POLITEHNICA UNIVERSITY OF BUCHAREST

Doctoral School of Electrical Engineering

PHD THESIS

Summary

ACTIONĂRI ELECTRICE PENTRU MONITORIZAREA ȘI DIAGNOSTICAREA CALIȚĂTII APELOR PROVENITE DIN PUȚURI FORATE

ELECTRICAL DRIVES FOR MONITORING AND DIAGNOSIS OF WATER QUALITY SYSTEMS FROM DRILLED WELLS

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CHAPTER 1

INTRODUCTION

1.1. PURPOSE OF THE DOCTORAL THESIS

The presented thesis proposes a set of steps that can be used to design and automate a pumping assembly necessary for modern drinking water distribution networks. In the chapters of the thesis, the stages of the first configuration of a pumping group are covered, having as a starting point the hydraulic requirements of the distribution network. Examples of sensors needed in the monitoring and automation process are presented, along with their advantages and limitations. At the same time, the thesis also contains concrete examples of industrial installations used in the technological process of obtaining drinking water through mechanical and chemical treatment. These installations are considered when sizing the pumping group and its automation.

A new aspect is given by the implementation of a software product integrated in the pump's module, intended to ensure the monitoring and self-diagnosis of the entire pumping assembly. This Expert System is primarily described in theoretical form as a table of possible scenarios. Later the system is implemented in a complete software product with database and actuation methods.

Another novelty element is provided by the intention to implement the entire automation logic of the Expert System in the pumping and distribution group, using Internet of Things (IoT) technology. In this form the Expert System can successfully monitor and control the entire pumping and distribution process, unifying the process steps under a single central processing unit.

The appendices attached to the thesis present the set of code lines necessary for the development of the Human Machine Interface (HMI). This interface is only a component of the Expert System, the component that provides system status information to the supervisor.

1.2. GENERAL ELEMENTS REGARDING WATER QUALITY MONITORING AND DIAGNOSTIC SYSTEMS

The distribution of drinking water requires continuous monitoring due to the impact on the health of the population. The quality of drinking water must be ensured over the entire distance from the pumping group to the consumer. To ensure this sanitary safety, the drinking water is disinfected and maintained at a certain concentration of chlorine. The fragile balance of the chlorine concentration must also be maintained over time depending on consumption, but also when the network is not in demand. Turbidity generated in aging mains should be minimized as much as possible by using slow start practices of pumping sets and periodic cleaning of the mains. Bacteriological safety is ensured by disinfection and by active monitoring of water quality against pollution factors.

1.3. ELEMENTS OF LEGISLATION AND COMPANIES IN THE FIELD OF THESIS

The relevant national legislation regarding public water supply and sewerage services is summarized in: Law no. 241/2006, Law no. 51/2006, Law no. 31/1990, GEO 13/2008, Law no. 215/2001, Law no. 273/2006, GD 246/2006, Law no. 213/1998.

Local and county water companies responsible for the treatment and distribution of drinking water.

Companies selling and distributing the equipment needed to implement treatment systems and pumping and distribution systems, such as: ENVIROTRONIC SRL, NITECH SRL, EDAS EXIM SRL, SITLINE TECHNOLOGY SRL, HACH LANGE ROMANIA, ENDRESS & HAUSER ROMANIA, VEOLIA WATER SOLUTIONS etc.

Consulting companies for the design and implementation of drinking water treatment, distribution, and monitoring solutions, such as: PROTOBI, C&V WATER, RAMBOL, STRABAG, HOCHTIEF SOLUTIONS, DANEX INTERNATIONAL, POLIALFA etc.

Automation and electric drive companies such as: SITLINE TECHNOLOGY, POLIALFA, SIEMENS, BLUENOTE, CRYSTAL GRUP, DINOTEDAS, SOFTCONTROL etc.

1.4. THANKS

The completed thesis is the result of work conducted by me as a doctoral student during my doctoral internship. The development of this work was done in the Department of Machines, Materials and Electric Actuators of the Faculty of Electrical Engineering of the POLITEHNICA University in Bucharest. The tests and assemblies presented are made with the help of commercial companies with whom we have participated in various projects.

First, I would like to express special thanks to Mr. Prof. Dr. Eng. Constantin GHIȚĂ, the scientific leader of the work, embodied in the careful and competent guidance provided throughout the elaboration of this doctoral thesis. At the same time, I would also like to thank the professors from the guidance committee: Prof. Dr. Eng. Tiberiu TUDORACHE, Associate Dr. Eng. Aurel-Ionuț CHIRILĂ and Prof. Dr. Eng. Vasile PETRE, for the constructive discussions and suggestions made during the presentation of the research reports related to this thesis.

Next, I would like to personally thank Mr. Prof. Dr. Eng. Valentin NĂVRĂPESCU from whom I learned what the profession, thinking, logic and passion of an engineer really means.

I also thank ENVIROTRONIC SRL, which allowed me to get in touch with the projects without which this thesis could not have been realized, and for the equipment and data accumulated over the years of work and necessary research for conducting experiments. In this sense, I mention Mr. Lucian GAVRILESCU for his support, guidance, and patience throughout the development of this thesis.

Finally, but not least, I would like to thank my family for the conditions and support they created and offered me throughout the preparation of my doctoral thesis, which made it possible.

CHAPTER 2

SENSORS, TRANSDUCER, ELECTRONIC DEVICES AND EQUIPMENT FOR THE REALIZATION OF WATER QUALITY MONITORING SYSTEMS

- *pH measurement sensors*

The pH can be described as the concentration of hydrogen ions in a liquid solution to be measured, or it can be appreciated as the activity of those ions. A rod-shaped structure made of gas-permissive glass is used to measure this parameter. Inside this structure there are two measuring electrodes, or a combined electrode, which creates a variable potential difference depending on the concentration of the studied parameter.

- *Sensors for determining conductivity*

Conductivity is a measure of water's ability to conduct an electrical current. This is affected by the presence of dissolved inorganic solids such as anions (negatively charged ions) of chlorides, nitrates, sulphates and phosphates or cations (positively charged ions) of sodium, magnesium, calcium, iron, and aluminum. Organic compounds such as oil, phenol, alcohol, and sugar do not conduct electricity very well, so they have a low conductivity when present in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. Therefore, conductivity is reported as recorded at 25°C [1][2].

- *Transducers for measuring salinity*

Salinity refers to the total concentration of dissolved salts in water. Salts form ionic particles upon dissolution, so salinity becomes a strong component of conductivity. High salinity can be measured by full chemical analysis, a difficult and time-consuming method. More often, salinity is estimated using algorithms based on conductivity, an easier parameter to measure. Parameter values can be expressed as parts per mil (ppt) or as practical salinity units (psu) comparing the sample to a salinity standard such as seawater.

- *Sensors for the determination of total dissolved salts (tds)*

These transducers are used to measure all dissolved particles in the water sample, smaller than two microns. It includes all organic and inorganic substances in molecular, ionized, or micro-granular state in suspension. In clean water samples, TDS is equal to salinity, while TDS in polluted waters also includes organics. [3]

- *Equipment for monitoring dissolved oxygen (do)*

Atmospheric air has an oxygen concentration of 20%. Fish and other aquatic organisms also require oxygen. The term Dissolved Oxygen (DO or D.O.) refers to the amount of free oxygen dissolved in water, necessary for aquatic organisms to breathe. Water quality standards express minimum dissolved oxygen concentrations that must be maintained to support life and be beneficially used. Dissolved oxygen levels below 4-5 mg/l affect fish health and those below 2mg/l can have lethal consequences.

CHAPTER 3

EQUIPMENT AND ELECTRONIC DEVICES FOR HYDRAULIC SYSTEMS

Chapter 3 begins by describing the core of any hydraulic network: the pumps. Following the design of the set of pumps used, it is possible to continue with the choice of the monitoring, automation and protection equipment required for the pumps. Also here are presented the criteria on the basis of which the automation and control system is dimensioned, the architecture on which the automation platform is built, and some examples of industrial installations used in the field of drinking water treatment and pumping [4].

3.1. ELECTRICAL ACTUATION OF THE PUMPING ASSEMBLY

Pumps are mechanical equipment for generating hydraulic energy. This energy is characterized as the overpressure of a liquid moving at a certain speed or at a certain flow rate. Hydraulic power is the result of mechanical work done by an electric motor coupled to a fluid propulsion system.

Modern frequency converters (CF), with their outstanding technical and dimensional performance, have brought a revolution in pumping technology in recent years. They were integrated into the housing of the pumping units together with the pressure (flow) transducers and the automatic adjustment systems of these parameters. As a result, classic pumps have acquired new properties, becoming adjustable and flexible sources of hydraulic energy, being also called smart pumps. Such a pump is shown in figure 3.1.

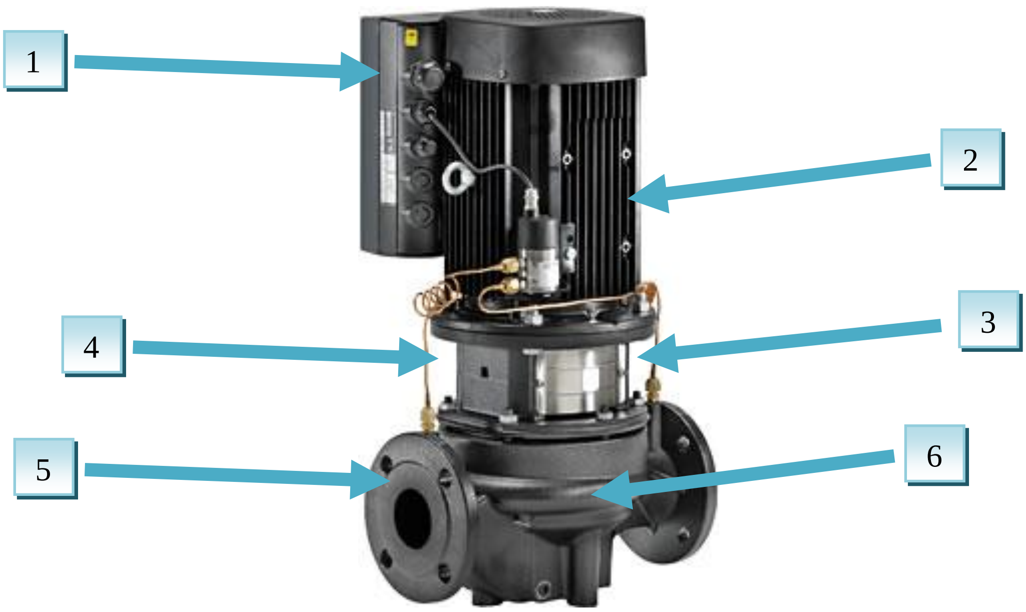

Fig. 3.1. Pump with integrated frequency converter

The meanings of the notations in figure 3.1. are the following:

1 – the connection terminals of the electric motor, the frequency converter, the pressure sensor regulator;

2 – electric drive motor;

3 – the mechanical coupling between the electric motor and the pumping shaft;

4 – the hydraulic differential measurement path of the pressure transducer;
5 – pressure coupling (DIN flange – notation according to German standards);
6 – The housing containing the pump shaft.

