* , author **Şşman** George Robert, Coordinator Prof. Dr. Ing. BIZON Nicu, Evaluation Committee : Conf. Dr. Ing.Eugen Diaconescu, CPI dr. ing. Corneliu Mihai Talpalariu, Assoc. dr. ing. Petre Anghelescu
2. **Scientific report no.4** : *Advanced process control systems* , author **Şşman** George Robert, Coordinator Prof. Dr. Ing. BIZON Nicu, Evaluation Committee : Prof. Eng. Ioan Liţă, Prof. Eng. Gheorghe Şerban, sl. Dr. ing. Corina Savulescu
3. **Scientific Report No. 3** : *Methods and mathematical tools for the acquisition and analysis of processes monitored* , author **Şişman** George Robert, Coordinator Prof. Dr. Ing. BIZON Nicu Commission of evaluation : Prof. dr. Eng. Gheorghe Serban, CPI Dr. . ing. Corneliu Mihail Talpalariu, Sl. Dr. Iana Gabriel, PhD
4. **Scientific report no.2** : *Electronic technologies and equipment for predictive maintenance* , author **Şişman** George Robert, Coordinator Prof. Dr. Ing. BIZON Nicu, Evaluation Committee : Conf. Dr. Ing. Eugen Diaconescu, CPI dr. Ing. Corneliu Mihail Talpalariu, Sl. Dr. Eng. Mihai Oproescu
5. **Scientific report no.1 :** *Predictive and corrective maintenance models - an overview* , author **Şişman** George Robert, Coordinator Prof. Dr. Ing. BIZON Nicu, Evaluation Committee : prof. Ing. Ioan Liţă, prof. Dr. ing. Silviu Ioniţă, Sl. Dr. Eng. Alin Mazăre

Research projects

Project co-financed from the European Social Fund through the Sectoral Operational Program for Human Resources Development 2007 - 2013 (POSDRU), Project title: Knowledge, innovation and development through doctoral scholarships, Contract Code: 155536, Beneficiary: POLITEHNICA University from Bucharest.

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