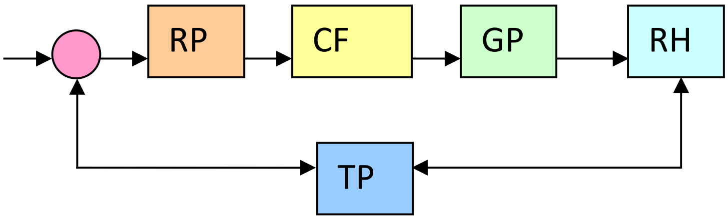

Fig. 3.2. Block diagram of the pressure regulator for controlling the pumping group

In figure 3.2. the block diagram of an active pressure regulator is shown. If the pumping group (GP) is fed from a frequency converter (CF) controlled by a pressure regulator (RP) in closed loop, no more pressure increases are possible because the transducer (TP) and the pressure regulator (RP) permanently controls the deviation of the actual pressure from the prescribed (nominal) pressure, keeping it zero and thus stabilizing the pressure p = const and the height H = HN = const by changing the engine speed and implicitly the pump up to the value n = n1. The modified characteristic HP(Q), for n = n1, in this case, moves parallel downwards, which leads to a reduction of the electrical power consumed, proportional to the differential height ΔH.

The electric motors in the pumps are three-phase asynchronous. Cooling is done with a duct system placed in the engine housing through which the cooling water circulates. It is allowed to run the pump with the motor exposed for short periods of less than 15 min, and the CEE power cable is equipped with an idle protection float. A frequency converter is used to drive the electric motor.

Frequency converters are used for electronic regulation of the speed of drive motors. By using these converters, electricity is saved, and material wear is considerably reduced. In general, frequency converters start and stop electric motors in a controlled and infinitely variable manner. Compared to direct-fed electric motors, frequency converter drive eliminates power and torque pulses, which mechanically protects the motor-to-pump transmission, pump, hydraulic network, and seals. This significantly reduces wear and extends the life of the pumping station. Maintenance procedures and repairs are done less often, and costs are reduced thanks to longer operating intervals and low material wear.

A compact and integrated solution, where the frequency converter is attached directly to the electric motor, ensures better coordination between the motor and the converter.

A pumping group uses the following sensors:

- Voltage sensors
- Current sensors
- Power sensors
- Sensors for determining the power factor - cos(φ)
- Pressure sensors
- Temperature sensors
- Vibration sensors
- Sensors for the presence of water in the oil

In the case of smart pumps (E-pump), all the mentioned sensors enter the command-and-control assembly mounted on the pump body. With all these sensors integrated and connected within the pump, there is no need to acquire data or implement additional actuation or protection rules, as the pump is already controlled locally, underwater, by the integrated sensor array.

3.2. PH CORRECTION FACILITY

In general, water with a low pH (<6.5) can be acidic, mild, and corrosive. Thus, the water can receive ions of metals such as iron, manganese, copper, lead and zinc from the point of treatment, fittings or pipes. As a result, water with a low pH can contain high concentrations of toxic metals, which can prematurely damage metal installations. This water can have problems such as a metallic or sour taste, stain clothing, and leave a characteristic blue-green color on sinks or drains. The main way to treat low pH water involves using a neutralizer. It dispenses a solution into the water that prevents reaction between the water and plumbing or electrolytic corrosion. A typical neutralizing solution is baking soda. Neutralization using baking soda increases the sodium content of the water.

Fig. 3.3. Soda dosing facility

Basically, the station consists of a metal case, chemically treated against corrosion, which will serve as mechanical protection and enclosure for the dosing subassembly. Inside the case, a panel made of chemically resistant, laboratory top will be mounted, on which the hydraulic routes, the dosing pumps, the electrical supply panel, the control and feedback panel, a block of sockets and a lamp will be installed as accessories. The components are shown in figure 3.3. and in figure 3.4.

Fig. 3.4. Soda dosing facility

The thesis presents in detail such a facility capable of correcting the pH in real time by dosing the reagent.

3.3. TECHNOLOGICAL STAGES OF DRINKING WATER TREATMENT

For raw water to become potable, it must go through the following stages:

- Preliminary treatment
- Coagulation / flocculation
- Sedimentation (clarification)
- Filtering
- Disinfection
- Sludge drying
- Fluoridation
- pH correction

3.4. MONITORING OF TECHNOLOGICAL STAGES OF DRINKING WATER TREATMENT

The first stage of the process is pretreatment. Here the water is cleaned of large particles such as stones, leaves, wood, etc. using sparse and dense grids. The first monitored parameter is the flow rate of the water entering the treatment plant. Depending on this flow rate, it is checked to ensure the amount of treated water needed by consumers.

In continuation of the water supply line is the inlet flow control valve. This valve is controlled by the instantaneous flow rate imposed by the operator. The flow recorded by the calibrated Parshall channel enters a differential equation along with the imposed flow, and the result leads to additional opening or closing of the inlet valve.

At the station entrance itself, there is an automatic sampler. The purpose of this sampler is to obtain a water sample from the station's supply line, to be evaluated by the laboratory staff.

In the continuation of the technological line is the turbidimeter for raw water. Its purpose is to monitor water turbidity. This parameter denotes the degree of clarity of the raw water. Particles such as dust or sand are detected by this sensor.

As the water progresses through the process, a pH transducer is found. Equipped with a gas-permeable glass electrode and a temperature sensor, the pH transducer converts the measured electrical potential into pH units.

Once the input parameters have been recorded and approved by the centralized data system, the process line begins the water treatment steps.

Polymers require a preparation station. Although a less expensive investment than aluminum sulfate, the polymers are purchased in granular form and must be prepared before being injected into the water supply line. An auger dosing system dispenses polymer powders into a small water tank. Then a mixer mixes and homogenizes the polymer with water.

Then, the mixture of raw water and polymer is mixed quickly to be homogenized. To disperse the reagent uniformly, powerful high-speed mixers controlled by frequency converters are used.

Also at this stage, the pH of the water is recorded to protect the water line against accidents or ingress of foreign matter. pH and temperature are transmitted via (4 - 20mA) to the local PLC.

Flocculation, the next technological step, allows water to flow at low speed through a reaction basin. Here the dust and residue particles begin to attract due to the positive ionic charge of the water and become flakes. Sedimentation (or clarification) starts as soon as the water goes through the flocculation process. At this stage, the water flows very slowly to give it time to clear.

Next, a mixer is used for further homogenization of the process water. Thus, any particles left in the water can no longer sediment or deposit on the installations. A final sample is collected by the laboratory operator to determine the efficiency of the filters and the sedimentation and flocculation steps.

Clear water wells benefit from chlorine disinfectant treatment. The organisms in the water are destroyed or neutralized by dosing chlorine (Cl2) in the water, the reagent being very practical, efficient, and economical.

Before pumping the finished water, the pH of the water is adjusted to the optimal level of 7.2 or 7.4 pH units. To adjust, lime is dosed using suspended tanks with a flow valve. Lime acts on chlorinated water and increases the slightly acidic pH because of the filtration and reagent dosing processes. This water is then pumped to the distribution system.

At the exit from the station, an electromagnetic flow meter records the flow of water supplied to the network and the total water supplied is counted for fiscal purposes. This total of water supplied is the basis on which the water treatment plant is paid for its services.

3.5. ECONOMIC BENEFITS OF AUTOMATING THE WATER TREATMENT PROCESS

Data collected from the industry indicates the highest maintenance and operating costs to be for labor (human factors), energy and chemicals (reagents). Thus, automation in these areas has enormous potential to generate savings. Investing in typical savings by applying automations shows values like:

- Savings in chemicals: usually between 15% and 40%;
- Savings in manual work: usually between 5% and 30%, but higher values were recorded in stations operated without human assistance;

- Energy savings: usually between 5% and 35%.

Certain savings shown may be due to the application of higher-level automation. Not all of these savings are attributable solely to unassisted operation.

3.6. WATER QUALITY MONITORING AND DIAGNOSTIC SYSTEM

The principle of monitoring, data acquisition and intervention on the system in real time is implemented in a modified structure for each individual system. In the case of a pumping group, the monitoring assembly consists of process sensors with short and very short response time, an important feature in fast reaction loops. At the same time, the sensors in turn need monitoring by a central system, fully equipped to establish the decision-making factors. Usually this system is called SCADA (Supervisory Control and Data Acquisition). But through its implementation method, SCADA can be purely theoretical, made up of software parts working together to record data and implement decisions, or it can be mixed, a complete system made up of Hardware and Software components, embedded in the feedback loop.

The surveillance systems are also implemented in graphic form, HMI (Human Machine Interface) so that they can be easily understood, followed, and modified by the operators of the stations. Also, graphical interfaces allow them to follow current or past trends as graphs, view or acknowledge alarms, change operating parameters even while the system is running, plus many other customized functions from application to application [5].

Comparing the electronic monitoring, acquisition, decision and intervention system with the physical reaction system, the predominant response time of the ensemble will always be that of the reaction elements. But this is not seen as a problem. We assume that a hydraulic system consisting of pipes and connections to consumers, has a pressure drop caused by the entry into operation of a large hydraulic consumer. The monitoring system senses the pressure drop immediately, the new values are instantly acquired in the SCADA system, the decision maker is quick, and the solution is accessed: increase the pressure by increasing the pumping speed (more volume, more pressure). Up to this point, the reaction time is fast, like an efficient electric drive. From here, the pump motors run at a higher speed, and ideally the pressure should equalize quickly. However, the hydraulic inertia of the system appears. That lack of volume that causes the pressure drop can only be filled by pumping, and the group is limited in flow, relative to time. That hydraulic inertia will cause a much higher response time (the system will be slower) as the whole monitoring, acquisition, decision, and reaction assembly. The more the feedback system follows from the sensor to the consumer, the response time increases exponentially.

The conclusion of this system involves the use of standard acquisition and monitoring components. No need for ultra-fast components or oversized pumping groups. Anyway, in the crucial points, designed to cope with sudden and large consumption, additional pumps are implemented with a redundant role but also with a role of activation in cases of emergency. If a pump encounters problems that lead to its complete shutdown, the second pump is started as soon as possible in order not to affect the technological process.

The diagnostic component of the system is different from the system mentioned above. To keep an assembly in the nominal regime (keeping that system healthy) it is necessary to monitor other functional parameters, in real time, different from those monitored in the process. Here, the temperature of the pumping group, the current absorbed by it, the absorbed powers, the working voltage, the vibrations, the revolutions of the mechanical reducers, etc. are monitored. These parameters can warn the system in time about potential problems, malfunctions or possible breakdowns. Acquisition sensors are as fast as process sensors, but the acquisition and reaction elements are much faster. Under these conditions, the aim is to protect the system, implicitly protecting the investment. We can only imagine what total failure of a pump means without self-diagnosis or on-site operator. The group is stopped for remediation and the final beneficiary is the main disadvantage. Implicitly there are financial repercussions at the level of the water company, once through the remedial investment and another time through the recorded monetary losses.

Another side of the centralized monitoring and diagnostics system is water quality assurance. This aspect is composed of the qualitative analyzes of the water reporting the physic-chemical parameters. Considering the technologies required to modify certain qualitative parameters, the parameters are monitored at certain stages of the treatment chain, stages after which intervention can be taken to correct the water. If, for example, the pH of a water is not stabilized in the neutral zone, in addition to the implications for the health of the beneficiary, it can lead to the rapid degradation of the pumping and supply facilities. Degradations are often manifested by mineral deposits, corrosion, destruction of membranes or gaskets, etc. From the preliminary stages of the treatment, the degree of acidity or alkalinity of the water can be corrected by dosing certain reagents.

The feedback loop designed for real-time diagnostics is much faster. It does not interact with the hydraulic network itself, but only with the group itself. The accumulation of information is also done with qualitative sensors, but the measured parameters differ. The protection cycle gathers information about the engine, about its physical parameters, about reactions occurring at the level of couplings, vibrations, mechanical stresses, revolutions, etc. But there is also the preventive cycle, the purpose of which is to monitor the quality (health) of the group. In principle, it looks for problems such as water infiltration in the oil baths of reducers or bearings, changes in the internal humidity of dry components, the appearance of noises outside the preset resonance area (prevention of cavitation) and others.

3.7. APPLICATION-SPECIFIC CONSIDERATIONS IN EQUIPMENT SIZING AND SELECTION

Starting from the parameters of the hydraulic installation, the pumping group is dimensioned. Next, the crucial and optional monitoring points of the hydraulic parameters are chosen. To keep the network in nominal mode, the following parameters are required as a minimum:

- Pressure in the distribution network
- Treated water tank level
- Instant water flow for consumption management
- Total flow provided for taxation

To monitor the state of the pumping group, it is necessary to install some additional sensors compared to the hydraulic ones. The electric motor and the mechanical reducer will be monitored using the following components:

- Power transducer
- Current transducer
- Voltage transducer

- Temperature transducer
- The speed converter
- Water in oil sensor
- Vibration sensor

3.8. ELEMENTS OF THE MONITORING AND DIAGNOSTIC SYSTEM

Following the reaction system of the process, the first component, and the most expensive, is the sensors. These elements transform the physical characteristics of the system into profitable quantities. For example, a piezoelectric pressure sensor measures the position of a sensitive membrane and converts this position into a value expressed in mA, in the range (4 – 20) mA. This industrial transmission protocol has been used for a very long time because its implementation is very simple. An analog measurement channel does not require additional power. The sensor is composed of a resistance that changes with the position of the membrane. Thus, instead of laying a cable with at least four conductors to the sensor, a cable with two conductors and shielding (loop power supply) is laid. The simplicity of the system gives it resistance over time. [6]

The sensors required to determine the functional parameters are:

- Pressure transducer
- Level transducer
- Speed converter
- Flow meters
- Water in oil detector
- Level switch

3.9. PROCESSING AND INTERPRETATION OF SIGNALS

Once the sensors are chosen according to the application, the sizing and configuration of the signal transducers begins. These interfaces must be able to acquire the signals transmitted by the sensors, filter these signals, rectify them where appropriate and pass them on, conditioned, to the analog and digital inputs of the PLC. At the same time, the interfaces protect the data acquisition system in case of overload, accidental discharges, short circuit. It is convenient that in such a system an amplifier fails, cheap and easy to replace. If the defect were located at the level of the PLC, the entire system would be disabled until it is fixed, with a large economic impact.

Next, the software component comes into play. The measured values are recorded in the memory registers, to be retrieved by the reaction system and at the same time stored in the long-term memory for future calls. Returning to the value fetch, the PLC interprets the value, passes it through the decision filters, and reacts, if necessary, within the feedback loop. If a higher or lower value is imposed, directly (by the operator) or indirectly (by an implemented operating curve), the loop reacts.

Next, the reaction elements translate the received signals into changes in the working parameters. A converter for example, operating in the preset frequency x, understands that it must change the frequency until it reaches the new value y. However, even reaction elements can have their own reaction loops. In real time, they monitor the quality of the emitted signal and physically intervene on it for shaping. All these loops denote reaction times, factors that must be considered at design time.

Just as the group responds slowly to new hydraulic demands, so does consumption (normally). A drop in pressure can be identified in time through continuous monitoring, and preventive action can be taken. This principle is put into practice in the form of "anticipated pressurization", a practice of water companies, near peak hours of consumption.

3.10. EXPERIMENTAL CASE STUDY – OPTIMIZATION OF LEACHATE TREATMENT SYSTEM BY REVERSE OSMOSIS

The case study presented below is the result of the procedure of parameterization, testing, optimization, and commissioning of the leachate treatment system (wastewater from the municipal waste storage cells) by reverse osmosis. In the application presented below it was necessary to identify the functional parameters and the correct operating settings for a leachate treatment plant with three batteries of RO cartridges (Reverse Osmosis – reverse osmosis), so that the plant is operating at full capacity regardless of the leachate concentration. The three cartridge batteries are arranged as follows: RO1 and RO2 are placed in container 1 and RO3 together with the ammonium stripper are placed in a container 2, attached to container 1. The experiments were conducted over 5 days, and each adjustment was evaluated individually, because the optimization procedure was an iterative one.

In its current form, the treatment plant operates based on the pressure data in the reverse osmosis columns and on the permeate flow rate requested by the user. This means that once turned on, the plant closes or opens the concentrate valve to obtain the flow required by the permeate at the exit from the reverse osmosis membranes. The maximum pressure set at the level of the osmosis cartridges is 60 bar, the hazard pressure is 64 bar – the pressure at which the installation is stopped urgently. The permeate flow rate requested by the user can be sustained by the RO1 stage for a fixed period, until the membranes are clogged and the pressure in the columns increases above the damage threshold. Thus, the installation requires a constant adjustment by the user of the permeate flow obtained at the RO1 output.

To correct this continuous adjustment, the issue of automation of the concentrate flow control valve (hereinafter PV101) at the output of RO1 was discussed. To increase the pressure in the reverse osmosis cartridges, it is necessary to gradually close the PV101 valve, in the reaction loop with the pressure in the columns. When the pressure is too high, the valve can open, releasing the pressure in the form of the concentrate flow that goes towards the additional treatment in RO3.

The permeate flow at the output of RO1, imposed by the operator, remains valid if the pressure in the installation remains below the set maximum value of 60 bar. The treatment plant will operate continuously, and the columns will gradually become clogged, which causes the pressure to increase. Upon reaching the maximum value of the pressure, the PV101 valve begins to open gradually, and the SCADA no longer takes into account the flow rate set by the user (the adjustment variable becomes the pressure on the reverse osmosis cartridges). Instead, the next decisive threshold is the minimum permeate flow of the station. By adjusting the concentrated flow control valve, the plant maintains a safe pressure in the reverse osmosis cartridges, but the permeate flow rate at the output of RO1 decreases. This flow rate must be greater than 0.5 m^3/h, otherwise the RO2 stage does not receive enough water to be treated.

When the permeate flow rate decreases below the critical value, the plant stops and begins the chemical washing procedure to unclog the osmosis cartridges.

These changes in the automation logic allow the treatment plant to operate at full capacity. The plant is built to treat high leachate loads (high concentrations of dissolved matter), present in fully loaded waste storage cells (full cells). When the station has to treat leachate cleanly or poorly loaded (e.g., after rain or melting snow), the flow rates it can work on are much higher because the weak load of the leachate creates a lower pressure drop than a loaded leachate. By optimizing the treatment stages with reverse osmosis, the yield of the entire plant increases, and the flow rate of treated water doubles. Now the station can operate constantly at maximum permissible pressure, regardless of the leachate load, which may differ depending on the season or weather conditions.

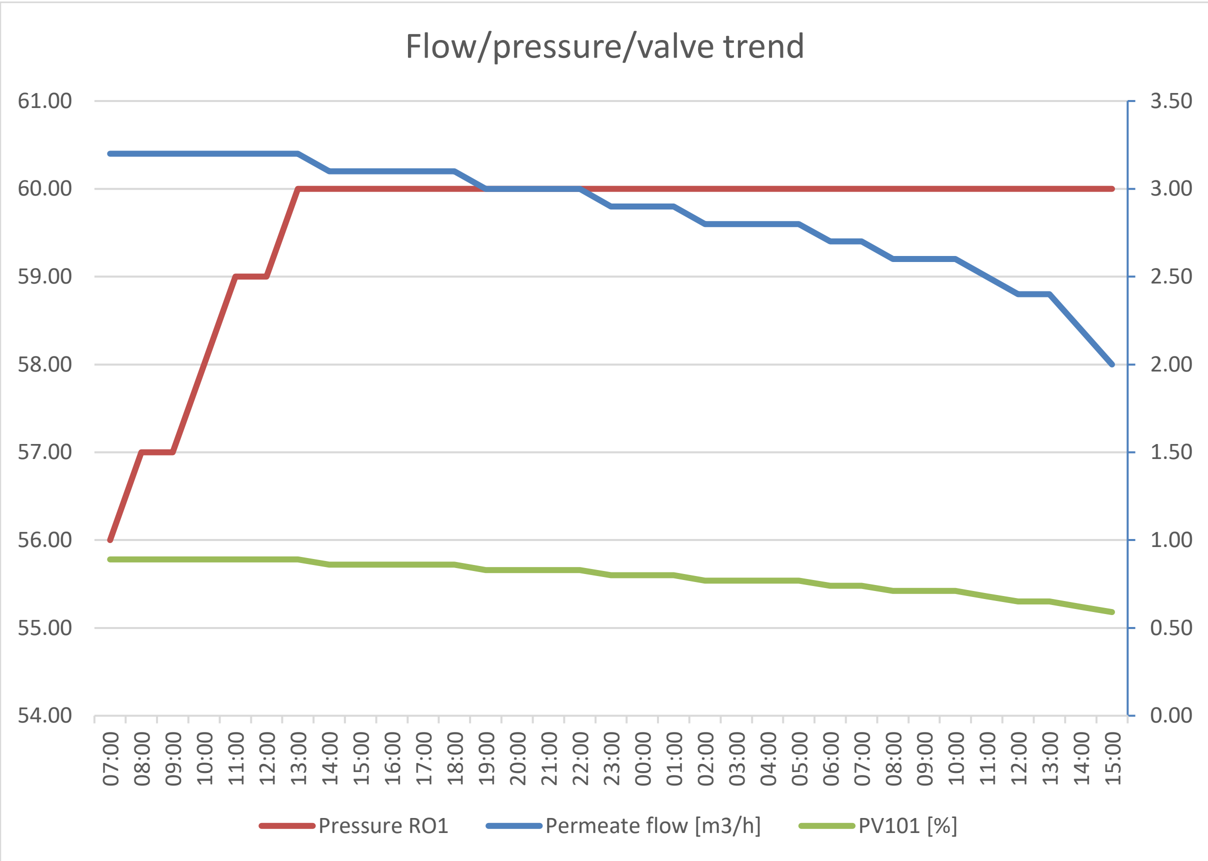

Fig. 3.5. Experimental results

In Figure 3.5. The adjustment logic of the PV101 valve is highlighted, provided that the maximum permissible pressure is reached. In this case, the maximum permissible flow rate, and imposed by the operator, is 3.2 m^3/h. The plant keeps the flow constant by opening and closing the PV101 valve. When the pressure reaches 60 bar, the valve is gradually opened to keep the pressure at the expense of flow.

CHAPTER 4

EXPERT SYSTEM DESIGNED FOR THE WATER TREATMENT PLANT

The expert system is a powerful calculation algorithm that incorporates the knowledge of an operator, an expert in the applied field. At the same time, this system manages to simulate the logic behind each human decision, thus reaching the solution of the problem that arose without encountering the inflexibility of purely numerical computing systems. The name of expert system derives from the ability of this algorithm to equal the power/decision criteria and the experience of the most trained experts in the field [7]. The basic architecture of an expert system is shown in Figure 4.1.

4.1. CHARACTERISTICS OF AN EXPERT SYSTEM

The key features of an expert system are:

- High performance – able to execute calculations much faster as an operator;
- Easy to understand – adapted to the universal language, in some cases the operator is not prepared on the domain but must be able to understand the system;
- Reliable – has no margin of error in case of wrong decisions;
- Short response time – like human intuition, the system decides in a very short time and acts on the process.

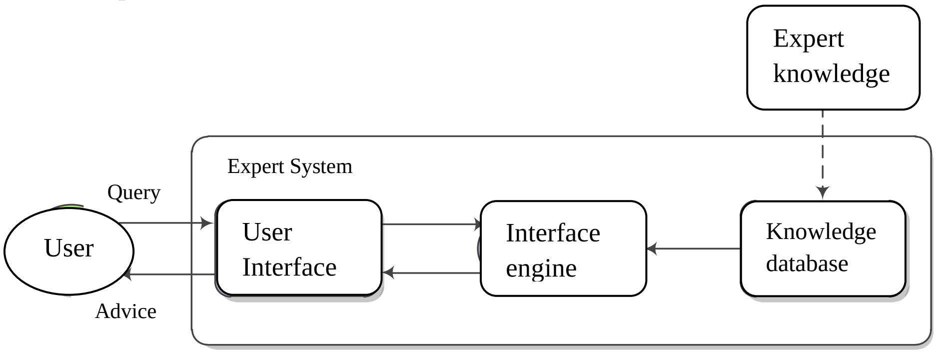

Fig. 4.1. Basic scheme of an expert system

4.2. KNOWLEDGE BASE

It contains data related to a specific field and high-quality knowledge. Knowledge is needed to demonstrate intelligence. The success of any expert system is based on the collection of accurate and accurate knowledge/experiences.

Dates are accumulations of events. Information is organized as data and events related to the field of a task. Past data, information, and experiences, placed together, are considered knowledge. The knowledge base of an expert system is an accumulation of factual and heuristic data:

- Factual knowledge – represents knowledge generally accepted by engineers and teachers in the field of pregnancy;
- Heuristic knowledge – part of the knowledge acquired through practice, precise judgment, the ability to evaluate and through presumptions.

4.3. INTERFACE ENGINE

The use of effective procedures and rules by the interface engine is essential in inferring a correct solution. In the case of a knowledge-based expert system, the interface engine accumulates and manipulates knowledge from an information base to achieve a particular solution. [8]

A rule-based expert system performs the following operations:

- Apply the rules repeatedly in events, obtained by applying the rules in the past;
- Add new knowledge to the base if needed;
- Resolves conflicts between rules when multiple rules apply to a particular case.

To recommend a solution, the interface engine uses the following strategies:

- Progressive chaining
- Regressive chaining

4.4. BENEFITS OF AN EXPERT SYSTEM

- Validity - are available thanks to the mass production of software programs;
- Low production costs - the price is a reasonable one, so they are affordable;
- Speed - they are very fast; they reduce the working time of each individual;
- Low error rate - the rate of occurrence of errors is lower than the human one;
- Risk reduction - can work in dangerous environments;
- Stable response - they can operate in nominal regime without emotions, without strain or fatigue.

4.5. APPLICATION OF A RULES-BASED EXPERT SYSTEM IN THE FIELD OF DRINKING WATER TREATMENT CONTROL

According to studies and the basic understanding of problems in water treatment, the reasons for the development of an expert system based on rules, in this area, can be summarized as follows:

- Knowledge in this field is based on experiences and these experiences have been obtained over many years;
- The field requires a wide range of knowledge;
- Knowledge and experiences are poorly documented;
- Problems are solved using techniques of symbolic logic;
- There are cooperative and eager experts in the field of water treatment plants;
- The issue is important enough to be considered.

➢ *Case study: empty chlorine cylinder*

The following describes a number of events in the reasoning procedure to identify the cause of the increase in turbidity of the treated water:

1. A high turbidity of the treated water was identified by the turbidimeter installed at the exit of the treatment plant. Noticing this problem, the general procedure in the operator's mind is to find the cause. If the problem had been caused by an equipment defect, then the appropriate theoretical solution filter is called. If the problem had been caused by changes in the turbidity of the raw water, the color of the raw water or other reasons,

then the dosage of alumina is adjusted in accordance with the turbidity of the treated water. The operator must determine which of the 2 causes generated the problem.

2. The operator may believe that the problem is caused by a change in the turbidity of raw water. If so, the next step is to determine an adjustment to the dosage of alumina. If not, the operator considers that it is dealing with a defect in equipment.
3. The operator shall confirm that the raw water source does not show any changes by checking it. Currently the operator is looking to identify an equipment defect in the station.
4. The level of turbidity after filters is checked in the control panel; it notes that all levels are normal
5. The next check was conducted at the level of the alumina dosage system. The set dosage rate can be compared with the calculated dosage rate. It has been identified that the current dosage rate is like the set value. This eliminates the possibility of a defect in the alumina dosage plant.
6. The operator then considered the possibility of a defect in the activated silicate system. This system includes a dosing flow meter, a water pump, chlorine cylinders, an automatic control valve, activated silicate tanks and silicates. Water and chlorine are delivered to the silicate to compose activated silicate. The proportions of water and chlorine are especially important in determining the quality of activated silicate. The chlorine pressure is controlled by an automatic valve. Silicate-activated silicate compound is delivered to the storage tanks.
7. The activated silicate dosage flow meter has been checked for deviations between the indicated value and the set value. There were no deviations. Then a gel test was conducted to check the quality of activated silicate. This test shows a low performance of silicate.
8. Low chlorine pressure is usually caused by an empty cylinder or a self-controlled valve defect. It was discovered that the chlorine cylinder was almost empty.

Then the conclusion was that the defect caused the problem of the increased turbidity of the treated water due to the causal relations expressed in this way:

1. The amount of chlorine in the cylinder was very small;
2. The quantity delivered to the silicate was much lower than the nominal;
3. The proportion of chlorine in activated silicate was not correct;
4. The quality of activated silicate was poor;
5. The coagulation of water in the mixing chambers and in the sedimentation tank was not effective;
6. The result was an increased turbidity of the treated water.

➢ *Case study: lime plug*

A case study like the one above, involving a lime stopper in the dosing plant, is detailed in the thesis.

➢ *Other examples of reasoning for expert systems*

➢ *Other examples presented in detail in the thesis:*

- Hypochlorinator - Automated chlorination system
- Gaseous chlorination
- Gas chlorinator, direct assembly

CHAPTER 5

DIAGNOSIS OF A PUMPING GROUP

5.1. DESCRIPTION OF THE SYSTEM

To supply water from the public network, the vast majority of enterprises and institutions use their own pumping systems. They have the role of providing a pressure to satisfy all the installed positions, and most of them also have buffer tanks capable of providing the amount of water needed both for the consumption during the night (when the pressure in the public network decreases a lot) and for possible firefighting interventions.

Due to the fact that for low consumption (for example at night) only one pump is used, the others being practically in reserve, unevenly distributed stresses occur. To evenly load the pumps (assets and hot reserves) and to equalize their degree of wear, the automation equipment must start with priority those with a shorter service life, respectively to apply a rotation procedure. Moreover, to eliminate prolonged working regimes, after a number of hours of continuous operation, a rotation procedure will also be applied.

The automation equipment must protect the pumping system from working without water (idle). For this he must be able to take over a signal supplied either by a sensor or a pressure transducer mounted on the suction pipe (if the supply is made directly from the public network), or from a sensor or from a level transducer installed in the tank. The signaling of the lack of water is also done through an audible and luminous warning.

5.2. DESCRIPTION OF THE PROBLEMS ENCOUNTERED

The problems arising in the operation of the pumping group, further denoted by 'P', arise because of various events or sequences of events, hereinafter referred to as reasons [9]. To establish the basis of operation of the expert system, describe the following potential problems:

P1 - Problems with commissioning
P2 - Problems with pump cycling
P3 - Main or secondary pumps cannot be stopped (with flow meter installed)
P4 - Main or secondary pumps cannot be stopped (without flow meter installed)
P5 - Pressure limiting valve problems
P6 - Phase monitor alarm
P7 - General phase monitor alarm
P8 - Low flow problem / alarm sensor (faulty flow meter)
P9 - Problem at the level of the flow sensor, General alarm

The following are presented in Table 5.1. for problems P1 and P2, reported Defects, Reasons for occurrence of defects, and Proposed solutions for eliminating the reasons and implicitly extinguishing the defects. Similarly, the problems P3 - P9 are described in the thesis.

Tab. 5.1. Link table between Problems, Defects, Reasons and Solutions

Problem		Defect		Reason		Solution	
P1	Problems with commissioning	D1.1	Pumps do not start	M1.1.1	Incorrect positioning of buttons	S1.1.1.1	Check the pump status buttons for indications.
						S1.1.1.2	The pumps are activated by positioning the buttons in the On position.
				M1.1.2	Operating alarms	S1.1.2.1	Check and confirm any active alarm.
				M1.1.3	Thermal fuses or switches activated	S1.1.3.1	Check the switches and the thermal fuses of the engines.
						S1.1.3.2	Turn off the power and reset the switches and fuses.
				M1.1.4	Triggered surge protectors	S1.1.4.1	Check the indicator of three-phase and single-phase surge protectors for green color.
						S1.1.4.2	Replace the triggered surge protectors.
		D1.2	The pumps do not start according to the working times, thus causing the discharge pressure to drop drastically	M1.2.1	Incorrect working pressure settings	S1.2.1.1	Reduce the setting parameter for the pressure range so that the pumps react to lower pressure conditions.
						S1.2.1.2	Reduce the pressure range and/or the duration of acceptance of the low pressure.
				M1.2.2	Incorrectly set low pressure range	S1.2.2.1	Reduce the working parameters for the Min and Max heads of the low-pressure range.
						S1.2.2.2	Test to ensure the operation of the main pump only in case of required flow rate and not in case of pressure maintenance.
		D1.3	The main pumps start when no flow is required	M1.3.1	Water losses through the hydraulic network	S1.3.1.1	Check the hydraulic network and discharge plugs for large water losses.
						S1.3.1.2	Check the pressure limiting valve for premature discharge or constant leakage.

						S1.3.1.3	Check automatic filtering systems for continuous cleaning.
				M1.3.2	Incorrect working pressure settings	S1.3.2.1	Reduce the setting parameter for the pressure range so that the pumps react to lower pressure conditions.
						S1.3.2.2	Reduce the pressure range and/or the duration of acceptance of the low pressure.
				M1.3.3	Incorrectly set low pressure range	S1.3.3.1	Increase the working parameter for the Min end of the low-pressure range so that the main pumps do not start at pressure maintenance events.
				M1.3.4	The check valves of the pumps leak	S1.3.4.1	Check the condition of the pump check valves.
P2	Problems with pump cycling	D2.1	The pumps do not seem to work alternately according to the controls	M2.1.1	Electrical, Mechanical and Hydraulic performance is not respected	S2.1.1.1	Check and reset the circuit breakers.
						S2.1.1.2	Check the hydraulic network for water loss.
						S2.1.1.3	Check the pumping station for water losses: pressure limiting valve, pump verification valves, automatic filtration system and other solenoidal control valves.
				M2.1.2	Start and stop parameters are not set properly	S2.1.2.1	Check the parameters for stopping at overpressure and starting at low pressure to ensure a sufficient working range
						S2.1.2.2	Check the waiting interval between the start of pump 1 and the start of pump 2 so as to allow stabilization of pump 1 before starting pump 2.

		D2.2	Pumps operate assisted by flow meter or frequency converter	M2.2.1	Working parameters according to the flow meter are not correctly implemented	S2.2.1.1	The flow rate must exceed the value of the parameter implemented for stop at flow, then fall below the value of the stop parameter.
						S2.2.1.2	Reduce the “stop at flow rate” parameter.
				M2.2.2	Working parameters according to the converter are not correctly implemented	S2.2.2.1	Compare the value indicated by the converter during the provision of the minimum flow rate. Subtract the working parameter of the converter by 5% from the stabilized value of the converter when providing the minimum flow rate.
		D2.3	Pumps operate according to pump curves	M2.3.1	Compare the schedule of the flow requirement with the pumping schedules of the pumps	S2.3.1.1	If the flow rate requested in the program is lower or at the limit compared to the minimum flow rate recommended by the pumping curves, the flow supply schedule is modified to operate closer to the nominal curves.
						S2.3.1.2	If the programmed flow rate is on or above the nominal curve, reduce the flow rate to 25 %, then gradually increase to 50 % and subsequently to 100 %. This adjustment will have the effect of reducing shocks and stabilizes the response of the pumps.

The following shows the dependency graphs between the diagnostic elements for the P1 and P2 problems.

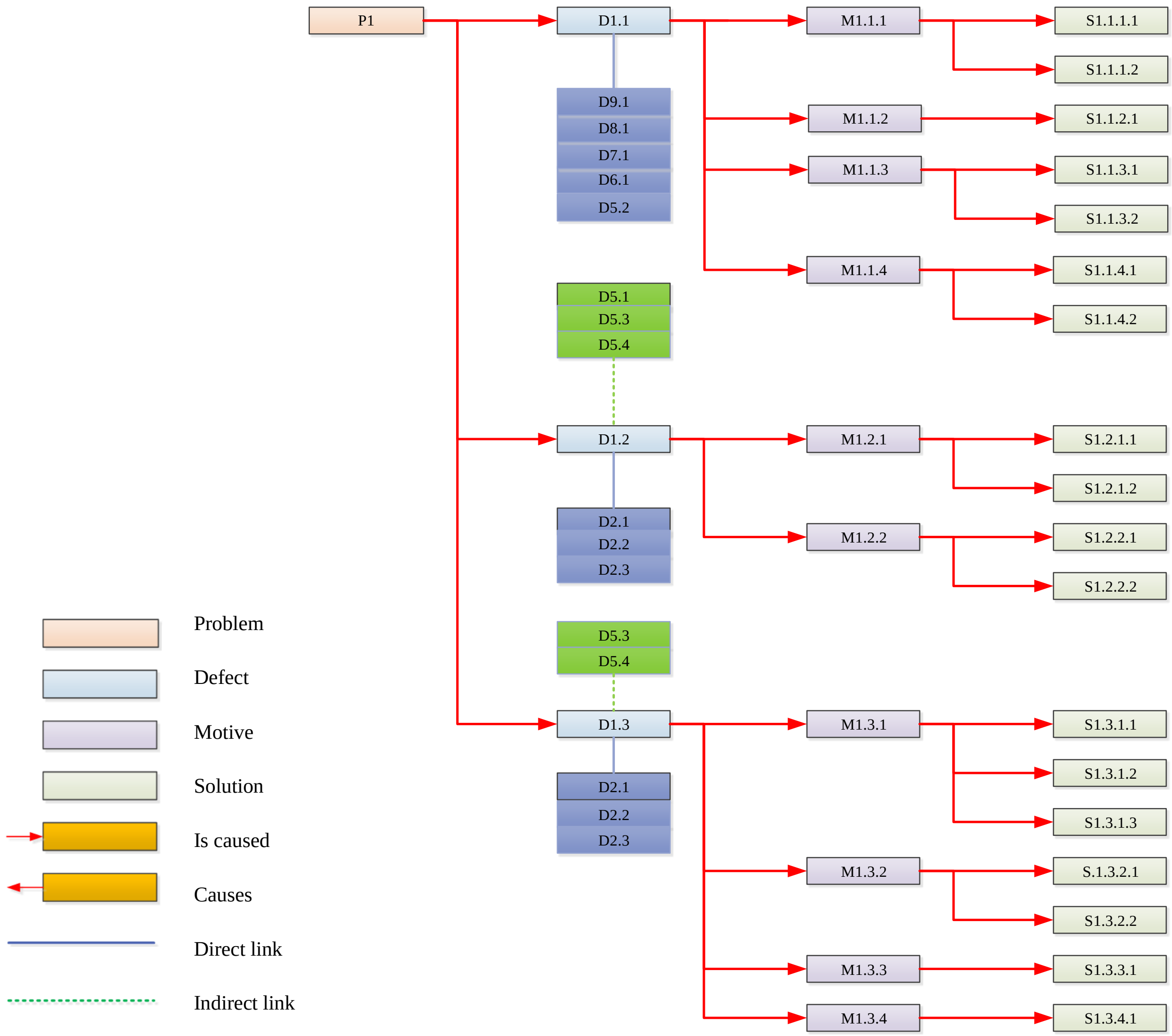

Fig. 5.1. P1 – Problems with commissioning

P1 describes the problems that may be encountered if the pumping group starts, at the first activation, after installation. The commissioning of the group offers the possibility of real testing and correct parameterization, with the necessary adaptations to the working environment. D1.1 imposes the lack of reaction of pumps in the event of their starting. As main reasons for the appearance of this defect we find:

- Incorrect positioning of the buttons. The buttons for selecting the power supply can be switched to the "Off" mode, and the pumps do not receive voltage, or the buttons for selecting the working mode (automatic or manual, locally or remotely) are not positioned according to the desired mode of use. This reason can be canceled by the proper positioning of the selectors, respectively of the buttons. Another reason may be the emergency button with restraint. If this button is not re-placed in the "normal-closed" position, the system is disconnected from the voltage.

- Operating alarms can have the effect of stopping the supply of pumps or interlocking the contactors/relays. These alerts can be informative or serious, resulting in a system blocked until problems are removed. As soon as the problem has been eliminated, the alarm messages are confirmed, an action that resets the interlocking systems.
- Thermal fuses or switches triggered can completely turn off the pumping system. The cause for which these fuses were triggered is tracked, and after solution and cooling, the pumps can be restarted. The dischargers lock the system in case of overload or overvoltage. Usually they are inhabited in case of triggering. Subsequently, the system resets.

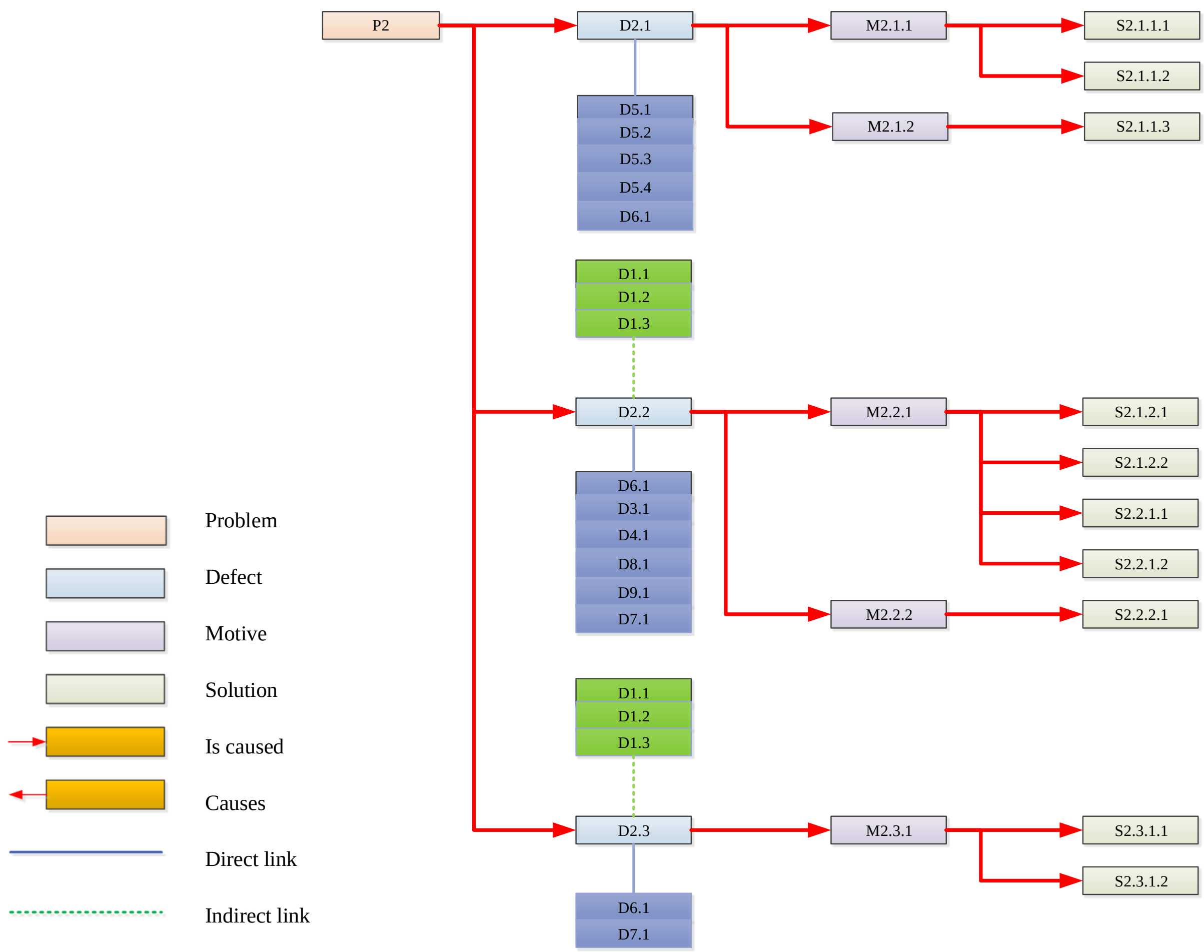

Fig. 5.2. P2 – Problems with pump cycling

Starting the pumps according to the working times is a procedure that must be adjusted at the time of commissioning. The initial or universal settings will not always apply to the situation encountered on the spot. Incorrect working pressure settings will entail problems in hydraulic insulation, failure of gaskets or membranes, and even destruction of water consumers and the hydraulic network. The pressure must be projected and maintained at a fixed value ± a margin of inertia. If the set starting pressure is higher than the existing pressure in the network, the pumps will not start. For troubleshooting, it will adjust the starting pressure close to zero. At the same time, the start-up delay interval may be too long, it can be reduced to zero in the commissioning phase.

After commissioning, the pumps have an operating conduct that complies with certain working steps and the designed actuation steps. In the nominal operating mode, a pumping group will cycle the pumps so that the wear is evenly distributed. The pumps will not work alternately if damage occurs in the operating mode, if the implemented settings do not allow alternative operation or if other additional actuators prevent this operation. A first step of checking the pumps in this situation is to reset any alarms and establish the appropriate position of the on/off switches, locally/distance. The waiting interval between the start of pump 1 and the start of pump 2 shall then be checked so as to allow pump 1 to stabilize before pump 2 starts. Another reason is any defects in the hydraulic installation. If water losses occur within the installation or within the verification, filtration and control valves, the maintenance pump will operate continuously and will not reach the set rest period, so it does not allow the secondary pump to interfere in operation.

If the operation of the pumps is semi-automatic, they operate according to the pumping curves implemented in SCADA. If these pumping graphs involve a lower flow rate than the nominal flow rate of the pumps, their operation may be affected. In such situations, a solution is chosen that requires raising the pressure in the hydraulic network, slightly above the maximum implemented, so that the network is hydraulically charged, and the pumps can enter the limp mode (the network is used as an expansion vessel).

In the thesis, the philosophy, graphs, and causality of the problems P3 – P9 are presented in detail.

Note: In the graphs shown in figures 5.1 and 5.2, the direct dependencies between defects, reasons and solutions are presented with full lines, which also appear in Table 5.1 and with dotted lines the indirect dependencies that do not appear in this table.

CHAPTER 6

IMPLEMENTATION OF A CONTAMINATION MONITORING SYSTEM

6.1. APPLICATION SUMMARY

The objective of the thesis is the realization of a software product for real-time monitoring of a water treatment plant. The monitored equipment consists of a central unit and sensors. Communication between the software interface and the physical equipment will be done via Ethernet cable. The main advantages and disadvantages of such an application are called into question, as well as its possible uses [10].

The TriOS sensor is connected by cable to a controller, TriBox 2. This controller is responsible for configuring the sensor and converting the basic raw data of the sensor into transmission units such as ModBUS protocol registers. The values saved in these registers are extracted through query response software techniques, such as a ModBUS survey [11].

6.2. APPLICATION CONTEXT

The automated systems for the treatment, treatment and processing of drinking, waste and industrial waters appeared simultaneously with the need to fulfill the harmful technological processes, conducted in toxic or flammable environments, or the processes in isolated areas or difficult to monitor by the user. At the same time, many stages of determination of organic compounds performed in the laboratory require analysis time, consumable reagents, qualified personnel, appropriate environments. The use of automated systems removes the need to ensure all the technological factors mentioned above, keeps the operating costs well below those of purchasing and ensures high accuracy at every step of the technological process

- *Starting point:*

The first step of the application was to choose the type of monitored technological process. In the European development project, the plant management wants to build a water treatment plant resulting from the technological process of oil processing. The entire monitoring area is considered an Ex-zone (with a danger of explosion), so a suitable equipment must be chosen. The parameters monitored at the entrance to the biological tanks of the treatment plant are COD-Cr (represents the oxygen mastic concentration equivalent to the amount of potassium bichromate consumed for the oxidation in acidic environment of the dissolved and suspended organic matter present in the wastewater), phenol and TSS (the amount of solid suspensions).

- *Basic concepts:*

The basic principle of the assembly refers to the acquisition of data by the physical equipment, the display of the data of the last measurement on the screen of the device, the display of the data of the last measurement on the software interface, the recording of all data in a database accessible online.

➢ *List of requests:*

The software must be able to successfully record in the database the information taken from the measuring equipment, to display the data of the last measurement, to have an authentication interface to secure the data and to benefit from the possibility of calling the database.

➢ *Tools:*

For the realization of the software is used:

- Dev-C++ - complete software development environment for the C and C++ programming languages, with integrated compiler [12];
- Microsoft Visual C++ 2010 Express – integrated development environment for C and C++ languages with the possibility of graphical development of the project under windows user interface [13];
- MySQL Workbench 6.0 CE – tool for developing, managing, designing, creating, and maintaining SQL databases [14];
- MySQL Connector Net 6.7.4 – software module developed by Oracle, designed to connect software that communicates through ODBC interface with a MySQL database;
- MySQL Server 5.6 – free communication management system between databases.

➢ *Program architecture:*

In principle, the program will consist of 3 windows: The first window will be the authentication one, where the user will enter his access data, and will be directed to the 2nd window if the data is correct. Window 2 represents the interface between the user and the measuring equipment. It will have several fields that will be updated with the information measured at the time interval set by the measuring equipment. When pressing the button related to the database, the program launches a 3rd window in which you can analyze the database recorded from the beginning of the process until now (Figure 6.1.). The significance of HMI in window 2 refers to human machine interface (Human Machine Interface)) [15].

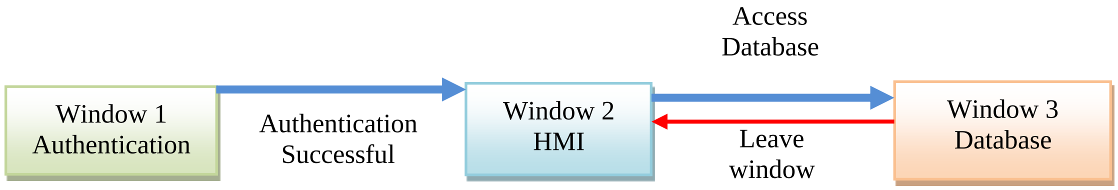

Fig. 6.1. Program architecture

6.3. APPLICATION DESIGN AND APPLICATION EXECUTION

To determine the type of communication protocol between the program and the measuring equipment, it is necessary to select an apparatus which satisfies the conditions mentioned in the preceding subparagraph. Thus, for this application, the TriOS ProPS spectrophotometric UV-VIS sensor is chosen, capable of determining the spectral absorption coefficient of the sample in the range of 200-380nm, the TriOS TriBox II central unit capable of taking information from the UV-VIS sensor and transforming it into data related to the concentrations of the compounds, allocating memory addresses to these data and transmitting it via the Ethernet cable using the ModBus TCP protocol [16]. The UV-VIS sensor can only measure the spectral absorption coefficient of the liquid at different wavelengths. Thus, the equipment has inscribed in memory an algorithm for translating this spectrum into data for the user. The absorption coefficient between 200 and 230 nm indicates in mg/l the concentration of nitrates in the water. Between 230 and 300 nm, the organic load (COD-Cr) of the water can be read, and between 300 and 360nm the suspended solids can be seen.

➢ *Elaboration of the database:*

In the MySQL Workbench programming environment, the connection to the local MySQL server to be used during the operation of the program is created. A database named "trios" is created. Inside this database, 2 tables are created. One will be called "login", which will contain the data necessary for authentication inside the program, and the 2nd table, "date", which will contain all the information stored during the program's running [17].

➢ *Elaboration of the purchase program of the date and time of the last measurement performed:*

Annex 1 contains the entire dialing code via ModBUS TCP of the Date and Time memory registers.

➢ *Elaboration of the purchase program of the name and value of each parameter measured during the last registration:*

Annex 2 presents the program designed for calling via ModBUS the measured values and the name of the measured parameter.

➢ *Elaboration of the purchase program of the unit of measurement related to each parameter measured during the last recording:*

Like Annex 1 and Annex 2, Annex 3 shows the retrieval of data related to the units of measurement used by the called equipment. After initializing and connecting to the database, the ModBUS dial telegram starts and the response is received.

➢ *Develop the authentication window (window 1):*

With the help of the Visual C++ 2010 Express development environment, all the windows of the graphical interface were created in a timely manner [18]. To begin with, the possibility of authenticating the user was implemented, to prevent the possibility of data theft. This page will contain a username field, a field for the user's password, an exit button, a confirmation button, the developer logo, and a link to the developer's web page. The development code for Window 1 can be found in annex 4.

➢ *Elaboration of the hmi window (window 2**):***

This page will contain a field for the current date and time, a field for the progress bar that graphically indicates the time remaining until the next measurement, an exit button, a database button, the developer logo and a field for the date and time of the last measurement performed. The development code for Window 2 can be found in the Annex 5.

➢ *Develop the database window (window 3):*

This page will contain a field for displaying the database, a button to load the database, and an exit button. The development code for Window 3 is shown in Annex 6.

➢ *Authentication window:*

When filling in the fields with erroneous logins, followed by pressing the "Login" button, the following window appears. When you press the output "x" button, the following window appears to confirm the application shutdown. When you click on the "COMPANY LOGO" banner, a browser web page opens to the address http://www.adresa_companiei.com. When pressing the "Exit" button, the application closes, and when you press the "Login" button, with the authentication data correctly entered, window 1 closes and window 2 is launched.

- *The hmi window (human machine interface):*

All data from the HMI window will be extracted from the MySQL database, from the last row entered by the 3 programs previously developed in Dev-C++. When you press the "Exit" button, the application stops. When pressing the "Database" button, window 2 is hidden and window 3 is launched.

- *Database window:*

When you press the "Exit" button, window 3 disappears and window 2 returns. When pressing the "Load" button, the field intended for the database is populated with the "data" table in the "trios" database.

6.4. ADVANTAGES AND DISADVANTAGES OF THE APPLICATION

The application shown above is custom built for the TriOS ProPS LSA sensor. All data obtained through custom developed scripts is interpreted and saved in the MySQL database in a specific format. When calling the database from the HMI data windows, the program is built specifically to read the database in a custom way so that it does not display the wrong values to the operator.

The entire software package is custom created for the TriOS sensor. The main advantage is that there will be no errors in reading data, writing data to the database, displaying the information acquired in HMI. Also, the program is already set for future improvements and development, such as: a custom date and period in which the data is displayed, a custom option of graphical representation, a function of exporting the database, a function of comparing between different data sets and others.

6.5. CONCLUSIONS REGARDING THE OPERATION OF THE APPLICATION

The entire software package is fast, takes up little space, and is easy to run. Most of the processes work in the background so that the operator is not distracted by unnecessary data. If the script cannot extract the data from the sensor, specific error messages are displayed for the operator to interpret the problem. The usefulness of this software can be summed up in its lack of complexity, and for this application it best suits the needs of the beneficiary. In this case, a quality laboratory PC unit was used to directly access the data from the TriOS sensor. There is no need for SCADA, PLC, and other complex hardware installations. A simple and direct PC-Sensor solution was required, designed, and supplied [10].

Such applications can be easily adapted to any type of sensor that can communicate through the ModBUS protocol, by simply changing the address of the data register in the query letters. Even if an analog sensor is used, a programmable logic controller (PLC) can get the 4-20mA signal. The measured value can be interpreted and scaled directly to a concentration value, which is then saved to a specific data log address. Thus, the presented application is universally adaptable.

CHAPTER 7

APPLICATION OF IOT TECHNOLOGY IN DRINKING WATER PUMPING INSTALLATIONS

➢ *Introduction*

Intelligent monitoring is defined as a method used for monitoring, controlling, managing and optimizing the network, using various computer techniques that provide customers with tools and information. The Internet of Things (IoT) is an important part of intelligent monitoring that connects people and equipment with wireless sensor technology [19].

➢ *Equipment and network*

Network monitoring equipment, be they flowmeters, pressure sensors or acoustic dataloggers [20], can be classified into the following types, depending on the mode of data transmission:

- With GSM/GPRS/LTE/5G transmission;
- With wireless transmission to a nearby receiver (e.g., a repeater or receiver installed on a nearby lighting pole);
- With wireless transmission, within a certain time interval, to a receiver in motion (patrol);

The same equipment can be:

- Equipment continuously fed to the mains (for accessible and easy areas);
- Battery-powered equipment for accumulators (for isolated and difficult to access areas).

➢ *Factors influencing water quality*

Physical factors include temperature, turbidity, and conductivity of water. Turbidity is the opacity or cloud effect due to microscopic materials dissolved in solution and has a typical value of over 1 NTU (Nephelometric Turbidity Units). The increased temperature affects the level of dissolved oxygen in the water and implicitly the quality of the water. Biological factors are determined by the presence of bacteria, viruses, algae, and pesticides, which also directly affect water quality.

The self-adaptive technological network is the technological factor that supports the concept of intelligent water. The selection of stations, the merger of data and the statistical forecasts work together for decisions taken quickly in real time, in an emergency [21].

Level, pressure, flow, and speed are qualitative factors of the water distributed, which must be taken into account during the data collection. Ultrasonic sensors and flowmeters can be used to detect speed and identify changes in water flow [22].

➢ *IoT structure applied to drinking water*

According to the diagram in figure 7.1. the reduction by up to 10% of the water consumption per consumer is achieved strictly by limiting the pressure at the level of the water column. If the pressure is monitored and transmitted to the dispatcher continuously, it is also actively adjusted.

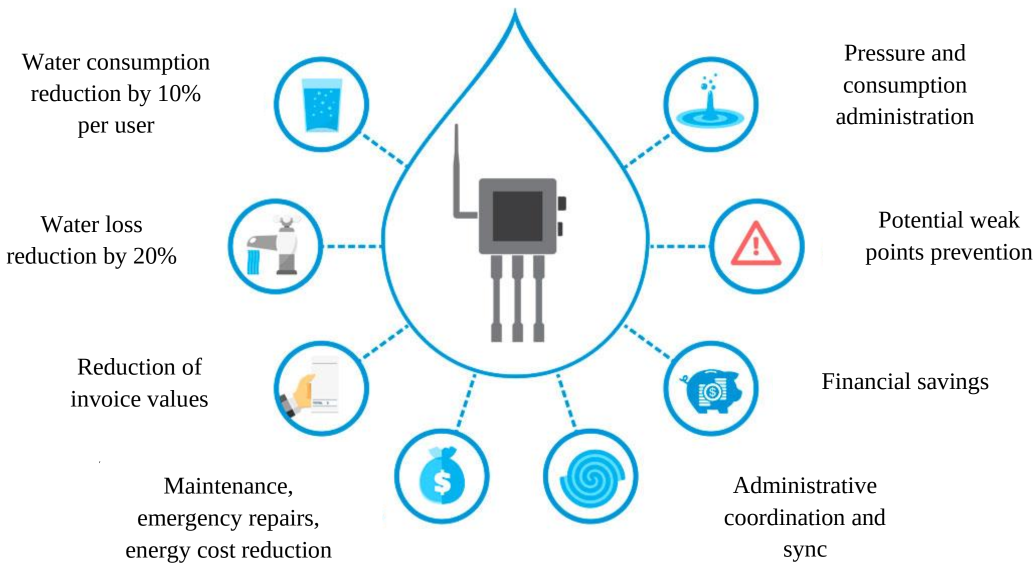

Fig. 7.1. The benefits of smart solutions in the water industry [23]

In the old pressure balancing schemes of a section, only the pressure at the most disadvantaged point was actively monitored, but the pressure of the entire section was compensated. Thus, certain areas of the section benefited from increased but unnecessary pressure, indirectly increasing the flow rate (index) at the level of the consumer [24].

Loss reduction by up to 20% is achieved by actively controlling water distribution during times of minimum consumption. At certain time intervals, such as at noon or at night, the consumption requirement is low, so the network can be actively adjusted for savings. At the same time, if the Expert system identifies an unusual failure or behavior of a certain network section, the dynamic elements can isolate this section, bypass it, and signal it appropriately for the perception of the system operator. The savings brought by such an active and self-detached system are substantial, but at the same time, the health of the installation is kept under control and continuously evaluated. [25]

Another branch in full swing is the monitoring and treatment of wastewater, through IoT technology, with the use of water resulting in household activities, bringing a considerable saving of drinking water [26].

- *Applications in the field of food safety – drinking water*

A set of equipment, equipped with means of internet connection, including a flow meter, a water pressure sensor, a pH or chlorine sensor, can work together to continuously monitor the quality of water in the transport network. The systems available on the market allow these checkpoints to be implemented easily at low cost. Data acquisition and processing interfaces are increasingly simplified, without the need for advanced knowledge or specialized training to be able to operate them. The purpose of these simplifications is precisely to ease the workload to which the operator is subjected, and expert systems tend to take over the tasks and responsibilities of operators [27].

CHAPTER 8

GENERAL CONCLUSIONS AND ORIGINAL ELEMENTS

8.1. GENERAL CONCLUSIONS

The work approaches a modern field of water quality monitoring and diagnostic systems used for domestic and industrial consumption, for irrigation systems and in any situations where clean water quantities are required. Water is an important factor influencing health and the economy, and because of this, all the problems related to the use of water must be treated with all seriousness. This is also the purpose of this doctoral thesis. The elaboration of the thesis was based on the development of simple, cost-free applications, of real-time monitoring of the parameters of a water treatment plant. Programming languages were used, available at no cost on online platforms. Drinking water distribution requires continuous monitoring due to the impact on the health of the population. The quality of drinking water must be ensured throughout its distribution route from the pumping group to the consumer.

Chapter 1 of the work presents an introduction to the issues of the doctoral thesis. It is presented the purpose of the doctoral thesis, the general and specific elements that the systems for monitoring and diagnosing the water quality must fulfill and the main companies involved in the field. It also highlights the main pieces of legislation governing the field of water. Thanks are made to those who helped the author of the work in the realization of the doctoral thesis.

Chapter 2 presents the main elements that make up the water quality monitoring systems. Describe the sensors, transducers, electronic devices, and equipment that are part of these elements: pH-measuring sensors, sensors for determining water conductivity, for measuring dissolved oxygen, transducers for measuring salinity and for determining salts dissolved in water.

Chapter 3 represents a consistent part of the doctoral thesis and refers to the main equipment and devices used in hydraulic systems. At the beginning, a pumping assembly is analyzed, starting from the description of the technical characteristics of the pumps used, showing the novelty elements used, such as the integrated frequency converters with outstanding technical performance. These converters have in recent years brought many novelties in the pumping technique being integrated into the housing of the pumping aggregates together with the pressure transducers and with the automatic parameter adjustment systems. Chapter 3 here is the water pH correction plant, and the technological stages of the water treatment processes: coagulation, sedimentation, filtration, disinfection, fluoridation. Describe the economic benefits of the water treatment process and describe the block scheme of a related system. The chapter ends with an experimental case study on the optimization of a wastewater treatment system from municipal waste storage cells by reverse osmosis using three successive special batteries. The experimental results are finalized with a general graph on the evolution of the water pressure, their flow rate and the operation of the concentrate flow control valve, so that the plant operates at its maximum capacity in any situation.

Chapter 4 sets out the main elements of an expert system used in water treatment plants. The key features of the system, the knowledge base of the system and its interface engine shall be analyzed. The steps to be followed for creating an expert system are described: the design of the system, its development, testing of the system and its maintenance. The benefits of an expert system for the hydraulic system are presented from the point of view of the contractor but also of the beneficiary, analyzing in detail the rules that must be applied in the stage of accumulation of knowledge and further development of the system. Three case studies are also presented on an automated gaseous chlorination system, a direct chlorination system and a system that identifies the causes that may cause an alarm in the milk dosing system of lime.

Chapter 5 deals with the technical diagnosis of a pumping group and is a natural continuation of Chapter 4. At the beginning, potential problems that may arise as a result of events or sequences of events are defined. These problems are denoted by P1, P2, ..., P9 and refer to the commissioning, the cycling of the main and emergency pumps, the failure of certain components of the hydraulic system, the possible alarms generated by failures, the non-fulfilment of normal operating conditions (fault sensors, low flow rate, etc.). For each of the 9 problems, the causes that led to the appearance of each problem, the possible solutions to solve and the possible fixes to remove the respective problem are centralized in a synthetic table. To better highlight the presentation of the 9 problems, there are also 9 graphs of direct dependencies (drawn with full lines) and indirect dependencies (drawn with dotted lines) between the diagnostic elements of the 9 problems. In this way you can follow, on these graphs, much easier, the links between the different defects, reasons, or improvement solutions.

In Chapter 6, a practical application is built, and a software product is developed for real-time monitoring of a water treatment plant. The monitoring equipment consists of a central unit and sensors. Communication between the software interface and the physical equipment is done via Ethernet cable. The main advantages and disadvantages of such an application are presented and its possible uses are called into question. The product made in the work is relatively inexpensive, easy to install and exploit on any Microsoft Windows operating platform, which benefits from a friendly interface, database, the possibility of calling the database and displaying the data acquired by the physical equipment located remotely. The basic principle of the application refers to the acquisition of data by the physical equipment, the display of the data of the last measurement on the screen of the device and on the software interface, and the recording of all data in a database accessible online. The realized software takes the data from the measurement equipment and secures these data using updated computing media (Dev-C++; Microsoft Visual C++ 2010; MySQL Workbench 6.0 CE; MySQL Connector Net 6.7.4; MySQL Server 5.6). In principle, the program consists of 3 windows (window for entering the user's access data, the window that provides the interface between the user and the measuring equipment and the window in which you can analyze the database recorded from the beginning of the process to the present). The executed application is secure and prevents the fraudulent retrieval of the obtained data and the processed results.

Chapter 7 shows the application of IoT (Internet of Things) technology to drinking water pumping installations. This is an intelligent technology and allows the transfer of information between various interconnected equipment. The structure of this technology contains the description of the components, the quantities to be monitored and the benefits brought in the concrete applications regarding the distribution of drinking water, emphasizing the safety and health of this distribution. The network of an IoT system, applied to water distribution, combines the processing, administration, and transmission of accumulated data through sensors. Network components and data transmission technologies are also managed using communication protocols. Automating the pumping process using IoT technology involves relatively high implementation costs, since each monitored and metered area needs pressure sensors installed in problem areas, water flow meters to control water supply, special equipment for acoustic detection of water losses and flow or pressure control valves.

8.2. ORIGINAL CONTRIBUTIONS

The doctoral thesis deals with a constantly expanding topic of interest regarding the hydraulic systems for the treatment and distribution of drinking water, systems that are found in large numbers in urban areas and increasingly also in rural areas.

The main original contributions of the thesis are as follows:

- Conducting an in-depth documentation regarding the sensors and transducers used in the hydraulic systems of treatment and monitoring of drinking water, with the description of each type and the presentation of their main technical and technological characteristics;
- Systematic presentation of the drinking water pumping assembly in the hydraulic system, establishment of criteria for the sizing of the system of automation and control of the assembly and definition of technical and technological requirements for optimal operation.
- Introduction of block schemes for hierarchical monitoring of the pumping group and the hydraulic network to automate the pumping and distribution processes of drinking water.
- Conducting an experimental case study on the optimization of a wastewater treatment system, originating from municipal waste storage cells, by reverse osmosis, using three successive special batteries, so that the plant operates at full capacity in all circumstances.
- Defining the characteristics of an expert system related to a drinking water treatment and pumping plant and building the system so that there is the possibility of continuously improving its performance based on the accumulation of practical experience in operation.
- Detailed hierarchical analysis of the problems (denoted by P), of the defects related to each problem (denoted by D), of the reasons for these defects (denoted by M) and of the improvement solutions (denoted by S) that occur in the operation of a water treatment and pumping plant.
- Explanation of the direct (full line) and indirect (dotted lines) links between elements P, D, M and S, described above, considering that a particular defect can be caused for several reasons, and this can lead to one or more system operating problems.
- Making figures with direct or indirect links between elements D, M and S, for each of the 9 problems considered when creating the expert system and marking them in a hierarchical way in order to facilitate their implementation within the expert system.
- Practical realization of a software application for real-time monitoring of a drinking water treatment and pumping plant and ensuring secure communication between the beneficiary of the application and the physical equipment of the station. Using this application, decisions can be made automatically for the correct operation of the hydraulic system. At

the same time, the application can automatically record in the database the information taken from the measurement equipment and display the data of the last measurement, also ensuring the security of this data.

- Conducting a study on intelligent monitoring, control, administration, and optimization of a hydraulic network based on IoT technology, a new concept recently proposed by Kevin Ashton, for the transfer of information between different interconnected equipment.

8.3. PERSPECTIVES OF FURTHER CONTINUATIONOF RESEARCH

The prospects of continuing the research carried out in this PhD thesis are multiple. The most important may be the following:

- Development with new elements of the expert system proposed in the work by considering several problems that may arise in the operation of the system and implicitly by increasing the number of solutions to remedy possible defects.
- Improving the software application for real-time monitoring of a water treatment and pumping plant.
- Expert systems development in other technical fields as well.
- Making collaborations with companies and specialists in the fields approached in the doctoral thesis.

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